Rec 9.3 Ref 55

USFA 2004 ✓

Fire Dept Name	HQ State	County	Total firefighters
Aiken County Hazmat Team	SC	AIKEN	40
Aiken Department of Public Safety	SC	AIKEN	119
Bath Volunteer Fire Department	SC	AIKEN	35
Beech Island Fire Department	SC	AIKEN	30
Belvedere Fire District	SC	AIKEN	25
Center Fire Department	SC	AIKEN	24
Clearwater Fire Department	SC	AIKEN	20
Couchton Volunteer Fire Department	SC	AIKEN	32
Eureka Volunteer Fire Department	SC	AIKEN	20
GVW Volunteer Fire Department	SC	AIKEN	43
Hollow Creek Fire Department	SC	AIKEN	19
Jackson VFD	SC	AIKEN	38
Langley Fire Department	SC	AIKEN	28
Merriwether Volunteer Fire Department	SC	AIKEN	23
Monetta Comunity Volunteer Fire Department	SC	AIKEN	11
Montmorenci Volunteer Fire Department	SC	AIKEN	20
New Ellenton Fire Dept`	SC	AIKEN	38
New Holland Volunteer Fire Department	SC	AIKEN	24
North Augusta Public Safety	SC	AIKEN	74
Salley VFD	SC	AIKEN	16
Sandy Ridge Volunteer Fire Department.	SC	AIKEN	13
Silver Bluff Volunteer Fire Department	SC	AIKEN	21
WAGENER FIRE DEPARTMENT	SC	AIKEN	17
Windsor Volunteer Fire Department	SC	AIKEN	22
Bamberg Fire Department	SC	BAMBERG	25
Denmark Department of Public Safety	SC	BAMBERG	41
Ehrhardt Fire Department	SC	BAMBERG	18
Hunters Chapel Fire Department	SC	BAMBERG	13
Olar Fire Department	SC	BAMBERG	15
Blackville Fire Department	SC	BARNWELL	22
Elko Fire Department	SC	BARNWELL	11
Friendship Community Fire Department	SC	BARNWELL	20
Hilda Volunteer Fire Department	SC	BARNWELL	28
Red Oak Volunteer Fire Department	SC	BARNWELL	0
Williston Fire Department	SC	BARNWELL	35
Batesburg-Leesville Fire Department Station 25	SC	LEXINGTON	36
Cayce Fire Department	SC	LEXINGTON	52
Columbia Metropolitan Airport Fire/Rescue	SC	LEXINGTON	15
Gaston Fire Station	SC	LEXINGTON	16
Irmo Fire District	SC	LEXINGTON	46
Oak Grove Fire Station	SC	LEXINGTON	25
Pine Grove Fire Station	SC	LEXINGTON	31
Sandy Run - Calhoun Volunteer Fire Departmer	SC	LEXINGTON	16
South Congaree Fire Station	SC	LEXINGTON	19
Voridian Fire & Rescue	SC	LEXINGTON	84
West Columbia Fire Department	SC	LEXINGTON	24
Chappells Volunteer Fire Department Station #1	SC	NEWBERRY	16
City of Newberry Fire Department	SC	NEWBERRY	37
Consolidated Volunteer Fire Department	SC	NEWBERRY	42
Fairview Volunteer Fire Department	SC	NEWBERRY	27
Pomaria Fire Department	SC	NEWBERRY	23

County total	
752	Aiken
112	Bamberg
94	Barnwell
364	Lexington
223	Newberry
352	Orangeburg
541	Richland
134	Saluda

Fire Dept Name	HQ State	County	Total firefighters	County total
Prosperity Fire Department	SC	NEWBERRY	25	
Silverstreet Volunteer Fire Department	SC	NEWBERRY	28	
Whitmire Fire Department	SC	NEWBERRY	25	
Bolentown Volunteer Fire Department	SC	ORANGEBURG	25	
Bowman Fire Department Station I	SC	ORANGEBURG	24	
Canaan Volunteer Fire Department	SC	ORANGEBURG	26	
Cordova Fire Department	SC	ORANGEBURG	16	
Edisto Volunteer Fire Department	SC	ORANGEBURG	22	
ELLOREE FIRE DEPARTMENT	SC	ORANGEBURG	12	
Eutawville Fire Department Inc.	SC	ORANGEBURG	19	
Four Holes Fire Department	SC	ORANGEBURG	18	
Holly Hill Fire Department	SC	ORANGEBURG	14	
Neeses Fire Department	SC	ORANGEBURG	12	
North Fire Department	SC	ORANGEBURG	25	
Norway Fire Department	SC	ORANGEBURG	12	
ORANGEBURG DEPARTMENT OF PUBLIC S/	SC	ORANGEBURG	79	
Pine Hill Fire & Rescue	SC	ORANGEBURG	26	
Providence Volunteer Fire Department	SC	ORANGEBURG	22	
Columbia Fire Department	SC	RICHLAND	492	
McEntire Air National Guard Fire Department	SC	RICHLAND	49	
Circle Volunteer Fire Department	SC	SALUDA	23	
Hollywood Volunteer Fire Department	SC	SALUDA	16	
Mayson Fire Department	SC	SALUDA	16	
Midland Volunteer Fire Department	SC	SALUDA	13	
OLD TOWN FIRE AND RESCUE	SC	SALUDA	17	
Ridge Spring Fire Department	SC	SALUDA	30	
Saluda Fire Department	SC	SALUDA	19	

Fire Dept Name	HQ City	HQ State	County	Total firefighters		County Total
Grovetown Dept of Public Safety	Grovetown	GA	COLUMBIA	34	209	COLUMBIA
Harlem Fire Dept	Harlem	GA	COLUMBIA	26	386	RICHMOND
Leah VFD	Appling	GA	COLUMBIA	22		
Martinez Volunteer Fire Department	Martinez	GA	COLUMBIA	127		
Augusta Fire Department	Augusta	GA	RICHMOND	312		
Fort Gordon Fire & Emergency Services	Fort Gordon	GA	RICHMOND	43		
Hephzibah Fire-Rescue	Hephzibah	GA	RICHMOND	31		

Sect. 9.3 Ref 56 USFWS 1990a

CANBY'S DROPWORT

Recovery Plan

RECOVERY PLAN

for

Canby's Dropwort (*Oxypolis canbyi* [Coulter & Rose] Fernald)

Prepared by:

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Approved: ______________________________
Regional Director, U.S. Fish and Wildlife Service

Date: April 10, 1990

Recovery plans delineate reasonable actions that are believed to be required to recover and/or protect the species. Plans are published by the U.S. Fish and Wildlife Service, sometimes prepared with the assistance of recovery teams, contractors, State agencies, and others. Objectives will be attained and any necessary funds made available subject to budgetary and other constraints affecting the parties involved, as well as the need to address other priorities. Recovery plans do not necessarily represent the views nor the official positions or approval of any individuals or agencies involved in the plan formulation, other than the U.S. Fish and Wildlife Service. They represent the official position of the U.S. Fish and Wildlife Service <u>only</u> after they have been signed by the Regional Director or Director as <u>approved</u>. Approved recovery plans are subject to modification as dictated by new findings, changes in species status, and the completion of recovery tasks.

Literature citations should read as follows:

U.S. Fish and Wildlife Service. 1990. Canby's Dropwort Recovery Plan. Atlanta, Georgia. 25 pp.

Additional copies of this plan may be purchased from:

Fish and Wildlife Reference Service
5430 Grosvenor Lane, Suite 110
Bethesda, Maryland 20814
Phone: 301/492-6403 or
1-800/582-3421

The fee for a plan varies depending on the number of pages in the plan.

Cover Illustration by: Robert Kral, 1981. Notes on Some "Quill" -Leaved Umbellifers; Sida 9(2):124-134.

EXECUTIVE SUMMARY

<u>Current Species Status:</u> <u>Oxypolis canbyi</u> is listed as endangered. There are 25 populations remaining; 9 have been destroyed. Of the 25 extant populations, most were severely affected by the droughts of the late 1980s. Only three plants now survive north of the Carolinas. Four sites have been acquired for preservation; however, even these are not completely protected from the broad-scale alterations of groundwater hydrology and habitat that threaten all remaining populations.

<u>Habitat Requirements and Limiting Factors:</u> This species is native to the coastal plain of Delaware, Maryland, North Carolina, South Carolina, and Georgia, where it occupies pond cypress savannas, the shallows and edges of cypress/pond-pine sloughs, and wet pine savannas. Maintenance of these shallowly flooded, open habitats depends upon a stable groundwater regime and protection from adverse alterations such as ditches, dams, etc. Reproductive requirements of the species are not fully understood.

<u>Recovery Objective:</u> Delisting

<u>Recovery Criteria:</u> Fourteen of the extant populations must be protected from habitat destruction (particularly hydrological alterations), and five additional populations must be found, reestablished, or (in the case of populations that are now marginal) augmented to the point where they can be self-sustaining. All 19 populations needed for recovery must be determined to be self-sustaining and permanently protected.

<u>Actions Needed:</u>
1. Survey suitable habitat for additional populations.
2. Monitor and protect existing populations.
3. Conduct research on the biology of the species.
4. Establish new populations or rehabilitate marginal populations to the point where they are self-sustaining.
5. Investigate and conduct necessary management activities at all key sites.

<u>Total Estimated Cost of Recovery:</u> Because so little is known about this species, it is impossible to determine costs beyond estimates for the first few years' work (in 1,000's):

Year	Need 1	Need 2	Need 3	Need 4	Need 5	Total
1990	20	7	61	5	8.5	101.5
1991	10	3.5	61	25	4.5	104
1992	10	3.5	21	11	9.5	55
1993						
1994						
1995						
1996						
1997						
1998						
1999						
2000						

<u>Date of Recovery:</u> Impossible to determine at this time.

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PART I

INTRODUCTION

Canby's dropwort (Oxypolis canbyi) is a rare plant native to the coastal plain of Delaware, Maryland, North Carolina, South Carolina, and Georgia, where it occupies pond cypress savannas, the shallows and edges of cypress/pond-pine ponds, sloughs, and wet pine savannas. Due to its rarity and vulnerability to threats, the species was federally listed as endangered on February 25, 1986 (U.S. Fish and Wildlife Service 1986). Oxypolis canbyi is officially listed as endangered by the States of Maryland and North Carolina, as threatened by the State of Georgia, and as threatened and of national concern by the State of South Carolina.

Current and Historical Distribution

Only 25 populations of Canby's dropwort are currently known to exist. Nine populations are known to have been extirpated. The distribution by State and County of extirpated and extant populations is as follows:

STATE	COUNTY	EXTIRPATED POPULATIONS	EXTANT POPULATIONS
DE	Sussex	1	0
MD	Queen Anne's	0	1
NC	Scotland	0	1
SC	Allendale	0	1
	Bamberg	0	1
	Barnwell	0	2
	Berkeley	1	1
	Clarendon	0	4
	Colleton	0	1
	Hampton	1	1
	Lee	0	1
	Orangeburg	0	1
	Richland	0	1
	Williamsburg	0	1
GA	Burke	2	0
	Dooly	0	4
	Lee	3	4
	Sumter	1	0
	Total:	9	25

Description, Ecology, and Life History

Canby's dropwort is one of five Southeastern species in the exclusively American genus Oxypolis. It is a perennial herb which grows 0.8 to 1.2 meters (2.6 to 3.9 feet) tall. The stems are erect or ascending, terete, slender but stiffish, and arise from scaly buds at the tips of the previous year's rhizomes, as well as from the first, second, or third nodes. Perennation from the nodes occurs most often in wetter habitats or following damage to the stem. Stems usually branch only well above mid-stem, with the branches arching-ascending and forking or ternately rebranching. The "quill-like" leaves are slender, terete, hollow, and septate (Kral 1981, Boyer 1988). The compound umbels of small five-parted flowers appear from mid-August to October with white petals and pale green sepals, some of which are tinged with red or pink. The five sepals are triangular-subulate, mostly about 0.5 mm (0.02 inch) long, rarely persisting on ripe fruit. The five petals are each about 1.2 to 1.3 mm (0.04 to 0.05 inch) long and short-clawed (Kral 1983, Radford et al. 1964, Gleason 1952). The fruit is a schizocarp about 4 to 6 mm (0.16 to 0.24 inch) long, broadly obovoid or ellipsoidal, and strongly compressed dorsoventrally. The medial surface over the seed cavity is often sparsely but evidently muricate (Tucker et al. 1983). The lateral margins of the fruit are expanded into thick, corky wings (one of the best distinguishing features of this species [Tucker, et al. 1983]). The rootstock of Canby's dropwort is very distinctive and, along with the mature fruit, is one of the features that distinguishes this species from similar ones such as Oxypolis filiformis (Walt.) Britt. Kral (1981) describes the rhizome and the vegetative reproductive capability of the plant as follows:

> "The rootstock of O. canbyi is a fairly slender, ascending rhizome that develops as a branch bud from [the] rather deep-set, slender, forking horizontal rhizome. This ascending rhizome expands distally into an erect, purplish or pinkish, short-internoded, fistulose stem base which is usually submersed or imbedded in peat-muck and which produces from its close-set nodes whorls both of roots and lax, elongate, pale, stoloniferous rhizomes, some several decimeters in length and which root at their distant nodes to produce new plants. In short, this is a strongly cloning species which can in some cases become an aspect dominant."

Oxypolis canbyi was originally described as a variety of the more common O. filiformis (Coulter and Rose 1900). Fernald (1939) later elevated the taxon to a full species based on differences in leaf and fruit characters. Kral (1981) and Tucker et al. (1983) agree with Fernald's taxonomic judgement.

Oxypolis canbyi can be confused with two other taxa in the family Apiaceae--Ptilimnium nodosum and O. filiformis. Ptilimnium nodosum can be distinguished from O. canbyi by its much smaller terete and wingless fruits and by the difference in flowers. In Ptilimnium, the petals are incurved at the tips only; in Oxypolis the entire petal blade is strongly incurved.

The following table was developed by Aulbach-Smith (1985) from information in Kral (1983) and Tucker et al. (1983) for distinguishing O. canbyi from O. filiformis:

Character	O. canbyi	O. filiformis
Perennating organs:	stoloniferous rhizomes	crown buds
Lower internodes:	suffused with pink or purple	usually green
Primary rays of the umbel:	5 to 9, rarely more	10 to 20
Fruits:	dorsally flattened with dilated margins (i.e., thickest at the edges)	dorsally flattened with wings thinnest at the edges

(The differences in rhizomes and fruits are considered the most reliable distinguishing characters [Franz and Boyer 1987].)

Oxypolis canbyi has been found in a variety of coastal plain habitats, including natural ponds dominated by pond cypress, grass-sedge dominated Carolina bays, wet pine savannas, shallow pineland ponds, and cypress-pine swamps or sloughs. Bowling (1986) found that in Georgia, habitats occupied by this species were usually at the heads of small drainages leading off broad flat "ridges" of higher ground between larger drainages. The largest and most vigorous populations have been found to occur in open bays or ponds that are wet throughout most of the year but which have little or no canopy cover. Soils are sandy loams or acidic peat-mucks underlain by clay layers which, along with the slight gradient of the areas, result in the retention of water. Soil types known to support Canby's dropwort include Rembert loam, Portsmouth loam, McColl loam, Grady loam, Coxville fine sandy loam, and Rains sandy loam. All of these soil types are characterized by medium to high organic content and high water table; they are also deep, poorly drained, and acidic (Aulbach-Smith 1985). Most observers agree that an important key to the ecology of the species and the determination of management requirements is an understanding of the species' relationship with depth and duration of the water table over time. Bowling (1986) stated that natural drainage in areas supporting O. canbyi is often accomplished only through underground channels or by evaporation, and he found evidence of infrequent and shallow (5 to 30 cm [2 to 12 inches]) inundations at sites occupied by the species. The plant's water requirements are narrow;

either too much or too little water present on the site can be detrimental (Rayner et al. 1987). As might be expected, sites with what appears to be optimum habitat (water levels, soil types, topographic position, and canopy characteristics as described above) are less affected by severe droughts than sites supporting less than optimum habitat for this species. For instance, two populations of Canby's dropwort in South Carolina were being monitored during the severe drought of 1986. One of these was an apparently optimum site in Bamberg County; the other was a marginal site in Colleton County. The water level in the Bamberg County site dropped to only 13 inches below the surface during this time, while the water table at the Colleton County site dropped 70 inches below the surface. The Colleton County population went from over 500 plants in 1982 to fewer than 5 in 1986, presumably as a result of the effects of the drought. The Bamberg County site, on the other hand, showed only an insignificant decrease in plant numbers during this time (Rayner 1988). Boyer (1988) observed similar negative effects of this drought on the single extant North Carolina population of O. canbyi, where the number of stems declined by 80 percent from 1986 to 1987. Fruit production in the remaining plants was also drastically affected. The single remaining Maryland population was similarly affected, declining from 200 plants in the mid-1980s to only 7 plants during the severe drought of 1988. The drought was followed by an extremely wet year in 1989, and the population declined again to only three plants. Although there has been no fruit set in Maryland O. canbyi in recent years, soil cores have been taken to search for banked seed.

At most of the extant sites, common associates of Canby's dropwort include the following species; Taxodium ascendens (usually composing an open canopy), Ilex cassine var. myrtifolia, Myrica cerifera, Clethra alnifolia, Nyssa biflora, Pinus serotina, Rhynchospora spp., Rhexia aristosa, Carex walteriana, Polygala cymosa, Pluchea rosea, Hypericum denticulatum, Woodwardia virginica, Erianthus strictus, E. giganteus, Sarracenia flava, Iris spp., Andropogon sp., Panicum hemitomon, Centella asiatica, Lachnanthes caroliniana, Pontederia lancifolia, Nymphaea odorata, Aristida affinis, Agalinis linifolia, Manisuris rugosa, and Stillingia aquatica. Boone et al. (1984) rediscovered O. canbyi on the Delmarva Peninsula in 1982, where the species had been considered extirpated since Canby's last collection in 1894. At this northernmost locality, the habitat is dominated by Carex walteriana, Cladium mariscoides, and Panicum hemitomon. Other associated species at the Maryland site include Sagittaria engelmanniana, Panicum verrucosum, P. longifolium, Erianthus giganteus, Eleocharis microcarpa, E. melanocarpa, Juncus canadensis, Hypericum adpressum, H. virginicum, Ludwigia sphaerocarpa, Proserpinaca pectinata, Utricularia geminiscapa, Cephalanthus occidentalis, Acer rubrum, Liquidambar styraciflua, and Diospyros virginiana. In addition, Canby's dropwort sometimes occurs with other rare species, some of which are federally listed or are candidates for Federal listing, including Lobelia boykinii, Rhexia aristosa, and, less commonly, Ptilimnium nodosum (listed as endangered) and Ilex amelanchier.

Very little specific information is available on the life history and population biology of Canby's dropwort. Boyer (North Carolina Plant Conservation Program, personal communication, 1988) has successfully grown plants from rhizomes in continuously inundated beds, but she has not been successful in germinating seeds (however, only a small number of seeds were available for the project). The rhizomes do not survive well in intermittently dry beds. As mentioned earlier, under the right conditions this stoloniferous perennial can vegetatively become an aspect dominant. The flowers can be either unisexual or bisexual, with the inner flowers of some umbels being male and the outer flowers female. Bisexual flowers may facilitate some self-pollination; however, the flowers are protandrous, which is indicative of some degree of outcrossing. Aulbach-Smith (1985) states:

> "Outcrossing results in increased recombination and heterozygosity, thereby insuring increased evolutionary potential. Sexual reproduction theoretically should act as a sort of evolutionary buffer enabling species to survive environmental changes. This may not be the case in O. canbyi due to a possible high selfing rate and/or the isolation of small populations."

Boyer (personal communication, 1988) found that selfing in this species is possible, but the rate is low because of the protandry. Boyer commented further that the clonal habit may indicate that each population is just one or a few genetic individuals with very little genetic variation available, even if the apparent outcrossing rate is high. Other observers have questioned this; research is needed to determine genetic variability within and between populations through such techniques as isozyme analysis.

The pollinators of this species are unknown. However, since Canby's dropwort, like many umbellifers, is a favored food plant for the larvae of the black swallowtail butterfly (Papilio polyxenes asterius Stoll), the metamorphosed adults may visit the flowers and act as pollinators. Ironically, predation by the black swallowtail may be a factor in reducing the sexual reproductive potential of O. canbyi since this caterpillar chews through the stems just below the inflorescences. Permanent plots being monitored in South Carolina populations have shown predation rates of as high as 17 percent (plant tips eaten); scale insects and grasshoppers, in addition to swallowtail larvae, have been observed to damage plants of this species (Rayner, unpublished data). Deer have also been observed to browse upon O. canbyi (Tom Patrick, Georgia Natural Heritage Program, personal communication, 1989). It is unknown to what extent such predation affects the vigor or long-term survival of Canby's dropwort since even the relative importance to the species of vegetative versus sexual reproduction is unknown.

Threats and Population Limiting Factors

The most serious threat to Canby's dropwort is the loss or degradation of the wetland habitats in which it occurs. Ditching and draining of wetlands has altered the groundwater table and changed the vegetative composition in many areas of the mid-Atlantic coastal plain where the species historically occurred (Godfrey and Wooten 1979, Ormes et al. 1985, U.S. Fish and Wildlife Service 1986). Much of this habitat destruction has been for agricultural and silvicultural purposes, including conversion of land to row crops, lowland pasture, and pine plantations. Shallow ponds and depressions have also been dredged and deepened to create small reservoirs for watering livestock. The lowering of the water table, in addition to its direct deleterious effects on Canby's dropwort, enables competitive species to become established, thus modifying the natural scheme of vegetative succession on these sites. This usually results in the sites' becoming unsuitable for the growth and reproduction of Canby's dropwort.

Highway construction and maintenance/improvements are believed to have adversely affected populations of the species at several sites in South Carolina and threaten most of the known sites in Georgia. The only known population in Maryland is within the area that would be affected by the Soil Conservation Service's channelization project for the Upper Chester River watershed, should the project be reactivated.

Because of the proximity of many of the extant O. canbyi populations to power line and highway rights-of-way, agricultural fields, and pine plantations, there is a possibility for damage of plants from off-target herbicide drift. No instances of this have yet been documented, but the potential cannot be ignored, particularly where aerial application is involved.

Altered sites, such as the one in Colleton County, South Carolina, which has been planted in slash pine, are more threatened by severe drought than populations in optimum habitat. These sites may require some form of active management, such as canopy thinning or removal and prescribed burning (Rayner et al. 1987, Rayner 1988).

Predation by various insects, as previously described, may be having adverse effects on the sexual reproduction and long-term viability in at least some populations. Ineffective seed dispersal may also be limiting population expansion and colonization. Increasing demands on groundwater supplies caused by expanding suburban and industrial development could also threaten the species' continued survival if water tables are seriously altered.

An important aspect of threats to this species is that many, if not all, populations are severely threatened by stochastic events alone. Small, isolated populations, such as the one in Maryland, are at high risk of extirpation, even without any additional adverse anthropogenic impacts. Such populations are in imminent peril due solely to natural population fluctuations (which can be drastic in this species) and relatively minor natural catastrophes. As stated by Rodney Bartgis of the Maryland Natural Heritage Program, "In a sense, the successful management of such a site probably will depend upon successfully identifying and anticipating such events" (personal communication, 1989).

Although this species is not showy, and therefore, not generally of interest to horticulturalists, some of the populations are so small that over-collection for research or educational purposes could seriously threaten the survival of the plants at those sites.

Conservation Efforts

The U.S. Fish and Wildlife Service and the United States Department of Agriculture Soil Conservation Service signed an interagency agreement on January 13, 1983, in an effort to resolve potential conflicts between this species and the Upper Chester River watershed project. Although plans for this project have since been canceled, the Soil Conservation Service is undertaking a 5-year groundwater monitoring study adjacent to existing ditches on the Delaware side of the Upper Chester River drainage. When available, the results from this study should provide valuable information on the impacts of ditching on this species' wetland habitat.

In 1988, the Maryland Natural Heritage Program, with U.S. Fish and Wildlife Service Section 6 funding, began monitoring the existing population and assessing the feasibility of reestablishing additional populations in Maryland. By 1989, Maryland's only remaining population had declined to only three plants; the Maryland Natural Heritage Program, in cooperation with The Nature Conservancy and the Center for Plant Conservation, then brought two of the surviving plants into cultivation at the North Carolina Botanical Garden in the hope of preserving and propagating this genotype for eventual reintroduction to suitable sites in the Delmarva area (Bartgis, personal communication, 1989).

The North Carolina Department of Agriculture's Plant Conservation Program has set up permanent plots to monitor that State's only population, and has collected seed, stems, and rhizomes for cultivation and long-term storage. Thus far, stems with rhizomes attached have proven to be the most productive for artificial propagation (Boyer, personal communication, 1989). Seedbank investigations are ongoing. The Program is also planning to begin monitoring groundwater levels in the vicinity of the population.

The South Carolina Wildlife and Marine Resources Department's Heritage Trust Program manages the two protected sites in South Carolina for the benefit of the species and is engaged in monitoring and biological research at these and other sites.

State agencies charged with protecting rare plants in the States of Maryland, North Carolina, South Carolina, and Georgia are pursuing protection of additional sites by agreements with landowners or outright acquisition. Conservation agencies in these States, as well as in Delaware (where no known populations remain), are also actively conducting surveys of potential habitat in hopes of finding and protecting additional populations of the species.

The Nature Conservancy has significantly contributed to conservation efforts for this species by acquiring the habitat of four of the known populations in North Carolina, South Carolina and Maryland. The Conservancy is continuing to work with State agencies and the Fish and Wildlife Service to protect other sites.

PART II

RECOVERY

A. <u>Recovery Objectives</u>

Canby's dropwort (<u>Oxypolis canbyi</u>) will be considered for delisting when there are at least 19 self-sustaining populations in existence that are protected to such a degree that the species no longer qualifies for protection under the Endangered Species Act (see criteria below). A self-sustaining population is a reproducing population that is large enough to maintain sufficient genetic variation to enable it to survive and respond to natural habitat changes. The number of individuals necessary and the quantity and quality of habitat needed to meet this criterion will be determined as one of the recovery tasks. The populations should be distributed throughout the species' historic range. This recovery objective is considered an interim goal because of the lack of data on biology and management requirements of the species. As new information is acquired, the estimate of self-sustaining populations required for the species' survival may be readjusted. The recovery objective for <u>O. canbyi</u> will be reassessed at least annually in light of any new information that becomes available.

Rapid declines can occur even in seemingly stable <u>O. canbyi</u> populations. In South Carolina, the stronghold for this species, a recent 100-year drought event unexpectedly decimated all but 2 of the 15 extant populations. The survival of these severely reduced populations is now in question. Drastic fluctuations such as this indicate that it may be necessary to protect more than 19 populations to ensure long-term survival of the species. This also confirms that future research will be necessary to accurately determine what actually constitutes recovery.

In order to accomplish the goal of removing Canby's dropwort from the list of endangered and threatened species, it is necessary to protect all existing populations and to manage the habitat to ensure their continued survival until it can be determined which of these has the best potential for long-term viability. Because so little is known about this species, it is also necessary, for the full protection of the plants, to conduct demographic studies and ecological research for the purpose of gaining the understanding needed to develop appropriate protection and management strategies. The ultimate effects of various kinds of disturbance on <u>O. canbyi</u> populations must be determined and prevented. Therefore, Canby's dropwort shall be considered for removal from the Federal list when the following criteria are met:

1. It has been documented that at least 14 of the currently extant populations are self-sustaining and that necessary management

actions have been undertaken by the landowners or cooperating agencies to ensure their continued survival.

2. Through reintroduction, rehabilitation, and/or discovery of new populations, five additional self-sustaining populations exist within the species' historical range.

3. All 19 populations and their habitat are protected from present and foreseeable human-related and natural threats that may interfere with the survival of any of the populations.

B. <u>Narrative Outline</u>

1. <u>Protect existing populations and essential habitat.</u> Only 25 populations of Canby's dropwort are currently known to exist, all within the States of Maryland, North Carolina, South Carolina, and Georgia. Until more is known about the species' biology and specific habitat requirements, and about the measures necessary to protect the hydrology of occupied sites, all existing populations should be protected. The long-term survival of 19 populations is believed to be essential to the recovery of the species as a whole.

   1.1 <u>Develop interim research and management plans in conjunction with landowners.</u> Very little is known about specific management practices necessary to ensure the long-term survival of this species. Therefore, immediate emphasis will be on protection (i.e., little or no management, prevention of drainage and other site alterations that are known to be detrimental), in cooperation with the landowners, until appropriate management procedures have been developed through research. Ongoing studies in South Carolina incorporate plans for controlled canopy thinning at one site where the natural habitat of the species has been altered by introduction of slash pine. Pre- and post-management demographic studies should provide important insights into management needs at this and other <u>O. canbyi</u> sites.

   1.2 <u>Search for additional populations.</u> Although several intensive searches for the species have been conducted within parts of the historic habitat, a thorough, systematic effort to locate additional populations is still needed (very small populations, consisting of only a few plants, particularly at overgrown sites, are easily missed in less intensive efforts). Searches should be preceded by an examination of soil and topographic maps and aerial photographs to determine potential habitat and to develop a priority list of sites to search. Also, searches should only be conducted in optimal years, as determined by site visits to at least one-third of the extant populations in the State or geographic area to be searched.

1.3 Determine habitat protection priorities. Because of the small number of existing populations and the pervasive and imperfectly understood threats to the habitat, it is essential to protect as many as possible. However, efforts should be concentrated first on the sites in protective ownership, or where current private landowners are cooperative, and where the largest and most vigorous populations occur.

1.4 Evaluate habitat protection alternatives. The greatest possible protection should be obtained for those existing populations that are considered critical to the recovery of the species. Fee simple acquisition or conservation easements provide the greatest degree of protection. However, it is unknown as yet how much buffer land around each population is necessary to protect the hydrological regime of occupied sites. Protection through management agreements or short-term leases may provide adequate short-term protection but should only be considered as intermediate steps in the process of ultimately providing for permanent protection. Short-term protection strategies may be necessary if private landowners are not agreeable to, or monies are not available for, acquisition of conservation easements, hydrologic easements, or fee simple title. Conservation agreements with adjacent landowners or owners of rights-of-way (power companies and highway departments) should be developed to prevent inadvertent adverse alterations of the habitat. This has been accomplished for several of the South Carolina sites.

2. Determine and implement management necessary for long-term reproduction, establishment, maintenance, and vigor. Although protection of the species' habitat is the obvious first step in ensuring its long-term survival, this alone may not be sufficient. Management of the habitat may be necessary to allow the species to successfully perpetuate its life cycle over the long term. However, since very little is known about this species, information on its population biology and ecology is necessary before management guidelines can be formulated and implemented.

2.1 Determine population size and stage-class distribution for all populations. Population size and stage-class distribution data are essential to predicting what factors may be necessary for populations to become self-sustaining (Menges 1987; Menges, in preparation). Such data are needed for the existing populations and for any new populations discovered in the course of additional surveys.

2.2 Study abiotic and biotic features of the species' habitat. An understanding of the hydrology of the habitats occupied by the species is essential to the long-term survival and recovery of Canby's dropwort. Ongoing monitoring programs should be continued and expanded. Such studies should include populations within a wide range of habitats, both altered and undisturbed. Permanent plots should be selected and established to determine the relationship between abiotic factors (such as soil depth and type, frequency and depth of inundation, and light intensity) and biotic factors (such as reproduction, germination, and degree of competition and predation). This information is necessary to determine what type of active management, if any, is necessary to ensure continued vigor of existing populations and to accurately select good potential sites for reintroduction.

Experimentation with plants under controlled (e.g., greenhouse) conditions is also essential to understanding recovery prerequisites. Exposure of cultivated plants to controlled stress such as drought, while studying the physiological response of the plants, would provide insight into why some seemingly stable populations respond so drastically to temporary environmental changes.

The vectors of seed dispersal must be determined and their effectiveness under different ecological and spatial conditions assessed. At least some seed dispersal is by wind; however, little else is known, including how far seeds can be dispersed by this vector and others and what conditions are optimal for dispersal. Major pollinators need to be determined. Although various insects have been observed visiting the flowers, the pollinators and pollination mechanisms of the species remain unidentified.

The relative importance of sexual (selfing and outcrossing) and vegetative reproduction to the long-term survival of the species is unknown and must be determined for effective management and protection to take place. Genetic variability within and between populations must be determined through isozyme analysis, electrophoresis, or other appropriate research.

Relationships with competing species must be investigated. It is believed that competition from invading species is controlled by periodic inundation of the sites occupied by _O. canbyi_. Some other form of periodic disturbance, perhaps naturally occurring fire, may also play a part in defining these relationships. However, the effects of and exact interactions between this species and potential competitors are unknown.

2.3 _Conduct long-term demographic studies._ Long-term demographic studies should be conducted in permanent plots located within each study site established for habitat analysis. For at least 4 consecutive years, plots should be visited annually at the peak of flowering and after seed set has occurred. The locations of individual plants of all stage-classes should be mapped; data should be collected for each mapped plant, as applicable, on height, stem diameter at base, number of nodes, inflorescence size, fruit size and number, and seed set. Larger plots surrounding each of the smaller, more intensively measured and mapped plots should be monitored for seed germination and seedling establishment. Seedlings should be mapped and measured. Any changes in the habitat within each plot (soil disturbance, increases or decreases in light intensity, hydrology, etc.) should be noted at each visit (see Task 2.2 on study-site selection).

2.4 Determine the effects of past and ongoing habitat disturbance. Establishment and long-term monitoring of permanent plots may be the most effective means of assessing the effects of disturbance. One of the most likely candidates for this type of study is the Colleton County, South Carolina, site, which has been disturbed by road construction, power line right-of-way construction, and introduction of a slash pine overstory. Appropriate methodology for this must be determined but will likely include measurement of many of the parameters specified in Tasks 2.2 and 2.3. Such techniques as soil coring and examination of historical and current aerial photography should yield information on fire history and successional closure of the bays where *O. canbyi* occurs.

2.5 Define prerequisites for self-sustaining populations and develop appropriate habitat management guidelines based upon the data obtained from Tasks 2.2 through 2.4. There are currently insufficient data to determine what this species requires in order for populations to be self-sustaining. Research as described under Tasks 2.2 through 2.4 should provide the information needed to protect and manage occupied habitat so that the continued survival of healthy populations is assured.

2.6 Implement appropriate management techniques as they are developed from previous tasks.

2.7 Develop techniques and reestablish populations in suitable habitat within the species' historic range. Techniques for seed or rhizome/stem collection, germination, propagation, and transplantation are unknown for this species. This information will need to be developed in conjunction with knowledgeable individuals in greenhouse or nursery facilities. Transplant sites in native habitat must be closely monitored to determine success and to adjust methods of reestablishment. Also, information on seedbanks in wild populations must be obtained to determine whether, and under what conditions, decimated colonies can recover naturally (research on this topic is currently being conducted by the North Carolina Department of Agriculture's Plant Conservation Program).

3. Develop a cultivated source of plants and provide for long-term seed storage. There are at present no known cultivated sources of this species. Techniques for seed storage, germination, and maintenance of cultivated specimens must be developed in cooperation with botanical gardens, nurseries, and other appropriate facilities. Maintaining the "genotypes" of small, isolated populations (such as the Delmarva population) in cultivation should be of high priority; preservation of the Delmarva genetic material may be particularly important since it represents the only known remnant of species populations north of the Carolinas and is very close to extinction in the wild. Given the recent precipitous declines at most sites, seed or vegetative propagules should be collected as soon as possible from all populations that are still healthy enough to tolerate such harvest. (Work toward this end has been initiated with the Center for Plant Conservation and with cooperating botanical gardens.) A ready source of cultivated material should ease the threat of taking from wild populations.

4. Enforce laws protecting the species and/or its habitat. The Endangered Species Act (Act) prohibits taking of *O. canbyi* from Federal lands without a permit, and regulates trade. Section 7 of the Act provides additional protection of the habitat from impacts related to federally funded or authorized projects. In addition, for listed plants the 1988 amendments to the Act prohibit: (1) their malicious damage or destruction on Federal lands; and (2) their removal, cutting, digging, damaging, or destroying in knowing violation of any State law or regulation, including State criminal trespass law. The State of North Carolina prohibits taking of the species without a permit and the landowner's written permission and regulates trade in the species (North Carolina General Statute 19-B,202.12-202.19). The State of Maryland prohibits taking of the species from private property without the landowner's written permission and from State property without a permit and regulates trade in the species (Code of Maryland Regulations 08.03.08). The State of Georgia prohibits digging, removal, or sale of State-listed plants from public lands without the approval of the State management authority (Georgia Department of Natural Resources; Georgia Wild Flower Preservation Act of 1973). Federal and State enforcement agents whose jurisdiction includes the known range of *O. canbyi* should be made aware of the threat to the species and be able to identify specimens.

5. Develop materials to inform the public about the status of the species and the recovery plan objectives. Public support for the conservation of Canby's dropwort could play an important part in encouraging landowner assistance and conservation efforts. Informational materials should not identify the plant's locations so as not to increase the threat of taking.

   5.1 Prepare and distribute news releases and informational brochures. News releases concerning the status and significance of the species and recovery efforts should be prepared and distributed to major newspapers in the range of the species, as well as to smaller newspapers in the vicinity of the species' habitat. Publicity should not specify locations of plants.

   5.2 Prepare articles for popular and scientific publications. The need to protect the species in its native habitat and cooperation among local, State, and Federal organizations and individuals should be stressed. Scientific publications should emphasize additional research that is needed and solicit research assistance from colleges and universities that may have conducted studies on closely related species.

6. Annually assess success of recovery efforts for the species. Review of new information, evaluation of ongoing actions, and redirection, if necessary, is essential for assuring that full recovery is achieved as quickly and efficiently as possible.

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PART III
IMPLEMENTATION SCHEDULE

KEY TO IMPLEMENTATION SCHEDULE COLUMNS 1 & 4

General Category (Column 1):

Information Gathering - I or Research - R

1. Population status
2. Habitat status
3. Habitat requirements
4. Management techniques
5. Taxonomic studies
6. Demographic studies
7. Propagation
8. Migration
9. Predation
10. Competition
11. Disease
12. Environmental contaminant
13. Reintroduction
14. Other information

Acquisition - A

1. Lease
2. Easement
3. Management agreement
4. Exchange
5. Withdrawal
6. Fee title
7. Other

Other - O

1. Information and education
2. Law enforcement
3. Regulations
4. Administration

Management - M

1. Propagation
2. Reintroduction
3. Habitat maintenance and manipulation
4. Predator and competitor control
5. Depredation control
6. Disease control
7. Other management

Priorities within this section (Column 4) have been assigned according to the following:

Priority 1 - An action that must be taken to prevent extinction or to prevent the species from declining irreversibly in the foreseeable future.

Priority 2 - An action that must be taken to prevent a significant decline in species population/habitat quality or some other significant negative impact short of extinction.

Priority 3 - All other actions necessary to provide for full recovery of the species.

*1 GENERAL CATEGORY	PLAN TASK	TASK NUMBER	PRIORITY	TASK DURATION	RESPONSIBLE AGENCIES *2 FWS REGION	FWS DIVISION	OTHERS *3	ESTIMATED FISCAL YEAR COSTS *4 FY 1	FY 2	FY 3	COMMENTS/NOTES
A3, I4, and M3	Develop interim research and management plans in conjunction with landowners.	1.1	1	2 years	4, 5	FWE	SCA	5	5	---	
I1 and I2	Search for additional populations.	1.2	2	3 years	4, 5	FWE	SCA	20	10	10	
I2 and M7	Determine habitat protection priorities.	1.3	1	1 year	4, 5	FWE	SCA	1	---	---	
M7	Evaluate habitat protection alternatives.	1.4	1	2 years	4, 5	FWE	SCA	1	1	---	
I/R6	Determine population size and stage-class distribution for all populations.	2.1	2	2 years	4, 5	FWE	SCA	15	15	---	
I/R2, 3, and 10	Study abiotic and biotic features of the species' habitat.	2.2	2	5 years	4, 5	FWE	SCA	25	15	15	
I/R6	Conduct long-term demographic studies.	2.3	2	5 years	4, 5	FWE	SCA	16	6	6	
I/R14	Determine the effects of past and ongoing habitat disturbance.	2.4	2	3 years	4, 5	FWE	SCA	8	4	4	

IMPLEMENTATION SCHEDULE

#1 GENERAL CATEGORY	PLAN TASK	TASK NUMBER	PRIORITY	TASK DURATION	RESPONSIBLE AGENCIES #2 FWS REGION	RESPONSIBLE AGENCIES #2 FWS DIVISION	RESPONSIBLE AGENCIES #2 OTHERS #3	ESTIMATED FISCAL YEAR COSTS #4 FY 1	ESTIMATED FISCAL YEAR COSTS #4 FY 2	ESTIMATED FISCAL YEAR COSTS #4 FY 3	COMMENTS/NOTES
I4	Define prerequisites for self-sustaining populations and develop appropriate habitat management guidelines based upon the data obtained from Tasks 2.2 through 2.4.	2.5	2	1 year	4, 5	FWE	SCA	---	---	5	
M3	Implement appropriate management techniques as they are developed from previous tasks.	2.6	2	Unknown	4, 5	FWE	SCA	?	?	?	
R7 and M2	Develop techniques and reestablish populations in suitable habitat within the species' historic range.	2.7	3	5 years	4, 5	FWE	SCA	---	20	10	
M1 and R7	Develop a cultivated source of plants and provide for long-term seed storage.	3	2	3-5 years	4, 5	FWE	SCA	5	5	1	
O2	Enforce laws protecting the species and/or its habitat.	4	1	Ongoing	4, 5	FWE	SCA	2	2	2	
O1	Prepare and distribute news releases and informational brochures.	5.1	3	Ongoing	4, 5	FWE	SCA	2	1	1	

*1 GENERAL CATEGORY	PLAN TASK	TASK NUMBER	PRIORITY	TASK DURATION	RESPONSIBLE AGENCIES *2 FWS REGION	FWS DIVISION	OTHERS *3	ESTIMATED FISCAL YEAR COSTS *4 FY 1	FY 2	FY 3	COMMENTS/NOTES
01	Prepare articles for popular and scientific publications.	5.2	3	Ongoing	4, 5	FWE	SCA	1	.5	.5	
04	Annually assess success of recovery efforts for the species.	6	3	Ongoing	4, 5	FWE	SCA	.5	.5	.5	

*1 - See page preceding this Implementation Schedule entitled "Key to Implementation Schedule Columns 1 & 4."

*2 - FWS - U.S. Fish and Wildlife Service
FWE - Fish and Wildlife Enhancement
SCA - State Conservation Agencies: State plant conservation agencies of participating states (in North Carolina, these are the Plant Conservation Program [North Carolina Department of Agriculture] and the Natural Heritage Program [North Carolina Department of Natural Resources and Community Development]; in South Carolina, the Heritage Trust Program [South Carolina Wildlife and Marine Resources Department]; in Georgia, the Natural Heritage Inventory [Georgia Department of Natural Resources]; in Maryland, the Natural Heritage Program [Maryland Department of Natural Resources]; and in Delaware, the Office of Nature Preserves [Delaware Department of Natural Resources and Environmental Control]).

*3 - Other agencies' responsibility would be of a cooperative nature or projects funded under a contract or grant program. In some cases contracts could be let to universities or private enterprises.

*4 - All estimates are for FWS funds only (in thousands).

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USFWS 1990b

Sec 9.3 Ref 57

SCEG-502

HARPERELLA (*Ptilimnium nodosum*)

RECOVERY PLAN

Prepared by

[illegible] Heritage

for

U.S. Fish and Wildlife Service, Region 5

Harperella (*Ptilimnium nodosum* (Rose) Mathias)

Recovery Plan

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Date: MAR 5 1991

* * *

The following recovery plan, prepared by the Maryland Natural Heritage Program for the Northeast Region of the U.S. Fish and Wildlife Service, delineates reasonable actions directed toward recovering and/or protecting the endangered harperella (Ptilimnium nodosum). Recovery objectives will be attained and funds made available subject to budgetary and other constraints, as well as the need to address other priorities.

The plan does not necessarily represent the approval or official position of any individuals or agencies other than the U.S. Fish and Wildlife Service. This approved recovery plan is subject to modification as dictated by new findings, changes in species status, and the completion of recovery tasks.

Literature citations should read as follows:

U.S. Fish and Wildlife Service. 1990. Harperella (Ptilimnium nodosum) Recovery Plan. Newton Corner, Massachusetts. 60 pp.

Additional copies may be purchased from:

Fish and Wildlife Reference Service
5430 Grosvenor Lane, Suite 110
Bethesda, Maryland 20814
301/492-6403 or 1-800/582-3421

Fees vary depending on number of pages.

EXECUTIVE SUMMARY

Current Status: Harperella (Ptilimnium nodosum) consists of 13 known populations in seven southeastern states, down from 26 historical populations. The plant is threatened by small population sizes and hydrological manipulations of the habitat. This species was listed as endangered in September, 1988.

Habitat Requirements: P. nodosum is a rare plant native to seasonally flooded rocky streams and coastal plain ponds. One site occurs on a granite outcrop. In both its riverine and pond environments (and its outcrop occurrence), the plant occurs only in a narrow range of water depths; it is intolerant of deep water or conditions that are too dry. The riverine form is found in microsites that are sheltered from rapidly moving water.

Recovery Objective: To delist the species.

Recovery Criteria: To downlist: (1) 13 stable populations and (2) permanent protection for all 13 populations. To delist: (3) 26 self-sustaining populations, (4) distribution throughout the historical range, and (5) permanent protection of all populations.

Recovery Strategy: Nine currently large or stable populations must be protected and maintained at current status or increased. Four marginal populations must be protected and augmented to the point where they can be self-sustaining. Thirteen additional populations must be discovered or established. These levels will be achieved through habitat protection and watershed conservation measures, increased understanding and implementation of management and propagation techniques, and increased public awareness.

Actions Needed:

1. Protect plants and their habitat through landowner cooperation, land protection, and regulatory authorities.

2. Where needed, seek conservation of watersheds to protect populations.

3. Search for additional populations.

4. Study species and habitat characteristics.

5. Develop a cultivated sources of plants and provide for seed storage.

6. Implement appropriate management techniques, particularly for pond populations.

7. Re-establish populations within the species' historical range.

8. Inform the public about the plant's status and recovery needs.

Estimated Costs and Time Frame: The total cost over the next three fiscal years for recovery of P. nodosum, exclusive of the cost of land acquisition and conservation easements, amounts to $185,000. Costs for full recovery have not been estimated at this time. The time frame for achieving full recovery is unknown, pending further studies of the species' requirements.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

PART I: INTRODUCTION

Ptilimnium nodosum (Harperella) is a small member of the carrot family (Apiaceae) that was originally described by Rose (1905) and taxonomically revised by Kral (1981) to include P. fluviatile Rose. It is a rare plant native to (1) seasonally flooded rocky streams in Maryland, West Virginia, North Carolina, Alabama, and Arkansas, and (2) coastal plain ponds in South Carolina (Figure 1). The sole Georgia site occurs on a granite outcrop.

In both its riverine and pond environments, P. nodosum occurs only in a narrow band of water depths: neither too shallow, for the plant cannot tolerate dry conditions, nor too deep for the plant to complete its life cycle. The plant is threatened by small population sizes and hydrological manipulations of the habitat such as upstream water impoundments, declining water quality, and pond drainage.

Despite the taxonomic synonymy between the pond ("Nodosum") and riverine ("Fluviatile") forms, important ecological, genetic, and conservation distinctions remain that affect the protection strategy outlined in this plan. For example, the pond form is both profoundly threatened (by habitat disturbance and very small population sizes) and genetically distinct from the riverine form, necessitating particular recovery emphasis. As for the riverine form, annual flooding cycles cause significant dynamism in the distribution of plants within populations, warranting a broad view of habitat protection.

Ptilimnium nodosum was Federally listed as an endangered species on September 28, 1988 (U.S. Fish and Wildlife Service 1988). It is also listed as endangered in Maryland and

Figure 1. Flowering stem of _Ptilimnium nodosum_

North Carolina. An unofficial list of rare plants in Alabama records it as threatened (Freeman et al. 1979), and the South Carolina Heritage Trust lists it as a species "of national concern." State listing of P. nodosum in Georgia and Arkansas is pending.

Taxonomic and Morphological Description

The genus Ptilimnium contains four species (P. nodosum, P. costatum, P. capillaceum, and P. nuttallii), of which all but one (P. nuttallii) are found in the southeastern United States. While all Ptilimnium species are found in swampy or wet areas, the other Ptilimnium species differ from P. nodosum in having finely compounded leaves.

Rose (1905) originally described two new species collected from southwestern Georgia and northern Alabama. These plants were named Harperella nodosum Rose and H. fluviatilis Rose. Rose also collected a related plant in the Potomac River basin, near Hancock, Maryland. He named this plant H. vivipara because of its tendency to form asexual buds (Rose 1911).

Mathias (1936) determined that Harperella did not differ fundamentally from members of the genus Ptilimnium, despite differences in leaf morphology. She renamed the species Ptilimnium nodosum (Rose) Mathias, P. fluviatilis (Rose) Mathias, and P. viviparum (Rose) Mathias.

Easterly (1957) decided that the relative size of P. fluviatilis and P. viviparum, which had been used to separate the types, was too variable a character to distinguish the species. Consequently, he joined the two forms under the name P. fluviatile.

Kral (1981) studied the quantitative differences in morphology and phenology between P. nodosum and P. fluviatile (Easterly 1957). He concluded that the species' characteristics differed in mean but broadly overlapped and were probably the result of environmental factors -- particularly the extent of flooding -- rather than genotypic differences that would warrant a species rank. Additionally, Kral (1981) noted that P. nodosum and P. fluviatile have an identical haploid chromosome number (N = 6) differing from other species in the genus (Easterly 1957). Thus, Kral (1981) synonymized the two species under the earlier name, Ptilimnium nodosum. As listed under the Endangered Species Act, P. nodosum includes P. fluviatile.

Despite the synonymy, there are significant differences in some basic life history features and the genetic composition of populations. For example, while the coastal plain pond form is apparently a true annual (i.e., germinates, flowers, and dies within one season or year), the riverine form is a perennial (or at least a biennial that can flower in both years) (Maddox and Bartgis 1989).

P. nodosum (nodosum vs. fluviatile) populations are genetically variable (Kress et al. 1990), although like most rare species it is genetically depauperate. Preliminary evidence suggests that the pond form is genetically distinct from the riverine form, although the difference does not necessarily warrant a species rank. Genetic studies, funded by the Maryland Natural Heritage Program and the U.S. Fish and Wildlife Service, are continuing.

A summary of morphological characters for the riverine and pond forms of P. nodosum is given in Table 1. The primary morphological distinction between the Nodosum and Fluviatile forms is that the former is somewhat larger and flowers earlier in the summer (Easterly 1957, Radford et al. 1968, Kral 1981).

Many workers have noted that the Fluviatile form tends to proliferate at the nodes (Easterly 1957, Kral 1981, Maddox and Bartgis 1989) while the Nodosum form does not. Easterly (1957) observed that the leaves of "P. fluviatile" were

Table 1. Morphological characteristics of the "Nodosum" and "Fluviatile" forms. Based on Easterly (1957), Radford et al. (1968), Kral (1981), and Maddox and Bartgis (1989).

Character	Nodosum	Fluviatile
Height (cm)	40 - 100	20 - 50
Leaf length (cm)	8 - 30	4 - 12
Bract length (mm)	2 - 5	1 - 4
Number of primary rays	4 - 16	3 - 15
Ray length (cm)	1 - 2.5	0.5 - 1.5
Calyx teeth length (mm)	1 - 2	1 - 2
Color of anthers	rose	rose
Flower	for both forms, each umbel contains both perfect and male florets (i.e., andromonoecy)	
Styles (mm)	0.4 - 0.8	0.4 - 0.8
Fruit Shape	elliptical	elliptical
Fruit lateral ribs	inconspicuous	inconspicuous
Fruit length (mm)	1.5 - 2.0	1.5 - 2.0
Pollen grain length (μ)	20.1 - 23.5	17.1 - 22.1
Pollen grain width (μ)	10.4 - 13.6	9.8 - 12.6
Chromosome number	6	6
Flower Phenology	May - June	July - October
Germination period	probably spring?	fall
Asexual reproduction	no	yes
Habitat	edges of coastal plain ponds, also a wet granite outcrop	shoals, bedrock outcrops, and protected banks of seasonally flooded rocky streams

"evergreen" and conspicuously present throughout the winter, while Nodosum leaves were not. Easterly (1957) called "P. fluviatile" an asexual annual, that is, a plant that produces asexual buds that live one year. Maddox and Bartgis (1989, 1990a) found that such asexual buds can survive over two years and flower each year, suggesting that it is a (perhaps short-lived) perennial.

Current and Historical Distribution

Thirteen populations of P. nodosum are currently known to exist in seven states (Figure 2). Eleven populations have been extirpated, and two are of uncertain status (Table 2).

Nine of the extant populations contain the riverine form for the species, and four populations (in South Carolina and Georgia) contain the coastal plain pond form. The plant has been extensively searched for in much potential habitat; new populations were verified in 1988 (Maryland) and 1990 (Arkansas), and a population was rediscovered in 1990 (Alabama). The discovery in Arkansas is particularly notable because it expands the known range of the species, and shows that it is important to search for the plant in previously unsurveyed areas. Further searches in Arkansas, as well as new searches in southern Missouri and eastern Oklahoma, are warranted.

Although no records for the plant exist from Tennessee or Pennsylvania, activities in these states may affect P. nodosum. Three populations occur along creeks that pass through these states: Sideling Hill and Fifteen Mile Creeks in Maryland originate in Pennsylvania and contain suitable habitat (R. Bartgis and D. Maddox pers. obs.); Town Creek in Alabama originates in Tennessee.

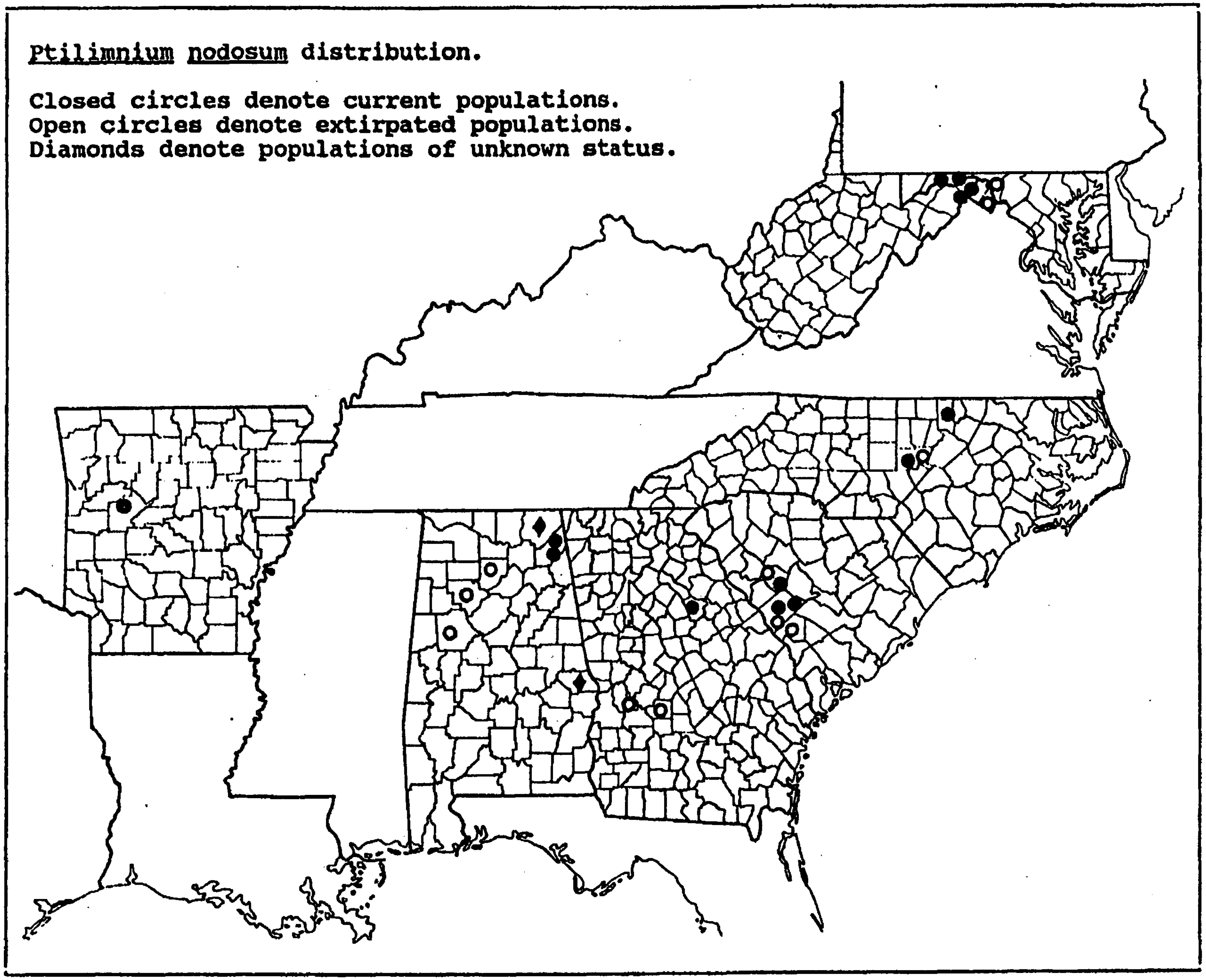

Figure 2. Distribution of current and historical *P. nodosum* populations.

Table 2. State and county locations of current and historical *P. nodosum* populations.

STATE	COUNTY	EXTIRPATED POPULATIONS	SITES NOT VERIFIED	EXTANT POPULATIONS
AL	Cullman	1	0	0
AL	DeKalb	0	0	2*
AL	Jackson	0	1	0
AL	Lee	0	1	0
AL	Tuscaloosa	1	0	0
AL	Walker	1	0	0
AR	Yell	0	0	1
GA	Dooley	1	0	0
GA	Greene	0	0	1
GA	Schley	1	0	0
MD	Allegany	0	0	2**
MD	Washington	1	0	0
NC	Chatham	1	0	1
NC	Granville	0	0	1
SC	Aiken	1	0	2
SC	Barnwell	1	0	0
SC	Saluda	1	0	1
WV	Jefferson	1	0	0
WV	Morgan	0	0	2
	TOTAL	11	2	13

* One site partially in Cherokee County.

** Sideling Hill population on border between Allegany and Washington Counties.

Population Status

A state-by-state summary of the size and protection status of each population follows.

Alabama

Two extant populations occur in Alabama (see Table 3). One consists of several thousand individuals distributed among fewer than ten subpopulations along 10-15 miles of the Little River, which occurs on the border of Cherokee and DeKalb Counties. A second population of < 100 plants was recently confirmed on Town Creek in DeKalb County (Scott Gunn and Mark Bailey, Alabama Natural Heritage Program, pers. comm. 1990); prior to 1990, this occurrence had been last seen in 1960 (S. Gunn pers. comm. 1989).

Approximately one-third of the Little River site is within DeSoto State Park, and one-third is under private ownership but leased to the Department of Game and Fisheries; the other third is in private ownership. The population on Town Creek is entirely under private ownership.

In 1979, Freeman et al. reported the plant from Jackson and Lee Counties and made deposits in the Auburn University Herbarium. Although these two sites have not been recently confirmed (S. Gunn pers. comm. 1989), they make Jackson and Lee Counties high priority for future searches. The occurrence of populations in other counties such as Tuscaloosa, Cullman, and Walker is unlikely due to heavy strip-mining and extensive impoundment of rivers (S. Gunn pers. comm. 1989).

There is some residential development in the area of the Little River population. In addition, there are several small abandoned dams upstream from the population. Flooding could damage the population if any of these dams was to

Table 3. Current status of extant populations.

ST	County	Site Name	Most Recent Survey	Size	Ref.	Ownership
AL	DeKalb	Little River	1990	thousands	1	public/ private
AL	DeKalb	Town Creek	1990	< 100	1	private
AR	Yell	Irons Fork	1990	hundreds	2	public
GA	Greene	Outcrop	1990	< 100	3	private
MD	Allegany	Sideling Hill	1990	30,000	4	public
MD	Allegany	Fifteen Mile	1990	500	4	public
NC	Chatham	Deep River	1989	200-300	5	private
NC	Granville	Tar River	1989	200-300	5	private
SC	Aiken	Monetta Sink	1990	51-100	6	private
SC	Aiken	Windmill	1990	100's	6	private
SC	Saluda	High Ponds	1990	50-100	6	private
WV	Morgan	Sleepy Creek	1990	1,000,000	7	private
WV	Morgan	Cacapon	1990	10,000	7	private

References:

1 - S. Gunn (AL Heritage)
2 - V. Bates (AR Heritage and TNC)
3 - T. Patrick (GA Heritage)
4 - Maddox and Bartgis (1989)
5 - M. Boyer and R. Sutter (NC Plant Conservation Program)
6 - J. Nelson (SC Heritage)
7 - B. McDonald (WV Heritage)

collapse. Construction of new dams and the consequent permanent inundation of habitat is also a potential threat.

Analysis of Little River water samples revealed high levels of human choleriform bacteria, suggesting a high amount of sewage input (S. Gunn pers. comm. 1990). Also, some sites contained heavy algal populations (R. Bartgis pers. obs.), which may reduce the number of suitable sites for establishment of young plants. Acidic runoff from abandoned but unreclaimed strip mines may pose a pollution threat to both populations, but especially to Town Creek (S. Gunn pers. comm. 1990). There is no state legal protection for P. nodosum (or any plant) in Alabama.

A section of the Little River which includes a major subpopulation is currently under review for possible inclusion in the National Park system.

Arkansas

The single extant population in Arkansas was discovered in 1990 on Irons Fork in Yell County (Vernon Bates, Arkansas Natural Heritage Program and TNC, pers. comm. 1991). The population contains several hundred plants distributed among three subpopulations over 5-7 miles of river.

At the present time, all three subpopulations are in relatively good condition. Two of the subpopulations are within the Ouachita National Forest, and appear unthreatened. The third subpopulation occurs on private land, on a gravel bar that is often used as a source of gravel for roads. Although the plant is due for state listing, this will not afford any state legal protection to these subpopulations.

Discovery of the Arkansas population dramatically increases the known range of P. nodosum, and suggests the possibility that the plant may occur in several heretofore unsurveyed areas, including southern Missouri, eastern

Oklahoma, and the Boston Mountains in northwest Arkansas (V. Bates pers. comm. 1991).

Georgia

The single extant population in Georgia occurs in Greene County on a small (0.25 acre) granite outcrop that is in private ownership. The site is within 0.5 mile of a freeway exit ramp, but there are currently no known plans to expand the freeway or develop this area.

The population has no legal protection; although the plant is proposed for inclusion on the state list of endangered plants, state legal protection is extended only to populations on public lands. Further, because it is very small and isolated, it is especially susceptible to chance events in weather or demography.

Plants in this population number approximately 100 in a good year and as few as two in a poor year, and grow at the edges of a small seasonal pond. Although this outcrop site would seem to be atypical P. nodosum habitat, it is similar to other sites in regard to the seasonality of water levels. The plants grow at an intermediate water depth where they are neither drowned nor desiccated (Tom Patrick, Georgia Natural Heritage Inventory, pers. comm. 1989). The site has been used for experimental transplants of several granite outcrop species; however, P. nodosum is thought to be a natural occurrence (T. Patrick pers. comm. 1989).

Two historical sites in Schley and Dooley Counties still have appropriate habitat but contained no P. nodosum in 1989. Both sites are coastal plain pond habitats.

No other granite outcrop sites have been discovered despite intensive surveys (over 150 granite outcrops in Georgia, Alabama, and South Carolina have been checked for P. nodosum) by Jim Allison and others (T. Patrick pers. comm. 1989). Many coastal plain ponds in Georgia have been surveyed either for P. nodosum or a related species, Oxypolis canbyi, and no new pond populations are expected to be found in the state. However, rocky streams in the northern half of the state need investigation because the Little River (the P. nodosum site in Alabama) originates in Georgia's Cumberland Plateau.

Maryland

Both extant Maryland populations appear to have a stable population size and distribution within their habitats. The larger of the two Maryland populations occurs in Sideling Hill Creek on the border of Allegany and Washington Counties, and contains at least 30,000 individuals divided among 50-60 subpopulations (Maddox and Bartgis 1989). About three-quarters of these subpopulations are on state-owned sites (State Forest, Wildlife Management Area, or State Highway Administration lands) or sites that are unlikely to be developed (a Boy Scout Reservation).

Taking endangered species on Maryland state lands is prohibited without a permit, and land managers are required to consider the plant when planning land management activities. Subpopulations within the wildlife management area occur in designated Natural Heritage Areas, but specific management prescriptions for these or other state-owned areas have not yet been developed. The State is negotiating for acquisition of the largest privately-owned tract of P. nodosum habitat on Sideling Hill Creek. The National Guard leases this area, but their activities have not affected the plant or its habitat.

The second population (Fifteen Mile Creek) consists of a single subpopulation containing less than 500 individuals. The plants occur on state forest land, but no specific management program for protecting this habitat has been developed.

Major bridge and freeway construction projects recently occurred on both streams, causing erosion and heavy siltation problems. Experimental transplants of P. nodosum exhibited poor survivorship at the freeway construction site on Sideling Hill Creek despite the existence of appropriate habitat (Maddox and Bartgis 1990a), suggesting that environmental perturbations from construction (chemical or sediment runoff) may be detrimental to the plant's survival.

Despite these projects, both creeks remain generally undisturbed, and there is little residential development on the adjacent uplands, although some agriculture occurs in the floodplain on Sideling Hill Creek. Human impacts may eventually increase since tourism and vacation home development are expected in the future.

Several other stream systems in the state, including the Potomac River (with a historical harperella site adjacent to the C&O Canal National Historic Park), contain apparently potential habitat for P. nodosum. The Potomac, however, has been heavily polluted in the past by industrial (especially coal mining) and agricultural waste; experimental transplants on a Potomac River site experienced 100% mortality within nine months (Maddox and Bartgis 1989, 1990a).

Most other streams in the area that appear to be physically suitable and relatively undisturbed have been surveyed for the plant. Although the Fifteen Mile Creek site was not verified until 1988, no new sites in Maryland are expected to be found.

North Carolina

The two North Carolina populations are found on the Tar and Deep Rivers. Each population consists of a single subpopulation containing less than 300 individuals, and both have been relatively stable since 1985. Both populations are in private ownership and are not protected.

A historical site on the Haw River, near its confluence with the Deep River, was destroyed by construction of a dam. This site occurs one kilometer downstream from the confluence with the Rocky River, suggesting that additional sites may exist on the Rocky River.

Three proposed projects upstream from the extant Deep River _P. nodosum_ population are potential threats: expansion of a sewage treatment facility in Siler City, which may affect the water quality of the Rocky River; an industrial park in Siler City; and reactivation of a coal mine (last operative in the 1800's) on the Deep River.

Currently under review is designation of a High Quality Water Administrative Rule (General Statutes 143-214 and 143-215) that provides limited protection to drainage systems containing rare species. Both _P. nodosum_ sites would be strong candidates for a High Quality Water designation.

South Carolina

Four of seven historically known populations were reported as extant in 1989. However, one of the four did not contain _P. nodosum_ in 1990 (John B. Nelson, South Carolina Heritage Trust, pers. comm.). Instead the site contained _P. cappillaceum_, and there is now some doubt as to whether it ever contained _P. nodosum_ (in Table 2 the site is classified as "extirpated").

All seven populations occur or occurred in seasonal coastal plain ponds (sometimes called "Carolina Bays" or "boggy ponds"), which have been disturbed by drainage ditches. The three extant populations appear to be feeble or declining. All three populations are relatively small and experience wide yearly population fluctuations. The causes of such fluctuations are unknown, although _Oxypolis canbyi_ experiences population fluctuations caused by annual variation in water levels (Boyer 1988).

None of the extant sites is protected. Coastal plain pond sites are affected by ditching and dredging that is done to make land more suitable for agriculture, silviculture, or livestock watering. The plant is very intolerant of dry conditions, and such activities pose severe and immediate threats to the populations.

Because these populations are small and isolated, they are particularly susceptible to chance natural events.

West Virginia

The Sleepy Creek population, the larger of the two extant West Virginia populations, contained as many as one million individuals in 1990, with many subpopulations distributed over 15 river miles (Brian McDonald, West Virginia Natural Heritage Program, pers. comm.). The second population, on the Cacapon River, contained approximately 100,000 individuals in 20 subpopulations in 1990, distributed over 20 river miles.

P. nodosum was reported in 1830 at Harpers Ferry (probably on the Shenandoah River). This area was subsequently heavily disturbed by industrialization, dams, Civil War events, and severe floods; recent attempts to find P. nodosum there were unsuccessful. Although excellent habitat occurs on several other streams in West Virginia, all have been extensively surveyed for P. nodosum (a total of 422 km) and apparently do not contain the species (R. Bartgis pers. obs.).

Much of the area where P. nodosum occurs in West Virginia has been subdivided and sold for vacation home sites. From 1970 to 1985, 47% of the river frontage on the Cacapon was subdivided into lots of ten acres or less. Possible threats to the species posed by shoreline use include (1) tree clearing along the river banks and consequent erosion, (2) herbicide and pesticide runoff, and

(3) trampling and bank destabilization through human use. In 1984 on Sleepy Creek, up to 10,000 plants were destroyed by soil dumping and siltation from one construction project. The highly fragmented land ownership patterns on Sleepy Creek and the Cacapon River seriously complicate habitat protection activities.

In terms of impending threats, a ski resort has been proposed along the Cacapon River. Potential impacts of the resort include increased sediment runoff from steep mountains during slope clearing and heavy use of river water for snow-making.

Further, the West Virginia Department of Commerce, Labor and Environmental Resources is proposing to divert water from the Cacapon River for a golf course and other state park facilities. Both the ski resort and the commerce department proposals would divert water from the Cacapon watershed and release it into the Sleepy Creek watershed.

Only one of the subpopulations in West Virginia occurs on a protected site (a Nature Conservancy easement on one Cacapon River stand); however, The Nature Conservancy has included in its Registry Program some of the landowners on both streams whose land was known to contain P. nodosum in 1985.

Habitat, Life History, and Ecology

Published reports (e.g., Easterly 1957, Kral 1981) and current observations (Rob Sutter, The Nature Conservancy; T. Patrick; J. Nelson; B. McDonald; Maddox and Bartgis 1989) confirm that P. nodosum comprises populations that occupy two somewhat distinct habitats. These differences in habitat constitute the historical P. nodosum and P. fluviatile division. There is also some evidence that the Nodosum and Fluviatile forms are genetically differentiated, although not necessarily at the level of distinct species (Kress et al. 1990).

Since differences in both habitat and biology are potentially important to issues of conservation and stewardship, the ecology of each form, or ecotype, is discussed separately in the following sections.

Pollination and seed viability do not appear to be limiting for either form, although much more is known about Fluviatile in these respects. Plants of both forms contain both bisexual and male florets and at least some self-pollination is possible (Easterly 1957).

Neither form has any reported herbivores, although slugs killed some experimental transplants in drier sites in Maryland (Maddox unpubl. data).

Fluviatile Ecotype

Life History:

Fluviatile grows on rocky and sandy shoals and, rarely, on muddy banks of seasonally flooded and quickly moving streams in Maryland, West Virginia, North Carolina, Alabama, and Arkansas.

Plants flower in July and August, and fluctuating water levels tend to knock over flowering stems. In the Potomac watershed, seeds germinate in September, often clustered at the site of the fallen flower. Decumbent flowering stems proliferate by developing rooting shoots at each node (Rose 1911; Easterly 1957; Maddox and Bartgis 1989, 1990a). The flowering stems then decompose, leaving physically distinct parent and offspring shoots; the flowering stem thus acts as a stolon. The parent plants, the asexual buds, and the surviving seedlings then overwinter as evergreens under high water. All plants may grow and produce flowering stems the next season (Maddox and Bartgis 1989, 1990a).

Thus, the Fluviatile type behaves as a perennial in the manner of such stoloniferous perennials as _Fragaria virginiana_ and _Viola_ species, which produce vegetative daughters that live up to three years (Cook 1983).

Perennial behavior in Fluviatile was originally recorded by Rose (1911) and Easterly (1957), and has been recently observed in West Virginia (B. McDonald pers. comm. 1989), North Carolina (R. Sutter pers. comm. 1990), and Alabama (S. Gunn pers. comm. 1989). Easterly (1957) believed that the asexual buds survived only two years (asexual biennality) and described the plant as an asexual annual. It may be more appropriate, however, to call Fluviatile a short-lived perennial (Maddox and Bartgis 1989, 1990a).

An alternative possibility is that Fluviatile is a long-lived annual that does not annuate because it is protected from cold and drought by high winter water (i.e., a facultative perennial). However, Fluviatile is somewhat frost hardy. Ten Maryland plants grown in pots (five submerged and five in water up to the soil surface) survived eight weeks in intermittently sub-zero weather occasionally as low as -10°C (Maddox unpubl. data).

The major adaptive significance of vegetative spread in this plant may be that it permits the plant to maintain a grip on a substrate that is continuously eroded by heavy water flow in winter and spring. Seedlings, which at the onset of winter high water have only cotyledons or one small leaf, may be too small and insecurely rooted to survive winter flood in meaningful numbers. In 1988 in Maryland, Maddox and Bartgis (1990a) observed significant over-winter mortality among seedlings. No seedlings were produced in 1989 because of unusually high summer and fall water levels.

Seeds readily float, so dispersal probably is mediated by water flow; however, safe sites downstream are infrequently and haphazardly found. Further, seeds have no structures to facilitate aerial dispersal and drop quickly to the ground, with many seeds germinating directly under the parent plant. Thus, seed dispersal to new sites is probably a rare event. The longevity of seeds in the soil or water is unknown.

Vegetative buds (leaves plus roots) can live indefinitely floating in water, and can root themselves when grounded under wet and stable conditions. Vegetative dispersal downstream is thus possible. Slow dispersal upstream may occur as subpopulations expand along the river banks or by the movement of shoals through upstream accumulation of sediments.

Habitat Description and Requirements:

Fluviatile typically grows on rocky shoals, in crevices in exposed bedrock, and, rarely, along sheltered muddy banks. The largest subpopulations are often found in sunny sections of creeks.

Within such areas the plants are found in microsites that are sheltered from the erosive effects of rapidly moving water; for example, plants are usually found on the downstream side of large rocks or amidst thick clones of water willow (Justicia americana (Acanthaceae)). This anecdotal evidence indicates that Fluviatile is restricted to sites that are somewhat protected from the onslaughts of flood waters and, possibly, ice scouring.

Fluviatile is restricted to a very narrow range of mean water depths. For instance, the presence of Fluviatile in Maryland was strongly associated with certain intermediate water depths (Maddox and Bartgis 1990a). The plant was entirely absent from the shallowest or driest areas and deep waters, even though such areas could include J. americana

There are three basic explanations for this restriction to intermediate water depths. First, P. nodosum may be too small to complete its life cycle in very deep water. Seed germination would be especially problematic in continuously inundated areas. Second, water depth is strongly correlated with water velocity. P. nodosum may be physically eliminated from deeper water simply because the plants cannot hold on to the substrate. Maddox and Bartgis (1989, 1990a) observed significant mortality among experimental transplants placed in slightly deeper water. Third, P. nodosum may be absent from shallow water because of either the negative effects of competition by other species and/or physiological intolerance of dry conditions. Potted P. nodosum in a greenhouse are very sensitive to even moderately dry conditions experienced for short periods (D. Maddox pers. obs.). Sufficiently watered individuals survive well in otherwise similar conditions.

Associated Species:

Typical associates of Fluviatile in riverine habitats include: (1) on rocky shoal sites, Justicia americana, Isoetes riparia, and Orontium aquaticum; (2) on sandy banks at the water's edge, Eupatorium coelestinum, Eupatorium fistulosum, Lobelia cardinalis, Arthraxon hispidus, Lysimachia terrestris, Andropogon gerardi, Tripsacum dactyloides, Panicum spp., Carex torta, and Scirpus expansus.

In Arkansas, associated species include Juncus repens, Dulichium arundinaceum, Xyris spp., Hydrolea ovata, Alnus serrulata, and Gratiola brevifolia.

Demography:

Fluviatile populations exhibit considerable substructure consisting of many small units situated on small patches of appropriate habitat. Two observations concerning population substructure are potentially important: (1) there is significant turnover in subpopulations, and (2) a large majority of subpopulations are small, containing less than 200 individuals.

There is significant dynamism in the persistence of individual stands. Fifteen percent (15%) of subpopulations at Maryland's Sideling Hill Creek were extirpated or created during 1988-1989 (Maddox and Bartgis 1990a). Over a five-year period, 25% of stands along a 1.5 km section of Sleepy Creek in West Virginia were lost or created (5% per year). There was a 30% rate of stand turnover on the Cacapon River from 1984 to 1988.

This dynamism is correlated with the size of subpopulations: small stands are more likely to be reduced in size or extirpated altogether (Maddox and Bartgis 1990a). This observation has important ramifications, since most subpopulations range-wide are small, containing less than 200 individuals.

The fact that small stands have a relatively high probability of extirpation or decline is critical to management and recovery. High rates of stand dynamism suggest that populations made up of one or a few small stands, such as the two populations in North Carolina, Maryland's Fifteen Mile Creek, and to a lesser extent West Virginia's Cacapon River, are at significant annual risk. Even in large populations, subpopulation turnover rates of 5-15% per year suggest that a series of several "poor" years could transform these large populations into relatively small ones.

The implication for the development of a protection or recovery strategy is that the species cannot be protected by preserving a few of the exemplary subpopulations. For example, several West Virginia sites containing _P. nodosum_ were registered on the basis of 1985 data, but contained no

P. nodosum in 1989. A broader view of protection -- a watershed perspective -- must be adopted that accounts for *P. nodosum's* sensitivity to environmental stochasticity.

Nodosum Ecotype

Significantly less is known about Nodosum because it is less common and has not been the subject of intensive research. What is known comes from the publications of Mathias (1936), Easterly (1957), and Kral (1981), from observations during site visits by local biologists (T. Patrick, GA Heritage; J. Nelson, SC Heritage Trust; Doug Rayner, Wofford College), and extrapolation from research on Fluviatile. The lack of knowledge about Nodosum and its extreme rarity suggest that further research into its ecological requirements and conservation needs is urgent.

Life History:

Nodosum occupies the edges of coastal plain ponds in South Carolina and a granite flatrock site in Georgia. Five other historical sites in South Carolina and southern Georgia, now extirpated or destroyed, were coastal plain ponds.

Nodosum does not tend to proliferate (Easterly 1957), perhaps because flowering stems are not made decumbent by high water (Kral 1981). The plant behaves as a true annual on these sites, germinating, growing, and flowering in one season. Seedling germination has not been observed, but the fall die-back of adults suggests that germination occurs in spring.

The plant apparently annuates without experiencing a frost; rather, dry conditions seem to stimulate die-back (T. Patrick pers. comm.). The Fluviatile type has also been shown to be extremely sensitive to dry conditions (Easterly 1957, Maddox and Bartgis 1989). Decreasing photoperiod could also play a role in Nodosum's annual behavior.

Dispersal in Nodosum has not been studied. Like Fluviatile, seed dispersal within a site is probably mediated by water flow. Because Nodosum does not proliferate at the nodes, it does not disperse locally through vegetative spread. The longevity of seeds in the soil or water is unknown.

The natural founding of new pond populations is probably very rare because of the plant's (apparently) poor capacity for long distance dispersal and the fragmented dispersion of appropriate habitat. However, the mechanism and frequency of dispersal to new sites has not been studied. Aerial dispersal is possible given the small seeds (without other mechanisms for aerial dispersal, however). Seeds or vegetative shoots may disperse on the feet or coats/feathers of animals, but this has not been observed.

Habitat Description and Requirements:

The few existing sites for Nodosum in the coastal plain are shallow pineland ponds and low savanna meadows. An exception is the Georgia population, which exists on a granite outcrop. Both habitats are seasonally flooded, typically with standing water from late fall through early summer and saturated conditions for the balance of the year. Soils tend to be a peat muck overlying sand or sandy-silt.

Like Fluviatile, Nodosum probably requires intermediate water levels. This is not precisely known and more research could be beneficial, but the conjecture is supported by the fact that Nodosum grows at the edges of its native ponds. Continuously inundated areas are probably too deep for the plant to complete its life cycle, and Nodosum is probably excluded from drier areas by physiological intolerance of drought and by inter-specific competition.

Associated Species:

The dominant species at P. nodosum sites is often Panicum hemitimon. Other species may include many sedges in the genera Rhynchospora (e.g., R. perplexa, R. microcarpa), Carex (e.g., C. walteri, C. lupulina), Eleocharis (e.g., E. tricostata, E. melanocarpa), Psilocarya, Dichromena colorata, and Fimbristylis. Dicot associates include Hypericum fasciculatum, H. denticulatum, H. myrtifolium, Rhexia virginica, R. mariana, R. aristosa, Proserpinaca pectinata, several Ludwigia species, and Sclerolepis uniflora (Kral 1983).

Population Genetics of Both Forms

In a study of electrophoretically detectable genetic variation conducted by the Smithsonian Institution and the Maryland Natural Heritage Program (Kress et al. 1990), seven populations from Maryland, West Virginia, and the Carolinas were sampled (all were Fluviatile populations except for one Nodosum population). Thirteen loci were scored for 118 individual plants.

Levels of genetic variation in P. nodosum were exceptionally low. The mean number of alleles per locus was 1.1 with very little variation among populations. The mean observed heterozygosity (HO) for all populations was 0.011 (Kress et al. 1990). Most genetic variation was found between populations, and at least two populations exhibited significant departures from Hardy-Weinberg equilibrium (i.e., showed a deficiency of heterozygotes). These observations suggest a primarily inbreeding type of breeding system.

Further, analysis suggested that, based on a single Nodosum sample, Nodosum and Fluviatile are genetically distinct.

This work is continuing and will ultimately include all thirteen populations.

Threats and Conservation Needs

Threats to Fluviatile Populations:

Primary threats to the persistence of P. nodosum in riverine habitats involve manipulations of water flow and water quality. Because Fluviatile tends to occupy a narrow range of water depths, manipulations of water flow upstream from populations can easily destroy suitable habitat by inundation or persistent desiccation. Dams, reservoirs, or other water impoundments or diversions would almost certainly threaten any P. nodosum downstream.

Natural fluctuation in water flow causes significant yearly variation in subpopulation persistence. Small subpopulations are particularly susceptible to loss during normal high water events. Thus, small populations such as those in North Carolina or Maryland's Fifteen Mile Creek are at significant yearly risk. Hydrological manipulations on rivers with small populations should be strictly avoided or controlled.

Fluviatile is apparently also sensitive to reductions in water quality. Siltation caused by heavy construction, residential development, and agriculture has been cited as detrimental to the plant. The negative effect of sediment on Fluviatile was substantiated in a greenhouse experiment: turbidity equal to that near a bridge construction site reduced Fluviatile growth rate by 40% (Maddox and Bartgis 1990b).

Another greenhouse experiment indicates that stream acidification (especially pH < 5.0) may cause significant plant mortality (Maddox and Bartgis 1990b). Plants growing in water with pH approximately equal to 3.4 had a 70% mortality rate; in water with pH = 4.6 plants grew at a significantly lower rate than controls. This is potentially important in Alabama, where the extant population has historically experienced low pH due to mining. At Maryland and West Virginia sites, the pH is typically 7.0. However, the acid neutralizing capacity is very low, suggesting that minor acid inputs could significantly lower pH. Other water quality variables, such as increased sewage or nitrate concentration, may also be detrimental.

Finally, habitat moves up and down the river as water flow rearranges the distribution of rocky shoals on the landscape. Thus, protection of small areas of habitat are likely to be ineffective.

This wide range of stream influences on Fluviatile survival and distribution suggests that a broad view of habitat conservation should be adopted. Specific areas of habitat and population occurrence along river corridors will require protection. However, these should be designed as corridors that allow populations to track moving habitat. The integrity of the drainage system upstream is critical and should be protected from perturbations resulting from intensive land use practices such as mining, dams, reservoirs, construction, and agriculture.

Fluviatile grows only in microsites that contain few other plants. This constitutes circumstantial evidence that (a) few other plants are adapted to this plant's harsh flooded environment, and/or (b) P. nodosum is a poor competitor (although no explicit assessment of the plant's competitive ability has been made). The exotic grass Arthraxon hispidus is a potential threat in West Virginia and Maryland, where it occasionally occurs at P. nodosum microsites. However, casual observations in Maryland suggest that Arthraxon's annual habit makes it susceptible to high turbulent water. Unusually high water levels in 1989 apparently eliminated the grass from many P. nodosum areas in Maryland. Nevertheless, the presence of Arthraxon in P. nodosum sites is a threat and should be monitored.

Threats to Nodosum Populations:

Nodosum, like Fluviatile, depends on intermediate water levels and is threatened by either dry conditions or total inundation. Thus, the primary threats to Nodosum populations are hydrological manipulation and physical destruction of their pond habitats.

Coastal plain ponds everywhere are threatened by active drainage for conversion to pine plantations or row crops (Godfrey and Wooten 1979). Lowered water tables are probably detrimental to Nodosum through increased competitive and physiological stress. While hydrological manipulations directly to the pond are clearly detrimental, ditching and other manipulations of the water table from some distance away may affect coastal plain ponds, although the exact area of effect is not known (Pat Phillips, U.S. Geological Survey, pers. comm. 1989). The effective distance of such manipulations clearly is important in determining the zone around a population needed to ensure protection of the hydrological resource.

Occasionally ponds are dredged to create deep ponds for livestock; these deeper water levels probably disrupt the life cycle of Nodosum, a small plant.

No experiments have been conducted to determine the sensitivity of the Nodosum type to declines in water quality.

Despite these threats, P. nodosum sites are spatially discrete and, as such, their protection needs may be easily identified (although the effect of more distant hydrological disturbances remains a question). Since all Nodosum sites have been disturbed by drainage attempts, active management of the sites may be required.

The ecological and life history uniqueness of the Nodosum type and the small size of the few populations suggest that conservation measures for Nodosum should have high priority.

Current Conservation Measures

State Natural Heritage and Endangered Species Programs and The Nature Conservancy have been active in searching for new P. nodosum populations (all states within the species' range except Arkansas), monitoring extant sites (all states except Arkansas), conducting studies of life history and ecology (Maryland), and negotiating voluntary protection agreements with landowners (Maryland, West Virginia). No work has been conducted in Arkansas because, until recently, the state had not been known to be within the plant's range.

While none of the smallest and most immediately threatened sites are protected, a few of the populations are located, at least in part, on state-owned lands, and two of the three Arkansas subpopulations are located on Federal property.

Conservation and management activities accomplished to date are summarized below.

- Population surveys and inventories have been performed at all current sites by State Heritage Programs or botanists from various universities. Active population monitoring occurs only in Maryland and West Virginia.

- Surveys for new populations have been undertaken in all states containing extant populations, except Arkansas. New populations were verified in Maryland in 1988 and Arkansas in 1990. Significant potential habitat or recent unconfirmed records remain to be investigated in Alabama, Georgia, North and South Carolina, Arkansas, southern Missouri, and eastern Oklahoma.

- The Nature Conservancy, Western Pennsylvania Conservancy, and Maryland Department of Natural Resources have begun a comprehensive program to protect Sideling Hill Creek, including upstream areas as buffer. To date, a number of tracts have been registered in Maryland and Pennsylvania, a tract has been acquired on the border of Maryland and Pennsylvania, and the potential purchase of the most significant tract supporting P. nodosum is being negotiated by the State of Maryland and The Nature Conservancy.

- The Nature Conservancy has acquired an easement on one Cacapon River subpopulation. Additional subpopulations in West Virginia have been added to the Conservancy's registry program. The U.S. Fish and Wildlife Service contracted with The Nature Conservancy in 1990 to expand landowner contact efforts on the Cacapon River.

- The Maryland Natural Heritage Program has conducted an extensive two-year investigation of the ecology and life history of Fluviatile (Maddox and Bartgis 1989, 1990a, 1990b).

- The Maryland Natural Heritage Program has collaborated with the Smithsonian Institution on a study of electrophoretically detectable genetic variation throughout the range of P. nodosum. This study is expected to be completed in spring of 1991.

- The Maryland Natural Heritage Program has produced and distributed several information brochures on the biology of P. nodosum and its habitat.

- In a 1988 survey conducted by the Center for Plant Conservation to determine the plant taxa in most imminent danger of extinction, P. nodosum was identified by botanists as a "B" priority taxon, i.e., one which could go extinct in the wild within the next ten years. The Center has assisted in the recovery of the plant: 7,500 seeds have been collected as part of the National Collection of Endangered Plants and are housed at the North Carolina Botanical Garden (NCBG), one of the Center's participating institutions in the region. All seeds were collected from the Tar River area in Granville County, North Carolina. Although not currently being propagated at NCBG, these seeds provide a valuable conservation resource.

Recovery Strategy

To reach recovery, nine currently large or stable populations must be protected and either maintained at current status or increased. Four marginal populations must be protected and augmented to the point where they can be self-sustaining. Thirteen additional populations must be discovered or established.

Initial recovery efforts will focus on site protection and gaining a better understanding of species and habitat characteristics. Most of the existing populations are on private lands and are not protected. Acquisition of land containing significant populations will be sought on a willing seller basis, or agreements with landowners for permanent protection will be negotiated. Where permanent protection is not possible, voluntary landowner registry will be pursued. Habitats with priority for near-term habitat protection include the pond sites and the significant riverine habitats.

Continued monitoring of all populations will be conducted to assess population trends and habitat disturbances, and to identify potential threats and problems. Appropriate management techniques will be implemented as soon as possible to stabilize disturbed habitats of existing populations. Active management may be required at some coastal plain pond sites, and attempts to reverse hydrological manipulations may be required to make some populations self-sustaining.

Over the longer term, a broad-based approach to protection will be undertaken. Sources of potential impacts throughout the watersheds of known populations will be identified, and watershed-wide conservation measures will be sought. To reach full recovery, searches for additional populations will be conducted and/or populations will be re-established within the historic range of P. nodosum, using propagation and transplant techniques developed through ongoing investigations into the plant's requirements.

PART II: RECOVERY

Recovery Objectives

The recovery goal for Ptilimnium nodosum (Harperella) is to delist the species. This will be accomplished by meeting the following recovery objectives.

P. nodosum will be considered for **reclassification** to threatened status when:

1. Thirteen populations (the number of currently extant populations) have been relatively stable in population size for five years.

2. All thirteen populations are permanently protected.

P. nodosum will be considered for **delisting** when:

3. There are at least 26 self-sustaining populations in existence. To reach this level, at least thirteen new populations will have to be discovered or established. This is the total number of current and historically known populations.

   Self-sustaining populations of P. nodosum are defined as being large enough to have a high probability of (1) surviving normal population cycles, (2) persisting through natural extremes in weather, and (3) containing sufficient genetic variation to adapt to natural habitat changes.

4. The populations are distributed throughout the historical range from Arkansas to Maryland.

Specifics such as the exact location of populations, the number of individuals required in each population, and their potential response to environmental variation will be studied among the recovery tasks.

3. All 26 populations are permanently protected.

This recovery objective is subject to modification based on information gathered during the completion of the recovery tasks. The recovery process will be assessed annually, after which recovery objectives may be revised upward or downward and recovery tasks redirected.

Recovery Tasks

1.0 Protect existing populations and essential habitat. Thirteen populations of *P. nodosum* were extant in 1990. Several of these populations are small or declining and only four populations contain 1,000 or more individuals; three of the four are in the northern part of the range. Because of the low number of extant populations and their generally small size, all known populations should be protected.

1.1 Delineate essential habitat for existing populations. The geographic limits of the pond populations and five of the riparian populations (in West Virginia, Alabama, and Maryland) are known, but limits have not been fully determined for the North Carolina populations, several unconfirmed Alabama populations, and the newly discovered Arkansas population. Essential habitat for all known populations will be delineated using available information about habitat and species characteristics. Delineation of riparian habitats will take into account the dynamic spatial patterns of these populations, and will include unoccupied stream-side sections that may be colonized in the future.

1.2 Identify and monitor threats to all known populations. Activities that may affect *P. nodosum* habitat are widespread and continually changing. Populations that are most threatened at the current time will be identified, and existing threats will be closely monitored. Over the longer term, existing and potential threats to all known populations -- including development, drainage, filling, water diversion, sedimentation, declining water quality, and appearance of alien (non-native) competitors -- will be monitored and documented. Further, remote sensing or aerial photographs will be used to monitor watershed trends such as changes in land use patterns. For both riparian and pond populations, impacts to the watershed at some distance from occupied habitat may affect the *P. nodosum*. Sources of impacts will be identified within watersheds of all populations.

1.3 Determine habitat protection priorities. Initial protection efforts will focus on the most significant populations, i.e., those of particular ecological importance and/or those that are particularly threatened.

As a preliminary strategy, priority will be given to all four Nodosum populations due to their ecological and life history distinctiveness, as well as their extreme vulnerability to habitat impacts.

For riparian systems, priority sites should include both North Carolina populations (because of their small size), Little River, Alabama and Irons Fork, Arkansas (to represent the southern and western range limits), and at least one of the large northern populations (Sideling Hill Creek, Maryland; Sleepy Creek, West Virginia; or Cacapon River, West Virginia).

Priorities will be refined, and modified if necessary, as habitat protection activities proceed and/or conditions change.

1.4 Seek cooperation and active support of private landowners in protecting known sites. Landowners of all known sites will be informed of how their activities may affect the species, and voluntary protection by landowners will be sought when appropriate. In riparian systems, voluntary protection will be sought for unoccupied and upstream sections to provide adequate buffers for water quality maintenance and protect sites for potential future colonization.

1.5 Secure permanent protection of occupied habitats. Means of providing permanent protection to each known population in order to meet the conditions of the reclassification objective will be defined. As a preliminary strategy, private and public conservation organizations will seek fee title or conservation easements on occupied habitat (and suitable buffer) on a willing seller basis. Efforts will focus on areas where voluntary cooperation may not provide complete protection, particularly if landownership has a high turnover rate (as in West Virginia), or where necessary to alleviate impending threats or actively manage the population.

1.6 Develop management plans for populations on public lands. Several significant sections of riparian P. nodosum populations occur on land owned by public agencies. In cooperation with these agencies, management plans will be developed to address potential impacts, maintain suitable habitat and the vigor of the population, and maintain appropriate streamside and upstream buffer zones.

1.7 Evaluate effectiveness of protection programs and redirect efforts as necessary. Because the species' demography and habitat are so dynamic, the effectiveness of protection efforts for any population will be evaluated annually in terms of (1) spatial and temporal changes in the dispersion of individuals, (2) changes in land use and impacts to habitat, and (3) adequacy of existing protection tools.

People involved in acquisition and registry activities in riparian systems should annually assess the current pattern of population distribution in order to redirect efforts to new subpopulation occurrences.

2.0 Develop watershed protection programs. It may prove necessary to go beyond localized habitat protection to secure long-term protection for P. nodosum populations.

2.1 Identify populations in need of watershed-wide protection. It will be necessary to go beyond localized protection if (1) significant threats occur away from occupied habitat (as in parts of Maryland), or (2) landowner cooperation or habitat acquisition provide insufficient protection for any reason. Potential sources of impacts will be identified for all populations. Populations will be given priority for securing watershed-wide protection based on extent of threats, adequacy of localized site protection, and/or public support for watershed conservation.

2.2 Delineate appropriate watershed boundaries (area of effect) for the populations identified in Task 2.1. Using available information, hydrologic modelling, and other methods, the watershed area that must be protected to ensure a stable water regime for each population specified in the preceding task will be determined.

2.3 Seek watershed-wide conservation measures for specified populations. Watershed-wide conservation measures will be implemented as part of the protection program for specified populations of P. nodosum. Strategies to offset identified impacts will be identified, and measures will be sought to maintain suitable riparian and pond habitat, natural hydrologic regimes, and water quality. Specific measures will vary by watershed, but may include local zoning and planning regulations, landowner contacts, site acquisition or easements on a willing seller basis, or some combination of these.

3.0 <u>Enforce laws protecting the species and/or its habitat.</u> Provisions of the Endangered Species Act of 1973, as amended, and of Maryland regulations prohibiting the taking of the species from private property without the landowner's written permission and from state property without a permit (Code of Maryland Regulations 08.03.08) will be enforced. Over the longer term, the passage of laws and promulgation of regulations that will promote protection of <u>P. nodosum</u> throughout its range will be encouraged.

4.0 <u>Search for additional populations, and extend protection to newly discovered populations.</u> In most states, discovery of new populations is unlikely. However, much potential habitat remains to be searched in Arkansas, southern Missouri, and eastern Oklahoma. These are areas that were not previously believed to be within the range of <u>P. nodosum,</u> so no field work designed to locate the species has been conducted. Other locations deserve continued searches, particularly North Carolina, northwestern Georgia, and the Piedmont rivers of Alabama. Searches will be continued and expanded as warranted by any new information developed in Task 5.0. Protection as described in Tasks 1-3 will be extended if and when additional populations are found.

5.0 Investigate species and habitat characteristics. More information on habitat requirements and life history characteristics of the species is needed in order to accurately evaluate potential impacts and to fully identify appropriate protection and management strategies.

5.1 Monitor size and spatial distribution of populations. Since spatial distribution of subpopulations in riparian systems can change significantly from year to year, distribution patterns in these systems will be redetermined every three years and after major natural (drought or severe flood) or human (land use) perturbations.

5.2 Conduct long-term demographic studies. P. nodosum populations are quite dynamic and appear to be largely controlled by annual or permanent changes in hydrology. Small riparian stands appear to be at high risk of extirpation over short time periods; pond populations may be more stable, at least in the absence of major hydrologic disturbance.

For pond populations, permanent plots will be established and visited annually for at least four consecutive years at the peak of flowering. Data will be collected on the density of P. nodosum and its neighbors, plant size, number of flowering stems, and water depth. Complete counts of the number of individuals will be made in smaller populations, while estimates will suffice for populations with individuals too numerous to count. This information will also be gathered during and after hydrologically unusual years in order to understand the influence of such events on population trends.

For riparian populations, comprehensive demographic studies at all sites would be prohibitive because of the difficulty in working along rivers, the large numbers of individuals, and the wide distribution of subpopulations. Detailed studies on the structure of three large subpopulations in Maryland's Sideling Hill Creek will continue to provide insight into long-term stand dynamics. Otherwise, bi-annual estimates of the number of individuals and mapping of subpopulation distribution should suffice. Such surveys will also be conducted during and after hydrologically unusual years or other major perturbations. For small riparian populations actual counts or careful estimates of populations size will be made.

These efforts will provide data on global and local trends in population size, advance warning of potential threats to P. nodosum, and help in the evaluation of protection efforts. A standard monitoring methodology will be developed so that data can be compared among years and sites throughout the plant's range. A proposed methodology is outlined in Appendix A.

5.3 Continue to define habitat requirements of the species. Little is known about the habitat requirements of pond populations. While some extrapolations can be made from knowledge of riparian plants, questions unique to the pond habitat remain: the potential for competitive stress from neighbors, the importance of water quality, the effects of fire or fire suppression, and the mechanistic effects of drought and flooding.

Much has been learned about habitat requirements of riparian populations through studies in Maryland. However, some questions remain, including the plant's susceptibility to habitat acidification, heavy sedimentation, and other water quality variables.

5.4 Delineate potential habitat. The habitat characterization derived from Task 5.3, as well as information derived from protection efforts conducted in Tasks 1-3, will be used to delineate habitat that may potentially support the species. Potential habitat throughout the species' historical range will be delineated. These areas will then provide the basis for future searches and attempts to establish new populations.

5.5 Correlate past and ongoing habitat disturbances with population trends. Studies will be initiated to correlate habitat disturbances over time with population trends. This will heighten understanding of potential impacts and possibly help in identifying management actions that could reduce or reverse negative impacts. Basic water quality data will be gathered for all riparian sites to use as baseline information in monitoring the effects of impacts.

5.6 Determine the extent of P. nodosum seed storage in ponds. While riparian plants utilize asexual and sexual reproduction to varying degrees depending on seasonal hydrologic regimes, pond populations appear to be restricted to sexual reproduction. It will be determined whether Nodosum are obligate sexual reproducers. The frequency and longevity of stored seed will also be determined.

5.7 Refine and implement appropriate management techniques based on information derived from tasks 5.1-5.6. When species and habitat characteristics are more fully understood, current population and habitat management techniques will be refined, and/or additional techniques will be developed. This information will be incorpated, as appropriate, into the management plans developed through Task 1.6.

5.8 Develop transplant techniques. The riparian form, at least, is easily propagated asexually and field transplants in Maryland have been somewhat successful. Mortality of transplants has been high at several sites that appeared superficially suitable, but where water quality impacts were known to have occurred. A refined understanding of what constitutes suitable habitat (as defined in Tasks 5.3 and 5.4) should help in this regard. The long-term success of transplants is unknown. Nothing is known about the ease of propagating the pond form.

6.0 Conduct further genetic studies. Electrophoretic analyses that have been performed to date suggest that further study of genetic distinctions between the Nodosum and Fluviatile forms may be warranted. Studies will be designed to further characterize genetic distinctions or similarities between the two forms, and to further determine the genetic composition of all extant populations.

7.0 <u>Develop a cultivated source of plants and provide for long-term seed storage</u>. For smaller populations that are ecologically unusual (e.g., the granite outcrop site in Georgia) or at great risk (the North and South Carolina sites), long-term storage of material may maintain genetic material if the population is lost. There is no current need to maintain material from the larger populations, but this should be re-evaluated if population declines occur.

7.1 <u>Determine requirements for cultivation of live plants</u>.

7.2 <u>Determine conditions necessary for long-term seed storage</u>.

7.3 <u>Develop techniques for re-establishment of populations using cultivated material</u>.

8.0 <u>Re-establish populations in suitable habitat within the species' historical range</u>. Up to thirteen reintroduced populations may be required to reach the delisting objective, if no additional existing populations are located. While some reintroduction efforts could take place on historical sites, several such sites have been destroyed. Thus, suitable sites that have not previously contained the species must be identified.

9.0 Develop materials to inform the public about the status of P. nodosum and the recovery plan objectives. Public support of recovery efforts for P. nodosum could play a significant role in encouraging landowner assistance and raising awareness of activities in behalf of the species. This is particularly important considering the large number of landowners along the occupied riparian corridors and within occupied watersheds. Informational materials will continue to be developed and distributed to landowners and the general public.

In addition, more specialized educational materials or workshops on rare plants, off-site conservation techniques, and reintroduction methods will be designed and conveyed to conservationists.

10.0 Annually assess success of recovery efforts for the species. Recovery efforts are likely to result in the rapid accretion of information available on P. nodosum, its habitat, and potential threats. Recovery efforts should be reviewed annually in order to redirect recovery efforts as necessary.

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PART III: IMPLEMENTATION SCHEDULE

The following schedule indicates recovery tasks that will be initiated sometime during the next three fiscal years. It outlines responsibilities and costs, and provides a general indication of how long it will take to achieve a given task. The tasks are arranged in priority order.

Priorities shown in Column 1 have been assigned based on the following criteria:

Priority 1 = An action that must be taken to prevent extinction or to prevent the species from declining irreversibly in the foreseeable future.

Priority 2 = An action that must be taken to prevent a significant decline in the species population/habitat quality or some other significant negative impact short of extinction.

Priority 3 = All other actions necessary to provide for full recovery of the species.

Responsible agencies, designated in columns 5 and 6, are abbreviated as follows:

USFWS = U.S. Fish and Wildlife Service

R4, R5 = Regions 4 and 5 of the U.S. Fish and Wildlife Service

SCA = State Conservation Agencies of participating states, including:

Alabama Natural Heritage Program (AL Department of Conservation and Natural Resources)

Arkansas Natural Heritage Program

Georgia Natural Heritage Inventory (GA Department of Natural Resources)

Maryland Natural Heritage Program (MD Department of Natural Resources

North Carolina Plant Conservation Program (NC Department of Agriculture)

South Carolina Heritage Trust Program (SC Wildlife and Marine Resources Department)

West Virginia Natural Heritage Program (WV Department of Commerce, Labor and Environment Resources).

TNC = The Nature Conservancy

CPC = The Center for Plant Conservation

IMPLEMENTATION SCHEDULE
Harperella (Ptilimnium nodosum)

March, 1991

Priority	Task Description	Task Number	Duration	Responsible Agency		Cost Estimates, $000			Comments
				USFWS	Other	FY1	FY2	FY3	
1	Delineate essential habitat for existing populations.	1.1	2 years	R4, R5	SCA	3	3		Completed WV, MD, GA. Needed for AL, SC, NC, and AR.
1	Identify and monitor threats to known populations.	1.2	Ongoing	R4, R5	SCA	3	3	3	
1	Determine habitat protection priorities.	1.3	2 years	R4, R5	SCA	1.5	1.5		
1	Seek cooperation of landowners.	1.4	Ongoing	R4, R5	SCA, TNC	10	8	6	Being implemented MD, WV.
1	Identify populations in need of watershed-wide protection.	2.1	2 years	R4, R5	SCA		3	3	
1	Delineate watershed boundaries for specified populations.	2.2	2 years	R4, R5	SCA		4.5	4.5	
1	Enforce laws protecting species and habitat.	3.0	Ongoing	R4, R5	SCA	2	2	2	
1	Search for additional populations.	4.0	2 years	R4, R5	SCA		6	6	
1	Monitor size and distribution of populations.	5.1	Ongoing	R4, R5	SCA	3	3	3	
1	Conduct long-term demographic studies.	5.2	5 years	R4, R5	SCA	5	5	5	Ongoing for Fluviatile type. Needed for Nodosum type.
2	Secure permanent protection of occupied habitats.	1.5	10 years	R4, R5	SCA, TNC				Costs undetermined.
2	Develop management plans for populations on public lands.	1.6	5 years	R4, R5	SCA	3	3	3	

Harperella Implementation Schedule -- March, 1991

Priority	Task Description	Task Number	Duration	Responsible Agency		Cost Estimates, $000			Comments
				USFWS	Other	FY1	FY2	FY3	
2	Seek watershed-wide conservation measures.	2.3	5 years	R4, R5	SCA	2.5	2.5	2.5	
2	Annually assess recovery efforts.	10.0	Ongoing	R4, R5	SCA	1	1	1	
3	Evaluate effectiveness of protection programs.	1.7	Ongoing	R4, R5	SCA	.5	.5	.5	
3	Continue to define habitat requirements.	5.3	4 years	R4, R5	SCA	5	5	5	Ongoing for Fluviatile type. Needed for Nodosum type.
3	Delineate potential habitat.	5.4	2 years	R4, R5	SCA			3	
3	Correlate habitat disturbance with population trends.	5.5	Ongoing	R4, R5	SCA	2	2	2	Greatest urgency is at pond sites.
3	Determine length of seed storage in ponds.	5.6	4 years	R4	SCA	4	2	2	
3	Refine and implement appropriate management techniques.	5.7	Ongoing	R4, R5	SCA		3	5	Greatest urgency is at pond sites.
3	Develop transplant techniques.	5.8	2 years	R4	SCA, CPC				Not currently a need in R5. Germplasm resource at NC Botanical Gardens.
3	Conduct further genetic studies.	6.0	2 years	R4, R5	SCA	5	5		
3	Develop a cultivated source of plants.	7.0	2 years	R4, R5	SCA, CPC		3	3	
3	Re-establish populations within historical range.	8.0	Ongoing	R4, R5	SCA, CPC				Contingent on other studies.
3	Develop information materials.	9.0	2 years	R4, R5	SCA, CPC	4.5		4.5	

Appendix A

Proposal for Monitoring Methodology

The two most important issues in any monitoring program are:

(a) Make population size counts or estimates that are comparable primarily among years within sites and, secondarily, among sites. Within-site reliability is of highest importance because it facilitates meaningful assessments of population trends. Reliability (whether the counts are consistently obtained and relatively correct) is more important than precision (whether the count is actually correct).

A counting scale recommended here is:

(i) for populations with < 100 individuals perform an actual count;
(ii) for populations containing 100-1,000 individuals round an estimate to the nearest hundred;
(iii) for populations containing 1,000-10,000 individuals round an estimate to the nearest 1,000;
(iv) and so on for larger orders of magnitude.

(b) Make a rough map of individual distribution within the site. These maps need not be quantitative, but should be sufficient to relocate subpopulations and verify changes in dispersion (e.g., subpopulations associated with a topographic feature or flagged marker).

P. nodosum can be difficult to count because of its morphology (small, densely packed rosettes). There can be many rosettes packed into small areas, which can be connected or physiologically distinct (Maddox and Bartgis 1990a). Also, there can be genetic variation at small scales (Kress et al. 1990). These facts make counts based on rosettes unreliable and subject to large observer bias.

Consequently, we recommend that all counts of P. nodosum be made based on the number of flowering stems. This can be an underestimate of the number of rosettes in riverine populations (Maddox and Bartgis 1989), but it is likely to be the most consistently reliable estimate among sites and observers.

Coastal Plain Pond Populations (Nodosum)

Coastal plain pond sites are relatively easy to census because their boundaries are clear and they tend to support small populations of P. nodosum. Thus, at each census an attempt should be made to:

(a) conduct a complete count of the number of individuals, or an estimate based on the scale above;

(b) create a map of individual dispersion, grounded with either flagged stakes or topographic features.

Riverine Populations (Fluviatile)

Riverine populations can be large with considerable population substructure, both of which are important in a monitoring program. At each census an attempt should be made to:

(a) conduct a complete count of the number of individuals, or an estimate based on the scale above;

(b) create a map of individual dispersion, grounded by referring each subpopulation to a location on a topographic map; this will facilitate (i) the relocation of subpopulations in future censuses, (ii) verification of subpopulation loss or gain, and (iii) analyses of patterns in subpopulation loss that could be used in management decisions.

Appendix B

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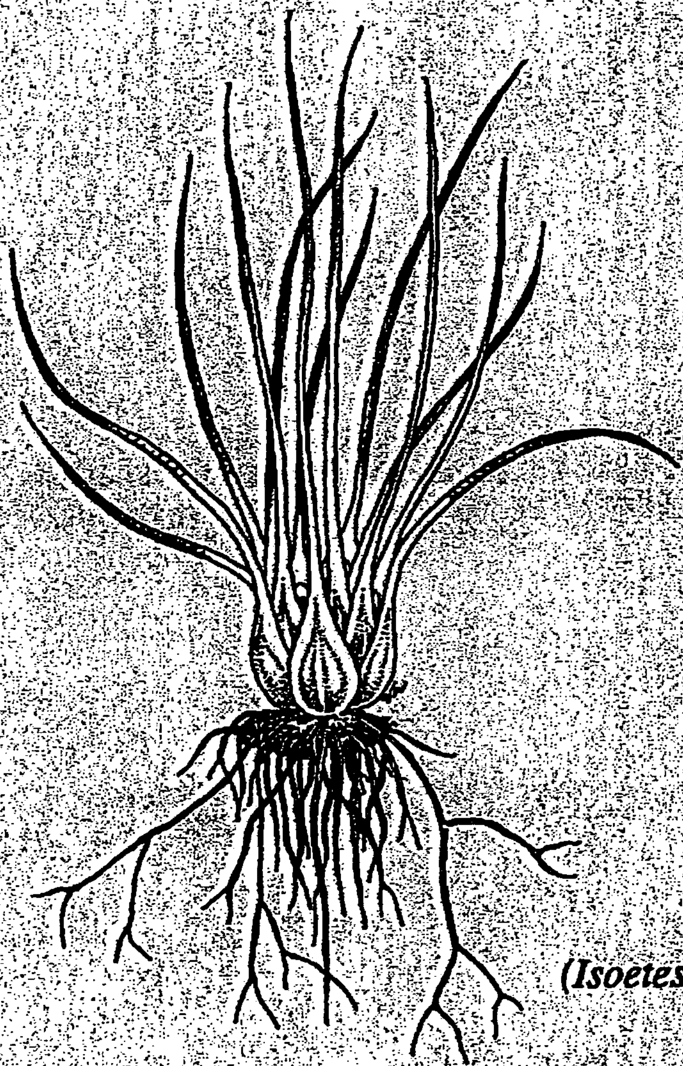
USFWS 1993

Sec 9.3 Ref 58

SCEG-503

Recovery Plan

Three Granite Outcrop Plants



(*Isoetes melanospora*)

U.S. Fish and Wildlife Service

RECOVERY PLAN

FOR

THREE GRANITE OUTCROP PLANT SPECIES

Prepared by

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Freshwater Wetlands and Heritage Inventory Program
Social Circle, Georgia

for

U.S. Fish and Wildlife Service
Jackson, Mississippi

Southeast Region
Atlanta, Georgia

Approved: James W. Pulliam, Jr.
Regional Director, U.S. Fish & Wildlife Service

Date: July 7, 1993

Recovery plans delineate reasonable actions which are believed to be required to recover and/or protect the species. Plans are prepared by the U.S. Fish and Wildlife Service, sometimes with the assistance of recovery teams, contractors, State agencies, and others. Objectives will only be attained and funds expended contingent upon appropriations, priorities, and other budgetary constraints. Recovery plans do not necessarily represent the views nor the official positions or approvals of any individuals or agencies, other than the U.S. Fish and Wildlife Service, involved in the plan formulation. They represent the official position of the U.S. Fish and Wildlife Service only after they have been signed by the Regional Director or Director as approved. Approved recovery plans are subject to modification as dictated by new findings, changes in species status, and the completion of recovery tasks.

Literature citations should read as follows:

U.S. Fish and Wildlife Service. 1993. Recovery Plan for Three Granite Outcrop Plant Species. Jackson, Mississippi. 41 pp.

Additional copies may be purchased from:

Fish and Wildlife Reference Service
5430 Grosvenor Lane, Suite 110
Bethesda, Maryland 20814

Telephone: 301/492-6403 or
1-800-582-3421

Fees for recovery plans vary, depending upon the number of pages.

EXECUTIVE SUMMARY

Current Status: *Isoetes melanospora* (black-spored quillwort) and *Isoetes tegetiformans* (mat-forming quillwort) are listed as endangered species. They are thought to be extant at only eight and seven locations, respectively, all in Georgia. *Amphianthus pusillus* (amphianthus) is federally listed as a threatened species. It is currently known from 57 locations (4 in Alabama, 3 in South Carolina, and 50 in Georgia).

Habitat Requirements and Limiting Factors: All three species are rooted aquatics restricted to temporary pools formed in depressions on outcrops of granitic rock. Due to their extreme specialization, these species were probably already rare at the time of European contact. The greatest threat to these species is the continuing destruction of habitat from quarrying activities. Other sites have been degraded due to their inclusion in pasture (eutrophication of pools), dumping, and heavy recreational use (i.e., off-road vehicles, vandalism).

Recovery Objectives: Reclassification of both *Isoetes* spp. to threatened, and delisting of *Amphianthus pusillus*.

Recovery Criteria: Reclassification of either *Isoetes* species to threatened will be considered if 10 viable and geographically distinct populations (separate outcrops), each with at least two occupied pools, are protected from any foreseeable threats. Delisting of *Amphianthus* will be considered if 20 of the known populations (including at least two populations each in Alabama and South Carolina) are protected. Population viability should be confirmed through periodic monitoring for at least a 10-year period.

Actions Needed:

1. Protect populations and habitat.
2. Preserve genetic stock from acutely threatened populations.
3. Monitor populations to determine trends and developing threats.
4. Search for additional populations.
5. Reestablish populations and augment extant populations at protected locations, if deemed necessary.
6. Use management techniques to maintain and/or enhance populations.
7. Educate the public about the value and fragility of these species and their habitat.

Estimated Cost of Recovery: It is not possible to determine costs beyond the first few years. The cost of implementation of tasks over the next 3 years, for which cost estimates have been made, totals $50,000. This does not include the cost of land acquisition.

Date of Recovery: Impossible to determine at this time.

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I. INTRODUCTION

A. Background

On February 5, 1988, the U.S. Fish and Wildlife Service (1988) published in the Federal Register a final rulemaking determining that three granite outcrop plant species were either endangered (Isoetes melanospora Engelm., black-spored quillwort, and I. tegetiformans Rury, mat-forming quillwort) or threatened species (Amphianthus pusillus Torr., amphianthus) under the Endangered Species Act of 1973, as amended. All three species are restricted to the Piedmont Physiographic Province of the Southeast, where they are found only in rock-rimmed temporary pools on ancient weathered exposures of granitic bedrock. Isoetes tegetiformans is known only from Georgia. Isoetes melanospora is extant in Georgia and is historically known from South Carolina. Amphianthus pusillus occurs in both of these States, as well as in Alabama.

Both Isoetes species have been considered extremely rare ever since discovered, with I. melanospora and I. tegetiformans having been collected at only 16 and 10 locations, respectively. All three species have been suffering significant habitat loss during the last 60 years, with the majority of extinctions due to the quarrying of natural exposures of the granite bedrock.

B. Taxonomy and Description

Isoetes melanospora (black-spored quillwort) is a member of the Isoetaceae, one of the families of fern allies. This species was discovered by William Canby in 1869 and later described by Engelmann (1877). It is a typical Isoetes, in that it is a rooted perennial with hollow, finely septate, linear leaves (sporophylls) which are spirally arranged (on mature plants). Leaves are typically less than 7 centimeters (cm) (2.75 inches) long, but may extend up to 15 cm (6 inches) in length. The subterranean bases of the leaves are enlarged and overlapping (imbricate). The leaf bases emanate from the upper portion of a short, squat, corm-like stem, which in this species is bilobed and typically somewhat shreddy. The corm is often somewhat flattened in I. melanospora, and some plants retain a juvenile, distichous leaf arrangement longer than most Isoetes species (Johnson 1938, Rury 1978). When the inner face of the enlarged base of a fertile leaf is examined, a small (1 to 2 millimeters [mm]) (0.4 to 0.8 inches) round to oval sporangium can be seen. The inner face of each sporangium is overlain by a thin, translucent membrane (velum), which in this species completely covers the front of the unpigmented sporangium. Sporangia contain either female spores (megaspores), ca. 0.28 to 0.44 mm in diameter (.01 to .02 inch), i.e., approximately the size of the period at the end of this sentence) or dust-sized male spores (microspores). The mature megaspores of I. melanospora are unique among Southeastern quillworts in that they are gray when dry, black when wet. The megaspore surface varies from tuberculate to nearly smooth (Matthews and Murdy 1969).

The three occurrences of morphological intergradation (I. melanospora X I. piedmontana) documented by Matthews and Murdy (1969) caused them and other authors (e.g., Rury 1978) to question the distinctiveness of the putative parental species. However, Boom (1980) subsequently demonstrated that hybridization is possible in Isoetes, even between species long regarded as only distantly related.

The species of Isoetes considered most closely related to I. melanospora is I. lithophila Pfeiffer (Pfeiffer 1922, Reed 1965, Boom 1982), also restricted to temporary pools on granitic outcrops, but found only in Texas. In the latest plant Notice of Review (U.S. Fish and Wildlife Service 1990), I. lithophila was assigned a category 2 status (i.e., in need of study to determine the appropriateness of listing under the Endangered Species Act). In addition to habitat type, these two taxa share a number of character-states, including dark-pigmented megaspores, a complete velum, and an unpigmented sporangium. Apart from geographic location, these two species have been separated on the basis of leaf length and megaspore size. Both of the latter characters have since been shown to be of uncertain systematic value (e.g., Kott and Britton 1985, Hickey et al. 1989). Further investigation into the relationship of these two taxa would be useful.

Isoetes tegetiformans (mat-forming quillwort or Merlin's-grass) was described by Rury (1978) from material he collected in 1976 in Columbia County, Georgia. It is considered North America's most distinctive quillwort, unique in its distichous leaf-arrangement (never spiraled); its matted growth form due to adventitious budding; and its unbranched, dimorphic roots (Rury 1978). The leaves are typically less than 7 cm long (2.75 inches), but in deeper water they may reach 15 cm (6 inches). Its megaspores are tuberculate and brown (dark brown when wet). A velum completely covers the unpigmented sporangial wall. The stem is commonly surficial rather than being distinctly subterranean. Despite its unique features, Isoetes tegetiformans shows affinity with I. melanospora, as suggested by a significant number of shared characteristics, including darkly pigmented megaspores, unpigmented sporangium, complete velum coverage, lack of peripheral vascular strands in the leaves, habitat requirements, geographic latitude, and phenology.

Additional descriptive information on Isoetes melanospora and/or I. tegetiformans can be found in Boom 1982, Engelmann 1882, Johnson 1938, Lellinger 1985, Pfeiffer 1922, and Rury 1978.

The most common quillwort species of granitic outcrops, Isoetes piedmontana (Pfeiffer) Reed (I. melanopoda Gay & Dur., in the broad sense) possesses white megaspores, an incomplete velum and a pigmented sporangial wall. It is frequently larger than I. melanospora, whose leaves are seldom more than 10 cm (4 inches) long.

Isoetes melanospora and I. tegetiformans have a distinctly different phenology from the common outcrop species I. piedmontana, a distinguishing feature neglected in published studies, although Wherry (1964) appears to have been aware of it. The cycle of growth and dormancy for Isoetes piedmontana is similar to that exhibited by I. butleri (Baskin and Baskin 1979) in that the dormancy induced by late spring or early summer drought is not broken until cool weather returns in autumn. In Isoetes melanospora and I. tegetiformans, dormancy is broken by the presence of ample moisture at any time of the year. Therefore, unlike I. piedmontana, the two listed Isoetes spp. may be found in midsummer, following heavy rains.

Isoetes engelmannii A. Br. is another quillwort occasionally found on granitic outcrops but it has white, reticulate megaspores, a narrow velum, and its leaves are usually longer than 10 cm (4 inches).

Amphianthus pusillus, a member of the flowering plant family Scrophulariaceae, was the first of these three species to be discovered (in 1836) and described (Torrey 1837). The genus contains only this species (monotypic genus), and will henceforth be referred to simply as Amphianthus. It is considered to be a highly specialized form, without close living relatives; similar forms, such as are found in rock pools in Africa (Chamaegigas) and Australia (Glossostigma) are thought to appear similar due to convergent evolution (Pennell 1935).

Amphianthus (amphianthus, little amphianthus, pool sprite, or snorkelwort) is a small, aquatic annual with very short (to ca. 6 mm) (0.25 inch), leafy, rooted, submerged stems which produce flowers and one or more threadlike scapes. The tip of each scape bears two small, ovate to lanceolate, oppositely arranged bracts. The scapes elongate as necessary (to ca. 15 cm (6 inches)) to permit the bracts to float upon the surface of the water. A single small (to 4 mm (0.16 inch) long) white to pale purplish flower is borne between the two bracts. Other flowers borne on the usually submerged short stem are similar to the emersed flowers. The fruit is a small, shallowly bilobed capsule. Seeds are ca. 1 to 1.5 mm (.04-.06 inch) long, dark brown to black, and are oblong (often slightly curved).

Additional descriptive information on Amphianthus can be found in Pennell 1935, Lunsford 1939, and Rayner 1986.

C. Distribution and Ownership

Isoetes melanospora is thought to be extant at only eight locations, all in Georgia (Butts, DeKalb, Gwinnett, Heard, and Rockdale Counties). It is extinct at five historical sites in Georgia (DeKalb and Newton Counties). Due to hybridization with the more common Isoetes piedmontana, it is considered extinct or essentially so at the sole reported site in South Carolina (Lancaster County) and at two additional sites in Georgia (Butts and DeKalb Counties). Only one site supports more than three inhabited pools. The typical site has one or two pools totaling only a few square meters (m^2).

Two of the eight extant locations for Isoetes melanospora are publicly owned. Both of the publicly owned sites are in DeKalb County. The type locality, Stone Mountain, lies within State-owned Georgia's Stone Mountain Park. The largest remaining population of this species occurs at Davidson-Arabia Mountain Park (Arabia Mountain Park) in DeKalb County (Department of Recreation, Parks, and Cultural Affairs).

Isoetes tegetiformans is restricted to Georgia (Columbia, Greene, Hancock, and Putnam Counties). These four Counties lie to the east of the five Counties known to have extant I. melanospora. Three of the seven extant sites for I. tegetiformans are in Columbia County; prior to quarrying activities, it occurred at three additional outcrops in that County. The largest population (multiple pools, but only totaling about 6 m^2) occurs in Hancock County.

All sites for I. tegetiformans are in private ownership. The type locality, Heggies Rock, is owned by The Nature Conservancy and occupies a single, larger-than-average, vernal pool. The population is healthy and shows recovery from past vehicular traffic (Allison 1989b). The two largest populations (in Greene and Hancock Counties) are owned by the Georgia-Pacific Corporation.

Amphianthus has a broader distribution than the two Isoetes spp., encompassing the ranges of both. It is found from Chambers and Randolph Counties, Alabama, eastward and northward to Lancaster and York Counties, South Carolina. Some 50 of the 57 extant locations occur in Georgia, with 4 small populations in Alabama and 3 in South Carolina. It has been extirpated at least eight sites, all in Georgia (DeKalb, Newton, Rockdale, and Walton Counties).

Amphianthus occurs at all but two sites presently supporting Isoetes melanospora, and at all I. tegetiformans sites. Thus, a total of 13 sites support both Amphianthus and one of the listed Isoetes species.

All but 6 of the 57 known extant locations for Amphianthus are privately owned. The largest and most extensive population on private land is at Heggies Rock, owned by The Nature Conservancy. A small population occurs near the summit of Stone Mountain, within State-owned Georgia's Stone Mountain Park. A moderate-sized population exists on State-owned land in South Carolina, at the Flat Creek Heritage Preserve (Forty Acre Rock, Lancaster County). The largest publicly owned population is in Georgia at Arabia Mountain Park (DeKalb County Department of Recreation, Parks, and Cultural Affairs). A much smaller, less viable, population occurs at the Clinton Nature Preserve, owned by Douglas County, Georgia. A moderate-sized population in multiple pools occurs on land recently acquired by Rockdale County, Georgia, and a small population is located on property owned by Heard County, Georgia.

D. Habitat and Limiting Factors

Isoetes melanospora, I. tegetiformans, and Amphianthus are restricted to eroded depressions or (rarely) quarry pools formed on flat-to-doming granitic (either granite or granite-gneiss) outcrops. These species have maintained themselves for millennia by specializing in a nutrient-poor, seasonally fluctuating micro-environment which in recent centuries, at least,

(1) occurred at perhaps 70 to 100 outcrops, ranging in size from 1 to more than 200 acres, but,

(2) each outcrop only supporting 1 m^2 to 25 m^2 of habitat occupied by these species, typically less than 5 m^2 of same, and,

(3) with the rangewide aggregate area occupied by all three species together of less than 1 acre.

The rock varies from fine-grained granite (e.g., Stone Mountain), to coarse-grained (porphyritic) granite (e.g., Heggies Rock) to granite-gneiss (e.g., Arabia Mountain). These exposures are dotted with round or irregularly shaped islands of vegetation surrounded by nearly bare rock, the latter supporting at most a scant cover of mosses and lichens. Where depressions have been eroded in the granite, rain water collects. The three listed species occur almost exclusively in those depressions which have an intact rim restricting drainage, and with an accumulation of a few centimeters of mineral soil. This soil is low in essential nutrients, particularly nitrogen (Lammers 1958). Pools sustaining the listed species, especially the Isoetes species, are most often found on the higher ground of an outcrop, such that surface flow of water, with its scouring action and siltational effects, is minimized. The higher points on an outcrop are also less likely to be shaded by trees. Water normally stands in the occupied pools from late autumn to mid-spring, but only following showers from summer to mid autumn. For extended periods during the warmer months, the soil is desiccated in these depressions. Consequently, the microhabitat supports only the limited number of species adapted to (1) a substrate of acidic, nutrient-poor mineral soil, and (2) an environment fluctuating between hydric and xeric several times between May and October.

The water depth capacity of extant pools typically varies from about 3 to 10 cm (1.25 to 4 inches). Where water depth is less, such depressions are frequently invaded by annual species, especially Diamorpha smallii, which, like Amphianthus, evade the summer droughts by flowering and setting seed in spring, or by drought-tolerant perennials such as Juncus georgianus or by mosses, such as Polytrichum commune (or P. juniperinum according to Doug Rayner, pers. comm. 1991). With increased water depth, soil depth, or organic matter, moisture is retained for longer periods, enabling less specialized aquatic plants such as Callitriche heterophylla, Ranunculus pusillus, Eleocharis obtusa, and Lindernia monticola to predominate.

The three listed species occur most frequently as near-monocultures over at least that portion of the microenvironment where the soil and/or water is too shallow or too deep to support the above-mentioned competitors. In cultivation, where competitors can be excluded, the listed species grow well in deeper soil or if provided with supplemental watering. This suggests that their exclusion from areas of deeper soil or water in the wild is due at least in part to poor competitive ability, as shown for the outcrop species Diamorpha smallii and Arenaria uniflora (Sharitz and McCormick 1973).

Because of the specialized microhabitat, the list of frequently associated species is a short one. Typical Amphianthus pools may contain areas where either Diamorpha, Juncus georgianus, Isoetes piedmontana or, rarely, Isoetes melanospora or I. tegetiformans predominates. Typical pools supporting I. melanospora may contain areas dominated by Diamorpha, Amphianthus, Juncus georgianus, or Andropogon virginicus. Pools of Isoetes tegetiformans usually support only a sparse growth of Amphianthus and/or Isoetes piedmontana, rarely other species, such as Selaginella tortipila, Diamorpha, Andropogon virginicus, or Bulbostylis capillaris.

Where Isoetes melanospora is found in quarry pools, it is usually associated with Pilularia americana and/or Eleocharis microcarpa. Isoetes tegetiformans has not been found in any of the few old quarry pools within its range. Most quarry pools appear to be too deep to support Amphianthus, whose scapes are limited in how long they can grow in seeking the water's surface. Only one small quarry pool, in Pike County, Georgia, is known to support Amphianthus.

E. Reproductive Biology

Isoetes melanospora exhibits typical isoetaceous reproduction. In time, the older, outer leaves die and decompose, releasing either megaspores or microspores. The male or female gametophyte develops within the micro- or megaspore wall. When conditions are favorable for fertilization, a flap opens in the megaspore wall, exposing one or more funnel-like necks, through which the motile male gametes (spermatozoids) may enter and fertilize the single egg located at the base of each neck. Following fertilization, a single zygote develops into a sporophyte, enclosed within the megaspore wall. A single juvenile leaf and root are soon produced and after continued growth the old megaspore wall is shed. Sporelings are usually found in late winter or early spring. How rapidly plants reach sexual maturity under the extreme conditions of their habitat is unknown. In cultivation, they can reach maturity in at most a few years. Once mature, a plant of Isoetes melanospora produces mega- and microspores, but typically only one or the other at any one time. These cycles are not synchronized; both types of spores can be found in the population when sporulation is terminated by the onset of drought-induced dormancy. Once the soil is desiccated, the leaves quickly die and soon no trace of the plant can be found above ground. Eventually, a summer thunderstorm will bring rainfall sufficient to saturate the soil of the depression, stimulating revegetation of Isoetes melanospora (or I. tegetiformans). The plants begin to form new roots and leaves within about 24 hours, and continue to grow until dormancy is reimposed by subsequent drought.

Isoetes tegetiformans exhibits sexual reproduction as in I. melanospora (the author has seen and preserved sporelings of both species with dark megaspore walls still retained). Isoetes tegetiformans is nearly unique among Isoetes species in that it also exhibits clonal reproduction. Because its leaves are produced in a single row on each side of the central axis, the base of the plant (i.e., the stem) is flattened and elongated, rather than globose and corm-like. As the older portion of the stem is displaced outwardly by the (central) newer growth, it is sloughed off and decays in typical Isoetes. In this species, however, areas of dead-looking plant base produce adventitious regrowth, such that a single plant may have several (to many?) distinct areas of leaf/root initiation. The plants are typically crowded and appear as a turf on the floor of a depression.

Amphianthus, being a winter annual, persists during the hot, drought-prone summer only as seeds resting on or within the soil. Germination begins (normally) in late autumn and peaks in late winter or early spring. Light is required for germination (Lunsford 1939), hence buried seeds remain dormant and constitute a hedge (seed bank) against sudden extinction due to unusually early drought. Flowering begins in February or March and continues until the microhabitat is desiccated by a spring drought (sometime from March to May), killing the plants.

Although the flowers borne above water do open, no pollinator has ever been reported to visit a flower, and the stigma is located in such close contact with the anthers that self-pollination is predominant (Lunsford 1939). Those flowers borne at the base of the plant do not open while submerged, and self-pollinate. When the water evaporates and these flowers are exposed to air, however, they open and function as do the flowers borne on floating stems (i.e., they are "hydrocleistogamous"; Lunsford 1939).

The inbreeding inherent in self-pollination systems results in reduced genetic variation within populations. Indeed, an electrophoretic study of Amphianthus (Rott 1988) detected little genetic variation (12 loci <enzyme systems> examined), either within or between three large and/or well separated populations. In a habitat that is exceedingly slow to undergo any physical alteration and that supports few competitors, variability (and hence adaptive flexibility) is of reduced importance. Self pollination can be an advantage, as it permits the rapid elimination of less than optimal genotypes. The same could be said for the asexual reproduction seen in I. tegetiformans; it (and I. melanospora) exhibit little or no variation at the loci examined electrophoretically (Hickey et al. 1989; N. Luebke, Milwaukee Public Museum, pers. comm. 1991). However, the number of loci examined is only a minute fraction of the total genetic information of any of these species, and not a sufficient sample, from a statistical standpoint, to approximate with confidence the amount of genetic variation present. These studies do suggest that, as expected, variability in these species may be reduced in comparison to species that have wider ranges or in which outcrossing is prevalent.

When mature, Amphianthus capsules dehisce along the sutures, releasing the seeds. The seeds are dormant when shed, and this dormancy is maintained by high summer temperatures (Lunsford 1939). With the onset of cooler weather (and hence, reduced evaporation rate), this dormancy is broken and germination occurs. Rarely, plants can be found in late summer, but always in low numbers.

F. Threats

As these species are adapted to an extremely stable habitat, any disturbance is normally deleterious to their health.

1. Quarrying. By far, the greatest threat to these species is the destruction of habitat due to quarrying activities. Of the 16 documented local extinctions of the listed species (see Appendix A, map 5), eleven can be attributed to this cause. Amphianthus may have been extirpated at up to four additional sites which are now being quarried. The numerous exposures of granites and gneisses in the Piedmont, particularly in Georgia, have been quarried extensively since the Civil War (Watson 1902, 1910), and an unknown number of undocumented populations of the listed species (most likely Amphianthus), were doubtless unknowingly destroyed.

   There are many more abandoned quarries than active ones. Most of the abandoned quarries are small, and may have areas of intact outcrop habitat, sometimes supporting the listed species. These quarries mostly date from the time when granite production consisted of stone for building or ornamental purposes ("dimension stone"). In recent decades, tonnage of crushed stone has greatly outstripped production of dimension stone. A quarry producing crushed stone can easily destroy acres of outcrop in one or a few years, as in the case of the extirpated populations of I. tegetiformans.

   Populations of the listed species (and other granite outcrop organisms) may be impacted by accumulation of rock dust when quarry operations are undertaken nearby. As late as 1979, Isoetes melanospora could be found in two pools at Bradley Mountain (name used in Herrmann 1954) in DeKalb County. Areas near these pools (within several hundred feet) were quarried after 1980 and prior to

1990. Although the depressions themselves are extant, the endangered quillwort has not been seen in them in recent years. The microhabitat of Isoetes melanospora there may have been altered by the accumulation of quarry dust. Studies are needed which specifically address the effects of quarry dust on vernal pool vegetation because current focus in the permitting process is on immediate human health effects rather than long-term effects on the natural environment.

2. Farm animals. At other sites, the habitat supporting these species has been degraded through conversion to pasture. Excessive animal wastes have resulted in eutrophication of pools, promoting excessive algal growth, which competes with these species for dissolved carbon dioxide and light. Addition of matter to the habitat increases soil depth, with concomitant reduction in potential water depth. Increased soil depth and organic matter may benefit these species in the short term, but soon result in the invasion of more aggressive native species, such as Callitriche heterophylla, Eleocharis obtusa, Ranunculus pusillus, and various Juncus spp., as well as exotic weeds, such as Poa annua.

   At a Butts County (Georgia) outcrop supporting Amphianthus in past years, evidence was seen in 1992 of the activities of feral hogs. The hog "wallow" seen was not in an Amphianthus pool. The threat to the three listed granite outcrop species from feral swine is uncertain.

3. Dumping. Because granitic outcrops are regarded by the uninformed as worthless, they are frequently subjected to dumping of waste materials. This leads, in some cases, to destruction of the microhabitat through covering over or filling in of pools, or through eutrophication.

4. Vehicular traffic. Vehicular traffic is a serious problem at many of the extant sites. This can be due to recreational traffic, such as off-road vehicles, motorbikes, or even automobiles in some cases. Even more destructive are the heavy vehicles used in logging operations. At one outcrop in DeKalb County, Georgia, a solitary pool supporting a dense growth of I. melanospora and sparse Amphianthus was destroyed when the adjacent Hayden Quarry Road was paved, because heavy equipment operators used the outcrop as a convenient place to turn around. A unique example of vehicle-related extirpation occurred in Walton County, Georgia, at an outcrop formerly used as a storage site for explosives. These were stored in tractor-trailers on the outcrop. As part of the site preparation, many depressions, including all Amphianthus pools, were filled with concrete to provide a smoother surface.

5. Recreational impacts. Many sites exhibit signs of recreational overuse or abuse. Although those sites that are publicly owned are

protected from quarrying, they are subjected to excess foot traffic, littering, or vandalism, such as spray painting. An example of vandalism occurred in the largest I. melanospora/Amphianthus pool at Arabia Mountain Park: stones in the pool were rearranged from a random pattern to form a rock "archipelago", with the death of those plants which ended up beneath the stones. A similar rearrangement of stones in the only pool supporting listed species in Gwinnett County, Georgia, has caused or contributed to a serious decline of Isoetes melanospora and Amphianthus there. At Stone Mountain, the remaining pools supporting I. melanospora and Amphianthus occur in an area which is subject to intense foot traffic, and cigarette butts and other litter usually can be found in these pools. Litter is also a problem in pools at Arabia Mountain. Another recreational abuse is fire-building within the microhabitat. This has impacted the sole Amphianthus pool in Henry County, Georgia, and may be a factor in the decline of I. tegetiformans in Putnam County, Georgia. Evidence of firebuilding has been seen at other sites, e.g., Saluda County, South Carolina (Rayner 1986), but by chance occurred outside the pool containing Amphianthus. At another South Carolina outcrop, some Amphianthus pools may have been inadvertently poisoned: the water was discolored in 1990 and the depression contained the remains of fireworks (Rayner 1990).

6. Hybridization (Isoetes melanospora only). At three outcrops where I. melanospora occurred with I. piedmontana, I. melanospora has seemingly been outcompeted by hybrids between these two species (Matthews and Murdy 1969). In the early to mid-1980's, the author made collections from all three of these sites, particularly from quarry pools at Rollaway, DeKalb County, Georgia, where the hybrid was first discovered (Dorris 1964). A sizeable collection of plants uprooted by vehicular traffic was made from the South Carolina location. Smaller collections were made from the Butts County hybrid site. None of these collections yielded plants which could be referred unequivocally to Isoetes melanospora, consisting instead of hybrids, putative backcrosses, and I. piedmontana. In particular, these "populations" exhibited extreme variability in the extent of velum development. Analysis of these hybrids is complicated because the distinguishing characteristics of I. melanospora and I. piedmontana are found in the subterranean portion of the plants; each individual plant can be identified only by removing it from the substrate.

   The hybrids have brown megaspores (darker when wet), a wide but incomplete velum, and a pigmented sporangial wall. They are thus intermediate between the presumed parental species (Dorris 1964). As one of the Georgia intermediate populations is found in old quarry pools and the other is adjacent to a highway and agricultural land, these cases of seeming hybridization appear to be disturbance-related (Matthews and Murdy 1969). However, the South Carolina hybrid population may be a natural development. Although the

Isoetes on the main exposure there has been disturbed by vehicular traffic, a pool on an essentially undisturbed exposure, screened from the main outcrop by forest, also appears to support hybrids rather than *I. melanospora*. The apparent hybridization there may be related to the fact that this site is greatly disjunct from those sites supporting typical *I. melanospora*. This South Carolina hybrid population (and the existence of *I. lithophila* in Texas?) suggests that *I. melanospora* may have had a significantly broader range at one time.

Isoetes tegetiformans grows intermixed with *I. piedmontana* at three outcrops, and though hybrids have been searched for, none has been found to date.

7. Other factors. In some cases, other environmental factors are suspected to have led to the decline of certain populations of these species. As these species require high light intensities (Lammers 1958), excessive tree growth is suspected to be a problem at a few sites, due to shading. A few pools appear to be moving toward a later stage of succession due to excessive soil accumulation. In most cases, however, this development can be attributed to the activities of man, such as at *Isoetes melanospora* site no. 8 in Rockdale County, Georgia (close to dirt road and subjected to heavy dumping).

Isoetes melanospora is susceptible to damage or even killed when subjected to abnormally low temperatures (below ca. -12°C [10°F]). When the largest population was visited on January 2, 1984, many, if not most, of the quillworts had shed their outermost leaves. Many of these plants were evidently killed by record cold temperatures of December 1983. During a less severe freeze in December 1937, sufficient to freeze these same pools solid, freeze damage was also observed (Johnson 1938) but did not result in high mortality. *Amphianthus* is also sometimes killed by freezes but, being an annual, can recover population size more rapidly. Freeze damage may also be a factor in the decline of *Isoetes tegetiformans* at site no. 8 in Putman County, and perhaps no. 4 in Columbia County, Georgia (see Appendix B).

The effects of widespread environmental changes, such as acid rain and possible global warming, are unclear. For example, both the buffering capacity of outcrop soil and the tolerance of these species to lowered pH are unknown.

8. Inadequacy of existing regulation. The Georgia Wildflower Preservation Act (discussed next page) has not had a significant effect upon retarding habitat loss, the primary threat to the listed species.

Recreational overuse of publicly owned sites is not always addressed by current ordinances. Existing ordinances against littering, spray-painting, fire-building, off-road vehicles, etc., have proved difficult to enforce, and not fully effective.

G. Conservation Measures

1. State protective measures. Under the provisions of Georgia's Wildflower Preservation Act, *Amphianthus*, *Isoetes melanospora*, and *Isoetes tegetiformans* are legally protected species. This law protects State listed plant species by regulating their removal from State-owned lands (McCollum and Ettman 1991). It further requires that any removal of State-protected plants from private land be with the written permission of the landowner, and it also regulates any traffic in these plants by requiring both transport tags and permits to sell or collect in Georgia. Whenever federally listed plant species are involved, provisions of this law (or any other State law or regulation, including State criminal trespass laws), are enforceable by Federal agents under Section 9 of the Endangered Species Act of 1973, as amended.

   Of the three States where *Amphianthus* occurs, only Georgia has a native plant conservation law. However, the three federally listed outcrop endemics are recognized as species of concern by conservation agencies in all three States where they occur. Databases are being compiled and updated for such species, with information on each occurrence, such as site name, location, population size and ownership. These databases are used to evaluate relative rarity and degree of threat, to assign protection priorities, and to provide information relative to specific sites for purposes such as environmental impact statements.

   An additional Georgia State law affording some protection to these and other listed species is the Georgia Environmental Policy Act (GEPA). Modeled after the National Environmental Policy Act (NEPA), this 1991 law established requirements and procedures for assessing the environmental effects of all proposed State government actions that "may significantly adversely affect the quality of the environment." Guidelines for implementation of GEPA, as promulgated by the Georgia Department of Natural Resources, Environmental Protection Division, describe certain types of activities as "clearly significant", among these being any "action that affects threatened or endangered species or their habitats" (Georgia DNR 1991).

2. Habitat preservation. Due to public ownership or private nature preserve status, six sites supporting *Amphianthus*, two of these with *Isoetes melanospora* and one of them with *I. tegetiformans*, have been protected from quarrying; however, recreational impacts and vehicular traffic continue to pose problems at some sites.

Protection of additional sites through acquisition or negotiation of management agreements is being pursued by The Nature Conservancy field offices, usually in conjunction with State Heritage Programs, in each of the three States where Amphianthus occurs.

3. Studies. Due to their well defined boundaries, granite outcrop communities are among the better studied of all ecosystems. Comprehensive investigations include Oosting and Anderson 1939; McVaugh 1943; Burbanck and Platt 1964; and Shure and Ragsdale 1977; and a number of other ecological studies are summarized in Baker 1945; and McCormick et al. 1974. Graduate studies (all at Emory University, Atlanta) concerning one or more of the listed species include Dorris 1964; Johnson 1938; Lammers 1958; and Lunsford 1939.

The three listed species have been well searched for, particularly since the discovery of Isoetes tegetiformans in the mid-1970's. Status surveys have been conducted for Amphianthus in each State in which it occurs (Miller 1985, Garris 1980, Rayner 1986). Since 1978, the author has visited several hundred granitic outcrops in the Piedmont of the Southeast (Appendix, Map 1), discovering approximately 6 of 16 extant or historic sites for I. melanospora, 9 of the 10 I. tegetiformans sites (Rury 1985), and approximately 38 of 65 sites for Amphianthus.

The Nature Conservancy has conducted monitoring of I. tegetiformans and Amphianthus at its Heggies Rock Preserve during the years 1985, 1987, 1988, and 1989 (Bridges 1986, Allison 1987, 1989a, 1989b). Monitoring of Amphianthus has also been conducted at Forty Acre Rock in South Carolina (Rayner 1990, Pittman and Sablo 1991).

4. Cultivation. The two listed Isoetes species and others (including I. lithophila) are in cultivation for research purposes by the Milwaukee Public Museum (N. Luebke pers. comm. 1991). The two Isoetes species are also in indoor cultivation at the Atlanta Botanical Garden. Isoetes tegetiformans is being cultivated by the North Carolina Botanical Garden, as part of the Center for Plant Conservation's National Collection of Endangered Plants.

Amphianthus is not known to be in cultivation by any horticultural or conservation institution. Because of its annual duration and apparently narrow requirements for germination of its seed, greenhouse cultivation of Amphianthus is more difficult to maintain than either of the listed Isoetes species.

II. RECOVERY

A. Recovery Objective

Reclassification of Isoetes melanospora or Isoetes tegetiformans to threatened will be considered if 10 viable and geographically distinct populations (separate outcrops), averaging at least two pools each, are protected. Delisting will be considered for Amphianthus if 20 such populations (including at least two populations each in Alabama and South Carolina) are permanently protected for that species to such a degree that the species no longer qualifies for protection under the Endangered Species Act. Viability of populations will be assessed through periodic monitoring for a period of not less than 10 years. A viable population has the reproductive capability to sustain itself.

Recovery criteria are preliminary and may be revised on the basis of new information (including information gained from identified recovery tasks).

B. Narrative Outline

1. Protect populations

1.1 Protect existing publicly owned populations.

1.1.1 Georgia's Stone Mountain Park, DeKalb County, Georgia. This State-owned park is operated by a public authority, the Stone Mountain Memorial Association. The Association has recently adopted a Master Plan which envisions a number of significant changes to the park. The Stone Mountain Memorial Association acknowledges that it, like any other agency of Georgia State Government, is subject to the provisions of the Georgia Environmental Policy Act in implementing the proposed alterations to the mountain. Two of the planned actions, if not implemented with adequate safeguards, have the potential to adversely affect Isoetes melanospora and Amphianthus populations occurring in several pools below the summit of the mountain. These changes are (1) the removal of the buildings now found on the summit and (2) the construction of an inclined railway up the mountain.

It is critical that the demolition of the buildings be conducted with stringent safeguards in place to avoid impacts to the listed species, such as vehicular traffic and the washing or blowing of any debris, chemicals or other matter into their microhabitat.

The inclined railway would run from the base of the mountain up to an Interpretive Center to be built in the general vicinity of some of the pools supporting the listed species. It is essential that construction activities employ all necessary safeguards so as to avoid any impact upon the listed species.

Completion of an inclined railway and the holding of some events of the 1996 Summer Olympics within the park could be expected to lead to an increase in the number of visitors to the upper mountain. The Isoetes melanospora and Amphianthus growing near the summit of the mountain are within an area that is already subjected to intensive foot traffic and considerable littering, jeopardizing the continued existence of these populations. The Stone Mountain Memorial Association is aware of this danger; the Master Plan for Georgia's Stone Mountain Park (Robert & Co. 1992) states that "visitor access to the top of the mountain will be restricted to those areas of the upper plateau which do not contain rare or endangered species habitat." Nearby, steeper areas of the mountain are already off limits to visitors, a policy enforced by fencing, signs, and patrolling by park security personnel. The only practical and effective solution to the problem of foot traffic and littering in the microhabitat of Isoetes melanospora and Amphianthus pusillus would appear to be the relocation of the fencing so as to place the listed species and nearby potential habitat within the excluded area. Care must be taken to ensure the use of appropriate fencing material upslope from vernal pools. Certain types of galvanized fencing could leach heavy metals such as zinc in amounts potentially toxic to the listed species, and associated rare life forms, such as "fairy shrimp" and "clam shrimp."

1.1.2 Arabia Mountain Park, DeKalb County, Georgia. This County park contains by far the largest and most critical population of I. melanospora together with one of the largest populations of Amphianthus. The two species grow intermingled in multiple vernal pools at the summit of the mountain. In addition, Amphianthus is present in a number of other pools scattered on the flanks of the mountain, and Isoetes melanospora occurs in quarry pools at the northwestern base of the mountain.

The park is currently undeveloped, and until recently there has been only occasional enforcement of regulations against off-road vehicles, fire-building, littering, and vandalism. Fortunately, a group of local citizens have formed a group called Friends of Arabia Mountain, Inc. to organize support for protection of the park. The public interest and concern demonstrated by this group's activities (such as a well attended Park Cleanup Day) has resulted in the commitment of additional resources by the DeKalb County Parks and Recreation Department to the park. This includes (but is not limited to) the permanent assignment of a resident, full-time, Park Ranger.

Aside from protecting the populations of Amphianthus and Isoetes melanospora from the threats mentioned above, an additional management activity should be mentioned: it might be desirable to cut down some pines around the periphery of the quarry pool occurrences of Isoetes melanospora, particularly if monitoring indicates a decline attributable to excessive shading.

1.1.3 Clinton Nature Preserve, Douglas County, Georgia. This County-owned property includes a granitic outcrop supporting a very small population of Amphianthus. When the site was visited in 1990, only a single small plant was seen. This decline is probably attributable to eutrophication caused by horse manure. Steps (such as fencing) need to be taken to exclude horses from the outcrop area.

1.1.4 Rusty Rock, Heard County, Georgia. This property, owned by Heard County, is currently home to Capitol Rock, Inc., a crushed stone quarry. The site was visited April 23, 1992 with A.C. Boyd, owner of Capitol Rock, Inc. A portion of the outcrop has been destroyed, along with several pools supporting Amphianthus. However, one small pool was found with extant Amphianthus. At the present low rate of production it may be 10 or more years until the blasting front reaches the vicinity of the extant pool (A.C. Boyd, pers. comm., 1992). It would be desirable to work out a way to preserve the small population of Amphianthus which persists here, or failing that, arrange for removal of seed-bearing soil from the pool for use in captive breeding.

1.1.5 Bald Rock, Rockdale County, Georgia. This outcrop contains about five pools supporting Amphianthus. Use of the portion of the outcrop with the latter as a pasture has resulted in some eutrophication of pools and the introduction of some exotic species, such as Poa annua. The outcrop was recently acquired by Rockdale County as a portion of a much larger tract to be developed as the Georgia International Horse Park, venue for equestrian events at the 1996 Summer Olympic Games. The Conyers-Rockdale Amateur Athletics Authority was informed of the presence of a listed species on the property and invited the author to survey the population and to provide them with basic information. According to County authorities, no development is planned that should result in impact to the rock outcrop. An end to the use of the area with Amphianthus pusillus as pasture should result in improved conditions for that species.

1.1.6 Forty Acre Rock, Lancaster County, South Carolina. This is a State-owned natural area, managed by the South Carolina Wildlife and Marine Resources Department. Despite the part-time presence of a caretaker, the placement of barriers to exclude automobiles, and the arrests of a few violators, vehicular traffic (particularly motorbikes) and other abuses are continuing (Stu Greeter and Doug Rayner, pers. comms. 1990). A strategy must be developed to diminish these threats.

1.2 Secure plants on private property. Populations on private property may be protected by negotiation of management agreements between owners and public agencies or private conservation groups, or through land acquisition. Land acquisition would provide the best possible means of protection and may be particularly feasible for a number of the smaller sites. Indirect protection may be provided for these species in certain instances through State permitting processes and by way of the formal consultation provisions of Section 7 of the Endangered Species Act of 1973, as amended.

1.2.1 Landowner contacts. This is the first step towards securing plants on private property. Landowner information should be obtained for all Isoetes populations. Landowners should be contacted, the importance of populations on their lands should be explained to them, and possible management options should be discussed.

Due to the large number of sites for Amphianthus, landowner information for this species should first be determined for the best populations.

1.2.2 Enforce laws protecting species and their habitat. The single greatest threat to these species on private lands is from quarrying, especially for crushed stone (aggregate). Granite is an exceedingly durable rock in inexhaustible supply and hence the crushed stone is a standard roadbuilding material. Fortunately, many, if not the majority of currently operating crushed stone quarries, are not located on natural exposures. These quarries operate by removing the mantle of soil ("overburden") from an area, exposing the underlying bedrock.

Some of those few quarries at outcrops that support one or more listed species supply stone for use in highway construction, which is funded in part by Federal Highway Trust monies. Use of such stone in these circumstances requires compliance with Section 7 of the Endangered Species Act of 1973, as amended (Act). Formal consultation is required between any responsible agency (e.g., the Federal Highway Administration) and the Fish and Wildlife Service to insure that the agency's actions are not likely to jeopardize the continued existence of any federally listed species.

Other means of protection for plants on private property need to be investigated. Under Section 9 of the Act, it is unlawful to take or damage endangered plants in knowing violation of any State law or regulation, including State criminal trespass law. Some populations continue to be impacted by off-road vehicular traffic and vandalism. Any such damage to these listed species should be carefully examined to determined if such occurred during the course of a State law or regulation violation, which would provide the nexus for penalties under the Act.

In Georgia, Surface Mining Permits are issued to prospective operators by the Department of Natural Resources, Environmental Protection Division (EPD), only after surface mine land use plans are reviewed. The Georgia Surface Mining Act of 1968 has as one of its stated purposes to "advance the protection and restoration of land, water, and other resources affected by mining" (GA Laws 1968, p. 9, et seq.). The law, however, contains no language explicitly mentioning protected species. At the least, procedures need to be developed to insure that information compiled by the Game and Fish Division of the Georgia Department of Natural Resources is available for consideration by EPD during its evaluation of permit applications.

The preceding paragraph focuses on Georgia because that State has both the preponderance of populations of the listed species and is the leading producer of granite aggregate in the United States. The same principles apply, however, to the mining regulatory process in Alabama and South Carolina.

2. Preserve genetic stock and conduct germination experiments on Amphianthus.

2.1 Preserve genetic stock from acutely threatened populations. Due to the scarcity of extant populations, particularly of Isoetes melanospora and I. tegetiformans, conservation of the genetic diversity that remains in these species is a high priority. Therefore, some living material of these species should be moved from those populations facing imminent local extinction (i.e., where protection is not feasible or cannot be initiated in time to prevent extirpation).

Fortunately, the listed species can be cultivated; however, cultivation is more difficult with Amphianthus. The author has for years cultivated salvaged material of all three species. Simulated granite outcrops have been constructed at the North Carolina Botanical Garden (see photo, p. 165, in McCormick et al. 1974; see also Platt and McCormick 1964) and might be modified to provide a more aquatic habitat, or new artificial habitat could be constructed.

2.2 Conduct research on germination requirements of Amphianthus. As discussed above, there appears to be difficulty with germinating seed of Amphianthus. Maintenance of stock in cultivation is dependent upon successful germination of seed. Research is needed to determine this species' germination requirements.

3. Monitor populations to determine trends and developing threats. All sites supporting one of the listed Isoetes species should be censused yearly for a period of not less than 10 years. All but two of these sites support Amphianthus, which should be surveyed at the same time, ideally in early to mid-March. All Amphianthus populations in Alabama and South Carolina should be assessed yearly, as well as at least the best Georgia sites lacking either Isoetes species. Approximate numbers, vigor, areal extent, etc., should be noted, as well as any unfavorable developments (increasing competition, dumping, etc.). Bridges (1986) developed forms to standardize the collection of data on Amphianthus and Isoetes tegetiformans during his monitoring project at Heggies Rock. Photography may be of use in comparing density, area of coverage, etc., over time (Allison 1989a, 1989b).

4. Search for additional populations. As indicated above, these species have been searched for extensively. However, a few outcrops remain to be explored at the optimal time of year (January through March), particularly in Randolph County, Alabama; Heard, Meriwether, and Hancock Counties, Georgia; and perhaps Kershaw and Lancaster

Counties, South Carolina. For the sake of efficiency, these travels should involve other recovery objectives, where appropriate (e.g., landowner determination/contact and population monitoring).

5. Reestablish populations and augment populations at protected locations, if deemed necessary. This requires that the microhabitat of the listed species be present or that similar microhabitat occurs which can be modified or maintained by addition or removal of soil. The necessity/desirability of such invasive techniques will be dependent on the success or failure of other recovery actions.

6. Use management techniques to maintain and/or enhance populations. As the listed species are adapted to an environment in which successional change is very slow, maintenance of populations chiefly requires protection from disturbance. Results of the monitoring program should indicate whether certain natural or experimental microhabitats would benefit from such actions as manipulation of soil depth or the cutting of nearby trees.

7. Educate the public about the value and fragility of these species and their habitat. Granite outcrops support the most distinctive natural community in the Piedmont Physiographic Province, based on the number of endemic species. Since most of the landscape of the Piedmont is developed, in cultivation, or in a successional state, relatively undisturbed outcrops can provide an all-too-rare primeval experience. They also have the potential to serve as outdoor classrooms for studying geology, as well as important ecological and/or evolutionary concepts such as primary succession, competition, endemism, and ecotypic differentiation. A strong effort to inform the public about the significance of these places and their biota is critical to combating the common misconception that these are "waste places."

   At present, interpretive programs concerning granite outcrops are confined to the commendable program at Panola Mountain State Conservation Park in Georgia (but which unfortunately lacks extant populations of the listed species). Georgia's Stone Mountain Park, in addition to *Isoetes melanospora* and *Amphianthus*, supports many other rare or otherwise interesting organisms and natural communities (Federal candidate plant species *Aster avitus* and *Sedum pusillum*, to name but two). Because Stone Mountain is also the granite outcrop which receives by far the greatest visitation by the public, a natural history interpretive program could reach a large segment of the public here. The Master Plan for the park indicates that the planned inclined railway will have its upper terminus in an Interpretive Center, which "will tell the 'story of the Mountain' and its environs via professionally researched and prepared interpretive displays," and it states that "outdoor interpretive displays will also be provided at strategic overlook points around the Mountain top" (Robert & Co. 1992).

DeKalb County authorities, responsible for Mt. Arabia Park, are being encouraged by Friends of Arabia Mountain, Inc. to help educate the public on the importance of conserving these species and their habitat.

In addition to interpretive programs that include public presentations and guided tours, illustrative brochures and teaching packets should be developed relating to such topics as Piedmont geology and granite outcrop ecology.

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III. IMPLEMENTATION SCHEDULE

The Implementation Schedule that follows outlines actions and estimated costs for the first 3 years of the recovery program. It is a guide for meeting the objective discussed in Part II of this plan. This schedule indicates task priorities, task numbers, task descriptions, duration of tasks, the responsible agencies, and lastly, estimated costs.

Priorities in column one of the following Implementation Schedule are assigned as follows:

1. **Priority 1** - An action that must be taken to prevent extinction or to prevent the species from declining irreversibly in the foreseeable future.

2. **Priority 2** - An action that must be taken to prevent a significant decline in species population/habitat quality or some other significant impact short of extinction.

3. **Priority 3** - All other actions necessary to meet the recovery objective.

Key to acronyms used in Implementation Schedule

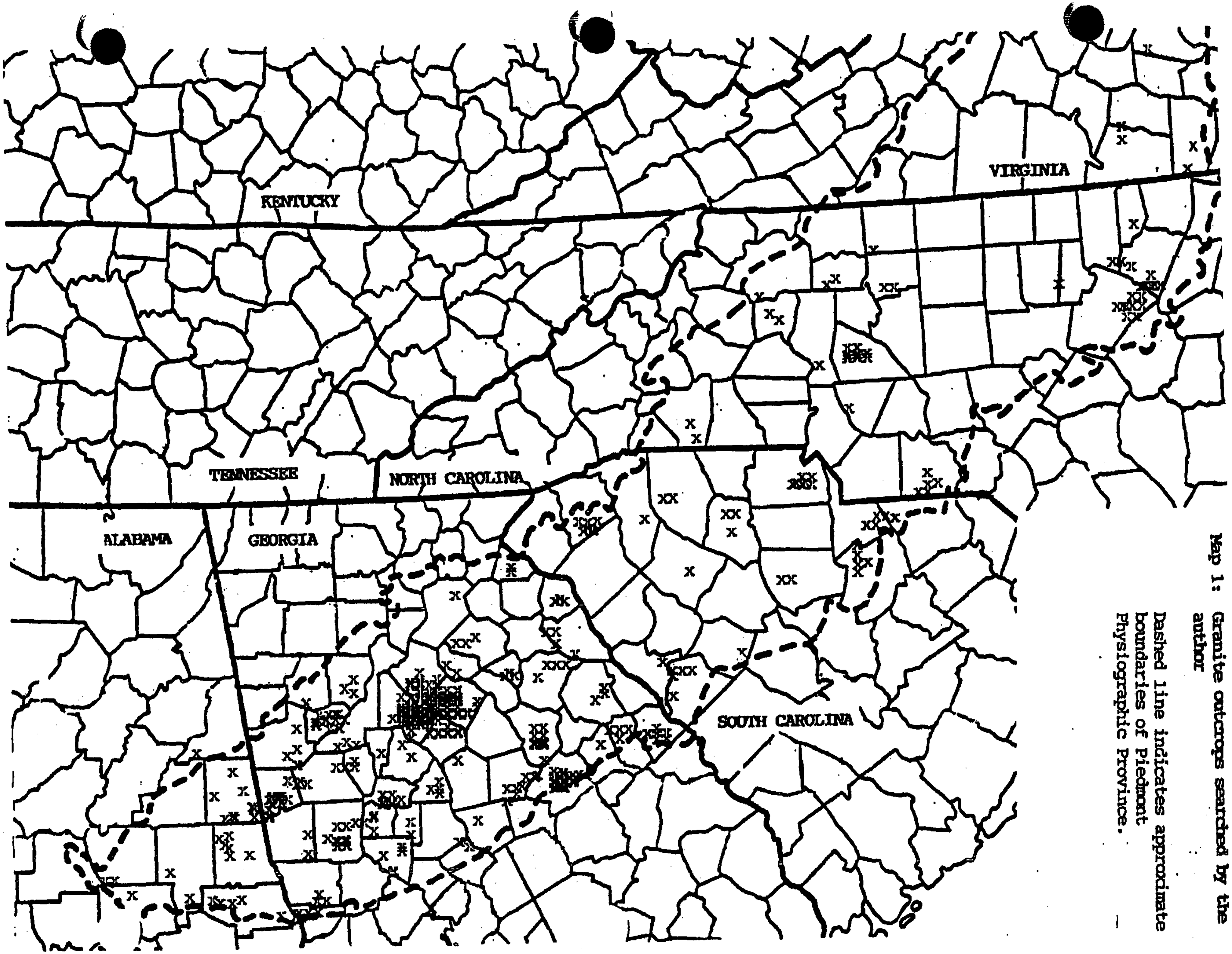
ALNHP	Alabama Natural Heritage Program
CPC	Center for Plant Conservation
Co.	County agencies responsible for administration of Mt. Arabia Park or Clinton Nature Preserve
TE	Endangered Species Division, U.S. Fish and Wildlife Service
GADNR	Georgia Department of Natural Resources
SCWMR	South Carolina Wildlife and Marine Resources Department
SMP	Stone Mountain State Park
TNC	The Nature Conservancy
USFWS	U.S. Fish and Wildlife Service

IMPLEMENTATION SCHEDULE

PRIORITY #	TASK #	TASK DESCRIPTION	TASK DURATION	RESPONSIBLE PARTY: USFWS Region	RESPONSIBLE PARTY: USFWS Division	RESPONSIBLE PARTY: Other	COST ESTIMATES ($K) FY 1	FY 2	FY 3	COMMENTS/NOTES
1	1.1	Improve protection of publicly owned populations	2 years	4	TE	GADNR, SCWMR, SMP,Co.				Costs undetermined.
1	1.2.1	Seek landowner cooperation	Ongoing	4	TE	GADNR, TNC, SCWMR, ALNHP	2.0	2.0		Intensive effort for 2 years to make contact with landowners.
1	1.2.2	Enforce laws protecting species	Ongoing	4	TE	GADNR				
1	2.1	Preserve genetic stock	Ongoing	4	TE	GADNR, CPC	2.5	2.5	2.5	
	2.2	Research germination requirements of *Amphianthus*					3.5	3.5	3.5	
2	3	Monitor populations	Ongoing	4	TE	GADNR, SCWMR, ALNHP	5.0	2.5	2.5	
2	4	Search for additional populations	2 years	4	TE	GADNR, SCWMR, ALNHP	4.0	4.0		
2	5	Reestablish and/or augment populations		4	TE	GADNR, CPC, ALNHP, SCWMR				Contingent on other studies.
2	6	Investigate and implement appropriate management	Ongoing	4	TE	GADNR, SCWMR, ALNHP, SMP, Co.				Cost to be determined.
3	7	Educate public about species	Ongoing	4	TE	GADNR, TNC, CPC, SMP, Co.	5.0	2.5	2.5	

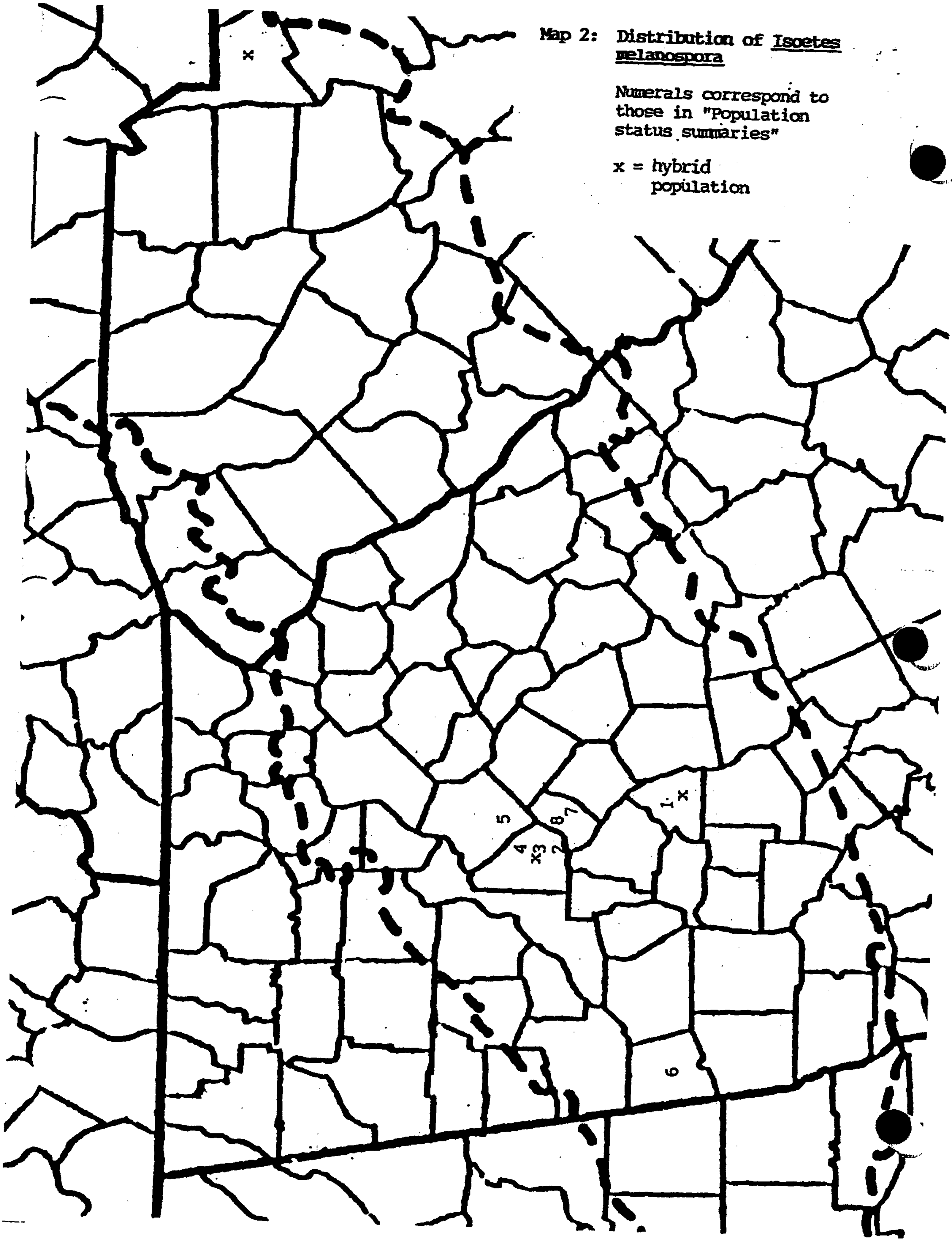
IV. APPENDIX

All known historical or extant populations are summarized in tabular form. Extant sites have been assigned site numbers. Other site names are preceded by a minus sign (-) for extinct populations or, in the case of Isoetes melanospora, an "x" for hybrid populations. The names of publicly owned locations are rendered in bold type. The next column provides the date on which the population was last observed by the author. The symbol "#" follows the date if the site was last visited out-of-season for these plants, provided that the habitat appeared unaltered. To assist in assigning priority for recovery efforts among sites, each population has been assigned a ranking, taking into consideration population size and acuteness of threat. Finally, known threats are summarized. To save space, "vehicular traffic" is abbreviated as "VT". In the case of extirpated populations, the apparent cause of extinction is enclosed in parentheses.



Map 1: Granite outcrops searched by the author

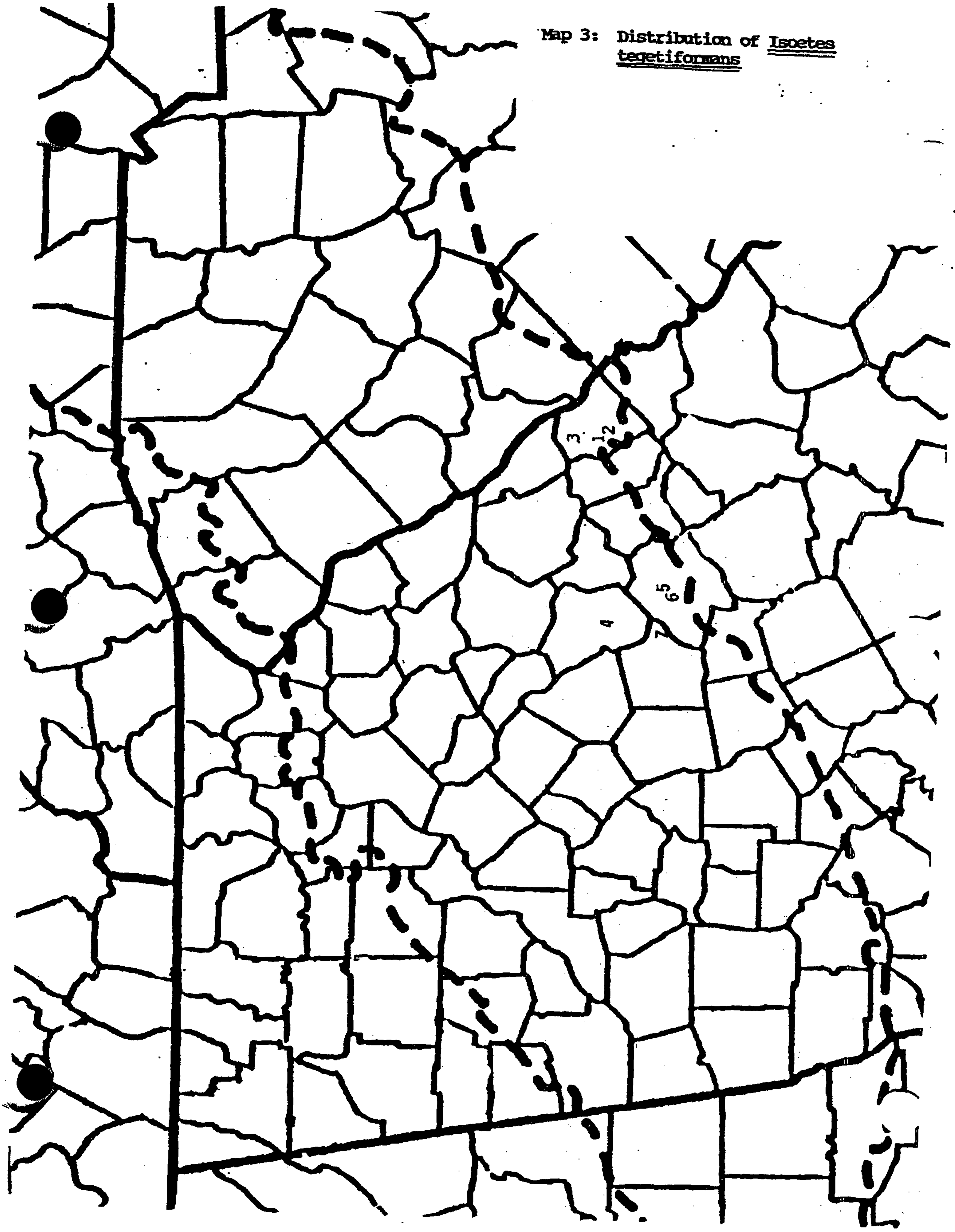
Dashed line indicates approximate boundaries of Piedmont Physiographic Province.



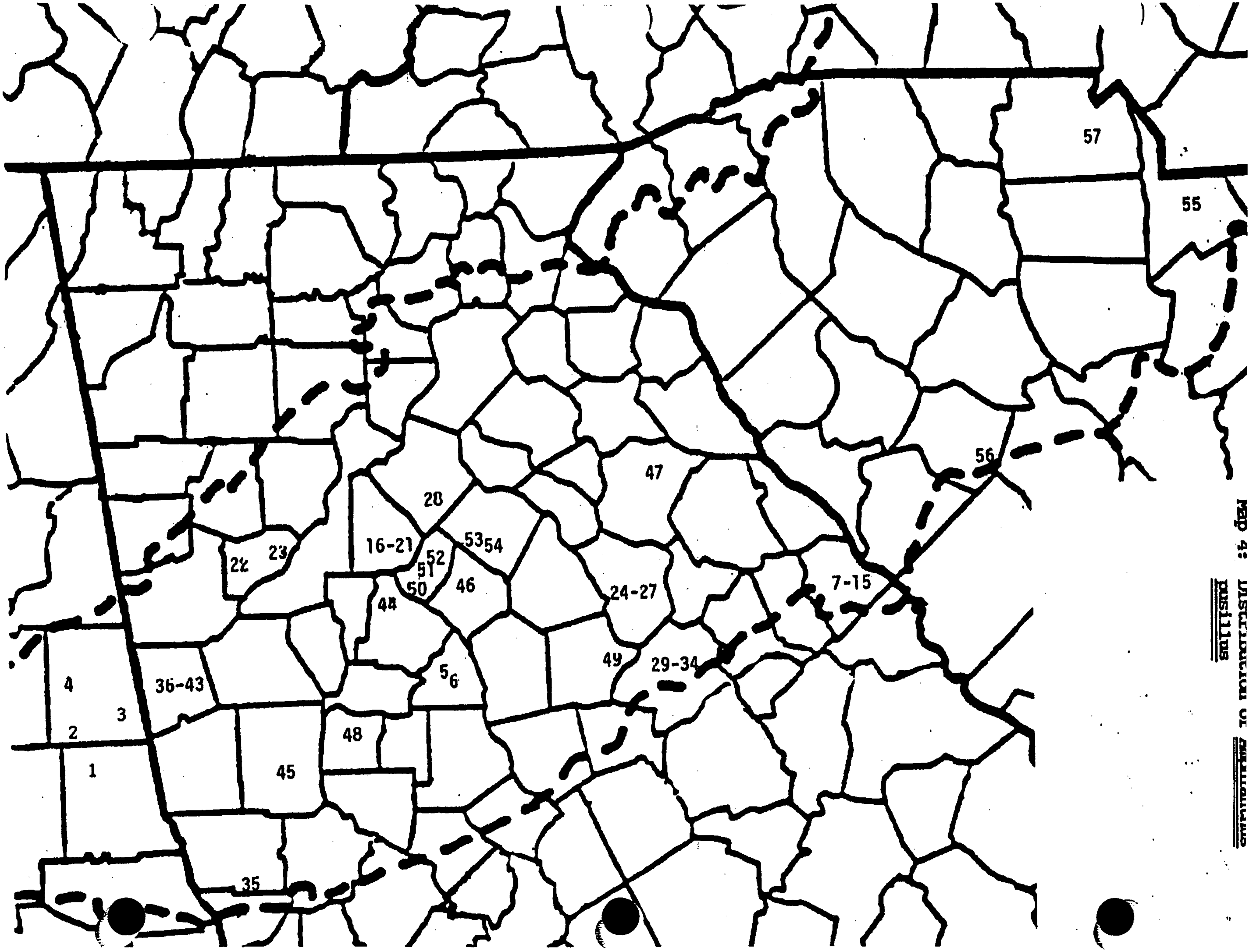
Map 2: Distribution of <u>Isoetes melanospora</u>

Numerals correspond to those in "Population status summaries"

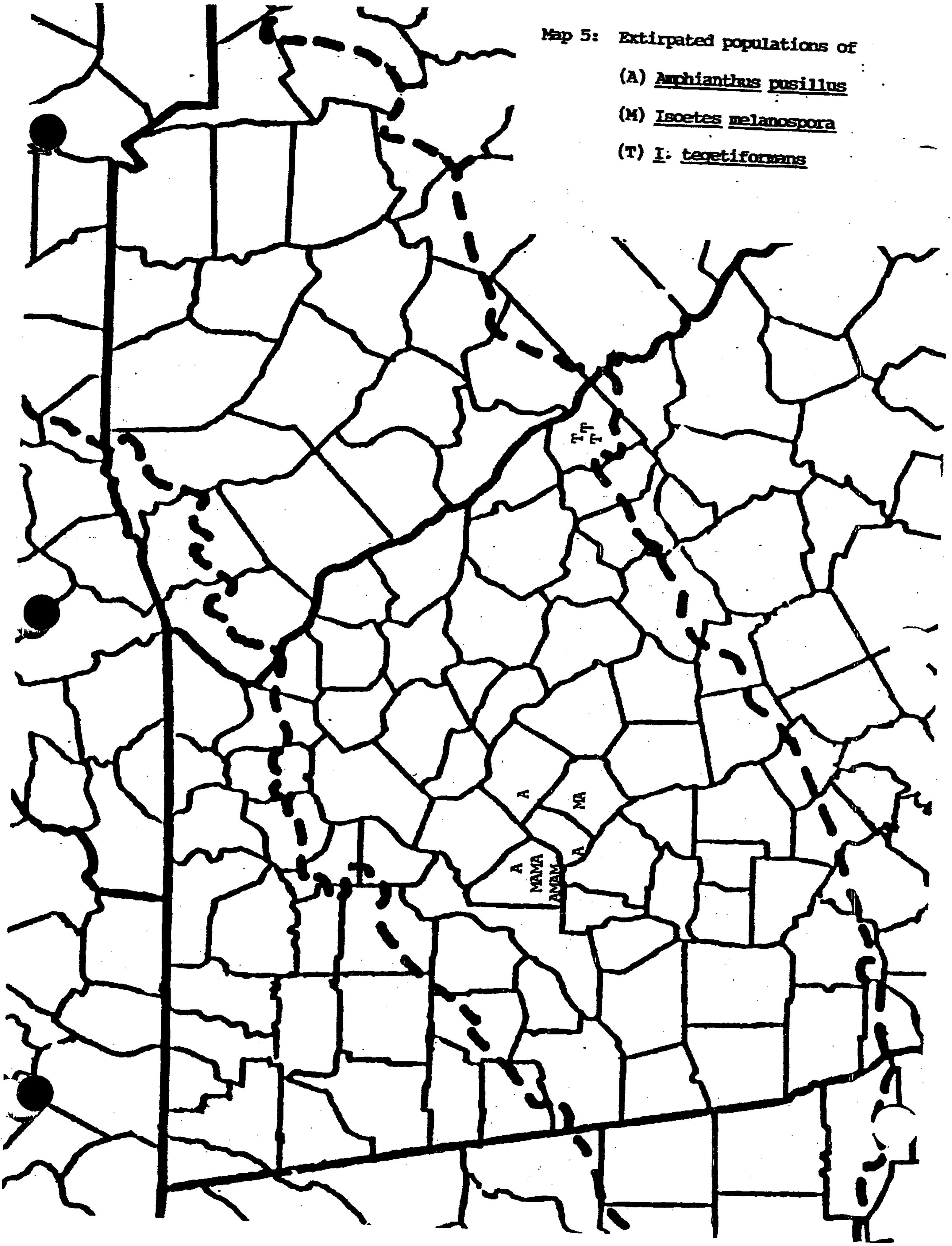
x = hybrid population



Map 3: Distribution of <u>Isoetes tegetiformans</u>



Map 4: Distribution of *[illegible]* *pusillus*

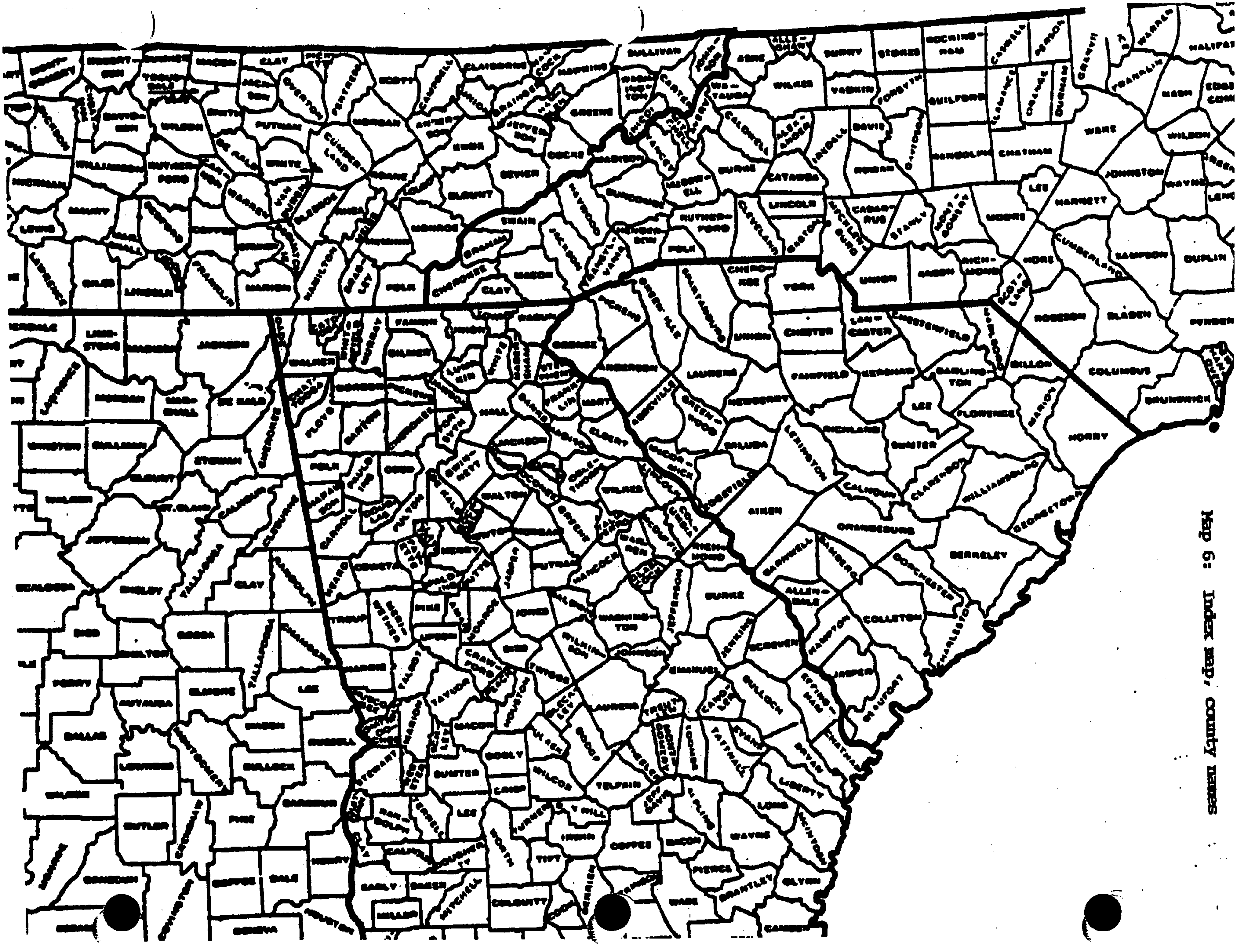


Map 5: Extirpated populations of

(A) Amphianthus pusillus

(M) Isoetes melanospora

(T) I. tegetiformans



Map 6: Index map, county names

POPULATION STATUS SUMMARIES

STATE/COUNTY	SITE NAME	LAST SEEN	SOUGHT SINCE?	RANKING[1]	THREATS
Isoetes melanospora					
GA Butts	1 Mountain Rock	1992-01-03		G	potential quarrying
	x Highway 36	1992-01-03		P	hybrid pop.; road-improvement-VT
Dekalb	2 Arabia Mountain	1992-06-10		E	recreational overuse; VT
	- Bradley Mountain	1979-12-26	1992-06-10	EXT	(fire-building; quarrying)
	- Hayden Quarry Road	1982-00-00	1992-06-10	EXT	(road-paving VT)
	3 Lithonia Rock	1992-06-10		F	dumping; potential quarrying
	- Pine Mountain	1897-05-15	90-02-13	EXT	(quarrying)
	- Rock Chapel Mountain	1939-03-15		EXT	(site destroyed by quarrying)
	x Rollaway	1989-07-01		P	hybrid pop.; quarrying
	4 Stone Mountain	1993-02-15		G-P	recreational overuse
Gwinnett	5 Baker's Rock	1993-04-21		P	vandalism; shading? [9 pls. seen]
Heard	6 Camp Meeting Rock	1993-04-24		G	VT; quarrying
Newton	- Ellis Farm	1984-04-20	1987	EXT	(quarried; [some salvaged])
Rockdale	7 Gleaton Road	1992-05-02		P	eutrophication; shading?
	8 Philadelphia Road	1992-05-02		P	VT; dumping; competition
SC Lancaster	x Forty Acre Rock	1993-04-18		P	hybridization
Isoetes tegetiformans					
GA Columbia	1 Anderson Farm	1989-01-12		G	potential quarrying
	2 Crater Rock	1988-04-07		G-P	potential quarrying
	3 Heggies Rock	1993-01-21		E	
	- Little Kickee Creek	1982-12-25	1986-03-16	EXT	(quarried;[some salvaged])
	- Lost Rock	1989-01-29		EXT	(quarried; [some salvaged])
	- Mt. Gemini	1991-07-31	1993-01-21	EXT	(deliberately extirpated)
Greene	4 Greensboro	1992-04-07		E-P	quarrying in progress
Hancock	5 Forty Acre Rock	1987-02-06		F	eutrophication; competition
	6 Pinkston Creek	1992-04-07		E	logging and other VT; quarrying
Putnam	7 Eatonton	1991-01-29		P	freeze-damage?; VT?

STATE/COUNTY	SITE NAME[2]	LAST SEEN	SOUGHT SINCE?	RANKING	THREATS
Amphianthus pusillus (continued)					
AL Chambers	1 Penton	1992-04-15		F	VT; potential quarrying
Randolph	2 Bald Rock	1992-04-15		F	dumping; quarrying; VT
	3 Blakes Ferry	1992-04-15		F	vehicular traffic; fire-building
	4 Wehadkee Creek	1990-04-11		F	resumption of quarrying
GA Butts	5 *Mountain Rock	1992-01-03		E	vehicular traffic; quarrying
	6 *Highway 36	1988-04-08		F	road-improvement; VT
Columbia	7 *Anderson Farm	1989-01-12		F	VT; potential quarrying
	8 *Crater Rock	1988-04-07		G	VT; potential quarrying
	9 Crescent Rock	1991-07-31#		E	VT; potential quarrying
	10 *Heggies Rock	1993-01-21		E	
	11 Hwy 232-L'il Kiokee	1987-04-08		F	VT; potential quarrying
	12 Little Heggies Rock	1989-01-29		G	VT; potential quarrying
	13 *Little Kiokee Creek	1982-12-25		P? EXT?	quarrying in progress
	14 *Lost Rock	1989-01-29		P? EXT?	quarrying in progress
	15 *Mt. Gemini	1993-01-21		F-EXT	quarrying application submitted
Dekalb	16 *Arabia Mountain	1992-06-10#	1992-06-10	E	recreational overuse; VT
	17 *Bradley Mountain	1990-03-14	1990-03-14	F	quarrying; competition
	- *Hayden Quarry Rd.	1982-00-00	1992-06-10	EXT	(road-paving VT)
	18 Little Rock Chapel Mtn.	1987-09-07#		P	extinct?; quarrying in progress
	19 North Rock Chapel Mtn.	1986-04-19		P	quarrying
	- *Pine Mountain	1897-05-15?		EXT	(quarrying)
	- *Rock Chapel Mountain	1939-03-15		EXT	(site destroyed by quarrying)
	20 Rock Chapel Park	1992-06-10		F	competition; road-improvement-VT
	- *Rollaway	1979-03-17	1983-12-17	EXT	(quarrying; vehicular traffic)
	21 *Stone Mountain	1993-02-15		F	recreational overuse
	- Stone Mountain-"Flatrock"	1950's (?)	1984-03-22	EXT	(construction?; quarrying?)
Douglas	22 Clinton Nature Preserve	1990-04-06		P	eutrophication? (horse manure)
	23 Pope Road	1990-04-06		F	vehicular traffic; dumping
Greene	24 *Greensboro	1992-04-07		E-P	quarrying in progress
	25 Greensboro South	1992-04-07		G-P	proposed crushed stone quarry
	26 Old Sparta Road	1992-04-07		G-P	logging VT; road improvements
	27 Siloam	1993-01-21		G	logging VT; eventual development
Gwinnett	28 *Baker's Rock	1993-04-21		P	vandalism; shading?
Hancock	29 Culverton South	1989-02-21		G	VT; potential quarrying
	30 *Forty Acre Rock	1987-02-06		G-P	grazing; eutrophication

STATE/COUNTY	SITE NAME	LAST SEEN	SOUGHT SINCE?	RANKING	THREATS
Hancock	31 Galilee Rock	1987-02-06		F-P	Competition, eutrophication; VT
	32 Granite Hill	1989-01-28		F	VT; potential quarrying
	33 *Pinkston Creek	1992-04-07		E	logging and other VT; quarrying
	34 Rocky Flats	1990-03-20		G	competition; eutrophication
Harris	35 Gray Rock	1988-10-23#		E	potential quarrying
Heard	36 Big Rock	1990-01-00		F	eutrophication; quarrying
	37 Boggy Rock	1990-04-26		G	eutrophication; quarrying
	38 *Camp Meeting Rock	1993-04-24		E	quarrying; VT; dumping
	39 Flat Rock North	1987-10-10#		G	potential quarrying
	40 Mile Post Six	1988-09-17#		G? F?	potential quarrying
	41 Rusty Rock	1992-04-23		F-EXT	quarrying in progress
	42 Sunflower Rock	1988-09-10#		G	potential quarrying
	43 Mt. Carrie Church South	1992-04-15		F	VT; dumping of logging refuse
Henry	44 Wolf Rock	1990-04-14		P	fire-building; VT
Meriwether	45 Wright Branch North	1992-03-31		F	logging VT; quarrying
Newton	-*Ellis Farm	1984-05-20	1987	EXT	(quarrying)
	46 Geezer Rock	1986-03-15		P-EXT?	eutrophication; competition
Oglethorpe	47 Echols Mill	1986-10-12#		F-EXT?	quarrying in process
Pike	48 Concord	1991-06-01#		G	quarrying; eutrophication; VT
Putnam	49 *Eatonton	1991-01-29		G-F	fire-building; VT
Rockdale	50 Bald Rock	1992-05-02		G-P	eutrophication; competition
	- Panola Mountain	1939-02-12	1992-04-14	EXT	(succession?)
	51 *Philadelphia Road	1992-05-02		P	VT; dumping
	52 The Rocks	1992-05-02		F	potential quarrying; VT
Walton	53 Anglin Farm	1980-02-26		F	eutrophication; competition?
	54 Rock of the Ages	1991-07-12#		F	quarrying; logging VT
	- Walnut Grove	1979-04-28	1991-02-24	EXT	(pools filled w/concrete)
SC Lancaster	55 Forty Acre Rock	1993-04-18		G	VT (motorbikes/bicycles)
Saluda	56 (Batesburg) Flat Rock	1993-04-10		F	VT; quarrying
York	57 Hilltop Lane	1993-04-18		F-G	VT; dumping

[1] EXT = extinct; E = excellent; G = good; F = fair; P = poor. Hyphenated symbols: first symbol is rating with landowner cooperation, second symbol is rating without cooperation; these populations face immediate threats.

[2] * = *Amphianthus* site which also supports/supported *Isoetes melanospora* or *I. tegetiformans*.

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USFWS 2007

Rec 9.3 Ref 59

County Species Lists

T=Threatened
E=Endangered
S/A=Similarity of Appearance to a Threatened Taxon

Listed Species in Abbeville County				
Species	Federal Status	State Status	Habitat	Threats
Birds				
Bald eagle *Haliaeetus leucocephalus*	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once they have successfully established a nest	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for young

Listed Species in Aiken County				
Species	Federal Status	State Status	Habitat	Threats
Birds				
Bald eagle *Haliaeetus leucocephalus*	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once they have successfully established a nest	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for young
Wood Stork *Mycteria americana*	E	E	primarily feed in fresh and brackish wetlands and nest in cypress or other wooded swamps	decline due primarily to loss of suitable feeding habitat; other factors include loss of nesting habitat, prolonged drought/flooding, racoon predation on nests, and human disturbance of rookeries
ed-cockaded			nest in mature pine with low understory vegetation (<1.5m);	reduction of older age pine stands and to

woodpecker *Picoides borealis*	E	E	forage in pine and pine hardwood stands >30 years of age, preferably>10" dbh	encroachment of hardwood midstory in older age pine stands due to fire suppression
Fishes				
Shortnose sturgeon *Acipenser brevirostrum*	E	E	occur in most major river systems along the eastern seaboard	habitat alterations from discharges, dredging or disposal of material into rivers, or related development activities involving estuarine/riverine mudflats and marshes; commercial exploitation up until the 1950s
Plants				
Relict Trillium *Trillium reliquum*	E	E	mature, moist, undisturbed hardwood forests, generally free from fire	logging, road construction, agricultural conversion, residential and industrial development, stone quarrying, exotic weeds
Smooth coneflower *Echinacea laevigata*	E	E	prairie remnants, open woods, cedar barrens, roadsides, clearcuts, dry limestone bluffs, and power line rights-of-way, usually on magnesium and calcium rich soils	collection, fire suppression, exotic weeds
Harperella *Ptilimnium nodosum*	E	E	seasonally flooded rocky streams and edges of coastal plain ponds	hydrological alteration

Listed Species in Allendale County

Species	Federal Status	State Status	Habitat	Threats
Birds				
Bald eagle *Haliaeetus leucocephalus*	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once they have successfully established a nest	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for young
				decline due primarily to

Wood stork *Mycteria americana*	E	E	primarily feed in fresh and brackish wetlands and nest in cypress or other wooded swamps	loss of suitable feeding habitat; other factors include loss of nesting habitat, prolonged drought/flooding, racoon predation on nests, and human disturbance of rookeries
Red-cockaded woodpecker *Picoides borealis*	E	E	nest in mature pine with low understory vegetation (<1.5m); forage in pine and pine hardwood stands > 30 years of age, preferably > 10" dbh	reduction of older age pine stands and to encroachment of hardwood midstory in older age pine stands due to fire suppression
Fishes				
Shortnose sturgeon *Acipenser brevirostrum*	E	E	occur in most major river systems along the eastern seaboard	habitat alterations from discharges, dredging or disposal of material into rivers, or related development activities involving estuarine/riverine mudflats and marshes; commercial exploitation up until the 1950s
Plants				
Smooth Coneflower *Echinacea laevigatava*	E	E	prairie remnants, open woods, cedar barrens, roadsides, clearcuts, dry limestone bluffs, and power line rights-of-way, usually on magnesium and calcium rich soils	collection, fire suppression, exotic weeds
Canby's dropwort *Oxypolis canbyi*	E	E	found in pond-cypress savannahs in Carolina Bay formations dominated by grasses and sedges or ditches next to bays; prefer borders and shallows of cypress-pond pine ponds and sloughs	loss or alteration of wetland habitats

Listed Species in Anderson County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Birds				
			coastlines, rivers, large lakes	

Bald eagle _Haliaeetus leucocephalus_	T	E	or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once they have successfully established a nest	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for young
Plants				
Smooth Coneflower _Echinacea laevigata_	E	E	prairie remnants, open woods, cedar barrens, roadsides, clearcuts, dry limestone bluffs, and power line rights-of-way, usually on magnesium and calcium rich soils	collection, fire suppression, exotic weeds

Listed Species in Bamberg County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Birds				
Wood stork _Mycteria americana_	E	E	primarily feed in fresh and brackish wetlands and nest in cypress or other wooded swamps	decline due primarily to loss of suitable feeding habitat; other factors include loss of nesting habitat, prolonged drought/flooding, racoon predation on nests, and human disturbance of rookeries
Red-cockaded woodpecker _Picoides borealis_	E	E	nest in mature pine with low understory vegetation (<1.5m); forage in pine and pine hardwood stands > 30 years of age, preferably > 10" dbh	reduction of older age pine stands and to encroachment of hardwood midstory in older age pine stands due to fire suppression
Plants				
Canby's dropwort _Oxypolis canbyi_	E	E	found in pond-cypress savannahs in Carolina Bay formations dominated by grasses and sedges or ditches next to bays; prefer borders and shallows of cypress-pond pine ponds and sloughs	loss or alteration of wetland habitats

Listed Species in Barnwell County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Birds				
Bald eagle *Haliaeetus leucocephalus*	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once they have successfully established a nest	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for young
Wood Stork *Mycteria americana*	E	E	primarily feed in fresh and brackish wetlands and nest in cypress or other wooded swamps	decline due primarily to loss of suitable feeding habitat; other factors include loss of nesting habitat, prolonged drought/flooding, racoon predation on nests, and human disturbance of rookeries
Red-Cockaded Woodpecker *Picoides borealis*	E	E	nest in mature pine with low understory vegetation (<1.5m); forage in pine and pine hardwood stands > 30 years of age, preferably > 10" dbh	reduction of older age pine stands and to encroachment of hardwood midstory in older age pine stands due to fire suppression
Fishes				
Shortnose sturgeon *Acipenser brevirostrum*	E	E	occur in most major river systems along the eastern seaboard	habitat alterations from discharges, dredging or disposal of material into rivers, or related development activities involving estuarine/riverine mudflats and marshes; commercial exploitation up until the 1950s
Plants				
Smooth Coneflower *Echinacea laevigata*	E	E	prairie remnants, open woods, cedar barrens, roadsides, clearcuts, dry limestone bluffs, and power line rights-of-way, usually on magnesium and calcium rich soils	collection, fire suppression, exotic weeds

Pondberry *Lindera melissifolia*	E	E	found in swamp and pond margins, sandy sinks, swampy depressions or wet flats that are subject to drying but the roots are submerged at times	drainage ditching and subsequent conversion of habitat to other uses, lack of seedling production
Canby's dropwort *Oxypolis canbyi*	E	E	found in pond-cypress savannahs in Carolina Bay formations dominated by grasses and sedges or ditches next to bays; prefer borders and shallows of cypress-pond pine ponds and sloughs	loss or alteration of wetland habitats
Harperella *Ptilimnium nodosum*	E	E	seasonally flooded rocky streams and edges of coastal plain ponds	hydrological alteration
American chaffseed *Schwalbea americana*	E	E	found in various sandy soil areas on the coastal plain; plants are usually found on margins of savannas and cypress ponds that are seasonally wet; best managed by prescribed fire	fire suppression, habitat conversion, and incompatible agriculture and forestry practices

Listed Species in Beaufort County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Mammals				
West Indian manatee *Trichechus manatus*	E	E	coastal waters, estuaries, and warm water outfalls	initial decreases probably due to overharvesting for meat, oil and leather; current mortality due to collisions with boats and barges; decline also related to coastal development and loss of suitable habitat, particularly destruction of seagrass beds
Birds				
Bald eagle *Haliaeetus leucocephalus*	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for

			to the same nest tree, once they have successfully established a nest	young
Wood Stork *Mycteria americana*	E	E	primarily feed in fresh and brackish wetlands and nest in cypress or other wooded swamps	decline due primarily to loss of suitable feeding habitat; other factors include loss of nesting habitat, prolonged drought/flooding, racoon predation on nests, and human disturbance of rookeries
Red-Cockaded Woodpecker *Picoides borealis*	E	E	nest in mature pine with low understory vegetation (<1.5m); forage in pine and pine hardwood stands > 30 years of age, preferably > 10" dbh	reduction of older age pine stands and to encroachment of hardwood midstory in older age pine stands due to fire suppression
Piping plover *Charadrius melodus*	T	T	winters on SC coast; prefers areas with expansive sand or mudflats (for foraging) in close proximity to a sand beach (for roosting)	habitat alteration and destruction and human disturbance in nesting colonies; recreational and commercial development have contributed greatly to loss of breeding habitat
Reptiles				
Kemp's ridley sea turtle *Lepidochelys kempii*	E		outside of nesting season, primarily found in the nearshore and inshore waters of the Gulf of Mexico, although immatures have been observed along the Atlantic as far north as Massachusetts	overharvesting of eggs and adults for food and skins, drowning when caught in shrimp nets
Leatherback sea turtle *Dermochelys coriacea*	E		rarely nests in SC, visits often coincide with periodic abundance of cannonball jellyfish; distributed worldwide in tropical and temperate waters of the Atlantic, Pacific and Indian Oceans; most pelagic of the sea turtles	human exploitation, beach development, high predation of hatchlings, and drowning when caught in nets of commercial shrimp and fish trawls and longline and driftnet fisheries
Loggerhead sea turtle *Caretta caretta*	T		nests on SC ocean beaches, forages primarily on mollusks and crustaceans in shallow ocean waters and stream channels, widely distributed	loss or degradation of nesting habitat due to coastal development and beach armoring; disorientation of hatchlings by beachfront lighting; and

			throughout the world	incidental take from channel dredging and commercial trawling
Green sea turtle *Chelonia mydas*	T		rarely nests in SC, generally found in fairly shallow waters (except when migrating) inside reefs, bays and inlets	exploitation for food, high levels of predation, loss of nesting habitat due to human encroachment, hatchling disorientation due to artificial lights on beaches, and drowning when trapped in fishing and shrimping nets
Amphibians				
Flatwoods salamander *Ambystoma cingulatum*	T	E	adults and subadults are fossorial; found in open mesic pine/ wiregrass flatwoods dominated by longleaf or slash pine and maintained by frequent fire. During breeding period, which coincides with heavy rains from October to December, move to isolated, shallow, small depressions (forested with emergent vegetation) that dry completely on a cyclic basis	habitat destruction as a result of agricultural and silvicultural practices (e.g., clearcutting, mechanical site preparation), fire suppresion and residential and commercial development
Fishes				
Shortnose sturgeon *Acipenser brevirostrum*	E	E	occur in most major river systems along the eastern seaboard	habitat alterations from discharges, dredging or disposal of material into rivers, or related development activities involving estuarine/riverine mudflats and marshes; commercial exploitation up until the 1950s
Plants				
Pondberry *Lindera melissifolia*	E	E	found in swamp and pond margins, sandy sinks, swampy depressions or wet flats that are subject to drying but the roots are submerged at times	drainage ditching and subsequent conversion of habitat to other uses, lack of seedling production
Canby's dropwort *Oxypolis canbyi*	E	E	found in pond-cypress savannahs in Carolina Bay formations dominated by grasses and sedges or ditches next to bays; prefer borders	loss or alteration of wetland habitats

			and shallows of cypress-pond pine ponds and sloughs	
American chaffseed *Schwalbea americana*	E	E	found in various sandy soil areas on the coastal plain; plants are usually found on margins of savannas and cypress ponds that are seasonally wet; best managed by prescribed fire	fire suppression, habitat conversion, and incompatible agriculture and forestry practices

Listed Species in Berkeley County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Mammals				
West Indian manatee *Trichechus manatus*	E	E	coastal waters, estuaries, and warm water outfalls	initial decreases probably due to overharvesting for meat, oil and leather; current mortality due to collisions with boats and barges; decline also related to coastal development and loss of suitable habitat, particularly destruction of seagrass beds
Birds				
Bald eagle *Haliaeetus leucocephalus*	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once they have successfully established a nest	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for young
Wood Stork *Mycteria americana*	E	E	primarily feed in fresh and brackish wetlands and nest in cypress or other wooded swamps	decline due primarily to loss of suitable feeding habitat; other factors include loss of nesting habitat, prolonged drought/flooding, racoon predation on nests, and human disturbance of rookeries
			nest in mature pine with low	reduction of older age pine

Red-cockaded woodpecker *Picoides borealis*	E	E	understory vegetation (<1.5m); forage in pine and pine hardwood stands > 30 years of age, preferably > 10" dbh	stands and to encroachment of hardwood midstory in older age pine stands due to fire suppression
Reptiles				
Loggerhead sea turtle *Caretta caretta*	T		nests on SC ocean beaches, forages primarily on mollusks and crustaceans in shallow ocean waters and stream channels, widely distributed throughout the world	loss or degradation of nesting habitat due to coastal development and beach armoring; disorientation of hatchlings by beachfront lighting; and incidental take from channel dredging and commercial trawling
Amphibians				
Flatwoods salamander *Ambystoma cingulatum*	T	E	adults and subadults are fossorial; found in open mesic pine/ wiregrass flatwoods dominated by longleaf or slash pine and maintained by frequent fire. During breeding period, which coincides with heavy rains from October to December, move to isolated, shallow, small depressions (forested with emergent vegetation) that dry completely on a cyclic basis	habitat destruction as a result of agricultural and silvicultural practices (e.g., clearcutting, mechanical site preparation), fire suppresion and residential and commercial development
Fishes				
Shortnose sturgeon *Acipenser brevirostrum*	E	E	occur in most major river systems along the eastern seaboard	habitat alterations from discharges, dredging or disposal of material into rivers, or related development activities involving estuarine/riverine mudflats and marshes; commercial exploitation up until the 1950s
Plants				
Pondberry *Lindera melissifolia*	E	E	found in swamp and pond margins, sandy sinks, swampy depressions or wet flats that are subject to drying but the roots are submerged at times	drainage ditching and subsequent conversion of habitat to other uses, lack of seedling production
			found in pond-cypress savannahs in Carolina Bay	

Canby's dropwort *Oxypolis canbyi*	E	E	formations dominated by grasses and sedges or ditches next to bays; prefer borders and shallows of cypress-pond pine ponds and sloughs	loss or alteration of wetland habitats
American chaffseed *Schwalbea americana*	E	E	found in various sandy soil areas on the coastal plain; plants are usually found on margins of savannas and cypress ponds that are seasonally wet; best managed by prescribed fire	fire suppression, habitat conversion, and incompatible agriculture and forestry practices

Listed Species in Calhoun County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Birds				
Bald eagle *Haliaeetus leucocephalus*	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once they have successfully established a nest	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for young
Red-cockaded woodpecker *Picoides borealis*	E	E	nest in mature pine with low understory vegetation (<1.5m); forage in pine and pine hardwood stands > 30 years of age, preferably > 10" dbh	reduction of older age pine stands and to encroachment of hardwood midstory in older age pine stands due to fire suppression
Fishes				
Shortnose sturgeon *Acipenser brevirostrum*	E	E	occur in most major river systems along the eastern seaboard	habitat alterations from discharges, dredging or disposal of material into rivers, or related development activities involving estuarine/riverine mudflats and marshes; commercial exploitation up until the 1950s

Listed Species in Charleston County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Mammals				
West Indian manatee *Trichechus manatus*	E	E	coastal waters, estuaries, and warm water outfalls	initial decreases probably due to overharvesting for meat, oil and leather; current mortality due to collisions with boats and barges; decline also related to coastal development and loss of suitable habitat, particularly destruction of seagrass beds
Birds				
Bald eagle *Haliaeetus leucocephalus*	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once they have successfully established a nest	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for young
Bachman's warbler *Vermivora bachmanii*	E		nests in low, wet, swampy areas forested with mature sweet gum, oaks, hickories, black gum, and other hardwoods; also seems to prefer an opening in the forest covering and ground densely covered with cane, palmetto, blackberry, gallberry, and other shrubs and vines	loss of habitat, believed to be extinct
Wood stork *Mycteria americana*	E	E	primarily feed in fresh and brackish wetlands and nest in cypress or other wooded swamps	decline due primarily to loss of suitable feeding habitat; other factors include loss of nesting habitat, prolonged drought/flooding, racoon predation on nests, and human disturbance of rookeries
Red-cockaded woodpecker	E	E	nest in mature pine with low understory vegetation (<1.5m); forage in pine and pine	reduction of older age pine stands and to encroachment of hardwood midstory in older age pine

Picoides borealis			hardwood stands > 30 years of age, preferably > 10" dbh	stands due to fire suppression
Piping plover *Charadrius melodus*	T	T	winters on SC coast; prefers areas with expansive sand or mudflats (for foraging) in close proximity to a sand beach (for roosting)	habitat alteration and destruction and human disturbance in nesting colonies; recreational and commercial development have contributed greatly to loss of breeding habitat
Reptiles				
Kemp's ridley sea turtle *Lepidochelys kempii*	E		outside of nesting season, primarily found in the nearshore and inshore waters of the Gulf of Mexico, although immatures have been observed along the Atlantic as far north as Massachusetts	overharvesting of eggs and adults for food and skins, drowning when caught in shrimp nets
Leatherback sea turtle *Dermochelys coriacea*	E		rarely nests in SC, visits often coincide with periodic abundance of cannonball jellyfish; distributed worldwide in tropical and temperate waters of the Atlantic, Pacific and Indian Oceans; most pelagic of the sea turtles	loss or degradation of nesting habitat due to coastal development and beach armoring; disorientation of hatchlings by beachfront lighting; and incidental take from channel dredging and commercial trawling
Loggerhead sea turtle *Caretta caretta*	T		nests on SC ocean beaches, forages primarily on mollusks and crustaceans in shallow ocean waters and stream channels, widely distributed throughout the world	loss or degradation of nesting habitat due to coastal development and beach armoring; disorientation of hatchlings by beachfront lighting; and incidental take from channel dredging and commercial trawling
Green sea turtle *Chelonia mydas*	T		rarely nests in SC, generally found in fairly shallow waters (except when migrating) inside reefs, bays and inlets	exploitation for food, high levels of predation, loss of nesting habitat due to human encroachment, hatchling disorientation due to artificial lights on beaches, and drowning when trapped in fishing and shrimping nets
Amphibians				
			adults and subadults are fossorial; found in open mesic	

Flatwoods salamander *Ambystoma cingulatum*	T	E	pine/ wiregrass flatwoods dominated by longleaf or slash pine and maintained by frequent fire. During breeding period, which coincides with heavy rains from October to December, move to isolated, shallow, small depressions (forested with emergent vegetation) that dry completely on a cyclic basis	habitat destruction as a result of agricultural and silvicultural practices (e.g., clearcutting, mechanical site preparation), fire suppresion and residential and commercial development
Fishes				
Shortnose sturgeon *Acipenser brevirostrum*	E	E	occur in most major river systems along the eastern seaboard	habitat alterations from discharges, dredging or disposal of material into rivers, or related development activities involving estuarine/riverine mudflats and marshes; commercial exploitation up until the 1950s
Plants				
Sea-beach amaranth *Amaranthus pumilus*	T	T	Atlantic coast barrier island beaches, on overwash flats at accreting ends of islands and lower foredunes of non-eroding beaches	beach-armoring, construction of other beach-stabilization structures, beach grooming, insect herbivory, off-road vehicles
Canby's dropwort *Oxypolis canbyi*	E	E	found in pond-cypress savannahs in Carolina Bay formations dominated by grasses and sedges or ditches next to bays; prefer borders and shallows of cypress-pond pine ponds and sloughs	loss or alteration of wetland habitats
Pondberry *Lindera melissifolia*	E	E	found in swamp and pond margins, sandy sinks, swampy depressions or wet flats that are subject to drying but the roots are submerged at times	drainage ditching and subsequent conversion of habitat to other uses, lack of seedling production
American chaffseed *Schwalbea americana*	E	E	found in various sandy soil areas on the coastal plain; plants are usually found on margins of savannas and cypress ponds that are seasonally wet; best managed by prescribed fire	fire suppression, habitat conversion, and incompatible agriculture and forestry practices

Listed Species in Cherokee County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Plants				
Dwarf-flowered heartleaf *Hexastylis naniflora*	T	T	acidic sandy loam soils along bluffs and nearby slopes, hillsides and ravines, in boggy areas adjacent to creekheads and streams	site conversion from woodlands to pasture, residential/ industrial development, reservoir construction, herbicides

Listed Species in Chester County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Birds				
Bald eagle *Haliaeetus leucocephalus*	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once they have successfully established a nest	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for young
Red-cockaded woodpecker *Picoides borealis*	E	E	nest in mature pine with low understory vegetation (<1.5m); forage in pine and pine hardwood stands > 30 years of age, preferably > 10" dbh	reduction of older age pine stands and to encroachment of hardwood midstory in older age pine stands due to fire suppression

Listed Species in Chesterfield County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Birds				
ald eagle	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May;	human activities that can cause them to abandon nest, or to not properly

Haliaeetus leucocephalus			tend to return year after year to the same nest tree, once they have successfully established a nest	incubate eggs, or care for young
Red-cockaded woodpecker *Picoides borealis*	E	E	nest in mature pine with low understory vegetation (<1.5m); forage in pine and pine hardwood stands > 30 years of age, preferably > 10" dbh	reduction of older age pine stands and to encroachment of hardwood midstory in older age pine stands due to fire suppression
Fishes				
Shortnose sturgeon *Acipenser brevirostrum*	E	E	occur in most major river systems along the eastern seaboard	habitat alterations from discharges, dredging or disposal of material into rivers, or related development activities involving estuarine/riverine mudflats and marshes; commercial exploitation up until the 1950s
Invertebrates				
Carolina heelsplitter *Lasmigona decorata*	E	E	inhabits cool, slow-moving, small to medium sized streams and rivers; individuals usually found in mud, muddy sand, or muddy gravel substrates along stable, well shaded stream banks	impoundments, poor water quality, sedimentation

Listed Species in Clarendon County

Species	Federal Status	State Status	Habitat	Threats
Birds				
Bald eagle *Haliaeetus leucocephalus*	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once they have successfully established a nest	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for young
Red-cockaded			nest in mature pine with low understory vegetation (<1.5m);	reduction of older age pine stands and to

Woodpecker *Picoides borealis*	E	E	forage in pine and pine hardwood stands > 30 years of age, preferably > 10" dbh	encroachment of hardwood midstory in older age pine stands due to fire suppression
Fishes				
Shortnose sturgeon *Acipenser brevirostrum*	E	E	occur in most major river systems along the eastern seaboard	habitat alterations from discharges, dredging or disposal of material into rivers, or related development activities involving estuarine/riverine mudflats and marshes; commercial exploitation up until the 1950s
Plants				
Canby's dropwort *Oxypolis canbyi*	E	E	found in pond-cypress savannahs in Carolina Bay formations dominated by grasses and sedges or ditches next to bays; prefer borders and shallows of cypress-pond pine ponds and sloughs	loss or alteration of wetland habitats
American chaffseed *Schwalbea americana*	E	E	found in various sandy soil areas on the coastal plain; plants are usually found on margins of savannas and cypress ponds that are seasonally wet; best managed by prescribed fire	fire suppression, habitat conversion, and incompatible agriculture and forestry practices

Listed Species in Colleton County

Species	Federal Status	State Status	Habitat	Threats
Birds				
Bald eagle *Haliaeetus leucocephalus*	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once they have successfully established a nest	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for young
				decline due primarily to

Wood stork *Mycteria americana*	E	E	primarily feed in fresh and brackish wetlands and nest in cypress or other wooded swamps	loss of suitable feeding habitat; other factors include loss of nesting habitat, prolonged drought/flooding, racoon predation on nests, and human disturbance of rookeries
Red-cockaded woodpecker *Picoides borealis*	E	E	nest in mature pine with low understory vegetation (<1.5m); forage in pine and pine hardwood stands > 30 years of age, preferably > 10" dbh	reduction of older age pine stands and to encroachment of hardwood midstory in older age pine stands due to fire suppression
Piping plover *Charadrius melodus*	T	T	winters on SC coast; prefers areas with expansive sand or mudflats (for foraging) in close proximity to a sand beach (for roosting)	habitat alteration and destruction and human disturbance in nesting colonies; recreational and commercial development have contributed greatly to loss of breeding habitat
Reptiles				
Kemp's ridley sea turtle *Lepidochelys kempii*	E		outside of nesting season, primarily found in the nearshore and inshore waters of the Gulf of Mexico, although immatures have been observed along the Atlantic as far north as Massachusetts	overharvesting of eggs and adults for food and skins, drowning when caught in shrimp nets
Leatherback sea turtle *Dermochelys coriacea*	E		rarely nests in SC, visits often coincide with periodic abundance of cannonball jellyfish; distributed worldwide in tropical and temperate waters of the Atlantic, Pacific and Indian Oceans; most pelagic of the sea turtles	loss or degradation of nesting habitat due to coastal development and beach armoring; disorientation of hatchlings by beachfront lighting; and incidental take from channel dredging and commercial trawling
Loggerhead sea turtle *Caretta caretta*	T		nests on SC ocean beaches, forages primarily on mollusks and crustaceans in shallow ocean waters and stream channels, widely distributed throughout the world	loss or degradation of nesting habitat due to coastal development and beach armoring; disorientation of hatchlings by beachfront lighting; and incidental take from channel dredging and commercial trawling

Green sea turtle *Chelonia mydas*	T		rarely nests in SC, generally found in fairly shallow waters (except when migrating) inside reefs, bays and inlets	exploitation for food, high levels of predation, loss of nesting habitat due to human encroachment, hatchling disorientation due to artificial lights on beaches, and drowning when trapped in fishing and shrimping nets
Fishes				
Shortnose sturgeon *Acipenser brevirostrum*	E	E	occur in most major river systems along the eastern seaboard	habitat alterations from discharges, dredging or disposal of material into rivers, or related development activities involving estuarine/riverine mudflats and marshes; commercial exploitation up until the 1950s
Plants				
Pondberry *Lindera melissifolia*	E	E	found in swamp and pond margins, sandy sinks, swampy depressions or wet flats that are subject to drying but the roots are submerged at times	drainage ditching and subsequent conversion of habitat to other uses, lack of seedling production
Canby's dropwort *Oxypolis canbyi*	E	E	found in pond-cypress savannahs in Carolina Bay formations dominated by grasses and sedges or ditches next to bays; prefer borders and shallows of cypress-pond pine ponds and sloughs	loss or alteration of wetland habitats

Listed Species in Darlington County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Birds				
Red-cockaded woodpecker *Picoides borealis*	E	E	nest in mature pine with low understory vegetation (<1.5m); forage in pine and pine hardwood stands > 30 years of age, preferably > 10" dbh	reduction of older age pine stands and to encroachment of hardwood midstory in older age pine stands due to fire suppression
Fishes				

Shortnose sturgeon *Acipenser brevirostrum*	E	E	occur in most major river systems along the eastern seaboard	habitat alterations from discharges, dredging or disposal of material into rivers, or related development activities involving estuarine/riverine mudflats and marshes; commercial exploitation up until the 1950s
Plants				
Rough-leaved loosestrife *Lysimachia asperulaefolia*	E	E	in the sandhills of the Carolinas in ecotones or edges between longleaf pine uplands and pond pine pocosins, on moist to seasonally saturated sands and on shallow organic soils overlaying sand	fire suppression, drainage, siltation from erosion, and, to a lesser extent, residential and industrial development

Listed Species in Dillon County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Birds				
Bald eagle *Haliaeetus leucocephalus*	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once they have successfully established a nest	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for young
Red-cockaded woodpecker *Picoides borealis*	E	E	nest in mature pine with low understory vegetation (<1.5m); forage in pine and pine hardwood stands > 30 years of age, preferably > 10" dbh	reduction of older age pine stands and to encroachment of hardwood midstory in older age pine stands due to fire suppression
Fishes				
Shortnose sturgeon	E	E	occur in most major river systems along the eastern	habitat alterations from discharges, dredging or disposal of material into rivers, or related development activities

Acipenser brevirostrum			seaboard	involving estuarine/riverine mudflats and marshes; commercial exploitation up until the 1950s

Listed Species in Dorchester County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Birds				
Bald eagle *Haliaeetus leucocephalus*	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once they have successfully established a nest	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for young
Wood stork *Mycteria americana*	E	E	primarily feed in fresh and brackish wetlands and nest in cypress or other wooded swamps	decline due primarily to loss of suitable feeding habitat; other factors include loss of nesting habitat, prolonged drought/flooding, racoon predation on nests, and human disturbance of rookeries
Red-cockaded woodpecker *Picoides borealis*	E	E	nest in mature pine with low understory vegetation (<1.5m); forage in pine and pine hardwood stands > 30 years of age, preferably > 10" dbh	reduction of older age pine stands and to encroachment of hardwood midstory in older age pine stands due to fire suppression
Fishes				
Shortnose sturgeon *Acipenser brevirostrum*	E	E	occur in most major river systems along the eastern seaboard	habitat alterations from discharges, dredging or disposal of material into rivers, or related development activities involving estuarine/riverine mudflats and marshes; commercial exploitation up until the 1950s
Plants				

Pondberry *Lindera melissifolia*	E	E	found in swamp and pond margins, sandy sinks, swampy depressions or wet flats that are subject to drying but the roots are submerged at times	drainage ditching and subsequent conversion of habitat to other uses, lack of seedling production
Canby's dropwort *Oxypolis canbyi*	E	E	found in pond-cypress savannahs in Carolina Bay formations dominated by grasses and sedges or ditches next to bays; prefer borders and shallows of cypress-pond pine ponds and sloughs	loss or alteration of wetland habitats

Listed Species in Edgefield County

Species	Federal Status	State Status	Habitat	Threats
Birds				
Bald eagle *Haliaeetus leucocephalus*	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once they have successfully established a nest	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for young
Red-cockaded woodpecker *Picoides borealis*	E	E	nest in mature pine with low understory vegetation (<1.5m); forage in pine and pine hardwood stands > 30 years of age, preferably > 10" dbh	reduction of older age pine stands and to encroachment of hardwood midstory in older age pine stands due to fire suppression
Invertebrates				
Carolina heelsplitter *Lasmigona decorata*	E	E	inhabits cool, slow-moving, small to medium sized streams and rivers; individuals usually found in mud, muddy sand, or muddy gravel substrates along stable, well shaded stream banks	impoundments, poor water quality, sedimentation
Plants				
Miccosukee gooseberry	T	T	steeply sloping land with deciduous forest more typically found further north;	residential/ industrial development, trampling, exotic species; logging;

Ribes echinellum			relatively cool microclimate	severe fire
Relict trillium *Trillium reliquum*	E	E	mature, moist, undisturbed hardwood forests, generally free from fire	logging, road construction, agricultural conversion, residential and industrial development, stone quarrying, exotic weeds

Listed Species in Fairfield County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Birds				
Bald eagle *Haliaeetus leucocephalus*	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once they have successfully established a nest	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for young

Listed Species in Florence County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Birds				
Bald eagle *Haliaeetus leucocephalus*	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once they have successfully established a nest	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for young
Red-cockaded woodpecker *Picoides borealis*	E	E	nest in mature pine with low understory vegetation (<1.5m); forage in pine and pine hardwood stands > 30 years of age, preferably > 10" dbh	reduction of older age pine stands and to encroachment of hardwood midstory in older age pine stands due to fire suppression
Fishes				

Shortnose sturgeon *Acipenser brevirostrum*	E	E	occur in most major river systems along the eastern seaboard	habitat alterations from discharges, dredging or disposal of material into rivers, or related development activities involving estuarine/riverine mudflats and marshes; commercial exploitation up until the 1950s
Plants				
American chaffseed *Schwalbea americana*	E	E	found in various sandy soil areas on the coastal plain; plants are usually found on margins of savannas and cypress ponds that are seasonally wet; best managed by prescribed fire	fire suppression, habitat conversion, and incompatible agriculture and forestry practices

Listed Species in Georgetown County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Mammals				
West Indian manatee *Trichechus manatus*	E	E	coastal waters, estuaries, and warm water outfalls	initial decreases probably due to overharvesting for meat, oil and leather; current mortality due to collisions with boats and barges; decline also related to coastal development and loss of suitable habitat, particularly destruction of seagrass beds
Birds				
Bald eagle *Haliaeetus leucocephalus*	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once they have successfully established a nest	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for young
Red-cockaded			nest in mature pine with low understory vegetation (<1.5m);	reduction of older age pine stands and to

woodpecker *Picoides borealis*	E	E	forage in pine and pine hardwood stands > 30 years of age, preferably > 10" dbh	encroachment of hardwood midstory in older age pine stands due to fire suppression
Wood stork *Mycteria americana*	E	E	primarily feed in fresh and brackish wetlands and nest in cypress or other wooded swamps	decline due primarily to loss of suitable feeding habitat; other factors include loss of nesting habitat, prolonged drought/flooding, racoon predation on nests, and human disturbance of rookeries
Piping plover *Charadrius melodus*	T	T	winters on SC coast; prefers areas with expansive sand or mudflats (for foraging) in close proximity to a sand beach (for roosting)	habitat alteration and destruction and human disturbance in nesting colonies; recreational and commercial development have contributed greatly to loss of breeding habitat
Reptiles				
Kemp's ridley sea turtle *Lepidochelys kempii*	E		outside of nesting season, primarily found in the nearshore and inshore waters of the Gulf of Mexico, although immatures have been observed along the Atlantic as far north as Massachusetts	overharvesting of eggs and adults for food and skins, drowning when caught in shrimp nets
Leatherback sea turtle *Dermochelys coriacea*	E		rarely nests in SC, visits often coincide with periodic abundance of cannonball jellyfish; distributed worldwide in tropical and temperate waters of the Atlantic, Pacific and Indian Oceans; most pelagic of the sea turtles	loss or degradation of nesting habitat due to coastal development and beach armoring; disorientation of hatchlings by beachfront lighting; and incidental take from channel dredging and commercial trawling
Loggerhead sea turtle *Caretta caretta*	T		nests on SC ocean beaches, forages primarily on mollusks and crustaceans in shallow ocean waters and stream channels, widely distributed throughout the world	loss or degradation of nesting habitat due to coastal development and beach armoring; disorientation of hatchlings by beachfront lighting; and incidental take from channel dredging and commercial trawling
				exploitation for food, high

Green sea turtle *Chelonia mydas*	T		rarely nests in SC, generally found in fairly shallow waters (except when migrating) inside reefs, bays and inlets	levels of predation, loss of nesting habitat due to human encroachment, hatchling disorientation due to artificial lights on beaches, and drowning when trapped in fishing and shrimping nets
Fishes				
Shortnose sturgeon *Acipenser brevirostrum*	E	E	occur in most major river systems along the eastern seaboard	habitat alterations from discharges, dredging or disposal of material into rivers, or related development activities involving estuarine/riverine mudflats and marshes; commercial exploitation up until the 1950s
Plants				
Sea-beach amaranth *Amaranthus pumilus*	T	T	Atlantic coast barrier island beaches, on overwash flats at accreting ends of islands and lower foredunes of non-eroding beaches	beach-armoring, construction of other beach-stabilization structures, beach grooming, insect herbivory, off-road vehicles
Pondberry *Lindera melissifolia*	E	E	found in swamp and pond margins, sandy sinks, swampy depressions or wet flats that are subject to drying but the roots are submerged at times	drainage ditching and subsequent conversion of habitat to other uses, lack of seedling production
Canby's dropwort *Oxypolis canbyi*	E	E	found in pond-cypress savannahs in Carolina Bay formations dominated by grasses and sedges or ditches next to bays; prefer borders and shallows of cypress-pond pine ponds and sloughs	loss or alteration of wetland habitats
American chaffseed *Schwalbea americana*	E	E	found in various sandy soil areas on the coastal plain; plants are usually found on margins of savannas and cypress ponds that are seasonally wet; best managed by prescribed fire	fire suppression, habitat conversion, and incompatible agriculture and forestry practices

Listed Species in Greenville County

Species	Federal Status	State Status	Habitat	Threats
Reptiles				
Bog turtle *Clemmys muhlenbergii*	T (S/A)	T (S/A)	spring seeps and open, marshy meadows in flat or gently rolling landscapes	black market pet trade, habitat loss to urban development
Plants				
Swamp-pink *Helonias bullata*	T	T	wetlands that are saturated but not flooded, including southern Appalachian bogs and swamps, Atlantic white cedar swamps, swampy forests bordering small streams; boggy meadows and spring seepage areas	wetland loss to urban, agricultural and silvicultural development; habitat degradation from offsite disturbance including groundwater withdrawal, sewage discharge, siltation from soil erosion, introduction of excess nutrients and toxic chemicals; trampling; collection
Dwarf-flowered heartleaf *Hexastylis naniflora*	T	T	acidic sandy loam soils along bluffs and nearby slopes, hillsides and ravines, in boggy areas adjacent to creekheads and streams	site conversion from woodlands to pasture, residential/ industrial development, reservoir construction, herbicides
Small whorled pogonia *Isotria medeoloides*	T	T	varies widely from white pine stands to open, dry deciduous woods with acid soil to rich cove hardwood mixed with hemlock; all sites have low shrub and sapling density	collection, and declines for unknown reasons
Bunched arrowhead *Sagittaria fasciculata*	E	E	seepage areas with very low water flow and no stagnation; soils are sandy loams overlain by muck 10-24 inches deep	wetland destruction, herbicide use in right-of-way maitenance
Mountain sweet pitcher-plant *Sarracenia rubra ssp. jonesii*	E	E	bogs and streamsides on granite rockfaces along the Blue Ridge Divide	wetland destruction, collection
White irisette *Sisyrinchium dichotomum*	E	E	rich, basic soils probably weathered from amphibolite, in clearings and the edges of upland woods where the canopy is thin and often where downslope runoff has removed	highway and powerline maintenance and improvement; residential development; exotic weed

			much of the deep litter layer ordinarily present on these sites	species
Rock gnome lichen *Gymnoderma lineare*	E	E	on rocks in areas of high humidity, either at high elevations or on boulders and large rock outcrops in deep river gorges at lower elevations	trampling; commercial, residential, and recreational development; possibly air pollution; collection; coniferous forest decline

Listed Species in Greenwood County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Invertebrates				
Carolina heelsplitter *Lasmigona decorata*	E	E	inhabits cool, slow-moving, small to medium sized streams and rivers; individuals usually found in mud, muddy sand, or muddy gravel substrates along stable, well shaded stream banks	impoundments, poor water quality, sedimentation

Listed Species in Hampton County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Birds				
Bald eagle *Haliaeetus leucocephalus*	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once they have successfully established a nest	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for young
Red-cockaded woodpecker *Picoides borealis*	E	E	nest in mature pine with low understory vegetation (<1.5m); forage in pine and pine hardwood stands > 30 years of age, preferably > 10" dbh	reduction of older age pine stands and to encroachment of hardwood midstory in older age pine stands due to fire suppression

Wood stork *Mycteria americana*	E	E	primarily feed in fresh and brackish wetlands and nest in cypress or other wooded swamps	decline due primarily to loss of suitable feeding habitat; other factors include loss of nesting habitat, prolonged drought/flooding, racoon predation on nests, and human disturbance of rookeries
Reptiles				
Eastern indigo snake *Drymarchon corais couperi*	T		den in zeric sandridge habitat during winter which is also preferred by gopher tortoises; forage in creek bottoms, upland forests, and agricultural fields during warm months	habitat loss due to uses such as farming, construction, forestry, and pasture and to overcollecting for the pet trade
Fishes				
Shortnose sturgeon *Acipenser brevirostrum*	E	E	occur in most major river systems along the eastern seaboard	habitat alterations from discharges, dredging or disposal of material into rivers, or related development activities involving estuarine/riverine mudflats and marshes; commercial exploitation up until the 1950s
Plants				
Canby's dropwort *Oxypolis canbyi*	E	E	found in pond-cypress savannahs in Carolina Bay formations dominated by grasses and sedges or ditches next to bays; prefer borders and shallows of cypress-pond pine ponds and sloughs	loss or alteration of wetland habitats

Listed Species in Horry County

Species	Federal Status	State Status	Habitat	Threats
Mammals				
West Indian manatee	E	E	coastal waters, estuaries, and	initial decreases probably due to overharvesting for meat, oil and leather; current mortality due to collisions with boats and

Trichechus manatus			warm water outfalls	barges; decline also related to coastal development and loss of suitable habitat, particularly destruction of seagrass beds
Birds				
Red-cockaded woodpecker *Picoides borealis*	E	E	nest in mature pine with low understory vegetation (<1.5m); forage in pine and pine hardwood stands > 30 years of age, preferably > 10" dbh	reduction of older age pine stands and to encroachment of hardwood midstory in older age pine stands due to fire suppression
Bald eagle *Haliaeetus leucocephalus*	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once they have successfully established a nest	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for young
Wood stork *Mycteria americana*	E	E	primarily feed in fresh and brackish wetlands and nest in cypress or other wooded swamps	decline due primarily to loss of suitable feeding habitat; other factors include loss of nesting habitat, prolonged drought/flooding, racoon predation on nests, and human disturbance of rookeries
Piping plover *Charadrius melodus*	T	T	winters on SC coast; prefers areas with expansive sand or mudflats (for foraging) in close proximity to a sand beach (for roosting)	habitat alteration and destruction and human disturbance in nesting colonies; recreational and commercial development have contributed greatly to loss of breeding habitat
Reptiles				
Kemp's ridley sea turtle *Lepidochelys kempii*	E		outside of nesting season, primarily found in the nearshore and inshore waters of the Gulf of Mexico, although immatures have been observed along the Atlantic as far north as Massachusetts	overharvesting of eggs and adults for food and skins, drowning when caught in shrimp nets
			rarely nests in SC, visits often	loss or degradation of nesting habitat due to

Leatherback sea turtle *Dermochelys coriacea*	E		coincide with periodic abundance of cannonball jellyfish; distributed worldwide in tropical and temperate waters of the Atlantic, Pacific and Indian Oceans; most pelagic of the sea turtles	coastal development and beach armoring; disorientation of hatchlings by beachfront lighting; and incidental take from channel dredging and commercial trawling
Loggerhead sea turtle *Caretta caretta*	T		nests on SC ocean beaches, forages primarily on mollusks and crustaceans in shallow ocean waters and stream channels, widely distributed throughout the world	loss or degradation of nesting habitat due to coastal development and beach armoring; disorientation of hatchlings by beachfront lighting; and incidental take from channel dredging and commercial trawling
Green sea turtle *Chelonia mydas*	T		rarely nests in SC, generally found in fairly shallow waters (except when migrating) inside reefs, bays and inlets	exploitation for food, high levels of predation, loss of nesting habitat due to human encroachment, hatchling disorientation due to artificial lights on beaches, and drowning when trapped in fishing and shrimping nets
Fishes				
Shortnose sturgeon *Acipenser brevirostrum*	E	E	occur in most major river systems along the eastern seaboard	habitat alterations from discharges, dredging or disposal of material into rivers, or related development activities involving estuarine/riverine mudflats and marshes; commercial exploitation up until the 1950s
Plants				
Sea-beach amaranth *Amaranthus pumilus*	T	T	Atlantic coast barrier island beaches, on overwash flats at accreting ends of islands and lower foredunes of non-eroding beaches	beach-armoring, construction of other beach-stabilization structures, beach grooming, insect herbivory, off-road vehicles
Pondberry *Lindera melissifolia*	E	E	found in swamp and pond margins, sandy sinks, swampy depressions or wet flats that are subject to drying but the roots are submerged at times	drainage ditching and subsequent conversion of habitat to other uses, lack of seedling production

Canby's dropwort *Oxypolis canbyi*	E	E	found in pond-cypress savannahs in Carolina Bay formations dominated by grasses and sedges or ditches next to bays; prefer borders and shallows of cypress-pond pine ponds and sloughs	loss or alteration of wetland habitats
American chaffseed *Schwalbea americana*	E	E	found in various sandy soil areas on the coastal plain; plants are usually found on margins of savannas and cypress ponds that are seasonally wet; best managed by prescribed fire	fire suppression, habitat conversion, and incompatible agriculture and forestry practices

Listed Species in Jasper County

Species	Federal Status	State Status	Habitat	Threats
Mammals				
West Indian manatee *Trichechus manatus*	E	E	coastal waters, estuaries, and warm water outfalls	initial decreases probably due to overharvesting for meat, oil and leather; current mortality due to collisions with boats and barges; decline also related to coastal development and loss of suitable habitat, particularly destruction of seagrass beds
Birds				
Bald eagle *Haliaeetus leucocephalus*	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once they have successfully established a nest	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for young
Red-cockaded woodpecker *Picoides borealis*	E	E	nest in mature pine with low understory vegetation (<1.5m); forage in pine and pine hardwood stands > 30 years of age, preferably > 10" dbh	reduction of older age pine stands and to encroachment of hardwood midstory in older age pine stands due to fire suppression

Wood stork *Mycteria americana*	E	E	primarily feed in fresh and brackish wetlands and nest in cypress or other wooded swamps	decline due primarily to loss of suitable feeding habitat; other factors include loss of nesting habitat, prolonged drought/flooding, racoon predation on nests, and human disturbance of rookeries
Piping plover *Charadrius melodus*	T	T	winters on SC coast; prefers areas with expansive sand or mudflats (for foraging) in close proximity to a sand beach (for roosting)	habitat alteration and destruction and human disturbance in nesting colonies; recreational and commercial development have contributed greatly to loss of breeding habitat
Reptiles				
Eastern indigo snake *Drymarchon corais couperi*	T		den in zeric sandridge habitat during winter which is also preferred by gopher tortoises; forage in creek bottoms, upland forests, and agricultural fields during warm months	habitat loss due to uses such as farming, construction, forestry, and pasture and to overcollecting for the pet trade
Kemp's ridley sea turtle *Lepidochelys kempii*	E		outside of nesting season, primarily found in the nearshore and inshore waters of the Gulf of Mexico, although immatures have been observed along the Atlantic as far north as Massachusetts	overharvesting of eggs and adults for food and skins, drowning when caught in shrimp nets
Leatherback sea turtle *Dermochelys coriacea*	E		rarely nests in SC, visits often coincide with periodic abundance of cannonball jellyfish; distributed worldwide in tropical and temperate waters of the Atlantic, Pacific and Indian Oceans; most pelagic of the sea turtles	loss or degradation of nesting habitat due to coastal development and beach armoring; disorientation of hatchlings by beachfront lighting; and incidental take from channel dredging and commercial trawling
Loggerhead sea turtle *Caretta caretta*	T		nests on SC ocean beaches, forages primarily on mollusks and crustaceans in shallow ocean waters and stream channels, widely distributed throughout the world	loss or degradation of nesting habitat due to coastal development and beach armoring; disorientation of hatchlings by beachfront lighting; and incidental take from channel dredging and commercial trawling

Green sea turtle *Chelonia mydas*	T		rarely nests in SC, generally found in fairly shallow waters (except when migrating) inside reefs, bays and inlets	exploitation for food, high levels of predation, loss of nesting habitat due to human encroachment, hatchling disorientation due to artificial lights on beaches, and drowning when trapped in fishing and shrimping nets
Amphibians				
Flatwoods salamander *Ambystoma cingulatum*	T	E	adults and subadults are fossorial; found in open mesic pine/ wiregrass flatwoods dominated by longleaf or slash pine and maintained by frequent fire. During breeding period, which coincides with heavy rains from October to December, move to isolated, shallow, small depressions (forested with emergent vegetation) that dry completely on a cyclic basis	habitat destruction as a result of agricultural and silvicultural practices (e.g., clearcutting, mechanical site preparation), fire suppresion and residential and commercial development
Fishes				
Shortnose sturgeon *Acipenser brevirostrum*	E	E	occur in most major river systems along the eastern seaboard	habitat alterations from discharges, dredging or disposal of material into rivers, or related development activities involving estuarine/riverine mudflats and marshes; commercial exploitation up until the 1950s
Plants				
Pondberry *Lindera melissifolia*	E	E	found in swamp and pond margins, sandy sinks, swampy depressions or wet flats that are subject to drying but the roots are submerged at times	drainage ditching and subsequent conversion of habitat to other uses, lack of seedling production
Canby's dropwort *Oxypolis canbyi*	E	E	found in pond-cypress savannahs in Carolina Bay formations dominated by grasses and sedges or ditches next to bays; prefer borders and shallows of cypress-pond pine ponds and sloughs	loss or alteration of wetland habitats
			found in various sandy soil	

American chaffseed *Schwalbea americana*	E	E	areas on the coastal plain; plants are usually found on margins of savannas and cypress ponds that are seasonally wet; best managed by prescribed fire	fire suppression, habitat conversion, and incompatible agriculture and forestry practices

Listed Species in Kershaw County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Birds				
Bald eagle *Haliaeetus leucocephalus*	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once they have successfully established a nest	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for young
Red-cockaded woodpecker *Picoides borealis*	E	E	nest in mature pine with low understory vegetation (<1.5m); forage in pine and pine hardwood stands > 30 years of age, preferably > 10" dbh	reduction of older age pine stands and to encroachment of hardwood midstory in older age pine stands due to fire suppression
Invertebrates				
Carolina heelsplitter *Lasmigona decorata*	E	E	inhabits cool, slow-moving, small to medium sized streams and rivers; individuals usually found in mud, muddy sand, or muddy gravel substrates along stable, well shaded stream banks	impoundments, poor water quality, sedimentation
Plants				
Michaux's sumac *Rhus michauxii*	E		sandy or rocky open woods, usually in association with basic soils; apparently dependent upon some form of disturbance to maintain the open quality of its habitat	loss or degradation of habitat due to fire suppression, industrial and residential development, conversion of sites for intensive silvicultural and agricultural purposes

Listed Species in Lancaster County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Invertebrates				
Carolina heelsplitter _Lasmigona decorata_	E	E	inhabits cool, slow-moving, small to medium sized streams and rivers; individuals usually found in mud, muddy sand, or muddy gravel substrates along stable, well shaded stream banks	impoundments, poor water quality, sedimentation
Plants				
Little amphianthus _Amphianthus pusillus_	T	T	vernal pools on large isolated granite domes or gently rolling granite outcrops in the Piedmont physiographic region	quarrying; off-road vehicle use and other vandalism associated with recreational use of granite outcrops
Smooth coneflower _Echinacea laevigata_	E	E	prairie remnants, open woods, cedar barrens, roadsides, clearcuts, dry limestone bluffs, and power line rights-of-way, usually on magnesium and calcium rich soils	collection, fire suppression, exotic weeds
Schweinitz's sunflower _Helianthus schweinitzii_	E	E	prairie and glade remnants, clearings and edges of upland woods on clayey soils with a high gravel content	highway and utility line right-of-way maintenance and expansion; residential and commercial development; exotic weeds
Black-spored quilwort _Isoetes melanospora_	E	E	found in rock-rimmed shallow pools on granite outcrops	habitat pools are susceptible to degradation and possible destruction by quarrying, vandalism, off-road vehicle abuse, dumping, foot traffic, and soil accumulation

Listed Species in Laurens County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Birds				
Red-cockaded woodpecker	E	E	nest in mature pine with low understory vegetation (<1.5m); forage in pine and pine	reduction of older age pine stands and to encroachment of hardwood

Picoides borealis			hardwood stands > 30 years of age, preferably > 10" dbh	midstory in older age pine stands due to fire suppression

Listed Species in Lee County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Birds				
Red-cockaded woodpecker *Picoides borealis*	E	E	nest in mature pine with low understory vegetation (<1.5m); forage in pine and pine hardwood stands > 30 years of age, preferably > 10" dbh	reduction of older age pine stands and to encroachment of hardwood midstory in older age pine stands due to fire suppression
Plants				
Canby's dropwort *Oxypolis canbyi*	E	E	found in pond-cypress savannahs in Carolina Bay formations dominated by grasses and sedges or ditches next to bays; prefer borders and shallows of cypress-pond pine ponds and sloughs	loss or alteration of wetland habitats
American chaffseed *Schwalbea americana*	E	E	found in various sandy soil areas on the coastal plain; plants are usually found on margins of savannas and cypress ponds that are seasonally wet; best managed by prescribed fire	fire suppression, habitat conversion, and incompatible agriculture and forestry practices

Listed Species in Lexington County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Birds				
Bald eagle *Haliaeetus leucocephalus*	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for young

			they have successfully established a nest	
Red-cockaded woodpecker *Picoides borealis*	E	E	nest in mature pine with low understory vegetation (<1.5m); forage in pine and pine hardwood stands > 30 years of age, preferably > 10" dbh	reduction of older age pine stands and to encroachment of hardwood midstory in older age pine stands due to fire suppression
Fishes				
Shortnose sturgeon *Acipenser brevirostrum*	E	E	occur in most major river systems along the eastern seaboard	habitat alterations from discharges, dredging or disposal of material into rivers, or related development activities involving estuarine/riverine mudflats and marshes; commercial exploitation up until the 1950s
Plants				
Smooth coneflower *Echinacea laevigata*	E	E	prairie remnants, open woods, cedar barrens, roadsides, clearcuts, dry limestone bluffs, and power line rights-of-way, usually on magnesium and calcium rich soils	collection, fire suppression, exotic weeds
Schweinitz's sunflower *Helianthus schweinitzii*	E	E	prairie and glade remnants, clearings and edges of upland woods on clayey soils with a high gravel content	highway and utility line right-of-way maintenance and expansion; residential and commercial development; exotic weeds

Listed Species in Marion County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Birds				
Bald eagle *Haliaeetus leucocephalus*	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once they have successfully established a nest	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for young

Red-cockaded woodpecker *Picoides borealis*	E	E	nest in mature pine with low understory vegetation (<1.5m); forage in pine and pine hardwood stands > 30 years of age, preferably > 10" dbh	reduction of older age pine stands and to encroachment of hardwood midstory in older age pine stands due to fire suppression
Wood stork *Mycteria americana*	E	E	primarily feed in fresh and brackish wetlands and nest in cypress or other wooded swamps	decline due primarily to loss of suitable feeding habitat; other factors include loss of nesting habitat, prolonged drought/flooding, racoon predation on nests, and human disturbance of rookeries
Fishes				
Shortnose sturgeon *Acipenser brevirostrum*	E	E	occur in most major river systems along the eastern seaboard	habitat alterations from discharges, dredging or disposal of material into rivers, or related development activities involving estuarine/riverine mudflats and marshes; commercial exploitation up until the 1950s
Plants				
Canby's dropwort *Oxypolis canbyi*	E	E	found in pond-cypress savannahs in Carolina Bay formations dominated by grasses and sedges or ditches next to bays; prefer borders and shallows of cypress-pond pine ponds and sloughs	loss or alteration of wetland habitats

Listed Species in Marlboro County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Birds				
Red-cockaded woodpecker *Picoides borealis*	E	E	nest in mature pine with low understory vegetation (<1.5m); forage in pine and pine hardwood stands > 30 years of age, preferably > 10" dbh	reduction of older age pine stands and to encroachment of hardwood midstory in older age pine stands due to fire suppression

Fishes				
Shortnose sturgeon *Acipenser brevirostrum*	E	E	occur in most major river systems along the eastern seaboard	habitat alterations from discharges, dredging or disposal of material into rivers, or related development activities involving estuarine/riverine mudflats and marshes; commercial exploitation up until the 1950s
Plants				
Canby's dropwort *Oxypolis canbyi*	E	E	found in pond-cypress savannahs in Carolina Bay formations dominated by grasses and sedges or ditches next to bays; prefer borders and shallows of cypress-pond pine ponds and sloughs	loss or alteration of wetland habitats

Listed Species in McCormick County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Birds				
Bald eagle *Haliaeetus leucocephalus*	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once they have successfully established a nest	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for young
Red-cockaded woodpecker *Picoides borealis*	E	E	nest in mature pine with low understory vegetation (<1.5m); forage in pine and pine hardwood stands > 30 years of age, preferably > 10" dbh	reduction of older age pine stands and to encroachment of hardwood midstory in older age pine stands due to fire suppression
Invertebrates				
Carolina heelsplitter *Lasmigona decorata*	E	E	inhabits cool, slow-moving, small to medium sized streams and rivers; individuals usually found in mud, muddy sand, or muddy gravel	impoundments, poor water quality, sedimentation

			substrates along stable, well shaded stream banks	
Plants				
Miccosukee gooseberry *Ribes echinellum*	T	T	steeply sloping land with deciduous forest more typically found further north; relatively cool microclimate	residential/ industrial development, trampling, exotic species; logging; severe fire

Listed Species in Newberry County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Birds				
Bald eagle *Haliaeetus leucocephalus*	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once they have successfully established a nest	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for young

Listed Species in Oconee County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Birds				
Bald eagle *Haliaeetus leucocephalus*	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once they have successfully established a nest	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for young
Plants				
Smooth coneflower *Echinacea laevigata*	E	E	prairie remnants, open woods, cedar barrens, roadsides, clearcuts, dry limestone bluffs, and power line rights-of-way, usually on magnesium and	collection, fire suppression, exotic weeds

			calcium rich soils	
Small whorled pogonia *Isotria medeoloides*	T	T	varies widely from white pine stands to open, dry deciduous woods with acid soil to rich cove hardwood mixed with hemlock; all sites have low shrub and sapling density	collection, and declines for unknown reasons
Persistent trillium *Trillium persistens*	E	E	deciduous or coniferous-deciduous woods of ravines or gorges, under or near *Rhododendron maximum* or *R. minus*	collecting, some types of timber harvest, esp. claercutting

Listed Species in Orangeburg County

Species	Federal Status	State Status	Habitat	Threats
Birds				
Bald eagle *Haliaeetus leucocephalus*	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once they have successfully established a nest	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for young
Red-cockaded woodpecker *Picoides borealis*	E	E	nest in mature pine with low understory vegetation (<1.5m); forage in pine and pine hardwood stands > 30 years of age, preferably > 10" dbh	reduction of older age pine stands and to encroachment of hardwood midstory in older age pine stands due to fire suppression
Amphibians				
Flatwoods salamander *Ambystoma cingulatum*	T	E	adults and subadults are fossorial; found in open mesic pine/ wiregrass flatwoods dominated by longleaf or slash pine and maintained by frequent fire. During breeding period, which coincides with heavy rains from October to December, move to isolated, shallow, small depressions (forested with emergent	habitat destruction as a result of agricultural and silvicultural practices (e.g., clearcutting, mechanical site preparation), fire suppresion and residential and commercial development

			vegetation) that dry completely on a cyclic basis	
Fishes				
Shortnose sturgeon *Acipenser brevirostrum*	E	E	occur in most major river systems along the eastern seaboard	habitat alterations from discharges, dredging or disposal of material into rivers, or related development activities involving estuarine/riverine mudflats and marshes; commercial exploitation up until the 1950s
Plants				
Canby's dropwort *Oxypolis canbyi*	E	E	found in pond-cypress savannahs in Carolina Bay formations dominated by grasses and sedges or ditches next to bays; prefer borders and shallows of cypress-pond pine ponds and sloughs	loss or alteration of wetland habitats

Listed Species in Pickens County

Species	Federal Status	State Status	Habitat	Threats
Birds				
Bald eagle *Haliaeetus leucocephalus*	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once they have successfully established a nest	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for young
Reptiles				
Bog turtle *Clemmys muhlenbergii*	T (S/A)	T (S/A)	spring seeps and open, marshy meadows in flat or gently rolling landscapes	black market pet trade, habitat loss to urban development
Plants				
Smooth coneflower *Echinacea laevigata*	E	E	prairie remnants, open woods, cedar barrens, roadsides, clearcuts, dry limestone bluffs, and power line rights-of-way,	collection, fire suppression, exotic weeds

			usually on magnesium and calcium rich soils	
Dwarf-flowered heartleaf *Hexastylis naniflora*	T	T	acidic sandy loam soils along bluffs and nearby slopes, hillsides and ravines, in boggy areas adjacent to creekheads and streams	site conversion from woodlands to pasture, residential/ industrial development, reservoir construction, herbicides
Black-spored quillwort *Isoetes melanospora*	E	E	found in rock-rimmed shallow pools on granite outcrops	habitat pools are susceptible to degradation and possible destruction by quarrying, vandalism, off-road vehicle abuse, dumping, foot traffic, and soil accumulation
Mountain sweet pitcher-plant *Sarracenia rubra ssp. jonesii*	E	E	bogs and streamsides on granite rockfaces along the Blue Ridge Divide	wetland destruction, collection

Listed Species in Richland County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Birds				
Bald eagle *Haliaeetus leucocephalus*	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once they have successfully established a nest	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for young
Red-cockaded woodpecker *Picoides borealis*	E	E	nest in mature pine with low understory vegetation (<1.5m); forage in pine and pine hardwood stands > 30 years of age, preferably > 10" dbh	reduction of older age pine stands and to encroachment of hardwood midstory in older age pine stands due to fire suppression
Fishes				
Shortnose sturgeon			occur in most major river	habitat alterations from discharges, dredging or disposal of material into rivers, or related

Acipenser brevirostrum	E	E	systems along the eastern seaboard	development activities involving estuarine/riverine mudflats and marshes; commercial exploitation up until the 1950s
Plants				
Smooth coneflower *Echinacea laevigata*	E	E	prairie remnants, open woods, cedar barrens, roadsides, clearcuts, dry limestone bluffs, and power line rights-of-way, usually on magnesium and calcium rich soils	collection, fire suppression, exotic weeds
Rough-leaved loosestrife *Lysimachia asperulaefolia*	E	E	in the sandhills of the Carolinas in ecotones or edges between longleaf pine uplands and pond pine pocosins, on moist to seasonally saturated sands and on shallow organic soils overlaying sand	fire suppression, drainage, siltation from erosion, and, to a lesser extent, residential and industrial development
Canby's dropwort *Oxypolis canbyi*	E	E	found in pond-cypress savannahs in Carolina Bay formations dominated by grasses and sedges or ditches next to bays; prefer borders and shallows of cypress-pond pine ponds and sloughs	loss or alteration of wetland habitats

Listed Species in Saluda County

Species	Federal Status	State Status	Habitat	Threats
Birds				
Red-cockaded woodpecker *Picoides borealis*	E	E	nest in mature pine with low understory vegetation (<1.5m); forage in pine and pine hardwood stands > 30 years of age, preferably > 10" dbh	reduction of older age pine stands and to encroachment of hardwood midstory in older age pine stands due to fire suppression
Plants				
Harperella *Ptilimnium nodosum*	E	E	seasonally flooded rocky streams and edges of coastal plain ponds	hydrological alteration
Little amphianthus			vernal pools on large isolated granite domes or gently rolling	quarrying; off-road vehicle use and other vandalism

Amphianthus pusillus	T	T	granite outcrops in the Piedmont physiographic region	associated with recreational use of granite outcrops

Listed Species in Spartanburg County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Plants				
Dwarf-flowered heartleaf *Hexastylis naniflora*	T	T	acidic sandy loam soils along bluffs and nearby slopes, hillsides and ravines, in boggy areas adjacent to creekheads and streams	site conversion from woodlands to pasture, residential/ industrial development, reservoir construction, herbicides

Listed Species in Sumter County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Birds				
Bald eagle *Haliaeetus leucocephalus*	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once they have successfully established a nest	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for young
Red-cockaded woodpecker *Picoides borealis*	E	E	nest in mature pine with low understory vegetation (<1.5m); forage in pine and pine hardwood stands > 30 years of age, preferably > 10" dbh	reduction of older age pine stands and to encroachment of hardwood midstory in older age pine stands due to fire suppression
Fishes				
Shortnose sturgeon *Acipenser brevirostrum*	E	E	occur in most major river systems along the eastern seaboard	habitat alterations from discharges, dredging or disposal of material into rivers, or related development activities involving estuarine/riverine mudflats and marshes;

				commercial exploitation up until the 1950s
Plants				
Canby's dropwort *Oxypolis canbyi*	E	E	found in pond-cypress savannahs in Carolina Bay formations dominated by grasses and sedges or ditches next to bays; prefer borders and shallows of cypress-pond pine ponds and sloughs	loss or alteration of wetland habitats
American chaffseed *Schwalbea americana*	E	E	found in various sandy soil areas on the coastal plain; plants are usually found on margins of savannas and cypress ponds that are seasonally wet; best managed by prescribed fire	fire suppression, habitat conversion, and incompatible agriculture and forestry practices

Listed Species in Union County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**

Listed Species in Williamsburg County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Birds				
Bald eagle *Haliaeetus leucocephalus*	T	E	coastlines, rivers, large lakes or streams which provide adequate feeding grounds; typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once they have successfully established a nest	human activities that can cause them to abandon nest, or to not properly incubate eggs, or care for young
Wood stork			primarily feed in fresh and brackish wetlands and nest in	decline due primarily to loss of suitable feeding habitat; other factors include loss of nesting

Mycteria americana	E	E	cypress or other wooded swamps	habitat, prolonged drought/flooding, racoon predation on nests, and human disturbance of rookeries
Red-cockaded woodpecker *Picoides borealis*	E	E	nest in mature pine with low understory vegetation (<1.5m); forage in pine and pine hardwood stands > 30 years of age, preferably > 10" dbh	reduction of older age pine stands and to encroachment of hardwood midstory in older age pine stands due to fire suppression
Fishes				
Shortnose sturgeon *Acipenser brevirostrum*	E	E	occur in most major river systems along the eastern seaboard	habitat alterations from discharges, dredging or disposal of material into rivers, or related development activities involving estuarine/riverine mudflats and marshes; commercial exploitation up until the 1950s
Plants				
Canby's dropwort *Oxypolis canbyi*	E	E	found in pond-cypress savannahs in Carolina Bay formations dominated by grasses and sedges or ditches next to bays; prefer borders and shallows of cypress-pond pine ponds and sloughs	loss or alteration of wetland habitats
American chaffseed *Schwalbea americana*	E	E	found in various sandy soil areas on the coastal plain; plants are usually found on margins of savannas and cypress ponds that are seasonally wet; best managed by prescribed fire	fire suppression, habitat conversion, and incompatible agriculture and forestry practices

Listed Species in York County				
Species	**Federal Status**	**State Status**	**Habitat**	**Threats**
Birds				
Bald eagle			coastlines, rivers, large lakes or streams which provide adequate feeding grounds;	human activities that can

Haliaeetus leucocephalus	T	E	typically nest in SC between late October and late May; tend to return year after year to the same nest tree, once they have successfully established a nest	cause them to abandon nest, or to not properly incubate eggs, or care for young
Plants				
Little amphianthus *Amphianthus pusillus*	T	T	vernal pools on large isolated granite domes or gently rolling granite outcrops in the Piedmont physiographic region	quarrying; off-road vehicle use and other vandalism associated with recreational use of granite outcrops
Schweinitz's sunflower *Helianthus schweinitzii*	E	E	prairie and glade remnants, clearings and edges of upland woods on clayey soils with a high gravel content	highway and utility line right-of-way maintenance and expansion; residential and commercial development; exotic weeds
Dwarf-flowered heartleaf *Hexastylis naniflora*	T	T	acidic sandy loam soils along bluffs and nearby slopes, hillsides and ravines, in boggy areas adjacent to creekheads and streams	site conversion from woodlands to pasture, residential/ industrial development, reservoir construction, herbicides

Home

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Water Resources Data South Carolina Water Year 2005

Cooney et al 2006

Water-Data Report SC-05-1

U.S. Department of the Interior
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By T.W. Cooney, P.A. Drewes, S.W. Elliser, T.H. Lanier, and F. Melendez

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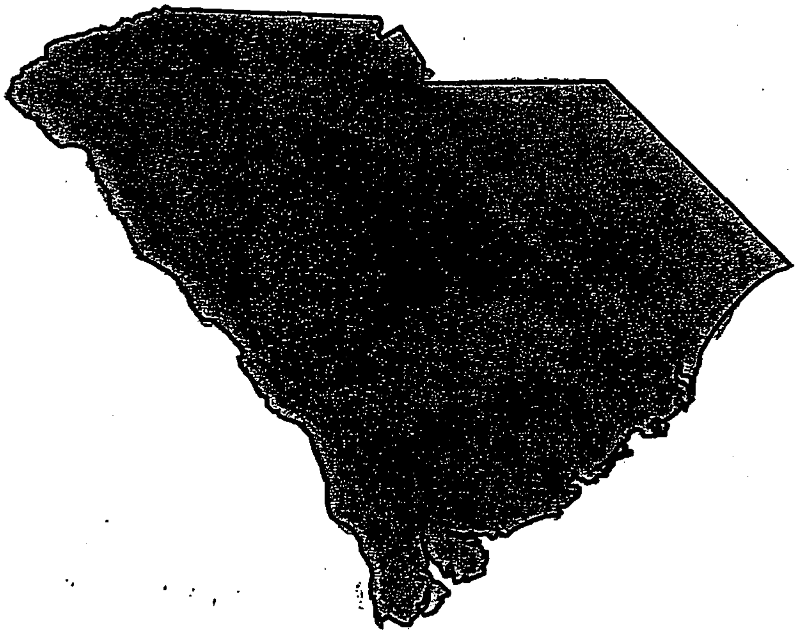

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U.S. Geological Survey
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13. ABSTRACT *(Maximum 200 words)*
Water Resources data for the 2005 water year for South Carolina consists of records of stage, discharge, and water quality of streams; stage and contents of lakes and reservoirs; and levels of ground-water wells. This volume contains records for water discharge at 92 gaging stations, stage only at 35 gaging stations, stage and contents at 11 lakes and reservoirs, water-quality at 45 gaging stations and one observation well, water levels at 28 observation wells, and precipitation at 27 gaging stations. Also included are data for 65 crest-stage partial-record stations and discharge measurement information at 8 miscellaneous sites. Locations of these sites are shown on figures 4, 5, 6, 7, 8 and 9. Additional water data were collected at various sites not involved in the systematic data-collection program. These data represent that part of the National Water Data System collected by the U.S. Geological Survey and cooperating State and Federal agencies in South Carolina.

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SURFACE-WATER STATIONS, IN DOWNSTREAM ORDER, FOR WHICH RECORDS ARE PUBLISHED IN THIS VOLUME

[Letters after station names designate type of data: (d) discharge, (c) chemical, (p) precipitation, (b) biological (m) microbiological, (s) sediment, (t) temperature, (e) elevation, gage heights, or contents]

SURFACE-WATER STATIONS, IN DOWNSTREAM ORDER, FOR WHICH RECORDS ARE PUBLISHED IN THIS VOLUME

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02156500 BROAD RIVER NEAR CARLISLE, SC

LOCATION.--Lat 34°35'46'', long 81°25'20'', Union County, Hydrologic Unit 03050106, on right bank at downstream side of bridge on State Highway 72, 1.3 mi upstream from Sandy River, 2.0 mi downstream from Seaboard Coast Line Railroad bridge, 2.5 mi east of Carlisle, 5.0 mi downstream from Neal Shoals Dam, and at mile 226.0.

DRAINAGE AREA.--2,790 mi^2, approximately.

WATER-DISCHARGE RECORDS

PERIOD OF RECORD.--October 1938 to current year. Monthly discharge only for some periods, published in WSP 1303.

REVISED RECORDS.--WSP 892: 1939(M), drainage area.

GAGE.--Data collection platform. Datum of gage is 290.79 ft above NGVD of 1929.

REMARKS.--Records good except for estimated daily discharges, which are poor. Some regulation at low and medium flow by powerplants above station. Capacity of reservoirs insufficient to affect monthly figures of runoff.

Discharge, cubic feet per second
WATER YEAR OCTOBER 2004 TO SEPTEMBER 2005
DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	5830	2090	3290	3720	3280	10100	8490	3490	2520	5060	3480	2100
2	5000	1930	3410	3510	3170	7270	6860	3500	5140	4140	3390	1840
3	4750	2470	3240	2890	3360	5410	6030	3230	6080	3570	2790	2130
4	4290	3810	3290	3020	4280	4280	5230	3120	4680	3150	2660	1800
5	3480	12000	e2990	3530	3900	4020	4550	2840	3730	4770	2380	1460
6	3580	7290	e2660	3740	3440	3930	4570	3040	3090	4760	2350	1400
7	3310	5190	3100	3760	2940	3330	4500	2930	2630	4970	2410	1270
8	2950	3920	3940	3380	2720	3600	4600	2760	3490	19600	2360	1970
9	3090	3310	3570	3480	3260	4600	5200	2430	3170	28900	3550	1500
10	2980	3580	12000	2950	3230	3860	4950	2540	4260	11800	5640	1600
11	2630	2930	25500	2740	3600	3300	4230	3330	4300	5860	6050	1670
12	2730	2910	10700	3390	3170	3590	4160	2580	3940	4980	4000	1310
13	2830	4290	6450	3300	2910	3290	5190	2720	3510	5090	3170	1330
14	2900	5480	5340	5340	2850	3040	7190	2570	3720	5880	2890	1080
15	2970	3880	4900	9180	2130	2870	7830	2850	3830	7870	2880	1480
16	2760	3190	4590	5880	2640	3760	6280	2510	3430	8300	2490	1710
17	2430	3220	4420	4410	2920	5280	5080	2600	2950	5370	2030	1720
18	1970	3050	3750	3660	3010	4840	4370	2790	2650	4320	2420	1500
19	1940	2970	3500	3790	2870	4100	4300	2700	2920	3970	2870	1310
20	2560	3110	3030	3440	2980	3500	4190	3000	2810	3780	3020	1120
21	2700	3100	3210	3430	2760	3220	4350	3530	3150	3460	2690	952
22	2420	2970	4060	3500	3810	3050	3260	3300	3000	3280	1970	1800
23	e2270	2640	4190	3530	4200	4030	3660	2770	2730	3150	2130	1430
24	e2400	3200	7100	2790	3900	6050	3370	2630	2120	3170	3210	1370
25	e2170	3640	7550	2950	4360	4960	3340	2640	2240	2950	2630	1080
26	e2160	4340	5820	3220	3890	4300	3410	2600	2340	2580	2140	1090
27	2390	3640	4690	2920	3550	4100	3520	2320	2150	2720	2040	1110
28	2410	3500	4000	3160	5550	15000	3670	2420	4230	2580	2120	1640
29	2430	3480	4190	3180	---	31200	2700	2390	7700	2840	2190	1380
30	2600	3160	4040	3190	---	17100	3220	2060	5940	3500	2350	1430
31	2520	---	3870	3300	---	8710	---	2070	---	3430	2160	---
TOTAL	91450	114290	166390	114280	94680	189690	142300	86260	108450	179800	88460	44582
MEAN	2950	3810	5367	3686	3381	6119	4743	2783	3615	5800	2854	1486
MAX	5830	12000	25500	9180	5550	31200	8490	3530	7700	28900	6050	2130
MIN	1940	1930	2660	2740	2130	2870	2700	2060	2120	2580	1970	952
CFSM	1.06	1.37	1.92	1.32	1.21	2.19	1.70	1.00	1.30	2.08	1.02	0.53
IN.	1.22	1.52	2.22	1.52	1.26	2.53	1.90	1.15	1.45	2.40	1.18	0.59

STATISTICS OF MONTHLY MEAN DATA FOR WATER YEARS 1939 - 2005, BY WATER YEAR (WY)

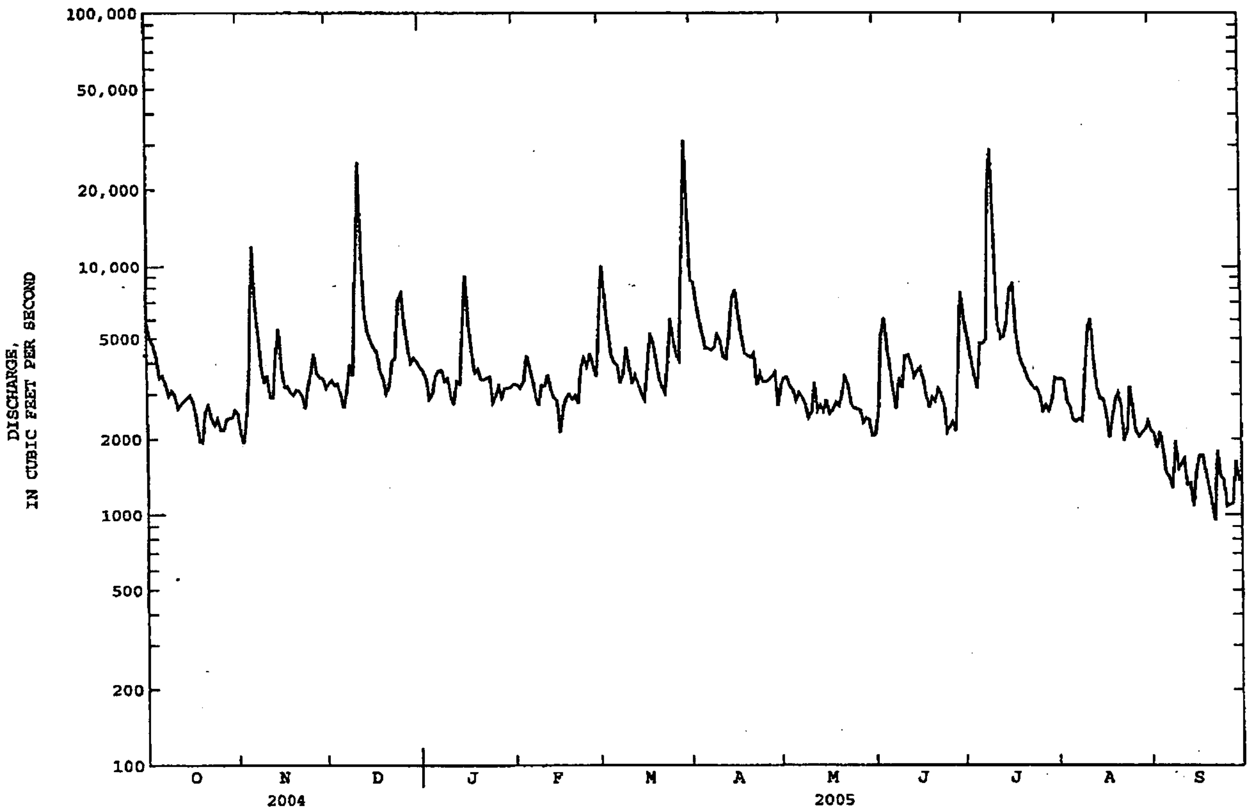
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
MEAN	3023	3014	3745	4763	5585	6164	5133	3837	3182	2780	2904	2522
MAX	14720	8651	7549	10610	13040	14920	11660	10220	6763	8092	9495	11010
(WY)	1965	1958	1946	1978	1960	1952	2003	2003	1973	1941	1949	2004
MIN	562	815	1150	1220	1546	2399	1889	1314	687	535	375	628
(WY)	1955	2002	2002	1956	2001	1988	2002	2001	2002	2002	2002	1954

02156500 BROAD RIVER NEAR CARLISLE, SC--Continued

SUMMARY STATISTICS	FOR 2004 CALENDAR YEAR		FOR 2005 WATER YEAR		WATER YEARS 1939 - 2005	
ANNUAL TOTAL	1379091		1420632			
ANNUAL MEAN	3768		3892		3880	
HIGHEST ANNUAL MEAN					5977	1965
LOWEST ANNUAL MEAN					1255	2002
HIGHEST DAILY MEAN	e 68500	Sep 9	31200	Mar 29	114000	Oct 10 1976
LOWEST DAILY MEAN	921	Aug 31	952	Sep 21	44	Sep 2 1956
ANNUAL SEVEN-DAY MINIMUM	1360	Aug 5	1260	Sep 21	220	Aug 9 2002
MAXIMUM PEAK FLOW			32900	Jul 9	a 123000	Oct 10 1976
MAXIMUM PEAK STAGE			15.62	Jul 9	31.51	Oct 10 1976
ANNUAL RUNOFF (CFSM)	1.35		1.40		1.39	
ANNUAL RUNOFF (INCHES)	18.39		18.94		18.89	
10 PERCENT EXCEEDS	5240		5710		6680	
50 PERCENT EXCEEDS	2660		3280		2830	
90 PERCENT EXCEEDS	1580		2080		1300	

a From rating curve extended above 66,000 ft^3/s on basis of computation of peak flow over Neal Shoals Dam.

e Estimated



13 ft (60 sec/min)(7.48/ft) = 5834.4 gpm

02156500 BROAD RIVER NEAR CARLISLE, SC--Continued

WATER-QUALITY RECORDS

PERIOD OF RECORD.--Water years 1948, 1963-64, 1969 to current year.

PERIOD OF DAILY RECORD.--

SPECIFIC CONDUCTANCE: October 1973 to current year.

pH: October 1973 to current year.

WATER TEMPERATURE: October 1973 to current year.

DISSOLVED OXYGEN: October 1973 to current year.

INSTRUMENTATION.--Water-quality multiprobe and data collection platform.

REMARKS.--Specific conductance records rated excellent except for Oct. 18-23, which are good, and Nov. 10-18, Feb 17-21, which are fair. pH records rated excellent except for Oct. 1 to Nov. 18, which are good. Temperature records rated excellent except for Oct. 1, Nov. 9-18, which are good. Dissolved oxygen records rated excellent except for Jan. 18-26, Apr. 27-29, May 17-29, Aug. 1-3, 16-19, Sep. 18-22, which are good, Oct. 6-22, Apr. 30 to May 2, May 30 to June 6, Aug. 20-22, which are fair, and Aug. 23-26, which is poor.

EXTREMES FOR PERIOD OF DAILY RECORD.--

SPECIFIC CONDUCTANCE: Maximum, 471 microsiemens, Aug. 27, 1987; minimum, 16 microsiemens, Mar. 18, 1990.

pH: Maximum, 9.2 units, Jun. 25, 1986; minimum, 5.1 units, Aug. 6, 7, 1992, Apr. 27, 2002.

WATER TEMPERATURE: Maximum, 35.5°C, Jul. 13, 1992; minimum, less than 0.5°C, Dec. 24-26,1989, Jan. 20, 1994, Jan. 3, 4, 2001.

DISSOLVED OXYGEN: Maximum, 15.4 mg/L, Jan. 3, 2001, Jan. 11, 1993; minimum, 3.0 mg/L, Jul. 6, 1994.

EXTREMES FOR CURRENT YEAR.--

SPECIFIC CONDUCTANCE: Maximum, 124 microsiemens, Sep. 29, 30; minimum, 24 microsiemens, July 9.

pH: Maximum, 8.1 units, May 9, 10, Sep. 14; minimum, 6.5 units, July 8.

WATER TEMPERATURE: Maximum, 30.9°C, July 27, 28; minimum, 3.4°C, Jan. 20.

DISSOLVED OXYGEN: Maximum measured, 14.4 mg/L, Dec. 28, 29; minimum measured, 6.0 mg/L, Oct. 21.

Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius
WATER YEAR OCTOBER 2004 TO SEPTEMBER 2005

DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN
	OCTOBER			NOVEMBER			DECEMBER			JANUARY		
1	---	---	---	95	92	94	72	68	70	66	61	64
2	66	63	65	95	92	93	74	71	73	66	64	65
3	69	65	68	96	91	92	77	74	76	68	64	66
4	73	69	70	103	91	100	80	77	79	72	66	68
5	75	69	72	91	64	73	79	75	76	75	72	74
6	79	74	75	67	64	65	79	74	76	73	69	71
7	82	76	79	67	64	65	79	77	78	71	68	69
8	82	79	80	68	65	67	81	78	79	71	69	70
9	83	80	82	71	67	70	79	73	77	76	69	73
10	86	81	84	81	68	75	75	45	68	75	73	74
11	87	83	84	85	74	80	54	44	49	82	73	76
12	86	83	84	88	76	82	55	53	54	82	77	80
13	85	76	82	93	79	85	59	55	57	79	74	78
14	83	75	79	90	71	80	63	59	60	78	73	75
15	86	81	83	79	66	72	64	63	63	77	63	71
16	91	81	86	80	69	74	67	64	65	64	60	62
17	84	81	82	85	74	80	71	67	69	66	61	63
18	85	82	83	84	76	79	73	71	72	70	66	69
19	86	84	85	81	77	80	77	72	76	74	69	73
20	90	86	89	84	80	82	84	76	80	76	73	74
21	93	90	92	83	80	81	84	78	80	76	73	74
22	93	90	91	81	79	80	80	73	75	79	76	78
23	---	---	---	83	81	82	77	73	75	79	76	78
24	---	---	---	86	79	82	76	69	73	79	77	77
25	---	---	---	85	78	82	69	55	60	82	77	79
26	---	---	---	81	75	78	56	53	54	82	80	81
27	94	91	93	76	70	74	56	55	56	84	80	82
28	95	93	94	71	64	68	61	56	59	84	81	82
29	94	91	92	65	64	64	62	57	60	84	82	83
30	95	92	94	69	64	66	63	57	61	84	81	82
31	96	92	94	---	---	---	64	61	63	83	81	81
MONTH	---	---	---	103	64	78	84	44	68	84	60	74

02156500 BROAD RIVER NEAR CARLISLE, SC--Continued

Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius
WATER YEAR OCTOBER 2004 TO SEPTEMBER 2005

DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN
		FEBRUARY			MARCH			APRIL			MAY	
1	88	82	85	75	56	67	61	56	59	---	---	---
2	88	87	88	64	52	58	64	61	63	---	---	---
3	89	85	87	64	60	62	66	64	65	80	77	79
4	85	81	83	69	64	66	68	66	67	78	76	77
5	85	82	83	73	69	71	70	68	69	81	76	78
6	85	81	83	75	73	74	72	70	71	84	78	81
7	83	82	82	78	75	77	72	71	72	83	81	82
8	85	81	83	81	75	76	73	71	72	84	81	83
9	87	84	85	78	75	76	75	72	74	86	83	84
10	88	84	87	77	74	76	75	72	73	86	82	84
11	86	82	83	79	75	77	77	70	72	87	84	86
12	83	80	81	82	76	79	79	75	76	87	81	85
13	83	80	81	84	81	83	---	---	---	90	79	83
14	87	82	84	81	79	80	---	---	---	87	83	84
15	89	87	88	85	80	83	69	63	66	89	84	86
16	93	85	89	86	81	83	67	63	65	89	86	88
17	101	93	98	81	77	79	66	63	64	90	85	88
18	103	91	97	80	78	79	69	65	67	86	83	85
19	102	91	99	79	76	78	71	69	70	87	84	85
20	96	89	94	79	77	78	72	71	71	87	82	85
21	102	87	93	82	78	80	75	71	72	85	81	83
22	90	85	88	88	81	83	80	74	77	90	84	87
23	88	83	85	83	78	81	80	74	78	86	83	84
24	83	76	80	82	78	80	83	77	81	84	82	83
25	80	77	78	78	74	76	85	81	83	83	80	81
26	81	79	80	77	75	76	86	80	84	87	80	84
27	81	79	80	78	74	75	80	76	77	90	84	88
28	82	74	76	74	55	63	80	77	79	90	87	88
29	---	---	---	55	46	48	82	80	81	93	88	90
30	---	---	---	51	47	50	91	79	85	105	93	95
31	---	---	---	58	51	54	---	---	---	94	88	90
MONTH	103	74	86	88	46	73	---	---	---	---	---	---

Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius

DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN
		JUNE			JULY			AUGUST			SEPTEMBER	
1	95	86	90	63	61	62	81	79	80	83	80	81
2	86	75	78	67	63	64	79	78	78	85	81	82
3	76	70	73	70	66	67	78	74	76	89	84	86
4	70	68	69	72	70	71	77	73	75	90	87	89
5	72	67	70	71	63	69	---	---	---	89	87	88
6	71	68	70	63	54	58	---	---	---	90	87	87
7	73	70	71	57	54	55	---	---	---	94	89	90
8	73	70	72	54	26	42	---	---	---	96	84	89
9	76	73	74	40	24	33	---	---	---	96	85	92
10	81	73	76	48	40	43	---	---	---	94	84	87
11	81	75	77	51	48	49	---	---	---	85	81	84
12	80	75	79	52	48	50	67	56	62	87	80	83
13	79	77	77	55	51	53	71	67	70	91	87	88
14	78	75	77	56	53	55	75	70	73	99	90	93
15	76	72	74	59	55	57	78	73	75	95	90	92
16	73	72	73	55	49	51	81	77	79	103	95	98
17	76	73	75	59	54	56	79	76	77	106	103	105
18	78	74	76	64	59	61	89	77	83	109	105	107
19	83	77	79	67	64	66	88	82	86	106	99	101
20	85	81	83	67	65	66	92	84	89	102	97	99
21	85	79	82	71	66	69	84	81	82	106	97	99
22	91	84	88	75	71	74	82	78	80	109	97	102
23	84	81	82	78	73	76	84	80	81	114	109	112
24	83	79	81	---	---	---	92	83	86	116	111	113
25	87	83	84	---	---	---	98	78	90	116	106	112
26	94	87	89	77	75	76	---	---	---	112	106	109
27	96	91	93	81	74	77	85	81	83	112	109	110
28	96	89	92	81	78	79	90	81	85	117	110	114
29	93	61	70	79	75	77	90	85	87	124	116	119
30	62	60	62	81	76	78	90	87	88	124	118	121
31	---	---	---	80	79	79	87	82	84	---	---	---
MONTH	96	60	78	---	---	---	---	---	---	124	80	98

02156500 BROAD RIVER NEAR CARLISLE, SC--Continued

pH, water, unfiltered, field, standard units
WATER YEAR OCTOBER 2004 TO SEPTEMBER 2005

DAY	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN
	OCTOBER		NOVEMBER		DECEMBER		JANUARY		FEBRUARY		MARCH	
1	7.2	7.2	7.3	7.0	7.5	7.4	7.3	7.2	7.5	7.4	7.3	7.2
2	7.2	7.2	7.3	6.9	7.5	7.4	7.3	7.2	7.5	7.4	7.2	7.2
3	7.3	7.2	7.3	7.0	7.5	7.4	7.3	7.2	7.4	7.4	7.3	7.2
4	7.3	7.1	7.3	7.2	7.5	7.4	7.3	7.2	7.4	7.4	7.4	7.3
5	7.3	6.7	7.2	6.8	7.5	7.3	7.4	7.3	7.4	7.4	7.4	7.3
6	7.3	6.8	7.0	6.8	7.4	7.3	7.4	7.3	7.5	7.4	7.5	7.4
7	7.2	7.1	7.1	7.0	7.4	7.3	7.4	7.3	7.5	7.4	7.5	7.4
8	7.1	6.8	7.2	7.0	7.5	7.4	7.4	7.3	7.5	7.4	7.4	7.3
9	7.2	7.0	7.2	7.0	7.4	7.3	7.4	7.3	7.5	7.4	7.4	7.4
10	7.4	7.1	7.3	7.0	7.4	6.8	7.5	7.3	7.6	7.4	7.5	7.4
11	7.3	7.0	7.2	7.0	6.9	6.8	7.4	7.3	7.6	7.4	7.5	7.4
12	7.2	6.9	7.3	7.1	7.0	6.9	7.5	7.3	7.7	7.4	7.6	7.4
13	7.3	6.9	7.4	7.2	7.1	7.0	7.5	7.4	7.6	7.4	7.7	7.4
14	7.4	7.3	7.4	7.2	7.1	7.1	7.4	7.3	7.5	7.4	7.6	7.4
15	7.4	7.2	7.3	7.1	7.2	7.1	7.3	7.2	7.6	7.3	7.8	7.4
16	7.4	7.2	7.3	7.1	7.2	7.2	7.2	7.2	7.7	7.4	7.5	7.4
17	7.2	6.9	7.4	7.1	7.2	7.2	7.3	7.2	7.8	7.5	7.4	7.3
18	7.2	6.7	7.4	7.2	7.2	7.2	7.4	7.3	7.8	7.5	7.4	7.4
19	7.3	6.8	7.4	7.4	7.3	7.2	7.4	7.3	7.8	7.5	7.5	7.4
20	7.2	6.9	7.4	7.4	7.3	7.3	7.4	7.4	7.7	7.5	7.6	7.4
21	7.3	7.1	7.4	7.4	7.3	7.3	7.4	7.3	7.5	7.3	7.6	7.4
22	7.2	6.8	7.4	7.3	7.3	7.3	7.4	7.4	7.5	7.4	7.6	7.4
23	---	---	7.4	7.3	7.3	7.3	7.4	7.4	7.6	7.4	7.5	7.4
24	---	---	7.4	7.4	7.3	7.3	7.4	7.3	7.4	7.4	7.5	7.4
25	---	---	7.5	7.4	7.3	7.2	7.4	7.4	7.4	7.4	7.5	7.3
26	---	---	7.5	7.4	7.2	7.2	7.5	7.4	7.5	7.4	7.5	7.4
27	7.1	6.9	7.4	7.4	7.2	7.2	7.5	7.4	7.5	7.4	7.4	7.3
28	7.1	6.9	7.4	7.4	7.3	7.2	7.5	7.4	7.4	7.3	7.3	6.9
29	7.1	7.0	7.4	7.4	7.3	7.2	7.5	7.4	---	---	7.0	6.8
30	7.3	7.0	7.5	7.4	7.3	7.2	7.5	7.4	---	---	6.9	6.7
31	7.3	7.1	---	---	7.3	7.2	7.5	7.4	---	---	6.8	6.8
MONTH	---	---	7.5	6.8	7.5	6.8	7.5	7.2	7.8	7.3	7.8	6.7

pH, water, unfiltered, field, standard units

DAY	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN
	APRIL		MAY		JUNE		JULY		AUGUST		SEPTEMBER	
1	6.9	6.8	7.4	7.1	7.6	7.4	7.1	7.1	7.2	7.1	7.6	7.3
2	7.0	6.9	7.8	7.1	7.5	7.3	7.1	7.1	7.2	7.2	7.6	7.3
3	7.0	7.0	7.8	7.5	7.4	7.3	7.1	7.1	7.3	7.2	7.6	7.3
4	7.1	7.0	8.0	7.5	7.4	7.3	7.2	7.1	7.3	7.2	7.6	7.3
5	7.1	7.0	7.8	7.5	7.4	7.3	7.2	7.1	---	---	7.6	7.3
6	7.2	7.0	7.8	7.5	7.4	7.1	7.2	7.1	---	---	7.6	7.3
7	7.2	7.1	7.9	7.5	7.4	7.1	7.2	7.1	---	---	7.7	7.3
8	7.2	7.1	8.0	7.5	7.4	7.1	7.2	6.5	---	---	7.6	7.4
9	7.2	7.1	8.1	7.4	7.3	7.1	6.7	6.6	---	---	7.7	7.4
10	7.2	7.1	8.1	7.4	7.1	7.0	6.8	6.7	---	---	7.7	7.4
11	7.2	7.1	7.8	7.5	7.1	7.0	7.0	6.8	---	---	7.7	7.4
12	7.1	7.1	8.0	7.4	7.1	7.0	6.9	6.8	7.1	6.9	7.8	7.3
13	7.2	7.1	7.7	7.4	7.1	7.1	7.0	6.9	7.2	7.1	7.8	7.3
14	7.2	7.2	7.7	7.4	7.2	7.1	7.1	7.0	7.3	7.2	8.1	7.3
15	7.2	7.2	7.7	7.4	7.2	7.1	7.1	7.0	7.3	7.2	7.8	7.3
16	7.2	7.1	7.8	7.4	7.2	7.1	7.0	6.8	7.3	7.2	7.7	7.3
17	7.2	7.1	7.7	7.4	7.2	7.1	7.0	6.9	7.3	7.2	7.7	7.3
18	7.2	7.1	7.7	7.4	7.2	7.1	7.0	6.9	7.4	7.2	7.7	7.3
19	7.1	7.1	7.6	7.4	7.2	7.2	7.1	7.0	7.4	7.3	7.7	7.3
20	7.2	7.0	7.5	7.4	7.3	7.2	7.1	7.0	7.4	7.2	7.6	7.3
21	7.1	7.1	7.5	7.4	7.2	7.1	7.1	7.0	7.4	7.2	7.7	7.3
22	7.2	7.0	7.6	7.4	7.2	7.2	7.2	7.1	7.3	7.2	7.5	7.4
23	7.3	7.0	7.5	7.4	7.2	7.2	7.2	7.1	7.5	7.2	7.7	7.3
24	7.4	7.1	7.6	7.4	7.3	7.1	7.2	7.1	7.3	7.3	7.6	7.3
25	7.4	7.1	7.7	7.5	7.3	7.1	7.2	7.1	7.5	7.3	7.6	7.4
26	7.4	7.2	7.7	7.5	7.4	7.2	7.2	7.1	7.3	7.2	7.6	7.4
27	7.4	7.2	7.7	7.5	7.3	7.2	7.2	7.1	7.5	7.3	7.7	7.4
28	7.4	7.2	7.6	7.5	7.3	7.2	7.3	7.2	7.7	7.3	7.6	7.3
29	7.5	7.2	7.6	7.5	7.2	7.0	7.3	7.2	7.5	7.3	7.7	7.4
30	7.4	7.2	7.5	7.4	7.1	7.1	7.2	7.1	7.5	7.4	7.6	7.4
31	---	---	7.7	7.4	---	---	7.2	7.2	7.6	7.3	---	---
MONTH	7.5	6.8	8.1	7.1	7.6	7.0	7.3	6.5	---	---	8.1	7.3

02156500 BROAD RIVER NEAR CARLISLE, SC--Continued

Temperature, water, degrees Celsius
WATER YEAR OCTOBER 2004 TO SEPTEMBER 2005

DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN
		OCTOBER			NOVEMBER			DECEMBER			JANUARY	
1	21.6	20.7	21.1	20.5	19.2	19.7	10.8	10.0	10.4	7.4	6.2	6.8
2	21.8	21.0	21.4	20.8	19.4	20.0	10.4	9.7	10.1	8.5	7.2	7.8
3	22.0	21.1	21.6	20.8	19.7	20.3	10.0	9.2	9.6	9.2	8.3	8.7
4	22.3	21.4	21.9	20.7	19.7	20.4	9.4	8.6	9.0	10.0	9.0	9.5
5	22.2	21.3	21.7	19.7	17.1	18.3	8.7	8.0	8.3	11.0	9.8	10.4
6	21.9	20.4	21.0	17.1	15.8	16.4	8.4	8.2	8.3	12.0	10.9	11.4
7	20.8	20.1	20.4	15.8	14.9	15.3	10.0	8.4	9.1	12.1	11.2	11.8
8	20.3	19.3	19.8	15.0	14.3	14.7	10.8	9.8	10.4	12.4	11.8	12.1
9	19.9	19.2	19.6	14.4	13.6	14.0	11.3	10.6	10.9	12.1	11.6	11.8
10	20.3	19.3	19.9	13.7	12.8	13.2	11.7	10.9	11.3	11.8	10.9	11.4
11	20.7	19.7	20.2	12.9	12.2	12.6	11.3	10.9	11.1	11.4	10.7	11.1
12	20.5	19.9	20.2	12.7	12.2	12.4	10.9	10.4	10.6	12.1	11.0	11.5
13	20.8	20.2	20.5	12.8	12.3	12.6	10.4	9.8	10.1	13.3	11.7	12.3
14	20.3	19.7	20.0	12.6	11.9	12.4	9.8	8.3	9.0	13.3	13.0	13.2
15	19.9	18.7	19.4	12.0	11.0	11.6	8.3	6.9	7.5	13.1	11.1	12.2
16	18.7	17.8	18.2	11.5	10.6	10.9	6.9	6.1	6.4	11.1	9.5	10.2
17	17.9	16.9	17.4	10.8	9.7	10.3	6.2	5.6	5.9	9.5	7.5	8.5
18	18.0	17.2	17.5	10.5	9.6	10.2	6.1	5.4	5.8	7.5	5.9	6.6
19	18.2	17.1	17.6	11.7	10.4	11.0	6.1	5.5	5.8	5.9	4.2	4.8
20	18.5	17.5	17.9	13.0	11.7	12.3	5.6	4.3	4.8	4.3	3.4	4.0
21	18.1	17.8	18.0	14.1	13.0	13.6	4.5	3.9	4.2	5.2	4.2	4.7
22	18.4	17.8	18.1	14.8	14.1	14.4	5.0	3.5	4.2	5.2	5.0	5.1
23	---	---	---	15.2	14.8	15.0	6.8	5.0	6.1	5.3	4.5	4.9
24	---	---	---	15.8	15.2	15.6	7.4	6.4	6.8	4.7	3.9	4.3
25	---	---	---	15.8	14.6	15.4	7.4	6.7	7.2	4.4	3.6	4.0
26	---	---	---	14.6	12.8	13.7	6.7	5.3	6.0	5.5	4.2	4.8
27	18.0	17.6	17.7	12.8	11.1	11.7	5.3	4.6	5.0	6.2	5.2	5.7
28	17.9	17.6	17.7	11.1	10.4	10.7	4.7	4.0	4.4	5.8	5.4	5.6
29	17.6	17.4	17.5	10.4	9.7	10.1	4.8	3.9	4.4	5.5	4.5	4.9
30	18.6	17.6	18.1	10.0	9.4	9.7	5.7	4.6	5.1	4.9	4.4	4.6
31	19.5	18.2	18.9	---	---	---	6.3	5.4	5.8	5.4	4.5	5.0
MONTH	---	---	---	20.8	9.4	13.9	11.7	3.5	7.5	13.3	3.4	8.1

Temperature, water, degrees Celsius

DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN
		FEBRUARY			MARCH			APRIL			MAY	
1	5.9	5.0	5.4	8.2	7.4	7.7	14.3	14.1	14.2	18.5	16.8	17.8
2	5.6	5.3	5.5	7.6	6.8	7.2	14.8	13.9	14.3	19.1	17.5	18.5
3	5.5	5.2	5.3	7.8	6.6	7.2	14.2	13.0	13.7	18.9	17.4	18.3
4	6.0	5.1	5.5	8.1	6.7	7.6	14.6	13.0	13.9	18.9	17.3	18.3
5	6.2	5.0	5.7	9.2	7.7	8.5	15.8	13.8	14.9	18.8	17.5	17.9
6	6.8	5.6	6.3	10.0	8.5	9.3	16.6	14.9	15.9	18.0	16.7	17.5
7	7.5	6.2	6.9	10.8	9.2	10.1	17.1	16.2	16.6	18.6	16.8	17.8
8	8.3	7.1	7.6	11.6	10.7	11.1	17.4	16.8	17.0	19.7	17.9	18.9
9	8.9	8.3	8.5	11.1	10.0	10.6	18.0	16.8	17.4	20.8	19.2	20.1
10	9.7	8.6	9.0	10.6	9.4	10.1	18.4	17.0	17.8	21.5	20.3	20.8
11	9.2	8.2	8.7	10.2	9.5	9.9	19.0	17.4	18.3	22.2	20.4	21.2
12	8.4	7.3	7.9	10.8	9.1	10.1	18.8	18.1	18.4	23.4	21.0	22.3
13	7.7	7.2	7.3	12.2	10.3	11.3	18.2	16.4	17.3	23.2	22.2	22.6
14	7.5	7.2	7.3	12.5	12.0	12.2	16.4	15.2	15.9	23.1	22.0	22.6
15	8.1	7.5	7.8	12.5	11.6	12.1	15.4	14.6	15.0	23.3	22.5	23.0
16	10.1	8.1	9.2	12.3	10.5	11.3	15.4	14.5	15.0	23.2	22.2	22.8
17	10.8	10.0	10.3	10.5	9.0	9.7	16.1	14.2	15.3	22.9	22.2	22.5
18	10.3	9.7	10.0	9.5	8.3	9.0	16.7	14.8	15.9	23.1	22.0	22.5
19	10.1	9.1	9.7	10.3	8.6	9.5	17.7	16.0	16.9	23.1	22.1	22.6
20	9.7	9.3	9.6	11.6	9.5	10.6	18.7	17.0	17.9	22.8	21.5	22.0
21	9.7	9.2	9.5	12.1	10.9	11.6	19.7	17.8	18.8	22.0	20.8	21.6
22	10.3	9.2	9.7	12.0	11.2	11.6	20.5	18.9	19.8	22.4	21.0	21.9
23	11.1	9.6	10.4	12.9	11.3	12.1	20.6	19.1	19.9	22.9	21.3	22.3
24	11.0	10.6	10.8	13.7	12.2	13.0	19.1	17.5	18.3	22.8	21.8	22.3
25	11.0	10.2	10.5	14.6	13.0	13.9	17.6	16.3	17.1	22.1	21.3	21.6
26	10.8	9.6	10.3	15.2	14.3	14.8	17.0	15.6	16.1	22.1	21.0	21.7
27	10.3	9.6	9.9	15.2	14.9	15.1	16.6	15.4	16.1	22.7	21.4	22.1
28	9.6	8.2	8.7	14.9	13.4	14.3	16.9	15.0	16.1	23.4	22.1	22.6
29	---	---	---	13.4	12.6	12.9	17.6	16.3	17.0	23.1	21.7	22.4
30	---	---	---	14.4	13.1	13.8	17.6	17.0	17.4	22.0	20.4	21.2
31	---	---	---	14.4	14.0	14.2	---	---	---	21.8	20.4	21.0
MONTH	11.1	5.0	8.3	15.2	6.6	11.0	20.6	13.0	16.6	23.4	16.7	21.0

02156500 BROAD RIVER NEAR CARLISLE, SC--Continued

Temperature, water, degrees Celsius
WATER YEAR OCTOBER 2004 TO SEPTEMBER 2005

DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN
		JUNE			JULY			AUGUST			SEPTEMBER	
1	21.0	19.9	20.5	26.7	25.1	25.9	25.8	25.1	25.5	28.9	27.0	27.8
2	19.9	18.7	19.3	27.5	25.7	26.6	26.6	25.0	25.9	28.7	26.6	27.5
3	18.7	18.4	18.6	27.2	26.4	26.6	27.3	25.5	26.6	28.3	26.3	27.2
4	20.4	18.3	19.3	26.6	25.9	26.3	28.3	27.0	27.6	28.1	25.8	26.9
5	22.7	20.1	21.4	27.0	25.7	26.5	---	---	---	27.1	25.1	26.2
6	24.4	22.0	23.3	26.8	25.6	26.2	---	---	---	25.8	24.2	25.1
7	25.2	23.6	24.5	25.9	24.8	25.5	---	---	---	25.1	23.5	24.4
8	25.7	24.1	25.0	25.6	22.6	23.7	---	---	---	25.5	23.7	24.4
9	26.8	24.9	25.8	23.6	22.5	23.0	---	---	---	25.8	23.1	24.4
10	26.4	25.0	25.7	24.3	23.3	23.8	---	---	---	25.6	22.8	24.2
11	25.4	24.8	25.1	24.8	23.8	24.3	---	---	---	25.2	23.2	24.1
12	25.5	24.8	25.1	25.9	24.3	25.1	28.1	26.0	27.0	24.9	22.6	23.8
13	26.1	25.0	25.6	26.1	25.2	25.7	28.4	27.3	28.0	25.0	22.7	24.0
14	27.2	25.2	26.3	25.8	24.9	25.4	29.0	27.8	28.4	25.9	23.7	24.7
15	27.8	25.9	26.9	25.6	24.9	25.2	29.4	27.9	28.7	26.3	23.7	25.1
16	27.8	26.2	27.2	25.5	24.1	24.8	29.6	28.4	29.1	27.3	24.7	25.8
17	27.6	26.2	26.9	26.5	25.0	25.7	30.3	29.0	29.6	27.8	25.3	26.3
18	26.9	25.8	26.5	27.7	25.7	26.7	29.7	29.0	29.3	27.8	24.9	26.4
19	26.8	25.2	25.9	28.5	26.6	27.6	29.5	28.9	29.3	27.8	25.1	26.5
20	25.5	24.0	24.9	28.8	27.2	28.0	29.5	28.4	29.1	27.6	25.3	26.5
21	24.9	23.2	24.2	29.3	27.6	28.5	29.7	28.5	29.3	28.1	25.6	27.0
22	25.1	23.1	24.3	29.5	28.0	28.8	29.6	28.2	29.0	27.6	25.9	26.7
23	25.6	23.9	24.9	29.4	28.3	29.0	29.8	28.2	28.8	28.0	25.7	26.8
24	26.0	24.9	25.5	29.4	28.4	29.0	28.7	27.6	28.2	27.2	25.1	26.3
25	26.3	25.3	25.9	29.6	28.2	29.1	28.4	27.2	27.7	26.6	25.6	26.2
26	26.6	25.5	26.0	30.2	28.7	29.6	27.5	26.3	26.9	26.1	25.1	25.6
27	27.4	25.7	26.4	30.9	29.6	30.3	27.8	26.3	26.8	26.4	24.7	25.6
28	27.0	25.4	26.5	30.9	29.8	30.3	28.4	26.4	27.3	26.0	24.4	25.1
29	25.4	24.4	24.7	30.1	28.3	29.2	28.3	27.0	27.6	26.0	24.2	25.0
30	25.8	23.9	24.9	28.3	26.6	27.3	27.9	27.2	27.5	24.8	23.1	23.9
31	---	---	---	26.6	25.7	26.1	28.4	27.2	27.6	---	---	---
MONTH	27.8	18.3	24.6	30.9	22.5	26.8	---	---	---	28.9	22.6	25.6

02156500 BROAD RIVER NEAR CARLISLE, SC--Continued

Dissolved oxygen, water, unfiltered, milligrams per liter
WATER YEAR OCTOBER 2004 TO SEPTEMBER 2005

DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN
		OCTOBER			NOVEMBER			DECEMBER			JANUARY	
1	---	---	---	9.8	7.9	8.7	12.0	11.7	11.8	12.7	12.3	12.6
2	---	---	---	8.5	7.6	8.0	12.1	11.0	11.6	12.4	11.8	12.2
3	---	---	---	8.4	7.4	8.0	11.6	11.1	11.3	11.8	11.4	11.7
4	---	---	---	9.0	7.1	8.0	11.8	11.2	11.5	11.6	11.1	11.4
5	---	---	---	---	---	---	11.9	11.5	11.7	11.3	10.8	11.2
6	---	---	---	---	---	---	11.9	11.6	11.8	10.9	10.5	10.8
7	9.1	7.3	8.3	---	---	---	11.8	11.3	11.6	10.8	10.5	10.7
8	8.7	7.1	8.0	---	---	---	11.5	11.1	11.3	10.6	10.4	10.5
9	9.2	7.8	8.4	---	---	---	11.1	10.8	11.0	10.8	10.4	10.6
10	9.0	7.6	8.2	---	---	---	12.0	10.4	11.2	10.9	10.4	10.6
11	8.7	7.7	8.1	---	---	---	12.0	11.7	11.9	10.9	10.4	10.6
12	8.4	6.9	7.7	---	---	---	11.7	11.6	11.7	10.9	10.4	10.7
13	8.1	6.4	7.3	---	---	---	11.8	11.6	11.7	10.6	9.9	10.4
14	8.4	7.1	7.7	---	---	---	12.3	11.8	12.0	10.4	9.8	10.1
15	8.5	7.2	7.9	---	---	---	12.8	12.3	12.6	11.0	10.4	10.7
16	8.9	6.9	7.9	---	---	---	13.2	12.8	13.1	11.2	11.0	11.1
17	8.5	6.7	7.6	---	---	---	13.4	13.1	13.3	11.7	11.2	11.5
18	8.3	6.6	7.7	---	---	---	13.3	13.0	13.2	12.3	11.7	12.1
19	7.6	6.5	7.2	12.1	11.4	11.8	13.2	12.9	13.1	12.9	12.3	12.7
20	8.0	6.2	7.1	11.5	11.0	11.3	13.7	13.0	13.4	13.1	12.7	12.9
21	7.8	6.0	7.0	11.2	10.7	11.0	14.1	13.4	13.8	12.8	12.4	12.6
22	---	---	---	10.8	10.3	10.6	14.3	13.7	14.1	12.5	12.2	12.4
23	---	---	---	10.4	10.2	10.3	13.7	12.9	13.3	12.6	12.2	12.4
24	---	---	---	10.3	9.9	10.1	13.4	13.0	13.2	12.9	12.3	12.6
25	---	---	---	10.4	9.9	10.1	13.4	13.1	13.2	13.0	12.3	12.6
26	---	---	---	11.0	10.4	10.8	13.8	13.4	13.6	12.7	11.7	12.3
27	9.2	7.9	8.6	11.5	11.0	11.4	14.1	13.8	14.0	11.9	11.6	11.8
28	9.5	9.0	9.2	11.8	11.5	11.7	14.4	14.1	14.2	12.2	11.7	11.9
29	9.4	8.6	9.0	12.2	11.7	12.0	14.4	13.6	14.1	12.3	11.9	12.1
30	10.2	8.7	9.3	12.2	11.8	12.0	13.6	13.1	13.5	12.4	12.2	12.3
31	10.0	8.4	9.1	---	---	---	13.1	12.7	13.0	12.7	12.3	12.4
MONTH	---	---	---	---	---	---	14.4	10.4	12.6	13.1	9.8	11.6

Dissolved oxygen, water, unfiltered, milligrams per liter

DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN
		FEBRUARY			MARCH			APRIL			MAY	
1	12.6	12.0	12.3	12.6	12.1	12.4	10.7	10.4	10.6	9.9	9.1	9.5
2	12.5	12.1	12.3	12.8	12.1	12.5	10.6	10.2	10.4	10.1	9.1	9.4
3	12.3	12.2	12.3	12.7	11.9	12.4	10.9	10.5	10.7	10.3	9.2	9.7
4	12.6	12.3	12.4	12.6	11.7	12.2	10.8	10.3	10.6	10.6	9.3	9.9
5	12.7	12.2	12.4	12.2	11.6	12.0	10.6	10.1	10.3	10.3	9.4	9.8
6	12.6	12.0	12.3	12.2	11.4	11.9	10.4	9.8	10.1	10.6	9.6	10.1
7	12.4	11.7	12.0	11.8	11.0	11.4	10.0	9.7	9.9	10.6	9.4	10.0
8	12.1	11.3	11.8	11.1	10.5	10.8	10.0	9.7	9.8	10.6	9.2	9.9
9	11.7	11.3	11.4	11.5	11.0	11.2	9.9	9.4	9.7	10.6	9.0	9.7
10	11.6	11.3	11.4	11.8	11.1	11.5	10.2	9.6	9.9	10.3	8.7	9.4
11	12.0	11.4	11.7	11.8	10.9	11.4	9.9	9.2	9.6	10.1	8.8	9.3
12	12.4	11.6	12.0	12.0	11.0	11.5	9.6	9.3	9.4	9.9	8.5	9.1
13	12.4	11.7	12.1	12.0	10.8	11.5	10.2	9.6	9.7	9.5	8.4	8.8
14	12.3	11.8	12.1	11.0	10.4	10.7	10.9	10.2	10.6	9.3	8.3	8.8
15	12.4	11.6	11.9	11.9	10.6	11.2	11.2	10.9	11.1	9.2	8.2	8.6
16	12.0	11.0	11.7	11.5	10.9	11.3	11.2	10.8	11.0	9.3	8.2	8.7
17	11.8	10.9	11.2	12.3	11.5	11.9	11.2	10.7	11.0	9.3	8.4	8.7
18	12.2	10.9	11.4	12.6	11.8	12.2	11.6	10.8	11.2	9.3	8.4	8.7
19	12.4	11.1	11.7	12.6	11.8	12.2	11.6	10.9	11.3	9.1	8.3	8.7
20	12.3	11.4	11.8	12.5	11.4	12.0	11.2	10.7	11.0	8.7	8.3	8.5
21	11.7	11.2	11.5	11.7	10.8	11.3	11.1	10.3	10.8	9.0	8.3	8.7
22	12.0	11.4	11.7	11.7	11.0	11.3	10.7	9.8	10.2	8.8	8.5	8.7
23	11.9	10.8	11.5	11.5	10.8	11.1	10.2	9.7	9.9	8.8	8.2	8.5
24	11.0	10.8	10.9	11.6	11.0	11.3	10.5	9.8	10.1	8.9	8.2	8.5
25	11.3	10.8	11.1	11.3	10.6	11.0	10.5	9.9	10.1	9.5	8.3	8.8
26	11.5	10.9	11.2	11.0	10.4	10.7	10.5	9.9	10.2	9.5	8.5	8.9
27	11.6	11.1	11.4	10.5	10.3	10.4	10.6	9.9	10.2	9.1	8.4	8.7
28	12.1	11.2	11.5	11.8	9.4	10.8	10.8	9.6	10.2	8.8	8.3	8.5
29	---	---	---	12.2	11.8	12.1	10.3	9.3	9.7	8.8	8.2	8.5
30	---	---	---	12.1	10.8	11.5	9.6	9.3	9.4	8.6	8.3	8.4
31	---	---	---	10.8	10.5	10.7	---	---	---	9.2	8.3	8.6
MONTH	12.7	10.8	11.8	12.8	9.4	11.5	11.6	9.2	10.3	10.6	8.2	9.0

02156500 BROAD RIVER NEAR CARLISLE, SC--Continued

Dissolved oxygen, water, unfiltered, milligrams per liter
WATER YEAR OCTOBER 2004 TO SEPTEMBER 2005

DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN
		JUNE			JULY			AUGUST			SEPTEMBER	
1	9.0	8.4	8.7	8.4	7.4	7.9	7.6	7.4	7.5	7.7	7.0	7.3
2	9.6	8.6	8.8	7.6	7.2	7.4	7.7	7.5	7.6	7.7	7.1	7.3
3	9.8	8.8	9.2	7.3	7.2	7.3	7.6	7.0	7.3	7.8	7.1	7.4
4	9.1	8.6	9.0	7.4	7.2	7.3	7.3	6.9	7.1	8.0	7.3	7.6
5	8.6	8.1	8.5	7.8	7.3	7.6	---	---	---	8.3	7.4	7.8
6	8.2	7.5	8.0	7.8	7.6	7.7	---	---	---	8.5	7.5	7.9
7	8.2	7.5	7.7	7.9	7.7	7.8	---	---	---	8.8	7.5	8.0
8	8.2	7.3	7.9	9.6	7.7	9.0	---	---	---	8.4	7.7	8.0
9	7.7	7.2	7.3	9.6	8.9	9.3	---	---	---	8.6	7.9	8.2
10	7.3	7.1	7.2	8.9	7.7	8.3	---	---	---	8.8	7.9	8.2
11	7.1	7.0	7.1	8.6	7.6	7.9	---	---	---	8.9	7.9	8.3
12	7.2	7.0	7.1	7.7	7.5	7.6	7.0	6.9	6.9	9.1	8.0	8.5
13	7.2	7.1	7.1	7.9	7.5	7.6	7.2	6.9	7.1	9.2	7.7	8.4
14	7.2	7.1	7.1	8.0	7.5	7.7	7.3	7.0	7.2	9.6	7.7	8.4
15	7.2	7.0	7.1	8.6	7.8	8.0	7.5	7.0	7.2	9.0	7.7	8.2
16	7.1	6.9	7.0	8.6	7.7	8.1	7.5	7.0	7.2	8.6	7.5	7.9
17	7.3	6.9	7.1	7.7	7.3	7.5	7.6	7.0	7.2	8.3	7.4	7.8
18	7.4	7.1	7.2	7.5	7.2	7.3	7.6	7.1	7.3	8.3	7.3	7.7
19	7.5	7.1	7.3	7.4	7.1	7.3	7.7	7.1	7.3	8.6	7.3	7.8
20	7.7	7.3	7.5	7.4	7.1	7.3	7.5	7.1	7.3	8.4	7.3	7.7
21	7.8	7.5	7.6	7.2	6.9	7.1	7.7	7.2	7.4	8.5	7.2	7.7
22	7.9	7.6	7.8	7.0	6.8	6.9	7.7	7.2	7.4	8.0	7.1	7.5
23	7.9	7.3	7.6	7.0	6.7	6.9	7.9	7.3	7.5	8.0	7.0	7.4
24	7.7	7.3	7.5	7.2	6.7	7.0	7.6	7.4	7.5	8.1	7.0	7.5
25	7.8	7.3	7.5	7.2	6.9	7.0	8.1	7.5	7.8	8.2	7.2	7.6
26	7.7	7.4	7.5	7.2	6.6	7.0	7.8	7.6	7.7	8.0	7.3	7.5
27	7.5	7.2	7.3	7.3	6.6	7.0	---	---	---	8.4	7.4	7.7
28	8.2	7.1	7.4	7.1	6.8	6.9	---	---	---	8.2	7.3	7.7
29	8.6	8.2	8.4	7.2	6.9	7.0	---	---	---	8.5	7.7	7.9
30	8.7	8.3	8.6	7.5	7.0	7.3	---	---	---	8.5	7.7	8.1
31	---	---	---	7.8	7.4	7.6	---	---	---	---	---	---
MONTH	9.8	6.9	7.7	9.6	6.6	7.5	---	---	---	9.6	7.0	7.8

02160990 PARR SHOALS RESERVOIR AT PARR, SC

LOCATION.--Lat 34°15'40'', long 81°19'55'', Fairfield County, Hydrologic Unit 03050106, at Parr Shoals Dam, on Broad River 100 ft from left edge, 2.5 mi west of Jenkinsville and at mile 201.6.

DRAINAGE AREA.--4,750 mi^2 (from Federal Power Commission).

PERIOD OF RECORD.--October 1984 to current year.

GAGE.--Data collection platform. Datum of gage is NGVD of 1929 (South Carolina Electric and Gas reference mark). Prior to May 7, 1968, datum was 47.17 ft higher.

REMARKS.--Reservoir is formed by a concrete gravity dam. Project was completed in 1914. Spillway crest elevation: 257.1 ft sea level, 1,850 acres. Maximum power pool is 266 ft sea level, 4,400 acres. Reservoir water is used for cooling of nearby fossil-electric plant. Prior to October 2003, midnight readings and month-end and annual contents were published.

EXTREMES FOR PERIOD OF RECORD.--Maximum elevation, 266.98 ft, Jul. 8, 1988; minimum elevation, 254.62 ft, Oct. 5, 1996.

EXTREMES FOR CURRENT YEAR.--Maximum elevation, 266.47 ft, Nov. 27; minimum elevation, 256.05 ft, July 23.

Elevation above NGVD 1929, feet
WATER YEAR OCTOBER 2004 TO SEPTEMBER 2005

DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN
		OCTOBER			NOVEMBER			DECEMBER			JANUARY	
1	265.80	257.55	261.74	265.27	259.32	262.73	264.59	257.01	260.11	265.12	264.92	264.98
2	266.01	260.36	263.64	265.56	261.12	262.96	264.25	260.66	262.90	265.00	263.49	264.43
3	265.89	258.77	262.52	266.04	261.85	264.34	264.64	261.80	263.69	263.84	261.83	262.78
4	265.22	259.68	262.16	265.86	261.59	263.93	264.67	262.45	263.52	264.57	263.13	263.52
5	266.12	259.85	263.03	265.46	261.53	262.44	263.66	261.51	262.53	264.20	261.80	262.72
6	265.30	261.49	263.61	264.28	260.27	262.30	264.35	257.54	260.71	265.25	261.43	263.23
7	265.13	258.68	261.46	263.91	258.28	260.96	264.45	258.50	261.06	264.61	260.02	262.32
8	263.63	258.34	260.48	263.93	259.82	261.56	265.55	259.03	262.16	264.17	261.69	262.59
9	266.09	258.88	261.96	263.68	257.50	260.27	265.00	260.57	262.66	265.54	261.83	262.69
10	265.52	259.05	262.59	263.73	260.39	261.91	264.20	261.29	262.30	265.26	261.14	263.16
11	266.09	260.29	263.47	264.53	259.11	262.00	264.20	263.55	263.99	265.26	260.56	263.26
12	265.98	261.43	264.49	264.22	258.75	262.10	263.89	260.03	261.50	264.43	259.97	262.02
13	265.72	262.25	263.99	264.49	258.86	261.75	263.31	258.27	260.81	264.66	260.61	262.36
14	264.37	260.15	262.12	265.99	259.20	262.68	264.54	260.11	262.43	265.07	259.68	262.06
15	264.59	259.27	262.19	265.79	262.45	263.95	264.26	260.89	263.05	265.02	261.66	263.49
16	264.27	261.73	262.94	265.63	262.79	264.40	265.50	261.89	263.89	264.08	260.36	262.07
17	263.70	260.55	261.84	265.33	260.31	263.31	266.00	263.06	264.81	264.61	261.52	263.15
18	265.45	257.45	261.91	264.47	260.06	262.57	264.81	262.71	263.52	265.52	262.20	263.90
19	264.61	259.59	261.20	263.64	258.45	260.60	263.20	259.42	261.85	265.76	262.99	264.66
20	265.16	257.22	260.84	264.09	261.45	262.42	263.54	261.73	262.74	265.35	261.93	263.96
21	265.09	256.75	261.43	263.54	256.67	260.00	265.50	262.09	263.63	264.05	258.05	260.48
22	263.54	258.12	261.28	263.13	257.86	260.22	264.96	261.65	263.77	264.98	259.70	262.35
23	264.72	256.67	260.80	264.79	260.85	262.63	264.64	262.36	263.57	264.43	259.59	262.66
24	264.79	259.81	262.16	264.59	260.11	262.37	265.79	260.71	263.54	265.33	262.97	264.05
25	264.90	262.69	263.52	264.91	259.78	261.74	266.14	263.93	264.75	264.18	259.16	262.43
26	264.75	259.95	262.00	266.30	262.97	264.44	265.62	262.35	263.75	264.68	260.87	262.96
27	264.93	259.20	261.58	266.47	263.93	265.51	265.14	262.07	263.52	263.33	257.98	260.50
28	264.84	260.37	262.19	265.67	261.40	262.98	266.32	263.23	264.79	265.11	260.63	263.22
29	263.84	259.92	261.40	265.49	261.77	264.14	266.32	263.07	264.93	265.03	262.28	263.45
30	265.57	261.51	263.24	264.45	260.82	262.29	265.23	263.50	264.32	264.95	257.41	260.85
31	265.21	261.32	263.25	---	---	---	265.24	264.09	264.84	264.84	260.62	263.21
MONTH	266.12	256.67	262.29	266.47	256.67	262.52	266.32	257.01	263.09	265.76	257.41	262.89

02160990 PARR SHOALS RESERVOIR AT PARR, SC--Continued

Elevation above NGVD 1929, feet
WATER YEAR OCTOBER 2004 TO SEPTEMBER 2005

DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN
		FEBRUARY			MARCH			APRIL			MAY	
1	264.93	261.96	263.65	263.86	260.24	261.93	264.31	259.31	261.84	265.18	258.69	261.20
2	264.87	262.13	263.82	263.98	260.49	262.74	263.90	262.15	262.98	265.62	257.25	261.77
3	265.45	260.78	263.17	265.29	261.54	263.03	263.55	261.11	262.57	264.40	259.27	261.86
4	265.43	261.97	263.86	264.89	260.35	263.27	264.96	262.43	263.68	264.70	259.18	261.98
5	264.47	262.71	263.47	264.55	262.63	263.57	265.59	259.36	261.91	264.81	257.84	261.80
6	265.65	262.41	263.87	264.91	261.78	263.44	265.93	259.39	262.66	264.42	260.82	263.05
7	264.60	260.94	262.83	264.77	261.31	263.40	265.40	261.53	263.62	265.71	259.63	262.21
8	264.23	259.87	262.18	263.95	259.63	260.70	263.78	260.12	261.73	266.10	259.34	262.60
9	264.75	260.87	262.57	264.28	260.30	262.18	264.81	258.46	261.85	265.40	258.06	261.92
10	264.22	259.59	261.90	263.58	259.80	261.79	264.97	256.77	261.07	265.59	257.71	261.75
11	265.12	261.57	263.11	264.12	257.66	261.21	265.48	260.08	263.30	265.31	257.33	261.45
12	264.99	261.18	262.87	263.85	261.41	262.83	265.82	258.01	262.05	265.09	257.51	261.04
13	261.64	257.87	260.28	264.91	261.67	262.94	264.92	260.28	262.80	265.36	257.82	262.21
14	259.94	256.85	258.77	264.03	258.76	261.56	264.91	256.98	261.88	266.01	259.06	262.21
15	261.20	259.66	260.27	263.20	258.71	260.47	262.95	258.28	261.27	266.26	258.59	262.68
16	264.31	257.27	260.50	262.70	258.09	259.97	263.74	260.22	262.14	264.95	258.53	261.55
17	263.87	257.23	259.68	266.07	258.44	262.57	262.70	258.34	260.36	264.93	257.81	261.06
18	265.56	262.31	264.15	265.99	264.44	265.23	264.92	261.20	263.44	265.67	257.61	261.50
19	264.91	261.66	263.63	265.92	263.27	264.79	265.74	261.59	263.31	265.44	257.64	261.12
20	263.57	261.15	262.13	265.07	262.71	264.19	266.19	260.13	262.82	265.49	258.23	261.76
21	263.85	260.86	261.66	264.09	258.66	261.72	265.59	258.98	262.56	265.05	257.54	261.66
22	264.99	259.72	262.90	266.04	258.18	261.94	264.19	257.38	259.91	266.20	259.24	262.15
23	264.21	257.86	261.38	265.46	262.33	264.03	265.82	258.88	261.96	266.05	259.77	263.15
24	265.23	259.88	261.52	266.17	262.68	264.41	264.97	258.53	261.61	265.82	258.60	262.19
25	265.50	262.73	264.49	264.44	262.00	262.41	265.09	261.08	263.53	264.43	257.37	260.68
26	266.02	263.17	264.72	262.45	259.95	261.13	266.26	259.07	263.12	266.06	258.28	261.68
27	265.35	260.64	262.98	264.28	257.05	261.07	265.33	259.76	262.83	264.67	257.76	261.46
28	264.43	260.47	263.04	264.07	259.67	262.12	266.02	259.05	263.69	265.70	258.17	262.26
29	---	---	---	263.51	260.72	261.49	265.57	259.13	262.14	265.30	257.51	261.88
30	---	---	---	260.80	260.00	260.52	265.97	261.58	263.78	264.05	257.75	260.97
31	---	---	---	260.89	259.00	259.80	---	---	---	264.31	257.87	260.96
MONTH	266.02	256.85	262.48	266.17	257.05	262.34	266.26	256.77	262.41	266.26	257.25	261.80

Elevation above NGVD 1929, feet

DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN
		JUNE			JULY			AUGUST			SEPTEMBER	
1	265.03	259.25	262.47	265.81	259.22	262.81	265.71	259.38	262.66	265.37	257.77	261.67
2	265.72	259.20	263.36	265.76	257.66	262.43	265.65	258.65	262.26	265.09	258.14	261.87
3	262.67	258.07	260.84	266.13	257.17	261.85	265.15	257.66	261.12	265.13	257.39	261.86
4	265.14	258.41	261.48	266.46	259.41	262.99	265.03	257.18	261.60	264.57	257.07	261.10
5	266.12	257.73	261.72	265.80	257.75	262.58	264.95	257.44	261.38	264.65	257.93	260.69
6	266.04	257.92	262.11	266.06	258.18	262.17	264.84	257.26	261.68	265.15	256.38	260.59
7	265.83	257.67	261.80	266.34	258.79	263.16	265.15	257.36	261.89	265.34	256.07	260.98
8	265.99	257.23	261.76	264.56	257.23	260.97	265.07	257.74	261.49	265.71	256.56	260.94
9	265.40	258.09	262.32	261.87	259.24	260.05	265.60	257.97	262.56	265.58	257.63	261.46
10	266.11	257.99	262.13	261.77	258.89	260.14	265.55	258.25	262.02	265.52	257.49	262.08
11	264.48	258.25	261.11	265.48	257.98	262.39	265.03	259.75	261.81	265.74	257.38	261.53
12	265.97	259.82	262.56	266.19	258.40	262.74	265.79	258.09	262.60	266.06	257.47	261.30
13	265.56	259.69	262.40	265.28	257.43	261.71	266.31	256.35	262.22	265.48	257.47	262.10
14	266.09	257.06	261.65	266.21	260.39	263.05	266.35	257.38	262.42	264.75	258.20	261.27
15	266.26	256.96	261.97	265.89	259.87	262.74	265.76	258.59	262.66	265.17	257.20	261.43
16	265.97	256.83	261.31	265.15	260.18	262.56	265.86	258.40	262.49	265.70	256.55	261.69
17	265.80	259.13	262.15	265.74	257.35	262.06	265.38	257.76	262.02	266.05	257.47	262.64
18	265.43	257.62	261.60	266.24	259.31	262.48	265.88	258.39	262.14	265.96	258.36	262.84
19	264.55	257.24	260.37	265.60	259.03	262.66	266.25	259.11	263.23	265.99	257.97	261.99
20	265.99	257.27	261.17	266.09	259.84	262.74	266.18	259.40	263.41	265.38	259.63	262.46
21	265.57	257.72	261.26	265.29	257.39	261.47	266.34	258.35	263.01	265.57	257.20	261.87
22	265.48	258.22	261.79	265.57	256.95	262.07	265.58	259.25	262.36	265.91	257.82	261.77
23	265.46	257.49	261.53	265.98	256.05	261.89	265.46	258.62	262.19	265.94	257.38	261.46
24	265.41	257.69	261.54	265.76	258.09	262.20	265.79	257.82	261.67	266.03	257.66	262.49
25	264.67	257.17	260.62	265.93	257.53	261.55	265.39	258.09	261.89	265.33	258.69	262.17
26	265.78	257.32	261.70	266.24	257.20	261.85	265.04	256.98	261.30	265.24	257.56	261.88
27	265.40	257.68	262.34	265.45	256.16	261.66	265.49	257.97	261.71	265.25	258.06	261.45
28	265.77	256.49	261.11	263.91	256.91	260.85	265.27	256.79	261.59	265.60	256.49	260.87
29	265.36	260.30	262.64	264.17	257.08	260.87	265.70	256.91	262.11	265.68	257.26	261.79
30	265.53	257.74	261.84	264.93	258.30	261.65	265.47	259.46	263.44	264.78	258.64	261.94
31	---	---	---	265.84	258.98	262.56	265.51	258.85	262.65	---	---	---
MONTH	266.26	256.49	261.75	266.46	256.05	262.03	266.35	256.35	262.18	266.06	256.07	261.67
YEAR	266.47	256.05	262.29									

02160991 BROAD RIVER NEAR JENKINSVILLE, SC

LOCATION.--Lat 34°15'38'', long 81°19'50'', Fairfield County, Hydrologic Unit 03050106, in power house of dam, 0.3 mi upstream from Mayo Creek, 2.5 mi west of Jenkinsville, and at mile 201.4.

DRAINAGE AREA.--4,750 mi^2, approximately.

GAGE HEIGHT RECORDS

PERIOD OF RECORD.--October 1987 to current year.

GAGE.--Data collection platform. Datum of gage is NGVD of 1929.

REMARKS.--Regulated by flow from Parr Shoals Dam.

EXTREMES FOR PERIOD OF RECORD.--Maximum elevation, 242.98 ft, Oct. 14, 1990; minimum elevation, 219.24 ft, Sep. 12, 2002.

EXTREMES FOR CURRENT YEAR.--Maximum elevation, 232.60 ft, June 2; minimum elevation, 219.53 ft, Jan. 30.

Elevation above NGVD 1929, feet
WATER YEAR OCTOBER 2004 TO SEPTEMBER 2005

DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN
	OCTOBER			NOVEMBER			DECEMBER			JANUARY		
1	228.95	222.53	225.27	223.03	221.31	222.17	222.86	221.87	222.39	223.33	222.82	223.06
2	224.73	222.43	223.13	222.31	221.25	221.79	223.83	221.71	222.67	222.93	222.74	222.87
3	224.96	222.39	223.00	222.25	220.84	221.80	223.06	220.80	222.68	223.40	221.99	222.87
4	226.19	222.45	223.33	223.09	220.75	222.24	222.85	222.68	222.77	222.99	222.17	222.63
5	224.73	222.26	222.77	227.04	222.12	224.46	222.84	221.64	222.65	222.99	222.09	222.71
6	225.14	222.37	223.17	226.67	222.69	224.54	223.06	221.14	222.26	223.07	222.80	222.93
7	223.21	222.34	222.61	224.10	222.64	222.84	222.98	221.55	222.38	223.67	222.54	222.91
8	222.76	222.37	222.53	225.49	222.67	223.51	224.82	221.95	222.84	222.95	222.74	222.85
9	222.71	222.36	222.48	222.95	221.54	222.60	223.57	222.70	222.93	222.98	222.61	222.84
10	222.59	222.32	222.48	223.02	222.38	222.76	225.33	222.70	223.48	223.07	221.73	222.63
11	222.78	221.35	222.32	223.00	222.39	222.62	230.34	225.18	228.60	223.30	221.62	222.19
12	222.70	221.73	222.06	222.51	222.00	222.18	229.91	224.72	227.67	222.93	222.04	222.45
13	222.63	222.08	222.50	224.01	221.91	222.65	229.23	222.78	225.47	223.07	221.79	222.84
14	222.68	222.43	222.55	225.47	222.59	223.26	225.76	222.57	223.88	224.63	220.69	222.86
15	222.75	221.94	222.52	226.22	222.67	223.48	225.16	222.74	223.38	227.37	222.81	224.64
16	222.55	222.33	222.46	223.03	221.27	222.36	223.25	221.83	222.91	224.73	222.73	223.40
17	222.51	222.09	222.42	223.12	222.00	222.57	223.70	222.80	223.03	226.58	222.72	223.72
18	222.65	221.67	222.41	222.98	221.94	222.47	222.93	222.56	222.83	223.13	222.69	222.87
19	221.70	221.49	221.62	223.00	221.32	222.61	224.93	219.95	223.04	223.10	222.78	222.93
20	222.68	221.50	222.05	222.86	221.97	222.59	224.72	222.21	223.11	226.58	222.12	223.25
21	222.67	221.34	222.48	222.80	220.50	222.04	224.18	222.17	222.71	223.07	221.98	222.45
22	222.62	219.58	222.14	222.85	221.80	222.35	223.02	222.41	222.63	222.92	222.69	222.83
23	222.15	220.57	221.77	224.98	222.10	222.97	222.93	222.71	222.85	223.07	222.67	222.87
24	222.59	221.61	222.22	223.05	222.06	222.76	223.59	222.74	222.92	223.09	222.55	222.88
25	224.13	220.71	222.14	222.88	222.09	222.75	226.58	222.78	223.63	222.78	222.17	222.61
26	222.60	220.61	221.77	223.34	222.65	222.86	227.62	223.68	225.49	222.77	222.11	222.28
27	222.82	220.73	222.36	224.36	221.89	222.97	226.25	221.72	222.75	222.95	222.39	222.59
28	222.79	220.64	221.85	222.94	222.74	222.82	223.34	221.72	222.73	223.10	222.18	222.92
29	222.23	220.61	221.72	224.67	222.75	223.14	223.12	222.70	222.92	222.91	221.83	222.43
30	222.56	220.80	222.21	222.99	222.65	222.83	225.35	222.80	223.23	222.98	219.53	222.06
31	222.95	220.77	222.24	---	---	---	223.28	222.79	223.08	223.11	222.78	222.95
MONTH	228.95	219.58	222.47	227.04	220.50	222.77	230.34	219.95	223.42	227.37	219.53	222.85

02160991 BROAD RIVER NEAR JENKINSVILLE, SC--Continued

Elevation above NGVD 1929, feet
WATER YEAR OCTOBER 2004 TO SEPTEMBER 2005

DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN
		FEBRUARY			MARCH			APRIL			MAY	
1	223.07	222.78	222.94	228.06	222.91	224.63	226.80	222.42	224.08	223.00	222.77	222.88
2	223.10	222.83	222.96	228.03	222.84	225.29	227.17	223.14	224.39	223.22	220.73	222.72
3	223.25	222.80	222.97	224.81	222.65	223.18	225.88	221.86	223.27	223.35	222.73	222.96
4	223.68	222.74	222.99	224.67	222.57	223.44	225.57	223.09	223.94	223.41	222.77	222.96
5	223.16	222.89	222.99	223.94	222.91	223.27	225.42	222.55	223.43	222.91	221.68	222.46
6	224.13	222.86	223.16	224.20	222.70	223.27	224.89	222.72	223.41	223.27	221.81	222.70
7	223.26	222.79	223.01	223.98	222.83	223.29	224.84	222.83	223.56	223.00	221.88	222.47
8	223.19	222.82	222.99	224.18	222.77	223.20	223.51	222.78	223.02	223.35	221.80	222.57
9	223.23	222.64	222.98	226.35	223.05	224.42	226.37	222.71	223.77	223.07	220.17	222.38
10	223.77	222.71	222.91	225.80	222.86	223.33	224.37	222.45	223.08	222.67	220.77	222.08
11	223.12	222.63	222.94	223.62	222.54	222.97	225.93	220.89	223.82	223.02	221.55	222.53
12	223.00	222.52	222.84	222.99	222.85	222.93	223.95	222.59	223.09	222.98	221.84	222.59
13	222.89	222.40	222.79	223.01	222.83	222.91	226.79	222.83	224.74	223.06	222.05	222.57
14	222.88	219.69	221.71	223.15	222.73	222.93	226.13	222.02	224.10	222.42	222.06	222.20
15	223.08	222.16	222.65	222.97	222.22	222.58	225.44	222.74	224.08	223.22	221.83	222.54
16	223.12	221.79	222.49	224.32	222.42	222.99	225.93	222.97	224.53	223.04	222.08	222.76
17	223.09	221.38	222.52	227.36	222.78	224.45	224.86	222.65	223.01	222.97	221.68	222.40
18	224.49	222.64	222.98	225.68	223.12	224.10	223.71	222.55	223.12	223.43	221.49	222.35
19	222.96	221.35	222.09	224.79	222.98	223.56	225.71	222.87	223.70	223.24	221.39	222.64
20	222.36	222.11	222.19	223.91	222.93	223.13	225.90	221.50	223.58	223.24	222.46	222.80
21	223.10	219.90	222.51	223.34	222.54	223.00	225.78	220.62	223.02	223.00	222.49	222.84
22	227.79	222.42	224.07	223.65	222.35	223.09	222.99	222.73	222.84	223.56	222.74	222.92
23	224.37	222.69	223.14	223.35	222.68	223.01	222.95	220.84	222.82	224.84	221.42	223.18
24	225.53	222.79	223.81	227.70	222.91	223.79	222.92	222.34	222.47	223.05	220.71	222.71
25	228.00	222.87	224.03	226.53	224.08	224.47	225.95	222.39	223.25	222.63	221.35	222.30
26	223.68	222.89	223.05	224.34	222.86	223.48	224.50	222.73	223.24	223.16	220.93	222.43
27	226.17	222.81	223.54	224.16	222.74	223.14	223.78	222.71	223.11	222.97	220.93	222.11
28	225.03	222.89	223.57	230.63	222.82	226.11	223.71	222.23	222.73	223.03	222.00	222.27
29	---	---	---	232.56	229.10	230.60	223.07	222.64	222.88	222.96	221.68	222.19
30	---	---	---	231.30	228.36	230.01	223.03	222.82	222.94	222.95	222.02	222.52
31	---	---	---	229.49	223.53	227.33	---	---	---	222.96	221.27	222.26
MONTH	228.00	219.69	222.96	232.56	222.22	224.13	227.17	220.62	223.43	224.84	220.17	222.56

Elevation above NGVD 1929, feet

DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN
		JUNE			JULY			AUGUST			SEPTEMBER	
1	223.47	221.31	222.42	226.48	222.86	224.34	223.16	222.51	222.77	222.56	220.51	221.63
2	232.60	221.39	227.04	225.43	222.52	223.40	223.35	222.54	222.88	222.31	221.15	221.70
3	227.04	221.38	224.57	224.45	220.61	222.58	223.02	222.39	222.74	222.45	221.19	221.75
4	229.69	222.81	224.82	225.66	222.40	223.31	222.85	221.16	222.35	222.13	221.03	221.67
5	223.92	221.30	222.60	224.12	222.59	223.09	222.84	221.13	222.18	222.46	221.21	221.89
6	224.45	222.79	223.22	224.56	222.54	223.09	222.84	221.12	222.22	221.29	220.12	220.97
7	223.47	221.25	222.70	225.22	222.72	223.46	222.83	221.50	221.98	221.78	220.09	220.85
8	223.67	222.03	222.77	231.06	222.21	226.12	222.84	221.51	222.14	221.25	220.23	220.70
9	223.60	222.73	223.01	230.05	226.33	228.57	222.97	221.83	222.46	222.61	220.54	221.49
10	224.22	222.43	223.08	229.76	225.06	227.32	223.12	222.33	222.82	222.44	220.63	221.48
11	223.21	222.52	222.83	229.77	222.19	225.01	228.57	222.65	223.94	222.45	220.51	221.09
12	223.97	222.54	223.01	224.15	220.51	222.51	224.23	222.42	223.24	222.33	220.54	221.28
13	226.44	222.45	223.62	223.01	220.90	222.29	223.89	221.77	222.66	221.29	221.10	221.22
14	223.53	220.41	222.58	226.23	222.12	223.32	223.09	222.12	222.55	221.71	220.62	221.32
15	223.85	221.31	222.74	225.71	222.61	223.92	223.02	221.72	222.38	221.77	220.52	220.74
16	223.26	220.63	222.60	230.67	222.16	224.66	223.07	221.46	222.31	221.73	220.21	220.92
17	223.12	222.38	222.81	223.48	221.68	222.68	222.75	221.16	221.75	222.70	220.63	221.52
18	223.00	222.15	222.64	224.43	221.99	222.87	222.97	220.88	222.00	222.11	220.53	221.28
19	222.94	222.01	222.36	224.07	222.43	223.02	223.66	221.61	222.43	222.12	220.64	221.14
20	222.98	220.86	222.56	224.88	222.18	223.07	223.49	221.14	222.20	221.86	220.55	220.93
21	223.04	220.74	222.25	223.29	220.83	222.56	223.30	221.52	222.21	221.34	220.53	220.77
22	223.05	222.06	222.63	223.26	222.34	222.71	222.98	221.01	221.96	221.76	220.51	220.90
23	222.99	222.06	222.64	222.78	221.25	222.45	223.01	220.77	222.04	222.50	220.57	221.32
24	222.97	221.76	222.38	222.75	221.44	222.20	222.94	220.57	222.10	221.85	219.63	220.98
25	222.65	220.85	221.99	223.10	222.50	222.77	222.89	221.20	222.14	221.82	220.52	221.15
26	222.60	221.24	221.96	223.09	221.29	222.61	222.64	220.68	221.74	222.65	220.60	221.26
27	222.95	221.59	222.46	222.68	221.04	221.77	222.54	221.08	221.89	221.72	220.56	220.97
28	223.39	220.66	222.65	222.79	221.74	222.53	222.51	220.54	221.82	221.68	220.57	220.99
29	230.14	222.50	225.78	222.65	221.13	222.30	222.70	221.18	221.94	220.93	220.52	220.64
30	230.03	222.62	224.29	222.70	222.41	222.57	222.67	221.11	222.06	221.07	220.02	220.62
31	---	---	---	222.75	222.45	222.61	222.52	220.61	221.53	---	---	---
MONTH	232.60	220.41	223.10	231.06	220.51	223.41	228.57	220.54	222.30	222.70	219.63	221.17
YEAR	232.60	219.53	222.88									

02160991 BROAD RIVER NEAR JENKINSVILLE, SC--Continued

WATER-QUALITY RECORDS

PERIOD OF RECORD.--Water years 1974 to current year.

PERIOD OF DAILY RECORDS.--

SPECIFIC CONDUCTANCE: October 1973 to current year.

pH: October 1973 to current year.

WATER TEMPERATURE: October 1973 to current year.

DISSOLVED OXYGEN: October 1973 to current year.

INSTRUMENTATION.--Water-quality multiprobe and data collection platform.

REMARKS.--Specific conductance records rated excellent except for Nov. 25 to Dec. 2, July 4-11, July 20 to Aug. 3, Aug. 24-31, which are good, Oct. 1, which are poor. pH records rated excellent except for Oct. 1, 11-13, 21-28, Dec. 3, 4, 28, 29, which are good, and Oct. 29 to Nov. 4, which are fair. Temperature records rated excellent. Dissolved oxygen records rated excellent except for June 15-22, which are good, and June 23 to July 9, which are fair.

EXTREMES FOR PERIOD OF DAILY RECORD.--

SPECIFIC CONDUCTANCE: Maximum, 249 microsiemens, Oct. 15, 1996; minimum, 30 microsiemens, Mar. 30, 1980, and Aug. 21, 1986.

pH: Maximum, 8.3 units, Jul. 24, 1977; minimum, 5.0 units, Jul. 13, 1987.

WATER TEMPERATURE: Maximum, 32.5°C, Aug. 25, 1975, Jul. 25, 1976, Jul. 11, 16, 1977, and many days in Jul. 1986; minimum, less than 0.5°C, Jan. 19-21, 1977, Jan. 11, 1988, Jan. 20, 1994.

DISSOLVED OXYGEN: Maximum, 14.3 mg/L, many days in Jan. 1988; minimum, 0.6 mg/L, May 25, 2003.

EXTREMES FOR CURRENT YEAR.--

SPECIFIC CONDUCTANCE: Maximum, 103 microsiemens, Sep. 23, 28; minimum, 42 microsiemens, July 9, 10.

pH: Maximum, 7.6 units, several days in January and February, Apr. 24, 27, 29, May 5-7, 13; minimum 6.3 units, Oct. 7-9, 14, 16.

WATER TEMPERATURE: Maximum, 31.2°C, Aug. 20; minimum, 5.4°C, Jan. 30.

DISSOLVED OXYGEN: Maximum, 12.9 mg/L, Dec. 23; minimum, 3.8 mg/L, Aug. 24.

(31.2 × 1.8) + 32° = 88.16 °F
(5.4 × 1.8) + 32 = 41.72

Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius
WATER YEAR OCTOBER 2004 TO SEPTEMBER 2005

DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN
	OCTOBER			NOVEMBER			DECEMBER			JANUARY		
1	73	55	65	93	83	86	79	74	76	67	66	66
2	73	64	70	87	82	84	78	75	76	67	67	67
3	72	66	70	87	84	86	75	75	75	71	67	69
4	72	68	71	86	79	83	76	75	76	72	71	71
5	73	69	71	93	78	84	78	76	77	72	70	71
6	73	71	72	81	72	77	79	77	78	74	72	72
7	75	72	73	80	73	77	80	77	78	74	72	73
8	78	73	75	78	72	76	80	77	78	73	73	73
9	77	74	75	76	72	75	82	77	79	74	72	73
10	77	73	75	76	74	76	81	78	79	74	73	73
11	78	74	75	78	75	76	80	57	66	75	73	73
12	78	74	76	78	77	78	---	---	---	76	73	74
13	79	74	76	78	78	78	---	---	---	78	73	75
14	83	77	79	81	78	79	---	---	---	77	74	75
15	84	76	80	80	78	79	---	---	---	78	74	75
16	82	76	79	79	78	78	---	---	---	77	72	75
17	88	80	83	78	77	78	---	---	---	75	71	74
18	89	78	83	78	77	77	---	---	---	74	70	72
19	81	77	78	79	77	78	---	---	---	74	71	73
20	91	78	82	80	78	78	---	---	---	74	73	73
21	87	78	81	82	79	80	---	---	---	77	73	75
22	90	79	83	82	79	80	---	---	---	77	75	76
23	90	80	84	81	77	79	---	---	---	78	75	76
24	85	80	82	81	78	79	---	---	---	78	75	76
25	87	81	83	83	78	80	---	---	---	79	76	77
26	91	85	87	83	80	81	---	---	---	77	75	76
27	93	83	87	82	80	81	---	---	---	81	75	77
28	92	84	86	81	80	80	---	---	---	78	74	76
29	91	86	87	80	78	79	---	---	---	78	75	76
30	91	85	88	79	75	77	69	66	68	81	75	77
31	88	85	86	---	---	---	69	65	66	80	75	77
MONTH	93	55	79	93	72	79	---	---	---	81	66	74

02160991 BROAD RIVER NEAR JENKINSVILLE, SC--Continued

Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius
WATER YEAR OCTOBER 2004 TO SEPTEMBER 2005

DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN
		FEBRUARY			MARCH			APRIL			MAY	
1	80	76	78	78	71	75	72	56	64	81	76	77
2	81	78	79	78	70	74	72	61	63	82	75	77
3	85	77	80	76	70	73	69	62	65	81	75	77
4	83	77	79	75	67	73	72	65	68	80	76	77
5	87	78	84	75	71	73	74	67	69	78	76	76
6	84	80	82	76	70	73	74	71	73	77	75	76
7	84	79	81	76	74	75	74	73	74	79	76	77
8	82	78	80	78	75	76	74	74	74	82	77	78
9	81	78	80	78	76	77	75	74	74	83	77	78
10	82	78	79	78	76	77	76	74	74	81	77	78
11	83	78	80	78	77	77	75	74	74	83	77	79
12	83	78	81	77	77	77	76	73	74	84	77	79
13	83	78	80	78	77	77	74	73	74	82	78	79
14	86	78	81	80	77	78	74	72	74	81	77	78
15	84	78	81	80	78	79	74	68	73	81	78	79
16	86	78	80	82	79	80	74	68	71	82	77	79
17	87	78	82	80	77	78	74	68	71	85	77	80
18	81	78	78	78	74	76	72	67	70	85	78	80
19	81	78	79	76	73	74	73	70	72	83	78	80
20	87	81	83	77	76	76	73	73	73	81	77	79
21	88	84	86	78	77	77	74	73	74	81	78	79
22	88	79	83	79	77	77	75	74	74	82	77	79
23	84	79	80	78	77	77	76	74	74	80	78	79
24	80	78	79	80	78	79	78	74	75	80	78	79
25	79	78	78	80	78	79	77	74	75	80	78	79
26	78	77	77	79	76	77	79	74	75	80	78	79
27	78	77	78	80	76	77	80	75	76	80	78	79
28	78	77	78	77	68	76	78	75	76	81	78	79
29	---	---	---	69	52	58	78	76	76	82	78	79
30	---	---	---	67	49	52	78	75	76	84	77	79
31	---	---	---	74	51	61	---	---	---	85	79	80
MONTH	88	76	80	82	49	74	80	56	72	85	75	78

Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius

DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN
		JUNE			JULY			AUGUST			SEPTEMBER	
1	83	78	80	78	67	76	77	72	74	89	77	80
2	83	65	76	76	68	75	79	73	75	87	76	79
3	75	52	63	75	69	74	81	71	75	86	76	78
4	79	65	72	74	63	69	77	71	73	85	74	77
5	78	71	76	71	66	69	77	72	73	88	74	78
6	76	69	72	71	69	70	77	72	73	84	76	79
7	73	72	72	71	64	69	78	72	73	83	76	78
8	75	73	74	70	57	68	83	72	74	85	77	78
9	76	74	75	57	42	45	87	72	75	93	78	81
10	76	74	75	50	42	45	86	74	77	85	78	79
11	77	74	76	69	46	60	81	75	77	88	78	80
12	78	74	75	69	59	66	77	73	75	87	77	80
13	78	75	76	68	63	67	75	71	74	82	78	79
14	80	76	77	70	65	68	75	73	74	86	78	80
15	80	77	77	71	67	70	76	73	74	86	79	81
16	80	77	78	73	68	71	81	75	76	91	81	83
17	79	77	78	72	67	71	82	75	76	90	79	81
18	80	77	78	72	68	71	82	76	77	90	79	81
19	80	77	78	72	70	72	81	75	77	92	80	83
20	82	77	78	73	72	72	80	75	76	85	79	81
21	86	78	80	75	73	73	83	76	77	94	81	84
22	85	79	81	75	72	73	81	76	77	98	80	84
23	84	75	79	77	72	74	85	75	78	103	82	86
24	84	76	78	77	72	74	86	77	79	94	81	84
25	81	76	78	79	72	75	86	77	79	91	81	83
26	81	76	77	78	74	76	88	77	82	92	81	84
27	84	77	78	78	74	76	86	78	83	97	81	85
28	88	77	80	77	72	73	85	77	80	103	85	88
29	80	76	78	77	71	73	84	77	79	93	85	87
30	79	66	75	78	71	74	82	77	78	91	86	87
31	---	---	---	78	70	74	85	76	79	---	---	---
MONTH	88	52	76	79	42	70	88	71	76	103	74	82

02160991 BROAD RIVER NEAR JENKINSVILLE, SC--Continued

pH, water, unfiltered, field, standard units
WATER YEAR OCTOBER 2004 TO SEPTEMBER 2005

DAY	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN
	OCTOBER		NOVEMBER		DECEMBER		JANUARY		FEBRUARY		MARCH	
1	7.2	6.7	7.0	6.8	6.8	6.6	7.3	7.2	7.6	7.4	7.2	7.1
2	7.2	6.7	7.0	6.8	7.0	6.7	7.2	7.2	7.6	7.4	7.2	7.1
3	6.8	6.6	7.1	7.0	7.0	6.9	7.2	7.2	7.6	7.4	7.2	7.1
4	6.8	6.6	7.2	7.0	7.1	6.9	7.2	7.2	7.6	7.5	7.2	7.1
5	6.7	6.6	7.2	7.1	7.1	7.0	7.2	7.2	7.5	7.5	7.2	7.2
6	6.8	6.4	7.2	7.0	7.1	7.0	7.3	7.2	7.5	7.5	7.2	7.2
7	6.5	6.3	7.1	7.0	7.1	7.0	7.3	7.2	7.5	7.4	7.3	7.2
8	6.5	6.3	7.0	7.0	7.1	7.0	7.3	7.2	7.4	7.4	7.3	7.2
9	6.5	6.3	7.0	7.0	7.2	7.0	7.3	7.2	7.4	7.4	7.2	7.2
10	6.5	6.4	7.0	6.9	7.3	7.2	7.3	7.2	7.4	7.4	7.3	7.2
11	6.7	6.4	7.0	6.9	7.2	6.8	7.2	7.2	7.6	7.4	7.3	7.2
12	6.7	6.5	6.9	6.9	6.8	6.6	7.3	7.2	7.6	7.4	7.3	7.2
13	6.7	6.4	7.0	6.9	6.7	6.6	7.3	7.2	7.5	7.4	7.4	7.3
14	6.4	6.3	7.0	6.9	6.7	6.4	7.4	7.3	7.5	7.4	7.3	7.2
15	6.6	6.4	6.9	6.8	6.8	6.6	7.4	7.3	7.5	7.4	7.3	7.2
16	6.5	6.3	6.8	6.8	6.8	6.6	7.3	7.2	7.5	7.4	7.3	7.2
17	6.7	6.4	6.8	6.8	6.6	6.6	7.3	7.3	7.5	7.4	7.3	7.2
18	6.6	6.4	6.8	6.8	6.8	6.6	7.3	7.3	7.5	7.5	7.3	7.1
19	6.5	6.4	6.8	6.8	6.7	6.7	7.3	7.3	7.5	7.4	7.2	7.1
20	6.6	6.4	6.8	6.8	6.8	6.6	7.3	7.3	7.5	7.5	7.2	7.2
21	6.6	6.5	6.8	6.8	6.8	6.8	7.3	7.3	7.6	7.5	7.2	7.1
22	6.7	6.5	6.8	6.8	---	---	7.3	7.3	7.5	7.4	7.2	7.1
23	6.7	6.6	6.8	6.7	---	---	7.4	7.3	7.4	7.1	7.3	7.2
24	6.7	6.6	6.8	6.7	6.9	6.8	7.4	7.3	7.3	7.2	7.3	7.2
25	6.7	6.5	6.8	6.7	6.9	6.8	7.3	7.3	7.3	7.2	7.2	7.2
26	6.7	6.6	6.8	6.7	7.0	6.8	7.6	7.3	7.2	7.2	7.2	7.2
27	6.8	6.6	6.8	6.7	7.1	6.8	7.6	7.5	7.2	7.1	7.2	7.2
28	6.8	6.6	6.8	6.7	7.0	7.0	7.6	7.5	7.3	7.2	7.3	7.1
29	6.8	6.7	6.8	6.7	7.3	7.0	7.6	7.5	---	---	7.1	6.7
30	6.9	6.7	6.8	6.7	7.2	7.2	7.6	7.5	---	---	7.1	6.7
31	7.1	6.8	---	---	7.3	7.2	7.6	7.5	---	---	7.2	6.8
MONTH	7.2	6.3	7.2	6.7	---	---	7.6	7.2	7.6	7.1	7.4	6.7

pH, water, unfiltered, field, standard units

DAY	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN
	APRIL		MAY		JUNE		JULY		AUGUST		SEPTEMBER	
1	7.1	6.8	7.5	7.4	7.4	7.3	7.0	6.8	6.9	6.8	7.1	6.9
2	7.2	7.0	7.5	7.2	7.4	7.1	7.0	6.8	6.9	6.8	7.1	6.9
3	7.3	7.0	7.5	7.2	7.2	6.8	7.0	6.9	7.1	6.8	7.1	7.0
4	7.2	7.0	7.4	7.2	7.3	7.0	7.0	6.8	7.3	6.9	7.1	6.9
5	7.2	7.1	7.6	7.4	7.3	7.0	6.9	6.8	7.1	6.9	7.1	6.9
6	7.2	7.1	7.6	7.5	7.2	6.9	7.0	6.8	7.0	6.8	7.2	7.0
7	7.2	7.1	7.6	7.4	7.1	7.0	7.0	6.9	7.0	6.9	7.1	7.0
8	7.2	7.1	7.5	7.4	7.1	6.9	7.0	6.8	7.1	6.9	7.1	7.0
9	7.3	7.2	7.5	7.3	7.1	7.0	6.9	6.5	7.1	6.9	7.2	7.0
10	7.3	7.1	7.4	7.3	7.1	6.9	6.7	6.5	7.1	6.9	7.2	7.0
11	7.2	7.2	7.5	7.3	7.1	7.0	6.9	6.6	7.1	6.9	7.2	7.0
12	7.2	7.1	7.5	7.4	7.1	7.0	6.9	6.7	7.2	6.9	7.2	7.1
13	7.3	7.2	7.6	7.3	7.1	7.0	7.1	6.8	7.0	6.9	7.1	7.0
14	7.3	7.2	7.5	7.4	7.2	7.0	7.0	6.8	7.0	6.9	7.2	7.0
15	7.3	7.2	7.4	7.3	7.3	7.0	7.0	6.8	7.0	6.9	7.2	7.0
16	7.4	7.3	7.5	7.3	7.2	7.0	6.9	6.8	7.0	6.8	7.1	7.0
17	7.4	7.2	7.5	7.4	7.2	7.0	6.9	6.8	7.0	6.8	7.1	7.0
18	7.3	7.3	7.5	7.4	7.2	7.0	6.8	6.7	7.0	6.8	7.1	7.0
19	7.4	7.3	7.4	7.3	7.2	7.0	6.8	6.7	7.1	6.8	7.1	7.0
20	7.4	7.3	7.4	7.3	7.3	7.1	6.7	6.7	7.0	6.8	7.1	7.0
21	7.4	7.3	7.5	7.3	7.2	7.0	6.8	6.7	7.0	6.8	7.1	6.9
22	7.4	7.3	7.5	7.3	7.1	7.0	6.7	6.7	7.0	6.9	7.1	6.9
23	7.5	7.3	7.4	7.3	7.2	7.0	6.7	6.6	7.0	6.8	7.2	7.0
24	7.6	7.4	7.4	7.3	7.2	7.0	6.8	6.6	7.0	6.8	7.2	7.0
25	7.5	7.2	7.5	7.3	7.1	7.0	6.7	6.6	7.0	6.9	7.1	7.0
26	7.5	7.2	7.4	7.3	7.2	7.0	6.7	6.6	7.1	6.9	7.1	7.0
27	7.6	7.4	7.4	7.3	7.2	7.0	6.8	6.7	7.1	6.9	7.1	7.0
28	7.5	7.4	7.4	7.3	7.1	6.9	6.8	6.6	7.0	6.8	7.2	7.0
29	7.6	7.4	7.4	7.2	7.1	7.0	6.7	6.7	7.0	6.8	7.1	7.0
30	7.5	7.4	7.4	7.3	7.0	6.8	6.8	6.7	7.0	6.9	7.2	7.1
31	---	---	7.5	7.3	---	---	6.8	6.7	7.2	6.9	---	---
MONTH	7.6	6.8	7.6	7.2	7.4	6.8	7.1	6.5	7.3	6.8	7.2	6.9

02160991 BROAD RIVER NEAR JENKINSVILLE, SC--Continued

Temperature, water, degrees Celsius
WATER YEAR OCTOBER 2004 TO SEPTEMBER 2005

DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN
		OCTOBER			NOVEMBER			DECEMBER			JANUARY	
1	24.7	21.4	22.9	21.8	20.7	21.2	15.1	11.5	13.4	7.2	6.5	6.8
2	24.6	23.4	24.1	22.2	21.4	21.8	15.0	14.3	14.7	6.8	6.4	6.6
3	24.3	23.2	23.9	22.0	21.4	21.7	14.5	13.7	14.0	9.0	6.8	7.7
4	24.5	22.4	23.8	21.8	21.2	21.6	13.9	12.3	13.3	11.2	8.9	9.9
5	24.2	23.5	23.8	21.2	19.5	20.4	12.9	11.4	12.2	10.7	9.6	10.2
6	23.8	22.4	23.5	20.5	17.3	19.2	14.4	10.5	12.6	11.5	10.4	10.9
7	23.3	21.8	22.9	19.9	17.2	18.9	14.8	11.9	13.8	11.6	10.8	11.3
8	23.3	21.3	22.5	20.9	16.2	18.9	14.8	12.7	14.2	12.6	11.3	12.0
9	23.4	22.0	22.8	19.0	15.8	17.7	15.0	12.1	14.2	12.4	11.0	11.7
10	23.4	22.4	23.1	18.2	17.1	17.8	15.6	12.7	14.5	12.4	11.7	12.0
11	23.5	22.7	23.1	18.4	15.6	17.0	13.0	11.0	11.5	12.4	11.7	11.9
12	23.4	22.8	23.1	18.6	16.6	17.8	14.0	10.7	11.7	12.5	11.7	12.0
13	23.5	22.3	23.0	18.6	15.5	17.4	14.0	10.2	11.8	12.9	11.9	12.4
14	22.6	21.6	22.1	18.2	15.5	16.9	13.9	9.7	12.6	13.4	12.3	12.9
15	22.1	21.0	21.8	17.9	14.0	16.8	13.5	9.3	12.2	12.7	12.0	12.3
16	21.7	20.5	21.2	16.9	15.1	15.7	11.6	10.1	10.7	12.3	11.1	11.8
17	20.8	19.5	20.2	17.2	13.3	15.5	11.7	9.8	10.5	11.9	10.0	11.4
18	22.0	19.0	20.6	16.5	14.9	15.6	11.2	8.2	9.7	11.2	9.2	9.7
19	22.2	21.0	21.9	16.4	14.0	15.2	10.1	6.7	7.8	9.7	8.5	9.2
20	22.1	19.6	21.0	17.4	14.7	16.0	10.9	6.8	9.2	9.5	7.1	8.7
21	22.0	20.1	21.4	16.2	14.6	15.6	9.8	7.6	8.9	9.4	6.7	8.2
22	21.8	20.4	21.2	17.3	15.5	16.5	---	---	---	9.8	6.2	8.3
23	21.6	20.1	21.0	17.7	16.3	17.0	---	---	---	9.8	5.7	8.6
24	21.6	20.3	21.0	17.6	16.6	17.2	9.5	7.4	8.1	8.6	7.1	7.8
25	22.4	20.4	21.2	17.3	15.6	16.7	9.5	6.9	8.7	8.7	5.7	7.6
26	20.6	19.5	20.2	16.1	15.6	15.9	10.7	6.3	8.1	9.1	8.4	8.7
27	20.9	19.7	20.4	15.9	15.4	15.6	10.3	7.2	9.0	9.1	7.2	8.3
28	20.9	19.5	20.5	15.6	13.0	14.7	8.4	6.7	7.6	9.3	7.7	8.7
29	20.3	19.3	20.0	14.9	13.0	14.3	9.2	7.5	8.3	8.8	7.2	7.9
30	21.2	19.4	20.2	14.9	12.6	13.9	8.6	6.6	7.8	8.5	5.4	7.2
31	21.8	20.5	21.0	---	---	---	8.6	6.0	6.8	8.4	6.5	8.0
MONTH	24.7	19.0	21.9	22.2	12.6	17.4	---	---	---	13.4	5.4	9.7

Temperature, water, degrees Celsius

DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN
		FEBRUARY			MARCH			APRIL			MAY	
1	8.4	7.6	7.9	9.6	7.9	8.9	14.6	13.2	14.1	19.0	16.8	17.7
2	8.2	7.2	7.7	9.6	7.1	8.5	14.8	13.3	14.4	19.1	17.6	18.2
3	8.3	6.2	7.5	9.9	7.6	8.7	15.1	13.0	14.1	19.8	17.2	18.3
4	8.3	7.0	7.9	10.2	7.2	8.9	15.0	13.9	14.4	18.8	17.3	18.1
5	8.3	6.2	7.1	10.1	8.9	9.5	16.1	14.0	15.0	18.3	17.7	18.0
6	8.4	6.6	7.5	10.5	8.7	9.7	16.1	13.8	14.8	18.5	16.9	17.7
7	8.8	6.8	7.8	11.0	9.6	10.3	16.0	13.7	14.4	20.0	17.7	18.5
8	9.4	7.7	8.6	11.6	10.5	11.0	17.0	14.1	15.5	20.9	17.9	19.0
9	9.2	8.7	8.9	11.1	9.7	10.4	17.4	16.1	16.6	21.5	18.3	19.5
10	9.1	8.4	8.9	11.6	9.9	10.7	19.4	16.0	17.3	20.6	18.5	19.2
11	9.3	8.0	8.6	11.0	10.1	10.5	17.1	15.4	16.1	21.3	18.5	19.8
12	9.3	8.4	8.8	11.3	9.5	10.3	18.3	15.5	16.6	22.7	19.2	20.4
13	9.3	8.3	8.8	12.1	10.4	11.2	17.2	15.8	16.4	22.3	19.3	20.7
14	8.9	8.0	8.7	12.1	11.0	11.5	16.8	15.6	16.4	23.2	20.1	21.2
15	9.4	8.0	8.6	12.3	11.0	11.6	16.7	15.6	16.2	22.7	20.1	21.0
16	10.4	8.8	9.6	12.2	11.3	11.8	16.9	14.8	15.8	23.5	19.3	21.2
17	10.9	9.5	10.2	11.4	10.2	11.0	16.4	15.6	16.0	23.3	20.5	21.8
18	10.2	9.7	9.9	11.4	9.1	10.6	19.1	15.4	16.5	23.4	20.6	21.7
19	10.5	9.5	9.8	11.0	9.2	9.9	18.6	15.9	16.9	23.6	20.4	22.0
20	10.2	9.9	10.0	11.6	10.4	11.0	18.5	15.7	16.7	22.4	20.2	21.2
21	10.0	9.8	9.9	11.8	11.1	11.4	18.8	16.0	16.9	22.0	19.6	20.8
22	10.3	9.8	10.1	12.1	11.3	11.7	20.2	16.7	18.1	22.6	20.6	21.5
23	11.3	9.9	10.7	13.8	12.0	12.8	19.9	17.2	18.0	22.7	20.1	21.2
24	11.5	10.7	11.0	14.0	12.2	12.9	18.4	15.8	17.0	23.0	20.0	21.1
25	11.2	10.6	11.0	14.8	12.0	13.8	17.7	16.2	17.1	22.4	20.2	21.3
26	11.0	10.6	10.9	15.2	13.2	14.3	17.3	16.5	16.9	23.3	20.8	21.9
27	11.0	10.4	10.7	15.1	13.2	14.0	17.8	16.4	16.9	23.4	20.8	22.0
28	11.0	9.6	10.6	15.0	12.1	13.4	18.6	16.0	17.0	23.2	21.0	22.0
29	---	---	---	14.4	13.4	13.8	18.1	16.9	17.5	23.3	21.1	22.0
30	---	---	---	14.8	13.2	13.9	17.5	16.7	17.1	22.3	21.1	21.6
31	---	---	---	14.7	13.2	14.0	---	---	---	21.4	21.1	21.2
MONTH	11.5	6.2	9.2	15.2	7.1	11.4	20.2	13.0	16.2	23.6	16.8	20.4

02160991 BROAD RIVER NEAR JENKINSVILLE, SC--Continued

Temperature, water, degrees Celsius
WATER YEAR OCTOBER 2004 TO SEPTEMBER 2005

DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN
		JUNE			JULY			AUGUST			SEPTEMBER	
1	21.3	20.7	21.0	26.4	25.3	25.8	28.4	27.1	28.0	29.8	28.5	29.1
2	20.8	19.4	20.3	27.3	25.4	26.1	29.1	27.2	28.1	29.6	28.6	29.2
3	20.4	18.5	19.2	27.0	26.0	26.4	29.1	27.8	28.4	29.5	28.7	29.2
4	21.5	18.8	19.9	27.6	26.2	26.7	30.2	28.3	29.0	29.4	28.2	28.8
5	23.0	20.8	21.6	28.1	26.1	26.8	30.1	28.5	29.2	28.9	27.5	28.3
6	24.2	21.2	22.4	28.1	26.0	26.8	29.4	28.4	28.9	28.1	26.9	27.4
7	24.2	21.6	22.7	27.8	25.8	26.7	28.9	28.1	28.5	27.7	25.9	26.9
8	24.6	22.0	23.1	27.5	25.4	26.4	28.7	28.2	28.5	27.5	26.2	27.0
9	25.0	22.4	23.4	25.4	23.2	23.9	29.1	27.8	28.4	27.6	26.1	27.1
10	25.7	22.6	23.9	24.9	23.7	24.2	29.2	28.2	28.6	27.5	26.6	27.1
11	25.8	22.8	24.0	26.9	24.2	25.7	29.1	27.6	28.3	27.4	26.1	26.7
12	25.4	23.7	24.4	27.5	26.1	26.6	30.1	28.0	28.7	26.9	25.7	26.3
13	25.4	23.2	24.0	27.6	26.5	26.9	29.4	28.3	28.7	26.9	25.8	26.4
14	26.9	23.3	24.8	27.4	26.2	26.6	29.7	28.5	29.0	26.7	26.0	26.4
15	27.8	24.1	25.5	27.4	26.2	26.6	30.3	28.6	29.4	27.3	26.1	26.7
16	27.9	23.9	25.5	27.1	26.3	26.7	30.4	29.0	29.7	27.5	26.8	27.2
17	27.2	24.6	25.9	27.5	26.4	27.0	30.5	29.2	29.8	27.9	27.1	27.4
18	27.3	25.0	26.0	29.0	26.7	27.4	30.2	29.1	29.6	27.8	27.0	27.3
19	26.4	24.6	25.3	28.9	26.7	27.5	31.0	29.0	29.6	28.0	27.0	27.6
20	26.3	24.2	25.1	29.6	27.0	27.9	31.2	29.3	29.9	28.0	27.5	27.7
21	25.8	24.9	25.4	30.6	27.2	28.5	31.1	29.6	30.3	28.1	27.4	27.7
22	26.1	24.4	25.2	29.9	27.6	28.6	30.5	29.6	29.9	28.2	27.4	27.8
23	26.7	24.6	25.6	30.2	27.8	28.9	30.1	29.1	29.5	28.3	27.3	27.8
24	26.6	25.3	26.0	30.2	28.8	29.4	30.0	29.1	29.6	28.1	27.4	27.8
25	26.2	25.5	25.9	30.5	28.3	29.3	29.8	28.6	29.4	27.9	27.6	27.7
26	26.1	25.3	25.7	30.6	28.2	29.4	29.6	28.5	29.1	27.6	27.1	27.4
27	27.3	25.9	26.4	30.9	28.7	29.6	29.4	28.3	28.9	27.7	27.0	27.3
28	27.1	25.7	26.3	31.0	28.9	29.8	29.9	28.7	29.2	27.4	26.8	27.2
29	26.1	25.5	25.8	30.4	28.6	29.2	29.7	29.0	29.4	27.3	26.6	27.0
30	27.0	25.3	25.7	29.1	28.2	28.6	29.4	28.9	29.2	27.1	25.8	26.3
31	---	---	---	28.6	27.5	28.3	29.5	28.5	29.0	---	---	---
MONTH	27.9	18.5	24.2	31.0	23.2	27.4	31.2	27.1	29.1	29.8	25.7	27.5

02160991 BROAD RIVER NEAR JENKINSVILLE, SC--Continued

Dissolved oxygen, water, unfiltered, milligrams per liter
WATER YEAR OCTOBER 2004 TO SEPTEMBER 2005

DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN
		OCTOBER			NOVEMBER			DECEMBER			JANUARY	
1	---	---	---	---	---	---	10.9	9.0	9.8	12.1	11.6	11.9
2	---	---	---	---	---	---	9.4	8.8	9.1	12.0	11.9	12.0
3	---	---	---	---	---	---	9.4	9.0	9.2	11.9	11.0	11.5
4	---	---	---	---	---	---	10.0	9.2	9.5	11.1	10.3	10.7
5	---	---	---	---	---	---	10.5	9.7	10.0	10.9	10.6	10.8
6	---	---	---	8.9	7.9	8.3	11.1	9.2	9.9	10.7	10.1	10.3
7	---	---	---	8.6	7.4	8.0	10.9	9.1	9.7	10.3	9.8	10.1
8	---	---	---	8.8	7.6	8.0	10.7	9.4	9.8	10.2	10.0	10.1
9	---	---	---	9.2	8.2	8.5	10.9	9.2	9.7	10.1	9.9	10.0
10	---	---	---	8.8	8.1	8.5	10.7	9.6	10.0	10.0	9.8	9.9
11	---	---	---	9.1	8.0	8.5	11.8	10.5	11.4	10.0	9.8	10.0
12	---	---	---	8.7	7.8	8.2	11.5	10.0	11.0	10.1	9.8	10.0
13	---	---	---	9.3	7.9	8.4	11.1	10.0	10.6	10.2	9.9	10.0
14	---	---	---	9.3	8.1	8.7	11.3	10.0	10.3	10.1	9.7	9.9
15	---	---	---	9.8	8.1	8.7	11.4	10.1	10.5	10.1	10.0	10.0
16	---	---	---	9.1	8.6	8.9	11.2	10.7	11.0	10.3	10.1	10.2
17	---	---	---	9.6	8.5	8.9	11.4	10.6	11.0	10.4	10.1	10.2
18	---	---	---	9.3	8.6	8.9	12.2	10.6	11.4	10.7	10.2	10.5
19	---	---	---	10.0	8.7	9.2	12.8	11.2	12.2	11.0	10.4	10.6
20	---	---	---	9.7	8.5	9.0	12.5	10.8	11.4	11.4	10.4	10.9
21	---	---	---	9.8	8.9	9.1	12.2	11.1	11.6	12.1	10.4	11.1
22	---	---	---	9.6	8.4	8.9	---	---	---	12.4	10.6	11.3
23	---	---	---	9.2	8.5	8.9	12.9	---	---	12.3	10.5	11.0
24	---	---	---	9.0	8.3	8.6	12.8	11.5	12.2	11.8	10.9	11.3
25	---	---	---	9.3	8.5	8.9	12.8	11.3	11.8	12.3	11.0	11.4
26	---	---	---	9.2	8.7	8.8	12.8	11.1	12.1	11.2	10.5	11.0
27	---	---	---	9.1	8.8	8.9	12.3	11.0	11.5	11.5	10.5	11.0
28	---	---	---	9.8	8.9	9.2	12.5	11.8	12.2	11.1	10.3	10.7
29	---	---	---	9.8	9.2	9.4	12.3	10.7	11.4	11.2	10.7	11.0
30	---	---	---	10.2	8.9	9.5	11.8	10.8	11.2	11.9	10.5	11.2
31	---	---	---	---	---	---	12.3	11.0	11.8	11.7	10.7	11.0
MONTH	---	---	---	---	---	---	---	---	---	12.4	9.7	10.7

Dissolved oxygen, water, unfiltered, milligrams per liter

DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN
		FEBRUARY			MARCH			APRIL			MAY	
1	11.6	10.9	11.3	11.0	9.9	10.4	9.6	8.5	9.0	8.8	8.4	8.6
2	11.8	11.2	11.4	11.0	10.2	10.7	10.6	8.9	9.4	8.8	8.2	8.5
3	12.0	11.0	11.4	11.1	10.4	10.7	10.6	8.9	9.2	8.5	7.9	8.2
4	11.6	10.9	11.2	11.3	10.4	10.7	9.2	9.0	9.1	8.4	7.9	8.1
5	12.2	11.1	11.7	11.1	10.4	10.7	9.2	8.7	9.0	8.5	8.0	8.3
6	11.9	11.3	11.6	11.1	10.5	10.8	9.2	8.8	9.0	9.0	8.3	8.5
7	12.0	11.1	11.5	10.8	10.5	10.6	9.1	8.8	9.0	8.5	8.2	8.3
8	11.7	11.0	11.3	10.6	10.1	10.4	9.1	8.5	8.8	8.5	8.0	8.2
9	11.3	11.0	11.2	10.4	10.2	10.3	9.2	8.4	8.8	8.4	7.9	8.1
10	11.1	10.6	11.0	10.4	10.2	10.3	9.0	8.1	8.5	8.0	7.7	7.9
11	11.1	10.9	11.0	10.5	10.2	10.4	8.9	8.4	8.7	8.4	7.6	7.9
12	11.0	10.9	10.9	10.8	10.4	10.6	8.7	8.0	8.4	8.2	7.7	8.0
13	11.3	10.8	10.9	10.8	10.5	10.7	8.7	8.2	8.6	8.4	7.5	7.9
14	11.3	10.6	10.9	10.6	10.3	10.4	8.7	8.2	8.6	8.4	7.7	8.1
15	11.3	10.7	11.1	10.4	10.2	10.3	9.1	8.3	8.8	8.0	7.5	7.7
16	11.1	10.6	10.8	10.4	9.9	10.3	9.3	8.8	9.0	8.0	7.5	7.7
17	10.8	10.6	10.7	10.4	10.3	10.4	9.2	8.6	8.9	8.0	7.3	7.7
18	10.6	10.3	10.6	10.7	10.3	10.5	9.2	8.7	8.9	7.9	7.3	7.6
19	10.6	10.4	10.5	10.9	10.4	10.7	9.1	8.6	8.8	7.8	7.3	7.5
20	10.6	10.4	10.4	10.7	10.4	10.5	8.8	8.4	8.6	7.6	7.2	7.4
21	10.7	10.4	10.6	10.6	10.2	10.4	9.4	8.0	8.5	8.0	7.2	7.5
22	10.6	10.2	10.4	10.4	9.6	10.3	8.7	8.1	8.4	8.0	7.3	7.6
23	10.3	9.8	10.0	10.3	10.2	10.2	8.7	8.2	8.4	7.5	6.8	7.3
24	10.1	9.7	10.0	10.2	10.1	10.2	8.8	8.4	8.6	7.7	6.8	7.2
25	10.1	9.8	10.0	10.2	9.8	9.9	8.8	8.5	8.6	7.9	7.1	7.6
26	10.0	9.8	9.8	10.1	9.6	9.8	8.7	8.4	8.6	8.0	6.9	7.5
27	10.0	9.6	9.8	10.0	9.4	9.8	8.9	8.3	8.6	7.8	7.2	7.5
28	10.3	10.0	10.0	10.0	9.4	9.8	8.8	8.4	8.6	7.6	7.1	7.3
29	---	---	---	10.2	9.4	9.9	9.0	8.3	8.7	7.8	7.0	7.3
30	---	---	---	10.8	9.9	10.3	8.8	8.4	8.6	7.8	7.1	7.4
31	---	---	---	10.2	8.7	9.3	---	---	---	7.6	7.0	7.3
MONTH	12.2	9.6	10.8	11.3	8.7	10.3	10.6	8.0	8.8	9.0	6.8	7.8

02160991 BROAD RIVER NEAR JENKINSVILLE, SC--Continued

Dissolved oxygen, water, unfiltered, milligrams per liter
WATER YEAR OCTOBER 2004 TO SEPTEMBER 2005

DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN
		JUNE			JULY			AUGUST			SEPTEMBER	
1	7.5	7.1	7.4	6.2	5.3	5.8	6.4	5.1	5.5	6.7	5.3	5.9
2	7.6	7.3	7.4	6.0	5.4	5.7	6.6	5.2	5.8	6.8	5.5	6.3
3	7.4	6.4	7.1	6.1	5.4	5.8	6.5	5.3	5.9	7.0	5.9	6.5
4	7.7	6.6	7.3	6.0	5.4	5.7	7.0	5.4	6.0	6.8	6.0	6.4
5	7.6	6.7	7.1	5.7	4.8	5.4	6.3	5.1	5.7	7.1	6.1	6.6
6	7.3	6.2	6.8	6.1	4.9	5.4	5.9	4.9	5.4	7.3	6.5	6.8
7	6.8	6.1	6.5	6.3	5.0	5.5	6.0	5.0	5.4	7.2	6.5	6.8
8	6.6	6.0	6.3	7.0	4.9	5.6	6.3	5.2	5.5	7.1	6.5	6.7
9	6.6	6.0	6.3	---	---	---	6.2	5.0	5.4	7.4	6.5	6.8
10	6.8	5.9	6.4	---	---	---	6.3	5.0	5.6	7.3	6.6	6.9
11	6.7	6.1	6.4	---	---	---	6.4	5.1	5.7	7.5	6.9	7.1
12	6.8	6.4	6.6	6.1	5.4	5.6	6.8	4.9	5.6	7.6	7.0	7.1
13	6.6	6.2	6.4	6.4	5.2	5.6	6.0	5.2	5.6	7.3	6.8	7.0
14	7.3	6.1	6.6	6.5	5.3	5.8	6.0	5.2	5.6	7.3	6.8	7.0
15	7.6	6.1	6.8	6.7	5.3	5.9	6.1	5.0	5.4	7.2	6.7	6.8
16	7.1	6.0	6.4	6.6	5.3	5.7	5.8	4.7	5.3	7.0	6.3	6.7
17	7.1	6.2	6.5	6.5	5.6	6.0	5.9	4.7	5.3	7.0	6.2	6.7
18	7.0	6.4	6.6	6.5	5.3	5.8	5.6	4.6	5.1	7.0	6.2	6.5
19	7.0	6.3	6.6	6.2	5.1	5.7	6.1	4.5	5.0	7.1	6.2	6.7
20	7.2	6.4	6.8	6.2	5.3	5.6	5.6	4.6	4.9	7.1	6.3	6.7
21	6.9	6.4	6.7	6.4	4.8	5.5	5.6	4.4	4.9	6.6	5.7	6.2
22	7.0	6.1	6.5	5.8	5.0	5.5	5.3	4.7	4.9	6.6	5.8	6.3
23	6.8	5.8	6.4	5.8	4.6	5.2	5.4	4.3	4.9	6.9	5.9	6.5
24	6.7	5.9	6.3	6.5	4.5	5.4	5.5	3.8	5.0	7.0	6.1	6.6
25	6.6	5.9	6.2	6.5	5.0	5.5	5.9	4.8	5.3	6.8	6.3	6.6
26	6.6	6.0	6.3	6.2	4.0	5.2	6.3	5.1	5.5	6.7	6.0	6.3
27	6.5	6.0	6.2	5.8	4.6	5.2	6.2	5.0	5.4	6.6	6.0	6.3
28	6.3	5.4	5.9	6.0	4.8	5.5	6.3	4.7	5.4	6.8	6.0	6.4
29	6.2	5.6	5.9	6.3	5.1	5.5	5.8	4.8	5.3	6.7	6.2	6.4
30	6.2	5.4	5.8	6.4	5.1	5.5	5.9	5.0	5.5	7.0	6.1	6.7
31	---	---	---	6.3	4.9	5.3	6.8	5.2	5.8	---	---	---
MONTH	7.7	5.4	6.5	---	---	---	7.0	3.8	5.4	7.6	5.3	6.6

02161000 BROAD RIVER AT ALSTON, SC

LOCATION.--Lat 34°14'35'', long 81°19'11'', Fairfield County, Hydrologic Unit 03050106, on left bank at Southern Railway Alston-Peak trestle, 1.2 mi downstream from Parr Shoals Dam, and at mile 200.2.

DRAINAGE AREA.--4,790 mi^2.

PERIOD OF RECORD.--October 1896 to December 1907, October 1980 to current year.

REVISED RECORDS.--WRD SC-82-1: 1982(M).

GAGE.--Data collection platform. Datum of gage is 211.91 ft above NGVD of 1929. Oct. 1, 1896 to Dec. 31, 1907, nonrecording gage at same site at different datum.

REMARKS.--Records good except for estimated daily discharges, which are poor. Records for the 1897-1908 water years are poor. Regulation at low and medium flow by powerplants above station.

Discharge, cubic feet per second
WATER YEAR OCTOBER 2004 TO SEPTEMBER 2005
DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	15600	3560	3830	5340	4830	13000	11300	4520	3510	11700	4780	2620
2	6780	2730	4380	4700	4860	16000	13000	4300	23800	7800	5060	2660
3	6540	2910	4370	4710	4930	5780	8300	4680	13600	5100	4590	2660
4	7120	3630	4510	4200	5000	6410	9980	4670	13500	7040	3940	2620
5	4940	12200	4390	4350	5010	6040	7270	3750	4460	6000	3410	2930
6	6480	11600	3630	4860	6030	5900	7210	4080	5460	5940	3640	1600
7	4260	5190	3800	4860	5050	5980	7860	3710	4200	7780	3140	1410
8	4070	7880	4890	4660	4970	5710	5360	3970	4310	19000	3400	1290
9	3980	4320	5030	4670	5020	10100	10100	3570	4810	30700	4060	2380
10	3970	4600	6670	4320	4860	6570	6390	2840	5390	25700	4830	2370
11	3790	4350	27600	3380	4820	4880	10100	3620	4310	15900	10100	1840
12	3170	3510	25200	3830	4580	4760	5680	3860	4930	5890	6400	2130
13	3990	4500	15400	4690	4490	4700	12600	3760	7630	3860	4920	1910
14	4080	6280	9320	5260	2650	4760	10100	3100	4110	7280	4320	2100
15	4040	7470	7660	14100	4300	4050	10700	3710	4440	10500	4080	1330
16	3890	3860	4860	7340	3940	5300	12300	4160	4040	13800	3920	1560
17	3840	4290	5480	8060	3940	11200	5490	3400	4190	5040	2880	2540
18	3850	3980	4560	4650	4970	10300	5480	3330	3750	5770	3210	2110
19	2520	4340	5300	4760	3190	7220	6790	3860	3290	6260	4600	1830
20	3160	4160	6640	6220	3290	5620	7310	4190	3800	6270	4120	1610
21	3970	3350	4420	3840	4020	4990	5970	4230	3220	4520	4040	1360
22	3440	3750	4200	4570	10100	5270	4560	4410	3850	4520	3460	1570
23	2810	5630	4690	4630	6260	5120	4490	6000	3900	4090	3360	2120
24	3450	4580	5020	4700	9160	7700	3810	4100	3370	3430	3450	1720
25	3690	4550	8250	4080	10400	11000	6000	3150	2620	4630	3450	1840
26	2740	4840	15900	3500	5370	6810	5780	3440	2670	4450	2680	2020
27	3910	e5180	6560	4080	7610	5660	5300	2710	3460	2840	2930	1610
28	3050	e4830	4750	4810	8450	17400	4420	3130	4030	4090	2850	1600
29	2580	e5370	e5280	3780	---	38600	4550	2990	17400	3660	3130	1220
30	3620	4700	e5610	3460	---	37500	4670	3540	11400	4180	3270	1210
31	3600	---	5260	4850	---	26300	---	3170	---	4300	2500	---
TOTAL	136930	152140	227460	155260	152100	310630	222870	117950	183450	252040	124520	57770
MEAN	4417	5071	7337	5008	5432	10020	7429	3805	6115	8130	4017	1926
MAX	15600	12200	27600	14100	10400	38600	13000	6000	23800	30700	10100	2930
MIN	2520	2730	3630	3380	2650	4050	3810	2710	2620	2840	2500	1210
CFSM	0.92	1.06	1.53	1.05	1.13	2.09	1.55	0.79	1.28	1.70	0.84	0.40
IN.	1.06	1.18	1.77	1.21	1.18	2.41	1.73	0.92	1.42	1.96	0.97	0.45

STATISTICS OF MONTHLY MEAN DATA FOR WATER YEARS 1897 - 2005, BY WATER YEAR (WY)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
MEAN	4130	4432	6621	7795	10020	10650	8236	5529	5343	3949	5427	3950
MAX	17360	14500	15680	18770	22650	25610	20430	14830	20820	9319	27730	17100
(WY)	1991	1993	1908	1906	1903	1903	1901	2003	1903	1905	1901	1901
MIN	1059	1276	1894	2517	2537	3685	2864	1783	968	849	546	1042
(WY)	2002	2002	2002	2001	2001	1981	1986	2001	2002	2002	2002	1999

gpm < 1,853,544 | 2,971,505 | 4,496,976 | 3,696,317 | 2,397,938 | 2,435,638 |
1,989,082 3,498,396 4,779,720 2,481,415 1,772,30 1,772,760

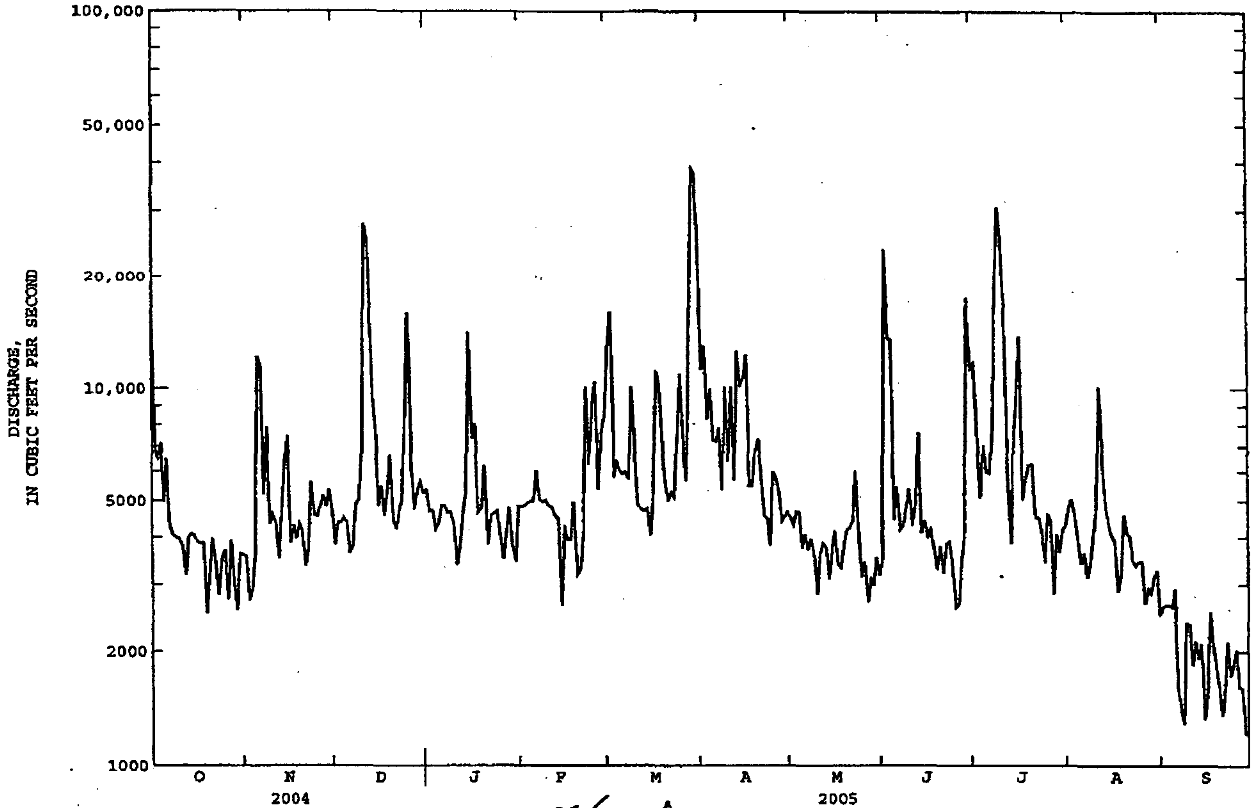
(cfs)(60s / 1 min)(7.48 g / cf) = gpm

02161000 BROAD RIVER AT ALSTON, SC--Continued

SUMMARY STATISTICS	FOR 2004 CALENDAR YEAR		FOR 2005 WATER YEAR		WATER YEARS 1897 - 2005	
ANNUAL TOTAL	1883323		2093120			
ANNUAL MEAN	5146		5735		6302	
HIGHEST ANNUAL MEAN					11750	1903
LOWEST ANNUAL MEAN					2153	2002
HIGHEST DAILY MEAN	90500	Sep 10	38600	Mar 29	130000	Jun 7 1903
LOWEST DAILY MEAN	846	Aug 11	1210	Sep 30	48	Sep 12 2002
ANNUAL SEVEN-DAY MINIMUM	1590	Aug 5	1600	Sep 24	200	Aug 11 2002
MAXIMUM PEAK FLOW			47000	Mar 29	a 140000	Jun 7 1903
MAXIMUM PEAK STAGE			17.27	Mar 29	a 29.02	Jun 7 1903
ANNUAL RUNOFF (CFSM)	1.07		1.20		1.32	
ANNUAL RUNOFF (INCHES)	14.63		16.26		17.87	
10 PERCENT EXCEEDS	8120		10100		12200	
50 PERCENT EXCEEDS	3620		4520		4190	
90 PERCENT EXCEEDS	2000		2700		1630	

a At datum then in use.

e Estimated



Water Resources Data South Carolina

7/20/06

~~[illegible]~~ 7Q10 Data

+ Toby Feaster USGS

864-656-6747 — He's out til 23rd

left message

02162093 SMITH BRANCH AT NORTH MAIN STREET AT COLUMBIA, SC

LOCATION.--Lat 34°01'38'', long 81°02'31'', Richland County, Hydrologic Unit 03050106, on left bank, 15 ft upstream from culvert opening at North Main Street in Columbia.

DRAINAGE AREA.--5.67 mi^2.

PERIOD OF RECORD.--October 1976 to current year.

GAGE.--Water-stage recorder. Datum of gage is 199.10 ft above NGVD of 1929.

REMARKS.--No estimated daily discharges. Records fair.

Discharge, cubic feet per second
WATER YEAR OCTOBER 2004 TO SEPTEMBER 2005
DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	3.7	2.5	3.0	1.9	2.9	9.7	15	3.7	20	12	13	2.1
2	3.3	2.7	2.3	1.9	2.5	5.6	7.1	3.5	19	3.0	6.4	2.1
3	4.2	2.8	2.2	2.0	20	4.7	5.5	3.6	29	5.7	4.7	2.0
4	3.0	7.4	2.1	2.1	19	4.1	5.0	3.5	4.6	3.0	4.4	2.0
5	2.8	2.4	2.1	2.2	4.1	3.9	4.9	3.4	3.3	2.4	3.9	1.9
6	2.8	2.1	3.9	2.1	3.4	3.8	4.7	3.5	2.9	2.2	3.7	1.9
7	2.7	2.3	2.0	2.1	3.2	4.2	16	3.3	50	2.1	3.3	1.9
8	2.6	2.3	2.1	2.3	3.1	24	36	3.1	6.6	2.3	8.3	1.9
9	2.6	2.3	2.3	2.1	2.9	6.9	9.6	3.2	11	2.3	3.8	2.0
10	2.6	2.7	13	2.1	19	3.8	5.9	11	4.2	2.8	11	1.9
11	2.5	2.6	2.1	2.1	3.6	3.4	5.4	4.0	3.1	2.8	3.2	2.1
12	2.6	19	2.0	2.3	3.1	3.5	17	3.5	2.8	2.3	2.8	2.2
13	2.6	2.6	2.1	2.3	2.9	3.4	15	3.6	5.2	13	17	2.0
14	2.5	2.1	2.3	64	2.8	3.4	5.7	3.3	2.7	29	24	2.0
15	4.2	2.1	2.0	7.8	9.2	3.2	5.0	3.3	2.6	33	3.4	2.1
16	2.3	2.1	2.2	2.9	3.0	13	4.7	3.6	2.6	16	2.6	2.2
17	2.4	2.1	2.3	2.5	2.8	27	4.6	3.4	2.5	17	6.0	2.2
18	2.8	2.1	2.3	2.3	2.7	5.4	4.5	4.2	2.3	19	3.1	2.2
19	2.6	2.1	2.3	2.2	2.6	4.3	4.4	11	2.3	83	2.4	2.4
20	2.5	2.2	2.3	2.3	2.5	3.9	4.1	68	2.3	26	2.3	2.5
21	2.5	2.7	2.3	2.2	3.9	3.8	4.1	4.8	2.4	5.3	8.1	2.8
22	2.5	3.0	2.5	2.1	26	3.9	10	2.9	2.3	26	9.1	2.3
23	2.4	22	5.1	2.1	4.2	29	12	2.7	2.3	5.2	2.9	2.4
24	7.3	6.0	1.9	2.1	29	7.4	3.9	2.5	2.3	3.1	2.3	2.1
25	2.2	3.1	1.9	2.1	14	4.5	3.7	2.4	2.4	2.7	2.2	2.2
26	2.1	2.7	16	2.2	4.9	4.1	3.8	2.4	14	2.6	2.1	2.4
27	2.2	14	2.4	2.3	4.0	33	3.9	2.4	2.3	2.5	2.1	2.2
28	2.3	4.7	2.0	2.1	46	86	3.6	2.4	27	17	2.1	2.1
29	2.3	2.4	2.0	2.1	---	17	3.6	2.3	4.6	3.4	2.1	2.2
30	2.3	2.6	1.9	22	---	7.6	10	19	2.5	147	13	2.2
31	2.3	---	1.9	3.8	---	14	---	2.9	---	81	2.3	---
TOTAL	87.7	131.7	96.8	156.6	247.3	351.5	238.7	196.4	241.1	574.7	177.6	64.5
MEAN	2.83	4.39	3.12	5.05	8.83	11.3	7.96	6.34	8.04	18.5	5.73	2.15
MAX	7.3	22	16	64	46	86	36	68	50	147	24	2.8
MIN	2.1	2.1	1.9	1.9	2.5	3.2	3.6	2.3	2.3	2.1	2.1	1.9
CFSM	0.50	0.77	0.55	0.89	1.56	2.00	1.40	1.12	1.42	3.27	1.01	0.38
IN.	0.58	0.86	0.64	1.03	1.62	2.31	1.57	1.29	1.58	3.77	1.17	0.42

STATISTICS OF MONTHLY MEAN DATA FOR WATER YEARS 1977 - 2005, BY WATER YEAR (WY)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
MEAN	6.79	6.67	8.06	11.7	11.6	13.4	9.12	7.22	9.71	10.0	8.88	8.45
MAX	25.7	16.0	25.5	27.6	24.4	29.9	28.0	21.0	34.3	31.3	24.5	19.8
(WY)	1991	1987	1977	1987	1998	1980	1998	1991	1995	1991	1986	2004
MIN	1.45	2.09	2.62	2.79	3.64	3.58	1.94	3.26	2.11	3.17	1.46	1.31
(WY)	2002	2002	1989	1986	1986	1985	1986	1977	1990	1993	1983	1985

02160991 BROAD RIVER NEAR JENKINSVILLE, SC--Continued

Dissolved oxygen, water, unfiltered, milligrams per liter
WATER YEAR OCTOBER 2004 TO SEPTEMBER 2005

DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN
	OCTOBER			NOVEMBER			DECEMBER			JANUARY		
1	---	---	---	---	---	---	10.9	9.0	9.8	12.1	11.6	11.9
2	---	---	---	---	---	---	9.4	8.8	9.1	12.0	11.9	12.0
3	---	---	---	---	---	---	9.4	9.0	9.2	11.9	11.0	11.5
4	---	---	---	---	---	---	10.0	9.2	9.5	11.1	10.3	10.7
5	---	---	---	---	---	---	10.5	9.7	10.0	10.9	10.6	10.8
6	---	---	---	8.9	7.9	8.3	11.1	9.2	9.9	10.7	10.1	10.3
7	---	---	---	8.6	7.4	8.0	10.9	9.1	9.7	10.3	9.8	10.1
8	---	---	---	8.8	7.6	8.0	10.7	9.4	9.8	10.2	10.0	10.1
9	---	---	---	9.2	8.2	8.5	10.9	9.2	9.7	10.1	9.9	10.0
10	---	---	---	8.8	8.1	8.5	10.7	9.6	10.0	10.0	9.8	9.9
11	---	---	---	9.1	8.0	8.5	11.8	10.5	11.4	10.0	9.8	10.0
12	---	---	---	8.7	7.8	8.2	11.5	10.0	11.0	10.1	9.8	10.0
13	---	---	---	9.3	7.9	8.4	11.1	10.0	10.6	10.2	9.9	10.0
14	---	---	---	9.3	8.1	8.7	11.3	10.0	10.3	10.1	9.7	9.9
15	---	---	---	9.8	8.1	8.7	11.4	10.1	10.5	10.1	10.0	10.0
16	---	---	---	9.1	8.6	8.9	11.2	10.7	11.0	10.3	10.1	10.2
17	---	---	---	9.6	8.5	8.9	11.4	10.6	11.0	10.4	10.1	10.2
18	---	---	---	9.3	8.6	8.9	12.2	10.6	11.4	10.7	10.2	10.5
19	---	---	---	10.0	8.7	9.2	12.8	11.2	12.2	11.0	10.4	10.6
20	---	---	---	9.7	8.5	9.0	12.5	10.8	11.4	11.4	10.4	10.9
21	---	---	---	9.8	8.9	9.1	12.2	11.1	11.6	12.1	10.4	11.1
22	---	---	---	9.6	8.4	8.9	---	---	---	12.4	10.6	11.3
23	---	---	---	9.2	8.5	8.9	12.9	---	---	12.3	10.5	11.0
24	---	---	---	9.0	8.3	8.6	12.8	11.5	12.2	11.8	10.9	11.3
25	---	---	---	9.3	8.5	8.9	12.8	11.3	11.8	12.3	11.0	11.4
26	---	---	---	9.2	8.7	8.8	12.8	11.1	12.1	11.2	10.5	11.0
27	---	---	---	9.1	8.8	8.9	12.3	11.0	11.5	11.5	10.5	11.0
28	---	---	---	9.8	8.9	9.2	12.5	11.8	12.2	11.1	10.3	10.7
29	---	---	---	9.8	9.2	9.4	12.3	10.7	11.4	11.2	10.7	11.0
30	---	---	---	10.2	8.9	9.5	11.8	10.8	11.2	11.9	10.5	11.2
31	---	---	---	---	---	---	12.3	11.0	11.8	11.7	10.7	11.0
MONTH	---	---	---	---	---	---	---	---	---	12.4	9.7	10.7

Dissolved oxygen, water, unfiltered, milligrams per liter

DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN
	FEBRUARY			MARCH			APRIL			MAY		
1	11.6	10.9	11.3	11.0	9.9	10.4	9.6	8.5	9.0	8.8	8.4	8.6
2	11.8	11.2	11.4	11.0	10.2	10.7	10.6	8.9	9.4	8.8	8.2	8.5
3	12.0	11.0	11.4	11.1	10.4	10.7	10.6	8.9	9.2	8.5	7.9	8.2
4	11.6	10.9	11.2	11.3	10.4	10.7	9.2	9.0	9.1	8.4	7.9	8.1
5	12.2	11.1	11.7	11.1	10.4	10.7	9.2	8.7	9.0	8.5	8.0	8.3
6	11.9	11.3	11.6	11.1	10.5	10.8	9.2	8.8	9.0	9.0	8.3	8.5
7	12.0	11.1	11.5	10.8	10.5	10.6	9.1	8.8	9.0	8.5	8.2	8.3
8	11.7	11.0	11.3	10.6	10.1	10.4	9.1	8.5	8.8	8.5	8.0	8.2
9	11.3	11.0	11.2	10.4	10.2	10.3	9.2	8.4	8.8	8.4	7.9	8.1
10	11.1	10.6	11.0	10.4	10.2	10.3	9.0	8.1	8.5	8.0	7.7	7.9
11	11.1	10.9	11.0	10.5	10.2	10.4	8.9	8.4	8.7	8.4	7.6	7.9
12	11.0	10.9	10.9	10.8	10.4	10.6	8.7	8.0	8.4	8.2	7.7	8.0
13	11.3	10.8	10.9	10.8	10.5	10.7	8.7	8.2	8.6	8.4	7.5	7.9
14	11.3	10.6	10.9	10.6	10.3	10.4	8.7	8.2	8.6	8.4	7.7	8.1
15	11.3	10.7	11.1	10.4	10.2	10.3	9.1	8.3	8.8	8.0	7.5	7.7
16	11.1	10.6	10.8	10.4	9.9	10.3	9.3	8.8	9.0	8.0	7.5	7.7
17	10.8	10.6	10.7	10.4	10.3	10.4	9.2	8.6	8.9	8.0	7.3	7.7
18	10.6	10.3	10.6	10.7	10.3	10.5	9.2	8.7	8.9	7.9	7.3	7.6
19	10.6	10.4	10.5	10.9	10.4	10.7	9.1	8.6	8.8	7.8	7.3	7.5
20	10.6	10.4	10.4	10.7	10.4	10.5	8.8	8.4	8.6	7.6	7.2	7.4
21	10.7	10.4	10.6	10.6	10.2	10.4	9.4	8.0	8.5	8.0	7.2	7.5
22	10.6	10.2	10.4	10.4	9.6	10.3	8.7	8.1	8.4	8.0	7.3	7.6
23	10.3	9.8	10.0	10.3	10.2	10.2	8.7	8.2	8.4	7.5	6.8	7.3
24	10.1	9.7	10.0	10.2	10.1	10.2	8.8	8.4	8.6	7.7	6.8	7.2
25	10.1	9.8	10.0	10.2	9.8	9.9	8.8	8.5	8.6	7.9	7.1	7.6
26	10.0	9.8	9.8	10.1	9.6	9.8	8.7	8.4	8.6	8.0	6.9	7.5
27	10.0	9.6	9.8	10.0	9.4	9.8	8.9	8.3	8.6	7.8	7.2	7.5
28	10.3	10.0	10.0	10.0	9.4	9.8	8.8	8.4	8.6	7.6	7.1	7.3
29	---	---	---	10.2	9.4	9.9	9.0	8.3	8.7	7.8	7.0	7.3
30	---	---	---	10.8	9.9	10.3	8.8	8.4	8.6	7.8	7.1	7.4
31	---	---	---	10.2	8.7	9.3	---	---	---	7.6	7.0	7.3
MONTH	12.2	9.6	10.8	11.3	8.7	10.3	10.6	8.0	8.8	9.0	6.8	7.8

02160991 BROAD RIVER NEAR JENKINSVILLE, SC--Continued

Dissolved oxygen, water, unfiltered, milligrams per liter
WATER YEAR OCTOBER 2004 TO SEPTEMBER 2005

DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN
		JUNE			JULY			AUGUST			SEPTEMBER	
1	7.5	7.1	7.4	6.2	5.3	5.8	6.4	5.1	5.5	6.7	5.3	5.9
2	7.6	7.3	7.4	6.0	5.4	5.7	6.6	5.2	5.8	6.8	5.5	6.3
3	7.4	6.4	7.1	6.1	5.4	5.8	6.5	5.3	5.9	7.0	5.9	6.5
4	7.7	6.6	7.3	6.0	5.4	5.7	7.0	5.4	6.0	6.8	6.0	6.4
5	7.6	6.7	7.1	5.7	4.8	5.4	6.3	5.1	5.7	7.1	6.1	6.6
6	7.3	6.2	6.8	6.1	4.9	5.4	5.9	4.9	5.4	7.3	6.5	6.8
7	6.8	6.1	6.5	6.3	5.0	5.5	6.0	5.0	5.4	7.2	6.5	6.8
8	6.6	6.0	6.3	7.0	4.9	5.6	6.3	5.2	5.5	7.1	6.5	6.7
9	6.6	6.0	6.3	---	---	---	6.2	5.0	5.4	7.4	6.5	6.8
10	6.8	5.9	6.4	---	---	---	6.3	5.0	5.6	7.3	6.6	6.9
11	6.7	6.1	6.4	---	---	---	6.4	5.1	5.7	7.5	6.9	7.1
12	6.8	6.4	6.6	6.1	5.4	5.6	6.8	4.9	5.6	7.6	7.0	7.1
13	6.6	6.2	6.4	6.4	5.2	5.6	6.0	5.2	5.6	7.3	6.8	7.0
14	7.3	6.1	6.6	6.5	5.3	5.8	6.0	5.2	5.6	7.3	6.8	7.0
15	7.6	6.1	6.8	6.7	5.3	5.9	6.1	5.0	5.4	7.2	6.7	6.8
16	7.1	6.0	6.4	6.6	5.3	5.7	5.8	4.7	5.3	7.0	6.3	6.7
17	7.1	6.2	6.5	6.5	5.6	6.0	5.9	4.7	5.3	7.0	6.2	6.7
18	7.0	6.4	6.6	6.5	5.3	5.8	5.6	4.6	5.1	7.0	6.2	6.5
19	7.0	6.3	6.6	6.2	5.1	5.7	6.1	4.5	5.0	7.1	6.2	6.7
20	7.2	6.4	6.8	6.2	5.3	5.6	5.6	4.6	4.9	7.1	6.3	6.7
21	6.9	6.4	6.7	6.4	4.8	5.5	5.6	4.4	4.9	6.6	5.7	6.2
22	7.0	6.1	6.5	5.8	5.0	5.5	5.3	4.7	4.9	6.6	5.8	6.3
23	6.8	5.8	6.4	5.8	4.6	5.2	5.4	4.3	4.9	6.9	5.9	6.5
24	6.7	5.9	6.3	6.5	4.5	5.4	5.5	3.8	5.0	7.0	6.1	6.6
25	6.6	5.9	6.2	6.5	5.0	5.5	5.9	4.8	5.3	6.8	6.3	6.6
26	6.6	6.0	6.3	6.2	4.0	5.2	6.3	5.1	5.5	6.7	6.0	6.3
27	6.5	6.0	6.2	5.8	4.6	5.2	6.2	5.0	5.4	6.6	6.0	6.3
28	6.3	5.4	5.9	6.0	4.8	5.5	6.3	4.7	5.4	6.8	6.0	6.4
29	6.2	5.6	5.9	6.3	5.1	5.5	5.8	4.8	5.3	6.7	6.2	6.4
30	6.2	5.4	5.8	6.4	5.1	5.5	5.9	5.0	5.5	7.0	6.1	6.7
31	---	---	---	6.3	4.9	5.3	6.8	5.2	5.8	---	---	---
MONTH	7.7	5.4	6.5	---	---	---	7.0	3.8	5.4	7.6	5.3	6.6

02161000 BROAD RIVER AT ALSTON, SC

LOCATION.--Lat 34°14'35'', long 81°19'11'', Fairfield County, Hydrologic Unit 03050106, on left bank at Southern Railway Alston-Peak trestle, 1.2 mi downstream from Parr Shoals Dam, and at mile 200.2.

DRAINAGE AREA.--4,790 mi^2.

PERIOD OF RECORD.--October 1896 to December 1907, October 1980 to current year.

REVISED RECORDS.--WRD SC-82-1: 1982(M).

GAGE.--Data collection platform. Datum of gage is 211.91 ft above NGVD of 1929. Oct. 1, 1896 to Dec. 31, 1907, nonrecording gage at same site at different datum.

REMARKS.--Records good except for estimated daily discharges, which are poor. Records for the 1897-1908 water years are poor. Regulation at low and medium flow by powerplants above station.

Discharge, cubic feet per second
WATER YEAR OCTOBER 2004 TO SEPTEMBER 2005
DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	15600	3560	3830	5340	4830	13000	11300	4520	3510	11700	4780	2620
2	6780	2730	4380	4700	4860	16000	13000	4300	23800	7800	5060	2660
3	6540	2910	4370	4710	4930	5780	8300	4680	13600	5100	4590	2660
4	7120	3630	4510	4200	5000	6410	9980	4670	13500	7040	3940	2620
5	4940	12200	4390	4350	5010	6040	7270	3750	4460	6000	3410	2930
6	6480	11600	3630	4860	6030	5900	7210	4080	5460	5940	3640	1600
7	4260	5190	3800	4860	5050	5980	7860	3710	4200	7780	3140	1410
8	4070	7880	4890	4660	4970	5710	5360	3970	4310	19000	3400	1290
9	3980	4320	5030	4670	5020	10100	10100	3570	4810	30700	4060	2380
10	3970	4600	6670	4320	4860	6570	6390	2840	5390	25700	4830	2370
11	3790	4350	27600	3380	4820	4880	10100	3620	4310	15900	10100	1840
12	3170	3510	25200	3830	4580	4760	5680	3860	4930	5890	6400	2130
13	3990	4500	15400	4690	4490	4700	12600	3760	7630	3860	4920	1910
14	4080	6280	9320	5260	2650	4760	10100	3100	4110	7280	4320	2100
15	4040	7470	7660	14100	4300	4050	10700	3710	4440	10500	4080	1330
16	3890	3860	4860	7340	3940	5300	12300	4160	4040	13800	3920	1560
17	3840	4290	5480	8060	3940	11200	5490	3400	4190	5040	2880	2540
18	3850	3980	4560	4650	4970	10300	5480	3330	3750	5770	3210	2110
19	2520	4340	5300	4760	3190	7220	6790	3860	3290	6260	4600	1830
20	3160	4160	6640	6220	3290	5620	7310	4190	3800	6270	4120	1610
21	3970	3350	4420	3840	4020	4990	5970	4230	3220	4520	4040	1360
22	3440	3750	4200	4570	10100	5270	4560	4410	3850	4520	3460	1570
23	2810	5630	4690	4630	6260	5120	4490	6000	3900	4090	3360	2120
24	3450	4580	5020	4700	9160	7700	3810	4100	3370	3430	3450	1720
25	3690	4550	8250	4080	10400	11000	6000	3150	2620	4630	3450	1840
26	2740	4840	15900	3500	5370	6810	5780	3440	2670	4450	2680	2020
27	3910	e5180	6560	4080	7610	5660	5300	2710	3460	2840	2930	1610
28	3050	e4830	4750	4810	8450	17400	4420	3130	4030	4090	2850	1600
29	2580	e5370	e5280	3780	---	38600	4550	2990	17400	3660	3130	1220
30	3620	4700	e5610	3460	---	37500	4670	3540	11400	4180	3270	1210
31	3600	---	5260	4850	---	26300	---	3170	---	4300	2500	---
TOTAL	136930	152140	227460	155260	152100	310630	222870	117950	183450	252040	124520	57770
MEAN	4417	5071	7337	5008	5432	10020	7429	3805	6115	8130	4017	1926
MAX	15600	12200	27600	14100	10400	38600	13000	6000	23800	30700	10100	2930
MIN	2520	2730	3630	3380	2650	4050	3810	2710	2620	2840	2500	1210
CFSM	0.92	1.06	1.53	1.05	1.13	2.09	1.55	0.79	1.28	1.70	0.84	0.40
IN.	1.06	1.18	1.77	1.21	1.18	2.41	1.73	0.92	1.42	1.96	0.97	0.45

STATISTICS OF MONTHLY MEAN DATA FOR WATER YEARS 1897 - 2005, BY WATER YEAR (WY)

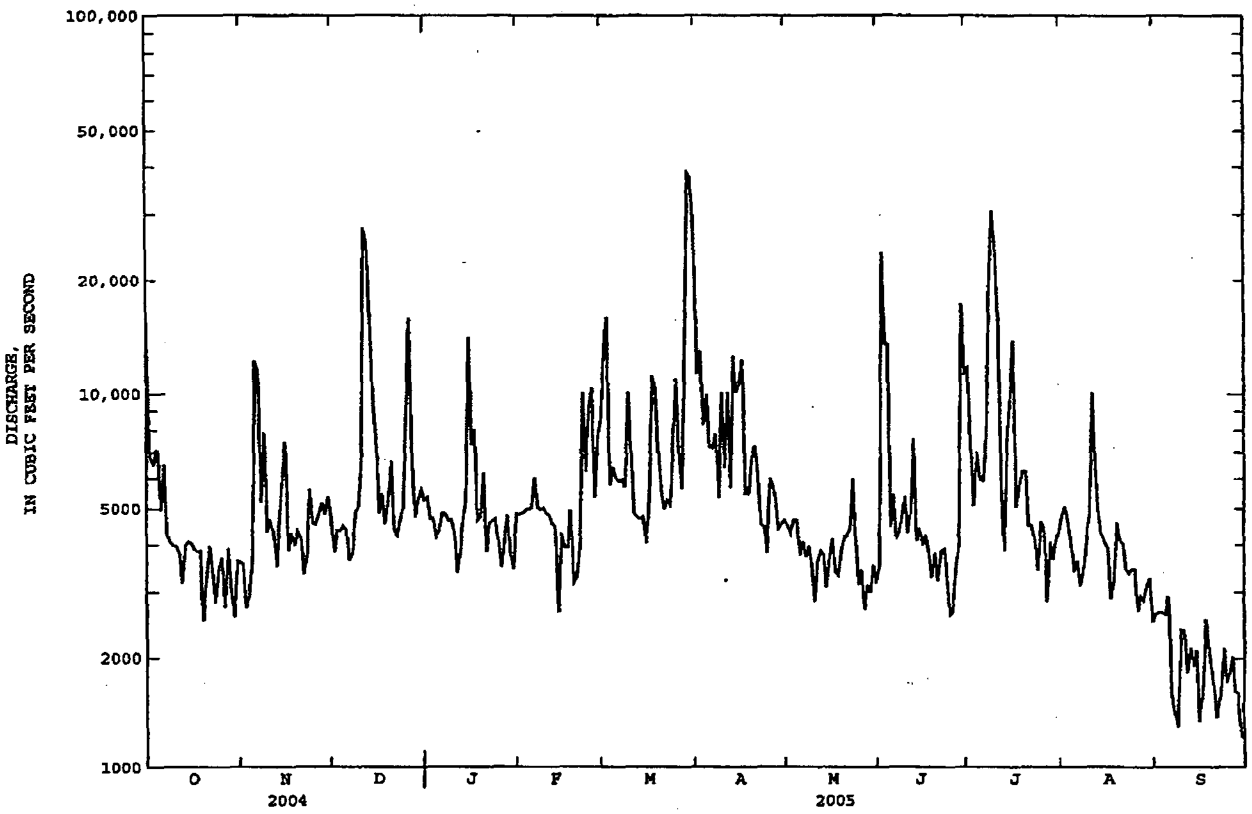
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
MEAN	4130	4432	6621	7795	10020	10650	8236	5529	5343	3949	5427	3950
MAX	17360	14500	15680	18770	22650	25610	20430	14830	20820	9319	27730	17100
(WY)	1991	1993	1908	1906	1903	1903	1901	2003	1903	1905	1901	1901
MIN	1059	1276	1894	2517	2537	3685	2864	1783	968	849	546	1042
(WY)	2002	2002	2002	2001	2001	1981	1986	2001	2002	2002	2002	1999

02161000 BROAD RIVER AT ALSTON, SC--Continued

SUMMARY STATISTICS	FOR 2004 CALENDAR YEAR		FOR 2005 WATER YEAR		WATER YEARS 1897 - 2005	
ANNUAL TOTAL	1883323		2093120			
ANNUAL MEAN	5146		5735		6302	
HIGHEST ANNUAL MEAN					11750	1903
LOWEST ANNUAL MEAN					2153	2002
HIGHEST DAILY MEAN	90500	Sep 10	38600	Mar 29	130000	Jun 7 1903
LOWEST DAILY MEAN	846	Aug 11	1210	Sep 30	48	Sep 12 2002
ANNUAL SEVEN-DAY MINIMUM	1590	Aug 5	1600	Sep 24	200	Aug 11 2002
MAXIMUM PEAK FLOW			47000	Mar 29	a 140000	Jun 7 1903
MAXIMUM PEAK STAGE			17.27	Mar 29	a 29.02	Jun 7 1903
ANNUAL RUNOFF (CFSM)	1.07		1.20		1.32	
ANNUAL RUNOFF (INCHES)	14.63		16.26		17.87	
10 PERCENT EXCEEDS	8120		10100		12200	
50 PERCENT EXCEEDS	3620		4520		4190	
90 PERCENT EXCEEDS	2000		2700		1630	

a At datum then in use.

e Estimated



Rec 9.3 Ref 61

NUREG-0099
Regulatory Guide 4.2
Revision 2

USNRC REGULATORY GUIDE SERIES

REGULATORY GUIDE 4.2, REVISION 2

PREPARATION OF ENVIRONMENTAL REPORTS FOR NUCLEAR POWER STATIONS

JULY 1976

U.S. NUCLEAR REGULATORY COMMISSION

Revision 2
July 1976

U.S. NUCLEAR REGULATORY COMMISSION

REGULATORY GUIDE

OFFICE OF STANDARDS DEVELOPMENT

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Main Report

Final Report

U.S. Nuclear Regulatory Commission

Office of Nuclear Regulatory Research

EG-362

Sec 9.3 Ref 63

Referenced in Chapter 1

U.S. NRC 1999, *Standard Review Plans for Environmental Reviews for Nuclear Power Plants*, NUREG-1555, October 1999.

SCEG-081

SECPOP V3.0 Population Data
Date: 09/05/2006 Time:10:25:21
Site Name: SCE&G COL
Latitude: 34ø17'8'' Longitude: 81ø19'15''
Population Multiplier: 1.

Radii(mi)	1.0000	2.0000	3.0000	4.0000	5.0000	10.0000
N	0	0	0	0	7	225
NNE	0	0	0	7	50	335
NE	0	0	77	11	57	104
ENE	0	33	0	13	0	542
E	0	13	101	0	0	625
ESE	80	3	0	91	15	218
SE	0	20	39	0	107	255
SSE	0	0	0	0	0	1886
S	0	0	0	73	60	1294
SSW	0	0	8	29	61	1737
SW	0	0	31	6	37	1044
WSW	0	24	11	0	111	661
W	0	0	0	16	41	462
WNW	0	12	0	4	36	571
NW	0	0	0	0	0	422
NNW	24	0	6	154	15	269
Sum	104	105	273	404	597	10650

Radii(mi)	20.0000	30.0000	40.0000	50.0000	Sum
N	602	4005	5172	17385	27396
NNE	446	7416	10583	71500	90337
NE	1411	2529	9318	37953	51460
ENE	8373	982	1397	11472	22812
E	3159	5291	14719	20208	44116
ESE	4102	60471	10288	6268	81536
SE	28191	187392	34059	8212	258275
SSE	47835	73130	23297	8921	155069
S	12382	19982	10399	7142	51332
SSW	7236	12835	6375	6849	35130
SW	3577	3379	7498	12580	28152
WSW	4151	2518	3479	5366	16321
W	15595	1658	4512	46446	68730
WNW	1854	2942	17480	23226	46125
NW	495	3295	4127	11816	20155
NNW	307	2212	18657	9409	31053
Sum	139716	390037	181360	304753	1027999

NUREG/CR-6525, Rev. 1

SECPOP2000: Sector Population, Land Fraction, and Economic Estimation Program

Sandia National Laboratories

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555-0001

NUREG/CR-6525, Rev. 1

SECPOP2000: Sector Population, Land Fraction, and Economic Estimation Program

Manuscript Completed: July 2003
Date Published: August 2003

Prepared by
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Pepared for
Division of Risk Analysis and Applications
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
NRC Job Code Y6594

Abstract

The Environmental Protection Agency's computer program, SECPOP, has been used to calculate population estimates since 1973. In 1997, SECPOP90, was created to run on a PC and to use 1990 population and economic data.

When the U.S. Census Bureau released 2000 census population data and 1997 economic data, Sandia National Laboratories was tasked to develop a new version, SECPOP2000, to include the new data, be compatible with current Windows operating systems, and also be compatible with the 1990 data.

SECPOP90 supports both site and regional analyses. Site analysis evaluates population, land use, and economic data on a polar grid centered on a prescribed site. Regional analysis screens potential sites in a geographical region against a population criterion.

SECPOP2000 currently supports only site analysis. Regional analysis can be performed by using SECPOP90 as a screening tool followed by a confirmatory calculation with SECPOP2000 to evaluate potential sites with 2000 census data.

This report provides verification of the SECPOP90 and SECPOP2000 codes by comparing them with licensee-provided population data. The verification shows that SECPOP90 and SECPOP2000 provide reasonable population estimates. SECPOP2000 also agrees well with census estimates from other sources.

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U.S. Nuclear Regulatory Commission
Office of Nuclear Reactor Regulation

NRR OFFICE INSTRUCTION

Change Notice

Office Instruction No.:	**LIC-203, Revision 1**
Office Instruction Title:	**Procedural Guidance for Preparing Environmental Assessments and Considering Environmental Issues**
Effective Date:	**May 24, 2004**
Primary Contact:	**Stacey Imboden, RLEP** **301-415-2462** **sxf@nrc.gov**
Responsible Organization:	**NRR/DRIP/RLEP**

Summary of Changes: This is a revision of NRR Office Instruction LIC-203. Changes to the guidance include the clarification of NRR Responsibilities under the Fish and Wildlife Coordination Act. There is a policy change in fulfilling NRR responsibilities under the National Historic Preservation Act. The Commission is presently formulating its policy statement on environmental justice matters. When finalized, appropriate modifications to this Office Instruction will be considered. Other than these, no significant policy or procedural changes have been made to the guidance document.

Training:	E-mail announcement with recommended self-study
ADAMS Accession No.:	**ML033550003**

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Office of Nuclear Reactor Regulation

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Training:	E-mail announcement with recommended self-study
ADAMS Accession No.:	**ML033550003**

Position	Primary Contact RLEP:DRIP:NRR	SC:RLEP:DRIP:NRR	OGC w/comments	PD:RLEP:DRIP:NRR	DRIP:DD	D:PMAS:NRR
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Date	03/25/2004	03/31/2004	05/03/2004	05/19/2004	05/24/2004	05/24/2004

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GImbro, EMEB
PLohaus, STP
MReinhart, SPSB
LReyes, EDO
SCollins, DEDR
MVirgilio, DEDE
PNorry, DEDM
HMiller, RI
WTravers, RII
JCaldwell, RIII
BMallett, RIV
SECY
EMerschoff CIO
JFunches, CFO
RDennig, SPSB
WKane, DEDH
MTschiltz, SPSB
RLEP r/f

NRR OFFICE INSTRUCTION
LIC-203, Revision 1

Procedural Guidance for Preparing Environmental Assessments and Considering Environmental Issues

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1. POLICY

It is the policy of NRR to establish procedures and guidance for its staff to meet the requirements established by legislation and regulation. The purpose of 10 CFR Part 51, "Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions," is to ensure that NRC meets its statutory obligations under the National Environmental Policy Act of 1969 (NEPA).

2. OBJECTIVE

This office instruction, along with the attached guidance documents, provide all staff in the NRC's Office of Nuclear Reactor Regulation (NRR) a basic framework for maintaining NRC's responsibility to comply with 10 CFR Part 51. This office instruction is intended to:

- define the responsibilities of the License Renewal and Environmental Impacts Branch (RLEP) to ensure that NRR is consistent in its implementation of NRC regulations and other Federal environmental requirements;
- define NRR staff responsibilities; and,
- provide guidance to NRR staff on the procedural requirements for demonstrating compliance with environmental statutes and regulations covering environmental issues for regulated facilities.

The office instruction contains guidance for preparing environmental assessments (EAs), in accordance with the NEPA and 10 CFR Part 51, and for considering environmental issues associated with:

- Executive Order (E.O.) 12898,
- Coastal Zone Management Act of 1972 (CZMA),
- Endangered Species Act of 1973 (ESA),
- National Historic Preservation Act of 1966 (NHPA), and
- Fish and Wildlife Coordination Act (FWCA) of 1934.

This office instruction describes, in part, how the staff should determine whether or not a proposed action would have an impact on protected coastal zones, threatened or endangered species, archaeological or historical sites, or disparate impacts on minority populations or low-income populations. This office instruction does not address the preparation of an environmental impact statement (EIS). This office instruction supersedes previous guidance on these subjects.

3. BACKGROUND

Office Letter 906, Revision 2, "Procedural Guidance for Preparing Environmental Assessments and Considering Environmental Issues", was issued on September 21, 1999. A revision to Attachment 3 of Office Letter 906, Revision 2, was issued on October 7, 1999. These documents were issued to include guidance on environmental justice in the office letter and to make improvements to the format and content of an example EA. On November 5, 2003 (68 FR 62642), the Commission published for comment a draft policy statement on the treatment of environmental justice matters in NRC regulatory and licensing activities. It is not formalized, but the procedural guidance from this office instruction and the earlier Office Letter 906 is consistent with the draft Policy Statement.

Office Instruction LIC-203 is a revision to Office Letter 906, providing minor clarifications to guidance. The initial issuance of Office Instruction LIC-203 was June 21, 2001.

4. BASIC REQUIREMENTS

4.1 RLEP Staff

RLEP is responsible for providing implementation guidance and technical support to the NRR staff for the resolution of environmental issues for regulated facilities. RLEP is also responsible for coordinating environmental issues with other NRC offices, for ensuring NRR meets its obligations under Federal environmental requirements and for properly implementing the requirements of 10 CFR Part 51.

4.2 All NRR Staff

In addition to its regulatory responsibilities embodied in the health and safety requirements of the Atomic Energy Act, NRC has responsibilities that are derived from NEPA and from other environmental laws (such as the CZMA, the ESA, the NHPA, and the FWCA). The NRR staff should consider environmental issues when performing license amendment activities including, but not limited to:

- increasing the authorized power level of commercial power reactors beyond the power rating stated in the original Environmental Impact Statement or the Final Environmental Statement (power uprate);

- changing the license expiration date to recapture time between the construction permit and actual operation (construction recapture);
- performing decommissioning activities under 10 CFR Part 50; and,
- revising Appendix B of a licensee's operating license (environmental protection plan).

The NRR staff should consider environmental issues when processing license renewal applications under 10 CFR Part 54, requests for exemptions from NRC regulations, and when conducting rulemaking.

However, the staff need not perform an environmental review when performing licensing and regulatory activities eligible for categorical exclusions under 10 CFR 51.22(c). The Division of Licensing Project Management (DLPM) and Office of General Counsel (OGC) will determine whether an action qualifies as a categorical exclusion and, if so, include the criterion in the licensing documents. The NRR staff is encouraged to seek early assistance from RLEP in dealing with environmental issues that are unique, particularly difficult, or unfamiliar. Moreover, the NRR staff may request formal guidance in developing EAs from RLEP. Since environmental reviews are fee recoverable under 10 CFR Part 170, when seeking concurrence, assistance, or safety evaluation input, the NRR staff should provide a Technical Assignment Control (TAC) number for tracking and billing purposes.

5. RESPONSIBILITIES AND AUTHORITIES

5.1 RLEP Staff

RLEP will:

- Review and concur on plant-specific and generic EAs prepared by the NRR staff for the activities listed above.
- Prepare input for or originate EAs when appropriate (e.g., extended power uprates).
- Review and provide guidance and support to the NRR staff participating in the preparation of all EISs (draft, final, and supplements).
- Participate in environmental rulemaking activities. RLEP will ensure that NRR is current with appropriate environmental legislation, statutes, regulations, and guidance, and will participate in Federal Government-wide meetings. RLEP will provide guidance to the NRR staff regarding the implementation of other applicable environmental statutes.

- Review new and emerging environmental issues and provide support to the NRR staff in resolving environmental issues.

- Review environmental documents submitted by other Federal and State agencies, when appropriate.

- Review recovery plans for endangered species and prepare or direct the preparation of biological assessments (BAs) as required by the ESA.

- Coordinate environmental issues with other NRC Headquarters and Regional offices and Federal, State, and Tribal agencies.

- Maintain and update this office instruction.

5.2 All NRR Staff

Individual NRR staff members are responsible for implementing the procedural requirements of this office instruction; the staff should consult with RLEP when reviewing environmental issues or safety issues that require an environmental assessment.

5.2.1 NRR Responsibilities under NEPA: EAs and EISs

As previously discussed under "Basic Requirements," EAs must be prepared for certain licensing and rulemaking activities. Although most environmental reviews performed by NRC result in EAs, it is important to understand the distinction between an EA and an EIS, and when an EA or an EIS is used.

The process used to determine whether an action will significantly impact the environment is the development of an EA. If the review documented in an EA demonstrates that the proposed action will not have a significant impact on the environment, a finding of no significant impact (FONSI) is made in the conclusion of the EA and no EIS need be prepared. If, on the other hand, the environmental review in the EA reveals that the proposed action will, or has the potential to, significantly affect the environment, then the EA must conclude that a more detailed review of the environmental effects (i.e., an EIS) should be prepared. NEPA requires that a detailed statement of the environmental impact of the proposed action and alternatives be prepared for "major Federal actions significantly affecting the quality of the human environment." This detailed statement takes the form of an EIS. In general, an EIS contains much more detail about the specific environmental impacts of the proposed action and alternatives than an EA, and requires extensive public participation, public comment, and coordination with other agencies. Normally, project managers (PMs) prepare EAs; should an EIS need to be prepared, RLEP will assign an environmental Project Manager (EPM) who will be responsible for coordinating the preparation of the EIS with the PM.

Licensing Actions: Upon receipt of a proposed action, the PM should determine whether an environmental review is needed and, if so, the type of review that should be prepared. If the proposed action is unique or involves unusual circumstances, then the PM should consult with the RLEP staff before initiating the environmental review. Additionally, as mentioned previously in this office instruction, 10 CFR 51.22 identifies categories of actions that are excluded from environmental reviews because the NRC has determined that these actions do not individually or cumulatively have a significant effect on the human environment. If the PM, in consultation with OGC, determines that the proposed action is not within one of the excluded categories, then the PM should prepare the EA in accordance with the requirements in 10 CFR 51.30. If the EA concludes that the proposed action will result in significant environmental impacts, then the PM should contact RLEP, and an EIS will be prepared. Section 51.30 requires that an EA:

(1) identify the proposed action,

(2) briefly discuss the need for the proposed action,

(3) briefly discuss the alternatives to the proposed action,

(4) describe the environmental impacts of the proposed action and alternatives, and

(5) list agencies and persons consulted and identify sources used.

EAs should not duplicate the safety details of the review; only the environmental impacts of the proposed action should be considered. An EA should include a FONSI if the EA supports a conclusion that the proposed action will not have a significant effect on the quality of the human environment. If such a finding cannot be made, then an EIS will have to be prepared.

The preparation of the EIS by RLEP will be coordinated with the PM. Appendix B of this office instruction provides a flow chart outlining the process and detailed guidance for each step in the preparation of an EA. Appendix C contains a sample (template) of the appropriate form and content of an EA for licensing actions. The sample is intended to be used as guidance and is not a substitute for an objective consideration of the impacts. PMs must independently determine whether any template statements used are correctly applied to the specific action being reviewed. The templates are to ensure stability and predictability whenever appropriate.

Rulemaking Activities: When an EA is written in support of rulemaking activities that affect NRR regulatory practices, the initiating office, if other than NRR, may implement additional procedures. Detailed guidance is provided in the NRC Regulations Handbook, NUREG/BR-0053. If the EA is not included in the preamble to the proposed rule or final rule (i.e., if the EA is presented in a separate document), then the form and content of the sample (template) EA for rulemaking referenced in Appendix C is appropriate. If the EA review is documented in the preamble for a final or proposed rule, guidance and language in the NRC Regulations Handbook should be followed. The guidance states that the text of the environmental assessment should be considered for paragraphs entitled "Finding of No Significant Environmental Impact: Environmental Assessment." The environmental impacts of the proposed action and the alternative actions should be discussed. Appendix C contains template language that can be considered for this situation.

In general, after the Federal Register notice (FRN) for the proposed rule is signed by the Secretary to the Commission or the Executive Director for Operations (EDO), and, before the FRN is published, a cover letter with a copy of the draft EA and the FRN should be sent to the State Liaison Officer requesting comments from State organizations. As with an EA for a licensing action, the consultation must be documented in a brief summary in the EA, and must address the comments and staff response. A sample letter is included in NUREG/BR-0053.

5.2.2 NRR Responsibilities Regarding Environmental Justice

In February 1994, the President issued an Executive Order mandating that Federal agencies make "environmental justice" part of each agency's mission by addressing disproportionately high and adverse human health or environmental effects of Federal programs, policies, and activities on minority populations and on low-income populations. The Council on Environmental Quality developed guidelines on how to integrate environmental justice into the NEPA process. The guidelines are contained in the document "Environmental Justice Guidance Under the National Environmental Policy Act," December 10, 1997. On November 5, 2003 (68 FR 62642) the Commission published for comment a draft policy statement on the treatment of environmental justice matters in NRC regulatory and licensing actions. NRR has developed a corresponding procedure (Appendix D) for incorporating environmental justice into the licensing process, which is consistent with the draft policy statement.

Environmental justice reviews will be performed for all actions requiring preparation of an EIS (or a supplement thereto). An environmental justice review is not usually required for an EA in which a FONSI is made. In most cases, when a FONSI is reached, the staff can conclude that there are no disproportionately high and adverse human health or environmental effects associated with the proposed action. However, special circumstances may warrant an environmental justice review for an EA in which a FONSI is made. These cases may include regulatory actions that involve a significant site modification with an identifiable impact on the environment or that have substantial public interest. In these circumstances, the staff will inform NRR senior management and a decision will be made on a case-by-case basis as to whether the circumstances warrant an environmental justice review for an EA. If there is a clear potential for significant offsite impacts from the proposed action to minority and low-income communities, then an appropriate environmental justice review might be needed to provide a basis for concluding that there are no unique impacts that would be significant. If the impacts are significant because of the uniqueness of the communities, then a FONSI may not be possible and mitigation or an EIS should be considered. Appendix D provides a more detailed explanation of environmental justice and a flow chart for conducting environmental justice reviews.

5.2.3 NRR Responsibilities under CZMA

The CZMA was promulgated to encourage and assist States and territories in developing management programs that preserve, protect, develop, and, where possible, restore the resources of the coastal zone. A "coastal zone" is generally described as the coastal waters and the adjacent shore lands strongly influenced by each other. This includes islands, transitional and intertidal areas, salt marshes, wetlands, beaches, and Great Lakes waters. Activities of Federal agencies that are reasonably likely to affect coastal zones shall be consistent with the approved coastal management program (CMP) of the State or territory to the maximum extent practical. The CZMA provisions apply to all Federal licenses and actions requiring Federal approval (new plant licenses, license renewals, materials licenses, and major amendments to existing licenses) that affect the coastal zone in a State or territory with a Federally approved CMP. Appendix E of this office instruction lists those States and territories with Federally approved CMPs.

PMs should determine whether the State or territory has an approved CMP and whether their licensee is within the boundary of the CMP because it will influence the schedule for completing certain licensing actions. If the plant is located within the CMP boundary, the PM should consult with RLEP. Within the CMP, predetermined activities are listed that may affect the coastal zone. When the PM determines that a proposed licensing activity may affect coastal uses or resources, the PM should inform the licensee of the need to contact the government of the State or territory and to comply with the provisions of the CZMA.

National Oceanic and Atmospheric Administration (NOAA) regulations also specifically require consistency certification for license renewal applications and major amendments that will affect any coastal use or resource. Regulations implementing the Federal consistency provisions of the CZMA have been promulgated by NOAA at 15 CFR Part 930. Amendments to NOAA's federal consistency certification (65 FR 77124) define major amendments as activities involving a change that affects any coastal use or resource in a way that is substantially different than the description or understanding of the effects at the time of the original activity. Applicants for Federal licenses that are likely to affect a State's coastal zone must submit to the State and Federal licensing agency a certification that the proposed activity is consistent with the State's CMP. Appendix E contains a draft model certification for license amendment applicants, however, some States require use of a state-specific form for consistency certification. If a Federal agency receives an application for an activity that has been pre-listed in a State's CMP, that agency has an obligation to withhold approval until the State has concurred or the Secretary of Commerce overrides any State objection. If an applicant seeks a license or license amendment potentially affecting the coastal zone for an activity that is not listed in the State's CMP, the State has the responsibility to inform the Federal agency and the applicant within 30 days of being notified of the activity that the activity requires State review. Otherwise, the State waives its right to review the unlisted activity.

In general, the only NRC licensing actions requiring a consistency certification are (1) new plant construction permit and operating license applications, and (2) license renewal applications. However, the Act provides States with the right to request a consistency certification for any unlisted activity affecting any coastal use or resource. Potentially affected States have 30 days from the notice of the proposed action in the *Federal Register* to notify the NRC and applicant of the need for a consistency review. The following guidance is provided regarding operating reactor PMs' responsibilities under the CZMA consistency certification requirements.

(1) PMs should determine whether their assigned facility is located in a State's coastal zone *or is located such that changes in the facility could reasonably be expected to affect any coastal use or resource of any coastal zone (e.g, any coastal zone is within a reasonable downstream distance from a facility sited on a river)*. A list of State coastal management program summaries, with links

to the individual programs, is available at http://www.ocrm.nos.noaa.gov/czm/czmsitelist.html.

For plants located in a coastal zone or located such that activities could reasonably be expected to affect any coastal use or resource of any coastal zone, identify listed activities requiring a consistency certification (typically, new plant licenses and license renewals are the only listed activities).

(2) Upon receipt of an application for a listed activity, ensure the licensee has provided a consistency certification. Approval of the requested action should be withheld until the State has concurred with the licensee's consistency determination, or the Secretary of Commerce has overridden any State objection.

Note: For new plant licenses and license renewals, RLEP will be responsible for review of the action and will ensure consistency certification, as required.

(3) Upon receipt of an application for an unlisted activity, make a determination as to whether coastal effects are reasonably foreseeable due to the requested action (e.g., significant change in effluents, construction of shoreline structures, etc). Consult with RLEP as needed.

a. For routine licensing actions where coastal effects may be reasonably foreseeable, NRC approval should be withheld for 30 days from the date of issuance of the FR notice to allow the State to notify the NRC that a consistency review is required. If the State has not notified the NRC within 30 days that review is necessary, the State waives its right to conduct a review and the action may be approved.

b. For exigent or emergency actions where coastal effects may be reasonably foreseeable, the PM should consult with RLEP and, if determined to be necessary, should contact the cognizant State agency to ensure timely State determination of the need for consistency review.

c. In either of the above cases, upon notification that consistency review is required, approval of the requested action may be withheld until the State has concurred with the licensee's consistency determination, or the Secretary of Commerce has overridden any State objection.

5.2.4 NRR Responsibilities under ESA

The ESA was promulgated to ensure protection of endangered or threatened species and critical habitats. Section 7 of the ESA imposes two basic requirements on Federal agencies. First, Section 7 requires each Federal agency to ensure that any action authorized, funded, or carried out by an agency is not likely to jeopardize the continued existence of any endangered species or threatened species, or result in the destruction or impairment of any critical habitat for such species. "Action" has been interpreted broadly and comprises licensing, rulemaking, and lesser regulatory actions that could jeopardize an endangered species. A Federal agency should act, if possible (where it has the legal authority), to prevent endangered species and their habitats from being threatened or destroyed.

Second, Section 7 requires that Federal agencies fulfill the requirements of the ESA in consultation with, and with the assistance of, the Secretary of the Interior (for freshwater and terrestrial species through the Fish and Wildlife Service [FWS]) or the Secretary of Commerce (for oceanic and coastal matters through the National Oceanic and Atmospheric Administration Fisheries [NOAA Fisheries], formerly National Marine Fisheries Service). If the Federal agency fails to consult with FWS or NOAA Fisheries, and the action by the agency or its licensee results in the "taking" (harassment, harm, pursuit, hunting, shooting, wounding, killing, trapping, capture, collection, or attempt to engage in such activities) of an endangered species or the impairment or destruction of a critical habitat, then the Federal agency (here, the NRC) would be in violation of the ESA. NRR PMs are expected to remain vigilant regarding operational activities that may have an adverse impact on listed species or critical habitats; should takings approach limits in incidental take statements or new takings where take statements do not exist be reported to the NRC, then the NRR PM should contact RLEP at the earliest opportunity. RLEP will initiate consultation early in the review process for activities requiring preparation of an EIS. When an activity requires preparation of an EIS, RLEP will request a list of threatened or endangered species from FWS or NOAA Fisheries early in the review process for the site area and surroundings associated with the proposed action.

Under Section 7 of the ESA, four consultation processes can be used and are discussed briefly below. The two main types of consultation are informal and formal; early consultation and conference are related processes.

Early Consultation: The applicant (licensee) can request that the Federal agency enter into early consultation with FWS or NOAA Fisheries. This may be done if the applicant believes one or more listed species or critical habitats may be affected by the proposed action. Early consultation occurs prior to an applicant filing an application. The agency initiates early consultation in writing. The process followed is the same as the one discussed under "Formal Consultation"; however, a preliminary biological opinion (BO) is issued. A preliminary BO does not constitute the authority to "take" listed species. The action agency may request confirmation of a preliminary BO as a final BO after the licensee submits an application.

Conference: The conference process is designed to be used at an early planning stage, and is used to discuss effects on proposed species or habitat. Formal and informal consultations are used to discuss effects on listed species or habitat. Conference involves informal discussions between a Federal agency and FWS or NOAA Fisheries regarding the impact of a proposed action on proposed species or proposed critical habitat and recommendations to minimize or avoid harm (mitigation). A conference is required when the proposed action is likely to jeopardize the continued existence of a proposed species or proposed critical habitat.

Informal Consultation: Most consultations with FWS or NOAA Fisheries are informal consultations. Informal consultation is a process of discussion between FWS or NOAA Fisheries and the Federal agency that may result in formal consultation. A Federal agency may also elect to proceed directly to formal consultation. A biological assessment (BA) may be prepared as part of the informal consultation process. A BA is prepared when a major activity takes place that may affect listed species or critical habitats. The Federal agency requests a list from FWS or NOAA Fisheries of endangered or threatened species and critical habitats or sends FWS or NOAA Fisheries a list of species and habitats that are being reviewed in the BA. Within 30 days of the request, FWS or NOAA Fisheries provides an initial response (provides a list or concurs on the list that was prepared by the Federal agency). If no species or critical habitats are affected, then no further action is required. If only proposed species or habitats (not yet listed as an endangered or threatened species or critical habitat) are involved, then the Federal agency must confer with FWS or NOAA Fisheries, but a BA is not required to be submitted to FWS or NOAA Fisheries. If listed species or critical habitats are involved, then the Federal agency must begin the BA within 90 days of the initial FWS or NOAA Fisheries response. (Although the NRC may coordinate the preparation of the BA with others (e.g., applicant, licensee, contractor) all correspondence with FWS or NOAA Fisheries should be transmitted by the NRC and the NRC is ultimately responsible for assuring the reliability of the information presented.) The BA may include the findings of onsite inspections, opinions of recognized experts, results of an information review, an analysis of the proposed actions, and alternatives. The BA must be submitted to FWS or NOAA Fisheries within 180 days of their initial response. If the BA concludes that the action is not likely to jeopardize the listed species or critical habitat and FWS or NOAA Fisheries concurs, no further consultation is required. If the BA concludes that the action affects listed species or critical habitat, then the Federal agency may initially request an informal consultation to determine whether the action can be modified so that the species or critical habitats are not adversely affected. Otherwise, formal consultation is required.

Formal Consultation: Formal consultation is a process between FWS or NOAA Fisheries and the Federal agency that takes place after the BA has been prepared determining that the action affects or may affect listed species or critical habitats. Appendix F of this instruction contains a flow chart illustrating the formal ESA consultation process. The Federal agency sends a written request for formal consultation to FWS or NOAA Fisheries. The written request for consultation must be accompanied by a BA containing a description of the action, a description of the area, a description of the listed species, the effects of the action, an analysis of the cumulative effects, and a review of reports and other information. Within 90 days of formal consultation initiation, FWS or NOAA Fisheries is expected to issue a BO. The BO contains a summary of the action, the effects, an opinion on whether the species is in jeopardy as a result of the action, alternatives, incidental "take" provisions, and any proposed conservation measures. After the consultation is complete, the Federal agency must determine whether it has taken all necessary actions. Although the Federal agency is not legally bound to comply with FWS or NOAA Fisheries opinions and can adopt measures that differ from the recommendations, the courts give substantial weight to FWS or NOAA Fisheries opinions. The NRC then provides the BO, including the incidental "take" provisions and conservation measures, to the applicant or licensee for implementation.

5.2.5 NRR Responsibilities under NHPA

The National Historic Preservation Act (NHPA) was promulgated in 1966 and amended in 1992 and 2000 to coordinate and support public and private efforts to identify, evaluate, and protect significant historic and archaeological resources. Section 106 of the NHPA directs Federal agencies to consider the effects of their undertakings on historic properties. The Act allows the Advisory Council on Historic Preservation (ACHP) an opportunity to review and comment on any Federal agency action that might harm historic property. Appendix G is a flow chart illustrating the Section 106 process. "Undertakings" denotes a broad range of Federal activities, including the issuance of NRC licenses and permits. "Historic property" is any property listed in or eligible for inclusion in the National Register of Historic Places (National Register).

The NHPA statute also provides provisions for review of historic properties in conjunction with a NEPA review (36 CFR 800.8). In 36 CFR 800.8, "Coordination with the National Environmental Policy Act", the NHPA consultation can be achieved in conjunction with the NEPA process to demonstrate Section 106 compliance. RLEP will use the NEPA process to fulfill the requirements of the NHPA when preparing an EIS. Under 36 CFR 800.8, an agency can use the NEPA process to comply with Section 106 as an alternative to the procedures set forth in 36 CFR 800.3 through 36 CFR 800.6. This allows an agency to "streamline" its overall environmental and Section 106 review process. The key to using the NEPA process to comply with Section 106 of the NHPA is early coordination.
The Agency must do the following:

(1) *Early coordination*. Coordinate section 106 compliance through NEPA. Agencies should plan their section 106 responsibilities as early as possible in the NEPA process, and plan public participation, analysis, and review requirements of both statutes. The Agency must also determine whether the undertaking is a "major Federal action significantly affecting the quality of the human environment." If the Agency determines that the undertaking is a "major Federal action significantly affecting the quality of the human environment", then NEPA requires the preparation of an EIS.

(2) *Consulting party roles*. Identify the appropriate State Historic Preservation Office (SHPO) or Tribal Historic Preservation Office (THPO), Indian tribes, Native Hawaiian organizations, local governments, preservation organizations, and individuals who may be concerned with the possible effects of the proposed undertaking on historic properties in a manner consistent with Section 800.3(f)

(3) *Inclusion of historic preservation issues*. Identify historic properties and assess effects on them in a manner consistent with Section 800.4 through 800.5, but the scope and timing of identification and effect determination may be "phased to reflect the Agency Official's consideration of project alternatives in the NEPA process" and the effort of the Agency shall be "commensurate with the assessment of other environmental factors."

(4) *Coordination.* Coordinate with the SHPO/THPO, Indian tribes, Native Hawaiian organizations, and other parties during NEPA scoping, analysis, and documentation. As commensurate with the Agency's NEPA process, the public must be invited to participate.

(5) *Development of an EIS.* Develop alternatives and mitigation measures in consultation with other stakeholders, and describe these measures in its EIS.

Therefore, when using the NEPA process to comply with Section 106 of the NHPA, the Agency must perform the substantive steps that the Section 106 regulations call for, but the Agency does not have to follow precisely the same procedures it would if it were following the standard Section 106 review. The Agency has the flexibility to accomplish its assessment in "phases," and the level of effort it puts forth will be similar to that for other kinds of environmental resources.

Section 800.8(c)(2) requires that an EIS be reviewed by the SHPO/THPO and other consulting parties. Since the product of NRC's NEPA analysis is an EIS, NRC must notify the ACHP by letter of the proposed undertaking and submit the EIS (both draft and final) to the ACHP. If any of these parties objects within the comment period, the Agency will refer the matter to the ACHP, which has thirty days to review the objection. If comment is not received within the thirty day period, then the Agency can complete its NEPA review and make its decision (record of decision [ROD] and in the NRC's case, issue the licensing action) without further Section 106 review. Section 800.4(c)(4) also requires the Agency to specify within its ROD the measures that it will take to mitigate adverse effects on historic properties.

5.2.6 NRR Responsibilities under FWCA

The FWCA was promulgated in 1934 to ensure that water resource development projects (e.g., impounding, damming, diverting, flood control, hydroelectric power) do not conflict with the conservation of fish and wildlife resources. Conversely, water resource development projects can be designed to enhance the quality and enjoyment of fish and wildlife resources if such goals are incorporated into the project plans.

The FWCA requires that a Federal agency consult with the Department of the Interior, through FWS, when any body of water is proposed or authorized to be modified for any reason. Types of modification include impounding a body of water, damming, diverting a stream or river, deepening a channel, irrigation, or altering a body of water for navigation or drainage. The FWCA also requires that provisions must be made for the conservation of wildlife and its habitat upon modification of any body of water. The Secretary of the Interior is authorized under the FWCA to investigate water resource development projects to determine effects on wildlife. The Secretary of the Interior will conduct investigations through FWS or the U.S. Bureau of Mines. These agencies are authorized to investigate to determine the effects of polluting substances (sewage, wastes, erosion silt) from water resource development projects on wildlife, and report to Congress with recommendations to alleviate negative effects. The Secretary of the Interior is also authorized to consult with Federal agencies regarding protection and stocking of wildlife, minimizing loss of wildlife and its habitat through disease, minimizing effects of overabundant species, and providing public hunting and fishing areas.

PMs should determine whether the licensee is planning any water resource development projects, including any of the modifications mentioned above. If any type of modification is occurring, the PM should ensure that measures are in place for the conservation of wildlife and its habitat. Such activities at regulated facilities will likely result in an environmental review under NEPA. Consequently, the requirements of the FWCA are satisfied through NRC's compliance with NEPA, and separate consultation with FWS is not required.

6. PERFORMANCE MEASURES

Not applicable

7. PRIMARY CONTACT

Stacey F. Imboden
NRR/RLEP
301-415-2462
sxf@nrc.gov

8. RESPONSIBLE ORGANIZATION

NRR/DRIP/RLEP

9. EFFECTIVE DATE

May 24, 2004

10. REFERENCES

- 10 CFR Part 50, "Domestic Licensing and Production and Utilization Facilities"
- 10 CFR Part 51, "Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions"
- 10 CFR 51.22, "Criterion for categorical exclusion; identification of licensing and regulatory actions eligible for categorical exclusion or otherwise not requiring environmental review."
- 10 CFR 51.30, "Environmental assessment."
- 10 CFR Part 170, "Fees for Facilities, Materials, Import and Export Licenses, and Other Regulatory Services Under the Atomic Energy Act of 1954, as Amended"
- 59 FR 7629-7633. 1994. Executive Order 12898, *"Federal Actions to Address Environmental Justice in Minority and Low-Income Populations."* Washington, D.C.
- 68 FR 62642. 2003. Policy Statement on the Treatment of Environmental Justice Matters in NRC Regulatory and Licensing Actions. Washington, D.C.
- Atomic Energy Act of 1954, 42 USC 2011 et seq.
- Coastal Zone Management Act of 1972, as amended, 16 USC 1451 et seq.
- Council on Environmental Quality. 1997. *"Environmental Justice: Guidance Under the National Environmental Policy Act."* Council on Environmental Quality, Executive Office of the President, Washington, D.C.
- Endangered Species Act of 1973, as amended, 16 USC 1531 et seq.
- Fish and Wildlife Coordination Act of 1934, as amended, 16 USC 661 et seq.
- National Environmental Policy Act of 1969, as amended, 42 USC 4321 et seq.
- National Historic Preservation Act of 1966, as amended, 16 USC 470 et seq.
- National Ocean and Atmospheric Administration, 2003. State and Territory Coastal Management Program Summaries. <http://www.ocrm.nos.noaa.gov/czm/czmsitelist.html> (accessed April 25, 2003).
- U.S. Fish and Wildlife Service. Digest of Federal Resource Laws of Interest to the U.S. Fish and Wildlife Service: Fish and Wildlife Coordination Act. <http://laws.fws.gov/lawsdigest/fwcoord.html> (accessed April 30, 2003).

- U.S. Fish and Wildlife Service and National Marine Fisheries Service, 1998. Endangered Species Consultation Handbook: Procedures for Conducting Consultation and Conference Activities Under Section 7 of the Endangered Species Act.

- U.S. Nuclear Regulatory Commission, 1996. *Generic Environmental Impact Statement for License Renewal of Nuclear Plants.* NUREG-1437, Volumes 1 and 2, Washington, D.C.

- U.S. Nuclear Regulatory Commission, 2001. *U.S. Nuclear Regulatory Commission Regulations Handbook.* NUREG/BR-0053, Revision 5, Washington, D.C.

- U.S. Nuclear Regulatory Commission, 2003. "Delegation of Signature Authority", Office Instruction ADM-200. Washington, D.C.

Appendices:

Appendix A: Change History

Appendix B: Environmental Assessment Guidance and Procedural Flow Chart

Appendix C: Format and Content of an Environmental Assessment for a Licensing Action and Rulemaking

Appendix D: Environmental Justice Guidance and Flow Chart

Appendix E: List of States with Federally approved Costal Management Programs, Examples of Consistency Certification, and Coastal Zone Management Act Flow Chart

Appendix F: Endangered Species Act Consultation Flow Charts

Appendix G: National Historic Preservation Act Flow Chart

Appendix A - Change History

Office Instruction LIC-203, "Procedural Guidance for Preparing Environmental Assessments and Considering Environmental Issues"

LIC-203 Change History - Page 1 of 1			
Date	**Description of Changes**	**Method Used to Announce & Distribute**	**Training**
06/21/2001	This OI is a conversion of OL-906. Changes to the guidance include minor clarifications offered by the NRR staff. No significant policy or procedural changes have been made to the guidance document	(1) E-mail to all staff (2) Copies to SES and licensing assistants	E-mail announcement with recommended self-study
05/24/2004	This is a revision of NRR Office Instruction LIC-203. Changes to the guidance include the clarification of NRR Responsibilities under the Fish and Wildlife Coordination Act. There is a policy change in fulfilling NRR responsibilities under the National Historic Preservation Act. The Commission is presently formulating its policy statement on environmental justice matters. When finalized, appropriate modifications to this OI will be considered. Other than these, no significant policy or procedural changes have been made to the guidance document.	E-mail to all staff	E-mail announcement with recommended self-study

Appendix B - Environmental Assessment Guidance and Procedural Flow Chart

This guidance is intended to provide assistance in developing an environmental assessment (EA). It outlines specific sections in an EA and provides insight on the content that should be in each of those sections. They are:

- identification of the proposed action,
- the need for the proposed action,
- the environmental impacts of the proposed action,
- the environmental impacts of alternatives to the proposed action,
- the alternative use of resources, and
- agencies and persons consulted.

The specific sections of the EA are differentiated below by the underscore. Figure 1, a procedural flow chart, also follows.

<u>Identification of the Proposed Action</u>

This section should briefly describe the action proposed and reference the pertinent licensee application.

<u>The Need for the Proposed Action</u>

Section 51.30(a)(1)(i) of Title 10 of the Code of Federal Regulations requires that an EA shall contain a brief discussion of the need for the proposed action. When writing this portion of the EA, the person preparing the EA should discuss the applicant's motivation for submitting the application to the NRC. For example, does the requested exemption or amendment provide some benefit to the applicant if granted? How would the applicant be affected if the application was not approved?

<u>Environmental Impacts of the Proposed Action</u>

The environmental impacts of the proposed action must be evaluated by the Commission in accordance with 10 CFR 51.30(a)(1)(iii). The person writing the EA should describe how the environmental resource (e.g., land or water) is used, how the resource would be affected by a change in (or addition of) a plant component (e.g., the construction of a building) or a change in the operation of the plant (the amount of water taken in by the plant), and the significance of the relationship between the environmental resource and the change. For example, air (the environmental resource) would be affected by a release of radioactive chemicals from plant effluents (the plant component) and the significance of the release would depend on the types and amounts of the emission. Is the emission for the contaminant above the regulatory limits or is it a small fraction of the regulatory limits? These are the relationships that should be described. The section should include an evaluation of radiological and non-radiological impacts. The impacts section should also certify that the proposed action will not significantly increase the probability of accidents or entail an NRC undertaking involving historic sites. Additionally, if the proposed action (typically a change in a plant component or a change in plant operation) does not affect any environmental resources, explain that in this section.

Environmental Impacts of the Alternatives to the Proposed Action

Sections 51.30(a)(1)(ii) and (iii) require that an EA include alternatives to the proposed action and the environmental impact of the alternatives. NEPA requires NRC to consider alternatives in the preparation of all EAs whenever the following two conditions are present: (1) there is some identifiable environmental impact from the proposed action and (2) there is an unresolved conflict of available resources. The fact that the EA involves a finding of no significant impact (FONSI) does not automatically exempt the person preparing the EA from considering alternatives. As long as there is some identifiable impact on the environment from the proposed action, the person preparing the EA should consider alternatives. At a minimum, all EAs must include the no-action alternative.

For those actions involving a small impact, it is reasonable to consider a limited range of alternatives. In fact, in several decisions, the courts have stressed that the range of alternatives an agency must consider in an EA decreases as the environmental impact of the proposed action becomes less and less substantial.

A non-significant impact does not equate to no impact. Therefore, if an even less harmful alternative is feasible, then it ought to be considered. If the environmental impact of a proposed action is zero, there is no need to consider alternatives because there is no use of natural resources associated with the action. In those cases involving no environmental impact at all, it is reasonable to limit the discussion of alternatives to consideration of the no-action alternative. If the "no-action" alternative is the only alternative examined, the alternatives section may contain the following:

> "As an alternative to the proposed action, the staff considered denial of the proposed action (i.e., the "no-action alternative"). Denial of the proposed action would result in no change in current environmental impacts. The environmental impacts of the proposed action and the alternative action are similar."

Alternative Use of Resources

In accordance with Section 102(2)(E) of NEPA, agencies must consider alternative courses of action if the proposed action involves an unresolved conflict on how available resources, such as water, land, or other physical materials, will be used under the proposed action. This consideration will take place when the objective of the proposed action can be achieved in one of two or more ways that will have differing impacts on the environment even if a FONSI has been made.

Agencies and Persons Consulted

Section 51.30(a)(2) requires the EA to list Federal and State agencies and persons consulted and to identify the sources used. The person preparing the EA must consult with the affected State before the EA is issued and must solicit comments on the environmental impact of the proposed action and any other comments the State may have. Additionally, the person preparing the EA is responsible for ensuring that other appropriate agencies are contacted if an action may involve some impact on the natural or physical environment. The consultation must be documented in a brief summary in the EA and should contain (1) the name of the agency or person contacted (consulted with), (2) the date and purpose of the consultation, (3) a brief summary of the views or comments expressed and the staff's resolution, and (4) references to publicly available documents containing additional information, as applicable.

The person preparing the EA should briefly describe why the consultation was initiated. For example, if the National Marine Fisheries Service was contacted on July 25, 1995, to discuss a specific issue involving short-nosed sturgeon, the summary could make the following statement:

> "The National Marine Fisheries Service was contacted on July 25, 1995, to discuss the evaluation of the ability of short-nosed sturgeon to avoid capture after the proposed modification of the river water intake."

If the consultation was made to meet strictly a programmatic requirement and not a specific issue, the consultation with the State could be summarized as follows:

> "In accordance with its stated policy, on [insert date], the staff consulted with the [insert name of State] State official, [insert name of official] of the [insert name of agency], regarding the environmental impact of the proposed action. The State official had [choose one - comments or no comments]."

If comments are received from the State or agency, the comments should be summarized in the EA. Minor comments could be characterized as "general agreement" or "no objection" by the State or agency. More extensive comments require the person preparing the EA to summarize the details of the issues and the resolution of the comments in the EA or to place them in a separate document and reference them in the EA. Resolution of the comments should be placed in the NRC Public Document Room (PDR) to ensure public access.

Before issuing an EA supporting an exemption to the regulations, the person preparing the EA should contact the State government to solicit comments on the environmental impact of the proposed action. Although notifying the State is not required by 10 CFR 50.91, it is required by NEPA. This requirement may be met by sending a copy of the incoming exemption request to the State. If the State has a comment, the person preparing the EA should resolve and document the comments in the EA, as previously discussed.

Appendix C - Format and Content of an Environmental Assessment for a Licensing Action and Rulemaking

Format and Content of an Environmental Assessment and Cover Letter for a Licensing Action

(Addressee)

SUBJECT: PLANT NAME - (TAC NOS. MXXXX and MXXXXX)

Dear:

Enclosed is a copy of the Environmental Assessment and Finding of No Significant Impact related to your application for [amendment/exemption] dated ____, as supplemented on ____. The proposed [amendment/exemption] would ____.

The assessment is being forwarded to the Office of the Federal Register for publication.

Sincerely,
[Signature Authority as Outlined in NRR Office Instruction ADM-200, "Delegation of Signature Authority"]
Project Directorate
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Docket Nos. ____ and ____

Enclosure: Environmental Assessment

cc w/encl: See next page[1]

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[1][PREPARER: WHEN PROCESSING THE ENVIRONMENTAL ASSESSMENT FOR CONCURRENCE, ATTACH A NOTE TO THE ENVIRONMENTAL ASSESSMENT FOR THE THE OGC MAILROOM THAT IDENTIFIES THE STANDARD REVIEW PLAN SECTION NUMBER TO WHICH THE PROPOSED ACTION PERTAINS. THE OGC MEMBER THAT REVIEWS THE SAFETY EVALUATION REPORT FOR THE PROPOSED ACTION SHOULD ALSO REVIEW THE ENVIRONMENTAL ASSESSMENT FOR THE PROPOSED ACTION.]

7590-01

UNITED STATES NUCLEAR REGULATORY COMMISSION

(LICENSEE)

(DOCKET NOS.)

(PLANT NAME)

ENVIRONMENTAL ASSESSMENT AND FINDING OF

NO SIGNIFICANT IMPACT

The U.S. Nuclear Regulatory Commission (NRC) is considering issuance of an [amendment to/ exemption from 10 CFR 50.__ for] Facility Operating License Nos. ____ and ____, issued to [insert name of licensee] (the licensee), for operation of the [facility name], located in ____. Therefore, as required by 10 CFR 51.21, the NRC is issuing this environmental assessment and finding of no significant impact.

ENVIRONMENTAL ASSESSMENT

Identification of the Proposed Action:

The proposed action would [briefly describe what the amendment/exemption would do].

The proposed action is in accordance with the licensee's application dated ____, as supplemented by letter dated ____.

The Need for the Proposed Action:

The proposed action [describe why amendment/exemption is needed].

Environmental Impacts of the Proposed Action:

The NRC has completed its safety evaluation of the proposed action and concludes [give safety conclusion]. The details of the staff's safety evaluation will be provided in the [license amendment or exemption] that will be issued as part of the letter to the licensee approving the [license amendment or exemption to the regulation].

The proposed action will not significantly increase the probability or consequences of accidents. No changes are being made in the types of effluents that may be released off site. There is no significant increase in the amount of any effluent released off site. There is no significant increase in occupational or public radiation exposure. Therefore, there are no significant radiological environmental impacts associated with the proposed action.

With regard to potential non-radiological impacts, the proposed action does not have a potential to affect any historic sites. [PREPARER SHOULD DECIDE IF THE PROPOSED ACTION IS A TYPE OF ACTION THAT HAS THE POTENTIAL TO AFFECT HISTORIC PROPERTIES]. It does not affect non-radiological plant effluents and has no other environmental impact. Therefore, there are no significant non-radiological environmental impacts associated with the proposed action.

Accordingly, the NRC concludes that there are no significant environmental impacts associated with the proposed action.

Environmental Impacts of the Alternatives to the Proposed Action:

As an alternative to the proposed action, the staff considered denial of the proposed action (i.e., the "no-action" alternative). Denial of the application would result in no change in current environmental impacts. [PREPARER PLEASE NOTE THAT ANY OTHER ALTERNATIVES CONSIDERED TO BE REASONABLE SHOULD BE EVALUATED AND DISCUSSED.] The environmental impacts of the proposed action and the alternative action are similar.

Alternative Use of Resources:

The action does not involve the use of any different resources than those previously considered in the Final Environmental Statement for the [insert name of facility], NUREG___, dated ____ [and the Final Supplemental Environmental Impact Statement (NUREG-1437 Supplement__) dated___].

Agencies and Persons Consulted:

On [insert date], the staff consulted with the [insert name of State] State official, [insert name of official] of the [insert name of agency], regarding the environmental impact of the proposed action. The State official had no comments.

FINDING OF NO SIGNIFICANT IMPACT

On the basis of the environmental assessment, the NRC concludes that the proposed action will not have a significant effect on the quality of the human environment. Accordingly, the NRC has determined not to prepare an environmental impact statement for the proposed action.

For further details with respect to the proposed action, see the licensee's letter dated _____, as supplemented on _____. Documents may be examined, and/or copied for a fee, at the NRC's Public Document Room (PDR), located at One White Flint North, 11555 Rockville Pike (first floor), Rockville, Maryland. Publicly available records will be accessible electronically from the Agencywide Documents Access and Management System (ADAMS) Public Electronic Reading Room on the NRC Web site, http://www.nrc.gov/reading-rm/adams.html. Persons who do not have access to ADAMS or who encounter problems in accessing the documents located in ADAMS should contact the NRC PDR Reference staff at 1-800-397-4209, or 301-415-4737, or send an e-mail to pdr@nrc.gov.

Dated at Rockville, Maryland, this ____day of ____.

FOR THE NUCLEAR REGULATORY COMMISSION
[Signature Authority as Outlined in NRR Office Instruction ADM-200, "Delegation of Signature Authority"]
Project Directorate
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Format and Content of an Environmental Assessment for a Rulemaking[1]

UNITED STATES NUCLEAR REGULATORY COMMISSION

ENVIRONMENTAL ASSESSMENT AND FINDING OF

NO SIGNIFICANT IMPACT

FOR [AN AMENDMENT TO 10 CFR PART XX / THE PROPOSITION OF A NEW RULE]

The U.S. Nuclear Regulatory Commission (NRC) is evaluating the environmental impacts of [an amendment to its regulations in 10 CFR Part ___/a proposed new rule]. Therefore, as required by 10 CFR 51.21, the NRC is performing this environmental assessment review and documenting its finding of no significant impact.

ENVIRONMENTAL ASSESSMENT

Identification of the Proposed Action:

The proposed action would [DESCRIBE THE AMENDMENT TO THE RULE OR THE NEW RULE].

The Need for the Proposed Action:

The proposed action is [DESCRIBE WHY THE AMENDMENT TO THE RULE OR NEW RULE IS NEEDED].

---

[1]This is an example format and content of an environmental assessment for when the rulemaking review is documented in a separate document apart from the preamble. The provision of the NRC Regulatory Handbook should be followed when *summarizing* the findings of the environmental assessment in the preamble. No formal cover letter is needed, as the environmental assessment documented apart from the preamble is inserted into the rulemaking package to the Commission. When the environmental assessment review is documented in the text of the preamble, the NRC Regulatory Handbook should be followed, and the sample language for the sections titled "Environmental Impacts of the Proposed Action," "Environmental Impacts of the Alternatives to the Proposed Action, " and "Alternative Use of Resources" can be used as guidance where the NRC Regulatory Handbook directs the authors of the preamble to "insert the text of the environmental assessment."

Environmental Impacts of the Proposed Action:

The NRC has completed its evaluation of the proposed action and concludes that [DISCUSS THE ENVIRONMENTAL IMPACTS. IF IT IS LOGICAL THAT THERE WOULD BE NO ENVIRONMENTAL IMPACTS OF THE PROPOSED ACTION, STATE THAT LOGIC].

The proposed action will not significantly increase the probability or consequences of accidents. No changes are being made in the types or quantities of radiological effluents that may be released. There is no significant increase in occupational or public radiation exposure. Therefore, there are no significant radiological environmental impacts associated with the proposed action.

With regard to potential non-radiological impacts, the proposed action does not have a potential to affect any historic sites [PREPARER SHOULD DECIDE IF THE PROPOSED ACTION IS A TYPE OF ACTION THAT HAS THE POTENTIAL TO AFFECT HISTORIC PROPERTIES]. No changes are being made in the type or quantities of non-radiological plant effluents and there are no changes in activities that would disrupt the environment. Therefore, there are no significant non-radiological environmental impacts associated with the proposed action.

Accordingly, NRC concludes that there are no significant environmental impacts associated with the proposed action.

Environmental Impacts of the Alternatives to the Proposed Action:

As an alternative to the proposed action, the staff considered denial of the proposed action (i.e., the "no-action" alternative). Denial of the proposed action would result in no change in the current environmental impacts. [PREPARER - IDENTIFY ANY ALTERNATIVES OUTLINED IN THE REGULATORY ANALYSIS AND DOCUMENT THE ENVIRONMENTAL IMPACTS OF THOSE ALTERNATIVES. THE ALTERNATIVES ANALYZED IN THE EA

SHOULD MATCH THE ALTERNATIVES ANALYZED IN THE REGULATORY ANALYSIS.]

The environmental impacts of the proposed action and the alternative action [(s)] are similar.

Alternative Use of Resources

This action does not involve the use of any different resources than those previously considered in the original rule dated ____. [IF THE PROPOSED ACTION IS A NEW RULE, LIST THE RESOURCES (I.E., LAND, WATER, OTHER PHYSICAL MATERIALS) THAT ARE EXPECTED TO BE AFFECTED BY THE NEW RULE AND STATE IF THERE ARE ANY UNRESOLVED CONFLICTS OVER THE USE OF THOSE RESOURCES.]

Agencies and Persons Consulted:

The NRC has sent a copy of the [proposed/final] rule to every State Liaison Officer and requested their comments on the environmental assessment. [STATE WHETHER COMMENTS WERE RECEIVED AND IF SO, WHAT THE COMMENTS WERE]

FINDING OF NO SIGNIFICANT IMPACT:

On the basis of the environmental assessment, the NRC concludes that the proposed action will not have a significant effect on the quality of the human environment. Accordingly, the NRC has determined not to prepare an environmental impact statement for the proposed action.

For further details with respect to the proposed action, see the [proposed/final] rule dated ____. Documents may be examined, and/or copied for a fee, at the NRC's Public Document Room (PDR), located at One White Flint North, 11555 Rockville Pike (first floor), Rockville, Maryland. Publicly available records will be accessible electronically from the Agencywide Documents Access and Management System (ADAMS) Public Electronic Reading Room on the NRC Web site, http://www.nrc.gov/reading-rm/adams.html. Persons who do not have access to ADAMS or who encounter problems in accessing the documents located in ADAMS should contact the NRC PDR Reference staff at 1-800-397-4209, or 301-415-4737, or send an e-mail to pdr@nrc.gov.

Dated at Rockville, Maryland, this ____day of ____.

FOR THE NUCLEAR REGULATORY COMMISSION
[Signature Authority as Outlined in NRR Office Instruction ADM-200, "Delegation of Signature Authority"]
Policy and Rulemaking Program
Division of Regulatory Improvement Programs
Office of Nuclear Reactor Regulation

Appendix D - Environmental Justice Guidance and Flow Chart

BACKGROUND

This procedure provides guidance to the Office of Nuclear Reactor Regulation (NRR) staff on conducting environmental justice (EJ) reviews for proposed actions requiring an environmental impact statement, and in special cases an environmental assessment, as part of NRC's compliance with the National Environmental Policy Act (NEPA). This guidance does not create any new NEPA-related requirements, as consideration of environmental justice is consistent with the purposes and policies of NEPA. This guidance is intended to ensure that NRR is fully discharging its existing NEPA responsibilities. Executive Order 12898, "Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations," 59 FR 7629 (1994), directs Federal agencies in the Executive Branch to "make achieving environmental justice part of its mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of its programs, policies, and activities" on minority and low-income populations. Although an independent agency, the NRC indicated its willingness to comply with the Executive Order.

The Council on Environmental Quality (CEQ) developed guidelines to assist Federal agencies with integration of EJ into the NEPA process. The guidelines are contained in CEQ's December 10, 1997, document, "Environmental Justice Guidance Under the National Environmental Policy Act." CEQ's guidance is not binding on NRC activities; however, much of CEQ's guidance has been incorporated in this procedure. On November 5, 2003, the Commission published for comment a draft policy statement on the treatment of environmental justice matters in NRC regulatory and licensing actions. It is not finalized, but the following guidance is consistent with the draft policy statement and previous practice.

SCOPE OF ENVIRONMENTAL JUSTICE FOR NRR REVIEWS

Environmental justice reviews will be performed for all regulatory actions, including licensing actions and rulemaking activities, requiring preparation of an environmental impact statement (EIS). An EIS is required for licensing and regulatory actions that are major Federal actions significantly affecting the quality of the human environment or actions that involve a matter which the Commission has determined should be covered by an EIS. A list of types of actions requiring an EIS is found in 10 CFR 51.20(b), and includes issuance of a limited work authorization or a permit to construct a nuclear power reactor and issuance or renewal of a full power or design capacity license to operate a nuclear power reactor. It is important to note that agency consideration of impacts on minority or low-income populations may lead to the identification of disproportionately high and adverse human health or environmental effects that are significant and that otherwise could be overlooked.

For environmental assessments (EAs) with a Finding of No Significant Impact (FONSI) determination, the staff concludes, as part of its analysis, that there will be no significant environmental impacts as a result of the proposed action. The potential for environmental justice impacts should be considered when preparing an EA to ensure that minority and low-income populations are not significantly impacted by the proposed action. If significant environmental impacts are identified, then a FONSI determination cannot be made. For most licensing actions requiring an environmental assessment, there will be no potential for disproportionately high and adverse human health or environmental effects to minority or low-income populations and an environmental justice review will not be necessary. However, under special circumstances, environmental justice reviews may be needed for actions in which an EA is prepared if there is the potential that an analysis of environmental justice issues may identify significant environmental impacts that would otherwise not be identified. If a potential for environmental justice impacts is recognized either as a result of public interest in the proposed action, knowledge about particular groups that may be effected, or the nature of the impacts, then RLEP, the program responsible for environmental reviews, should be notified for assistance. RLEP concurs on all EAs issued by NRR and will notify management if it appears that an environmental justice review is warranted. NRR management will then make a decision on a case-by-case basis whether the circumstances are such that a minority or low-income population may be affected and an environmental justice review should be performed for the action. An environmental justice review is not required for those actions listed in 10 CFR 51.22 as being categorically excluded from environmental review.

GENERAL PRINCIPLES OF ENVIRONMENTAL JUSTICE

Environmental justice issues encompass the usual broad range of impacts normally covered by NEPA. The staff should be sensitive to the fact that environmental justice issues may arise at any step of the NEPA process.

The staff should consider the composition of the affected area to determine whether minority or low-income populations are present in the area and may be affected by the proposed action. If there are significant impacts from the proposed action, the staff needs to determine whether there may be disproportionately high and adverse human health or environmental effects on minority or low-income populations.

The staff should develop effective public participation strategies. The staff should acknowledge and seek to overcome linguistic, cultural, institutional, geographic, and other barriers to meaningful participation and should incorporate active outreach to affected groups.

The staff should strive for meaningful community representation in the process. The staff should be aware of the diverse constituencies within any community and should endeavor to have complete representation of the community as a whole. The staff should be aware that community participation must occur as early as possible if it is to be meaningful.

The staff should seek Tribal agency representation in the process in a manner that is consistent with government-to-government relations.

The staff should consider relevant public health data and industry data concerning the potential for multiple or cumulative exposure to human health or environmental hazards in the affected population and historical patterns of exposure to environmental hazards, to the extent such information is reasonably available.

The staff should recognize the interrelated cultural, social, occupational, historical, or economic factors that may amplify the natural and physical environmental effects of the proposed agency action. These factors should include the physical sensitivity of the community or population to particular impacts; the effect of any disruption on the community structure associated with the proposed action; and the nature and degree of impact on the physical and social structure of the community.

The review is forward looking and should focus on the action being taken. For example, if the action is a license amendment, only the activities covered by the amendment and not the overall impact from the issuance of the original license should be reviewed even if an EJ review was not performed for the original action.

Under NEPA, the identification of a disproportionately high and adverse human health or environmental effect on a minority or low-income population does not preclude a proposed agency action from going forward, nor does it necessarily compel a conclusion that a proposed action is environmentally unsatisfactory. Rather, the identification of such an effect should heighten agency attention to alternatives (including alternative sites), mitigation strategies, monitoring needs, and preferences expressed by the affected community or population.

PROCEDURES FOR LICENSING ACTIONS

The following guidance should be used when performing an environmental justice review. This procedure may not address all situations that may occur. Project managers should consult with RLEP whenever an environmental justice review is undertaken. See Figure 1 on page D-5 for an environmental justice process flow chart.

1. *Determine if the action requires an environmental justice review.* Determine whether the regulatory action will be supported by an EIS or by an EA. When the regulatory action requires the preparation of an EIS, an EJ review must be conducted using the process discussed in steps 2 through 5, below. When the regulatory action involves the siting or licensing of new facilities, or requires the evaluation of alternative sites, then environmental justice information must be developed for each site.

   Under most circumstances, no environmental justice review is required when an EA is prepared. However, in special cases, the staff will conduct an environmental justice analysis in preparing an EA. As discussed in the scope section above, such a determination will be made on a case-by-case basis and only when there is a clear potential that the consideration of specific demographic information may identify significant impacts that would not otherwise be considered. In the event that an environmental justice analysis is performed for an EA, the process outlined in steps 2 through 5, below, should be followed.

2. *Conduct a screening for minority and low-income groups and integrate environmental justice into the scoping process.* Early on in the process (before or at the beginning of scoping), the staff should attempt to identify the location of any minority or low-income groups in the area potentially affected by the proposed action, usually within a 50-mile radius, using the procedures in the following subsection, "Identifying Minority and Low-income Populations." If any potentially affected minority or low-income groups are identified, then the staff should develop a strategy for effective public involvement in the NRC's scoping process.

3. *Identifying minority and low-income populations*

The staff should use the following steps to assist with identification of minority and low-income populations at the beginning of the review (before or at the beginning of scoping). These steps can also be used to help determine whether there are any disproportionately high and adverse human health or environmental effects, when a potentially effected minority or low-income group is identified. In the latter case, environmental impact areas will be defined for potentially significant environmental impacts and the steps will be used to determine if there is a minority or low-income population within the environmental impact area.

A. Determine geographic area for comparison

In determining whether a minority or low-income population exists, define the geographic area to be used for the comparative analysis . The area used for the comparative analysis is larger and encompasses the entire area of potential impact from the proposed action or all of the environmental impact areas (it is called the geographic area). See Figures 2 and 3 for examples.

When a regulatory action is being considered that involves alternative site considerations, such as an early site or construction permit, then, in addition to determining the individual geographic area for each site as defined above, determine an overall geographic area that encompasses all of the alternative site geographic areas. See Figure 3 for an example.

If the environmental impact areas overlap more than one government jurisdiction (State, County, etc.), then the geographic area will encompass parts of each government jurisdiction. The geographic area does not have to follow established boundaries such as county or State lines.

B. Determine the minority and low-income composition in the geographic area

Determine the percentage of the total population within the geographic area for each minority and low-income category and for the aggregate minority population.

The staff should use the most recent demographic data available from the Bureau of the Census (the Bureau) to identify the composition of the potential geographic area. Geographic distribution by race, ethnicity, and income, as well as delineation of tribal lands and resources, should be examined. Information may be found through demographic information and studies, such as the LandView environmental mapping software developed by the Bureau to assist in utilizing data from a geographic information system. This information is also contained in RLEP's Geographical Environmental & Siting Information System (GEn&SIS).

Minority categories are defined as: American Indian or Alaskan Native; Asian; Native Hawaiian or other Pacific Islander; or Black races; or Hispanic ethnicity ("other" may be considered a separate minority category).[2]

Low-income households should be identified using the annual statistical poverty thresholds from the Bureau.

C. Determine the minority and low-income composition in the environmental impact area

For the area of potential impact for all impacts (typically, a 50-mile radius) or for the environmental impact area for a particular impact, determine the percentage of each minority category in the area and for the aggregate minority categories. Likewise, determine the percentage of the households within the area that are below the poverty level (low-income). The selection of the appropriate unit of geographic analysis may likely be a census block group because this geographic area is small enough so as not to dilute a potential minority or low-income population within the larger general population. At the beginning of the scoping process, it is more appropriate to compare individual census block groups, or other similar geographic unit, with the larger area of potential impact for all impacts associated with the proposed action in order to determine the location of any potential minority or low-income groups. If, during the review, it appears that a minority or low-income group may be affected, then it will be necessary to focus the review on potentially significant impacts and to determine the environmental impact area for each potentially significant environmental impact. The percentage of minorities and low-income households in the census block groups, or other similar geographic unit, that are located in the environmental impact area should be used in the comparison to determine if the area contains a minority or low-income population. A determination of whether or not a census block group that only partially falls in an environmental impact area should be included in the comparison may be based on the population density of the census block group within the environmental impact area or use of other appropriate criteria.

D. Determine if there are any minority or low-income populations

A "minority population" is considered to be present if: 1) the minority population in the census block group or environmental impact site exceeds 50 percent, or 2) the minority population percentage of the environmental impact area is significantly greater (typically at least 20 percentage points) than the minority population percentage in the geographic area chosen for the comparative analysis, for example, the county or State.

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[2]The 2000 Census included multi-racial data. The staff should consider multi-racial individuals in a separate minority category, in addition to the aggregate minority category when the Bureau releases the updated information.

A "low-income population" is considered to be present if: 1) the low-income population in the census block group or the environmental impact area exceeds 50 percent, or 2) the percentage of households below the poverty level in an environmental impact area is significantly greater (typically at least 20 percentage points) than the low-income population percentage in the geographic area chosen for the comparative analysis.

In identifying minority or low-income populations, reviewers may consider a community either as a group of individuals living near one another or a group of individuals that experience common conditions of environmental exposure or effect. The criteria listed above should only serve as a guideline for determining the presence of a minority or low-income population. If it is apparent through interviews, public comment/interest, or by investigation that there is a distinct minority or low-income population that may be adversely effected by the proposed action, then the reviewer should proceed with the environmental justice review, even if the population is not identified through use of the census data.

If no minorities or low-income households are identified in the potentially affected area or environmental impact area, then document the conclusion. The environmental justice review is complete.

Consistent with scoping activities conducted under NEPA, the staff may consider measures for increasing participation of minority and low-income groups such as outreach through minority business and trade organizations, schools, colleges, labor organizations, or other appropriate organizations. Meetings open to the public should be advertised through locally-targeted media, mailings, and the internet. Other means of advertising include posting of flyers in local shopping, community, government and other public places. If representatives of the affected group(s) are identified, these individuals should be included on the mailing list for the review. When communicating with the public, the staff should consider innovative approaches to overcoming linguistic, institutional, cultural, economic, historical, or other potential barriers to effective participation in the decision-making process. During the scoping process the staff should supplement the census data with inquiries of the local planning departments, social service agencies, and other local offices to identify minority or low-income groups that may not be identified through the census data.

If no minority or low-income groups are found during scoping or later on in the review, then the results should be documented and the environmental justice review is complete.

4. *Determine whether there are potentially significant environmental impacts to minority or low-income populations.* If any minority or low-income groups are identified during the scoping process or at any other stage of the review, then the staff should determine the significance of environmental impacts to these groups during development of the EIS. The staff should use a graded approach and focus the review on any adverse human health or environmental impacts that are known to be significant or perceived as significant by groups and/or individuals. The locations that have been identified as areas affected by the proposed action are called environmental impact areas. More than one environmental impact area may exist if multiple impacts can occur from the

proposed action. The size, shape, and geographic location of the environmental impact area will vary according to the nature of the impact and should be consistent with the areas used to review environmental impacts in the EIS. For example, an environmental impact area may include transmission line rights-of-way, a river or other surface water body, a 10-mile radius, etc. Environmental impact areas may or may not follow political jurisdictions. Typically, the severity of environmental impacts will vary inversely with the distance from the facility; therefore, the review should be focused on areas closer to the site. See Figure 2 for examples of individual environmental impact areas and the larger geographic area.

The percentage of minorities and low-income households in the census block groups, or other similar geographic unit, that are located in the environmental impact area should be used in the comparison to determine if the area contains a minority or low-income population using the steps outlined in the subsection, "Identifying Minority and Low-Income Populations."

If there are no minority or low-income populations within the impact area(s) or if there are no potentially significant environmental impacts, then these results should be documented and the environmental justice review is complete.

5. *Determine whether there are disproportionately high and adverse human health or environmental effects to minority or low-income populations.* When the review does identify minority or low-income populations in a potentially significant environmental impact area(s), the staff needs to determine whether disproportionately high and adverse effects result from the proposed action by considering the following:

- Are the radiological or other health effects significant or above generally accepted norms? Is the risk or rate of hazard significant and appreciably in excess of the general population? Do the radiological or other health effects occur in groups affected by cumulative or multiple adverse exposures from environmental hazards?

- Is there an impact on the natural or physical environment that significantly and adversely affects a particular group? Are there any significant adverse impacts on a group that appreciably exceed or is likely to appreciably exceed those on the general population? Do the environmental effects occur or would they occur in groups affected by cumulative or multiple adverse exposure from environmental hazards?

Reviewers should recognize that the impacts to minority or low-income populations may be different from impacts on the general population due to a community's distinct cultural practices. In addition, reviewers should take into account different patterns of living and consumption of natural resources, such as subsistence consumption.

Reviewers should assess the significance or potential significance of such adverse impact on each minority or low-income population and also provide an assessment of the degree to which each minority or low-income population is disproportionately receiving benefits compared to the entire geographic area.

If there are significant impacts to the minority or low-income population, then it is necessary to look at mitigative measures and benefits. The reviewer should determine and discuss whether there are any mitigative measures that could be taken to reduce the impact. To the extent practicable, mitigation measures should reflect the needs and preferences of the affected minority or low-income populations. The conclusion may be that there are disproportionately high and adverse impacts to minority or low-income populations; however, factors such as the mitigative measures and/or the benefits of a project may outweigh the disproportionate impacts. In any case, the facts should be presented so that the ultimate decision-maker can weigh all aspects in making the agency decision. The Executive Order does not prohibit taking an action when the agency taking the action determines that there are disproportionate high and adverse impacts to minority or low-income populations.

6. *Make a determination regarding environmental justice impacts and document the conclusion.* Each EIS shall contain a section titled, "Environmental Justice," which will either contain the complete environmental justice review or a reference to another document containing the review. If a reference to another document is used, a summary of the review and its conclusions should be included in the EIS section. An EA will only have an environmental justice section in the rare situation where a review was performed as a result of an NRR management decision.

   The staff should clearly state the conclusion regarding whether or not the proposed action will have disproportionately high and adverse environmental impacts on minority or low-income populations. This statement should be supported by sufficient information to allow the public to understand the rationale for the conclusion. The underlying information should be presented as concisely as possible, using language that is understandable to the public and that minimizes use of acronyms or jargon.

PROCEDURES FOR RULEMAKING ACTIVITIES

1. The staff responsible for rulemaking should integrate EJ into the proposed and final rules that require an EIS to the same extent that it integrates other relevant environmental considerations.

2. If it is known in advance that a particular rulemaking might impact a specific population disproportionately, then the NRC staff should ensure that the population knows about the rulemaking and is given the opportunity to participate. Such actions may include translating the *Federal Register* Notice (FRN) into a language other than English for publication in a local newspaper and holding public outreach meetings in the affected area.

3. As noted in the "Scope" section, there may be special circumstances under which a rulemaking that has an EA/FONSI prepared may identify special environmental impacts not otherwise identified. In these cases, the staff will inform NRR senior management and a decision will be made on a case-by-case basis whether the circumstances warrant an environmental justice review.

4. If an environmental justice analysis is performed for a rulemaking activity, then the staff should include language contained in NUREG/BR-0053, Revision 5, "NRC Regulations Handbook," Section 5.15 and Section 7.15 in the FRN to seek public comments on environmental justice. The staff should follow steps 2-5 of "Procedures for Licensing Actions," above, to perform the environmental justice review.

5. Public comments received pertaining to environmental justice on a rulemaking should be addressed in the final FRN in the same section and at the same level of detail as comments received on other aspects of the environmental considerations for the rule.

6. When a rule is being modified or developed that contains siting evaluation factors or criteria for siting a new facility, the staff should consider including specific language in the rule or supporting regulatory guidance to state that an environmental justice review will be included as part of the normal environmental analysis performed in siting a new facility.

Appendix E - List of States With Federally-Approved Coastal Management Programs, Example of Consistency Certification, and Coastal Zone Management Flow Chart

List of States with Federally-Approved Coastal Management Programs

1. Alabama
2. Alaska
3. American Samoa
4. California
5. Connecticut
6. Delaware
7. Florida
8. Georgia
9. Guam
10. Hawaii
11. Indiana
12. Louisiana
13. Maine
14. Maryland
15. Massachusetts
16. Michigan
17. Minnesota
18. Mississippi
19. New Hampshire
20. New Jersey
21. New York
22. North Carolina
23. Northern Mariana Islands
24. Ohio
25. Oregon
26. Pennsylvania
27. Puerto Rico
28. Rhode Island
29. South Carolina
30. Texas
31. Virginia
32. Virgin Islands
33. Washington
34. Wisconsin

Example of Consistency Certification for Federal Permit and License Applicants

The Coastal Zone Management Act of 1972 (CZMA) requires that any applicant for a Federal license or permit or authorization, certification, approval, or other form of permission, which any Federal agency is empowered to issue to an applicant to conduct an activity, inside or outside of the coastal zone, affecting any land or water use or natural resource of the coastal zone of that State, shall certify in the application to the approving Federal agency that the proposed activity complies with the enforceable policies of the State's approved program and that such activity will be conducted in a manner consistent with the program. At the same time, the applicant shall furnish to the State or its designated agency a copy of the certification, with all necessary information and data. See 16 U.S.C. 1456(c)(3)(A); 15 CFR 930.51(a). At the earliest practicable time, the State agency shall notify the Federal agency and the applicant whether the State agency concurs or objects to a consistency certification. [15 CFR 930.63(a).]

[Insert name of State] has an approved CZMA Program, which includes [insert the statutory provisions and regulations of the State's CZMA Program].

Consistency Certification:

[Insert name of applicant] has determined that the proposed [insert name of project] complies with the [insert name of State] approved coastal management program (CMP) and will be conducted in a manner consistent with such program.

Necessary Data and Information:

1. This section provides a detailed description of the proposed activity and its associated facilities. [Provide a copy of the Federal application and other materials pursuant to 15 CFR 930.58(a)(1), which will permit adequate assessment of probable coastal zone effects by the State.]

2. This section contains the necessary information and data required by the State's CMP as described in the State's CMP program document and subsequent approved amendments. [Provide information pursuant to 15 CFR 930.58(a)(2) and 930.56(b).]

3. This section contains a brief assessment relating the probable effects of the proposed [insert name of project] and its associated facilities on any land or water use or natural resource of the coastal zone to the relevant enforceable policies of the [insert name of State] CMP. [Contact the State coastal management agency to help determine relevant enforceable policies, briefly describe the relevant policies, and write a brief assessment of how the effects of the proposed activity relate to the relevant policies.]

4. This section contains a brief set of findings, derived from the assessment, that the proposed [insert name of project], its associated facilities, and their effects are all consistent with the enforceable policies of the [insert name of State] CMP. [Prepare a set of findings for each distinguishable aspect of the proposed activity-essentially a conclusion of fact based on the assessment.]

By this certification that the [insert name of project] is consistent with the [insert name of State] CMP, the State of [insert name of State] is notified that it has 6 months from receipt of this letter and accompanying information in which to concur with or object to [insert name of applicant] certification. However, pursuant to 15 CFR 930.63(b), if [insert name of State] has not issued a decision within 3 months following commencement of State agency review, it shall notify [insert name of applicant] and the Federal agency of the status of the matter and the basis for further delay. The State's concurrence, objection, or notification of review status shall be sent to [insert name of applicant contact].

USCB 2000a

GEO_ID	GEO_ID2	SUMLEVEL	GEO_NAME	P003001	P003003	P003004	P003005	P003006	P003007	P003008	P003009	P004002	
Geography Identifier	Geography Identifier	Geographic Summary Level	Geography	Total population: Total	Total population: Population of one race; White alone	Total population: Population of one race; Black or African American alone	Total population: Population of one race; American Indian and Alaska Native alone	Total population: Population of one race; Asian alone	Total population: Population of one race; Native Hawaiian and Other Pacific Islander alone	Total population: Population of one race; Some other race alone	Total population: Population of two or more races	Total population: Hispanic or Latino	Aggregate
04000US37	37	040	North Carolina	8049313	5804656	1737545	89551	113689	3983	186629	103260	378963	2244857
						21.58625214	1.236783933	1.412406251	0.049482484	2.318570541	1.282842399	4.708016697	27.88831775

GEO_ID	GEO_ID2	SUMLEVEL	GEO_NAME	P003001	P003003	P003004	P003005	P003006	P003007	P003008	P003009	P004002	
Geography Identifier	Geography Identifier	Geographic Summary Level	Geography	Total population: Total	Total population: Population of one race; White alone	Total population: Population of one race; Black or African American alone	Total population: Population of one race; American Indian and Alaska Native alone	Total population: Population of one race; Asian alone	Total population: Population of one race; Native Hawaiian and Other Pacific Islander alone	Total population: Population of one race; Some other race alone	Total population: Population of two or more races	Total population: Hispanic or Latino	Aggregate
04000US45	45	040	South Carolina	4012012	2695560	1185216	13718	36014	1628	39926	39950	95076	1316452
						29.54168632	0.341923205	0.897654344	0.040578144	0.99518153	0.995759734	2.36970354	32.81276

NUREG-1767, Vol. 1

Environmental Impact Statement on the Construction and Operation of a Proposed Mixed Oxide Fuel Fabrication Facility at the Savannah River Site, South Carolina

Chapters 1 through 8 and Appendices A through E

Final Report

U.S. Nuclear Regulatory Commission
Office of Nuclear Material Safety and Safeguards
Washington, DC 20555-0001

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Final Report

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Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

ABSTRACT

The U.S. Department of Energy (DOE) has contracted with Duke Cogema Stone & Webster (DCS) to design, construct, and operate a proposed Mixed Oxide (MOX) Fuel Fabrication Facility that would convert depleted uranium and weapons-grade plutonium into MOX fuel. The proposed MOX facility would be located on the DOE's Savannah River Site in South Carolina. Use of the proposed facility to produce MOX fuel would be part of the DOE's surplus plutonium disposition program. The purpose of the DOE program is to ensure that plutonium produced for nuclear weapons and declared excess to national security is converted to proliferation-resistant forms.

This final environmental impact statement (FEIS) was prepared in compliance with the National Environmental Policy Act (NEPA), the U.S. Nuclear Regulatory Commission's (NRC's) regulations for implementing NEPA, and the guidance provided by the Council on Environmental Quality regulations implementing the procedural provisions of NEPA. This FEIS evaluates the potential environmental impacts of the proposed action. The document discusses the purpose and need for the proposed action, describes the proposed action and its reasonable alternatives, describes the environment potentially affected by the proposal, presents and compares the potential environmental impacts resulting from the proposed action and its alternatives, and identifies mitigation measures that could eliminate or lessen the potential environmental impacts. The document also includes comments received on the draft environmental impact statement and NRC's responses.

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ONLY
CHAPTER 3
WERE USED AS
REFERENCE
ENTIRE DOCUMENT
AVAILABLE
ELECTRONICALLY

NRC 2005

3 AFFECTED ENVIRONMENT

3.1 General Site Description

The Mixed Oxide (MOX) Fuel Fabrication Facility (the proposed MOX facility) and its support facilities, the Pit Disassembly and Conversion Facility (PDCF) and the Waste Solidification Building (WSB), are proposed for construction at the U.S. Department of Energy's (DOE's) Savannah River Site (SRS). The SRS is located in the southwestern portion of the state of South Carolina, as shown in Figure 3.1. The SRS is adjacent to the Savannah River, along the state border with Georgia, approximately 20 km (12 mi) southeast of Aiken, South Carolina, and 24 km (15 mi) east of Augusta, Georgia (Arnett and Mamatey 2001b). The U.S. Government owns the SRS, which was set aside in 1950 for the production of nuclear materials for national defense. Since the end of the Cold War in 1991, national priorities have shifted, and the site's priorities are now focused on waste management, environmental restoration, technology development and transfer, and economic development. The SRS covers approximately 803 km^2 (310 mi^2) in an approximately circular tract of land within Aiken, Barnwell, and Allendale Counties in South Carolina. Public access to the SRS is limited according to DOE security regulations.

The proposed facility sites are located adjacent to the north-northwest edge of F-Area near the center of the SRS (see Figure 1.2). F-Area contains facilities for chemical separations, including F Canyon, which is the main processing facility, and waste storage, which includes 20 of the 49 active liquid high-level (radioactive) waste (HLW) tanks on the SRS.

3.2 Geology, Seismology, and Soils

This section summarizes the geology, seismology, and soil conditions of the SRS and discusses site-specific conditions at F-Area. Geologic resources include mineral ores, fossil fuels, and aggregate (sand and gravel) materials that can have significant economic value. The value of soil resources depends upon the soil's ability to grow plants. Certain soils are classified by the U.S. Department of Agriculture, Natural Resources Conservation Service, as prime farmland or other important farmlands. The Farmland Protection Policy Act (*United States Code*, Title 7, Section 4201 *et seq.* [7 U.S.C. 4201] *et seq.*) and its implementing regulations (*Code of Federal Regulations*, Title 7, Part 658 [7 CFR Part 658]) require federal agencies as part of the National Environmental Policy Act (NEPA) process to consider the extent to which federal projects and programs contribute to the unnecessary conversion of important farmlands to nonagricultural uses. The site's geology and soil conditions are important in evaluating how water and potential contaminants move through the subsurface, in evaluating erosion impacts, and in predicting subsidence or landslides. Seismology is important in determining potential impacts from earthquakes.

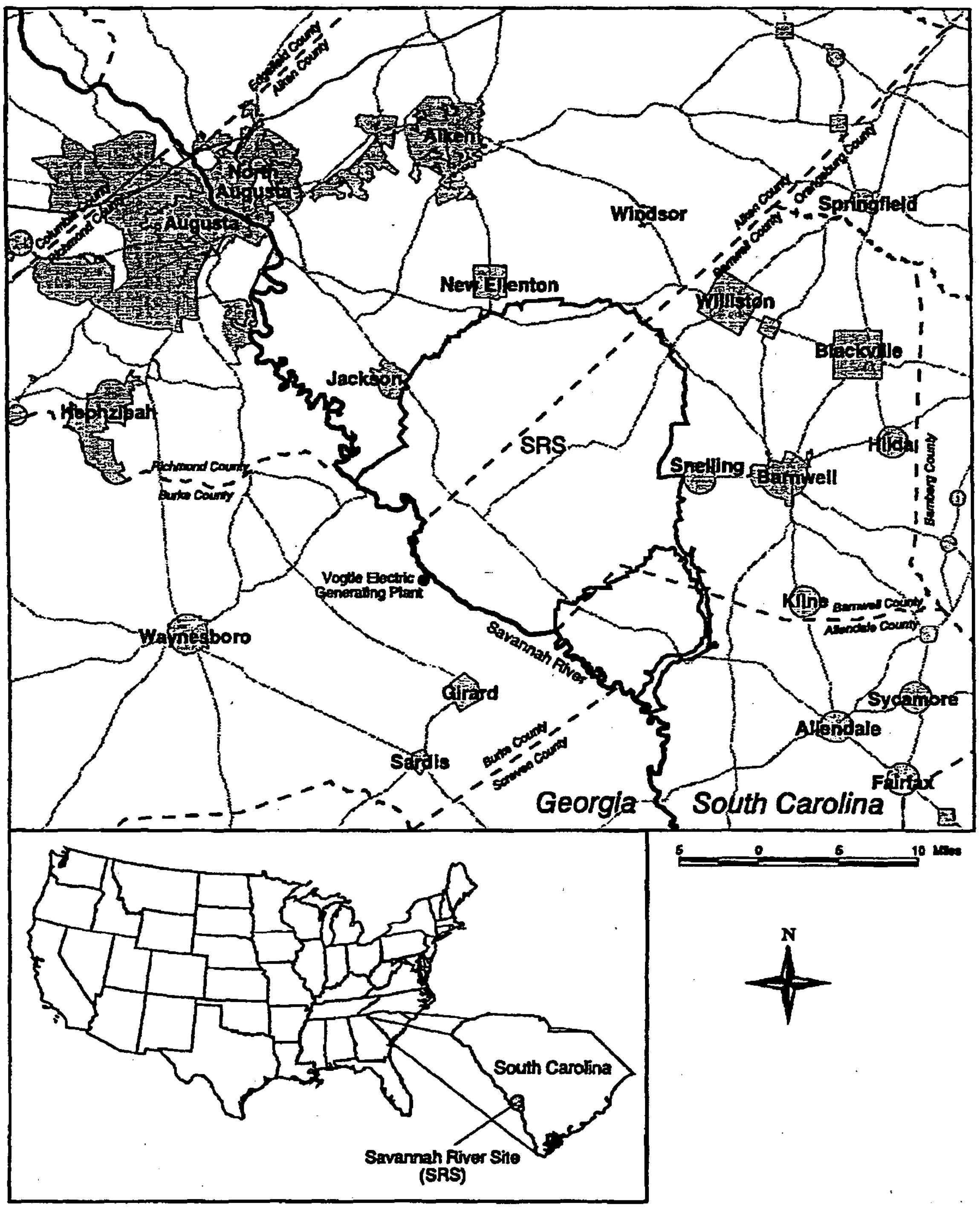

Figure 3.1. Regional location of the SRS.

3.2.1 Geology

The SRS is located in the Aiken Plateau portion of the Upper Atlantic Coastal Plain approximately 32 km (20 mi) east of the Fall Line. The Fall Line is a major physiographic and structural feature that separates the Piedmont and Coastal Plain physiographic provinces in southeastern South Carolina (DOE 1996). Soils within the Piedmont are predominantly derived from the weathering of bedrock. In contrast, soils within the Coastal Plain are predominantly sediments deposited by water. The Coastal Plain sediments are located above bedrock that consists of Paleozoic-age crystalline rock (such as granite) and Triassic-age sedimentary rock (such as siltstone) of the Dunbarton Basin. These sediments thicken from near zero at the Fall Line to about 1,220 m (4,000 ft) at the South Carolina coast (DCS 2003c). In general, the sediments have a regional dip (slant of the top surface) to the southeast. The Aiken Plateau is highly cut by narrow, steep-sided valleys separated by broad, flat areas.

Above the bedrock, the first layer of sediments at the SRS consists of about 210 m (700 ft) of Upper Cretaceous-age quartz sand, pebbly sand, and kaolinitic clay. The next ascending layer (known as the Tinker/Santee Formation) consists of 18 m (60 ft) of Paleocene-age clayey and silty quartz sand, and silt (DCS 2002). Within this layer, there are occasional beds of clean sand, gravel, clay, or carbonate. Deposits of pebbly, clayey sand, conglomerate, and Miocene- and Oligocene-age clay occur at higher elevations. This layer is noteworthy because it contains small, discontinuous, thin calcareous sand zones (i.e., sand containing calcium carbonate) that are potentially subject to dissolution by water. These "soft-zone" areas have the potential to subside, causing settling of the ground surface (WSRC 2000a; DCS 2003c). These areas were encountered in exploratory borings in F-, S-, H-, and Z-Areas of the SRS at depths between 33 and 45 m (100 and 150 ft) (DOE 1995).

The upper sediment layer in F-Area consists of primarily shallow marine quartz sand containing sporadic clay layers (known as the Barnwell Group) (DOE 1999). This layer is about 21 m (70 ft) thick near the western boundary of the SRS and about 52 m (170 ft) thick near the eastern boundary.

There are 11 deep boreholes at the SRS. The closest deep borehole is located just north of an unnamed tributary of Upper Three Runs Creek. The remaining 10 deep boreholes are not located in the vicinity of F-Area.

In 2000, 13 exploratory borings and 63 cone penetration test (CPT) holes were used to identify subsurface conditions at the proposed MOX facility site (DCS 2002). The CPT holes ranged from about 19.5 m (64 ft) to 42.7 m (140 ft) below the existing grade. Some soft zones related to past dissolution and deposition activity were identified at depth. The CPT holes were used to define the limits of the soft zones. The planned locations of heavily loaded structures, such as the MOX Fuel Fabrication Building and the Emergency Diesel Generator Building, were changed to minimize the potential impact of these underlying soft zones.

Except for some small gravel deposits, no economically viable geologic resources occur in the vicinity of F-Area (DOE 1995).

3.2.2 Seismology

On the basis of previous studies at the SRS and elsewhere, there are no known faults capable of producing an earthquake (referred to as capable faults) within the 320-km (200-mi) radius of the site that influence the seismicity of the region, except for poorly constructed faults associated with the Charleston seismic zone (DCS 2003c).

> **Capable Fault**
>
> A fault is described as capable if it has had movement at or near the ground surface at least once within the past 35,000 years, or recurrent movement within the past 500,000 years.

Several faults have been identified from subsurface mapping and seismic surveys beneath the SRS. The largest of these is the Pen Branch Fault. It passes through the SRS in a northeast-southwest direction and is located about 5.6 km (3.5 mi) southeast of F-Area (WSRC 2000a). Because there is no evidence of movement along this fault within the last 38 million years, the Pen Branch Fault is considered not capable.

Two large earthquakes have occurred within 300 km (186 mi) of the SRS. The larger of these was the Charleston earthquake of 1886. The Charleston earthquake is the most damaging earthquake known to have occurred in the southeastern United States and one of the largest historic shocks in eastern North America. This earthquake had an estimated Modified Mercalli Intensity of X (USGS 2001); it damaged or destroyed many buildings in the old city of Charleston, killed 60 people, and produced structural damage up to several hundred kilometers from its epicenter. At the SRS, this earthquake had an estimated Richter Scale magnitude ranging from 6.5 to 7.5. The SRS area experienced an estimated peak ground acceleration[1] of 0.10 g (1/10 the acceleration of gravity — 9.81 m/s/s [32.2 ft/s/s]) during this event (DCS 2002).

> **Modified Mercalli Intensity Scale**
>
> The Modified Mercalli Intensity (MMI) Scale is a measure of the shaking strength of an earthquake at different locations in the region where an earthquake is felt. Earthquake intensities are characterized in terms of how the shaking affects people and buildings. The MMI Scale was originally developed in Italy nearly a century ago and includes 12 degrees of shaking. It was modified for use in the United States in 1931.

> **Richter Scale**
>
> The magnitude of an earthquake is a measure of the energy released during the event. It is often measured on the Richter Scale, which runs from 0.0 upwards, with the largest earthquakes recorded having a magnitude of 8.6. The Richter Scale is logarithmic; a quake of magnitude 5 is 10 times more destructive than a quake of magnitude 4. Earthquakes greater than magnitude 6.0 can be regarded as significant, with the likelihood of damage and loss of life (Press and Siever 1982).

Three earthquakes have occurred at the SRS during recent years. They occurred on June 8, 1985, August 5, 1988, and May 17, 1997. These earthquakes were small, shallow events and were probably the result of strain release near intrusive bodies or the edges of metamorphic belts, typical of South Carolina Piedmont type seismic

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1 Peak ground acceleration is the maximum acceleration amplitude (change in velocity with respect to time) measured by a seismic recording of an earthquake (called a strong motion accelerogram).

activity (WSRC 2000a). None of these earthquakes were associated with major faults (e.g., the Pen Branch Fault) in the area. Rather, these earthquakes are inferred to have seismic sources in the lower Paleozoic platform rock at a depth of about 12 km (7.5 mi) (DCS 2001a). These earthquakes had Richter Scale magnitudes of 3.2 or less and had epicenters that were within the SRS boundaries. Earthquakes of this magnitude are not felt, but do register on seismic instruments (Kirkham and Rogers 1981). Seismic alarms at the SRS reactor buildings were not triggered by any of these events (WSRC 2000a).

An earthquake with an average peak ground of 0.20 g is estimated to have an annual probability of exceedance of 1 in 10,000 (1×10^{-4}) at the SRS (DCS 2002, 2003b).

3.2.3 Soils

As discussed in Section 3.2.1, the surface soils at the SRS consist of Coastal Plain sediments. The surface soils are primarily sands and sandy loams with sporadic clay layers (DOE 1999). Currently, a stockpile of soils removed from the Actinide Packaging and Storage Facility (APSF) site on the SRS is mounded up to 15 m (50 ft) thick on the central portion of the proposed facility site in the F-Area. These soils are similar in texture to the natural soils at the site and would be removed from the site during construction.

The majority of soils in F-Area are classified by the U.S. Department of Agriculture, Natural Resources Conservation Service, as the Fuquay-Blanton-Dothan Association. These soils are nearly level to sloping and are well drained. Soils along stream floodplains are classified as the Troup-Pickney-Lucy Association. Both of these soil associations are subject to erosion. Slope stability, however, has not been a significant regional issue.

The surface soils allow precipitation to drain rapidly. Because of their sandy texture and drainage characteristics, some soil units at the SRS meet the requirements as prime farmland. However, the U.S. Department of Agriculture, Natural Resources Conservation Service, does not identify these areas as prime farmlands because they are not available for agricultural use.

Soil sampling was performed in the area of the proposed MOX facility and support buildings as part of a preconstruction baseline environmental monitoring survey conducted between September 2000 and March 2002 (SRS 2002). Fifty locations were identified for sampling by using a statistically based sampling grid. Samples were obtained from depths of between 0 and 30.5 cm (12 in.). Samples were analyzed for metals and radionuclides. None of the metal concentrations exceeded industrial use standards, and all of the radionuclides were well below SRS-developed scenario-specific radionuclide limits.

3.3 Hydrology

This section discusses the hydrologic environment of the SRS and the proposed site for the facilities. Hydrology deals with the properties, distribution, and circulation of water, particularly surface water and groundwater. The surface waters emphasized in this section are the

Savannah River and on-site streams, including treated effluent and runoff discharges to them. Groundwater resources are waters that occur within aquifers (e.g., water-bearing strata that can store and transmit water in significant quantities). These resources are discussed in relation to their use and potential contamination.

3.3.1 Surface Water

The principal surface water feature at the SRS is the Savannah River (see Figure 3.2). It borders the southwest boundary of the site for 32 km (20 mi) (DOE 1996). Six major streams flow through the SRS and discharge to the Savannah River: Upper Three Runs Creek, Beaver Dam Creek, Fourmile Branch, Pen Branch, Steel Creek, and Lower Three Runs Creek. Upper Three Runs Creek has two named tributaries, Tims Branch and Tinker Creek. Pen Branch has one tributary, Indian Grave Branch. Steel Creek also has one tributary, Meyers Branch. None of these bodies of water are federally designated as Wild and Scenic Rivers (DCS 2002). In the vicinity of the F-Area, Upper Three Runs Creek has two unnamed tributaries (see Figure 3.3) that flow to the northwest.

Two man-made lakes are located at the SRS: L Lake, which discharges to Steel Creek, and Par Pond, which discharges to Lower Three Runs Creek (DCS 2002). There are also about 50 other small man-made ponds and about 300 natural Carolina bays (closed depressions capable of holding water) at the SRS. The Carolina bays do not receive any direct effluent discharge; however, they do receive storm-water runoff.

The SRS withdraws surface water from the Savannah River mainly for industrial cooling. In 2000, the SRS withdrew about 49.7 billion L (13.1 billion gal) of water from the river. Most of this water is returned to the river through various discharges (DOE 1999).

The average flow in the Savannah River is 269 m^3/s (9,493 ft^3/s). The 7-day low flow, 10-year recurrence (referred to as "7Q10") flow is 123 m^3/s (4,332 ft^3/s) (WSRC 2000a). This flow is the lowest flow recorded over any 7 consecutive days within any 10-year period. Three large upstream reservoirs (Hartwell, Richard B. Russell, and Strom Thurmond/Clarks Hill) regulate flow in the Savannah River. This regulation is done to lessen the impacts of drought and flooding downstream. Several communities in the area use the Savannah River as a source for domestic water. The closest downstream water intake to the SRS is that of the Beaufort-Jasper Water Authority at Hardeeville, South Carolina, about 130 river miles downstream of the SRS (WSRC 2000a), which withdraws about 340 L/s (5,390 gpm) of water to service a population of 51,000 people.

Treated effluent is discharged to the Savannah River from upstream communities and from treatment facilities at the SRS. The average annual volume of flow discharged by the sewage treatment facilities at the SRS is about 700 million L (185 million gal). These effluents are released under National Pollutant Discharge Elimination System (NPDES) permits. The SRS has five NPDES permits, two (SC0000175 and SC0044903) for industrial wastewater discharges, two (SCR000000 and SCR1000000) for general storm-water discharges, and one (ND0072125) for land application (DOE 1999). Permit SC0000175 regulates 76 outfalls

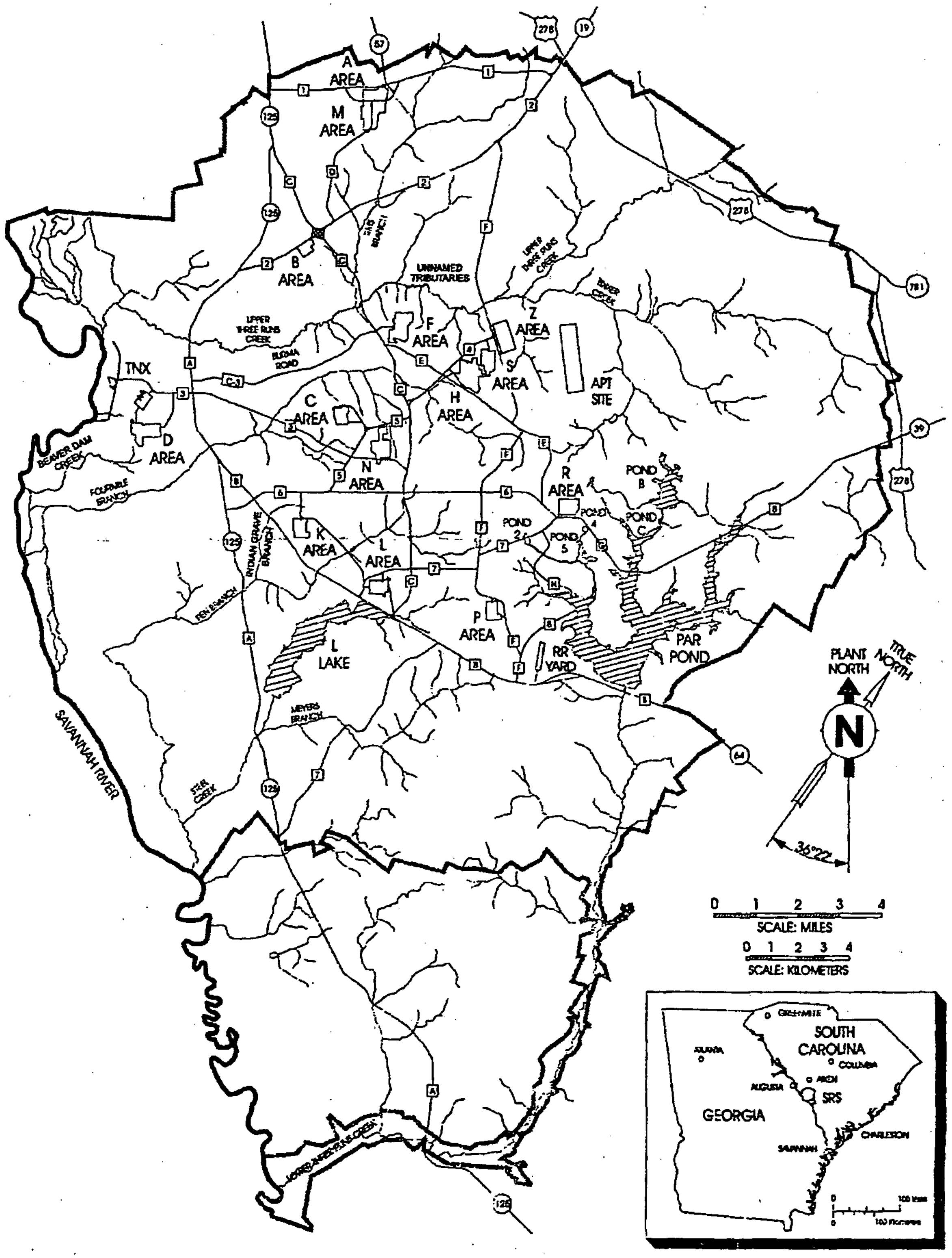

Figure 3.2. Locations of principal surface water features at the SRS (*Source*: DCS 2002).

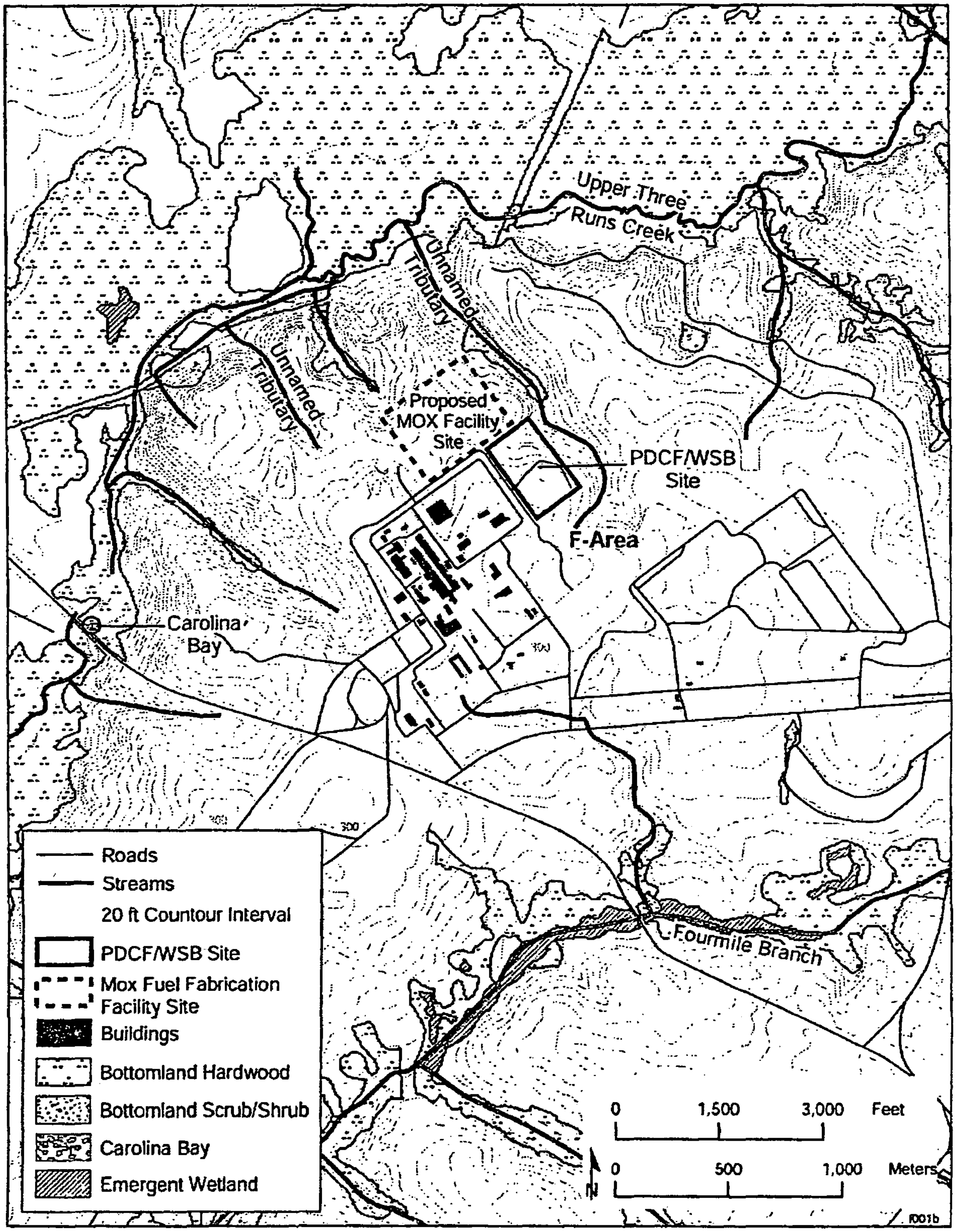

Figure 3.3. Locations of surface water and wetlands in the F-Area (*Source*: Modified from DCS 2002).

(points of discharge); permit SC0044903 regulates another 7 outfalls. The 2000 compliance for these outfalls was 99.7%. The 48 storm-water-only outfalls regulated by the site's storm-water permits are monitored as required. A sediment reduction and erosion plan is required for storm-water runoff from any construction area that exceeds 2 ha (5 acres).

The Savannah River is classified as a freshwater source that is suitable for primary and secondary contact recreation, drinking after appropriate treatment, balanced native aquatic species development, and industrial and agricultural purposes. Primary contact means direct contact with the water, such as while swimming. Secondary contact means having some direct contact with the water but where swallowing is unlikely to occur, such as while fishing. Data from the river's monitoring locations generally indicate that South Carolina's freshwater standards are being met.

Runoff from the land area around F-Area drains to Upper Three Runs Creek and Fourmile Branch (DOE 1999). Runoff from the proposed facilities area drains into unnamed tributaries of Upper Three Runs Creek and flows to the northwest. Runoff from southern portions of the F-Area flow to the southeast into Fourmile Branch. The location for the proposed MOX facility is approximately 670 m (2,200 ft) southeast of Upper Three Runs Creek (WSRC 2000a). An unnamed tributary to Upper Three Runs Creek is located within about 150 m (500 ft) of the proposed MOX facility site (see Figure 3.3). The proposed MOX facility is located about 2,100 m (6,900 ft) north of Fourmile Branch.

Upper Three Runs Creek is a large, cool blackwater stream (i.e., a freshwater stream that has a dark color because of organic debris and tannin-containing compounds) that flows into the Savannah River along the western boundary of the SRS (see Figure 3.2). It drains an area of about 544 km^2 (210 mi^2) and had a mean discharge of 6.9 m^3/s (245 ft^3/s) near its mouth during water year 1995 (WSRC 2000a). A water year is measured from October 1 through September 30. The 7Q10 low-flow is about 2.8 m^3/s (100 ft^3/s). The stream is about 40 km (25 mi) long. It receives water from groundwater aquifer discharges and permitted discharges from several areas at the SRS, including F-Area, S-Area, the Central Sanitary Waste Treatment Facility, and treated industrial wastewater from the Chemical Waste Treatment Facility steam condensate. The stream, however, has never received heated discharges of cooling water from the former SRS production reactors. Flow from the sanitary wastewater discharge averages less than 0.001 m^3/s (0.035 ft^3/s).

Fourmile Branch is a blackwater stream that has been affected by past operational practices at the SRS (DOE 1999). Its headwaters are near the center of the SRS, and it flows southwesterly to the Savannah River. Until June 1985, it received large volumes of hot cooling water from the production reactor in C-Area. While the C-Area reactor was operational, the ambient temperature in Fourmile Branch was 60°C (140°F) (DOE 1999). It has a watershed area of about 54 km^2 (21 mi^2) and receives permitted effluent discharges from F-Area and H-Area. Average flow in the stream is approximately 1.8 m^3/s (64 ft^3/s). The 7Q10 low flow at the same location is about 0.23 m^3/s (8.2 ft^3/s) (WSRC 2000a). In its lower reaches, the stream widens and flows via braided channels through a delta. Downstream of the delta, it reforms into one main channel, with most of the flow discharging into the Savannah River at river mile 152.1; the remainder of the flow enters the Savannah River Swamp.

Under NPDES permit SC0000175, five outfalls discharge effluent to Fourmile Branch. Permitted discharges include 186 basin overflows, cooling water, floor drains, steam condensate, process wastewater, laundry effluent, storm water, sanitary treatment wastewater, ash basin runoff, and lab drains. Within the vicinity of F-Area, there are four permitted outfalls: F2, F3, F4, and F5. Discharge from the F2 outfall averages 0.0048 m^3/s (0.17 ft^3/s). F5 has a flow of 0.0013 m^3/s (0.046 ft^3/s). Outfall F3 is not currently used, but discharges storm water. Outfall F4 is an "administrative outfall" (i.e., an outfall with no pollutant load).

When the Savannah River floods, water from Fourmile Branch flows along the northern boundary of the floodplain and joins with other streams to exit the swamp via Steel Creek instead of flowing directly into the Savannah River. The location for the proposed facilities would not be within the 100-year floodplain of Upper Three Runs Creek (DCS 2002). Similarly, estimated water levels for the probable maximum flood (PMF) for Upper Three Runs Creek are about 15 m (50 ft) below the lowest elevation in F-Area (67 m [220 ft]).

3.3.2 Groundwater

Sole Source Aquifer

- An aquifer that supplies at least 50% of the drinking water to the area above the aquifer.
- Areas that have no other water supply capable of physically, legally, or economically providing drinking water to local populations.

Several aquifers occur at the SRS (see Figure 3.4). However, no federally designated sole-source aquifers occur there. The uppermost aquifer is known as the Upper Three Runs Aquifer. It occurs at an elevation of about 55 to 67 m (180 to 210 ft) above mean sea level (MSL) in F-Area (DCS 2002). The Upper Three Runs Aquifer lies on top of the leaky Gordon Confining Unit (Green Clay aquitard), which forms a confining layer for the Gordon Aquifer (Congaree Aquifer). The Upper Three Runs Aquifer along with the Gordon Confining Unit and the Gordon Aquifer constitute the Floridan Aquifer System (WSRC 2000a). To the north, the Gordon Confining Unit is not present, and the Gordon and Upper Three Runs Aquifers merge to form the Steed Pond Aquifer. Beneath the Gordon Aquifer is the leaky Crouch Branch Confining Unit (Ellenton aquitard), which, in turn, confines the Crouch Branch Aquifer (Cretaceous Aquifer) (DOE 1999; WSRC 2000a).

Groundwater in aquifers predominantly flows horizontally to points of discharge, such as streams and swamps. In addition, some flow also occurs vertically to either underlying or overlying groundwater aquifers. Groundwater in the Upper Three Runs Aquifer, in general, flows horizontally and discharges to nearby streams. A small portion of the groundwater flows vertically downward to the Gordon Aquifer. Flow in the Gordon Aquifer is mostly horizontal to eventual stream discharge or discharge to the Savannah River, depending on location. Some of the water also flows downward to the underlying Crouch Branch Aquifer. Water in the Crouch Branch Aquifer primarily discharges to Upper Three Runs Creek and the Savannah River. Groundwater beneath the SRS flows slowly at rates that range from inches per year in the clay aquitards that confine the aquifers to several hundred feet per year in the sandy aquifers

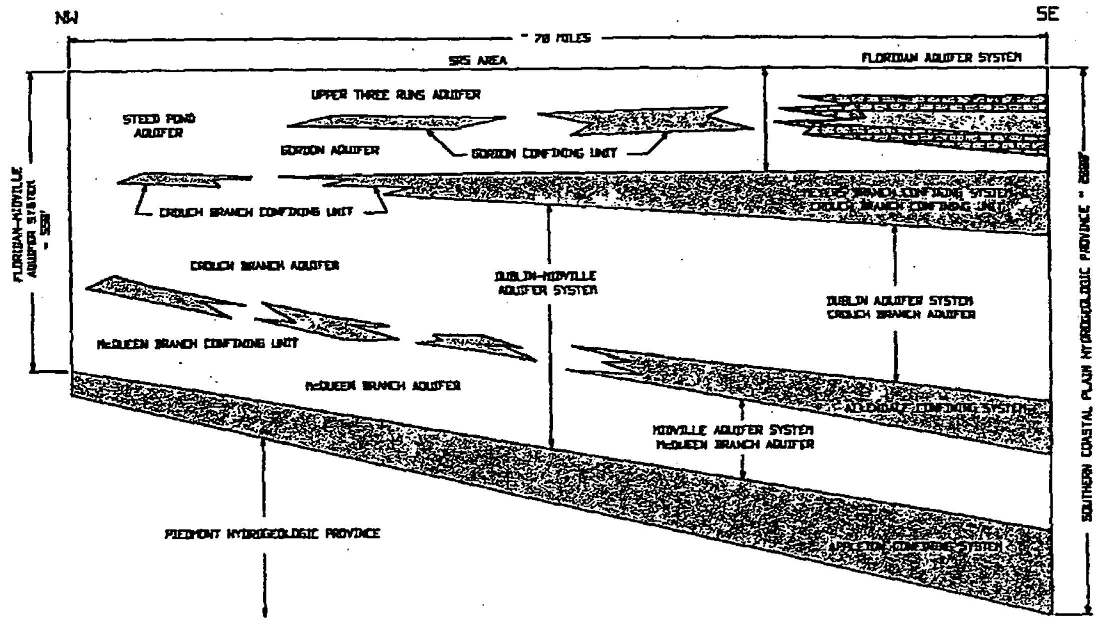

Figure 3.4. Aquifers at the SRS (*Source*: DCS 2001a).

(WSRC 2000c). Average annual recharge to the Upper Three Runs Aquifer is 35.6 cm (14 in.) (WSRC 1997a).

The Crouch Branch Aquifer is an abundant and important water resource for the SRS region. At the SRS, groundwater is the only source of domestic water. All groundwater at the SRS is classified by the U.S. Environmental Protection Agency (EPA) as a Class II water source (i.e., a current and potential source of drinking water). In 2000, the SRS withdrew 7.95 billion L (2.1 billion gal) of groundwater from the Crouch Branch Aquifer in support of site operations. Some nearby towns, such as Aiken, South Carolina, obtain groundwater from the Crouch Branch Aquifer, but most of the rural population draws water from the Gordon, Upper Three Runs, or Steed Pond Aquifers. About 8 billion L/yr (2.1 billion gal/yr) of groundwater is withdrawn from these upper aquifers within a 16-km (10-mi) radius of the site (DCS 2002).

F-Area is located on a groundwater divide between Fourmile Branch and Upper Three Runs Creek. Near-surface groundwater in the southern portion of the F-Area primarily moves laterally and discharges to Fourmile Creek and its tributaries to the south. In the northern portion of the F-Area, including the proposed location of the facilities, near-surface groundwater also primarily moves laterally, but discharges to Upper Three Runs Creek and its tributaries to the north (WSRC 2000c). F-Area is located in a region of groundwater recharge from precipitation.

Beneath the site for the proposed MOX facility, the Upper Three Runs Aquifer is divided into upper and lower zones by the Tan Clay confining unit of the Dry Branch Formation (DCS 2002).

In the area near the proposed MOX facility site, the topography drops sharply to the north toward Upper Three Runs Creek, and the water table occurs in the lower aquifer zone beneath the Tan Clay confining unit. Water table elevation data and computer modeling indicate that shallow groundwater flows away from the Old F-Area Seepage Basin (OFASB) in a north-northwesterly direction and is discharged to a tributary of Upper Three Runs. A small component of this groundwater flows beneath the westernmost corner of the proposed MOX facility site. Depth to groundwater in the area of the OFASB and the proposed MOX facility site ranges from 23.2 to 28.3 m (76 to 93 ft) below the present ground surface. Site preparation for the proposed MOX facility, PDCF, and WSB would involve shallow grading and excavation to a depth of about 12.2 m (40 ft). These activities would not encounter groundwater.

Groundwater varies in quality across the SRS. In some areas, it meets drinking water quality standards; in other areas, such as near waste sites, it does not. The deep Crouch Branch Aquifer is generally unaffected by site operations, except for a location near A-Area, where trichloroethylene contamination has been found. Tritium has been reported in the Gordon Aquifer under the Separation Areas (F- and H-Areas). The Upper Three Runs Aquifer is contaminated with solvents, metals, and low levels of radionuclides near several SRS areas and facilities, including the F-Area.

Groundwater is the only source of domestic water at the SRS. The existing capacity at the SRS is approximately 33.5 billion L/yr (8.9 billion gal/yr). Groundwater rights in South Carolina are associated with the absolute ownership rule. Owners of land overlying a groundwater resource are allowed to withdraw as much water as they desire; however, the state requires users who withdraw more than 138 million L/yr (36.5 million gal/yr) to report their withdrawals. Because the groundwater use at the SRS exceeds this value, DOE is required to report its usage to the state (DCS 2002).

Within F-Area, four groundwater wells are used for process water. Pumping capacities for these wells range from 1,500 to 3,800 L/min (400 to 1,000 gpm). They extract groundwater from the Crouch Branch Aquifer. Two of these wells were formerly used for domestic water supply. The current annual groundwater use at F-Area is 374 million L (98.8 million gal). The estimated capacity of the wells in F-Area is about 4.2 billion L/yr (1.1 billion gal/yr) (DCS 2002).

The F-Area wells are part of a SRS A-Area domestic water loop. The combined capacity of the F-Area and A-Area wells is about 11,360 L/min (3,000 gal/min) (DCS 2003a,b). Water consumption in 2000 averaged 2,850 L/min (754 gal/min). Therefore, an excess capacity of about 8,500 L/min (2,250 gal/min) exists for the A-Area loop. The A-Area loop supplies water to both A-Area and F-Area.

Groundwater quality in F-Area is not significantly different from that of groundwater throughout the rest of the SRS. It is abundant, usually soft, slightly acidic, and low in dissolved solids. F-Area groundwater can exceed drinking water standards for several contaminants. In 1999, 18% of 365 wells sampled at the General Separations and Waste Management Areas (Areas F, E, H, S, and Z) had metal concentrations that exceeded metal drinking water standards; 10% of 471 wells sampled had organic concentrations that exceeded organic drinking water standards; 53% of 483 wells sampled exceeded drinking water standards for tritium; 40% of 372 wells sampled exceeded drinking water standards for other radionuclides; and 31% of 307 wells sampled exceeded drinking water standards for other constituents. The sources of the detected groundwater contamination included burial grounds, waste management facilities, canyon buildings, seepage basins, and saltstone disposal facilities (WSRC 2000c).

Near the F-Area seepage basins and inactive process sewer line, there is widespread radionuclide contamination. Near the F-Area Tank Farm, tritium, mercury, nitrate-nitrite (as nitrogen), cadmium, gross alpha, and lead were detected in concentrations that exceeded drinking water standards in one or more wells. At the Sanitary Sludge Application Site, tritium, specific conductance, lead, and copper values exceeded their drinking water standards in one or more wells. In addition, a subsurface plume of tritium and strontium contamination has recently been found in F-Area. The source of groundwater contamination is from various heavy industrial and nuclear operations over the past 50 years in the F-Area. The contaminant plume appears to originate inside F-Area and extend beneath the MOX facility site, with movement in a fan-like direction of groundwater flow under the proposed MOX facility site.

Contaminated groundwater also exists beneath the OFASB. The OFASB is located about 180 m (600 ft) north of F-Area, immediately adjacent to the western boundary of the proposed MOX facility site. The OFASB has been remediated by filling the basin with clean soil, capping, and stabilizing the contaminated soil within the basin with grout (WSRC 1997a). The results of sampling in the compliance wells for the OFASB indicated that concentrations of several target constituents were above drinking water standards in several wells. These contaminants included iodine-129, nitrate, radium-226, radium-228, strontium-90, tritium, uranium (total), and lead. There is, however, some uncertainty about whether these exceedances are related entirely to OFASB, to upgradient F-Area facilities, or to both. A small component of the contaminant plume from OFASB flows beneath the westernmost corner of the proposed MOX site. Groundwater is monitored on a regular basis with 15 wells. Contaminant fate and transport models predict that the aquifer is expected to return to an uncontaminated state (i.e., a condition in which no maximum contaminant levels are exceeded) within 2 to 115 years, depending on the specific contaminant.

The results of recent groundwater sampling of nine wells distributed uniformly across the proposed MOX facility site indicate that shallow groundwater (i.e., groundwater in the Upper Three Runs Aquifer) is contaminated (SRS 2002). Gross alpha and beta activity, tritium, uranium, and trichloroethylene exceeded maximum contaminant levels for drinking water. Contamination is present beneath the entire MOX site, but is greatest beneath the western edge of the site. The contaminant plume appears to originate inside the F-Area fence and was and is related to F-Area nuclear operations and waste management practices at OFASB.

Groundwater in the Upper Three Runs Aquifer beneath the proposed MOX facility site is contaminated with various heavy industrial and nuclear contaminants. The proposed construction activities will take place at least 9.1 m (30 ft) above the zone of contaminated groundwater.

3.4 Meteorology, Emissions, Air Quality, and Noise

This section discusses the existing meteorology, current airborne pollutant emissions, air quality, and noise environment in the vicinity of the SRS. Section 3.4.1 describes the meteorology, or weather conditions, around the SRS. Meteorology includes the atmospheric conditions that determine where pollutants released into the atmosphere travel and how they are mixed with existing air and become diluted as they travel. Section 3.4.2 describes existing air emissions from the SRS and the surrounding area. Section 3.4.3 describes regional air quality and air quality standards. Air emissions from the proposed MOX facility, the PDCF, and the WSB would combine with existing emissions to affect local and regional air quality. Comparing the resulting combined air quality against the standard levels provides one measure of the facilities' impact on air quality. Section 3.4.4 describes the existing noise environment and applicable regulations. Noise generated by the facilities would combine with existing levels to produce the overall noise impact.

3.4.1 Meteorology[2]

To provide a thorough picture of weather conditions at a given location often requires the use of data from several locations. Different locations that record meteorological data may record different parameters. Data recorded near the site of the proposed action is generally considered most representative of the site. Meteorological data for F-Area (the site of the proposed facilities), H-Area, and Bush Field in Augusta, Georgia, were used to describe meteorological conditions of the affected environment.

Meteorology

Meteorology deals with weather conditions. Air pollution meteorology emphasizes weather conditions that determine how pollutants released into the air travel and mix with the air. The more important weather conditions involved in this process include wind speed and direction and atmospheric stability, a measure of how much mixing is occurring in the atmosphere.

The climate at the SRS is characterized by short, mild winters and long, humid summers (DCS 2002). Mountains to the north and west prevent or delay the approach of many cold air masses (Ruffner 1985).

The annual average wind speed is 2.8 m/s (6.2 mph) at Bush Field, which is located in Augusta, Georgia, about 24 km (15 mi) northwest of F-Area. Wind speed is highest in the spring, averaging 3.1 m/s (7.0 mph). March has the highest monthly average wind speed of 3.4 m/s (7.7 mph) and August the lightest, 2.3 m/s (5.1 mph). The prevailing monthly wind direction is from the west-northwest from November through February and variable for the rest of the year. On the basis of observations for 1995-1999, the highest 2-minute wind speed was 20 m/s

[2] Unless otherwise noted, the information presented in this section is based on meteorological data collected at Bush Field in Augusta, Georgia, about 24 km (15 mi) northwest of F-Area, and summarized by the National Climatic Data Center (NOAA 1999).

(45 mph) from the north-northwest in June 1998, and the maximum gust (5-second wind speed) was 25 m/s (55 mph) from the north-northwest in April 1997.

A wind rose based on data from the 5-year period 1992 through 1996 from the 62-m (200-ft) meteorological tower in H-Area at the SRS is presented in Figure 3.5. The wind rose indicates no strongly predominant prevailing wind direction, but the wind is from the northeast about 10% of the time and from the west-southwest over 9% of the time. Annual average wind speeds ranged from 3.6 to 4.2 m/s (8.0 to 9.4 mph) during the 5-year period (DCS 2002).

Wind Rose

A *wind rose* summarizes wind speed and direction graphically as a series of bars pointing in different directions. The direction of a bar shows the direction *from* which the wind blows. Each bar is divided into segments. Each segment represents wind speeds in a given range of speeds, for example, 6-8 m/s. The length of a given segment represents the percentage of the summarized hours that winds blew from the indicated direction with a speed in the given range.

The driest period occurs during the months of October and November, with rainfall increasing after then to a peak in March. A dry period extends from April through early June, followed by a wet period from late June through early September caused primarily by thunderstorms and showers (Ruffner 1985). Average annual precipitation at Bush Field is 114 cm (44.7 in.). Data from 1967 to 1996 at the SRS show an average annual precipitation of 126 cm (49.5 in.) (DCS 2002). Average monthly precipitation ranges from 6.30 cm (2.48 in.) in November to 11.8 cm (4.65 in.) in March. The greatest amount of precipitation recorded in a single month was 37.6 cm (14.8 in.) in October 1990, and the least amount was in October 1953, when only trace amounts of rainfall were recorded. The greatest amount of precipitation recorded in a 24-hour period was 21.8 cm (8.57 in.) in October 1990. Snowfall occurs only one to three times in the winter and usually remains on the ground for only a short period (Ruffner 1985). Annual snowfall averages 3.3 cm (1.3 in.). The greatest monthly snowfall occurred in February 1973, with 35.6 cm (14.0 in.), and the greatest 24-hour snowfall was 34.8 cm (13.7 in.) in the same month. Freezing rain may occur one to three times per winter (Ruffner 1985).

The average annual temperature at Bush Field is 17.5°C (63.5°F). At the SRS, the average annual temperature is 17.3°C (63.2°F) (DCS 2002). January is the coldest month, with an average temperature of 7.39°C (45.3°F), and July the warmest, averaging 26.7°C (80.1°F). Daily extreme temperatures have ranged from 42.2°C (108°F) in August 1983 to -18°C (-1°F) in January 1985. An average of 309 freeze-free days (days with a minimum temperature greater than 0°C [32°F]) occur per year. There are no freeze days from May through September. Temperatures above 32°C (90°F) occur about 73 days per year, with 56 of them occurring in June, July, and August.

Average annual relative humidity at Bush Field ranges from 83% in the early morning to 51% in the afternoon. In July and August, the early morning relative humidity averages 90%, with afternoons averaging 55-56%. At the SRS, comparable values for August are 97% and 50% (DCS 2002). Dew point temperatures at Bush Field range from 1.33°C (34.4°F) in January to 21.0°C (69.7°F) in July. Heavy fog with visibility less than 0.40 km (0.25 mi) occurs on an

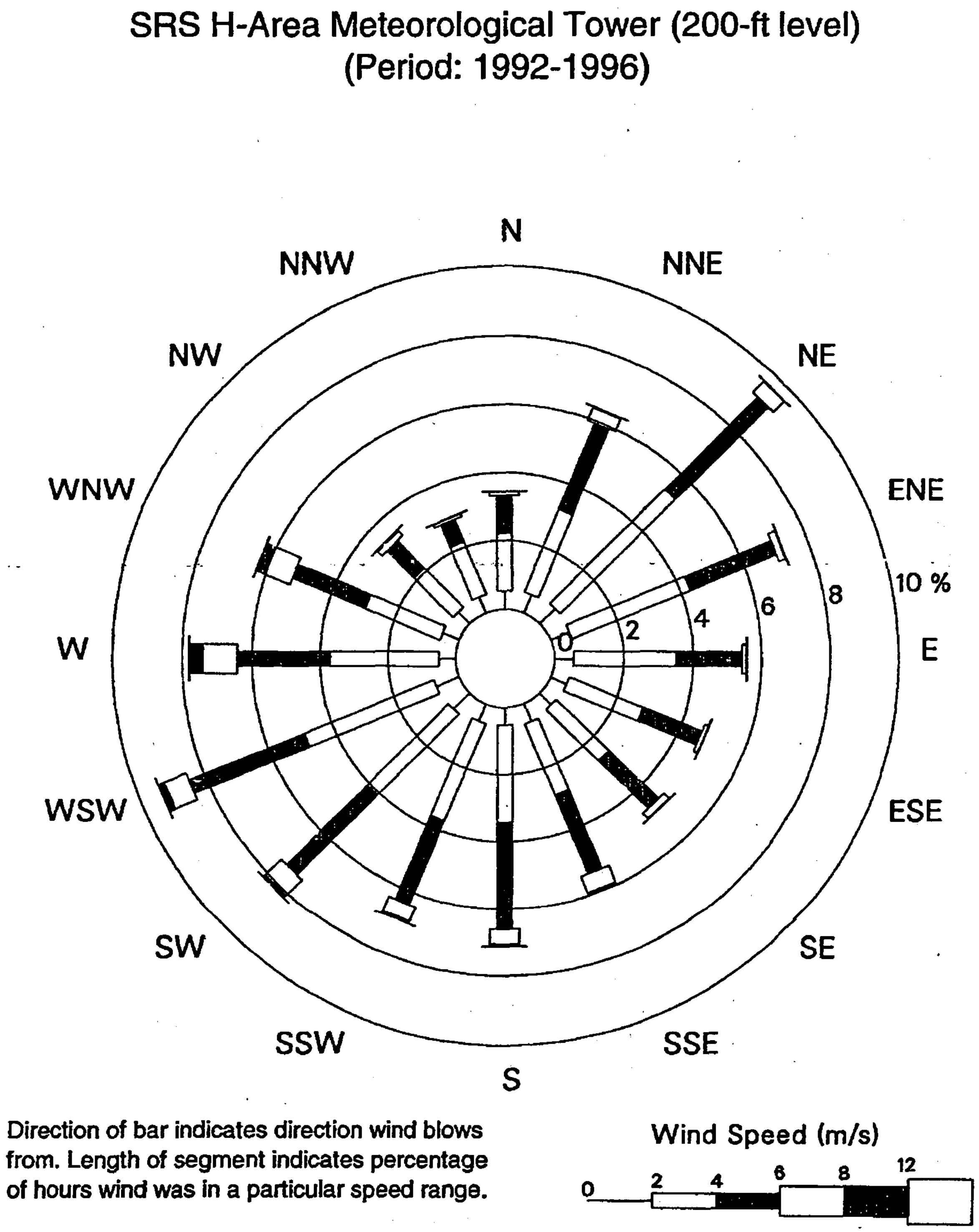

Figure 3.5. Annual wind rose for the SRS (*Source*: Arnett and Mamatey 2000a, Table 31).

average of about 32 days per year. Heavy fog occurs throughout the year but is most likely in November and December.

Thunderstorms, tornadoes, and hurricanes provide occasional severe weather to South Carolina (Ruffner 1985). Thunderstorms occur on an average of 53 days per year at Bush Field. July averages 12.6 thunderstorm days, December 0.7. More than 70% of the thunderstorms occur in the four-month period from May through August. They are most common in the summer months, but the more violent storms generally occur along active cold fronts in spring (Ruffner 1985). Hail with thunderstorms is infrequent and occurs about once every 2 years on the average (DCS 2002).

Tornadoes are rare in South Carolina. Most that do occur are during the period March through June. April is the peak month for tornadoes, with a smaller peak in August and September (Ruffner 1985). For the 49-year period of 1950-1998, an average of 11 tornadoes per year occurred in South Carolina (Storm Prediction Center 2001). Between 1880 and 1995, a total of 17 significant tornadoes were reported in Aiken and Barnwell Counties, South Carolina, and Burke County, Georgia. Nine tornadoes have caused damage on the SRS, one with estimated wind speeds as high as 67 m/s (150 mph). None have caused damage to buildings on the SRS (DCS 2002).

Tropical storms or hurricanes affect South Carolina about once every 2 years. Most do little damage and affect only the costal areas, decreasing in intensity as they move inland. Those that do move far inland can cause considerable flooding (Ruffner 1985). Thirty-six hurricanes caused damage in South Carolina between 1700 and 1989, and the interval between them has ranged from 2 months to 27 years. About 80% have occurred in August and September. Between 1886 and the present, 17 storms (10 hurricanes and 7 tropical storms) have passed within 64 km (40 mi) of the proposed MOX facility site. All the hurricanes had been downgraded to tropical storms or tropical depressions before reaching SRS (Weather Site, Inc. 2003). The only hurricane-force winds measured at the SRS were associated with Hurricane Gracie on September 29, 1959, when wind speeds of 34 m/s (75 mph) were measured at F-Area (DCS 2002).

3.4.2 Emissions

The SRS is classified as a "major source" (of airborne pollutant emissions) under the Clean Air Act (CAA), with potential emissions of more than 227,000 kg/yr (250 tons/yr). The SRS has construction and operating permits from the South Carolina Department of Health and Environmental Control (SCDHEC), Bureau of Air Quality, for about 199 point sources. Thirty-eight of these sources are permitted for air toxics. During 2000, 137 sources operated at least part of the year, and 62 were on cold standby or under construction.

Significant sources of criteria air pollutants[3] or their precursors and toxic air emissions at the SRS include coal-fired powerhouse boilers (two in A-Area and three in H-Area) and No. 2 oil-fired package steam generators (two in K-Area and two portable units). Other facilities emitting nonradiological emissions include 128 pieces of equipment powered by diesel engines, the Defense Waste Processing Facility, groundwater air strippers, the Consolidated Incineration Facility, and controlled burning. During 2000, the SRS continued to be in compliance with permitted emission rates and special conditions (Arnett and Mamatey 2001b).

SRS point source emissions for 1999 are compared with point source and total emissions within the four surrounding counties — Aiken, Allendale, and Barnwell Counties in South Carolina and Burke County in Georgia — in Table 3.1. The SRS contributed less than 6% of the four-county point source emissions of nitrogen oxides (NO_x), sulfur dioxide (SO_2), volatile organic compounds (VOCs), and particulate matter less than 10 µm and less than 2.5 µm in diameter, (PM_{10} and $PM_{2.5}$, respectively) in 1999. The SRS contributed about 17% of the four-county area point source emission of carbon monoxide (CO). However, CO is generated primarily by mobile sources, and the SRS emitted only about 0.20% of the total point and nonpoint CO for the four-county area. Arnett and Mamatey (2001a) provide an inventory of about 200 toxic air pollutant emissions from the SRS for 1999. Table 3.2 lists the emissions that exceeded 0.9 MT (1 ton) per year.

3.4.3 Air Quality

The SRS is located in the Augusta-Aiken Interstate Air Quality Control Region (AQCR) #53, which comprises 6 counties in South Carolina and 13 in Georgia (see Figure 3.6) (EPA 1972). Both South Carolina and Georgia have adopted State Ambient Air Quality Standards (SAAQS) identical to the federal National Ambient Air Quality Standards (NAAQS) for the criteria pollutants (see adjacent text box). In addition, South Carolina has retained the annual standard for total suspended particulates (TSP) and adopted an additional standard for gaseous fluorides (SCDHEC 2000; GDNR 2000).

Air Quality Terms

Particulate matter (PM) is dust, smoke, other solid particles, and liquid droplets in the air. The size of the particulate is important and is measured in micrometers (µm). A micrometer is 1 millionth of a meter (0.000039 in.).

Total suspended particulate (TSP) is PM with a diameter less than 30 µm. *PM_{10}* is PM with a diameter less than 10 µm and *$PM_{2.5}$* is PM with a diameter less than 2.5 µm. The U.S. Environmental Protection Agency (EPA) has set standards for PM_{10} and $PM_{2.5}$ designed to protect human health and welfare.

Criteria pollutants are pollutants for which the EPA has prepared documents detailing their health and welfare impacts and set standards specifying the air concentrations that avoid these impacts. The criteria pollutants are sulfur oxides, nitrogen dioxide, carbon monoxide, PM_{10}, $PM_{2.5}$, lead, and ozone.

Volatile organic compounds (VOCs) are organic vapors in the air that can react with other substances, principally nitrogen oxides, to form ozone. The reactions are energized by sunlight.

Background is a concentration value, usually based on measured pollutant data, that accounts for the impacts of emission sources not included explicitly in the air quality model.

[3] "Criteria" air pollutants are common air pollutants for which federal standards have been established.

Table 3.1. Estimated emissions from four counties around the SRS and SRS point sources in 1999[a]

	Four-county area emissions (tons/yr)[b]		SRS emissions		
				As percentage (%) of four-county area	
Pollutant[c,d]	Point	Total	Total (tons/yr)	Point	Total
CO	712	62,300	124	17	0.20
NO_x	6,800	17,700	337	5.0	1.9
SO_2	14,600	15,400	346	2.4	2.3
PM_{10}	1,250	1,747	54.5	4.4	3.1
$PM_{2.5}$	696	1,120	37.9	5.4	3.4
VOCs	1,770	8,330	7.45	0.42	0.089

[a]Four SRS border counties: Aiken, Barnwell, and Allendale, South Carolina; and Burke, Georgia. "Point" values are for all point sources. "Totals" are for all sources, including point, area, and mobile.

[b]To convert tons to kilograms, multiply by 907.2.

[c]The reference does not include lead. Lead emissions have been lowered by reductions in the lead content of gasoline.

[d]Ozone is not emitted directly and is not listed in this table. It is formed in the air by chemical reactions involving VOCs and NO_x.

Source: EPA (2001).

South Carolina is currently designated as being in attainment (i.e., in compliance with standards) for all criteria pollutants (40 CFR 81.341). Georgia is designated as in attainment except for the 13-county area around Atlanta, which is designated as nonattainment for the 1-hour ozone standard (40 CFR 81.311). A list of the ambient standards and the high and low ambient concentrations at air quality monitoring stations within 80 km (50 mi) of the proposed MOX facility site is shown in Table 3.3. The regulations for Prevention of Significant Deterioration (PSD) of air quality (40 CFR 52.21) place limits on the total

National Ambient Air Quality Standards (NAAQS)

The EPA sets NAAQS for criteria pollutants (sulfur oxides, PM_{10}, $PM_{2.5}$, carbon monoxide, nitrogen dioxide, lead, and ozone). The primary NAAQS specify maximum ambient (outdoor air) concentrations of the criteria pollutants that would protect public health with an adequate margin of safety. Secondary NAAQS specify maximum concentrations that would protect public welfare. If both a primary and a secondary standard exist, the lower (more restrictive) standard is normally used for assessment purposes. Some of the NAAQS for an averaging time of 24 hours or less allow the standard values to be exceeded a limited number of times per year.

Table 3.2. Toxic air pollutant emissions at the SRS in 1999

Pollutant[a]	CAS number[b]	Emissions (tons/yr)[c]
Benzene	71-43-2	4.16
Chloroform	67-66-3	6.30
Formaldehyde	50-0-0	1.28
Formic acid	64-18-6	3.45
Hexane	110-54-3	1.14
Hydrochloric acid	7647-1-0	1.73
Hydrogen sulfide	7783-6-4	5.71
Methoxychlor	67-56-1	1.46
Nitric acid	7697-37-2	1.04
Sodium hydroxide	1310-73-2	1.32
Tetrachloroethylene	127-18-4	2.17
Toluene	108-88-3	1.87
Trichloroethylene	79-1-6	5.53
Xylenes	1330-20-7	4.96

[a]Only pollutants with emissions of more than 1 ton are listed.

[b]Chemical Abstract Services (CAS) number — a number assigned to a specific chemical by CAS. The number avoids the ambiguity associated with multiple names for the same chemical and also avoids problems associated with name differences between languages.

[c]To convert tons to kilograms, multiply by 907.2.

Source: Arnett and Mamatey (2001a, Table 45).

increase in ambient pollution levels above established baseline levels for SO_2, NO_2, and PM_{10}. Under those regulations, the allowable increases are smallest in Class I areas (national parks and wilderness areas). The rest of the country is subject to PSD II increments. States can choose a less stringent set of Class III increments, but no states have chosen to do so. The Cape Romain National Wildlife Refuge, the PSD Class I area closest to the SRS, is about 160 km (100 mi) to the east. The facilities at the SRS have not been required to obtain PSD permits (DCS 2002).

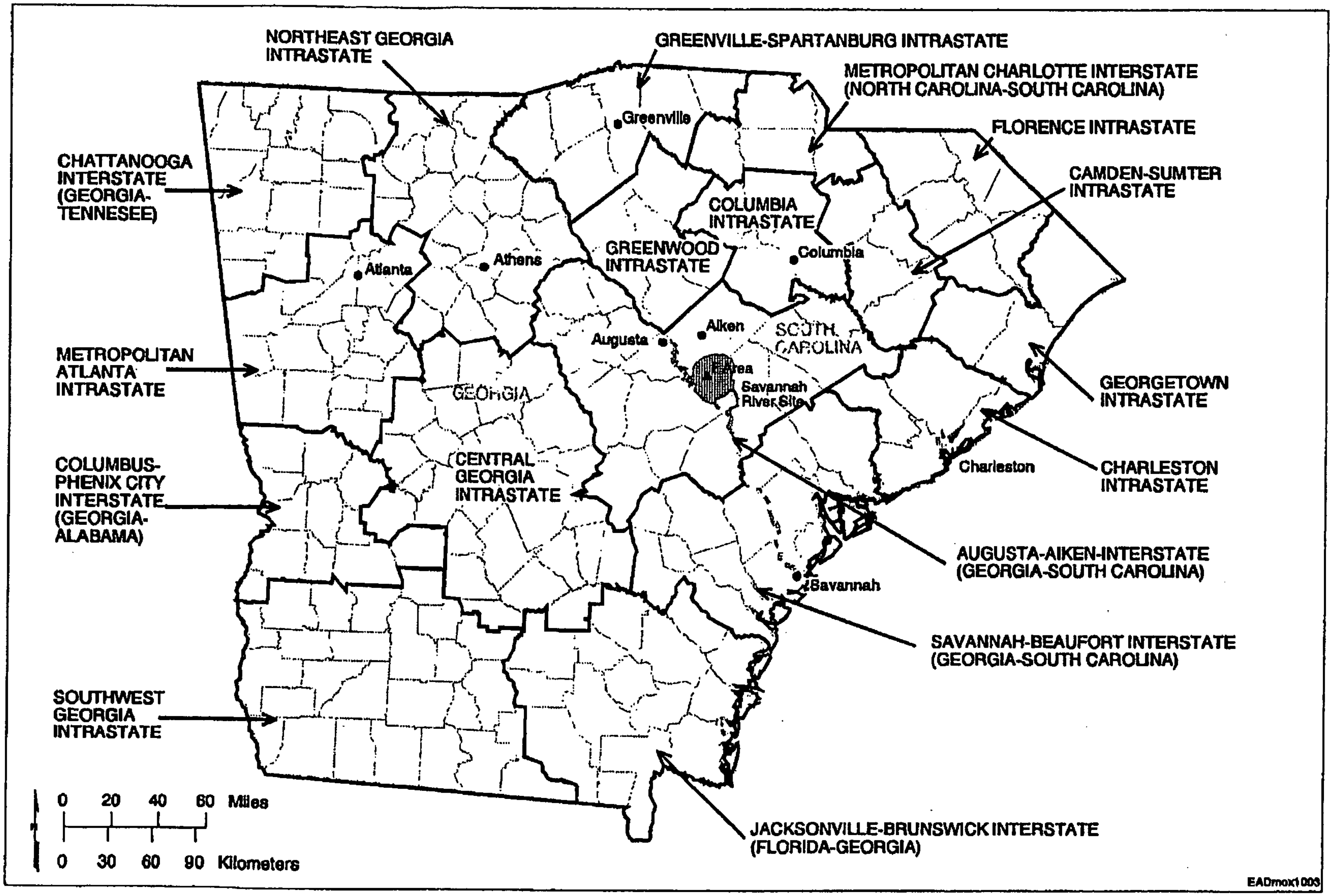

Figure 3.6. Air quality control regions, South Carolina and Georgia.

Table 3.3. Ambient air quality standards and range of pollutant levels in the vicinity of the SRS

Pollutant	Averaging time	Ambient standard (µg/m³)[b,c]	Highest/lowest levels in vicinity of SRS[a] Concentrations (µg/m³)	Locations (city, county, state)	Years
SO_2	3 hours	1,300[d]	180	–, Barnwell, SC	1999
			58	–, Barnwell, SC	1997
	24 hours	365[e]	55	Augusta, Richmond, SC	1997-2000
			13	–, Barnwell, SC	1997-1998
	Annual	80[e]	5.2[f]	–, Aiken, SC/ Augusta, Richmond, GA	1999/ 1997-2000
			2.6[f]	–, Aiken, SC/ –, Barnwell, SC	1996-1998/ 1997-2001
NO_2	Annual	100[g]	9.4	–, Aiken, SC	1997-2000
			5.6	–, Barnwell, SC	1999, 2001
CO	1 hour	40,000[e]	–[h]		–
	8 hours	10,000[e]	–[h]		–
O_3	1 hour	235[g]	233[i]	Augusta, Richmond, SC/ –, Edgefield, SC	1998/1998
			165[i]	–, Edgefield, SC	2001
	8 hours[j]	157[g]	194[k]	Augusta, Richmond, SC	1998
			145[k]	–, Barnwell, SC	2001
PM_{10}	24 hours	150[g]	165[l]	–, Lexington, SC	1997
			36[l]	–, Aiken, SC	2001
	Annual	50[g]	29	–, Lexington, SC	1999
			17	–, Aiken, SC	2001

Table 3.3. Continued

Pollutant	Averaging time	Ambient standard (μg/m³)[b,c]	Highest/lowest levels in vicinity of SRS[a] Concentrations (μg/m³)	Locations (city, county, state)	Years
$PM_{2.5}$	24 hours[j]	65[g]	42[l]	Augusta, Richmond, GA	1999
			17[l]	–, Colleton, SC	2000
	Annual[j]	15[g]	19.9	Augusta, Richmond, GA	1999
			11.2	–, Colleton, SC	2000
Pb	Calendar Quarter	1.5[g]	0.04	–, Lexington, SC	1999
			0.00	Multiple	1997-2001
TSP[m]	Annual	75[e]	41[n]	–, Aiken, SC	1998
			26[n]	–, Lexington, SC	2001

[a]Based on available data for 1997 through 2001 unless otherwise noted. The vicinity of the SRS was taken to be the area within 80 km (50 mi) of the proposed MOX facility and includes all or part of Aiken, Bamberg, Barnwell, Colleton, Edgefield, Hampton, Lexington, and Orangeburg Counties in South Carolina and Burke, Columbia, Jenkins, Richmond, and Screven Counties in Georgia. The listed concentrations are not always directly comparable to the ambient standards. Except for 13 counties around Atlanta, Georgia, that are nonattainment for 1-hour O_3, both South Carolina and Georgia have been designated as in attainment for all implemented standards. Footnote b summarizes criteria for determining standard attainment.

[b]Unless otherwise noted, South Carolina and Georgia SAAQS are the same as NAAQS. South Carolina has additional standards for gaseous fluorides that are not shown because they are not emitted by the proposed facility.

Footnotes continued on next page.

Table 3.3. Continued

[c]Methods of determining whether standards are attained depend on pollutant and averaging time. The 3-hour and 24-hour SO_2 standards and the 1-hour and 8-hour CO standards are not to be exceeded more than once per calendar year. The annual TSP, SO_2, and NO_2 standards are not to be exceeded in any calendar year. The lead standard is not to be exceeded in any calendar quarter. The 1-hour ozone (O_3) standard is attained when the expected number of days per calendar year with maximum hourly concentrations above the standard is less than or equal to one and applies only in areas designated nonattainment when the 8-hour O_3 standard was adopted in July 1977. The 8-hour O_3 standard is attained when the 3-year average of the annual fourth-highest daily maximum 8-hour concentrations is less than or equal to the standard. The 24-hour PM_{10} standard is attained when the expected number of days per calendar year with a 24-hour average concentration above the standard is less than or equal to one. In areas that meet certain criteria, attainment of the 24-hour PM_{10} standard is based on having the 3-year average of the 99th percentile 24-hour averages less than or equal to the standard. The annual PM_{10} standard is met when the 3-year average of the annual means is less than or equal to the standard. The 24-hour $PM_{2.5}$ standard is met when the 3-year average of the 98th percentile 24-hour averages is less than or equal to the standard. The annual $PM_{2.5}$ standard is met when the 3-year average of the annual means is less than or equal to the standard.

[d]Secondary (welfare-based) standard.

[e]Primary (health-based) standard.

[f]Years 2000 and 2001 data for Aiken County not available; years 1999 and 2000 data for Richmond County not available.

[g]Primary and secondary standard.

[h]No CO data in vicinity of SRS for 1997-2001.

[i]Second highest concentration.

[j]NAAQS only; implementation of the standard has been delayed, and states have not developed attainment plans.

[k]Fourth highest concentration.

[l]98th percentile concentration.

[m]South Carolina standard.

[n]Based on South Carolina data for 1998-2001.

Sources: 40 CFR 50; SCDHEC (2002a-d); EPA (2002, 2003a).

3.4.4 Noise

The *Noise Control Act of 1972* and subsequent amendments (*Quiet Communities Act of 1978*, 42 U.S.C. 2901-4918) delegate the authority to regulate noise to the states. However, South Carolina and Georgia do not have noise regulations. The Aiken County Zoning and Development Standards Ordinance limits noise levels by frequency band (see Table 3.4). The EPA guideline recommends an L_{dn}[4] of 55 dBA[5] to protect the public from the effects of noise in typically quiet outdoor and residential areas (EPA 1974). To protect the general population against hearing loss, the EPA guideline recommends an $L_{eq}(24)$[6] (L_{eq} averaged over 24 hours)

Table 3.4. Aiken County maximum allowable noise levels[a]

Frequency band (Hz)	Nighttime[b] sound pressure level at property boundary (dB)	
	Nonresidential	Residential
20-75	69	65
75-150	60	50
150-300	56	43
300-600	51	38
600-1,200	42	33
1,200-2,400	40	30
2,400-4,800	38	28
4,800-10,000	35	20

[a]This table gives nighttime sound pressure levels (SPLs). Allowable daytime levels are generally louder than nighttime levels.

[b]Nighttime: 9:00 p.m. to 7:00 a.m.

Source: DOE (1996).

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4 L_{dn} is a 24-hour average sound level that gives additional weight to noise that occurs during the night (10:00 p.m. to 7:00 a.m.).

5 dBA is A-weighted decibels, a unit of weighted sound-pressure level measured by specific methods and using the A-weighting specified by the American National Standards Institute (ANSI). It duplicates the ear's sensitivity to sound.

6 For sounds that vary with time, L_{eq} is the steady sound level that would contain the same total sound energy as the time-varying sound over a given time.

of 70 dBA or less over a 40-year period. The Federal Aviation Administration and the Federal Interagency Committee on Urban Noise have issued land use compatibility guidelines indicating that yearly day-night average sound levels (L_{dn}) of less than 65 dBA are compatible with residential land uses and that, if a community determines it is necessary, levels up to 75 dBA may be compatible with residential uses and transient lodgings (but not mobile homes) if such structures incorporate suitable noise reduction features (14 CFR 150, Appendix A).

Major noise sources in active areas at the SRS include industrial facilities and equipment such as cooling systems, transformers, engines, vents, paging systems; construction and materials-handling equipment; and vehicles. Outside of active operational areas, vehicles and trains generate noise. Most industrial facilities at the SRS are located far enough from the site boundary that the associated noise levels at the boundary would be barely distinguishable from background levels.

Noise impacts to the general public arise primarily from transportation of people and materials to and from the site by vehicles, helicopters, and trains (DCS 2002). A noise survey was conducted in the SRS area in 1989 and 1990 (NUS 1990). Seven off-site locations were selected along major routes used by SRS employees entering and leaving the site. Summer L_{dn} levels ranged from 62 to 72 dBA; winter L_{dn} levels ranged from 51 to 70 dBA. Summer 24-hr L_{eq} levels ranged from 60 to 67 dBA; winter values ranged from 54 to 65 dBA.

3.5 Ecology

> **Ecological Resources**
>
> Ecological resources include plant and animal species and the habitats on which they depend (e.g., forests, fields, wetlands, streams, and ponds).

This section describes the plant and animal resources at the SRS, with emphasis on those components that could be affected by the construction and operation of the proposed MOX facility and associated Pit Disassembly Conversion Facility/Waste Storage Building (PDCF/WSB) complex. Particular attention is given to species and special habitats protected by the federal government under the Endangered Species Act, as well as species of special concern listed by the states of South Carolina (Aiken and Barnwell counties) and Georgia (Burke County). In addition to federal and state regulations, DOE protects plants, animals, and Carolina bays in DOE Research Set-Aside Areas. Unless otherwise cited, the information presented in this section has been abstracted from DCS (2002).

3.5.1 Terrestrial

This section describes the native plant communities and wildlife species at the SRS and in the F-Area where the proposed facilities would be constructed. Wildlife habitats, wildlife management areas, and ecological research sites are also described.

3.5.1.1 Vegetation

At the time land for the SRS was purchased by the government in 1950, about 40% of the site was old field, crop land, or developed by the former town of Ellenton. The remainder of the area was forested (WSRC 1994). As the DOE developed the SRS, the vegetation changed over time. Many of the old fields reverted back to forested areas. In addition, this increase in wooded area also resulted from timber and watershed protection management directed by the U.S. Forest Service (WSRC 1994; DOE 1999).

In 1972, the entire SRS was designated as the nation's first National Environmental Research Park (NERP). Thirty specified areas within the SRS are designated as DOE Research Set-Aside Areas that are reserved for ecological research. These areas total 5,672 ha (14,005 acres), or about 7% of the SRS (Davis and Janecek 1997), and are selected and managed by the Savannah River Ecology Laboratory (SREL) (WSRC 1994). They serve as control areas, providing a context for comparisons with other areas on the SRS that may be affected by human activities. The set-aside areas are located in each of the major vegetation communities characteristic of the SRS (DOE 2000b). The closest set-aside area to the proposed facilities is Set-Aside Area No. 13 (Organic Soils), located about 500 m (1,640 ft) northwest of the proposed facilities. Most of this 310.8-ha (767.3-acre) area is located on the north side of Upper Three Runs Creek. Set-Aside Area No. 15 (Whipple/Office of Health and Environmental Research [OHER] Study Site) is located about 1.8 km [1.1 mi] northeast of the proposed facilities, and three other set-asides (No. 1 [Field 3-412/Ellenton Bay], No. 6 [Beech-Hardwood Forest], and No. 14 [Mature Hardwood Forest]) are located more than 3.4 km (2.1 mi) southwest of the facility area. Upper Three Runs Creek borders or runs through these set-aside areas (Davis and Janecek 1997).

In June 1999, the DOE designated a 4,055-ha (10,012-acre) area of the SRS as a biological and wildlife refuge. This area, known as the Crackerneck Wildlife Management Area (WMA) and Ecological Preserve (Crackerneck WMA), is located in the western portion of the SRS. It is bordered by a narrow buffer zone along South Carolina State Route 125 and by Upper Three Runs Creek. The South Carolina Department of Natural Resources (SCDNR) manages this area (DOE 2000b).

Currently, nearly 90% of the land (72,900 ha [180,000 acres]) at the SRS is forested with upland pine, hardwood, mixed (pine and hardwood), and bottomland hardwood forests. The major upland and wetland forest types at the SRS (including major species and coverage) are listed in Table 3.5. Pine forests cover about 65% of the upland areas of the SRS (DOE 1999). These pine forests are managed by the U.S. Forest Service and have displaced much of the upland hardwood communities (DOE 1991a). Natural resource management is actively practiced on more than 80% of the SRS, including about 73,710 ha (182,000 acres) of commercial forests and 4,860 ha (12,000 acres) of nonforest lands (DOE 2000b; WSRC 1994).

Approximately 5% of land at the SRS is developed with industrial and transportation infrastructure and grassland, old fields, or shrub vegetation (WSRC 1994). This land is generally classified as "facility." The industrial and transportation development includes administrative and production facilities, electrical substations, roads, and railroads and occupies

Table 3.5. Major forest types at the SRS

Forest type	Canopy species	Midstory species	Coverage [hectares (acres)]
Upland Forests			
Dry longleaf pine-scrub oak	Longleaf pine (sparse)	Oaks, black cherry, common persimmon (continuous)	3,058 (7,551)
Longleaf pine	Longleaf pine, loblolly pine, water oak	Black cherry, common persimmon, sand hickory, sassafras, water oak	15,533 (38,353)
Mixed yellow pine	Loblolly, slash and/or longleaf pines	American holly, black cherry, common persimmon, sand hickory, sassafras, water oak, sweetgum, red maple, redbay, sweetbay magnolia	27,020 (66,716)
Southern mixed hardwood	Oaks (white, scarlet, laurel, post, southern red, turkey, bluejack, blackjack), hickories (mockernut, pignut), yellow poplar, blackgum, red maple, sweetgum, white ash, pines (loblolly, longleaf)	Sparkleberry, vaccinium, American holly, black cherry, mockernut hickory, white ash, sassafras. dogwood, Georgia hackberry	12,805 (31,618)
Wetland Forests			
Bottomland	Oaks (water, laurel, overcup, willow), southern magnolia, sweetgum, elms (American, winged), red maple, yellow poplar, river birch, tag alder, waxmyrtle, loblolly pine	American holly, redbay, sweetbay magnolia, ironwood, southern hackberry, red buckeye, honeysuckle	12,531 (30,941)
Southern swamp	Bald cypress, water tupelo, sweetgum	Ashes (water, red), sourgum, red maple, American elm	4,285 (10,581)
Total:			75,232 (185,760)

Sources: DOE (1991a, 2000b); Workman and McLeod (1990); WSRC (1994).

about 1,587 ha (3,919 acres). Vegetated areas associated with the developed areas are actively maintained (lawns and landscaped areas). These associated vegetated areas occur primarily on power line rights-of-way, roadsides, some borrow pits, some burial sites, and in forest openings and occupy about 1,345 ha (3,322 acres) (DOE 2000b). Unless managed, most scrub-shrub areas will develop into forest within 5 to 10 years (WSRC 1994). The vegetated areas also include permanent upland meadows, scrub-shrub areas, and SRS wildlife food plots. Controlled burns of 6,075 to 7,290 ha (15,000 to 18,000 acres) of pine-dominated uplands are conducted annually to reduce flammable materials and to enhance the development of fire-tolerant plant communities and improve wildlife habitat. Additionally, improved planting techniques and seedling survival have resulted in conversion of significant areas of loblolly and slash pine forests to young longleaf pine forests over the past 10 years (DOE 2000b).

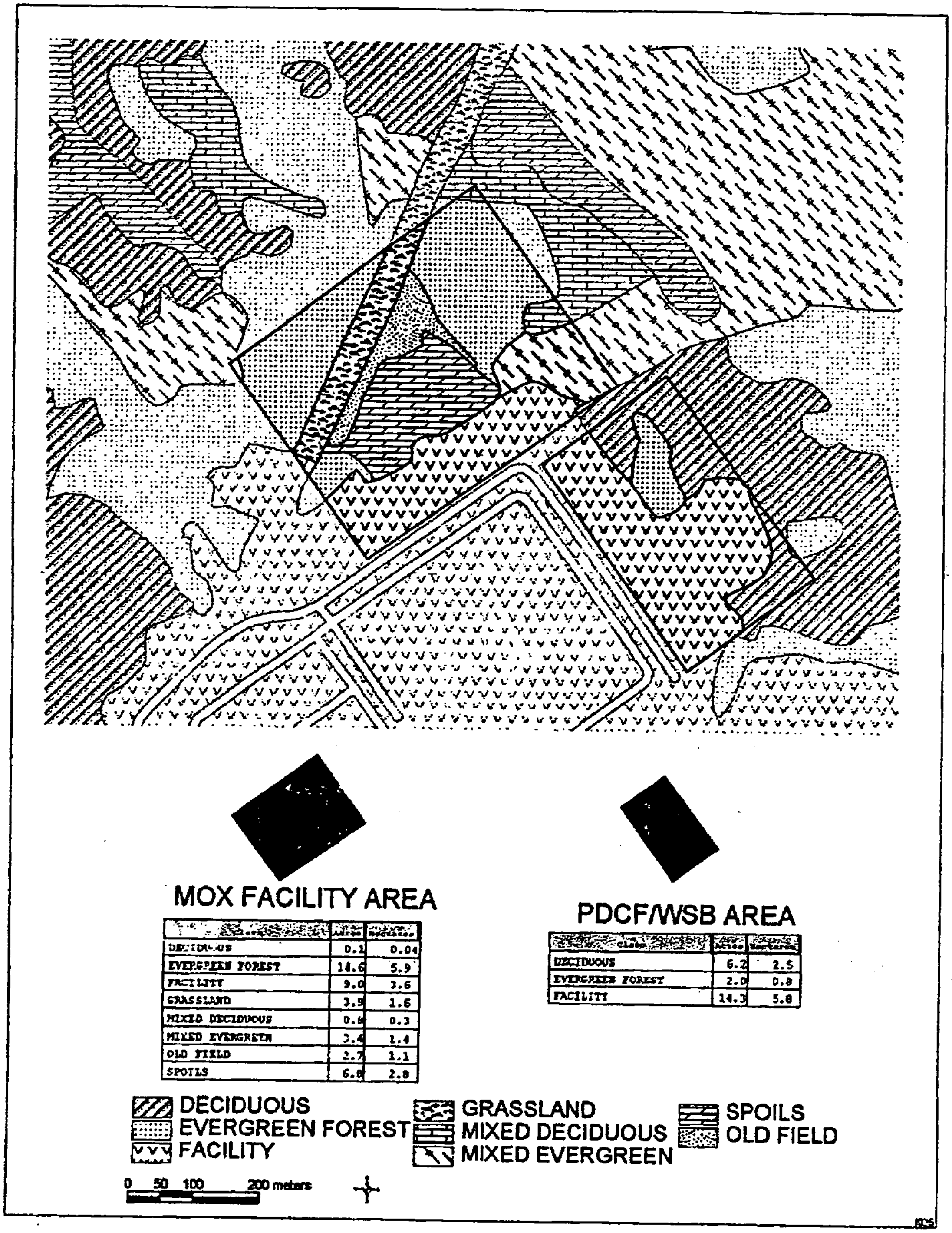
Habitats in the 16.7-ha (41.3-acre) area proposed for the MOX facility include pine (or evergreen) forest (5.9 ha [14.6 acres]), mixed pine (combination of both pine and deciduous [hardwood] species, with pine trees predominant) (1.4 ha [3.4 acres]), mixed deciduous (0.3 ha [0.8 acre]), grassland (1.6 ha [3.9 acres]), "facility" (developed) (3.6 ha [9.0 acres]), old field (fields formerly used for agriculture but now undergoing natural succession) (1.1 ha [2.7 acres]), spoils (2.8 ha [6.8 acres]), and deciduous (hardwood trees, essentially the southern mixed hardwood forest type of Table 3.5) (0.04 ha [0.1 acre]) (see Figure 3.7) grassland habitat occurs within the transmission line right-of-way that crosses the propc MOX site. The spoils habitat originated from the excavation for the Actinide Packaging .... Storage Facility (APSF) in the F-Area. Although soil was excavated, the APSF was not constructed. This area is covered primarily with various grass and forb species. The standard seed mixture used to establish a plant cover on such areas includes grass and forb species such as unhulled and hulled common Bermuda grass, browntop millet, and unscarified Appalachian lespedeza (Bowling 2001).

Habitats in the 9.1-ha (22.5-acre) area proposed for the PDCF and WSB include pine forest (0.8 ha [2.0 acres]), deciduous (2.5 ha [6.2 acres]), and facility (5.8 ha [14.3 acres]) (see Figure 3.7).

Forested and facilities areas primarily surround the immediate project area (see Figure 3.7). The forested areas are dominated by loblolly pine with some mixed hardwoods (e.g., sweetgum, turkey oak, and water oak). The sparse understory and shrub layers consist of sparkleberry, dogwood, jasmine, and wax myrtle. Also present are areas dominated by a closed canopy of longleaf pine with sweetgum and willow oak as minor components. Vegetation along the unnamed tributaries to Upper Three Runs Creek include loblolly pine, sweetgum, red oak, and sycamore in the canopy, with black cherry, dogwood, and young individuals of the canopy tree species in the understory (Wike and Nelson 2000). The grassland habitat associated with the transmission line also occurs in this area. The OFASB area located west of the proposed MOX facility site also contains a vegetated cover similar to that over the spoils area within the proposed MOX facility site.

3.5.1.2 Wildlife

Among the numerous wildlife species reported from the SRS are 44 species of amphibians, 59 species of reptiles, 258 species of birds, and 54 species of mammals. The SRS has among the highest biodiversity of herpetofauna (reptiles and amphibians) in the United States because of the area's warm, moist climate and its wide variety of habitats (DOE 2000b). Snakes that could occur in the project area include eastern hognose snake, eastern garter snake, eastern coachwhip, scarlet king snake, rat snake, corn snake, and pine snake. Lizards could include the green anole, southern fence lizard, several species of skinks, and the eastern glass lizard. Amphibians could include the southern toad and oak toad. The southern leopard frog, bullfrog, and other frogs and toads could occur in the small drainage basins near the site, while



MOX FACILITY AREA

	Acres	Hectares
DECIDUOUS	0.1	0.04
EVERGREEN FOREST	14.6	5.9
FACILITY	9.0	3.6
GRASSLAND	3.9	1.6
MIXED DECIDUOUS	0.6	0.3
MIXED EVERGREEN	3.4	1.4
OLD FIELD	2.7	1.1
SPOILS	6.8	2.8

PDCF/WSB AREA

Class	Acres	Hectares
DECIDUOUS	6.2	2.5
EVERGREEN FOREST	2.0	0.8
FACILITY	14.3	5.8

Figure 3.7. Current land cover in the area of the project site.

amphibians such as tree frogs and salamanders could occur within the unnamed tributary to Upper Three Runs Creek (Conant 1958; Mayer and Wike 1997).

Bird species at the SRS that are very common to abundant include black vulture, eastern kingbird, acadian flycatcher, common crow, northern mockingbird, blue-gray gnatcatcher, ruby-crowned kinglet, red-eyed vireo, northern parula, black-throated warbler, ovenbird, northern cardinal, savannah sparrow, white-throated sparrow, and song sparrow (WSRC 1994). As many as 17,000 ducks and coots are winter migrants at the SRS. Most of these congregate on Par Pond, L Lake, and other large ponds and Carolina bays (DOE 1991a). Wood ducks are the only waterfowl species that commonly breed on the SRS (WSRC 1994). Several mammal species can be found in old field/clearcuts, pine plantations, and scrub oak/longleaf pine habitats (these are the generalized habitat types that occur within the vicinity of the facilities). These species include southern short-tailed shrew, Virginia opossum, golden mouse, oldfield mouse, raccoon, eastern cottontail, and white-tailed deer. Other mammals that can occur within two of these habitat types include least shrew, striped skunk, raccoon, eastern harvest mouse, gray and fox squirrels, southeastern shrew, spotted skunk, feral hog, and gray fox. Several bat species also occur in one or more of these habitats (WSRC 1994).

Populations of white-tailed deer, feral hogs, and beaver are controlled through selective harvest strategies (DOE 2000b), which has included public hunts for white-tailed deer and feral hogs (Noah 1995; DOE 1996). The deer herd is estimated at about 3,000, with harvests averaging about 1,580 animals per hunting season. The feral hog population now exceeds 2,500 (DOE 2000b). The feral hogs originated from free-ranging domestic swine abandoned after resident farmers were relocated in 1952. They now occur over about 70% of the SRS (WSRC 1994). The hogs are trapped wherever they are found. Beavers are trapped where they compromise the safety or operations of roads, railroads, culverts, or research plots, or where they are causing significant resource damage. Increasing numbers of coyotes and armadillos may require the SRS to initiate control measures for these species in the future (DOE 2000b). Other commercial and recreational wildlife resources at the SRS are not exploited over most of the SRS because of restricted access and safety concerns. These species include bobcat, gray and red fox, mink, muskrat, Virginia opossum, river otter, eastern cottontail, raccoon, fox and gray squirrels, waterfowl, northern bobwhite, mourning dove, wild turkey, common snipe, and American woodcock (WSRC 1994). Hunting has been allowed for most of these species (except for bobcat, foxes, river otter, and fox squirrel) at the Crackerneck WMA (SCDNR 2000/2001). However, since late September 2001, hunting has been closed to the general public in this area. A controlled hunt was later allowed to help regulate the SRS deer herd.

The developed areas of the SRS include buildings, parking lots, infrastructure, and landscaped areas. Nevertheless, a number of wildlife species have been reported from these areas. A total of 43 species have been reported from the F-Area, including 4 species of amphibians, 12 species of reptiles, 18 species of birds, and 9 species of mammals. Several bird species are abundant: rock dove, common crow, northern mockingbird, American robin, and European starling. Common mammals include Virginia opossum, eastern cottontail, house mouse, feral cat, striped skunk, and raccoon. The densities of most wildlife species are higher in undeveloped areas then in developed areas. Exceptions include the house sparrow, house finch, rock dove, house mouse, Norway rat, and feral cat. Nevertheless, the use of developed areas of the SRS by wildlife is more common than previously reported, and these areas can be expected to contribute to the site's environmental diversity (Mayer and Wike 1997).

3.5.2 Aquatic

Six major streams and several associated tributaries flow through the SRS, and the Savannah River bounds the southwestern border of the SRS. More than 50 man-made ponds also occur at the SRS (DOE 1999). The two largest are L Lake (405 ha [1,000 acres]), which discharges into Steel Creek, and Par Pond (1,069 ha [2,640 acres]), which discharges into Lower Three Runs Creek (Section 3.3.1). These lakes do not have any direct interactions with the F-Area. Altogether, about 2,000 ha (4,940 acres) of open water occurs at the SRS (WSRC 1994).

At least 81 fish species have been identified at the SRS (DOE 2000b). Sport and commercial fishing on the SRS is allowed only within the Crackerneck WMA. Extensive fishing also occurs in the Savannah River. Commercial fish species include the American shad, hickory shad, and striped bass. Recreational species include largemouth bass, chain pickerel, crappie, bream, sunfish, and catfish (DOE 1996; WSRC 1994, 1997b). The man-made ponds support populations of bass and sunfish (DOE 1999).

Some SRS surface waters are classified as Category I resources. These waters are defined by the U.S. Department of the Interior as unique and irreplaceable on a national or eco-regional basis. These areas would include Carolina bays and cypress-tupelo swamps. Any surface waters supporting species of concern and areas containing high-quality wetlands or headwater streams (e.g., portions of Upper Three Runs Creek) would also be considered for Category I status (DOE 2000b).

The F-Area is drained by Upper Three Runs Creek and Fourmile Branch (see Figure 3.3). Upper Three Runs Creek is the most pristine stream at the SRS and would be considered a Category I resource. It contains more than 550 species of aquatic insects and supports about 60 fish species. The more abundant fish species include bowfin, American eel, redfin pickerel, dusky shiner, yellowfin shiner, coastal shiner, flat bullhead, tadpole madtom, mosquitofish, redbreast sunfish, warmouth, spotted sunfish, and blackbanded darter. More than 10 other fish species are common in Upper Three Runs Creek (Bennett and McFarlane 1983). Upper Three Runs Creek is an important spawning area for blueback herring and provides seasonal nursery habitat for American shad, striped bass, and other Savannah River species (DOE 1999). This stream also appears to be an important spawning site for the spotted sucker (WSRC 1994).

About 48 fish species have been collected from Fourmile Branch. Those in the stream's lower reaches include species common to the Savannah River. The only abundant fish species collected from Fourmile Branch are mosquitofish, redbreast sunfish, and spotted sunfish. Common species include longnose gar, bowfin, golden shiner, bluehead chub, creek chub, creek chubsucker, pirate perch, and brook silverside (Bennett and McFarlane 1983).

Water bodies in the vicinity of the proposed facilities include unnamed tributaries to Upper Three Runs Creek (see Figure 3.3) and small drainages and detention basins associated with permitted discharge outfalls. Macroinvertebrate (e.g., aquatic insects, snails, clams, and worms) and fish surveys indicate that Upper Three Runs Creek is unaffected by SRS NPDES-permitted discharges (Specht and Paller 2001).

3.5.3 Wetlands

> **Wetlands**
>
> *Wetlands* are areas that are inundated or saturated by surface water or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation adapted for life in saturated soil conditions.

More than 20% of the SRS consists of wetlands, including open waters. Most wetlands on the SRS are associated with floodplains, streams, and impoundments. Wetland types on the SRS include bottomland hardwoods, southern swamp (cypress-tupelo), freshwater marshes, and Carolina bays. Areal coverage of forested wetlands is given in Table 3.5. The freshwater marshes total 1,380 ha (3,407 acres), and the Carolina bays total about 785 ha (1,939 acres) (DOE 2000b). The conditions of many wetlands at the SRS are similar to conditions that existed before the government assumed control of the site, except for those wetlands along stream corridors and adjacent portions of the Savannah River swamp that were degraded by thermal releases from reactor operations. These areas have been recovering since cessation of cooling water releases (WSRC 1994).

Over 300 Carolina bays (closed depressions capable of holding water) occur on the SRS (DOE 2000b). Carolina bays are characterized by their elliptical or ovoid shape, with a northwest/southeast orientation of their long axis (WSRC 1994). The Carolina bays on the SRS have remained largely undisturbed since 1950 and thus are valuable examples of these regional wetlands (Schalles et al. 1989). The median size of the Carolina bays is about 0.8 ha (2.0 acres), and only 15 exceed 4 ha (10 acres). The Carolina bays have characteristics similar to other wetlands (e.g., shallow marshes, herbaceous bogs, shrub bogs, or swamp forests). They also have a xeric to hydric (dry to moist) gradient from their peripheral sand rim to the center depression (Schalles et al. 1989). More than 135 species of plants have been identified from these wetlands. Most are dominated by grasses and sedges (Schalles et al. 1989; WSRC 1994). Amphibians are the most prevalent vertebrates that utilize the Carolina bays, but many reptiles, birds, and mammals also have been observed at these wetlands (Schalles et al. 1989). Less than 20 of the Carolina bays contain permanent fish populations. Fish species include redfin pickerel, mud sunfish, lake chubsucker, and mosquito fish (DOE 1999). An accelerated program has been initiated at the SRS to restore impacted Carolina bays (DOE 2000b). No Carolina bays occur near the proposed facility sites.

No wetlands occur on the proposed facility sites. Wetland habitat does occur along the unnamed tributary to Upper Three Runs Creek located near the eastern border of the proposed facility site (see Figure 3.3). The dominant species of vegetation in this wetland are yellow poplar, laurel oak, red maple, red bay, and cherrybark oak. Maiden cane also occurs near the wetland boundary (Wike and Nelson 2000).

3.5.4 Protected Species

Table A.1 (Appendix A) lists the threatened, endangered, and other special status species that may be found in the vicinity of the SRS. Appendix A also discusses the federally and state-endangered red-cockaded woodpecker (*Picoides borealis*), which receives special attention at the SRS.

> **Protected Species**
>
> *Endangered species.* Any species in danger of extinction throughout all or a significant portion of its range.
>
> *Threatened species.* Any species likely to become endangered within the foreseeable future throughout all or a significant portion of its range.

No federal- or state-listed wildlife species have been reported from the proposed project area, but several species may exist in the general vicinity. The American alligator (*Alligator mississippiensis*) is federally threatened (by virtue of its similarity to the endangered American crocodile [*Crocodylus acutus*]). While it is fairly common at the SRS, it has only been recently observed near the F-Area, and its occurrence there is considered uncommon. The federally threatened (state-endangered) bald eagle (*Haliaeetus leucocephalus*) actively nests in the Pen Branch area and in an area south of Par Pond. These areas are 14 km (8.7 mi) and 12 km (7.5 mi) southwest and southeast of the proposed project area, respectively. The closest nesting area of the federally and state-endangered red-cockaded woodpecker to the proposed facility site is about 5 km (3.1 mi) away. The proposed area for the facilities does not occur within red-cockaded woodpecker management areas (see Appendix A). However, all areas containing pines, including those at the proposed sites, provide suitable forage areas for this species. The federally and state-endangered wood stork (*Mycteria americana*) has been observed near the Fourmile Branch delta, about 21 km (13 mi) from the proposed site. The federally endangered (state-endangered) shortnose sturgeon (*Acipenser brevirostrum*) occurs in the Savannah River as far upstream as the SRS.

Walk-through surveys did not reveal any federal- or state-listed wildlife species within the proposed facility area (USFS 2000). The Bachman's sparrow (*Aimophila aestivalis*) is adapted to open meadow and shrubby meadow habitats such as those that occur throughout F-Area. The eastern woodrat (*Neotoma floridana*) could inhabit the transitional areas between the hardwood forest and F-Area facilities, and the moist stream bottom area is suitable for the star-nosed mole (*Condylura cristata*). The upland pine and pine-oak ridge habitats are highly suitable for the southern hognose snake (*Heterodon simus*) and pine snake (*Pituophis melanoleucus*) (USFS 2000). The American sandburrowing mayfly (*Dolania americana*) is a relatively common aquatic insect in Upper Three Runs Creek (WSRC 1994). This species was formerly a candidate species for federal listing, but it is not currently listed by the U.S. Fish and Wildlife Service (USFWS) or State of South Carolina.

More than 1,300 species of plants occur at the SRS (WSRC 1994); however, only 53 species are considered to be sensitive, as determined by state, federal, and global ratings. The smooth coneflower (*Echinacea laevigata*) is the only federally listed (endangered) plant species at the SRS; it is also state endangered. Smooth coneflowers inhabit roadsides and open, sunny areas. The collection of plants from natural populations was a significant factor in the endangerment of the species (Arnold et al. 1998). Three populations of the smooth coneflower have been identified at the SRS. Activities near these known populations are highly restricted (DOE 2000b).

Nearly 300 populations of other sensitive plant species occur at the SRS (DOE 2000b). Included are three populations of the state-listed (species of concern) piedmont azalea (*Rhododendron flammeum*) that have been found along the steep slopes adjacent to the Upper Three Runs Creek floodplain in an area northwest of F-Area (DOE 1999).

Walk-through surveys of the proposed MOX facility site in October 1998 and March 2000 did not reveal any populations of the smooth coneflower (USFS 2000). Because this species is adapted to meadow and open forest habitats, the project area appears to be too disturbed or shady for the coneflower's establishment and successful survival. The survey did indicate that suitable habitat for several rare plant species exists in areas adjacent to the survey site. The hardwood slope provides habitat suitable for leech brush (*Nestronia umbellata*), piedmont azalea, and striped garlic (*Allium cuthbertii*). The moist bottom and lower slope sections are suitable for green-fringed orchid (*Platanthera lacera*) and least trillium (*Trillium pusillum* var. *pusillium*). The upland pine and pine-oak ridge areas are suitable for lance-leaf wild-indigo (*Baptisia lanceolata*) and bearded milk-vetch (*Astragalus villosus*) (USFS 2000).

3.6 Land Use

This section briefly describes land use patterns on and around the SRS. Land use is a classification of parcels of land relative to their suitability for or the actual presence of human activities (e.g., industry, agriculture, recreation, etc.) and natural uses. Natural resource attributes and other environmental characteristics could make a site more suitable for some land uses than for others. Changes in land use may have both beneficial and adverse effects on other resources (e.g., ecological, cultural, geological, and hydrological).

3.6.1 Savannah River Site Land Use

Existing land use at the SRS can be characterized into three main categories: (1) undeveloped/ forest, (2) wetlands/water, and (3) developed. Approximately 73% of the SRS is undeveloped; 22% consists of wetlands, streams, and lakes; and 5% is developed (e.g., facilities, roads, and utility corridors). The forested areas are managed for timber production. The U.S. Forest Service, under an interagency agreement with DOE, harvests approximately 728 ha (1,800 acres) of timber from the SRS each year. Prime farmland soils exist at the SRS, but areas of prime farmland are not identified within the SRS because the land is not available for agricultural activities (DCS 2002). A portion of the SRS is open for fishing, as discussed below for the Crackerneck WMA. Since late September 2001, hunting has been closed to the general public in this area. A limited hunting period was later allowed to control the SRS deer herd.

As discussed in Section 3.5.1.1, the SRS has been designated a National Environmental Research Park by DOE. The scientific community can use the site to study the impacts of human activity on cypress swamp and hardwood forest ecosystems. Approximately 5,700 ha (14,085 acres) of land is set aside at the SRS for nondestructive environmental research (DOE 1999).

The F-Area is generally classified by the SRS land use plan as developed; some areas within F-Area are classified as industrial or heavy industrial.

Future land use at the SRS is determined by the DOE through site development, land use, and future planning processes (DCS 2002). SRS planners have developed a land use zone planning model for the site that is consistent with their past support of a multiple-use planning concept where compatible. Three principal planning zones have been established: Site Industrial, Site Industrial Support, and General Support. The *SRS Long Range Comprehensive Plan* includes the construction and operation of the proposed facilities as part of the plan for its Nuclear Materials Stewardship mission (DOE 2000b). New missions for the SRS in the 21st Century, as stated in the *Savannah River Site Strategic Plan,* include the construction and operation of new facilities for tritium extraction and the storage and disposal of surplus plutonium. In addition to these new facilities, the SRS plans to play an increased role in the advancement of nuclear materials protection, control, and accounting (DOE 2000a).

3.6.2 Off-Site Land Use

Predominant regional land uses in the vicinity of the SRS include urban and residential, industrial, agricultural, and recreational areas. Forest and agricultural land predominantly border the SRS, with only limited urban and residential development. The nearest residences are located to the west, north, and northeast, some within 60 m (200 ft) of the SRS boundary. Farming is diversified throughout the region and includes such crops as peaches, watermelon, cotton, soybeans, corn, and small grains. Incorporated and industrial areas are also present near the site, including textile mills, polystyrene foam and paper plants, chemical processing plants, and a commercial nuclear power plant. Open water and nonforested wetlands occur along the Savannah River Valley. Recreational areas within 80 km (50 mi) of the SRS include Sumter National Forest, Santee National Wildlife Refuge, and Clark's Hill/Strom Thurmond Reservoir. State, county, and local parks include Redcliffe Plantation, Rivers Bridge, Barnwell and Aiken County State Parks in South Carolina, and Mistletoe State Park in Georgia. The Crackerneck WMA, which includes a portion of the SRS along the Savannah River, is open to the public for fishing (DOE 1999).

3.7 Cultural and Paleontological Resources

Cultural resources include archaeological sites and historic structures and features that are protected under the National Historic Preservation Act of 1966, as amended.

Cultural and Paleontological Resources

Cultural resources include archaeological sites, historic structures and features, and traditional cultural properties.

Paleontological resources are the fossil remains of past life forms.

Cultural resources also include traditional cultural properties that are important to a community's practices and beliefs and that are necessary to maintain the community's cultural identity. Cultural resources that meet the eligibility criteria for listing on the *National Register of Historic Places* (NRHP) are considered "significant" resources and must be taken into consideration during the planning of federal projects. Federal agencies are also required to consider the effects of their actions on sites, areas, or other resources (e.g., plants) that are of religious significance to Native Americans as established under the American Indian Religious Freedom Act. Native American graves and burial grounds are protected by the Native American Graves Protection and Repatriation Act.

Paleontological resources are the fossil remains of past life forms. Paleontological resources with significant research potential are protected under the Antiquities Act.

3.7.1 Archaeological Resources

The Savannah River Archaeological Research Program (SRARP) of the South Carolina Institute of Archaeology and Anthropology, University of South Carolina, has been conducting archaeological investigations at the SRS since 1973 (SRARP 1989). The SRARP prepared an archaeological resource management plan for the SRS in 1989. The purpose of the plan is to provide the DOE with a means of addressing future archaeological resource management needs at the SRS and to establish a series of research directions to facilitate better management of these resources. The SRS currently manages its archaeological resources under the terms of a 1990 Programmatic Agreement among the DOE Savannah River Operations Office, the South Carolina State Historic Preservation Officer (SCSHPO), and the Advisory Council on Historic Preservation.

Over a period of more than 25 years, members of the SRARP have been very active in recording more than 850 archaeological sites at the SRS.[7] Although most of these sites have not been formally evaluated for eligibility for listing on the NRHP, 67 sites have been identified as potentially eligible (DOE 1999). In general terms, prehistoric sites within the SRS consist of village sites, base camps, limited-activity sites, quarries, and workshops. Nearly 800 prehistoric sites have been recorded at the SRS (DCS 2002). As detailed below, several prehistoric sites have been recorded within or near the proposed facilities. Two prehistoric sites within the footprints of the proposed facilities and their associated grading area have been determined to be eligible for listing on the NRHP.

Historic sites at the SRS include farmsteads, tenant dwellings, mills, plantations, slave quarters, rice farm dikes, dams, cattle pens, ferry locations, churches, schools, towns, cemeteries, commercial buildings, and roads. About 400 historic sites have been recorded to date at the SRS (DOE 1999). No historic sites have been recorded within the vicinity of the proposed facilities.

[7] Of the 850 plus sites that have been recorded at the SRS, some are prehistoric, some are historic, and some have both a prehistoric and historic component. For this reason, the sum of prehistoric sites plus historic sites is much greater than the approximate total of 850 sites.

Archaeological surveys have been conducted in the F-Area in the vicinity of the proposed facilities. Fifteen prehistoric sites have been identified. Nine of these sites were recorded during 1993 and 1994 (Cabak et al. 1996). Four sites were recorded during SRS surveys conducted between 1973 and 1977 (Hanson et al. 1978). One site was recorded in 1983 (as cited in Cabak et al. 1996), and the remaining site was recorded in a 1999 survey covering unsurveyed lands remaining for the proposed location of the surplus plutonium disposition facilities (King and Stephenson 2000).

Four sites are located within the area of direct project disturbance. Two of the four prehistoric sites (38AK546/547 and 38AK757) are eligible for listing on the NRHP. Site 38AK546/547, located within the area of the proposed MOX facility, is eligible because of its potential to provide significant information about the prehistory of the Aiken Plateau, in particular the use of ridge slope settings during the Early Mississippian period (King and Stephenson 2000). Site 38AK757 is located within the boundary of the proposed PDCF facility and is important for learning more about the use of upland settings by prehistoric inhabitants of the area during the Mississippian Period (King and Stephenson 2000). Two sites within the area of the proposed MOX facility, 38AK330 and 38AK548, were determined not eligible in consultation with the SCSHPO, and no further work is required for these two sites (Green 2000, as cited in DCS 2002).

Date Ranges of Prehistoric Time Periods Used by Archaeologists at the SRS

Mississippian	A.D. 1100 - 1450
Late Woodland	A.D. 500 - 1100
Middle Woodland	600 B.C. - A.D. 500
Early Woodland	1000 B.C. - 600 B.C.
Late Archaic	3000 B.C. - 1000 B.C.
Middle Archaic	6000 B.C. - 3000 B.C.
Early Archaic	8000 B.C. - 6000 B.C.

Source: SRARP (1989).

Eleven prehistoric sites are located near the proposed facilities. Five of those sites (38AK106, 38AK155, 38AK563, 38AK564, and 38AK581) have been recommended eligible for listing on the NRHP. Site 38AK106 has been recommended eligible on the basis of its integrity, high density of artifacts, and research potential for providing information on the Early Archaic, Early Woodland, and Late Woodland time periods. Site 38AK155 is eligible because of its potential to yield important information on subsistence strategies and the use of upland streamside settings between 3000 B.C. and A.D. 1450 (between the Late Archaic and Early Mississippian periods). Site 38AK563 is important because it contains cultural deposits ranging from the Early Archaic Period through the Late Woodland Period and has the potential to provide information on the changes in human use of the floodplain over a considerable time range. Site 38AK564 has been recommended eligible because it contains stratigraphically[8] separated evidence of site use from the Early Archaic and Late Archaic/Early Woodland time periods. Site 38AK581 contains evidence of numerous occupations by prehistoric people during the Woodland Period. The site has been recommended eligible on the basis that these

[8] Archaeologists look at the position of artifacts relative to layers of soil and other artifacts to help determine sequences of events. Objects found closer to the surface of an undisturbed site were deposited more recently than objects found below them (i.e., an archaeologist would expect to find Woodland Period artifacts in one or more layers of soil above Archaic Period artifacts in a stratigraphically preserved site).

various occupations appear in a well-defined stratigraphic sequence and potentially contain important information about changes that occurred during that time period (Cabak et al. 1996).

3.7.2 Historic Structures

No architectural inventories have been conducted to date at the SRS. The SRS has a number of nuclear production facilities, including facilities important to tritium and plutonium production, that may have historic value as related to events during the Cold War. Construction of the F-Area began in 1951 under the Atomic Energy Commission. The F-Area was historically used for plutonium recovery during DOE's plutonium production phase (DCS 2002). The areas of construction for the proposed facilities do not contain structures. No existing buildings within the F-Area have been identified for reuse, modification, or demolition related to MOX facility activities.

3.7.3 Traditional Cultural Properties

Traditional cultural properties are places and resources important to traditional American cultures, which include, but are not restricted to, Native American cultures. Village sites, ceremonial locations, burials, cemeteries, and natural areas containing important resources, such as traditional plants, are typical types of properties of concern to Native American cultures. Properties of traditional value to immigrant groups (e.g., from Europe and Africa), such as cemeteries, also can be considered as traditional cultural properties. Native American groups with traditional ties to the area include the Apalachee, Cherokee, Chicksaw, Creek, Shawnee, Westo, and Yuchi (DCS 2002). Many of these groups were relocated to the Oklahoma Territory in the 1800s. However, issues related to the American Indian Religious Freedom Act have surfaced within the central Savannah River valley. Native American representatives have expressed concern over traditional plant resources that could exist at the SRS (DOE 1991b; DCS 2002). None of the identified plant resources is currently known to exist in the F-Area. Consultations with appropriate Native American Tribes, Bands, and Nations are underway regarding the proposed MOX facility (Appendix B).

3.7.4 Paleontological Resources

While some fossil-bearing strata are known to exist at the SRS, none are known within the F-Area. Paleontological resources that have been recorded within the SRS area mostly date to 54 to 39 million years ago during the Eocene Age. Those resources include fossil plants, invertebrate fossils, giant oysters, other mollusks, and bryozoa. Most known paleontological resources in the area are considered common and of low research potential (DOE 1999). The discovery of paleontological resources within the area of the proposed facilities is not anticipated.

3.8 Infrastructure

This section briefly describes the existing infrastructure of the SRS as it pertains to the proposed action. Site infrastructure includes utilities, roads, and railroads needed to support construction and operation of the facilities. A detailed discussion of the SRS infrastructure is provided in the DOE Surplus Plutonium Disposition EIS (DOE 1999).

3.8.1 Electricity

The SRS uses a 115-kV power line system in a ring arrangement to supply electricity to the operations areas. Power is supplied by three transmission lines from the South Carolina Electric and Gas Company. The F-Area receives power from the 200-F power loop supplied by the 251-F electrical substation. The current F-Area power consumption rate is about 63,000 MWh/yr; the F-Area total capacity is about 700,000 MWh/yr (DCS 2002). The total SRS usage of electrical power is 370,000 MWh/yr out of a site capacity of 4,400,000 MWh/yr.

3.8.2 Water

Domestic water supplies at the SRS come from a system composed of several wells and water treatment plants. The system includes three wells and a water treatment plant in the A-Area and two wells and a backup water treatment plant in the B-Area. A 43-km (27-mi) piping loop provides domestic water from the A- and B-Areas to other SRS operations areas, including the F-Area (DCS 2002). Current domestic water usage in F-Area is 378 million L/yr (100 million gal/yr) compared with a capacity of 890 million L/yr (235 million gal/yr).

Within F-Area, four deep groundwater wells are used for process water. Pumping capacities for these wells range from 1,500 to 3,800 L/min (400 to 1,000 gpm), and they extract groundwater from the Crouch Branch Aquifer. Two of these wells were formerly used for domestic water supply. The current annual groundwater use at F-Area is 1.4 billion L (370 million gal) (DCS 2002). The estimated capacity of the wells in F-Area is about 4.2 billion L/yr (1.1 billion gal/yr).

3.8.3 Fuel

Coal and oil are used at the SRS to power steam plants located in A-, D-, H- and K-Areas. The produced steam is distributed across the site in an aboveground pipeline distribution system. Coal is delivered by rail and is stored at coal piles in A-, D-, and H-Areas. Number 2 grade fuel oil is delivered by truck and is used in the K-Area. Natural gas is not used at the SRS.

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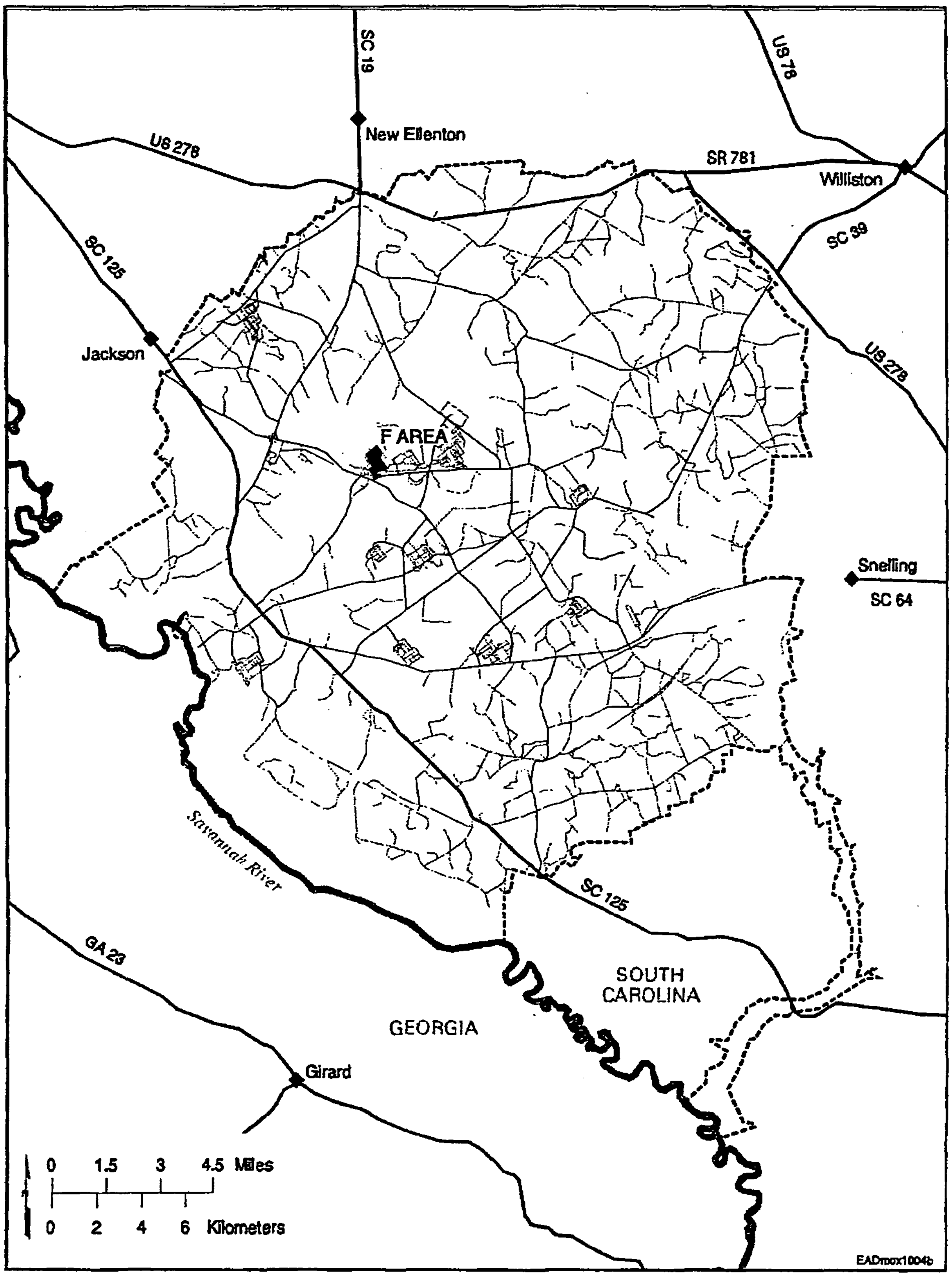

Figure 3.8. Roadways in the vicinity of the SRS.

Current waste generation rates and inventories at the SRS are presented in Table 3.6. Waste management practices at the SRS include minimization, characterization, treatment, storage, transportation, and disposal of waste generated from ongoing site activities. Waste minimization at the SRS is accomplished through source reduction, recycling, and employee participation in pollution prevention programs. Total solid waste volumes have decreased by 70% since 1991.

The types of waste currently managed at the SRS are high-level waste (HLW), transuranic (TRU) waste, mixed TRU waste, low-level waste (LLW), mixed LLW, hazardous waste, and

Table 3.6. Current waste generation rates and inventories at the SRS[a]

Waste type	Generation rate (m^3/yr)	Inventory[b] (m^3)
TRU[c]		
Contact handled	171	6,034
Remotely handled	0.6	1
LLW	8,195	1,616[d]
Mixed LLW		
RCRA	61	7,717
TSCA[e]	<1	3
Hazardous	74	1,416
Nonhazardous		
Liquid	416,100[f]	NA[g]
Solid	6,670	NA

[a]Sources for estimates presented in this table are DOE (1997) for TRU waste, LLW, and mixed LLW; DOE (1996) for hazardous and nonhazardous solid waste; and Sessions (1997) for nonhazardous liquid waste.

[b]Inventory projections were as of end of fiscal year 1996 for those presented in DOE (1997).

[c]Includes mixed TRU waste.

[d]LLW is disposed of on-site at the SRS. The estimated inventory shown is less than the generation rate (for FY1996) because it represents only LLW that had not been disposed of as of the end of FY 1996.

[e]TSCA = Toxic Substances Control Act.

[f]416,000 m^3/yr = 416,100,000 L/yr.

[g]NA = not applicable; nonhazardous wastes are not held in long-term storage.

nonhazardous waste. The first five types contain radioactive material. Of the seven waste types currently managed at the SRS, HLW would not be generated by the proposed MOX facility, the PDCF, or the WSB. The proposed MOX facility would generate a liquid high-alpha-activity waste that would be further processed, resulting in the generation of TRU waste and LLW (DCS 2002).

The TRU wastes generated at the SRS include contaminated equipment, protective clothing, and tools. Most of these wastes are stored on concrete pads that are not covered with soil. TRU waste generated before 1986 is stored on five concrete pads and one asphalt pad that have been covered with approximately 1.2 m (4 ft) of soil. TRU waste generated since 1986 is stored on 13 concrete pads that are not covered with soil. These storage pads are located in the Low-Level Radioactive Waste Disposal Facility, which is located in E-Area (DOE 1995). In 1996, it was decided to vent and purge all buried drums; this process was completed in 1999 (Arnett and Mamatey 2000b). A TRU waste characterization and certification facility to prepare TRU waste for treatment and to certify TRU waste for disposal at the Waste Isolation Pilot Plant (WIPP) is planned for 2007. This TRU waste facility would be built to manage other SRS TRU waste and is independent of the proposed action. In the interim, drums that are certified for shipment to WIPP will be stored on concrete pads in E-Area (DOE 1999).

Waste Types

Transuranic (TRU) waste: Refers to radioactive waste that contains more than 100 nanocuries per gram (nCi/g) of alpha-emitting isotopes with atomic numbers greater than 92 and half-lives greater than 20 years. Such waste results primarily from the fabrication of plutonium weapons and plutonium-bearing reactor fuel. Generally, little or no shielding is required.

Low-level waste (LLW): Refers to radioactive waste that is not classified as HLW, TRU, or spent nuclear fuel (SNF).

Hazardous waste: Refers to nonradioactive waste materials defined by the Resource Conservation and Recovery Act (RCRA) as hazardous wastes. These wastes are considered to pose potential hazard to human health when improperly treated, stored, disposed of, or otherwise managed because of their quantity, concentration, and physical and chemical characteristics. (Note: hazardous waste mixed with low-level [radioactive] waste or TRU waste is referred to as mixed low-level waste or mixed TRU waste, respectively.)

Liquid and solid LLW types are treated at the SRS. Aqueous LLW streams undergo filtration, reverse osmosis, and ion exchange at the F-and H-Area effluent treatment facility (ETF) to remove the radionuclide contaminants. The treated effluent is discharged to Upper Three Runs Creek.

Treatment residuals are eventually immobilized with grout for on-site disposal. Solid LLW is categorized into four groups: low-activity wastes (those that radiate less than 0.002 Sv/h [200 mrem/h] at 5.1 cm [2 in.] from the unshielded container); intermediate-activity wastes (those that radiate greater than 0.002 Sv/h [200 mrem/h] at 5.1 cm [2 in.]); intermediate-activity tritium waste (intermediate-activity waste with more than 3.7×10^{11} Bq [10 Ci] of tritium per container); and long-lived waste (waste contaminated with long-lived isotopes that exceed the waste acceptance criteria [WAC] for on-site disposal) (DCS 2002). Wastes in the first three categories are stored and disposed of in vaults, and wastes in the fourth category are placed in a waste storage building until treatment and disposal technologies are developed. Located in the E-Area, the vaults are below-grade concrete structures, and the storage building is a metal structure on a concrete pad. Disposal facilities at the SRS are projected to meet solid LLW disposal capacity needs for the next 20 years.

Mixed LLW is stored in various tanks and buildings located in the A-, E-, M-, N-, and S-Areas of the SRS. The current mixed waste program at the SRS primarily involves the safe storage of these wastes until treatment and disposal facilities become available. A site treatment plan (WSRC 2000b) for mixed wastes has been developed, as required by the Federal Facility Compliance Act, that specifies treatment technologies or technology development schedules for all SRS mixed waste. During 1999, plans for all mixed LLW were met in accordance with the site treatment plan (Arnett and Mamatey 2000b).

Hazardous waste is managed at the SRS either by accumulating the waste at the generating facility for a maximum of 90 days or storing it in Resource Construction and Recovery Act (RCRA)-permitted hazardous waste storage buildings or on interim storage pads located in the B- and N-Areas. Most of the waste is shipped off-site to commercial RCRA-permitted facilities. In 1999, 297 m^3 (388 yd^3) of hazardous waste was shipped off-site to commercial disposal facilities (Arnett and Mamatey 2000b).

The treatment of nonhazardous wastewater at the SRS has been centralized since 1994 with the completion and operation of the 2.8 million-L/day (0.75 million-gal/day) Central Sanitary Wastewater Treatment Facility. This facility treats sanitary wastewater by an extended aeration activated sludge process that separates the wastewater into clarified effluent and sludge.

The collection, hauling, and disposal of solid sanitary waste at the SRS is privatized, and the waste is sent to the Three Rivers Landfill southwest of the B-Area. Other nonhazardous waste consists of scrap metal, powerhouse ash, domestic sewage, scrap wood, construction debris, and used railroad ties. These wastes are disposed of by means appropriate to their nature.

3.10 Human Health Risk

Human health can be adversely affected by radioactive and hazardous chemical contaminants in the environment. This section discusses how humans can become exposed to these materials, the potential effects of this exposure, potential human receptors considered in this EIS, and the existing conditions at the SRS and the surrounding area. Methods used to estimate the potential for injuries or fatalities among workers are also discussed.

3.10.1 Hazard Exposure Pathways

3.10.1.1 Pathways for Human Exposure to Radiation and Radioactivity

Radioactivity released from the SRS reaches the environment and people in a variety of ways. The routes that radioactive materials follow to get from an SRS facility to the environment and then to people are called pathways. The primary human exposure pathways for these releases are discussed below:

- *Inhalation exposure pathway*: Individuals in the path of airborne emissions would receive a dose from breathing in the radioactive material. Some of this material also deposits on the ground and over time may become resuspended in the air, at which time it may also be inhaled.

- *Direct radiation from contaminated soil*: Material that is deposited on the ground from passing airborne emissions becomes an external exposure source of direct radiation.

- *Immersion in radioactive clouds*: Individuals in the path of radioactive airborne emissions would receive an external dose during immersion in the passing "cloud" of material.

- *Ingestion exposure pathway*: Radioactive materials can be transported through a variety of routes into the human diet. Airborne radioactive material may deposit directly on food crops or animal feed crops, resulting in potential exposure from human ingestion of the food crops or indirectly from ingestion of contaminated animal products. Material deposited on farmland may also be taken up through the roots by human and animal food crops. Material deposited on surface water or land may reach groundwater. Contaminated surface water or groundwater could be used for irrigating crops or direct consumption by humans. Contaminated surface water could also result in contamination of aquatic species, such as fish, which could subsequently be consumed by humans.

One important pathway of radioactive material released from the SRS in the form of particulate matter is the airborne pathway. After being discharged from a stack, the radioactive particulate matter will be carried by wind downwind of the facility, where it will either be inhaled by individuals or settle on the ground. Radioactivity in the soil will cause direct radiation exposures in individuals located near contaminated soil. Soil contamination may also be resuspended into the air by the wind and then inhaled farther downwind. Food produced on farmlands with contaminated soil will also contain this radioactivity. Precipitation runoff from downwind soil will carry radioactivity to local surface waters, such as lakes, rivers, and streams. Finally, radioactivity in surface water may accumulate in fish or other aquatic life that can be consumed by humans.

Radiation and Radioactivity

Radioactivity or *radioactive decay* is the process by which unstable atoms emit *radiation* to reach a more stable state.

Radiation is the movement of energetic particles or waves through matter and space. Radiation comes from radioactive material or from equipment such as x-ray machines. Radiation may be either ionizing radiation or non-ionizing radiation.

Ionizing radiation is radiation that has enough energy to cause atoms to lose electrons and become ions. For example, the radioactive decay of plutonium produces radiation that can ionize matter (e.g., tissue).

Radiation dose is the quantity of radiation energy that is deposited in a material. The radiation dose to humans is measured in units of sieverts (Sv). The unit of rem is also used. One sievert is equal to 100 rem.

Collective dose is the sum of the individual doses received in a given period of time by a specified population. The unit of collective dose is person-sieverts, or person-rem.

The DOE has determined the critical types of radioactivity and pathways for radioactive materials released from SRS operations. Tritium and cesium-137 are the primary contributors to doses to members of the public. The major pathways for tritium released into air were through breathing air and eating food, whereas the major pathway for tritium and cesium-137 released into site streams were through drinking river water and eating fish from the river (DOE 1999). Pathways or routes by which radioactive material moves through the environment to reach humans can be complex. For example, contaminants can settle on grass that is eaten by cows that produce milk that is consumed by humans. The meat of the cows can also be consumed by humans. Another example, more relevant to the SRS, would be game animals that consume contaminated vegetation and then are eaten by humans. A detailed discussion of the many pathways at the SRS is presented in the annual environmental report (Arnett and Mamatey 2001b).

3.10.1.2 Pathways for Human Exposure to Chemicals

Humans can also be exposed to nonradioactive chemicals released to the environment. The DOE has determined that the critical chemicals among those released from SRS operations to the environment are arsenic and benzene (Arnett and Mamatey 2000b). Exposures may occur primarily through inhaling pollutants released to air, drinking contaminated groundwater or surface water, ingesting contaminants in foodstuffs grown in contaminated soil or irrigated with contaminated groundwater, or ingesting contaminated soil.

3.10.1.3 Physical Hazards

Although not attributable to releases of contaminants to the environment, there is a risk of injuries and fatalities from physical hazards for construction and operation workers at any facility. The U.S. Bureau of Labor keeps statistics on the annual number of injuries and fatalities by industry type. Where possible, these statistics have been used to estimate the extent of physical hazard risk for the no-action and proposed action alternatives.

3.10.2 Receptors

Effects of radiation and chemical exposures for the no-action and proposed action alternatives during normal operations were estimated by first calculating the doses to relevant receptors. The analyses considered three groups of people: (1) members of the public, (2) SRS employees, and (3) facility workers. For purposes of this EIS, these three groups are defined as follows:

- *Members of the Public*: Individuals who live and work outside the SRS within 80 km (50 mi) of the proposed facilities:
  - Might be exposed to trace amounts of radioactive and chemical materials released to the environment through exhaust stacks.
  - Could receive radiation and chemical exposures primarily through inhalation of material in the air, external radiation from deposited radioactive material, and ingestion of contaminated food.
- *SRS Employees*: Individuals employed at the SRS who are not workers at the proposed MOX facility, the PDCF, or the WSB. SRS employees include those workers assigned radiological work at other nuclear facilities within the SRS boundary, as well as those who are not assigned radiological work, such as cafeteria workers or persons in administrative positions:
  - Might be exposed to direct radiation from radioactive materials (although at a great distance) and to trace amounts of plutonium or uranium released to the environment through site exhaust stacks.
  - Could receive radiation and chemical exposures primarily through inhalation of material in the air and external radiation from radioactive material deposited on the ground.
  - Work-related physical hazard risks are present.
  - Estimate of impacts to transient population groups (soda machine vendors, etc.) are bounded by impacts to this group.
- *Facility Workers*: Individuals who work at the proposed MOX facility, the PDCF, or the WSB and who receive a radiation dose in the course of employment in which the assigned duties of the individuals involve exposure to radiation or to radioactive material from licensed and unlicensed sources of radiation:

- Might be exposed to direct gamma radiation emitted from radioactive materials, such as depleted uranium compounds.

- Could receive small radiation doses from inhaling uranium, plutonium, or other radionuclides compared with the direct radiation doses resulting from enclosed processes; ventilation controls would be used to inhibit airborne emissions in facilities.

- Would be protected by a dosimetry program to control doses below the maximum regulatory limit of 0.05 Sv/yr (5 rem/yr) for workers (10 CFR 20.1201).

- For chemical exposures, facility workers are addressed under separate regulations (e.g., Occupational Safety and Health Act [OSHA]); their exposures are not quantitatively addressed in this FEIS. However, physical hazards (i.e., risks of injury and fatality) are addressed for both construction and operations workers.

Impacts to a maximally exposed individual (MEI) were also evaluated. The MEI is a hypothetical person who, because of proximity, activities, or living habits, could receive the highest possible dose of radiation or of a hazardous chemical from a given event or process. For members of the public, potential locations for an MEI would be at the site boundary, the closest possible public access points near the operations under consideration. For SRS employees not directly involved in facility operations, MEI locations are considered at distances of 100 m (330 ft) or more from a facility. An MEI for radiation exposure is not always considered for facility workers because these workers are monitored, and their exposure is expected to be kept as low as reasonably achievable (ALARA), with workers being rotated into and out of relatively higher exposure job functions. In such cases, an average worker dose was estimated.

3.10.3 Baseline Radiological Dose and Risk

The radiological baseline in the vicinity of the SRS includes background radiation, man-made (anthropogenic) sources, and radiation from ongoing SRS operations. Background radiation comes from natural sources, such as cosmic radiation and naturally occurring radioactive material, and from anthropogenic sources that cannot be controlled, such as global fallout from nuclear testing or nuclear accidents. Anthropogenic sources, including consumer products (e.g. television sets and smoke detectors) and medical procedures, account for additional exposure. Human exposure to radiation is measured in units of sieverts (Sv). Background radiation levels

What Is a Sievert?

A *sievert* is a unit of radiation dose. The effects of radiation exposure on humans depend on the kind of radiation received, the total amount absorbed by the body, and the tissues involved. A sievert (Sv) is calculated by a formula that takes these three factors into account. Another common unit of radiation dose is the rem (1 Sv = 100 rem). The U.S. average individual radiation dose is about 0.0036 Sv (0.36 rem) or 3.6 millisievert (mSv) [360 millirem (mrem)] from natural background and anthropogenic sources.

Latent Cancer Fatality (LCF)

What it is: The primary adverse health effect from the low-level radiation doses received from proposed MOX facility, PDCF, or WSB operations and potential accidents would be the possible induction of latent cancer fatalities (LCFs). LCFs are a measure of the expected number of additional cancer deaths in a population (or people dying of cancer) as a result of exposure to radiation. Death from cancer induced by exposure to radiation may occur at any time after the exposure takes place. However, latent cancers would be expected to occur in a population from one year to many years after the exposure takes place. To place the significance of these additional LCF risks from exposure to radiation into context, the average individual has approximately 1 chance in 4 of dying from cancer (LCF risk of 0.25).

How it is calculated: The U.S. Environmental Protection Agency has suggested (Eckerman et al. 1999) a conversion factor that for every 100 person-Sv (10,000 person-rem) of collective dose, approximately 6 individuals would ultimately develop a radiologically induced cancer. If this conversion factor is multiplied by the individual dose, the result is the individual increased lifetime probability of developing an LCF. For example, if an individual receives a dose of 0.00033 Sv (0.033 rem), that individual's LCF risk over a lifetime is estimated to be 2×10^{-5}. This risk corresponds to a 1 in 50,000 chance of developing a LCF during that individual's lifetime. If the conversion factor is multiplied by the collective (population) dose, the result is the number of excess LCFs. Because these results are statistical estimates, values for expected LCFs can be, and often are, less than 1.0 for cases involving low doses or small population groups. If a population group collectively receives a dose of 50 Sv (5,000 rem), which would be expressed as a collective dose of 50 person-Sv (5,000 person-rem), the number of potential LCFs experienced from within the exposure group is 3. If the number of LCFs estimated is less than 0.5, on average, no LCFs would be expected.

result in a national annual average individual exposure of approximately 3.0 mSv (300 mrem), with an additional 0.60 mSv (60 mrem) from other anthropogenic sources. A more detailed breakdown of these sources is presented in Table 3.7.

Radiation from SRS operations is estimated by analyzing monitoring data. The SRS has an extensive radiological monitoring network both on- and off-site to assess the effects of site operations on air, surface water, groundwater, soil, terrestrial and aquatic food products, and local game animals. These routine environmental surveillance activities include monitoring airborne and liquid effluent discharges from their points of origin at each operating facility on the SRS to determine compliance with applicable exposure standards. The results of the effluent monitoring and environmental surveillance and the potential radiation doses to members of the public in surrounding areas from those effluents are published annually by the Environmental Monitoring Section of Westinghouse Savannah River Company (e.g., Arnett and Mamatey 2001b).

Airborne emissions from the SRS operations for 2000 are summarized in Table 3.8. Liquid releases for 2000 are summarized in Table 3.9. The estimated off-site radiation doses from both airborne and liquid releases were below all applicable radiation exposure standards for humans and aquatic organisms (Arnett and Mamatey 2001b). The estimated exposures and the applicable standard for each exposure are summarized in Table 3.10. The estimated all-pathway dose to an MEI was 0.0018 mSv (0.18 mrem), which is 0.18% of the DOE's 1.0 mSv (100-mrem) all-pathway dose standard for annual exposure. For an NRC-licensed facility, such as the proposed MOX facility, a dose limit of 1.0 mSv/yr (100 mrem/yr) from operations for an individual member of the public is also applicable (10 CFR 20.1301).

Table 3.7. Sources and contributions to the U.S. average individual radiation dose[a]

Source	Effective dose equivalent [mSv/yr (mrem/yr)]
Natural background radiation	
Cosmic radiation	0.27 (27)
Rocks and soil (external)	0.28 (28)
Internal to body	0.40 (40)
Radon (internal/inhalation)	2.0 (200)
Subtotal	≈2.95 (≈295)
Man-made background radiation	
Weapons test fallout	<0.01 (<1)
Consumer products	0.10 (10)
Medical	
Diagnostic X-rays	0.39 (39)
Nuclear Medicine	0.14 (14)
Subtotal	≈0.64 (≈64)
Total	≈3.60 (≈360)

[a]*Source*: Modified from Arnett and Mamatey (2001b) and NCRP (1987).

Workers at the SRS with the potential to be exposed to external radiation or to inhale airborne radioactivity take part in a monitoring program in accordance with 10 CFR 835 ("Occupational Radiation Protection"). In 2000, 3,382 SRS workers had a measurable dose with a combined total effective dose equivalent (TEDE) of 1.632 person-sievert (person-Sv) (163.2 person-rem) for an average TEDE of 0.00048 Sv (0.048 rem) (DOE undated).

The primary health concerns attributed to radiation exposure are the development of cancer and hereditary (genetic) effects. Although radiation-induced genetic effects have been observed in laboratory animals (given very high doses of radiation), no evidence of genetic effects has been observed among the children born to atomic bomb survivors from Hiroshima and Nagasaki. Thus, latent cancer fatalities (LCFs) are the radiological health effect end point used in this EIS as a measure of human health impacts. A conservative assumption in this regard is that any amount of radiation may pose some risk for causing cancer, and that the risk is higher for higher radiation exposures. A linear, no-threshold dose response relationship is used to describe the relationship between radiation dose and the occurrence of cancer. This dose-response model suggests that any increase in dose, no matter how small, results in an incremental increase in risk. For the purposes of this EIS, the risk of a latent cancer fatality (LCF) is taken to be 0.06 LCF per person-Sv (0.0006 LCF per person-rem). (See the text box in this section for a discussion on LCFs.) This LCF risk factor is a gender- and age-averaged value that accounts for differences between male and female receptors from infancy through old age living in the United States (Eckerman et al. 1999). While female receptors were

Table 3.8. Radioactive atmospheric releases from SRS operations for 2000

Radionuclide	Curies[a]	Radionuclide	Curies[a]
Gases and Vapors		*Particulates (cont.)*	
H-3 (oxide)	3.24×10^{4}	Eu-152	4.13×10^{-5}
H-3 (elem.)	1.24×10^{4}	Eu-154	1.64×10^{-5}
H-3 total	4.48×10^{4}	Eu-155	4.02×10^{-6}
C-14	1.33×10^{-1}	Hg-203	2.23×10^{-10}
Kr-85	5.28×10^{4}	Ra-226	1.74×10^{-5}
I-129	1.71×10^{-3}	Ra-228	2.74×10^{-5}
I-131	6.96×10^{-6}	Ac-228	1.80×10^{-6}
I-133	1.18×10^{-4}	Th-228	5.76×10^{-7}
		Th-230	1.74×10^{-5}
Particulates		Th-232	2.58×10^{-6}
Cr-51	1.21×10^{-4}	Th-234	1.04×10^{-4}
Co-57	3.26×10^{-7}	Ba-133	5.4×10^{-10}
Co-58	1.27×10^{-4}	U-233	1.50×10^{-8}
Co-60	8.60×10^{-4}	U-234	3.98×10^{-4}
Ni-59	4.17×10^{-13}	U-235	1.80×10^{-5}
Ni-63	5.09×10^{-6}	U-236	4.16×10^{-11}
Zn-65	2.23×10^{-5}	U-238	5.20×10^{-4}
Sr-89,90	3.89×10^{-3}	Np-237	2.26×10^{-10}
Zr-95	1.68×10^{-5}	Pu-238	3.59×10^{-4}
Zr-85	1.07×10^{-9}	Pu-239	2.05×10^{-3}
Nb-94	3.95×10^{-10}	Pu-240	1.99×10^{-7}
Nb-95	1.13×10^{-4}	Pu-241	4.09×10^{-6}
Tc-99	8.75×10^{-5}	Pu-242	7.03×10^{-9}
Ru-103	4.23×10^{-5}	Am-241	1.46×10^{-4}
Ru-106	1.04×10^{-5}	Am-243	6.02×10^{-6}
Sb-124	5.63×10^{-10}	Cm-242	4.47×10^{-7}
Sb-125	5.34×10^{-5}	Cm-244	7.68×10^{-5}
Sn-113	6.20×10^{-10}	Cm-245	1.04×10^{-13}
Sn-126	6.45×10^{-14}	Cm-246	3.98×10^{-8}
Cs-134	1.31×10^{-4}	Ar-39	3.30×10^{-5}
Cs-137	8.15×10^{-3}	Na-22	7.90×10^{-11}
Ce-141	4.16×10^{-5}	Mn-54	1.30×10^{-10}
Ce-144	1.44×10^{-4}	Se-79	4.47×10^{-9}
Pa-233	2.23×10^{-10}		
Pr-144	3.68×10^{-13}	Alpha	7.35×10^{-4}
Pr-144m	4.43×10^{-15}	Beta-Gamma	3.57×10^{-2}
Pm-147	1.30×10^{-5}		

[a]One curie (Ci) equals 3.7×10^{10} becquerels (Bq). One Bq equals one disintegration per second (dps).

Source: Modified from Arnett and Mamatey (2001b).

Table 3.9. Radioactive liquid releases from SRS operations for 2000 (including direct and seepage basin migration releases)

Radionuclide	Curies[a]
H-3	5.34×10^{3}
Sr-90	5.44×10^{-2}
Co-60	1.62×10^{-3}
I-129	7.82×10^{-2}
Cs-137	8.81×10^{-2}
U-234	2.87×10^{-5}
U-235	6.18×10^{-6}
U-238	1.97×10^{-4}
Pu-238	2.21×10^{-5}
Pu-239	1.68×10^{-5}
Am-241	1.19×10^{-5}
Cm-244	7.01×10^{-6}
Alpha	1.96×10^{-2}
Beta-Gamma	4.44×10^{-2}

[a]One Ci equals 3.7×10^{10} Bq.

Source: Modified from Arnett and Mamatey (2001b).

estimated to have a slightly higher LCF rate than males, and infants a higher LCF rate than adults, the use of this risk factor for estimating collective LCF risks to the public in this EIS should provide a reasonable average based on current understanding of radiological effects in humans. On the other hand, the collective LCF risks to the facility workers and SRS employees evaluated in this EIS may be conservative (overestimated) because the more susceptible receptors, such as infants, considered in determining the LCF risk factor are not present in the SRS employee population.

3.10.4 Baseline Chemical Exposure and Risk

3.10.4.1 Chemical Risk Assessment Background

As stated in Section 3.10.2, human exposure to nonradioactive chemicals in air, water, or soil may occur through ingestion, inhalation, or contact with skin. Methods used to assess hazards associated with chemical exposures may simply involve a comparison of concentrations in air, water, or soil with health-risk based standards or guidelines available from state and federal agencies (see *SRS Baseline Risks* below). More detailed assessments estimate the extent of

Table 3.10. Estimated radiation exposures to the public from SRS emissions in 2000

Pathway/receptor	Dose	Standard
Air		
Maximally exposed individual [mSv (mrem)]	0.0004 (0.04)	0.10 (10)[a]
Collective population [person-Sv (person-rem)]	0.023 (2.3)	NA[b]
Liquid		
Maximally exposed individual [mSv (mrem)]	0.0014 (0.14)	0.04 (4)[c]
Collective population [person-Sv (person-rem)]	0.039 (3.9)	NA
Total		
Maximally exposed individual [mSv (mrem)]	0.0018 (0.18)[d]	1.0 (100)[e]
Collective population [person-Sv (person-rem)]	0.062 (6.2)[d]	NA

[a]Set by the EPA in "National Emission Standards for Hazardous Air Pollutants — Radionuclides," 40 CFR 61 Subpart H, December 15, 1989.

[b]NA = not applicable.

[c]Adopted from the EPA in DOE Order 5400.5 as set forth in "National Primary Drinking Water Standards," 40 CFR Part 141.11, July 9, 1976.

[d]Sum of the air and liquid pathways.

[e]All pathway dose standard from DOE Order 5400.5.

Source: Arnett and Mamatey (2001b).

human exposure due to a particular source and compare that exposure with benchmark levels for noncarcinogenic risks ("hazard index" approach) or benchmarks for carcinogenic risks.

In estimating either noncancer risks (that is, noncancer adverse health outcomes, such as liver damage or developmental impairment) due to chemical exposures or increased lifetime cancer risk, the first step is to estimate the chemical concentration in air, water, and/or soil, either present from natural sources or attributable to anthropogenic sources. The concentration estimate is combined with an estimate of the human intake level to produce a chemical-specific daily intake estimate. (The intake level is usually from the upper end of the expected range of possible intakes in order to make sure risk estimates take individuals who have unusually high intakes into account). Estimated intakes are compared with chemical-specific reference doses or cancer slope factors. The reference doses and cancer slope factors are developed by the EPA for many commonly used chemicals and are based on a broad range of toxicological data. See the text box for further information on risk estimation procedures.

3.10.4.2 SRS Chemical Baseline Risks

Public water supplies in the vicinity of the SRS are monitored and regulated to be in compliance with health-based federal standards, and remediation programs are underway at the SRS to

Concepts in Estimating Risks from Exposures to Chemicals in Air, Water, and Soil

Reference Dose: Intake level of a chemical that is very unlikely to have noncancer adverse effects; measured in units of milligrams per kilogram of body weight per day (mg/kg-d). Different reference doses often apply for oral and inhalation exposures.

Hazard Quotient: a comparison of the estimated intake level or dose of a chemical in air, water, or soil with its reference dose; expressed as a ratio.

Example: If 5 parts per billion (0.005 mg/L) benzene is in groundwater used for drinking and 2 L is ingested daily by a 70-kg (150-lb) person over a period of 10 years, then
Intake = (0.005 mg/L x 2 L/day)/70 kg = 0.00014 mg/kg-d.
The reference dose for chronic ingestion of benzene is 0.0003 mg/kg-d.
The benzene hazard quotient is 0.00014/0.0003 = 0.5. This hazard quotient is less than 1, indicating that the exposure is unlikely to cause adverse noncancer health effects.

Hazard Index: The sum of hazard quotients for all chemicals to which an individual is exposed. Used as a screening tool, a hazard index of less than 1 indicates that adverse health effects are unlikely. However, a hazard index of greater than 1 does not necessarily mean adverse health effects will occur, because different chemicals may react differently in the human body (that is, they may have different, nonadditive kinds of toxicity).

Slope Factor: an upper-bound estimate of a chemical's probability of causing cancer over a 70-year lifetime, based on the extent of intake during the exposure period and given in units of inverse intake [$(mg/kg\text{-}d)^{-1}$ or 1/(mg/kg-d)]. For a carcinogen, different slope factors often apply for oral and inhalation exposures.

Increased Lifetime Cancer Risk: an upper-bound estimate of the likelihood that an individual will develop cancer as a result of exposure to a cancer-causing chemical. It is the product of the intake level and the slope factor.

Example: benzene is also a cancer-causing chemical with an oral slope factor of up to 0.055 $(mg/kg\text{-}d)^{-1}$.

Assuming 5 parts per billion (0.005 mg/L) in water and calculating intake as above, but averaging over a lifetime of 70 years, the increased lifetime cancer risk for benzene ingestion would be:

0.00014 mg/kg-d x 0.055 $(mg/kg\text{-}d)^{-1}$ x 10-yr exposure/70-yr lifetime = 0.0000011 (also can be stated as 1.1×10^{-6} or 1.1 in 1 million).

This increased risk level would be considered to be small. It is at the lower end of the risk range of 0.000001 (10^{-6}, or 1 in 1 million) to 0.0001 (10^{-4}, or 1 in 10,000) which generally does not require mitigating actions.

control exposure to and eliminate areas of soil contamination. Therefore, the most important potential exposure pathway for workers and the general public would be through inhalation of contaminants released to air from ongoing SRS operations.

The SRS has approximately 200 regulated sources of air emissions. In 1991, the SCDHEC established Air Pollution Control Regulation 61-62.5, Standard No. 8, to regulate hazardous or toxic air pollutant emissions. To demonstrate compliance with this standard, the SRS completed an air emissions inventory and air dispersion modeling for all site sources in 1993, as summarized in Arnett and Mamatey (2001b). An update to the modeling was submitted in 1998 (Dukes 1998). The modeling effort provides estimates of maximum ambient concentrations at or beyond the SRS boundary due to SRS emission sources for about 200 toxic air pollutants (TAPs). The estimated maximum concentrations of the TAPs did not exceed values given in the 2001 version of the SCDHEC standard No. 8 (SCDHEC 2001).

Because regulatory standards are not developed exclusively on the basis of public health considerations, and because the basis for the SCDHEC standard concentrations is not described in available documentation (SCDHEC 2001), the potential for adverse human health impacts was assessed through comparison with health risk-based guideline levels. Specifically, the reported maximum ambient 24-hour average concentrations were modified by a factor of 0.2 to estimate annual average concentrations (based on EPA guidance [EPA 1992]). These estimated annual average concentrations were compared with health risk-based air concentrations developed by the EPA's Office of Air Quality Planning and Standards (OAQPS) (Smith et al. 1999) and with EPA-established reference concentrations for non-cancer effects (EPA 2003b). Although only two TAPs (TCDDs and tetrachloroethylene) exceeded the EPA guideline levels, 10 TAPs had estimated annual average concentrations between the EPA guideline cancer risk level values of 10^{-6} to 10^{-4} (see Table 3.11).

3.10.5 Baseline Physical Hazard Risks

Although worker physical hazard risks (i.e., risks of fatality or injury from on-the-job accidents) can be minimized when workers adhere to safety standards and use protective equipment as necessary, certain rates of accidents have been associated with all types of work. Risks can be calculated on the basis of historical industrywide statistics, as described below.

The expected annual numbers of worker fatalities and injuries for specific industry types are calculated on the basis of rate data from the Bureau of Labor Statistics, as reported by the National Safety Council (NSC 2001), and on the number of annual full-time equivalent (FTE) workers required for manufacturing activities. Employment at the SRS in 2000 was 13,227 people (DCS 2001b). It is assumed that, in general, the types of activities required for these employees would be similar to those for the manufacturing industrial sector, so those fatality and injury rates are used to estimate annual risks. A rate of 3.3 fatalities per 100,000 FTEs and 4.6 injuries per 100 FTEs is used. On the basis of these rates, the estimated annual number of fatalities for SRS workers is less than 1 (specifically, 0.44) per year. The estimated number of injuries is 610 per year (includes only injuries resulting in lost workdays, not including the day of injury). These physical hazard risks represent the baseline risks for existing SRS operations for comparison with impacts under the no-action and proposed action alternatives. However, actual injury and fatality risks over the past 10 years or more have been lower than those predicted on the basis of national statistics.

Table 3.11. Modeled site boundary ambient concentrations of select SRS toxic air pollutant (TAP) emissions in comparison with SCDHEC standards and EPA health risk-based guideline levels

Toxic air pollutant (TAP)	Number of SRS sources	SRS maximum modeled 24-hour average concentration (μg/m³)[a]	SRS Estimated Annual Average Concentration (μg/m³)[b]	SCDHEC standard (μg/m³)	EPA guideline level (μg/m³)[c]
TAPs with ambient level exceeding EPA guideline level					
TCDDs	1	0.00002	4×10^{-6}	0	3×10^{-8} to 3×10^{-6}
Tetrachloroethylene	36	99	20	3,350	0.17-17
TAPs with estimated annual ambient level between EPA Guideline 10^{-6} and 10^{-4} cancer risk level					
Arsenic	7	0.05	0.01	1.0	0.00023-0.023
Benzene	118	4.6	0.9	150	0.13-13 (30)
Beryllium	7	0.009	0.0020	0.01	0.00042-0.042 (0.02)
Bis(chloromethyl)ether	1	0.002	0.0004	0.03	2×10^{-5} to 2×10^{-3}
Carbon tetrachloride	16	4.2	0.84	150	0.067-6.7
Dimethyl benzidine	1	0.002	0.0004	NA	0.00038-0.038
Heptachlor	1	0.01	0.002	2.5	0.00077-0.077
Hydrazine	5	0.06	0.012	0.5	0.0002-0.02
Quinoline	1	0.004	0.0008	NA	0.00029-0.029
Trichloroethylene	38	23	5	6,750	0.5-50

[a]SCDHEC Standard No. 8 requires that the standards be compared with modeled maximum 24-hour average concentrations at or beyond the site boundary.

[b]EPA guideline values should be compared with annual average concentrations; these values were estimated as the maximum 24-hour ambient concentrations multiplied by 0.2.

[c]Where a range is given, the range corresponds to a 10^{-6} to 10^{-4} risk level (that is, the concentration that if inhaled for a lifetime would result in an increased individual risk of developing cancer of between 1 in 1 million and 1 in 10,000). Values in parentheses are verified reference concentrations established by the EPA (2003b), also recognized as important guidelines under SCDHEC Standard No. 8.

Sources: Dukes (1998); SCDHEC (2001); Smith et al. (1999, Table 2).

3.11 Socioeconomics

This section discusses existing socioeconomic conditions in the vicinity of the SRS as they relate to the proposed facilities. The socioeconomic data presented for the SRS describe a regional economic area (REA) comprising 15 counties around the site (see Appendix D) and a region-of-influence (ROI) surrounding the site comprising 4 counties — Columbia and Richmond Counties in Georgia and Aiken and Barnwell Counties in South Carolina. The REA is used to assess the potential regional economic impacts of site activities, specifically impacts on employment and unemployment and on personal income. The REA constitutes a broad market area defined by economic linkages between the various sectors in the regional economy.

The ROI was defined on the basis of the current residential locations of full-time SRS workers directly involved in the SRS activities and encompasses the area in which most of these workers spend their wages and salaries. The ROI is used to assess the impacts of site activities on population, housing, community services, and community fiscal conditions. More than 90% of SRS workers currently reside in these counties (DCS 2001b). In the following sections, data are presented for each of the counties in the ROI.

3.11.1 Population

The population of the ROI was at 475,095 in 2000 (U.S. Bureau of the Census 2002a) and was expected to reach 489,000 by 2001, as shown in Table 3.12. In 2000, 30% of the ROI total (142,552 people) resided in Aiken County (U.S. Bureau of the Census 2001), with 25,337 in the city of Aiken. Over the period 1990-2000, population in the ROI as a whole, in Aiken County, and in the city of Aiken grew slightly, with average growth rates of 1.4%, 1.7%, and 2.5%, respectively. Over the same period, population in South Carolina as a whole grew at a rate of 1.4%.

In 2000, 41% of the ROI population (195,182 persons) resided in the city of Augusta/Richmond County, Georgia, with 19% (89,288) located in Columbia County, Georgia, and 5% (23,478) in Barnwell County, South Carolina (U.S. Bureau of the Census 2000). Growth in Augusta/Richmond County over the period 1990-2000 was slight at 0.3%, relatively high in Columbia County over the same period at 3.1%, and moderate in Barnwell County at 1.5%. Other incorporated places in the immediate vicinity of the SRS are Barnwell (population 5,035 in 2000), Blackville (2,973), Elko (212), Hilda (436), Jackson (1,625), New Ellenton (2,250), North Augusta (17,574), and Willston (3,307) (U.S. Bureau of the Census 2002a).

3.11.2 Employment and Unemployment

Employment in the REA totaled 207,660 people in 2000 and was expected to reach 214,000 in 2002. Employment grew at an annual average rate of 1.6% between 1990 and 2000 (U.S. Bureau of the Census 1992, 2002b). The economy of the REA is dominated by the trade

Table 3.12. ROI population statistics for selected years

Entity	1990[a]	2000[a]	Average annual growth rate (%), 1990-2000	2002 (projected)
Georgia				
Columbia County	66,031	89,288	3.1	95,000
Richmond County/City of Augusta	189,719	195,182	0.3	196,000
South Carolina				
Aiken County	120,991	142,552	1.7	147,000
City of Aiken	19,872	25,337	2.5	27,000
Barnwell County	20,293	23,478	1.5	24,000
ROI Total	415,394	475,095	1.4	489,000
Georgia	6,478,216	8,186,453	2.4	8,580,000
South Carolina	3,486,703	4,012,012	1.4	4,130,000

[a]*Source*: U.S. Bureau of the Census (2002a).

and service industries, with these activities currently contributing almost 63% of all employment in the REA (see Table 3.13). The manufacturing sector is also a significant employer in the REA, with 27% of total REA employment. Employment at the SRS in 2000 was 13,227 people (DCS 2001b).

Unemployment in the REA steadily declined during the late 1990s from a peak rate of 8.0% in 1993 to the 2002 rate of 5.7% (see Table 3.14) (U.S. Bureau of Labor Statistics 2002). Unemployment in Georgia was 4.7% in August 2002; in South Carolina the rate was 5.7% in that month.

3.11.3 Income

Personal income in the REA was $14.8 billion in 2000 and was expected to reach $15.6 billion in 2002. Personal income grew at an annual average rate of 1.8% over the period 1990-1999 (see Table 3.15). Personal income per capita in the REA also rose in the 1990s and was expected to reach $24,700 in 2002, compared with $23,146 at the beginning of the period.

3.11.4 Housing

Total housing in Columbia County grew at an annual rate of 3.5% over the period 1990-2000 (see Table 3.16), with total housing units expected to reach 35,400 in 2002, reflecting the relatively high growth in county population. About 9,580 new units were added to the existing housing stock in the county between 1990 and 2000. On the basis of annual population growth rates, there were expected to be 2,340 vacant housing units in the county in 2002, with 420 expected to be rental units available to construction workers at the proposed facilities.

Table 3.13. REA employment by industry, 2000

Sector	Employment	Percent of REA total
Agriculture[a]	6,250	3.0
Mining	877	0.4
Construction	11,399	5.5
Manufacturing	55,853	27.0
Transportation and Public Utilities	5,028	2.4
Trade	34,389	17.0
Finance, Insurance and Real Estate	7,783	3.7
Services	86,673	42.0
Other	193	0.1
Total	207,660	

[a]1997 data; U.S. Department of Agriculture (1999).

Source: U.S. Bureau of the Census (2002b), except as noted.

Total housing in the City of Augusta/Richmond County grew at an annual rate of 0.6% over the period 1990-2000 (see Table 3.16), with total housing units expected to reach 82,800 in 2002, reflecting the relatively slow growth in county population. Only 5,000 new units were added to the existing housing stock in the county between 1990 and 2000. On the basis of annual population growth rates, there were projected to be 8,440 vacant housing units in the county in 2002, with 3,550 of those expected to be rental units available to construction workers at the proposed facilities.

Table 3.14. REA unemployment rates

Period	Rate (%)
REA	
1990-2000 average	6.7
2002[a]	5.7
Georgia	
1990-2000 average	5.0
2002[b]	4.7
South Carolina	
1990-2000 average	5.4
2002[b]	5.7

[a]Rate is for July 2002.

[b]Rate is for August 2002.

Source: U.S. Bureau of Labor Statistics (2002).

Total housing in Aiken County grew at an annual rate of 2.3% over the period 1990-2000 (see Table 3.16), with total housing units expected to reach 64,100 in 2002. Growth in the city of Aiken was 2.9% over this period, with 11,900 total housing units expected in 2002. Almost 12,700 new units were added to the existing housing stock in the county between 1990 and 2000, 2,830 of which were built in the city of Aiken. On the basis of annual population growth rates, there were expected to be 6,610 vacant housing units in the county in 2002, with 1,610 expected to be rental units available to construction workers at the proposed facilities.

Table 3.15. REA personal income (2003 dollars)

Parameter	1990[a]	2000[a]	Average annual growth rate (%), 1990-2000	2002 (projected)
Total personal income ($ millions)	12,426	14,814	1.8	15,600
Personal income per capita ($)	23,146	24,681	0.6	25,300

[a]*Source*: U.S. Department of Commerce (2002).

Total housing in Barnwell County grew at an annual rate of 2.6% over the period 1990-2000 (see Table 3.16), with total housing units expected to reach 10,500 in 2002, reflecting the moderate growth in county population. About 2,300 new units were added to the existing housing stock in the county between 1990 and 2000. On the basis of annual population growth rates, there were projected to be 1,210 vacant housing units in the county in 2002, with 300 of those expected to be rental units available to construction workers at the proposed facilities.

Total housing in the ROI as a whole grew at an annual rate of 1.8% over the period 1990-2000 (see Table 3.16), with total housing units expected to reach 202,000 in 2002. About 31,600 new units were added to the existing housing stock in the ROI between 1990 and 2000. On the basis of annual population growth rates, there were projected to be 19,600 vacant housing units in the ROI in 2002, with 5,910 of those expected to be rental units available to construction workers at the proposed facilities.

3.11.5 Community Resources

Construction and operation of the proposed MOX facility, PDCF, and WSB would result in increased revenues and expenditures for local government jurisdictions, including counties, cities, and school districts. Revenues would come primarily from state and local sales taxes associated with employee spending during construction and operation and local property taxes.

Additional revenues would be used to support additional local community services currently provided by each jurisdiction.

Construction and operation of the proposed facilities would result in increased demand for community services in the counties, cities, and school districts likely to host relocating construction workers and operations employees. Additional demands would also be placed on local medical facilities and physician services.

Tables D.1 and D.2 in Appendix D present information on revenues and expenditures by the various local government jurisdictions in the ROI. Tables 3.17 and 3.18 present data on employment and levels of service (number of employees per 1,000 population) for public safety, general local government services, and physicians. Tables 3.19 and 3.20 provide staffing data for school districts and hospitals.

Table 3.16. City, county, and ROI housing characteristics[a]

Parameter	1990[b]	2000[c]	2002 (projected)
Georgia			
Columbia County			
Owner occupied	17,322	25,557	27,100
Rental	4,519	5,563	5,900
Total unoccupied units	1,904	2,201	2,340
Total units	23,745	33,321	35,400
Richmond County/City of Augusta			
Owner occupied	38,762	42,840	43,100
Rental	29,913	31,080	31,300
Total unoccupied units	8,613	8,392	8,440
Total units	77,288	82,312	82,800
South Carolina			
Aiken County			
Owner occupied	33,491	42,036	43,400
Rental	11,392	13,551	14,000
Total unoccupied units	4,383	6,400	6,610
Total units	49,266	61,987	64,100
City of Aiken			
Owner occupied	5,130	6,804	7,140
Rental	2,619	3,483	3,660
Total unoccupied units	794	1,086	1,140
Total units	8,543	11,373	11,900
Barnwell County			
Owner occupied	5,194	6,810	7,010
Rental	1,906	2,211	2,280
Total unoccupied units	754	1,170	1,210
Total units	7,854	10,191	10,500
ROI Total			
Owner occupied	99,673	123,902	128,000
Rental	49,250	54,016	55,200
Total unoccupied units	16,520	19,116	19,600
Total units	165,443	197,034	202,000

[a]Column entries may not add up due to independent rounding.

[b]*Source*: U.S. Bureau of the Census (1994).

[c]*Source*: U.S. Bureau of the Census (2002a).

Table 3.17. Local public service employment (2001)

Part A: Georgia

	Columbia County		Grovetown		Harlem	
	Number	Level of service[a]	Number	Level of service[a]	Number	Level of service[a]
Police protection	147	1.8	17	2.8	7	3.9
Fire protection[b]	3	0	4	0.7	1	0.6
General	435	5.3	33	5.4	14	7.7
Total	585	7.2	54	8.9	22	12.1

	Augusta-Richmond County		Blythe		Hephzibah	
	Number	Level of service[a]	Number	Level of service[a]	Number	Level of service[a]
Police protection	357	1.8	1	1.4	4	1.0
Fire protection[b]	283	1.4	0	0	7	1.8
General	1,673	8.6	1	1.4	4	1.0
Total	2,313	11.9	2	2.8	15	3.9

	State of Georgia level of service[a,c]
Police protection	2.4
Fire protection[b]	1.1
General	52.0
Total	55.4

Part B: South Carolina

	Aiken County		Aiken		Jackson	
	Number	Level of service[a]	Number	Level of service[a]	Number	Level of service[a]
Police protection	131	1.4	54	2.1	4	2.5
Fire protection[b]	78	0.8	-[d]	-[d]	-[d]	-[d]
General	60	0.6	239	9.4	7	4.3
Total	269	2.8	347	13.7	11	6.8

	New Ellenton		North Augusta		Wagener	
	Number	Level of service[a]	Number	Level of service[a]	Number	Level of service[a]
Police protection	4	1.8	48	2.7	3	3.5
Fire protection[b]	-[d]	-[d]	6	0.3	-[d]	-[d]
General	5	2.2	125	7.1	5	5.8
Total	9	4.0	179	10.2	8	9.3

Table 3.17. Continued

	Barnwell County		Barnwell		Blackville	
	Number	Level of service[a]	Number	Level of service[a]	Number	Level of service[a]
Police protection	26	2.1	13	2.6	8	2.7
Fire protection[b]	-[d]	-[d]	3	0.6	1	0.3
General	150	12.3	22	4.4	11	3.7
Total	176	14.5	38	7.6	20	6.7

	Williston		State of South Carolina level of service[a,c]
	Number	Level of service[a]	
Police protection	9	2.7	2.5
Fire protection[b]	1	0.3	0.8
General	12	3.6	54.9
Total	22	6.7	58.2

[a]Level of service represents the number of employees per 1,000 persons in each jurisdiction.

[b]Does not include volunteers.

[c]2000 data.

[d]Police and fire services are provided by a combined department.

Sources: Aiken County: Powell (2001); Barnwell County: Aguilar (2001); Columbia County: J. Johnson (2001); Edgefield County: Harling (2001); Richmond County: Colliander (2001); City of Aiken: Rideout (2001); City of Jackson: S. Johnson (2001); Town of New Ellenton: Bledsoe (2001); City of North Augusta (2000); Town of Wagener: Salley (2001); City of Barnwell: Vargo (2001); Town of Blackville: McDonald (2001); Town of Williston: Fowler (2001); Town of Grovetown: Kent (2001) and Capatillo (2001); Town of Harlem: Moore (2001); City of Augusta (1999); Town of Blythe (2000); Town of Hephzibah (2000); U.S. Bureau of the Census (2000).

3.11.6 Traffic

Vehicular access to the SRS is provided from South Carolina SCs 19, 64, 125, 781, and U.S. Highway 278, as shown in Figures 3.1 and 3.8. Highway 19 runs north from the site through New Ellenton towards Aiken; SC 64 runs in an easterly direction from the site towards Barnwell; SC 125 runs through the site itself in a southeasterly direction between North Augusta and Allendale, passing through Beech Island and Jackson. U.S. 278 also runs through the site, in a southeasterly direction between North Augusta and Barnwell. SC 781 connects U.S. 278 with Willston to the northeast of the site. The northern perimeter of the site is about 16 km (10 mi) from downtown Aiken. Table 3.21 shows average annual daily traffic (AADT) flows over these road segments, together with congestion level designations (levels of service). Levels of service designations were developed by the Transportation Research Board (1985) and range from A to F. Designations A through C represent good traffic operating conditions with some minor delays experienced by motorists; F represents jammed roadway conditions.

Table 3.18. Local physicians data (1997)

County	Number of physicians	Level of service[a]
Georgia		
Columbia County	324	4.0
Richmond County	1,189	6.1
South Carolina		
Aiken County	190	1.4
Barnwell County	14	0.6

[a]Level of service represents the number of physicians per 1,000 persons in each county.

Source: American Medical Association (1999).

Table 3.19. Local school district data (2001)

School district	Number of teachers	Student-to-teacher ratio[a]
South Carolina		
Aiken County	1,486	17.0
Barnwell County		
School District 19	80	14.4
School District 29	70	14.9
School District 45	183	15.3
State total	44,967	15.2
Georgia		
Columbia County	1,064	17.0
Richmond County	2,200	16.0
State total	89,561	16.0

[a]The number of students per teacher in each school district.

Sources: Ferriter (2001); Georgia Department of Education (2000).

Table 3.20. Local medical facility data (2001)

Hospital	Number of staffed beds	Occupancy rate (%)[a]
Aiken Regional Medical Centers	245	56
Barnwell County Hospital	33	37
Georgia Regional Hospital at Augusta	196	79
Medical College of Georgia Hospital	446	56
Select Specialty Hospital	17	NA[b]
St. Joseph Hospital	151	48
University Hospital	553	50
Walton Rehabilitation Institute	58	78
ROI Total	1,699	-

[a]Percent of staffed beds occupied.

[b]NA = not available.

Source: SMG Marketing Group Inc. (Copyright 2001, used with permission).

Table 3.21. Average annual daily traffic (AADT) in the vicinity of the SRS (2000)

Road segment[a]	Traffic volume (AADT)	Level of service[b]
SC 125 in the vicinity of Jackson	13,400	B
U.S. 278 between SC 302 and Barnwell county line	5,400	A
SC 19 in the vicinity of New Ellenton	13,900	B
SC 781 between U.S. 278 and U.S. 78	2,700	A
U.S. 278 to SC 37	2,500	A
SC 64 between SC 20 and Barnwell	6,900	A
SC 125 between SC 17 and Martin	2,100	A

[a]SC = state route (highway); U.S. = U.S. highway.

[b]Level of service designations as developed by the Transportation Research Board (1985). Levels range from A to F, with A representing the best traffic operating conditions and F representing jammed roadway conditions.

Source: McCoy (2001), except as noted.

3.12 Aesthetics

Natural and man-made features give a landscape character and aesthetic quality. The character of a landscape is determined by the elements of form, line, color, and texture; each may influence the character of a landscape to a varying degree. The stronger the influence of any one or all of these elements, and the more visual variety that can successfully coexist in the landscape, the more aesthetic quality present in the landscape

3.12.1 General Description of the Site

The viewshed within the vicinity of the SRS consists principally of agricultural and forested land, with some residential and industrial development. The landscape is characterized mainly by wetland or forest on low mountains and hills with intermittent open land. Vegetation consists of hardwood forests in the low-lying areas and wetland forests, with oak and pine forests on higher ground.

3.12.2 Description of the Location of the Proposed Facilities

Various concrete industrial buildings and other structures, administrative and support buildings, and parking areas are located within the F-Area at the SRS. The largest structures are approximately 30 m (100 ft) high, with some stacks and towers reaching 60 m (200 ft) high. All of the industrial and administrative areas are brightly lit at night and are visible when approached on SRS access roads. The industrial and other developed areas in the vicinity of F-Area, including utility corridors, are generally consistent with a Bureau of Land Management visual resource management (VRM) Class IV designation (activities that lead to major modification of the existing character of the landscape). The remainder of the site fits a VRM Class III (hosting activities which at most only moderately change the existing character of the landscape) or IV designation (DOI 1986a,b).

The closest publicly accessible viewing location is from State Highway 125, about 6 km (4 mi) to the southwest. Public view of F-Area is restricted by the heavily wooded terrain between Route 125 and the site.

3.13 References for Chapter 3

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Preface

The *Savannah River Site Environmental Report for 2005* (WSRC–TR–2006–00007) is prepared for the U.S. Department of Energy (DOE) according to requirements of DOE Order 231.1A, "Environment, Safety and Health Reporting," and DOE Order 5400.5, "Radiation Protection of the Public and Environment." The report's purpose is to

- present summary environmental data that characterize site environmental management performance
- confirm compliance with environmental standards and requirements
- highlight significant programs and efforts
- assess the impact of SRS operations on the public and the environment

SRS has had an extensive environmental monitoring program in place since 1951 (before site startup). In the 1950s, data generated by the onsite environmental monitoring program were reported in site documents. Beginning in 1959, data from offsite environmental surveillance activities were presented in reports issued for public dissemination. SRS reported onsite and offsite environmental monitoring activities separately until 1985, when data from both programs were merged into one public document. The *Savannah River Site Environmental Report for 2005* is an overview of effluent monitoring and environmental surveillance activities conducted on and in the vicinity of SRS from January 1 through December 31, 2005. It is prepared by the Environmental Services Section (ESS) of Washington Savannah River Company (WSRC). The "SRS Environmental Monitoring Plan" (WSRC–3Q1–2–1000) and the "SRS Environmental Monitoring Program" (WSRC–3Q1–2–1100) provide complete program descriptions and document the rationale and design criteria for the monitoring program, the frequency of monitoring and analysis, the specific analytical and sampling procedures, and the quality assurance requirements.

Complete data tables are included on the CD inside the back cover of this report. The CD also features an electronic version of the report; an appendix of site, environmental sampling location, dose, and groundwater maps; and complete 2005 reports from a number of other SRS organizations. Variations in environmental report data reflect year-to-year changes in the routine monitoring program, as well as occasional difficulties in sample collection or analysis. Examples of such difficulties include adverse environmental conditions (such as flooding or drought), sampling or analytical equipment malfunctions, and compromise of the samples in the preparation laboratories or counting room.

Report Available on Web:
Readers can find the *SRS Environmental Report* on the World Wide Web at the following address:
http://www.srs.gov/general/pubs/ERsum/index.html
To inquire about the report, please contact:
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The following information should aid the reader in interpreting data in this report:

- Analytical results and their corresponding uncertainty terms generally are reported with up to three significant figures. This is a function of the computer software used and may imply greater accuracy in the reported results than the analyses would allow.
- Units of measure and their abbreviations are defined in the glossary (beginning on page 85) and in charts at the back of the report.
- The reported uncertainty of a single measurement reflects only the counting error—not other components of random and systematic error in the measurement process—so some results may imply a greater confidence than the determination would suggest.
- An uncertainty quoted with a mean value represents the standard deviation of the mean value. This number is calculated from the uncertainties of the individual results. For an unweighted mean value, the uncertainty is the sum of the variances for the individual values divided by the number of individual results squared. For a weighted mean value, the uncertainty is the sum of the weighted variances for the individual values divided by the square of the sum of the weights.

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Sampling Location Information

Note: This section contains sampling location abbreviations used in the text and/or on the sampling location maps. It also contains a list of sampling locations known by more than one name (see next page).

Location Abbreviation	Location Name/Other Applicable Information
4M	Four Mile
4MC	Four Mile Creek
BDC	Beaver Dam Creek
BG	Burial Ground
EAV	E-Area Vaults
FM	Four Mile
FMC	Four Mile Creek (Fourmile Branch)
GAP	Georgia Power Company
HP	HP (sampling location designation only; not an actual abbreviation)
HWY	Highway
KP	Kennedy Pond
L3R	Lower Three Runs
NRC	Nuclear Regulatory Commission
NSB L&D	New Savannah Bluff Lock & Dam
PAR	"P and R" Pond
PB	Pen Branch
RM	River Mile
SC	Steel Creek
SWDF	Solid Waste Disposal Facility
TB	Tims Branch
TC	Tinker Creek
TNX	Multipurpose Pilot Plant Campus
U3R	Upper Three Runs

Chapter 1

Introduction

Pete Fledderman and Al Mamatey
Environmental Services Section

THE Savannah River Site (SRS), one of the facilities in the U.S. Department of Energy (DOE) complex, was constructed during the early 1950s to produce materials (such as plutonium-239 and tritium) used in nuclear weapons. The site covers approximately 310 square miles in South Carolina and borders the Savannah River.

Mission

SRS's mission is to fulfill its responsibilities safely and securely in the stewardship of the nation's nuclear weapons stockpile, nuclear materials, and the environment. These stewardship areas reflect current and future missions to

- meet the needs of the enduring U.S. nuclear weapons stockpile
- store, treat, and dispose of excess nuclear materials safely and securely
- treat and dispose of legacy wastes from the Cold War and clean up environmental contamination

SRS will continue to improve environmental quality, clean up its legacy waste sites, and manage any waste produced from current and future operations. Managing this waste will include working with DOE, the State of South Carolina, the Environmental Protection Agency, and the Nuclear Regulatory Commission to ensure that there are safe and acceptable ways to (1) dispose of radioactive liquid waste and nuclear materials permanently off site, while grouting any remaining tank residue, and (2) determine mutually acceptable solutions for waste disposition.

Site Location, Demographics, and Environment

SRS covers 198,344 acres in Aiken, Allendale, and Barnwell counties of South Carolina. The site is approximately 12 miles south of Aiken, South Carolina, and 15 miles southeast of Augusta, Georgia.

The average population density in the counties surrounding SRS is about 91 people per square mile, with the largest concentration in the Augusta metropolitan area. Based on 2000 U.S. Census Bureau data, the population within a 50-mile radius of the center of SRS is approximately 712,780.

Various industrial, manufacturing, medical, and farming operations are conducted near the site. Several major industrial and manufacturing facilities are located in the area, and a variety of crops is produced on local farms.

Water Resources

SRS is bounded on its southwestern border by the Savannah River for about 35 river miles and is approximately 160 river miles from the Atlantic Ocean.

The Savannah River is used as a drinking water supply source for some residents downriver of SRS. The nearest use of the Savannah River as a drinking source is approximately 90 miles downriver of the site. The river also is used for commercial and sport fishing, boating, and other recreational activities. There are no known large-scale uses of the river for irrigation by farming operations downriver of the site.

Geology

SRS is located on the southeastern Atlantic Coastal Plain, which is part of the larger Atlantic Plain that extends south from New Jersey to Florida. The center of SRS is approximately 25 miles southeast of the geological Fall Line that separates the Coastal Plain from the Piedmont.

Land and Forest Resources

About 90 percent of SRS land area consists of managed pine plantations or natural forests. The site contains portions of three forest types: Oak-Hickory-Pine, Southern Mixed, and Southern Floodplain.

More than 370 Carolina bays exist on SRS. These unique wetlands provide important habitat and refuge for many plants and animals.

Animal and Plant Life

The majority of SRS is undeveloped; only about 10 percent of the total land area is developed or used for industrial facilities. The remainder is maintained in healthy, diverse ecosystems. About 260 species of birds, 60 species of reptiles, 40 species of amphibians, 80 species of freshwater fish, and 50 species of mammals exist on site.

Releases

Releases to the environment of radioactive and nonradioactive materials come from legacy contamination as well as from ongoing site operations. For instance, shallow contaminated groundwater—a legacy—flows slowly toward onsite streams and swamps and into the Savannah River. In ongoing site operations, releases occur during the processing of nuclear materials.

Meeting certain regulations, such as the Safe Drinking Water Act and the Clean Air Act, requires that releases of radioactive materials from site facilities be limited to very small fractions of the amount handled. The site follows a philosophy that emissions (discharges) will be kept far below the regulatory standards.

Pathways

The routes that contaminants can follow to get to the environment and then to people are known as exposure pathways. A person potentially can be exposed when he or she breathes the air, consumes locally produced foods and milk, drinks water from the Savannah River, eats fish caught from the river, or uses the river for recreational activities such as boating, swimming, etc.

One way to learn if contaminants from the site have reached the environment is through environmental monitoring. The site gathers thousands of air, water, soil, sediment, food, vegetation, and animal samples each year. The samples are analyzed for potential contaminants released from site operations, and the potential radiation exposure to the public is assessed. Samples are taken at the points where materials are released from the facilities (effluent monitoring) and out in the environment itself (environmental surveillance).

Research and Development

The Savannah River National Laboratory (SRNL), formerly the Savannah River Technology Center (SRTC)—the site's applied research and development laboratory—creates, tests, and implements solutions to SRS's technological challenges. Other environmental research is conducted at SRS by the following organizations:

- *Savannah River Ecology Laboratory (SREL)* - More information can be obtained by contacting SREL at 803–725–0156 or by viewing the laboratory's website at http://www.uga.edu/srel. Also, SREL's technical progress report for 2005 is included on the CD accompanying this document.
- U.S. *Department of Agriculture Forest Service–Savannah River (USFS–SR)* - More information can be obtained by contacting USFS–SR at 803–725–0006 or 803–725–0237 or by viewing the USFS–SR website at http://www.srs.gov/general/enviro/srfs.htm. Also, USFS–SR's 2005 report is included on the CD accompanying this document.
- *Savannah River Archaeological Research Program (SRARP)* - More information can be obtained by contacting SRARP at 803–725–3623.

Editor's note: An important change in waste terminology is evolving at SRS—and will be reflected in future site environmental reports. References to "high-level waste" will be changed to "radioactive liquid waste" or "liquid radioactive waste." The waste stored in the site's "high-level waste" tanks is in fact a mixture of high-level and other wastes, so it is believed that the revised terminology represents a more accurate description of the waste in question. During this "transition year," environmental report readers will see references to both terms, but the changeover to radioactive liquid waste is expected to be completed for the 2006 report.

Chapter 2

Environmental Management System

Dave Lester
Environmental Services Section

The Savannah River Site (SRS) conforms with DOE Headquarters (DOE–HQ)-directed performance metrics that demonstrate the successful implementation of an Environmental Management System (EMS) at SRS. The key performance metrics used in this determination include

- an issued EMS Policy Statement
- provision of EMS implementation training to the personnel establishing the EMS
- identification of significant environmental aspects for SRS operations
- identification of measurable environmental objectives and targets, including the establishment of environmental management programs/actions specifically to achieve each environmental objective and target
- implementation of a program for EMS awareness training for all site personnel
- establishment of EMS procedures
- full integration of EMS into the Integrated Safety Management System

Additionally, SRS conforms with the applicable requirements of International Standard, ISO 14001, "Environmental Management System"; Executive Order 13148, "Greening of Government Through Leadership in Environmental Management"; and DOE Order 450.1, "Environmental Protection Program."

The site successfully sought and received third-party certification of its EMS to the requirements of International Standard ISO 14001 in 1997 and again in 2000. This independent certification of conformance documented that SRS had attained all the key performance indicators listed above. The site's attainment of these key metrics is documented in DOE–HQ's "Environmental Management System Implementation Status Quarterly Report: June 2005."

The following is a copy of the current EMS Policy for the site:

Savannah River Site
Environmental Management System Policy
June 30, 2005

OBJECTIVE

To implement sound stewardship practices that are protective of the air, water, land, and other natural and cultural resources impacted by Savannah River Site (SRS) operations. All activities on SRS shall be conducted in compliance with applicable laws and regulations providing for the protection of public health and the environment, to reduce the use of procedures and processes that produce hazardous wastes, and to seek ways to continually improve the performance of activities protective of the environment. The objective of this policy is to establish a consistent sitewide approach to environmental protection through the implementation of an Environmental Management System (EMS) as part of the overall Integrated Safety Management System (ISMS). The EMS provides for the systematic planning, integrated execution, and evaluation of site activities for (1) public health and environmental protection, (2) pollution prevention (P2), (3) compliance with applicable environmental protection requirements, and (4) continuous improvement of the EMS.

DIRECTIVE

Recognizing that many aspects of operations carried out at SRS may impact the environment, the SRS policy is that all employees, contractors, subcontractors, and other entities performing work at SRS shall abide by the directives in this document. This document serves as the primary documentation for the environmental goals and objectives of SRS and shall be available to the public. It shall be centrally maintained and updated as necessary to reflect the changing needs, mission, vision, and goals of SRS. The Department of Energy–Savannah River Operations Office

Chapter 3

Environmental Compliance

Linda Karapatakis
Environmental Services Section

It is the policy of the U.S. Department of Energy (DOE) that all activities at the Savannah River Site (SRS) be carried out in full compliance with applicable federal, state, and local environmental laws and regulations, and with DOE orders, notices, directives, policies, and guidance. Compliance with environmental regulations and with DOE orders related to environmental protection is a critical part of the operations at SRS. The purpose of this chapter is to report on the status of SRS compliance with these various statutes and programmatic documents. Some key regulations with which SRS must comply, and the compliance status of each, are listed in table 3–1.

This chapter also will provide information on Notices of Violation (NOV) issued by the U.S. Environmental Protection Agency (EPA) or the South Carolina Department of Health and Environmental Compliance (SCDHEC). NOVs are the regulatory tool used to inform organizations when their activities do not meet expected requirements. These can include NOVs against the organization's permitted activities or against the general contents of environmental regulations, such as failing to obtain construction permits prior to construction of new air release sources.

Compliance Activities

Resource Conservation and Recovery Act

The Resource Conservation and Recovery Act (RCRA) was passed in 1976 to address solid and hazardous waste management. The law requires that EPA regulate the management of solid and hazardous wastes, such as spent solvents, batteries, and many other discarded substances potentially harmful to human health and the environment. Amendments to RCRA regulate nonhazardous solid waste and some underground storage tanks.

Hazardous waste generators, including SRS, must follow specific requirements for handling these wastes. SRS received no RCRA-related NOVs during 2005.

Land Disposal Restrictions

The 1984 RCRA amendments established Land Disposal Restrictions (LDRs) to minimize the threat of hazardous constituents migrating to groundwater sources. The same restrictions apply to mixed (hazardous and radioactive) waste.

Treatability variances are an option available to waste generation facilities if alternate treatment methods are appropriate for specific waste streams. SRS has identified three mixed waste streams that are potential candidates for a treatability variance. Because of special problems associated with radioactive components, these variances have been completed and sent to EPA, where they continue to await approval.

Federal Facility Compliance Act

The Federal Facility Compliance Act (FFCAct) was signed into law in October 1992 as an amendment to the Solid Waste Disposal Act to add provisions concerning the application of certain requirements and sanctions to federal facilities. A Site Treatment Plan (STP) consent order (95-22-HW, as amended) was obtained and implemented in 1995, as required by the FFCAct. A Statement of Mutual Understanding (SMU) for Cleanup Credits was executed in October 2003. The SMU allows SRS to earn credits for certain accelerated cleanup actions. Credits then can be applied to the STP commitments. SRS submitted to SCDHEC an annual update to the approved STP in November 2005 that identified changes in mixed waste treatment and inventory. Changes in the 2005 update include the addition of the transuranic (TRU) mixed waste from the Battelle Columbus (Ohio) Site, (SR–W092). The changes identified and approved by SCDHEC for the 2004 STP update also have been included in the 2005 update. STP updates will continue to be produced annually unless provisions of the consent order are modified.

Underground Storage Tanks

The 19 underground storage tanks at SRS that house petroleum products and hazardous substances, as defined by the Comprehensive Environmental the Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005. Section 3116 of the Act authorizes the Secretary of Energy, in consultation with the Nuclear Regulatory Commission, to determine that certain waste from reprocessing is not high-level waste. The criteria set forth in that section are as follows: (1) it does not require permanent isolation in a deep geologic repository for spent fuel or liquid radioactive waste; (2) it has had highly radioactive radionuclides removed to the maximum extent practical; (3) it does not exceed concentration limits for Class C low-level waste and will be disposed in accordance with Title 10, Subpart C, Part 61, of the Code of Federal Regulations and pursuant to a state-approved closure plan, or, if it exceeds Class C concentration limits, then will be disposed in accordance with Title 10, Section 61.55, of the Code of Federal Regulations and pursuant to a state-approved closure plan; and (4) it complies with performance objectives set out in subpart C of NRC regulations (10 CFR 61). DOE had begun preparation of the documentation by the end of 2004. A "Draft Section 3116 Determination for Closure of Tank 19 and Tank 18 at the Savannah River Site," dated September 30, 2005, has been issued to the NRC. DOE and the NRC have agreed to have several technical workshops open to the public to discuss issues related to the tank closure determination under Section 3116.

Activities are under way to revise the General Closure Plan and Tank Closure Modules for tanks 18F and 19F and the evaporator system, consistent with the new legislation to support closure. Federal Facility Agreement (FFA) dates for the operational closure of radioactive liquid waste tanks 18F and 19F were revised in 2004 with the approval of SCDHEC and EPA Region 4. The revised closure-complete dates for tanks 19F and 18F are October 31, 2006, and February 28, 2007, respectively, but DOE-SR will be renegotiating the FFA commitment in 2006.

Waste Minimization/Pollution Prevention (WMin/P2) Program

At the Savannah River Site (SRS), all operations are committed to increasing Pollution Prevention (P2) awareness and implementing waste management improvement opportunities. Pollution prevention is integral to the SRS Environmental Management Policy, Environmental Management System (EMS), and Integrated Safety Management System (ISMS). The Waste Minimization/Pollution Prevention Program provides SRS a safe, effective, and environmentally responsible strategy for implementing specific waste reduction techniques based on current and projected information on waste generation, waste characterization, and ultimate waste disposal costs. SRS embraces pollution prevention as a primary strategy to operate in a compliant, cost-effective manner that protects the environment and the safety and health of employees and the public. SRS's P2 Program establishes the environmental management preference of source reduction and recycling over treatment, storage, and disposal, and the preferred use of energy efficient and resource conservative practices and operations.

The Waste Minimization/Pollution Prevention Program scope includes both infield generator and sitewide coordination programs. The generator program, responsible for implementation of facility-specific improvement initiatives, is funded through each generator's operating budget.

Sitewide program coordination, which is managed by the Waste Management Area Project organization, is separately funded and provides the following:

- management support of Waste Minimization/ Pollution Prevention Program activities
- technical assistance for facility walkdowns, lifecycle waste cost analyses, and pollution prevention opportunity assessments
- forums for waste minimization and P2 information and technology exchanges
- employee P2 awareness and training programs
- contaminated-metal and large-equipment recycling and disposition
- mechanisms to increase waste generator accountability through the Solid Waste Management Committee
- completion of required annual plans and reports
- implementation of sitewide initiatives such as sanitary waste recycling, Green-Is-Clean (GIC) programs, and other cost-cutting measures
- establishing a P2 component into the Site Communication Plan to increase public awareness and support

P2 Program Results

The SRS Pollution Prevention Program is mature and well integrated with operations and cleanup activities. Accomplishments in 2005 included the following:

- SRS completed 44 documented P2 projects, resulting in an annualized avoidance of 5,684 cubic meters of waste in FY2005. Annual cost avoidance resulting from the 44 documented P2 projects was $28.3 million.

Table 3–2
SRS Reporting Compliance with Executive Order 12856

EPCRA Citation	Activity Regulated	Reported per Applicable Requirement
302–303	Planning Notification	Not Required[a]
304	Extremely Hazardous Substances Release Notification	Not Required[a]
311–312	Material Safety Data Sheet/ Chemical Inventory	Yes
313	Toxic Release Inventory Reporting	Yes

[a] Not required to report under provisions of "Executive Order 12856" and SARA Title III Reporting Requirements

National Environmental Policy Act

The National Environmental Policy Act (NEPA) establishes policies and goals for the protection, maintenance, and enhancement of the human environment in the United States. NEPA provides a means to evaluate the potential environmental impact of major federal activities that could significantly affect the quality of the environment and to examine alternatives to those actions.

In 2005, 316 reviews of newly proposed actions were conducted at SRS and formally documented. A summary of NEPA activities conducted on site in 2005 is presented in table 3–3. Among the specific activities were the following:

- *Environmental Assessment for the National Pollutant Discharge Elimination System Wastewater Compliance Alternatives at the SRS* – DOE evaluated the potential impacts of proposed and alternative actions at 10 industrial outfalls to achieve NPDES permit compliance (DOE/EA–1513).
- *Environmental Assessment for the Storage of Tritium-Producing Burnable Absorber Rods in K-Area Transfer Bay at the SRS* – DOE evaluated the potential impacts of proposed and alternative actions to provide safe and secure storage of irradiated tritium-producing burnable absorber rods until the Tritium Extraction Facility is ready to receive and process the material (DOE/EA–1528).
- *Environmental Assessment for the Safeguards and Security Upgrades for Storage of Plutonium Materials at the SRS* – DOE evaluated the potential impacts of proposed and alternative actions to meet DOE–STD–3013 surveillance and stabilization requirements and to enhance physical safety and security for plutonium-bearing materials stored at SRS (DOE/EA–1538).
- *Environmental Assessment for Natural Resources Management Activities at the SRS* – DOE evaluated the potential impacts of continued management of SRS natural resources. A revised finding of no significant impact was issued to signify that the recently published *Natural Resources Management Plan* would result in no impacts not evaluated within the scope of the original NEPA review.
- *Programmatic Environmental Impact Statement (PEIS) for Disposition of Scrap Metals (DOE/ EIS–0327)* – DOE will evaluate alternatives for disposition of DOE scrap metals that may have been in radiological areas. The disposition options to be analyzed include continuation of the suspension on unrestricted release of metals for recycling, unrestricted release of scrap metals for recycling, and disposal. The NEPA schedule is uncertain.

Table 3–3
Summary of NEPA Activities at SRS During 2005

Type of NEPA Documentation	Number
Categorical Exclusion	292
Tiered to Previous NEPA Documentation	19
Environmental Assessments	4
Engineering Evaluation/Cost Analysis	4
Environmental Impact Statement	1
Supplemental Environmental Impact Statement	1
Programmatic Environmental Impact Statement	1
Total	**322**

Notices of Violation (NPDES)

SRS's 2005 compliance rate for the NPDES program under the CWA was 99.97 percent.

Only one exceedance occurred at SRS NPDES outfalls in 2005. A section of the channel bank at the A–11 outfall collapsed during a March 8 storm event, resulting in a high total suspended solids concentration. A table showing outfall location, probable cause, and corrective actions can be found in chapter 4 (table 4–4).

The site did not receive any NOVs under the NPDES program in 2005.

Dredge and Fill; Rivers and Harbors

The CWA, Section 404, "Dredge and Fill Permitting," as amended, and the Rivers and Harbors Act, Section 9 and 10, "Construction Over and Obstruction of Navigable Waters of the United States," protect U.S. waters from dredging and filling and construction activities by the permitting of such projects. Dredge-and-fill operations in U.S. waters are defined, permitted, and controlled through implementation of federal regulations in 33 CFR and 40 CFR.

In 2005, SRS conducted activities under four Nationwide Permits (NWPs) as part of the NWP program (general permits under Section 404), but none under an individual Section 404 permit. The activities were as follows:

- Dam construction on an unnamed tributary to Fourmile Branch for the Mixed Waste Management Facility Groundwater Interim Measures project was completed in 2000 under NWP–38, "Hazardous Waste Cleanup." However, mitigation for the impact to wetlands still must be addressed before the permit can be considered closed.
- Construction of the Mixed Waste Management Facility dam intake structure modification continued under NWP–38, "Hazardous Waste Cleanup." The modification will improve the efficiency of the treatment system for tritium. The approved permit was received in 2004.
- The installation of a well by Soil and Groundwater Closure Projects in a wetland adjacent to Tims Branch was covered under NWP–5, "Scientific Measurement Devices."
- The installation of a sampling platform downstream of the Highway 125 bridge crossing Steel Creek was covered under NWP–5, "Scientific Measurement Devices."

Construction in Navigable Waters

SCDHEC Regulation 19–450, "Permit for Construction in Navigable Waters," protects the state's navigable waters. The only state navigable waters at SRS are Upper Three Runs Creek (through the entire site) and Lower Three Runs Creek (upstream to the base of the PAR Pond Dam).

No Construction in Navigable Waters permit activities occurred in 2005.

Federal Insecticide, Fungicide, and Rodenticide Act

The Federal Insecticide, Fungicide, and Rodenticide Act controls the application of restricted-use pesticides at SRS through a state-administered certification program. The site complies with these requirements through Procedure 8.1, "Federal Insecticide, Fungicide, and Rodenticide Act Compliance for Use of Pesticides," of the Environmental Compliance Manual (WSRC 3Q).

The SRS pesticide procedure provides guidelines for pesticide use and requires that applicators of restricted-use pesticides be state certified. Extensive revisions of the procedure, begun in 2004, were completed in 2005 to improve the efficiency of the site pesticide-application approval process. The most significant changes involved (1) dropping the requirement for a formal pesticide program plan for the application of *unrestricted* pesticides and (2) renewing emphasis on the importance of completing a Pesticide Activity Report (PAR) within 14 days (formerly 15) of any site pesticide application.

Clean Air Act

Regulation and Delegation

The Clean Air Act (CAA) and the Clean Air Act Amendments (CAAA) of 1990 provide the basis for protecting and maintaining air quality. Though EPA still maintains overall authority for the control of air pollution, regulatory authority for all types of emission sources has been delegated to SCDHEC. Therefore, SCDHEC must ensure that its air pollution regulations are at least as stringent as the federal requirements. This is accomplished through SCDHEC Regulation 61–62, "Air Pollution Control Regulations and Standards." The various CAAA Titles covered by these SCDHEC regulations are discussed below.

Title V Operating Permit Program

Under the CAA, and as defined in federal regulations, SRS is classified as a "major source" and, as such, falls under the CAAA Part 70 Operating Permit Program. On

During 2005, SRS personnel removed and disposed of an estimated 19,077 square feet, 8,380 linear feet, and 500 cubic feet of regulated asbestos-containing material. SRS personnel also removed 181,267 square feet and 10,309 linear feet of nonregulated asbestos-containing material.

Radiological asbestos waste was disposed of at the SRS E-Area low-level vaults, engineered trench, and slit trench, which are permitted by SCDHEC as asbestos waste disposal sites. Nonradiological asbestos waste was disposed of at the Three Rivers Solid Waste Authority Landfill and the C&D Landfill (Building 632-G), which also are SCDHEC-approved asbestos waste landfills.

Accidental Release Prevention Program

Under Title III of the CAAA, EPA established a program for the prevention of accidental releases of large quantities of hazardous chemicals. As outlined in Section 112(r), any facility that maintains specific hazardous or extremely hazardous chemicals in quantities above specified thresholds must develop a risk management program (RMP). The RMP establishes methods that will be used for the containment and mitigation of large chemical spills. No such accidental releases occurred at SRS during 2005.

SRS's RMP maintains hazardous and extremely hazardous chemical inventories below the threshold quantity. This cost-effective approach minimizes the regulatory burden of 112(r) but does not eliminate any liability associated with the general duty clause, as stated in 112(r)(1). To date, no hazardous or extremely hazardous chemical releases have been reported by SRS.

EPA issued a revision to its RMP final rule in 2004, changing reporting requirements of its chemical accident prevention regulations. Chemical facilities subject to these regulations now are required to submit significant-chemical-accident information and emergency contact information. These changes seek to improve and assist federal, state, and local risk management programs in implementing the new homeland security measures.

Ozone-Depleting Substances

Title VI of the CAAA of 1990 addresses stratospheric ozone protection. This law requires that EPA establish regulations to phase out the production and consumption of ozone-depleting substances (ODSs).

Several sections of Title VI of the CAAA of 1990, along with recently established EPA regulations found in 40 CFR 82, apply to the site. The ODSs are regulated in three general categories, as follows:

- *Class I substances* – chlorofluorocarbons (CFCs), Halons, carbon tetrachloride, methyl chloroform, methyl bromide, and hydrobromofluorocarbons (HBFCs)
- *Class II substances* – hydrochlorofluorocarbons (HCFCs)
- *Substitute substances*

The "Savannah River Site Refrigerant Management Plan," completed and issued in September 1994, provides guidance to assist SRS and DOE in the phaseout of CFC refrigerants and equipment.

SRS has reduced CFC refrigerant usage in large ODS emission sources more than 99 percent compared to 1993 baseline data.

The SRS CAAA of 1990 Title V operating air permit application includes ODS emission sources. All large (greater than or equal to 50-pound charge) heating, ventilation, and air conditioning/chiller systems for which there are recordkeeping requirements are included as fugitive emission sources.

SRS is phasing out its use of Halon as part of a goal to eliminate the use of Class I ODSs by 2010 "to the extent economically practicable." A Halon 1301 management plan (F–ESR–G–00120, November 16, 2005) and schedule have been developed by Fire Protection Services to help meet DOE's goal. The plan includes an SRS Halon 1301 fire suppression system inventory that identifies systems in operation, systems abandoned in place, and systems that have been dismantled and taken to the DOE complex's Halon repository, located at SRS.

Halon 1301 total inventory on site decreased from 75,664 pounds in 2004 to 73,800 pounds in 2005. The site had an inventory of 53,000 pounds of stored Halon 1301 at the end of 2005. In addition, 21,000 pounds are contained in the 90 operating systems (down from 111 in 2002).

Air Emissions Inventory

SCDHEC Regulation 61–62.1, Section III ("Emissions Inventory"), requires compilation of an air emissions inventory for the purpose of locating all sources of air pollution and defining and characterizing the various types and amounts of pollutants. To demonstrate compliance, SRS personnel conducted the initial comprehensive air emissions inventory in 1993. The inventory identified approximately 5,300 radiological and nonradiological air emission sources. Source

SRARP personnel reviewed 45 site-use packages during 2005, of which four proposed land modifications resulted in the need to survey 163 acres. The remainder of the site-use packages were found to have no activities of significant impact in terms of the NHPA. SRARP personnel also surveyed 895 acres in 2005 in support of onsite forestry activities.

The surveys of the 1,158 total acres resulted in 44 site investigations—34 of which involved new archaeological sites—and in revisits to 10 previously recorded sites for cultural resources management.

To comply with NHPA, Site 38AK155 was excavated as mitigation in anticipation of construction at the Surplus Plutonium Disposition Facilities site. The excavation was completed in 2004, and 64,185 artifacts were curated by SRARP in 2005.

Floodplains and Wetlands

Under 10 CFR, Part 1022 ("Compliance with Floodplains and Wetlands Environmental Review Requirements"), DOE establishes policies and procedures for implementing its responsibilities in terms of compliance with Executive Orders 11988 ("Floodplain Management") and 11990 ("Protection of Wetlands"). Part 1022 includes DOE policies regarding the consideration of floodplains/wetlands factors in planning and decision making. It also includes DOE procedures for identifying proposed actions involving floodplains/wetlands, providing early public reviews of such proposed actions, preparing floodplains/wetlands assessments, and issuing statements of findings for actions in floodplains.

A floodplains/wetlands assessment entitled "Floodplain/Wetland Assessment for Selected National Pollutant Discharge Elimination System Wastewater Permit Compliance Alternatives at the Savannah River Site" was begun in 2004 and completed in 2005.

Executive Order 11988

Executive Order 11988 ("Floodplain Management") was established to avoid long- and short-term impacts associated with the occupancy and modification of floodplains. The evaluation of impacts to SRS floodplains is ensured through the NEPA Evaluation Checklist and the site-use system. Site-use applications are reviewed for potential impacts by WSRC, DOE–SR, the USDA Forest Service–Savannah River and the Savannah River Ecology Laboratory (SREL), as well as by professionals from other organizations.

Executive Order 11990

Executive Order 11990 ("Protection of Wetlands") was established to mitigate adverse impacts to wetlands caused by the destruction and modification of wetlands, and to avoid new construction in wetlands wherever possible. Avoidance of impact to SRS wetlands is ensured through the site-use process, various departmental procedures and checklists, and project reviews by the SRS Wetlands Task Group. Many groups and individuals—including scientists from SRNL, SREL, and the Environmental Services Section—review site-use applications to ensure that proposed projects do not impact wetlands.

Environmental Release Response and Reporting

Response to Unplanned Releases

Environmental Permitting and Monitoring (EPM) personnel respond to unplanned environmental releases, both radiological and nonradiological, upon request by area operations personnel. No unplanned environmental releases occurred at SRS in 2005 that required the sampling and analysis services of EPM.

Occurrences Reported to Regulatory Agencies

Federally permitted releases comply with legally enforceable licenses, permits, regulations, or orders. If a nonpermitted release to the environment of a reportable quantity or more of a hazardous substance (including radionuclides) occurs, CERCLA requires notification of the National Response Center. Also, the CWA requires that the National Response Center be notified if an oil spill causes a "sheen" on navigable waters, such as rivers, lakes, or streams. Oil spill reporting has been reinforced with liability provisions in the CERCLA National Contingency Plan.

SRS had no CERCLA-reportable releases in 2005. This performance trend dates back to 2000. The site had one release in 1999 and one in 1998.

No notifications required by CERCLA or SCDHEC memoranda of understanding had to be made by SRS during 2005. The site recorded and cleaned up the following nonreportable spills; 11 chemical, four sewage, six motor oil, 19 hydraulic oil, eight diesel fuel, and two gasoline.

EPCRA (40 CFR 355.40) requires that reportable releases of extremely hazardous substances or CERCLA hazardous substances be reported to any local

- *Annual NPDES 3560 Compliance Audit* – SCDHEC conducted the annual 3560 environmental audit of the site's NPDES-permitted outfalls. As of December 31, SRS had not received the final audit report, so the final rating for the site was not known.
- *Quarterly Inspections of SRS Bottled Water Facility* – SCDHEC conducted quarterly inspections of the SRS Bottled Water Facility. The facility was found to be in compliance.
- *Burma Road C&D Landfill* was officially closed after a September 26, 2005, inspection by SCDHEC. A letter dated October 5 from SCDHEC documented the closure.
- *632–G C&D Landfill, 288–F Industrial Waste Landfill, and Saltstone Inspection* – SCDHEC conducted quarterly inspections, and all the sites were found to be satisfactory, with no observed deficiencies, but SCDHEC did express concern about the slope of the working face at 632–G.
- *Interim Sanitary Landfill* – SCDHEC personnel conducted an annual postclosure inspection, and the site was found to be satisfactory, with no observed deficiencies.
- *Groundwater Comprehensive Monitoring Evaluation* – SCDHEC conducted an unannounced RCRA inspection of SRS's groundwater program. No deficiencies or permit violations were cited.

Environmental Training

The site's environmental training program identifies training activities to teach job-specific skills that protect the employee and the environment, in addition to satisfying regulatory training requirements. Regularly scheduled classes in this program at SRS include such topics as Environmental Laws and Regulations, Hazardous Waste Worker, Hazardous and Radiological Waste Characterization, and the Environmental Compliance Authority course. A self-taught Environmental Laws and Regulations course is available on SHRINE for technical staff and is updated by the Environmental Services Section annually. More than 60 environmental program-related training courses are listed in the site training database, and individual organizations schedule and perform other facility-specific, environment-related training to ensure that operations and maintenance personnel, as well as environmental professionals, have the knowledge and skills to perform work safely and in a manner that protects the environment.

Environmental Permits

SRS had 417 construction and operating permits in 2005 that specified operating levels for each permitted source. Table 3–4 summarizes the permits held by the site during the past 5 years. These numbers reflect only permits obtained by WSRC for itself and for other SRS contractors that requested assistance in obtaining permits. It also should be noted that these numbers include some permits that were voided or closed some time during the calendar year (2005).

Chapter 4
Effluent Monitoring

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EFFLUENT monitoring at the Savannah River Site (SRS) is conducted to demonstrate compliance with applicable standards and regulations. Site effluent monitoring activities are divided into radiological and nonradiological programs. A complete description of sampling and analytical procedures used for effluent monitoring by the Environmental Permitting and Monitoring group of the site's Environmental Services Section can be found in sections 1101–1111 (SRS EM Program) of the *Savannah River Site Environmental Monitoring Section Plans and Procedures*, WSRC–3Q1–2, Volume 1. A summary of data results is presented in this chapter; more complete data can be found in tables on the CD included with this report.

Radiological Monitoring

Radiological effluent monitoring results are a major component in determining compliance with applicable dose standards. SRS management philosophy ensures that potential exposures to members of the public and to onsite workers are kept as far below regulatory standards as is reasonably achievable. This philosophy is known as the "as low as reasonably achievable" (ALARA) concept.

SRS airborne and liquid effluents that potentially contain radionuclides are monitored at their points of discharge by a combination of direct measurement and/or sample extraction and analysis. Each operating facility maintains ownership of, and is responsible for, its radiological effluents.

Unspecified alpha and beta releases (the measured gross activity minus the identified individual radionuclides) in airborne and liquid releases are large contributors—on a percentage basis—to offsite doses, especially for the airborne pathway from diffuse and fugitive releases (see definitions below).

The unspecified alpha and beta releases are listed separately in the effluent release tables. They conservatively include naturally occurring radionuclides such as uranium, thorium, and potassium-40, as well as small amounts of unidentified manmade radionuclides. For dose calculations, the unspecified alpha releases were assigned the plutonium-239 dose factor, and the unspecified beta releases were assigned the strontium-90 dose factor (chapter 6, "Potential Radiation Doses").

Airborne Emissions

Process area stacks that release, or have the potential to release, radioactive materials are monitored continuously by applicable online monitoring and/or sampling systems [SRS EM Program, 2001].

Depending on the processes involved, discharge stacks also may be monitored with "real-time" instrumentation to determine instantaneous and cumulative atmospheric releases to the environment. Tritium is one of the radionuclides monitored with continuous real-time instrumentation.

The following effluent sampling and monitoring changes were made during 2005:

- Quarterly sampling was added at TRU Pads 19 and 20.

Diffuse and Fugitive Sources

Estimates of radionuclide releases from unmonitored diffuse and fugitive sources are calculated on an annual basis and are included in the SRS radioactive release totals. A diffuse source is defined as an area source, such as a pond or disposal area. A fugitive source is defined as an undesignated localized source, such as an open tank or naturally ventilated building.

Diffuse and fugitive releases are calculated using the U.S. Environmental Protection Agency's (EPA's) recommended methods [EPA, 2002]. Because these methods are conservative, they generally lead to overestimates of actual emissions. Though these releases are not monitored at their source, onsite and offsite environmental monitoring stations are in place to quantify unexpectedly large diffuse and fugitive releases (see chapter 5, "Environmental Surveillance").

Liquid Discharges

Each process area liquid effluent discharge point that releases, or has potential to release, radioactive materials is sampled routinely and analyzed for radioactivity [SRS EM Program, 2001].

Depending on the processes involved, liquid effluents also may be monitored with real-time instrumentation to ensure that instantaneous releases stay within established limits. Because the instruments have limited detection sensitivity, online monitoring systems are not used to quantify SRS liquid radioactive releases at their current low levels. Instead, samples are collected for more sensitive laboratory analysis.

Monitoring Results Summary

Data from continuously monitored liquid effluent discharge points are used in conjunction with site seepage basin and Solid Waste Disposal Facility (SWDF) migration release estimates to quantify the total radioactive material released to the Savannah River from SRS operations. SRS liquid radioactive releases for 2005 are shown by source on the CD accompanying this report. These data are a major component in the determination of offsite dose consequences from SRS operations.

Direct Discharges of Liquid Effluents Direct discharges of liquid effluents are quantified at the point of release to the receiving stream, prior to dilution by the stream. The release totals are based on measured concentrations and flow rates.

Tritium accounts for nearly all the radioactivity discharged in SRS liquid effluents. The total amount of tritium released directly from process areas—i.e., reactor, separations, Effluent Treatment Facility (ETF)—to site streams during 2005 was 326 Ci, which was 57 percent less than the 2004 total of 756 Ci. This decrease was due to the fact that ETF continued to process wastewater with less tritium in it than in previous years.

Operations at D-Area and TNX were discontinued in 2000 and 2001, respectively. Releases from A-Area represent only a small percentage of the total direct releases of tritium to site streams. The reactor area releases include the overflows from PAR Pond and L Lake.

Direct releases of tritium to site streams for the years 1996–2005 are shown in figure 4–2. The migration and transport of radionuclides from site seepage basins and the SWDF are discussed in chapter 5.

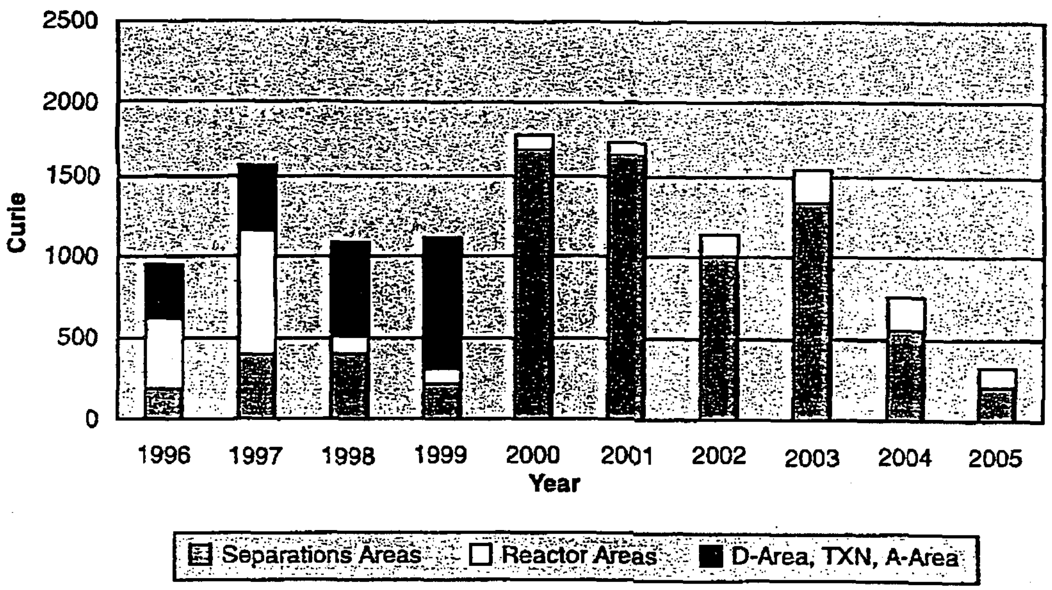

Figure 4–2 Ten-Year History of Direct Releases of Tritium to SRS Streams

Monitoring of SRS diesel-powered equipment consists of tracking fuel oil consumption monthly and calculating a 12-month rolling total for determining permit compliance with a site consumption limit.

SRS has several soil vapor extraction units and two air strippers that are sources of toxic air pollutants and VOCs. These units must be sampled monthly for VOC concentrations, and the total VOC emissions must be calculated for comparison against a 12-month rolling limit. The VOC emissions then are reported to SCDHEC on a quarterly basis.

Several SRS sources have pollutant control devices—such as multiclone dust collectors, baghouse dust collectors, or condensers—whose parameters must be monitored continuously or whenever the system is operated. The operating parameters must be recorded and compared against specific operating ranges.

Compliance by all SRS permitted sources is evaluated during annual compliance inspections by the local SCDHEC district air manager. The inspections include a review of each permit condition, i.e., daily monitoring readings, equipment calibrations, control device inspections, etc.

Table 4–1
2004 SRS Criteria Pollutant Air Emissions

Pollutant Name	Actual Emissions (Tons/Year)
Sulfur dioxide (SO_x)	2.15E+03
Total particulate matter (PM)	4.82E+02
Particulate matter $\leq$10 microns (PM_{10})	1.89E+02
Carbon monoxide (CO)	9.82E+02
Ozone (volatile organic compounds)	5.44E+02
Gaseous fluorides (as hydrogen fluoride)	1.39E–01
Nitrogen dioxide (NO_x)	4.24E+03
Lead (lead components)	1.58E-01

Monitoring Results Summary

In 2005, operating data were compiled and emissions calculated for 2004 operations for all site air emission sources. Because this process, which begins in January, requires up to 6 months to complete, this report provides a comprehensive examination of total 2004 emissions, with only limited discussion of available 2005 monitoring results for specific sources.

The 2004 total criteria and toxic air pollutant emissions results for all SRS sources, as determined by the air emissions inventory conducted in 2005, are provided in table 4–1 and on the CD accompanying this report. A review of the calculated emissions for each source for calendar year 2004 determined that SRS sources had operated in compliance with permitted emission rates. Actual 2005 emissions will be compiled and reported in depth in the *SRS Environmental Report for 2006*. Some toxic air pollutants (e.g., benzene) regulated by SCDHEC also are, by nature, VOCs. As such, the total for VOCs in table 4–1 includes toxic air pollutant emissions. This table also includes the emissions for some hazardous air pollutants that are regulated under the Clean Air Act but not by SCDHEC Standard No. 8 ("Toxic Air Pollutants"). These pollutants are included because they are compounds of some Standard No. 8 pollutants.

Two power plants with five overfeed stoker-fed coal-fired boilers are operated by Washington Savannah River Company (WSRC) at SRS. The location, number of boilers, and capacity of each boiler for these plants are listed in table 4–2. Because of an alternating test schedule, only A-Area boiler No. 1 was stack-tested in 2005 (February). At that time, the boiler's particulate matter, sulfur dioxide, and visible emissions were found to be in compliance with its permitted limit. Results from the test are shown in table 4–3.

SRS also has two package steam generating boilers in K-Area fired by No. 2 fuel oil. The percent of sulfur in the fuel oil burned during the first quarter of 2005 was certified by the vendor to meet the requirements of the permit.

The total diesel fuel consumption for portable air compressors, generators, emergency cooling water pumps, and fire water pumps was found to be well below the SRS limit for the entire reporting period.

As reported to SCDHEC during 2005, the calculated annual VOC emissions were well below the permit limit for each unit.

Table 4–2
SRS Power Plant Boiler Capacities

Location	Number of Boilers	Capacity (Btu/hr)
A-Area	2	71.7E+06
H-Area	3	71.1E+06

outfalls)—and the routine sampling can be found in the NPDES stormwater monitoring data table on the CD accompanying this report. All the routine and Phase III results were obtained by the required stormwater sampling protocol. Phase II results, however, should be reviewed for information only because many of the samples could not be collected by certified protocol due to the reduced timeframe required to support activities related to the new stormwater permit.

No sludge-application activities were conducted in 2005.

Table 4–4
2005 Exceedances of SCDHEC-Issued NPDES Permit Liquid Discharge Limits at SRS[a]

Facility/Division/Unit	Outfall	Date	Analysis	Possible Cause(s)	Corrective Action(s)
SRNL	A–11	March 5	TSS	Sample taken shortly after significant rain event that caused collapse of section of channel bank	Personnel instructed not to start composite samplers if the SRS weather prediction is for a 60% or greater chance of rain

Key: TSS – Total Suspended Solids

[a]The DOE-mandated NPDES compliance rate is 98 percent; SRS's compliance rate for 2005 was 99.97 percent.

Chapter 5

Effluent Surveillance

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ENVIRONMENTAL surveillance at the Savannah River Site (SRS) is designed to survey and quantify any effects that routine and nonroutine operations could have on the site and on the surrounding area and population. Site surveillance activities are divided into radiological and nonradiological programs.

As part of the radiological surveillance program, routine surveillance of all radiation exposure pathways is performed on all environmental media that could lead to a measurable annual dose at and beyond the site boundary.

Nonradioactive environmental surveillance at SRS involves the sampling and analysis of surface water, drinking water, sediment, groundwater, and fish. Results from the analyses of surface water, drinking water, sediment, and fish are discussed in this chapter. A description of the groundwater monitoring program analysis results can be found in chapter 7, "Groundwater."

The Environmental Services Section's Environmental Permitting and Monitoring (EPM) group and the Savannah River National Laboratory (SRNL) perform surveillance activities for SRS. The Savannah River also is monitored by other groups, including the South Carolina Department of Health and Environmental Control (SCDHEC), the Georgia Department of Natural Resources, and the Academy of Natural Sciences (ANS).

A complete description of the EPM surveillance program, including sample collection and analytical procedures, can be found in section 1105 of the *Savannah River Site Environmental Monitoring Section Plans and Procedures*, WSRC–3Q1–2, Volume 1 (SRS EM Program). Brief summaries of analytical results are presented in this chapter; complete data sets can be found in tables on the CD accompanying this report.

Radiological Surveillance

Air

Description of Surveillance Program

EPM maintains a network of 15 sampling stations in and around SRS to monitor the concentration of tritium and radioactive particulate materials in the air.

Surveillance Results Summary

Except for tritium, specific radionuclides were not routinely detectable at the site perimeter. Both onsite and offsite activity concentrations were similar to levels observed in previous years.

Average gross alpha results were slightly higher in 2005 than in 2004, while average gross beta results were slightly lower. However, they are consistent with historical results, which demonstrate long-term variability.

No detectable manmade gamma-emitting radionuclides were observed in 2005. These results are consistent with historical results, which indicate only a small number of air samples with detectable activity.

During 2005, detectable levels of uranium-234 were observed in all air samples, while uranium-238 was observed in most of these samples. These results are similar to those observed in 2004. Concentrations of the uranium isotopes were slightly higher than, but similar to, those observed in 2004. Aside from uranium, alpha-emitting radionuclide activity was observed in 11 samples from eight locations. Americium-241 was detected at five locations on the site perimeter and two 25-mile locations, while plutonium-238 was detected at one site perimeter location. Generally, these concentrations were consistent with historical results. All isotopes at the remaining locations were below detection levels. As observed in previous years, none of the samples showed strontium-89,90 above their mimimum detectable concentration (MDC).

discharge path. Gross alpha and gross beta were detected at all basins in amounts generally consistent with those of previous years.

Site Streams

Description of Surveillance Program

Continuous surveillance monitoring occurs downstream of several process areas to detect and quantify levels of radioactivity in effluents transported to the Savannah River.

Surveillance Results Summary

Demolition and construction activities are impacting some of the site stream surveillance locations. Due to construction activities at the MOX Fuel Fabrication Facility (MFFF), U3R–F3 was removed from service in 2005. Efforts are under way to relocate the sampling site.

Tritium, the predominant radionuclide detected above background levels in SRS streams, was observed at all stream locations in 2005.

No detectable concentrations of cobalt-60 and cesium-137 were observed at the farthest downstream locations on any of the five major SRS streams. As expected, gross alpha and gross beta were observed in all streams, and were elevated at the FMC–2B, U3R–1A, and Central Sanitary Wastewater Treatment Facility (G–10) locations. Iodine-129 and technetium-99 were detected only at the Four Mile Creek locations. Uraniam-234, 235, and 238 and plutonium-238 were detected only at U3R–1A, U3R–F3, G–10, and TNX–008. Plutonium-239 was observed at the U3R–F3 location. Americium-241 was observed at U3R–1A, U3R–F3, and G–10. Curium-244 was observed only at the U3R–F3 location. Demolition activities near U3R–F3 and TNX–008 are suspected as the reason for the actinide concentrations observed in 2005.

At U3R–1A, the SRS control point location, elevated gross alpha and gross beta levels were observed. It was determined in late 2005 that this situation was caused by placement of the sampler strainer in a shallow location near the edge of the stream, resulting in the collection of sediment and suspended solids. Moving the strainer provided a more representative sample, with an observed decrease in alpha activity. In addition, a laboratory error occurred, and nine unplanned, biweekly composite samples from U3R–1A were analyzed for actinides. Annual stream characterization samples are collected by the grab method. Because these samples were collected before the strainer was repositioned, they contained sediment and solids (as discussed above), and the results showed concentrations not typically seen. However, the data from these has been preserved for informational purposes only.

Seepage Basin and Solid Waste Disposal Facility Radionuclide Migration

To incorporate the migration of radioactivity to site streams into total radioactive release quantities, EPM continued to monitor and quantify the migration of radioactivity from site seepage basins and the Solid Waste Disposal Facility (SWDF) in 2005 as part of its stream surveillance program. Tritium, strontium-89,90, technetium-99, iodine-129, and cesium-137 were detected in migration releases.

Figure 5–1 is a graphical representation of releases of tritium via migration to site streams for the years 1996–2005. During 2005, the total quantity of tritium migrating from site seepage basins and SWDF was 2,180 Ci, compared to 1,927 Ci in 2004. This 13-percent increase is attributed mainly to increased rainfall in 2005, compared with 2004, and to the planned repair work on the Mixed Waste Management Facility Groundwater Retention Dam, which allowed a greater amount of contaminated water to reach Four Mile Creek. This repair work began in September 2005 and is scheduled for completion by April 2006.

Radioactivity previously deposited in the F-Area and H-Area seepage basins and SWDF continues to migrate via the groundwater and to outcrop into Four Mile Creek and Upper Three Runs.

Measured migration of tritium into Four Mile Creek in 2005 occurred as follows:

- from F-Area seepage basins, 630 Ci—a 20-percent increase from the 2004 total of 526 Ci
- from H-Area seepage basin 4 and SWDF, 592 Ci—a 134-percent increase from the 2004 total of 253 Ci
- from H-Area seepage basins 1, 2, and 3, 242 Ci—a 15-percent increase from the 2004 total of 211 Ci

The measured migration from the north side of SWDF and the General Separations Area (GSA) into Upper Three Runs in 2005 was 75 Ci, a 65-percent decrease from the 2004 total of 215 Ci. (The GSA is in the central part of SRS and contains all waste disposal facilities, chemical separations facilities, and associated high-level waste storage facilities, and numerous other sources of radioactive material.)

Savannah River

Description of Surveillance Program

Continuous surveillance is performed along the Savannah River at points above and below SRS, and includes the point at which liquid discharges from Georgia Power Company's Vogtle Electric Generating Plant enter the river.

Surveillance Results Summary

Tritium is the predominant radionuclide detected above background levels in the Savannah River. The annual mean tritium concentration at RM–118.8 in 2005 was about 3 percent of the drinking water standard.

The mean gross alpha concentrations at all river locations were below the representative MDC in 2005. Detectable gross beta activity was observed at all river sampling locations, and was consistent with long-term gross beta levels in the river.

Except for tritium, as indicated above, no manmade radionuclides were detected in Savannah River water.

Tritium Transport in Streams

Tritium is introduced into SRS streams and the Savannah River from former production areas on site. Because of the mobility of tritium in water and the quantity of the radionuclide released during the years of SRS operations, a tritium balance has been performed annually since 1960. The balance is evaluated among the following alternative methods of calculation:

- tritium releases from effluent release points and calculated seepage basin and SWDF migration (direct releases)
- tritium transport in SRS streams and the last sampling point before entry into the Savannah River (stream transport)
- tritium transport in the Savannah River downriver of SRS after subtraction of any measured contribution above the site (river transport)

The combined tritium releases in 2005 (direct discharges and migration from seepage basins and SWDF) totaled 2,494 Ci, compared to 2,683 Ci in 2004.

The total tritium transport in SRS streams decreased slightly, from 2,785 Ci in 2004 to 2,364 Ci in 2005.

The total tritium transport in the Savannah River for 2005 was 4,480 Ci, compared with the previous year's 3,630 Ci. Both Plant Vogtle and SRS contributed to these release values. Accounting for Plant Vogtle's contribution, SRS's calculated releases of tritium to the river in 2005 totaled approximately 2,620 Ci.

SRS tritium transport data for 1960–2005 are depicted in figure 5–2, which shows summaries of the past 46 years of direct releases, stream transport, and river transport, as determined by EPM.

Domestic and Drinking Water

Description of Surveillance Program

EPM collected domestic and drinking water samples in 2005 from locations at SRS and at water treatment facilities that use Savannah River water. Potable water was analyzed at offsite treatment facilities to ensure that SRS operations did not adversely affect the water supply and to provide voluntary assurance that drinking water did not exceed EPA drinking water standards for radionuclides.

Onsite domestic water sampling consisted of quarterly grab samples at large treatment plants in A-Area, D-Area, and K-Area and annual grab samples at wells and small systems. Collected monthly off site were composite samples from

- three water treatment plants downriver of SRS that supply treated Savannah River water to Beaufort and Jasper counties in South Carolina and to Port Wentworth, Georgia
- the North Augusta (South Carolina) Water Treatment Plant

Surveillance Results Summary

All domestic and drinking water samples collected by EPM were screened for gross alpha and gross beta concentrations to determine if activity levels warrant further analysis. No domestic water used for drinking purposes exceeded EPA's 1.50E+01-pCi/L alpha activity limit or 5.00E+01-pCi/L beta activity limit. Also, no onsite or offsite domestic or drinking water samples exceeded the 2.00E+04-pCi/L EPA tritium limit, and no domestic or drinking water samples exceeded the strontium 89,90 MDC.

No cobalt-60, cesium-137, or plutonium-239 was detected in any domestic or drinking water samples. At most locations, no uranium isotopes or plutonium-238 were detected.

at four sampling locations and in milk at one location. Cobalt-60 was detected in peanuts at one location. Strontium-89,90 was detected in collards and milk at two locations each. Tritium was detected in collards at two locations, beef at one location, and pecans at three locations. Pecans from the 25-mile location were not available for analysis. No other manmade radionuclides were detected in food products in 2005. These results appeared to be randomly distributed among the monitoring locations, and no underlying spatial distribution was observed.

Tritium in food products is attributed primarily to releases from SRS. Tritium was detected in collards, beef, and pecans. No tritium was detected in any other food samples. This is similar to results of previous years.

Aquatic Food Products

Description of Surveillance Program

The aquatic food product surveillance program includes fish (freshwater and saltwater) and shellfish. To determine the potential dose and risk to the public from consumption, both types are sampled.

Nine surveillance points for the collection of freshwater fish are located on the Savannah River—from above SRS at Augusta, Georgia, to the coast at Savannah, Georgia.

Surveillance Results Summary

Cesium-137 was the only manmade gamma-emitting radionuclide found in Savannah River edible composites. Strontium-89,90 and tritium were detected at most of the river locations. Plutonium-238 was found slightly above the MDC in composites from five locations. No manmade radionuclides were detected in shellfish. Except for the detection of plutonium-238, these results were similar to those of previous years.

Deer and Hogs

Description of Surveillance Program

Annual hunts, open to members of the general public, are conducted at SRS to control the site's deer and feral hog populations and to reduce animal-vehicle accidents. Before any animal is released to a hunter, EPM personnel use portable sodium iodide detectors to perform field analyses for cesium-137. Media samples (muscle and/or bone) are collected periodically for laboratory analysis based on a set frequency, on cesium-137 levels, and/or on exposure limit considerations.

Surveillance Results Summary

A total of 215 deer and 33 feral hogs were taken during the 2005 site hunts. As observed during previous hunts, cesium-137 was the only manmade gamma-emitting radionuclide detected during laboratory analysis. Generally, the cesium-137 concentrations measured by the field and lab methods were comparable. Field measurements from all animals ranged from 1 pCi/g to 8.1 pCi/g, while lab measurements ranged from 1 pCi/g to 5.3 pCi/g. The average field cesium-137 concentration was 2.32 pCi/g in deer (with a maximum of 8.1 pCi/g) and 1.68 pCi/g in hogs (with a maximum of 5.2 pCi/g).

Strontium levels are determined in some of the animals analyzed for cesium-137. Typically, muscle and bone samples are collected for analysis from the same animals checked for cesium-137, and the samples are analyzed for strontium-89,90. As in previous years, strontium-89,90 was not quantified in muscle samples. Lab measurements of strontium-89,90 in bone ranged from a high of 1.9 pCi/g to a low of 1.0 pCi/g.

Turkeys/Beavers

Description of Surveillance Programs

Prior to 2003, wild turkeys were trapped on site by the South Carolina Department of Natural Resources and used to repopulate game areas in South Carolina and other states.

The U.S. Department of Agriculture Forest Service–Savannah River harvests beavers in selected areas within the SRS perimeter to reduce the beaver population and thereby minimize dam-building activities that can result in flood damage to timber stands, to primary and secondary roads, and to railroad beds.

Both programs continued to remain inactive in 2005 because of reduced needs.

Soil

Description of Surveillance Program

The SRS soil monitoring program provides

- data for long-term trending of radioactivity deposited from the atmosphere (both wet and dry deposition)
- information on the concentrations of radioactive materials in the environment

The concentrations of radionuclides in soil vary greatly among locations because of differences in rainfall patterns and in the mechanics of retention and transport

Cobalt-60 was detected in sediment from the Four Mile Creek Swamp Discharge and R-Canal locations. The highest cobalt-60 concentration in streams, 1.01E+00 pCi/g, was measured at Four Mile Creek Swamp Discharge.

Strontium-89,90 was detected in sediment at one river and six stream locations. The maximum value was 1.75E+00 pCi/g, at the Four Mile Creek Swamp Discharge.

Plutonium-238 was detected in sediment during 2005 at all stream locations except Tinker Creek, and at one river location. The results ranged from a maximum of 6.11E+01 pCi/g at FM–A7 to below detection at several locations. Plutonium-239 was detected in sediment at most stream and two river locations. The maximum value was 2.73E-01 pCi/g—also at FM–A7. Uranium-234, 235, and 238 were detected at most locations.

The distribution and concentration of radionuclides in river sediment during 2005 were similar to those of previous years.

Concentrations of all isotopes generally were higher in streams than in the river. As indicated in the earlier discussion of cesium-137, this is to be expected. Differences observed when these data are compared to those of previous years probably are attributable to the effects of resuspension and deposition, which occur constantly in sediment media.

Grassy Vegetation

Description of Surveillance Program

The radiological program for grassy vegetation is designed to collect and analyze samples from onsite and offsite locations to determine radionuclide concentrations. Vegetation samples are obtained to complement the soil and sediment samples in order to determine the environmental accumulation of radionuclides and to help confirm the dose models used by SRS. Bermuda grass is preferred because of its importance as a pasture grass for dairy herds.

Vegetation samples are obtained from

- locations containing soil radionuclide concentrations that are expected to be higher than normal background levels
- locations receiving water that may have been contaminated
- all air sampling locations

Surveillance Results Summary

Radionuclides in the grassy vegetation samples collected in 2005 were detected as follows:

- tritium at one perimeter and one onsite location
- cesium-137 at seven perimeter and one offsite location
- strontium-89/90 at 13 locations (all the vegetation sampling sites except one perimeter location and the Savannah location)
- uranium-234 at 12 locations (all the vegetation sampling sites except two perimeter locations and one 25-mile location)
- uranium-235 at one perimeter location
- uranium-238 at 11 locations (all the vegetation sampling sites except four perimeter locations)
- plutonium-238 at one perimeter location
- amercium-241 at seven locations (the onsite location, five of the 10 perimeter locations, and the Savannah location)

These results are similar to those of previous years.

Savannah River Swamp Surveys

Introduction

The Creek Plantation, a privately owned land area located along the Savannah River, borders part of the southern boundary of SRS. In the 1960s, an area of the Savannah River Swamp on Creek Plantation—specifically, the area between Steel Creek Landing and Little Hell Landing—was contaminated by SRS operations. During high river levels, water from Steel Creek flowed along the lowlands comprising the swamp, resulting in the deposition of radioactive material. SRS studies estimated that a total of approximately 25 Ci of cesium-137 and 1 Ci of cobalt-60 were deposited in the swamp.

Comprehensive and cursory surveys of the swamp have been conducted periodically since 1974. These surveys measure radioactivity levels to determine changes in the amount and/or distribution of radioactivity in the swamp.

A series of 10 sampling trails—ranging from 240 to 3,200 feet in length—was established through the swamp. Fifty-two monitoring locations were designated on the trails to allow for continued monitoring at a consistent set of locations.

Sediment

The nonradiological sediment surveillance program provides a method to determine the deposition, movement, and accumulation of nonradiological contaminants in stream systems.

Surveillance Results Summary

In 2005, as in the previous 5 years, no pesticides or herbicides were found to be above the quantitation limits in sediment samples. Metals analyses results for 2005 also were comparable to those of the previous 5 years.

Fish

EPM personnel analyze the flesh of fish caught from the Savannah River to determine concentrations of mercury in the fish. The fish analyzed represent the most common edible species of fish in the CSRA (freshwater) and at the mouth of the Savannah River (saltwater).

Surveillance Results Summary

In 2005, 151 fish were caught from the Savannah River and analyzed for mercury. Concentrations of mercury generally were slightly higher than those observed in 2004, but were similar to those of previous years. The highest concentrations were found in bass at the mouth of Steel Creek (4.08 µg/g), bream at Augusta Lock and Dam (1.25µg/g), and catfish at the mouth of Steel Creek (2.11µg/g).

River Water Quality Surveys

Description of Surveys

ANS personnel conducted biological and water quality surveys of the Savannah River from 1951 through 2003, when EPM assumed this responsibility. The surveys were designed to assess potential effects of SRS contaminants and warm-water discharges on the general health of the river and its tributaries. This is accomplished by looking for

- patterns of biological disturbance that are geographically associated with the site
- patterns of change over seasons or years that indicate improving or deteriorating conditions

EPM conducted macroinvertebrate and diatom sampling during the spring and fall of 2005. The diatom slides were sent to ANS for archiving and processing of the 2005 spring collection. No adverse biological impacts were identified in the Savannah River diatom communities.

The number of macroinvertebrates collected from river traps during 2004 was similar to that of past surveys. No adverse biological impacts were observed in the macroinvertebrate communities. Collections from 2005 will be sorted and archived during 2006.

Chapter 6

Potential Radiation Doses

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THIS chapter presents the potential doses to offsite individuals and the surrounding population from the 2005 Savannah River Site (SRS) atmospheric and liquid radioactive releases. Also documented are potential doses from special-case exposure scenarios—such as the consumption of deer meat, fish, and goat milk.

Unless otherwise noted, the generic term "dose" used in this report includes both the committed effective dose equivalent (50-year committed dose) from internal deposition of radionuclides and the effective dose equivalent attributable to sources external to the body. Use of the effective dose equivalent allows doses from different types of radiation and to different parts of the body to be expressed on the same basis.

Descriptions of the effluent monitoring and environmental surveillance programs discussed in this chapter can be found in chapter 4, "Effluent Monitoring," and chapter 5, "Environmental Surveillance." A complete description of how potential doses are calculated can be found in section 1108 of the *Savannah River Site Environmental Monitoring Section Plans and Procedures*, WSRC–3Q1–2, Volume 1 [SRS EM Program, 2001]. All potential dose calculation results are presented in data tables on the CD accompanying this report.

Applicable dose regulations can be found in appendix A, "Applicable Guidelines, Standards, and Regulations," of this document.

Calculating Dose

Potential offsite doses from SRS effluent releases of radioactive materials (atmospheric and liquid) are calculated for the following scenarios:

- hypothetical maximally exposed individual living at the SRS boundary (see definition below)
- population living within an 80-km (50-mile) radius of SRS

Because the U.S. Department of Energy (DOE) has adopted dose factors only for adults, SRS calculates maximally exposed individual and collective doses as if the entire 80-km population consisted of adults [DOE, 1988]. For the radioisotopes that contribute the most to SRS's estimated maximum individual doses (i.e., tritium and cesium-137), the dose to infants would be approximately two to three times more than to adults. The dose to older children becomes progressively closer to the adult dose.

SRS also uses adult consumption rates for food and drinking water and adult usage parameters to estimate intakes of radionuclides. These intake values and

Dose to the Hypothetical Maximally Exposed Individual

When calculating radiation doses to the public, SRS uses the concept of the maximally exposed individual; however, because of the conservative lifestyle assumptions used in the dose models, no such person is known to exist. The parameters used for the dose calculations are as follows:

1) **For airborne releases:** Someone who lives at the SRS boundary 365 days per year and consumes milk, meat, and vegetables produced at that location.

2) **For liquid releases:** Someone who lives downriver of SRS (near River Mile 118.8) 365 days per year, drinks 2 liters of untreated water per day from the Savannah River, consumes 19 kg per year of Savannah River fish, and spends the majority of time on or near the river.

To demonstrate compliance with the DOE Order 5400.5 all-pathway dose standard of 100 mrem per year, SRS conservatively combines the airborne pathway and liquid pathway dose estimates, even though the two doses are calculated for hypothetical individuals residing at different geographic locations.

Table 6–1
2005 Radioactive Liquid Release Source Term and 12-Month Average Downriver Radionuclide Concentrations Compared to EPA's Drinking Water Maximum Contaminant Levels (MCL)

Nuclide	Curies Released	12-Month Average Concentration (pCi/mL)				
		Below SRS[a]	BJWSA Chelsea[b]	BJWSA Purrysburg[b]	Port Wentworth[c]	EPA MCL
H-3[d]	4.48E+03	5.46E-01	4.45E-01	4.48E-01[e]	4.96E-01	2.00E+01
Sr-90	3.76E-02	4.58E-06	3.73E-06	3.76E-06	4.16E-06	8.00E-03
Tc-99	4.43E-03	5.40E-07	4.40E-07	4.43E-07	4.90E-07	9.00E-01
I-129	8.00E-03	9.75E-07	7.95E-07	8.00E-07	8.86E-07	1.00E-03
Cs-137	1.34E-01	1.63E-05	1.33E-05	1.34E-05	1.48E-05	2.00E-01
U-234	5.54E-04	6.75E-08	5.50E-08	5.54E-08	6.13E-08	1.87E+02
U-235	2.68E-05	3.27E-09	2.66E-09	2.68E-09	2.97E-09	6.48E-02
U-238	3.78E-04	4.61E-08	3.75E-08	3.78E-08	4.18E-08	1.01E-02
Pu-238	9.85E-04	1.20E-07	9.78E-08	9.85E-08	1.09E-07	1.50E-02
Pu-239	4.42E-05	5.39E-09	4.39E-09	4.42E-09	4.89E-09	1.50E-02
Am-241	9.22E-05	1.12E-08	9.16E-09	9.22E-09	1.02E-08	1.50E-02
Cm-244	4.14E-05	5.05E-09	4.11E-09	4.14E-09	4.58E-09	1.50E-02
Alpha	1.66E-02	2.02E-06	1.65E-06	1.66E-06	1.84E-06	1.50E-02
Beta	2.96E-02	3.61E-06	2.94E-06	2.96E-06	3.28E-06	8.00E-03

[a] Near Savannah River Mile 118.8, downriver of SRS at the U.S. Highway 301 bridge
[b] Beaufort-Jasper, South Carolina, drinking water
[c] Port Wentworth, Georgia, drinking water
[d] Tritium concentrations are based on actual measurements of Savannah River water at the various locations. All other radionuclide concentrations are calculated based on the river flow rate.
[e] Because of rounding differences, this value appears as 4.47E-01 in the drinking water table accompanying the "Environmental Surveillance" chapter.

Radionuclide Concentrations in Savannah River Water, Drinking Water, and Fish

For use in dose determinations and model comparisons, the concentrations of tritium in Savannah River water and cesium-137 in Savannah River fish are measured at several locations along the river. The amounts of all other radionuclides released from SRS are so small that they usually cannot be detected in the Savannah River using conventional analytical techniques.

Radionuclide Concentrations in River Water and Treated Drinking Water The measured concentrations of tritium in the Savannah River near River Mile 118.8 and at the Port Wentworth and BJWSA water treatment facilities are shown in table 6–1, as are the calculated concentrations for the other released radionuclides.

The 12-month average tritium concentration measured in Savannah River water near River Mile 118.8 (0.546 pCi/mL) was 17 percent less than the 2004 concentration of 0.661 pCi/mL. The concentrations at the BJSWA Chelsea (0.445 pCi/mL) and Purrysburg (0.448 pCi/mL; see footnote "e" in table 6–1 above) facilities, and at the Port Wentworth (0.496 pCi/mL) water treatment plant, remained below the EPA maximum contaminant level (MCL) of 20 pCi/mL.

The MCL for each radionuclide released from SRS during 2005 is provided in table 6–1. The table indicates that all individual radionuclide concentrations at the three downriver community drinking water systems, as well as at River Mile 118.8, were below the MCLs.

Because more than one radionuclide is released from SRS, the sum of the fractions of the observed concentration of each radionuclide to its corresponding MCL must not exceed 1.0.

The sum of the fractions was 0.0241 at the BJSWA Chelsea facility, 0.0242 at the BJSWA Purrysburg facility, and 0.0268 at the Port Wentworth facility. These are below the 1.0 sum-of-the-fractions requirement. Refer to the "Liquid Releases and Concentrations Compared to EPA MCLs" table in the Environmental Data section of the CD accompanying this report for an explanation of how these sums of the fractions were determined.

For 2005, the sum of the fractions at the River Mile 118.8 location was 0.0295. This is provided only for comparison because River Mile 118.8 is not a community water system location.

Collective (Population) Dose

The collective drinking water consumption dose is calculated for the discrete population groups served by the BJWSA and Port Wentworth water treatment plants. The collective dose from other pathways is calculated for a diffuse population that makes use of the Savannah River. However, this population cannot be described as being in a specific geographical location.

In 2005, the collective dose from SRS liquid releases was estimated at 2.5 person-rem (0.025 person-Sv). This is 19 percent less than the 2004 collective dose of 3.1 person-rem (0.031 person-Sv).

Potential Dose from Agricultural Irrigation

Based on surveys of county agricultural extension agencies, there are no known large-scale uses of river water downstream of SRS for agricultural irrigation purposes. However, the potential for irrigation does exist, so potential doses from this pathway are calculated for information purposes only but are not included in calculations of the official maximally exposed individual or collective doses.

As in previous years, collective doses from agricultural irrigation were calculated for 1,000 acres of land devoted to each of four major food types—vegetation, leafy vegetation, milk, and meat. It is assumed that all the food produced on the 1,000-acre parcels is consumed by the 80-km population of 713,500.

For 2005, a potential offsite dose of 0.049 mrem (0.00049 mSv) to the maximally exposed individual and a collective dose of 3.5 person-rem (0.035 person-Sv) were estimated for this exposure pathway.

Air Pathway

Atmospheric Source Terms

The 2005 radioactive atmospheric release quantities used as the source term in SRS dose calculations are discussed in chapter 4.

Estimates of unmonitored diffuse and fugitive sources were included in the atmospheric source term, as required, for demonstrating compliance with NESHAP regulations.

Atmospheric Concentrations

Calculated radionuclide concentrations are used for dose determinations instead of measured concentrations. This is because most radionuclides released from SRS cannot be measured, using standard methods, in the air samples collected at the site perimeter and offsite locations. However, the concentrations of tritium oxide at the site perimeter locations usually can be measured and are compared with calculated concentrations as a verification of the dose models, as shown in data tables on the CD accompanying this report.

Dose to the Maximally Exposed Individual

In 2005, the estimated dose from atmospheric releases to the maximally exposed individual was 0.05 mrem (0.0005 mSv), which is 0.5 percent of the DOE Order 5400.5 air pathway standard of 10 mrem per year. This dose is slightly less than the 2004 maximally exposed individual dose of 0.06 mrem (0.0006 mSv). Table 6–3 compares the maximally exposed individual dose with the DOE standard.

Tritium oxide releases accounted for 66 percent of the dose to the maximally exposed individual, and iodine-129 emissions accounted for 10 percent of the dose. No other radionuclide accounted for more than 5 percent of the maximally exposed individual dose.

The potential dose to the maximally exposed individual residing at the site boundary for each of the 16 major compass point directions around SRS can be found in the "Maps" appendix (figure 14) on the CD accompanying this report. For 2005, the north sector of the site was the location of the highest dose to the maximally exposed individual.

The major pathways contributing to the dose to the maximally exposed individual from atmospheric releases were inhalation (43 percent) and the consumption of vegetation (41 percent), cow milk (10 percent), and meat (4 percent).

Additional calculations of the dose to the maximally exposed individual were performed substituting goat milk for the customary cow milk pathway. The potential dose using the goat milk pathway was estimated at 0.06 mrem (0.0006 mSv).

Collective (Population) Dose

In 2005, the collective dose was estimated at 2.5 person-rem (0.025 person-Sv)—less than 0.01 percent of the collective dose received from natural sources of radiation (about 214,000 person-rem).

Tritium oxide releases accounted for about 68 percent of the collective dose. The 2005 collective dose is 14 percent less than the 2004 collective dose of 2.9 person-rem (0.029 person-Sv).

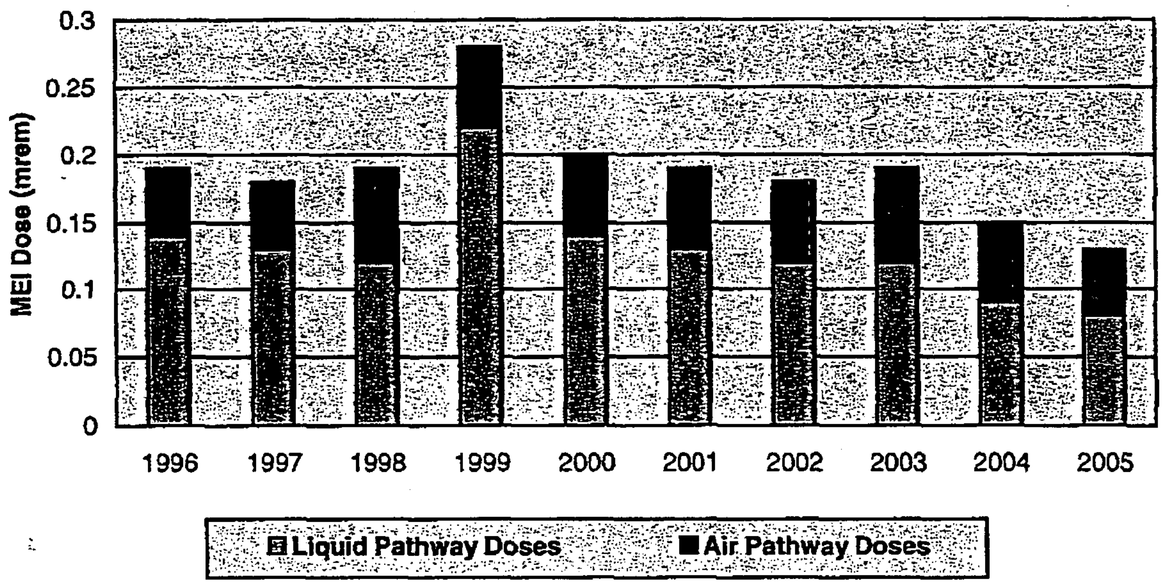

Figure 6–1 Ten-Year History of SRS Maximum Potential All-Pathway Doses

Savannah River Swamp, which was contaminated by SRS operations in the 1960s (chapter 5):

- External exposure to contaminated soil
- Incidental ingestion of contaminated soil
- Incidental inhalation of resuspended contaminated soil

Onsite Hunter Dose

Deer and Hog Consumption Pathway The estimated dose from the consumption of harvested deer or hog meat is determined for every onsite hunter.

During 2005, the maximum potential dose that could have been received by an actual onsite hunter was estimated at 8.8 mrem (0.88 mSv), or 8.8 percent of DOE's 100-mrem all-pathway dose standard (table 6–4). This dose was determined for an actual hunter who in fact harvested six animals (two deer and four hogs) during the 2005 hunts. The hunter-dose calculation is based on the conservative assumption that this hunter individually consumed the entire edible portion—approximately 175 kg (386 pounds)—of the animals he harvested from SRS.

Offsite Hunter Dose

Deer and Hog Consumption Pathway The deer and hog consumption pathway considered was for hypothetical offsite individuals whose entire intake of meat during the year was either deer or hog meat. It was assumed that these individuals harvested deer or hogs that had resided on SRS, but then moved off site.

Based on these low-probability assumptions and on the measured average concentration of cesium-137 in all deer (2.32 pCi/g) and hogs (1.68 pCi/g) harvested from SRS during 2005, the potential maximum doses from this pathway were estimated at 5.4 mrem (0.054 mSv) for the deer hunter and at 2.8 mrem (0.028 mSv) for the hog hunter.

A background cesium-137 concentration of 1 pCi/g is subtracted from the onsite average concentrations before calculating the doses. The background concentration is based on previous analyses of deer harvested at least 80 km from SRS (table 33, *SRS Environmental Data for 1994*, WSRC–TR–95–077).

Savannah River Swamp Hunter Soil Exposure Pathway The potential dose to a recreational hunter exposed to SRS legacy contamination in Savannah River Swamp soil on the privately owned Creek Plantation in 2005 was estimated using the RESRAD dosimetry [Yu et al., 2001]. It was assumed that this recreational sportsman hunted for 120 hours during the year (8 hours per day for 15 days) at the location of maximum radionuclide contamination.

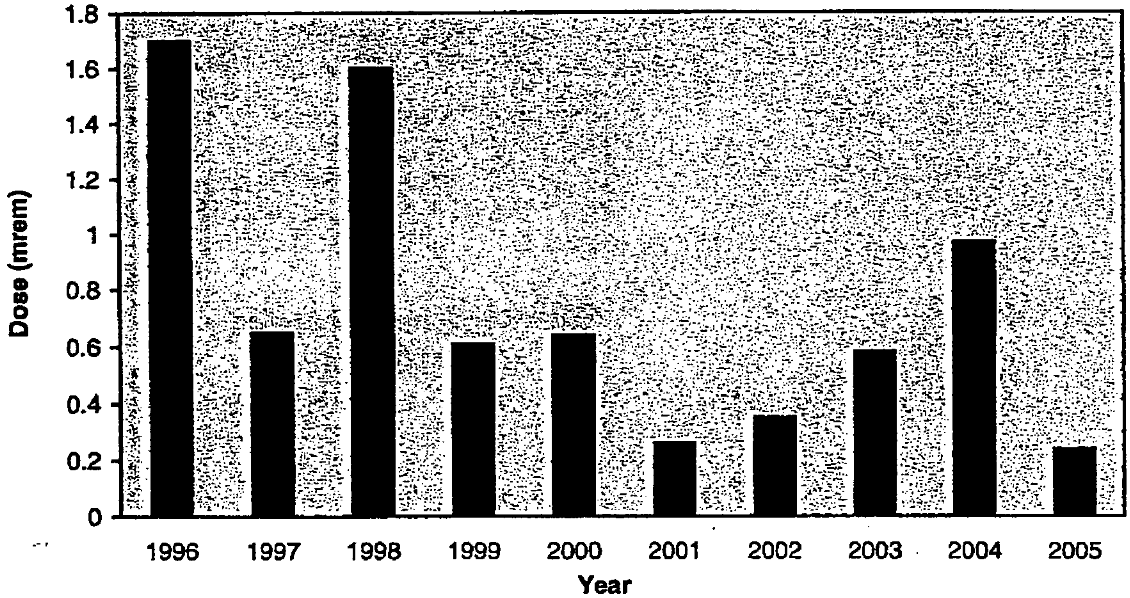

Figure 6–2 Ten-Year History of SRS Creek Mouth Fisherman's Dose

Savannah River Swamp Fisherman Soil Exposure Pathway The potential dose to a recreational fisherman exposed to SRS legacy contamination in Savannah River Swamp soil on the privately owned Creek Plantation in 2005 was estimated using the RESRAD dosimetry code [Yu et al., 2001]. It was assumed that this recreational sportsman fished on the South Carolina bank of the Savannah River near the mouth of Steel Creek for 250 hours during the year.

During the comprehensive survey of the Savannah River Swamp conducted in 2005, the location on Creek Plantation that was closest to the South Carolina bank of the Savannah River and the mouth of Steel Creek was on trail 1, at a distance of 0 feet from the Savannah River.

Using the radionuclide concentrations measured at this location, the potential dose to a fisherman from a combination of (1) external exposure to the contaminated soil, (2) incidental ingestion of the soil, and (3) incidental inhalation of resuspended soil was estimated to be 0.28 mrem (0.0028 mSv).

As shown in table 6–4, the maximum Steel Creek mouth fish consumption dose (0.24 mrem) and the Savannah River Swamp fisherman soil exposure pathway were conservatively added together to obtain a total offsite creek mouth fisherman dose of 0.52 mrem (0.0052 mSv). This potential dose is 0.52 percent of the DOE 100-mrem all-pathway dose standard.

Potential Risk from Consumption of SRS Creek Mouth Fish

During 1991 and 1992, in response to a U.S. House of Representatives Appropriations Committee request for a plan to evaluate risk to the public from fish collected from the Savannah River, SRS developed—in conjunction with EPA, the Georgia Department of Natural Resources, and the South Carolina Department of Health and Environmental Control—the *Westinghouse Savannah River Company/Environmental Monitoring Section Fish Monitoring Plan*, which is summarized in SRS EM Program, 2001. Among the reporting requirements of this plan are (1) assessing radiological risk from the consumption of Savannah River fish and (2) presenting a summary of the results in the annual *SRS Environmental Report*.

Risk Comparisons For 2005, the maximum potential radiation doses and lifetime risks from the consumption of SRS creek mouth fish for 1-year, 30-year, and 50-year exposure durations are shown in table 6–5 and are compared to the radiation risks associated with the DOE Order 5400.5 all-pathway dose standard of 100 mrem (1.0 mSv) per year.

The potential risks were estimated using the cancer morbidity risk coefficients from Federal Guidance Report No. 13 [EPA, 1999].

For 2005, the maximum recreational fisherman dose was caused by the consumption of bass collected at the mouth of Steel Creek.

Figure 6–2 shows a 10-year history of the annual potential radiation doses from consumption of Savannah River fish. No apparent trends can be discerned from these data. This is because there is large variability in

The terrestrial systems evaluation includes exposures to terrestrial plants and animals and is based on a 10-rad-per-day dose limit for plants and a 0.1-rad-per-day dose limit for animals. For the aquatic systems evaluation portion of the BCGs, an initial screening was performed using maximum radionuclide concentration data for the 10 Environmental Permitting and Monitoring (EPM) stream sampling locations from which co-located water and sediment samples are collected. An exception to this was made for sample location FM–2B (located on Four Mile Creek between F-Area and H-Area) because of its historically high cesium and tritium concentration levels. This location was included in the initial screening even though no co-located sediment sample is collected there.

The combined water-plus-sediment BCG sum of the ratios was used for the aquatic systems evaluation. A sum of the ratios less than one indicates the sampling site has passed the initial pathway screen.

For the terrestrial systems evaluation portion of the BCGs, an initial screening was performed using concentration data from the five EPM onsite radiological soil sampling locations. Only one soil sample per year is collected from each location.

For 2005, stream sampling locations R–1 (located adjacent to R-Reactor near the center of SRS), FM–2, and FM–2B failed the initial aquatic systems screen.

These locations failed because of relatively high maximum concentrations of cesium-137 in the water and sediment samples. All other locations, including the five soil sampling locations, passed.

For the four locations that failed, an additional assessment was performed using annual average radionuclide concentrations measured in the water and sediment samples. All locations passed this secondary screen (the sum of the ratios of each was less than 1.0).

Chapter 7
Groundwater

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GROUNDWATER protection at the Savannah River Site (SRS) has evolved into a program with the following primary components:

- Protect groundwater by good practices in managing chemicals and work.
- Monitor groundwater to identify areas of contamination.
- Remediate contamination as needed.
- Use groundwater wisely to conserve.

SRS operations have contaminated groundwater around certain waste disposal facilities. Extensive monitoring and remediation programs are tracking and cleaning up the contamination. Remediation includes (1) the closing of waste sites to reduce the migration of contaminants into groundwater and (2) the active treatment of contaminated water.

No offsite wells have been contaminated by the migration of SRS groundwater.

This chapter describes SRS's groundwater environment and the programs in place for investigating, monitoring, remediating, and using the groundwater.

Groundwater at SRS

SRS is underlain by sediment of the Atlantic Coastal Plain. The Atlantic Coastal Plain consists of a southeast-dipping wedge of unconsolidated sediment that extends from its contact with the Piedmont Province at the Fall Line to the edge of the continental shelf. The sediment ranges from Late Cretaceous to Miocene in age and comprises layers of sand, muddy sand, and clay with subordinate calcareous sediments. It rests on crystalline and sedimentary basement rock.

Water flows easily through the sand layers but is retarded by less permeable clay beds, creating a complex system of aquifers. Operations during the life of SRS have resulted in contamination migrating into groundwater at various site locations, predominantly in the central areas of the site. The ongoing movement of water into the ground, through the aquifer system, and then into streams and lakes—or even into deeper aquifers—continues to carry contamination along with it, resulting in spreading plumes.

The hydrostratigraphy of SRS has been subject to several classifications. The hydrostratigraphic classification established in Aadland et al., 1995, and in Smits et al., 1996, is widely used at SRS and is regarded as the current SRS standard. This system is consistent with the one used by the U.S. Geological Survey (USGS) in regional studies that include the area surrounding SRS [Clarke and West, 1997]. Figure 7–1 is a chart that indicates the relative position of hydrostratigraphic units and relates hydrostratigraphic units to corresponding lithologic units at SRS and to the geologic time scale. This chart was modified from Aadland et al., 1995, and Fallaw and Price, 1995.

The hydrostratigraphic units of primary interest beneath SRS are part of the Southeastern Coastal Plain Hydrogeologic Province. Within this sequence of aquifers and confining units are two principal subcategories, the overlying Floridan Aquifer System and the underlying Dublin-Midville Aquifer System. These systems are separated from one another by the Meyers Branch Confining System. In turn, each of the systems is subdivided into two aquifers, which are separated by a confining unit.

In the central to southern portion of SRS, the Floridan Aquifer System is divided into the overlying Upper Three Runs Aquifer and the underlying Gordon Aquifer, which are separated by the Gordon Confining Unit. North of Upper Three Runs Creek, these units are collectively referred to as the Steed Pond Aquifer, in which the Upper Three Runs Aquifer is called the M-Area Aquifer zone, the Gordon Aquifer is referred to as the Lost Lake Aquifer zone, and the aquitard that separates them is referred to as the Green Clay confining zone unit within which the water table usually occurs at SRS; hence, it is referred to informally as the "water table" aquifer. The water table surface can be as deep as 160 feet below ground surface (bgs), but intersects the ground surface in seeps along site streams. The top of the Gordon Aquifer typically is encountered at depths of 150–250 feet bgs. The Dublin-Midville Aquifer System is divided into the overlying Crouch Branch Aquifer and the underlying McQueen Branch Aquifer, which are separated by the McQueen Branch Confining Unit. The Crouch Branch Aquifer and McQueen Branch Aquifer are names that originated at SRS [Aadland et al., 1995]. These units are equivalent to the Dublin Aquifer and the Midville Aquifer, which are names originating with the USGS [Clarke and West, 1997]. The top of the Crouch Branch Aquifer typically is encountered at depths of 350–500 feet bgs. The top of the McQueen's Branch Aquifer typically is encountered at depths of 650–750 feet bgs.

Figure 7–2 is a three-dimensional block diagram of the hydrogeologic units at SRS and the generalized groundwater flow patterns within those units. These units are from shallowest to deepest: the Upper Three Runs/Steed Pond Aquifer (or water table aquifer), the Gordon/Lost Lake Aquifer, the Crouch Branch Aquifer, and the McQueen Branch Aquifer.

Groundwater recharge is a result of the infiltration of precipitation at the land surface; the precipitation moves vertically downward through the unsaturated zone to the water table. Upon entering the saturated zone at the water table, water moves predominantly in a horizontal direction toward local discharge zones along the headwaters and midsections of streams, while some of the water moves into successively deeper aquifers. The water lost to successively deeper aquifers also migrates laterally within those units toward the more distant regional discharge zones. These typically are located

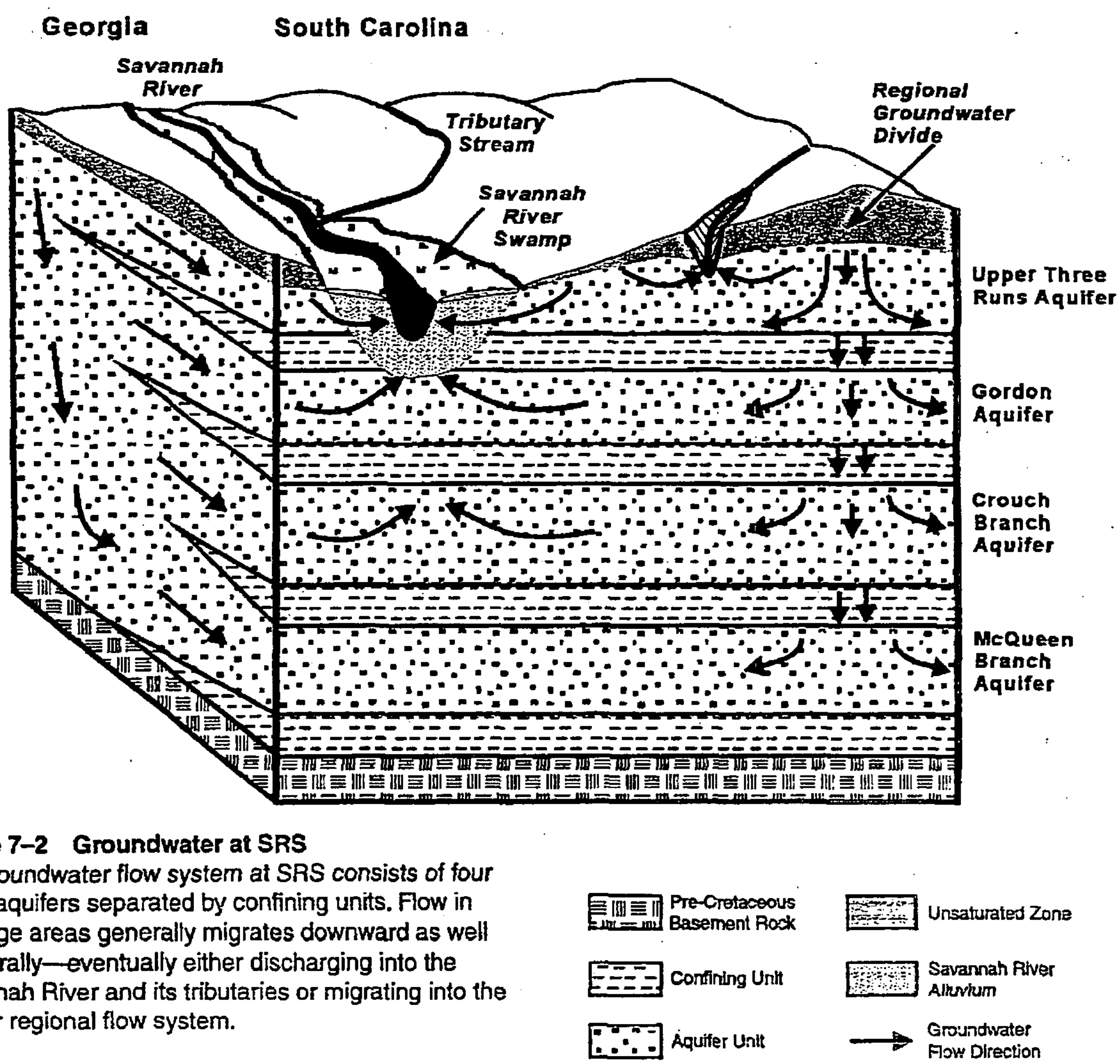

Figure 7–2 Groundwater at SRS
The groundwater flow system at SRS consists of four major aquifers separated by confining units. Flow in recharge areas generally migrates downward as well as laterally—eventually either discharging into the Savannah River and its tributaries or migrating into the deeper regional flow system.

Modified from Clarke and West, 1997

Examples of newer technologies include the use of

- direct-push technology, such as the cone penetrometer, to collect one-time groundwater samples at investigation sites and to help establish hydrostratigraphic contacts
- the "rotosonic" method for bore holes to collect cores and install wells

Models have been used extensively as analytical tools at SRS for both regional and local investigations. Models have been utilized for a variety of reasons, but primarily to (1) define the regional groundwater movement patterns at SRS and the surrounding areas, (2) enhance the understanding of contaminant migration in the subsurface, and (3) support the design of remediation systems. At SRS, major groundwater modeling efforts have focused on A/M-Area, F-Area, H-Area, the Burial Ground Complex, and several of the reactor areas where the most extensive subsurface contamination is known to exist.

Research on groundwater issues is conducted at SRS to obtain a better understanding of subsurface mechanisms, such as (1) the interaction of contaminants with the porous media matrix and (2) the factors that impact the rate of migration of contaminants within the groundwater flow system. Research to address relevant issues often is conducted through cooperative studies with investigators at various public universities and private companies, while other efforts are conducted exclusively by SRS employees.

Special Groundwater Study

A part of the SRS perimeter that has received special monitoring attention is across the Savannah River in Georgia's Burke and Screven counties. Since 1988, there has been speculation that tritiated groundwater from SRS could flow under the river and find its way into Georgia wells. Considerable effort has been directed at assessing the likelihood of transriver flow, and 44 wells have been drilled by the USGS and the Georgia Department of Natural Resources (figure 22 in the "SRS Maps" appendix on the CD accompanying this report).

As part of the data collection and analysis, the USGS developed a numerical model in 1997–98 to assess the possibility for such transriver flow to occur. Development of the model—and the resulting analyses—is documented in Clark and West, 1998.

The model represented the regional groundwater flow system in seven layers corresponding to the underlying hydrostratigraphic units, which was regarded as sufficiently detailed to evaluate whether groundwater originating at SRS could possibly flow beneath the Savannah River into Georgia. An extensive effort was undertaken to calibrate the model to water-level measurements obtained from wells on both sides of the Savannah River and screened in each of the hydrostratigraphic units represented in the model. The model concluded that groundwater movement in all hydrostratigraphic units proceeds laterally toward the Savannah River from both South Carolina and Georgia, and discharges into the river.

Once the model was calibrated, the USGS employed particle-track analysis to delineate areas of potential transriver flow. Transriver flow can occur in either an eastward or westward direction. The model indicated that all locations of transriver flow are restricted to the Savannah River's floodplain, where groundwater passes immediately prior to discharging into the river. Whether the transriver flow is eastward or westward depends primarily on the position of the Savannah River as it meanders back and forth within the floodplain.

With respect to "westward" transriver flow, the USGS model indicates that it primarily occurs in locations south of SRS and within the deeper aquifers (Crouch Branch and McQueen Branch). Particle-tracking analysis of westward transriver flow in these aquifers indicates that the groundwater crossing from South Carolina into Georgia originates as recharge in upland areas well to the east and south of SRS.

The model identified one area (less than one square mile) of westward transriver flow that has a recharge area located within SRS, and that conceivably could receive tritium or other contaminants from SRS as a result. The one-square-mile area occurs immediately adjacent to the Savannah River, where groundwater within the Gordon Aquifer flows immediately prior to discharging into the river.

Particle tracking indicates that recharge zones associated with the one square mile are located in the upland areas between D-Area and K-Area. There is no known subsurface contamination at these recharge zones. Travel times associated with the particles were calculated to range from 90 to 820 years, although these estimates are shorter than actual travel times since no accounting of transit time across the uppermost aquifer was included in the USGS estimate. It is important to note that the range of travel times represents seven to 66 half-lives of tritium (12.33 years), suggesting that even if tritium contamination existed at the recharge areas, it likely would decay away prior to discharging into the Savannah River.

The USGS is completing an update to the groundwater model to incorporate boundary conditions representative of 2002, which was a time of severe drought in the

Monitoring around known waste disposal sites and operating facilities provides the best means to detect and track groundwater contamination. To detect contamination from as-yet undiscovered sites, SRS depends on a sitewide groundwater monitoring and protection effort—the site Groundwater Surveillance Monitoring Program (GSMP). This program is an upgraded replacement of the site screening program.

Monitoring wells and production wells that no longer are needed should be properly abandoned. In 2005, SRS abandoned 64 monitoring wells, three deep rock borings (approximately 1,500 feet deep), and seven production wells. Additional abandonments are planned for 2006.

One goal of the GSMP is to protect potential offsite receptors from contamination by detecting contamination in time to apply appropriate corrective actions. SRS is a large site, and most groundwater contamination is located in its central areas. However, the potential for offsite migration exists, and the consequences of such an outcome are serious enough to warrant a comprehensive prevention program.

SRS has evaluated flow in each aquifer and determined where there is potential for flow across the site boundary. This gives a conservative indication of where offsite contamination might be possible and allows for a focused monitoring effort in those few areas. Another pathway for existing groundwater contamination to flow offsite is by discharge into surface streams and subsequent transport into the Savannah River. SRS monitors site streams for contamination, and new wells have been installed in recent years along several site streams to detect contamination before it enters the stream and to assess its concentration in groundwater.

The groundwater monitoring program at SRS gathers information to determine the effect of site operations on groundwater quality. The program is designed to

- assist SRS in complying with environmental regulations and DOE directives
- provide data to identify and monitor constituents in the groundwater
- permit characterization of new facility locations to ensure that they are suitable for the intended facilities
- support basic and applied research projects

The groundwater monitoring program at SRS includes two primary components: (1) waste site/remediation groundwater monitoring, overseen by the Geochemical Monitoring group of SGCP, and (2) groundwater surveillance monitoring, conducted by the Environmental Services Section. To assist other departments in meeting their responsibilities, personnel of both organizations provide the services for installing monitoring wells, collecting and analyzing samples, and reporting results.

Sample Scheduling and Collection

The Geochemical Monitoring group and the Environmental Services Section schedule groundwater sampling either in response to specific requests from SRS personnel or as part of their ongoing groundwater monitoring program. These groundwater samples provide data for reports required by federal and state regulations and for internal reports and research projects. The groundwater monitoring program schedules wells to be sampled at intervals ranging from quarterly to triennially.

Constituents that may be analyzed are commonly imposed by permit or work plan approval. These include metals, field parameters, and suites of herbicides, pesticides, volatile organics, and others. Radioactive constituents that may be analyzed by request include gross alpha and beta measurements, gamma emitters, iodine-129, strontium-90, radium isotopes, uranium isotopes, and other alpha and beta emitters.

Groundwater samples are collected from monitoring wells, generally with either pumps or bailers dedicated to the well to prevent cross-contamination among wells. Occasionally, portable sampling equipment is used; this equipment is decontaminated between wells.

Sampling and shipping equipment and procedures are consistent with EPA, SCDHEC, and U.S. Department of Transportation guidelines. EPA-recommended preservatives and sample-handling techniques are used during sample storage and transportation to both onsite and offsite analytical laboratories. Potentially radioactive samples are screened for total activity (alpha and beta emitters) prior to shipment to determine appropriate packaging and labeling requirements.

Deviations (caused by dry wells, inoperative pumps, etc.) from scheduled sampling and analysis for 2005 were entered into the site's groundwater database and issued in appropriate reports.

Table 7–1
Summary of Maximum Groundwater Monitoring Results for Major Areas Within SRS, 2004–2005

Location	Major Contaminants	Units	2005 Maximum	MCL[a]	2004 Maximum	Likely Outcrop Point
A-Area/M-Area	TCE PCE	ppb ppb	28,400 127,000	5 5	37,300 142,000	Tims Branch/Upper Three Runs Creek in East; Crackerneck Swamp in West
C-Area	TCE Tritium	ppb pCi/L	1,611 4,851,000	5 20,000	1,611 6,230,000	Tributaries of Fourmile Branch
D-Area	TCE Tritium	ppb pCi/L	490 1,030,000	5 20,000	395 1,030,000	Savannah River Swamp
E-Area	Tritium TCE	pCi/L ppb	45,700,000 570	20,000 5	82,300,000 606	Upper Three Runs/Crouch Branch in North; Fourmile Branch in South
F-Area	TCE Tritium Gross alpha Beta	ppb pCi/L pCi/L pCi/L	55 435,000 103 359	5 20,000 15 4 mrem/yr[a]	25.3 1,190,000 89.4 283	Upper Three Runs/Crouch Branch in North; Fourmile Branch in South
F-Area Seepage Basins	Tritium Gross alpha Beta	pCi/L pCi/L pCi/L	7,660,000 781 3,030	20,000 15 4 mrem/yr[a]	8,599,078 784 3,280	Fourmile Branch
H-Area	Tritium TCE Gross alpha Beta	pCi/L ppb pCi/L pCi/L	54,300 undetected 8.46 81.5	20,000 5 15 4 mrem/yr[a]	93,048 undetected 24.1 146	Upper Three Runs/Crouch Branch in North; Fourmile Branch in South
H-Area Seepage Basins	Tritium Gross alpha Beta	pCi/L pCi/L pCi/L	6,710,000 89 2,630	20,000 15 4 mrem/yr[a]	9,250,000 239 1,540	Fourmile Branch
R-Area	Tritium	pCi/L	111,000	20,000	164,000	Mill Creek in Northwest; tributaries of PAR Pond elsewhere
K-Area	Tritium TCE[b]	pCi/L ppb	26,900,000 17	20,000 5	1,560,971 12.7	Indian Graves Branch
L-Area	Tritium TCE	pCi/L ppb	1,250,000 21	20,000 5	1,250,000 13	L Lake
P-Area	Tritium[b] TCE	pCi/L ppb	18,400,000 13,600	20,000 5	523,000 8,460	Steel Creek in North; Meyer's Branch in South
Sanitary Landfill	TCE Vinyl chloride	ppb ppb	16 30	5 2	14.1 28.4	Upper Three Runs Creek
TNX	TCE	ppb	566	5	680	Savannah River Swamp
CMP Pits	TCE	ppb	1,090	5	713	Pen Branch

[a] MCL= Maximum contaminant level

[b] The activity (pCi/L) equivalent to 4 mrem/yr varies according to which specific beta emitters are present in the sample.

Chapter 8

Quality Assurance

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[Editors note: During 2005, responsibility for the environmental Quality Assurance (QA) program was divided among three groups—the Environmental Monitoring Laboratory (EML), the Environmental Permitting and Monitoring group (EPM), and the Geochemical Monitoring group (GM)].

SRS's environmental QA program is conducted to verify the integrity of data generated by onsite and subcontracted environmental laboratories.

The program's objectives are to ensure that samples are representative of the surrounding environment and that analytical results are accurate.

This chapter summarizes the 2005 QA program. Guidelines and applicable standards for the program are referenced in appendix A, "Applicable Guidelines, Standards, and Regulations."

A more complete description of the QA program can be found in *Savannah River Site Environmental Monitoring Program* (WSRC–3Q1–2, Section 1100) and in the *Savannah River Site Environmental Monitoring Section Quality Assurance Plan* (WSRC–3Q1–2, Section 8000).

The 2005 QA data and program reviews demonstrate that the data in this annual report are reliable and meet applicable standards.

QA for EPM

Internal Quality Assurance Program

Laboratory Certification

EPM is certified by the South Carolina Department of Health and Environmental Control (SCDHEC) Office of Laboratory Certification for field pH and total residual chlorine as stated under the Clean Water Act (CWA).

Blind pH Samples

EPM personnel routinely conduct a blind sample program for field measurements of pH to assess the quality and reliability of field data measurements.

During 2005, blind pH field measurements were taken for 24 samples. All field pH measurements except one outlier were within the U.S. Environmental Protection Agency's (EPA's) suggested acceptable control limit of ± 0.4 pH units of the true (known) value. The pH meter for the outlier was recalibrated and the sample was retested. The recalibrated results were within acceptable limits.

Blind Tritium Samples

Blind tritium samples provide an assessment of laboratory sample preparation and counting. During 2005, 12 blind samples were analyzed for tritium; all of the results were within control limits. Complete results can be found in the "Blind Sample Results for Tritium" table on the CD accompanying this report.

QA for EML

Internal QA Program

EML has a documented QA program that meets site and U.S. Department of Energy (DOE) requirements. Instruments are calibrated with known reference standards. Instrument performance is monitored through the use of checks and control charts. Analytical batch performance is measured through the use of quality control (QC) samples (blanks, spikes, tracers, laboratory control samples, and duplicates). QC results that fall outside of specified requirements may result in analytical batch or sample reruns. If a batch or sample is not rerun, the reason is documented in the data package.

Based on periodic inspections of instrument records and analytical data packages, no significant quality assurance issues or corrective actions were identified during 2005.

is performed to ensure that all the laboratories maintain technical competence and follow the required QA programs. Each evaluation includes an examination of laboratory performance with regard to sample receipt, instrument calibration, analytical procedures, data verification, data reports, records management, nonconformance and corrective actions, and preventive maintenance. Reports of the findings and recommendations are provided to each laboratory, and follow-up evaluations are conducted as necessary. No DOECAP evaluation was conducted for onsite laboratories.

Nonradiological Liquid Effluents

National Pollutant Discharge Elimination System (NPDES) samples are analyzed by three onsite laboratories groups—EML, EPM, and Site Utilities Division (SUD)—and one subcontracted laboratory. All these laboratories must be certified by SCDHEC for NPDES analyses.

Interlaboratory Program

During 2005, all laboratories performing NPDES analyses for WSRC participated in the Environmental Resource Associates (ERA) Water Pollution (WP) performance evaluation studies for compliance with the EPA-required Discharge Monitoring Report–QA Study 25. ERA, as required by EPA, is accredited by the National Institute of Standards and Technology.

SCDHEC uses the study results to certify laboratories for specific analyses. As part of the recertification process, SCDHEC requires that laboratories investigate the outside-acceptance-limit results and implement corrective actions as appropriate.

For the 2005 DMR–QA study, the subcontract laboratory, Shealy Environmental Services (SES), and the onsite laboratories, EPM and EML, participated in the WP 125 and 126 studies, while SUD participated in the WP 125 study.

In the initial WP 125 study, SES reported acceptable results for 12 of 13 NPDES parameters; EPM reported one unacceptable result for one of one parameter; EML reported acceptable results for 10 of 10 parameters; and SUD reported acceptable results for three of three parameters. Complete results can be found in the "Water Pollution Proficiency Testing Studies" table on the CD accompanying this report.

The unacceptable results reported in the WP 125 study were investigated. The initial lead concentration reported by SES was found to be "not acceptable." The most probable cause for this failure was a low bias by the instrument. The initial pH concentration reported by EPM was found to be "not acceptable." The most probable cause for this failure was analyzing the sample directly from the refrigerator without waiting for it to reach room temperature.

All results reported in the WP 126 study were acceptable. As WP 125 corrective actions, SES successfully analyzed lead, and EPM successfully analyzed pH.

During 2005, General Engineering Laboratories, Lionville Laboratory, Inc., and Severn Trent Laboratories, Inc., participated in various WP studies. The results for WP 121 through 127 (table 8–2) show that all the laboratories exceeded the 80-percent-acceptable-results level except Lionville, which reported results for WP 121 and WP 123 at 50-percent and 43-percent acceptable, respectively. In the WP 121 (four results) and WP 123 (seven results) studies, no values fell outside of the warning limits. Future WP study results from Lionville will be monitored—and follow-up corrective action initiated if necessary (table 8–2).

Intralaboratory Program

The environmental monitoring intralaboratory program reviews laboratory performance by analyzing duplicate and blind samples throughout the year.

SES and EML processed 79 duplicate analyses during 2005. Zero-difference results were reported for 48 of these analyses. Three of the 79 duplicate analyses exceeded the relative percent difference range (± 20-percent difference).

SES and EML processed 82 blind analyses during 2005. Zero-difference results were reported for 45 of these analyses. Three of the 82 blind analyses exceeded the relative percent difference range (± 20-percent difference). Results for the duplicate and blind sampling programs met expectations, with no indications of consistent problems in the laboratories.

Stream and River Water Quality

SRS's water quality program requires checks of 10 percent of the samples to verify analytical results. Duplicate grab samples from SRS streams and the Savannah River were analyzed by SES and EML in 2005.

SES and EML processed a total of 258 duplicate analyses during 2005. Zero-difference results were reported for 97 of these duplicate analyses. Thirty of 258 duplicate analyses exceeded the relative percent difference range (± 20-percent difference).

Table 8–3
Subcontract-Laboratory Performance on Mixed-Analyte Performance Evaluation Program (MAPEP)

Study	Matrix	General Engineering	Severn Trent	Eberline	SRS (EML)	Lionville
MAPEP–05–GrW13	Water	100%	100%	100%	100%	No Data
MAPEP–5–MaW13	Water	100%	94%[3,6]	94%[1]	93%[10,11]	100%
MAPEP–05–OrW13	Water	100%	84%	No Data	No Data	100%
MAPEP–05–MaS13	Solid	90%[1,4,a]	94%[2,6,7]	100%	100%	97%[2]
MAPEP–05–GrW14	Water	100%	100%	100%	100%	No Data
MAPEP–05–MaW14	Water	97%[b]	90%[2,6,7]	100%	100%	100%
MAPEP–05–OrW14	Water	100%	100%	No Data	No Data	100%
MAPEP–05–MaS14	Solid	92%[1,2,5]	92%[1,2]	94%[9]	100%	100%

[1]Results for strontium-90 were not acceptable.
[2]Results for antimony were not acceptable.
[3]Results for iron-55 were not acceptable.
[4]Results for selenium were not acceptable.
[5]Results for chromium were not acceptable.
[6]Results for nickel-63 were not acceptable.
[7]Results for uranium-238 were not acceptable.
[8]Results for uranium-233/234 were not acceptable.
[9]Results for technetium-99 were not acceptable.
[10]Results for arsenic were not acceptable.

[a]Results for chromium were acceptable with warning.
[b]Results for plutonium-238 were acceptable with warning.
[c]Results for nickel-63 were acceptable with warning.
[d]Results for plutonium-239/240 were acceptable with warning.

Many QA parameters are evaluated by automated processing of electronically reported data. Others are selectively evaluated by manual inspection of associated analytical records. A summary of findings is presented in each project narrative or validation report prepared by SGCP personnel.

Data Review

The QA program's detailed data review for groundwater and soil/sediment analyses is described in WSRC–3Q1–2, Section 1100.

In 2005, the major QA issues discovered and addressed in connection with these programs for soil/sediment and groundwater analyses included the following:

- Cyanide analysis without distillation checks at one laboratory
- Gas-flow proportional counting performed without alpha-beta cross-talk calibration at one laboratory
- False positives of total dioxins due to analyte misidentifications of furan internal standards

Previously identified items still being addressed include the following:

- Nitrate-nitrite analysis without reduction checks at one laboratory (this item inadvertently omitted from 2004 report)
- Incomplete record packages for validation
- Omissions and logic failures in electronically reported data

These findings illustrate that, although laboratory procedures are well defined, analytical data quality does benefit from technical scrutiny. A corrective action plan has been put into place to address these issues, which are expected to be resolved during 2006.

Appendix A

Applicable Guidelines, Standards, and Regulations

Jack Mayer
Environmental Services Section

THE Savannah River Site (SRS) environmental monitoring program is designed to meet state and federal regulatory requirements for radiological and nonradiological programs. These requirements are stated in U.S. Department of Energy (DOE) Order 5400.5, "Radiation Protection of the Public and the Environment"; in the Clean Air Act [Standards of Performance for New Stationary Sources, also referred to as New Source Performance Standards, and the National Emission Standards for Hazardous Air Pollutants (NESHAP)]; in the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA—also known as Superfund); in the Resource Conservation and Recovery Act (RCRA); in the Clean Water Act (i.e., National Pollutant Discharge Elimination System—NPDES); and in the National Environmental Policy Act (NEPA). Compliance with environmental requirements is assessed by DOE–Savannah River Operations Office (DOE–SR), the South Carolina Department of Health and Environmental Control (SCDHEC), and the U.S. Environmental Protection Agency (EPA).

The SRS environmental monitoring program's objectives incorporate recommendations of

- the International Commission on Radiological Protection (ICRP) in *Principles of Monitoring for the Radiation Protection of the Population*, ICRP Publication 43
- DOE Order 5400.5
- DOE/EH–0173T, "Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance"

Detailed information about the site's environmental monitoring program is documented in Section 1100 (SRS EM Program) of the *SRS Environmental Monitoring Section Plans and Procedures*, WSRC–3Q1–2, Volume 1. This document is reviewed annually and updated every 3 years.

SRS has implemented and adheres to the SRS Environmental Management System (EMS) Policy. Implementation of a formal EMS, such as that described in the International Organization for Standardization (ISO) 14001 standard, is an Executive Order 13148 ("Greening the Government Through Leadership in Environmental Management") and DOE Order 450.1 ("Environmental Protection Program") requirement. SRS maintains an EMS that fully meets the requirements of ISO 14001. The full text of the SRS EMS Policy appears in chapter 2.

Drinking water standards (DWS) can be found at http://www.epa.gov/safewater/standards.html on the Internet, and maximum allowable concentrations of toxic air pollutants can be found at http://www.scdhec.net/baq/. More information about certain media is presented in this appendix.

Air Effluent Discharges

DOE Order 5400.5 establishes Derived Concentration Guides (DCGs) for radionuclides in air. DCGs, calculated by DOE using methodologies consistent with recommendations found in ICRP publications 26 (*Recommendations of the International Commission on Radiological Protection*) and 30 (*Limits for Intakes of Radionuclides by Workers*), are used as reference concentrations for conducting environmental protection programs at DOE sites. DCGs are not considered release limits. DCGs for radionuclides in air are discussed in more detail on page 75.

Radiological airborne releases also are subject to EPA regulations cited in 40 CFR 61, "National Emission Standards for Hazardous Air Pollutants," Subpart H ("National Emission Standards for Emissions of Radionuclides Other Than Radon from Department of Energy Facilities").

Regulation of radioactive and nonradioactive air emissions—both criteria pollutants and toxic air pollutants—has been delegated to SCDHEC. Therefore, SCDHEC must ensure that its air pollution regulations are at least as stringent as federal regulations required by the Clean Air Act. This is accomplished by SCDHEC Regulation 61–62, "Air Pollution Control Regulations

Table A–2
Airborne Emission Limits for SRS Coal-Fired Boilers

Sulfur Dioxide	3.5 lb/10^6 Btu[a]
Total Suspended Particulates	0.6 b/10^6 Btu
Opacity	40%

[a] British thermal unit

As previously mentioned, some SRS sources have both SCDHEC and CFRs applicable and identified in their permits. For the package steam generating boilers in K-Area and two portable package boilers, both SCDHEC and federal regulations are applicable. The standard for sulfur dioxide emissions is specified in 40 CFR 60, Subpart Dc, "Standards of Performance for Small Industrial-Commercial-Institutional Steam Generating Units," while the standard for particulate matter is found in Regulation 61–62.5, Standard No. 1. Because these units were constructed after applicability dates found in both regulations, the opacity limit for the units is the same in both regulations. The emissions standards for these boilers are presented in table A–3.

Table A–3
Airborne Emission Limits for SRS Fuel Oil-Fired Package Boilers

Sulfur Dioxide	0.5 lb/10^6 Btu[a]
Total Suspended Particulates	0.6 b/10^6 Btu
Opacity	20%

[a] British thermal unit

(Process) Liquid Effluent Discharges

DOE Order 5400.5 establishes DCGs for radionuclides in process effluents. (DCGs for radionuclides in liquid are discussed in more detail on page 75.) DCGs were calculated by DOE using methodologies consistent with recommendations found in ICRP, 1987, and ICRP, 1979, and are used

- as reference concentrations for conducting environmental protection programs at DOE sites
- as screening values for considering best available technology for treatment of liquid effluents

DOE Order 5400.5 exempts aqueous tritium releases from best available technology requirements but not from ALARA (as low as reasonably achievable) considerations.

Three NPDES permits are in place that allow SRS to discharge water into site streams and the Savannah River: one industrial wastewater permit (SC0000175) and two stormwater runoff permits (SCR000000 for industrial discharges and SCR100000 for construction discharges).

A fourth permit (ND0072125) is a no-discharge water-pollution-control land application permit that regulates sludge generated at onsite sanitary waste treatment plants.

Detailed requirements for each permitted discharge point—including parameters sampled for, permit limits for each parameter, sampling frequency, and method for collecting each sample—can be found in the individual permits, which are available to the public through SCDHEC's Freedom of Information Office at 803–898–3882.

Drinking Water

The federal Safe Drinking Water Act—enacted in 1974 to protect public drinking water supplies—was amended in 1980, 1986, and 1996.

SRS drinking water systems are tested routinely by SRS and SCDHEC to ensure compliance with SCDHEC State Primary Drinking Water Regulations (R61–58) and EPA National Primary Drinking Water Regulations (40 CFR 141).

SRS drinking water is supplied by 17 separate systems, all of which utilize groundwater sources. The A-Area, D-Area, and K-Area systems are actively regulated by SCDHEC, while the remaining 14 site water systems receive less frequent regulatory inspections.

Under the SCDHEC-approved, ultrareduced monitoring plan, the A-Area consolidated system was sampled for lead and copper in 2004 and did not exceed the respective action levels. The A-Area system will be resampled for lead and copper in 2007. Both D-Area and K-Area were sampled in 2003 for lead and copper, and neither system exceeded the lead and copper action levels. These systems are not required to be sampled again until 2006.

The B-Area Bottled Water Facility no longer is listed by SCDHEC as a public water system, as its source water is provided by the A-Area water system. SCDHEC's Division of Food Protection will continue to conduct periodic inspections of this facility. Results from quarterly bacteriological and annual complete chemical analyses performed in 2005 met SCDHEC and FDA water quality standards.

DWS for specific radionuclides and contaminants can be found on the Internet at http://http://www.epa.gov/safewater/standards.html.

Groundwater

Groundwater is a valuable resource and is the subject of both protection and cleanup programs at SRS. More than 1,000 wells are monitored each year at the site for a wide range of constituents. Monitoring in the groundwater protection program is performed to detect new or unknown contamination across the site, and monitoring in the groundwater cleanup program is performed to meet the requirements of state and federal laws and regulations. Most of the monitoring in the cleanup program is governed by SCDHEC's administration of RCRA regulations.

The analytical results of samples taken from SRS monitoring wells are compared to various standards. The most common are final federal primary DWS—or other standards if DWS do not exist. The DWS are considered first because groundwater aquifers are defined as potential drinking water sources by the South Carolina Pollution Control Act. DWS can be found at http://www.epa.gov/safewater/mcl.html on the Internet. Other standards sometimes are applied by regulatory agencies to the SRS waste units under their jurisdiction. For example, standards under RCRA can include DWS, groundwater protection standards, background levels, or alternate concentration limits.

SRS responses to groundwater analytical results require careful evaluation of the data and relevant standards. Results from two constituents having DWS—dichloromethane and bis (2–ethylhexyl) phthalate—are evaluated more closely than other constituents and are commonly dismissed. Both are common laboratory contaminants and are reported in groundwater samples with little or no reproducibility. Both are reported, with appropriate flags and qualifiers, in detailed groundwater monitoring results that can be obtained by contacting the manager of the Washington Savannah River Company (WSRC) Environmental Permitting and Monitoring group at 803–952–6931. Also, the SCDHEC standard used for lead is 50 µg/L. The federal standard of 15 µg/L is a treatment standard for drinking water at the consumer's tap.

The regulatory standards for radionuclide discharges from industrial and governmental facilities are set under the Clean Water Act and Nuclear Regulatory Commission and DOE regulations. In addition, radionuclide cleanup levels are included in the site RCRA permit under the authority of the South Carolina Pollution Control Act. The proposed drinking water maximum contaminant levels (MCLs) discussed in this report are only an adjunct to these release restrictions and are not used to regulate SRS groundwater.

Many potential radionuclide contaminants are beta emitters. The standard used for gross beta is a screening standard; when public drinking water exceeds this standard, the supplier is expected to analyze for individual beta and gamma emitters. A gross beta result above the standard is an indication that one or more radioisotopes are present in quantities that would exceed the EPA annual dose equivalent for persons consuming 2 liters daily. Thus, for the individual beta and gamma

Comparison of Average Concentrations in Airborne Emissions to DOE Derived Concentration Guides

Average concentrations of radionuclides in airborne emissions are calculated by dividing the yearly release total of each radionuclide from each stack by the yearly stack flow quantities. These average concentrations then can be compared to the DOE DCGs, which are found in DOE Order 5400.5 for each radionuclide.

DCGs are used as reference concentrations for conducting environmental protection programs at all DOE sites. DCGs, which are based on a 100-mrem exposure, are applicable at the point of discharge (prior to dilution or dispersion) under conditions of continuous exposure (assumed to be an average inhalation rate of 8,400 cubic meters per year). This means that the DOE DCGs are based on the highly conservative assumption that a member of the public has direct access to, and continuously breathes (or is immersed in), the actual air effluent 24 hours a day, 365 days a year. However, because of the large distance between most SRS operating facilities and the site boundary, this scenario is improbable.

Average annual radionuclide concentrations in SRS air effluent can be referenced to DOE DCGs as a screening method to determine if existing effluent treatment systems are proper and effective.

Comparison of Average Concentrations in Liquid Releases to DOE Derived Concentration Guides

In addition to dose standards, DOE Order 5400.5 imposes other control considerations on liquid releases. These considerations are applicable to direct discharges but not to seepage basin and Solid Waste Disposal Facility migration discharges. The DOE order lists DCG values for most radionuclides. DCGs are used as reference concentrations for conducting environmental protection programs at all DOE sites. These DCG values are not release limits but screening values for best-available-technology investigations and for determining whether existing effluent treatment systems are proper and effective.

Per DOE Order 5400.5, exceedance of the DCGs at any discharge point may require an investigation of best-available-technology waste treatment for the liquid effluents. Tritium in liquid effluents is specifically excluded from best available technology requirements; however, it is not excluded from other ALARA considerations. DOE DCG compliance is demonstrated when the sum of the fractional DCG values for all radionuclides detectable in the effluent is less than 1.00, based on consecutive 12-month average concentrations.

DCGs, based on a 100-mrem exposure, are applicable at the point of discharge from the effluent conduit to the environment (prior to dilution or dispersion). They are based on the highly conservative assumption that a member of the public has continuous direct access to the actual liquid effluents and consumes 2 liters of the effluents every day, 365 days a year. Because of security controls and the considerable distances between most SRS operating facilities and the site boundary, this scenario is highly improbable, if not impossible.

For each SRS facility that releases radioactivity, the site's Environmental Permitting and Monitoring group compares the monthly liquid effluent concentrations and 12-month average concentrations against the DOE DCGs.

Environmental Management

SRS began its cleanup program in 1981. Two major federal statutes provide guidance for the site's environmental restoration and waste management activities—RCRA and CERCLA. RCRA addresses the management of hazardous waste and requires that permits be obtained for facilities that treat, store, or dispose of hazardous or mixed waste. It also requires that DOE facilities perform appropriate corrective action to address contaminants in the environment. CERCLA (also known as Superfund) addresses the uncontrolled release of hazardous substances and the cleanup of inactive waste sites. This act establishes a National Priority List of sites targeted for assessment and, if necessary, corrective/remedial action. SRS was placed on this list December 21, 1989 [Fact Sheet, 2000]. In August 1993, SRS entered into the Federal Facility Agreement (FFA) with EPA Region IV and SCDHEC. This agreement governs the corrective/remedial action process from site investigation through site remediation. It also describes procedures for setting annual work

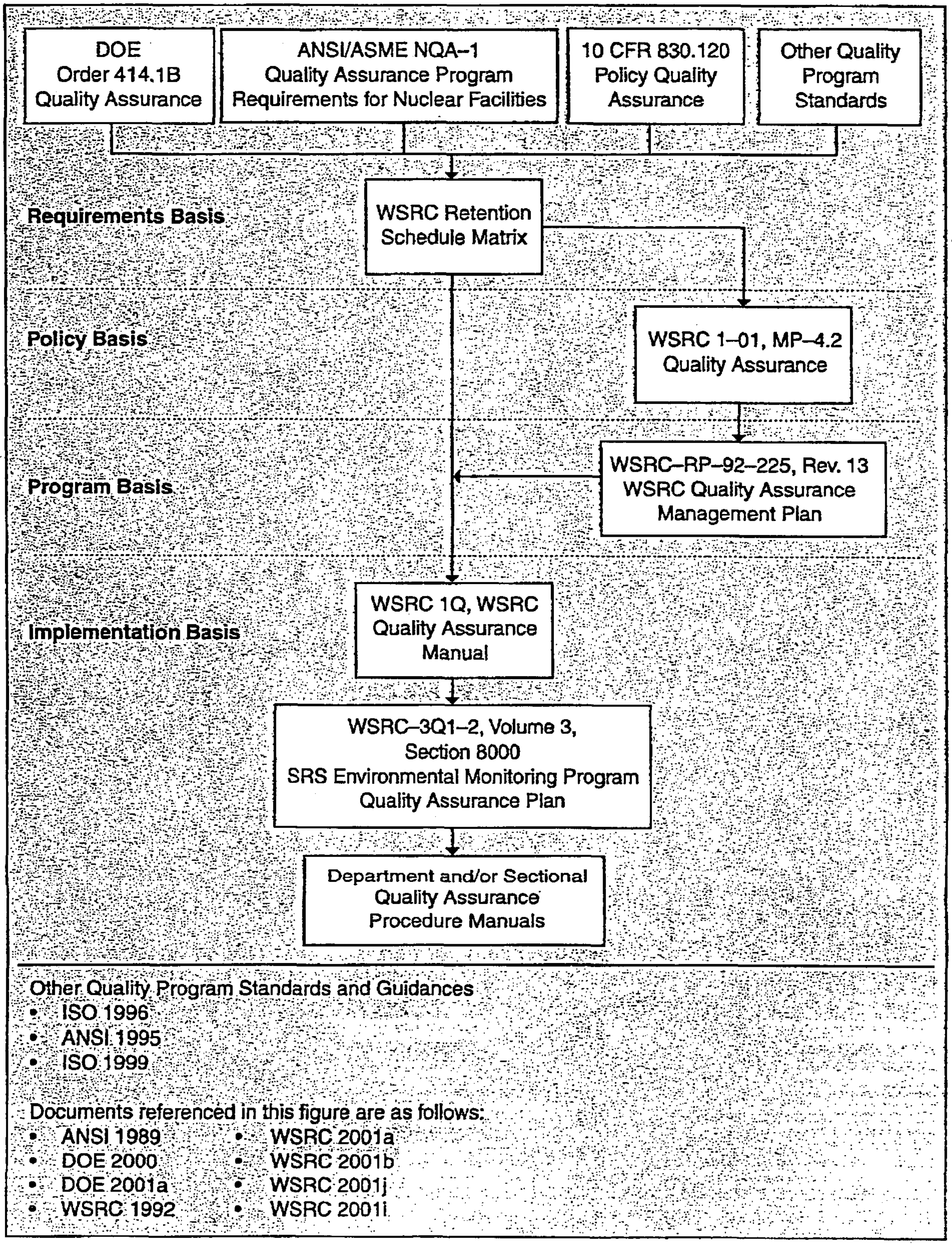

Figure A–1 SRS EM Program QA Document Hierarchy

This diagram depicts the hierarchy of relevant guidance and supporting documents for the QA program.

Radionuclide and Chemical Nomenclature

Nomenclature and Half-Life for Radionuclides

Radionuclide	Symbol	Half-life[a,b]	Radionuclide	Symbol	Half-life[a,b]
Actinium-228	Ac-228	6.15 h	Mercury-203	Hg-203	46.61 d
Americium-241	Am-241	432.7 y	Neptunium-237	Np-237	2.14E6 y
Americium-243	Am-243	7370 y	Neptunium-239	Np-239	2.355 d
Antimony-124	Sb-124	60.2 d	Nickel-59	Ni-59	7.6E4 y
Antimony-125	Sb-125	2.758 y	Nickel-63	Ni-63	100 y
Argon-39	Ar-39	269 y	Niobium-94	Nb-94	2.0E4 y
Barium-133	Ba-133	10.7 y	Niobium-95	Nb-95	34.97 d
Beryllium-7	Be-7	53.28 d	Plutonium-238	Pu-238	87.7 y
Bismuth-212	Bi-212	2.14 m	Plutonium-239	Pu-239	2.41E4 y
Bismuth-214	Bi-214	19.9 m	Plutonium-240	Pu-240	6560 y
Carbon-14	C-14	5714 y	Plutonium-241	Pu-241	14.4 y
Cerium-141	Ce-141	32.5 d	Plutonium-242	Pu-242	3.75E5 y
Cerium-144	Ce-144	284.6 d	Potassium-40	K-40	1.27E9 y
Cesium-134	Cs-134	2.065 y	Praseodymium-144	Pr-144	17.28 m
Cesium-137	Cs-137	30.07 y	Praseodymium-144m	Pr-144m	7.2 m
Chromium-51	Cr-51	27.702 d	Promethium-147	Pm-147	2.6234 y
Cobalt-57	Co-57	271.8 d	Protactinium-231	Pa-231	3.28E4 y
Cobalt-58	Co-58	70.88 d	Protactinium-233	Pa-233	27.0 d
Cobalt-60	Co-60	5.271 y	Protactinium-234	Pa-234	6.69 h
Curium-242	Cm-242	162.8 d	Radium-226	Ra-226	1599 y
Curium-244	Cm-244	18.1 y	Radium-228	Ra-228	5.76 y
Curium-245	Cm-245	8.50E3 y	Ruthenium-103	Ru-103	39.27 d
Curium-246	Cm-246	4.76E3 y	Ruthenium-106	Ru-106	1.020 y
Europium-152	Eu-152	13.54 y	Selenium-75	Se-75	119.78 d
Europium-154	Eu-154	8.593 y	Selenium-79	Se-79	6.5E5 y
Europium-155	Eu-155	4.75 y	Sodium-22	Na-22	2.604 y
Iodine-129	I-129	1.57E7 y	Strontium-89	Sr-89	50.52 d
Iodine-131	I-131	8.0207 d	Strontium-90	Sr-90	28.78 y
Iodine-133	I-133	20.3 h	Technetium-99	Tc-99	2.13E5 y
Krypton-85	Kr-85	10.76 y	Thallium-208	Tl-208	3.053 m
Lead-212	Pb-212	10.64 h	Thorium-228	Th-228	1.913 y
Lead-214	Pb-214	27 m	Thorium-230	Th-230	7.54E4 y
Manganese-54	Mn-54	312.1 d	Thorium-232	Th-232	1.40E10 y

[a] m = minute; h = hour; d = day; y = year
[b] Reference: Chart of the Nuclides, 15th edition, revised 1996, General Electric Company

Nomenclature for Elements and Chemical Constituent Analyses

Note: Some of the symbols listed in this table came from various databases used to format the data tables in this report and are included here to assist the reader in understanding the tables.

Constituent	Symbol	Constituent	Symbol
Aluminum	Al (or AL)	Nitrite, Nitrate	NO_2,NO_3 (or NO_2,
Ammonia	NH_3		NO_3, or NO_2/NO_3)
Ammonia as Nitrogen	NH_3-N (or AN)	pH	pH (or PH)
Antimony	Sb (or SB)	Phenol	PHE
Arsenic	As (or AS)	Phosphorus	P
Barium	Ba (or BA)	Phosphate	PO_4 (or PO_4-P or
Biological Oxygen Demand	BOD		PO_4-P)
Beryllium	Be	Polychlorinated Biphenyl	PCB
Boron	B	Potassium	K
Bromide	B-	Selenium	Se (or SE)
Cadmium	Cd (or CD)	Silver	Ag (or AG)
Chemical Oxygen Demand	COD	Sulfate	SO_4 (or SO_4)
Chlorine	Cl (or CHL)	Tetrachloroethene	PERCL
Chromium	Cr (or CR)	Tetrachloroethylene	
Cobalt	Co	(Perchloroethylene)	PERCL
Copper	Cu (or CU)	Trichloroethene	TRICL
Cyanide	CN	Trichloroethylene	TRICL
Dissolved Oxygen	DO	Tin	SN
Iron	Fe (or FE)	Total Dissolved Solids	TDS
Lead	Pb (or PB)	Total Kjeldahl Nitrogen	TKN
Magnesium	Mg (or MG)	Total Organic Carbon	TOC
Manganese	Mn (or MN)	Total Suspended Particulate	
Mercury	Hg (or HG)	Matter	TSP
Molybdenum	Mo	Total Suspended Solids	TSS
Nickel	Ni (or NI)	Total Volatile Solids	TVS
Nitrate	NO_3	Uranium	U
Nitrate as Nitrogen	NO_3-N	Vinyl Chloride	VC
Nitrite as Nitrogen	NO_2-N	Zinc	Zn (or ZN)

Appendix C

Errata

From 2004 Report

The following information was reported incorrectly in the *Savannah River Site Environmental Report for 2004* (WSRC–TR–2005–00005):

• **Page 29, right column, third bullet:** The increase in the measured migration of tritium into Four Mile Creek —from 206 Ci in 2003 to 211 Ci in 2004—should have been reported at 2.4 percent, rather than 5 percent.

• **Page 33, right column, lines one and two:** The average field cesium-137 concentration should have been reported as 5.3 pCi/g in deer and 3.1 pCi/g in hogs.

Glossary

A

accuracy - Closeness of the result of a measurement to the true value of the quantity.

actinide - Group of elements of atomic number 89 through 103. Laboratory analysis of actinides by alpha spectrometry generally refers to the elements plutonium, americium, uranium, and curium but may also include neptunium and thorium.

activity - See radioactivity.

air flow - Rate of flow, measured by mass or volume per unit of time.

air stripping - Process used to decontaminate groundwater by pumping the water to the surface, "stripping" or evaporating the chemicals in a specially designed tower, and pumping the cleansed water back to the environment.

aliquot - Quantity of sample being used for analysis.

alkalinity - Alkalinity is a measure of the buffering capacity of water, and since pH has a direct effect on organisms as well as an indirect effect on the toxicity of certain other pollutants in the water, the buffering capacity is important to water quality.

alpha particle - Positively charged particle emitted from the nucleus of an atom having the same charge and mass as that of a helium nucleus (two protons and two neutrons).

ambient air - Surrounding atmosphere as it exists around people, plants, and structures.

analyte - Constituent or parameter that is being analyzed.

analytical detection limit - Lowest reasonably accurate concentration of an analyte that can be detected; this value varies depending on the method, instrument, and dilution used.

aquifer - Saturated, permeable geologic unit that can transmit significant quantities of water under ordinary hydraulic gradients.

aquitard - Geologic unit that inhibits the flow of water.

Atomic Energy Commission - Federal agency created in 1946 to manage the development, use, and control of nuclear energy for military and civilian application. It was abolished by the Energy Reorganization Act of 1974 and succeeded by the Energy Research and Development Administration. Functions of the Energy Research and Development Administration eventually were taken over by the U.S. Department of Energy and the U.S. Nuclear Regulatory Commission.

B

background radiation - Naturally occurring radiation, fallout, and cosmic radiation. Generally, the lowest level of radiation obtainable within the scope of an analytical measurement, i.e., a blank sample.

bailer - Container lowered into a well to remove water. The bailer is allowed to fill with water and then is removed from the well.

best management practices - Sound engineering practices that are not required by regulation or by law.

beta particle - Negatively charged particle emitted from the nucleus of an atom. It has a mass and charge equal to those of an electron.

blank - Control sample that is identical, in principle, to the sample of interest, except that the substance being analyzed is absent. In such cases, the measured value or signal for the substance being analyzed is believed to be due to artifacts. Under certain circumstances, that value may be subtracted from the measured value to give a net result reflecting the amount of the substance in the sample. The U.S. Environmental Protection Agency does not permit the subtraction of blank results in Environmental Protection Agency-regulated analyses.

blind blank - Sample container of deionized water sent to a laboratory under an alias name as a quality control check.

blind replicate - In the Environmental Services Section groundwater monitoring program, a second sample taken from the same well at the same time as the primary sample, assigned an alias well name, and sent to a laboratory for analysis (as an unknown to the analyst).

blind sample - Control sample of known concentration in which the expected values of the constituent are unknown to the analyst.

decay time - Time taken by a quantity to decay to a stated fraction of its initial value.

deactivation - The process of placing a facility in a stable and known condition, including the removal of hazardous and radioactive materials to ensure adequate protection of the worker, public health and safety, and the environment—thereby limiting the long-term cost of surveillance and maintenance.

decommissioning - Process that takes place after deactivation and includes surveillance and maintenance, decontamination, and/or dismantlement.

decontamination - The removal or reduction of residual radioactive and hazardous materials by mechanical, chemical, or other techniques to achieve a stated objective or end condition.

decommissioning and demolition - Program that reduces the environmental and safety risks of surplus facilities at SRS.

derived concentration guide - Concentration of a radionuclide in air or water that, under conditions of continuous exposure for one year by one exposure mode (i.e., ingestion of water, submersion in air, or inhalation), would result in either an effective dose equivalent of 0.1 rem (1 mSv) or a dose equivalent of 5 rem (50 mSv) to any tissue, including skin and lens of the eye. The guides for radionuclides in air and water are given in U.S. Department of Energy Order 5400.5.

detection limit - See analytical detection limit, lower limit of detection, minimum detectable concentration.

detector - Material or device (instrument) that is sensitive to radiation and can produce a signal suitable for measurement or analysis.

diatometer - Diatom collection equipment consisting of a series of microscope slides in a holder that is used to determine the amount of algae in a water system.

diatoms - Unicellular or colonial algae of the class Bacillariophyceae, having siliceous cell walls with two overlapping, symmetrical parts. Diatoms represent the predominant periphyton (attached algae) in most water bodies and have been shown to be reliable indicators of water quality.

disposal - Permanent or temporary transfer of U.S. Department of Energy control and custody of real property to a third party, which thereby acquires rights to control, use, or relinquish the property.

disposition - Those activities that follow completion of program mission—including, but not limited to, surveillance and maintenance, deactivation, and decommissioning.

dissolved oxygen - Desirable indicator of satisfactory water quality in terms of low residuals of biologically available organic materials. Dissolved oxygen prevents the chemical reduction and subsequent leaching of iron and manganese from sediments.

dose - Energy imparted to matter by ionizing radiation. The unit of absorbed dose is the rad, equal to 0.01 joules per kilogram in any medium.

absorbed dose - Quantity of radiation energy absorbed by an organ, divided by the organ's mass. Absorbed dose is expressed in units of rad (or gray) (1 rad = 0.01Gy).

dose equivalent - Product of the absorbed dose (rad) in tissue and a quality factor. Dose equivalent is expressed in units of rem (or sievert) (1 rem = 0.01 sievert).

committed dose equivalent - Calculated total dose equivalent to a tissue or organ over a 50-year period after known intake of a radionuclide into the body. Contributions from external dose are not included. Committed dose equivalent is expressed in units of rem (or sievert).

committed effective dose equivalent - Sum of the committed dose equivalents to various tissues in the body, each multiplied by the appropriate weighting factor. Committed effective dose equivalent is expressed in units of rem (or sievert).

effective dose equivalent - Sum of the dose equivalents received by all organs or tissues of the body after each one has been multiplied by an appropriate weighting factor. The effective dose equivalent includes the committed effective dose equivalent from internal deposition of radionuclides and the effective dose equivalent attributable to sources external to the body.

collective dose equivalent/collective effective dose equivalent - Sums of the dose equivalents or effective dose equivalents of all individuals in an exposed population within a 50-mile (80-km) radius, and expressed in units of person-rem (or person-sievert). When the collective dose equivalent of interest is for a specific organ, the units would be organ-rem (or organ-sievert). The 50-mile distance is measured from a point located centrally with respect to major facilities or U.S. Department of Energy program activities.

H

half-life (radiological) - Time required for half of a given number of atoms of a specific radionuclide to decay. Each nuclide has a unique half-life.

heavy water - Water in which the molecules contain oxygen and deuterium, an isotope of hydrogen that is heavier than ordinary hydrogen.

hydraulic gradient - Difference in hydraulic head over a specified distance.

hydrology - Science that treats the occurrence, circulation, distribution, and properties of the waters of the earth, and their reaction with the environment.

I

in situ - In its original place. Field measurements taken without removing the sample from its origin; remediation performed while groundwater remains below the surface.

inorganic - Involving matter other than plant or animal.

instrument background - Instrument signal due to electrical noise and other interferences not attributed to the sample or blank.

ion exchange - Process in which a solution containing soluble ions is passed over a solid ion exchange column that removes the soluble ions by exchanging them with labile ions from the surface of the column. The process is reversible so that the trapped ions are removed (eluted) from the column and the column is regenerated.

irradiation - Exposure to radiation.

isotopes - Forms of an element having the same number of protons in their nuclei but differing in the number of neutrons.

> **long-lived isotope** - Radionuclide that decays at such a slow rate that a quantity of it will exist for an extended period (half-life is greater than three years).
>
> **short-lived isotope** - Radionuclide that decays so rapidly that a given quantity is transformed almost completely into decay products within a short period (half-life is two days or less).

L

laboratory blank - Deionized water sample generated by the laboratory; a laboratory blank is analyzed with each batch of samples as an in-house check of analytical procedures. Also called an internal blank.

legacy - Anything handed down from the past; inheritance, as of nuclear waste.

lower limit of detection - Smallest concentration/ amount of an analyte that can be reliably detected in a sample at a 95-percent confidence level.

M

macroinvertebrates - Size-based classification used for a variety of insects and other small invertebrates; as defined by the U.S. Environmental Protection Agency, those organisms that are retained by a No. 30 (590-micron) U.S. Standard Sieve.

macrophyte - A plant that can be observed with the naked eye.

manmade radiation - Radiation from sources such as consumer products, medical procedures, and nuclear industry.

maximally exposed individual - Hypothetical individual who remains in an uncontrolled area and would, when all potential routes of exposure from a facility's operations are considered, receive the greatest possible dose equivalent.

mean relative difference - Percentage error based on statistical analysis.

mercury - Silver-white, liquid metal solidifying at -38.9°C to form a tin-white, ductile, malleable mass. It is widely distributed in the environment and biologically is a nonessential or nonbeneficial element. Human poisoning due to this highly toxic element has been clinically recognized.

migration - Transfer or movement of a material through the air, soil, or groundwater.

minimum detectable concentration - Smallest amount or concentration of a radionuclide that can be distinguished in a sample by a given measurement system at a preselected counting time and at a given confidence level.

moderate - To reduce the excessiveness of; to act as a moderator.

moderator - Material, such as heavy water, used in a nuclear reactor to moderate or slow down neutrons from the high velocities at which they are created in the fission process.

reforestation - Process of planting new trees on land once forested.

regulatory compliance - Actions taken in accordance with government laws, regulations, orders, etc., that apply to Savannah River Site operations' effects on onsite and offsite natural resources and on human health; used interchangeably in this document with environmental compliance.

release - Any discharge to the environment. Environment is broadly defined as any water, land, or ambient air.

rem - Unit of dose equivalent (absorbed dose in rads x the radiation quality factor). Dose equivalent frequently is reported in units of millirem (mrem) which is one-thousandth of a rem.

remediation - Assessment and cleanup of U.S. Department of Energy sites contaminated with waste as a result of past activities. See environmental restoration.

remediation design - Planning aspects of remediation, such as engineering characterization, sampling studies, data compilation, and determining a path forward for a waste site.

replicate - In the Environmental Services Section groundwater monitoring program, a second sample from the same well taken at the same time as the primary sample and sent to the same laboratory for analysis.

Resource Conservation and Recovery Act (RCRA) - Federal legislation that regulates the transport, treatment, and disposal of solid and hazardous wastes. This act also requires corrective action for releases of hazardous waste at inactive waste units.

Resource Conservation and Recovery Act (RCRA) site - Solid waste management unit under Resource Conservation and Recovery Act regulation. See Resource Conservation and Recovery Act.

retention basin - Unlined basin used for emergency, temporary storage of potentially contaminated cooling water from chemical separations activities.

RFI/RI Program - RCRA Facility Investigation/ Remedial Investigation Program. At the Savannah River Site, the expansion of the RFI Program to include Comprehensive Environmental Response, Compensation, and Liability Act and hazardous substance regulations.

routine radioactive release - Planned or scheduled release of radioactivity to the environment.

S

seepage basin - Excavation that receives wastewater. Insoluble materials settle out on the floor of the basin and soluble materials seep with the water through the soil column, where they are removed partially by ion exchange with the soil. Construction may include dikes to prevent overflow or surface runoff.

sensitivity - Capability of methodology or instruments to discriminate between samples with differing concentrations or containing varying amounts of analyte.

settling basin - Temporary holding basin (excavation) that receives wastewater that subsequently is discharged.

site stream - Any natural stream on the Savannah River Site. Surface drainage of the site is via these streams to the Savannah River.

source - Point or object from which radiation or contamination emanates.

source check - Radioactive source (with a known amount of radioactivity) used to check the performance of the radiation detector instrument.

source term - Quantity of radioactivity (released in a set period of time) that is traceable to the starting point of an effluent stream or migration pathway.

spent nuclear fuel - Used fuel elements from reactors.

spike - Addition, to a blank sample, of a known amount of reference material containing the analyte of interest.

stable - Not radioactive or not easily decomposed or otherwise modified chemically.

stack - Vertical pipe or flue designed to exhaust airborne gases and suspended particulate matter.

standard deviation - Indication of the dispersion of a set of results around their average.

stormwater runoff - Surface streams that appear after precipitation.

Superfund - See Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

supernate - Portion of a liquid above settled materials in a tank or other vessel.

surface water - All water on the surface of the earth, as distinguished from groundwater.

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Units of Measure	
Symbol	**Name**
Temperature	
°C	degrees Centigrade
°F	degrees Fahrenheit
Time	
d	day
h	hour
y	year
Length	
cm	centimeter
ft	foot
in	inch
km	kilometer
m	meter
mm	millimeter
μm	micrometer
Mass	
g	gram
kg	kilogram
mg	milligram
μg	microgram
Area	
mi^2	square mile
ft^2	square foot
Volume	
gal	gallon
L	liter
mL	milliliter

Units of Measure	
Symbol	**Name**
Concentration	
ppb	parts per billion
ppm	parts per million
Rate	
cfs	cubic feet per second
gpm	gallons per minute
Conductivity	
μmho	micromho
Radioactivity	
Ci	curie
cpm	counts per minute
mCi	millicurie
μCi	microcurie
pCi	picocurie
Bq	becquerel
Radiation Dose	
mrad	millirad
mrem	millirem
Sv	sievert
mSv	millisievert
μSv	microsievert
R	roentgen
mR	milliroentgen
μR	microroentgen
Gy	gray

Notes

Section 9.4 References

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USER'S MANUAL FOR CORMIX: A HYDRODYNAMIC MIXING ZONE MODEL AND DECISION SUPPORT SYSTEM FOR POLLUTANT DISCHARGES INTO SURFACE WATERS

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Abstract

The Cornell Mixing Zone Expert System (CORMIX, Version 3.0 or higher) is a software system for the analysis, prediction, and design of aqueous toxic or conventional pollutant discharges into diverse water bodies. The major emphasis is on the geometry and dilution characteristics of the initial mixing zone – including compliance with regulatory constraints–, but the system also predicts the behavior of the discharge plume at larger distances. The highly user-interactive CORMIX system is implemented on microcomputers (IBM-PC, or compatible), and consists of three integrated subsystems:

—CORMIX1 for submerged single port discharges,
—CORMIX2 for submerged multiport diffuser discharges,
—CORMIX3 for buoyant surface discharges.

While CORMIX was originally developed under the assumption of steady ambient conditions, Version 3.0 also allows application to highly unsteady environments, such as tidal reversal conditions, in which transient recirculation and pollutant build-up effects can occur.

In addition, two post-processing models are linked to the CORMIX system, but can also be used independently. These are CORJET (the Cornell Buoyant Jet Integral Model) for the detailed analysis of the near-field behavior of buoyant jets, and FFLOCATR (the Far-Field Plume Locator) for the far-field delineation of discharge plumes in non-uniform river or estuary environments.

This user's manual gives a comprehensive description of the CORMIX system; it provides guidance for assembly and preparation of required input data for the three subsystems; it delineates ranges of applicability; it provides guidance for interpretation and graphical display of system output; and it illustrates practical system application through several case studies.

Acknowledgments

An earlier version of this user's manual covering the three separate CORMIX subsystems (Version 1.0) before they were integrated into a comprehensive single system was developed under support form the National Council of the Paper Industry for Air and Stream Improvement Inc. (NCASI) and was published as Technical Bulletin No. 624 of NCASI (Jirka and Hinton, 1992). With the permission of NCASI, that user's guide has up until recently also been distributed by the USEPA-Center for Environmental Assessment Modeling (CEAM), Athens, GA, as part of the modeling support for CORMIX.

With the completion of CORMIX Version 3.0 and its many new program features, the present revision and update of the user's manual has become necessary. This work was conducted at the DeFrees Hydraulics Laboratory, Cornell University, as a Cooperative Agreement with the United States Environmental Protection Agency. The authors would like to extend their appreciation to Dr. Hiranmay Biswas, Project Officer, for his guidance of the project.

Additional support for the development, testing and evaluation of CORMIX system elements was provided by the State of Delaware Department of Natural Resources (Mr. Rick Greene, Project Officer) during 1991, by the Austrian Verbundgesellschaft (Dr. Gerhard Schiller, Project Officer) during 1991/92, and by the State of Maryland Department of Natural Resources (Dr. Paul Miller, Project Officer) during 1992 to 1995.

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Table of Contents

Glossary

Actual Water Depth (HD) - the actual water depth at the submerged discharge location. It is also called local water depth. For surface discharges it is the water depth at the channel entry location.

Alignment Angle (GAMMA) - the angle measured counterclockwise from the ambient current direction to the diffuser axis.

Allocated Impact Zone - see mixing zone.

Alternating Diffuser - a multi-port diffuser where the ports do not point in a nearly single horizontal direction.

Ambient Conditions - the geometric and dynamic characteristics of a receiving water body that impact mixing zone processes. These include plan shape, vertical cross sections, bathymetry, ambient velocity, and density distribution.

Ambient Currents - A velocity field within the receiving water which tends to deflect a buoyant jet into the current direction.

Ambient Discharge (QA) - the volumetric flow rate of the receiving water body.

Average Diameter (D0) - the average diameter of the discharge ports or nozzles for a multi-port diffuser.

Average Depth (HA) - the average depth of the receiving water body determined from the equivalent cross sectional area during schematization.

Bottom Slope (SLOPE) - the slope of the bottom that extends from a surface discharge into the receiving water body.

Buoyant Jet - a discharge where turbulent mixing is caused by a combination of initial momentum flux and buoyancy flux. It is also called a forced plume.

Buoyant Spreading Processes - far-field mixing processes which arise due to the buoyant forces caused by the density difference between the mixed flow and the ambient receiving water.

Buoyant Surface Discharge - the release of a positively or neutrally buoyant effluent into a receiving water through a canal, channel, or near-surface pipe.

Coanda Attachment - a dynamic interaction between the effluent plume and the water bottom that results from the entrainment demand of the effluent jet itself and is due to low pressure effects.

Cumulative Discharge - refers to the volumetric flow rate which occurs between the bank/shoreline and a given position within the water body.

Cumulative Discharge Method - an approach for representing transverse plume mixing in river or estuary flow by describing the plume centerline as being fixed on a line of constant cumulative discharge and by relating the plume width in terms of a cumulative discharge increment

Darcy-Weisbach Friction Factor - a measure of the roughness characteristics in a channel.

Deep Conditions - see near-field stability.

Density Stratification - the presence of a vertical density profile within the receiving water.

Diffuser Length (LD) - The distance between the first and last port of a multi-port diffuser line. See diffuser line.

Diffuser Line - a hypothetical line between the first and last ports of a multi-port diffuser.

Discharge Velocity (U0) - the average velocity of the effluent being discharged from the outfall structure.

Discharge from Shore (DISTB) - the average distance between the outfall location (or diffuser mid-point) and the shoreline. It is also specified as a cumulative ambient discharge divided by the product UA times HA.

Distance from Shore (YB1, YB2) - the distance from the shore line to the first and last ports of a multi-port diffuser.

Discharge Flow Rate (Q0) - the volumetric flow rate from the discharge structure.

Discharge Channel Width (B0) - the average width of a surface discharging channel.

Discharge Channel Depth (H0) - the average depth of a surface discharging channel.

Discharge Conditions - the geometric and flux characteristics of an outfall installation that effect mixing processes. These include port area, elevation above the bottom and orientation, effluent discharge flow rate, momentum flux, and buoyancy flux.

Far-field - the region of the receiving water where buoyant spreading motions and passive diffusion control the trajectory and dilution of the effluent discharge plume.

Far-field Processes - physical mixing mechanisms that are dominated by the ambient receiving water conditions, particularly ambient current velocity and density differences between the mixed flow and the ambient receiving water.

FAST-CORMIX - a version of CORMIX data entry with short questions and without help sections; can be chosen in main menu; for advanced users.

Flow Classification - the process of identifying the most appropriate generic qualitative description of the discharge flow undergoing analysis. This is accomplished by examining known relationships between flow patterns and certain calculated physical parameters.

Flux Characteristics - the properties of effluent discharge flow rate, momentum flux and buoyancy flux for the effluent discharge.

Forced Plume - see buoyant jet.

Generic Flow Class - a qualitative description of a discharge flow situation that is based on known relationships between flow patterns and certain physical parameters.

Height of Port (H0) - the average distance between the bottom and the average nozzle centerline.

High Water Slack (HWS) - the time of tidal reversal nearest to MHW

Horizontal Angle (SIGMA) - the angle measured counterclockwise from the ambient current direction to the plane projection of the port center line.

Hydrodynamic Mixing Processes - the physical processes that determine the fate and distribution of effluent once it is discharged.

Input Data Sequence - a group of questions from one of four topical areas.

Intermediate-field Affects - induced flows in shallow waters which extend beyond the strictly near-field region of a multi-port diffuser.

Iteration Menu - the last menu (red panel) the user can choose after completion of a design case; allows iteration with different ambient/discharge/regulatory conditions.

Jet - see pure jet.

Laterally Bounded - refers to a water body which is constrained on both sides by banks such as rivers, streams, estuaries and other narrow water courses.

Laterally Unbounded - a water body which for practical purposes is constrained on at most one side. This would include discharges into wide lakes, wide estuaries and coastal areas.

Legal Mixing Zone (LMZ) - see regulatory mixing zone.

Length Scale - a dynamic measure of the relative influence of certain hydrodynamic processes on effluent mixing.

Length Scale Analysis - an approach which uses calculated measures of the relative influence of certain hydrodynamic processes to identify key aspects of a discharge flow so that a generic flow class can be identified.

Local Water Depth (HD) - see actual water depth.

Low Water Slack (LWS) - the time of tidal reversal nearest to MLW

Main Menu - the first menu (red panel) the user can choose from when entering CORMIX.

Manning's n - a measure of the roughness characteristics in a channel.

Maximum Tidal Velocity (Uamax) - the maximum velocity occurring within the tidal cycle

Mean Ambient Velocity (UA) - the average velocity of the receiving water body's flow.

Mean High Water (MLW) - the highest water level (averaged over many tidal cycles) in estuarine or coastal flows.

Mean Low Water (MLW) - the lowest water level (averaged over many tidal cycles) in estuarine or coastal flows.

Merging - the physical interaction of the discharge plumes from adjacent ports of a multi-port diffuser.

Mixing Zone - an administrative construct which defines a limited area or volume of the receiving water where the initial dilution of a discharge is allowed to occur. In practice, it may occur within the near-field or far-field of a hydrodynamic mixing process and therefore depends on source, ambient, and regulatory constraints.

Mixing Zone Regulations - The administrative construct that intends to prevent any harmful impact of a discharged effluent on the aquatic environment and its designated uses.

Momentum Jet - see pure jet.

Multi-port Diffuser - a structure with many closely spaced ports or nozzles that inject more than one buoyant jet into the ambient receiving water body.

Near-field - the region of a receiving water where the initial jet characteristic of momentum flux, buoyancy flux and outfall geometry influence the jet trajectory and mixing of an effluent discharge.

Near-Field Region (NFR) - a term used in the CORMIX printout for describing the zone of strong initial mixing where the so called near-field processes occur. It is the region of the receiving water where outfall design conditions are most likely to have an impact on in-stream concentrations.

Near-field Stability - the amount of local recirculation and re-entrainment of already mixed water back into the buoyant jet region. Stable discharge conditions are associated with weak momentum and deep water and are also sometimes called deep water conditions. Unstable discharge conditions have localized recirculation patterns and are also called shallow water conditions.

Negative Buoyancy - the measure of the tendency of an effluent discharge to sink in a receiving water.

Non-buoyant Jet - see pure jet.

Open Format - data input which does not require precise placement of numerical values in fixed fields and which allows character strings to be entered in either upper or lower case letters.

Passive Ambient Diffusion Processes - far-field mixing processes which arise due to existing turbulence in the ambient receiving water flow.

Plume - see buoyant jet.

Positive Buoyancy - the measure of the tendency of an effluent discharge to rise in the receiving water.

Post-Processor - several options available within CORMIX (main menu or iteration menu) for additional computation or data display, including a graphics package, a near-field buoyant jet model, and a far-field plume delineator.

Pure Jet - a discharge where only the initial momentum flux in the form of a high velocity injection causes turbulent mixing. It is also called momentum jet or non-buoyant jet.

Pure Plume - a discharge where only the initial buoyancy flux leads to local vertical accelerations which then lead to turbulent mixing.

Pycnocline - a horizontal layer in the receiving water where a rapid density change occurs.

Pycnocline Height (HINT) - the average distance between the bottom and a horizontal layer in the receiving water body where a rapid density change occurs.

Region Of Interest (ROI) - a user defined region of the receiving water body where mixing conditions are to be analyzed.

Regulatory Mixing Zone (RMZ) - the region of the receiving water where mixing zone regulations are applied. It is sometimes referred to as the legal mixing zone.

Relative Orientation Angle (BETA) - the angle measured either clockwise or counterclockwise from the average plan projection of the port centerline to the nearest diffuser axis.

Schematization - the process of describing a receiving water body's actual geometry with a rectangular cross section.

Shallow Water Conditions - see near-field stability.

Stable Discharge - see near-field stability.

Staged Diffuser - a multi-port diffuser where all ports point in one direction, generally following the diffuser line.

Stagnant Conditions - the absence of ambient receiving water flow. A condition which rarely occurs in actual receiving water bodies.

Submerged Multi-port Diffuser - an effluent discharge structure with more than one efflux opening that is located substantially below the receiving water surface.

Submerged Single Port Discharge - an effluent discharge structure with a single efflux opening that is located substantially below the receiving water surface.

Surface Buoyant Jets - positively or neutrally buoyant effluent discharges occurring horizontally at the water surface from a latterly entering channel or pipe.

Surface Width (BS) - the equivalent average surface width of the receiving water body determined from the equivalent rectangular cross sectional area during schematization.

Tidal cycle - the variation of ambient water depth and velocity as a function of time occurring due to tidal (lunar and solar) influences.

Tidal period (PERIOD) - the duration of the tidal cycle (on average 12.4 hours).

Tidal reversal - the two instances in the tidal cycle when the ambient velocity reverses its direction.

Toxic Dilution Zone (TDZ) - the region of the receiving water where the concentration of a toxic chemical may exceed the acute effects concentration.

Unidirectional Diffuser - a multi-port diffuser with all ports pointing to one side of the diffuser line and all ports oriented more or less normally to the diffuser line.

Unstable Discharge - see near-field stability.

Vertical Angle (THETA) - the angle between the port centerline and the horizontal plane.

Wake Attachment - a dynamic interaction of the effluent plume with the bottom that is forced by the receiving water crossflow.

Zone of Initial Dilution - a term sometimes used to describe the mixing zone for the discharge of municipal wastewater into the coastal ocean, limited to the extent of near-field mixing processes.

Metric Conversion Factors for Dimensions Used in CORMIX

Length:	1 m	= 3.281 ft = 39.37 in = 0.0006214 mile
Velocity:	1 m/s	= 3.281 ft/s (fps) = 2.237 miles/hr (mph) = 1.943 knots
Discharge:	1 m^3/s	= 35.31 ft^3/s (cfs) = 22.82 million-gal/day (mgd)
Density:	1000 kg/m^3	= 62.43 lb/ft^3
Temperature:	°C	= (°F - 32.0) * 0.5556

I Introduction

The Cornell Mixing Zone Expert System (CORMIX) is a software system for the analysis, prediction, and design of aqueous toxic or conventional pollutant discharges into diverse water bodies. It was developed under several cooperative funding agreements between U.S. EPA and Cornell University during the period 1985-1995. It is a recommended analysis tool in key guidance documents (1,2,3) on the permitting of industrial, municipal, thermal, and other point source discharges to receiving waters. Although the system's major emphasis is on predicting the geometry and dilution characteristics of the initial mixing zone so that compliance with water quality regulatory constraints may be judged, the system also predicts the behavior of the discharge plume at larger distances.

The highly user-interactive CORMIX system is implemented on IBM-DOS compatible microcomputers, utilizes a rule-based systems approach to data input and processing, and consists of three subsystems. These are: (a) CORMIX1 for the analysis of submerged single port discharges, (b) CORMIX2 for the analysis of submerged multiport diffuser discharges and (c) CORMIX3 for the analysis of buoyant surface discharges. Without specialized training in hydrodynamics, users can make detailed predictions of mixing zone conditions, check compliance with regulations and readily investigate the performance of alternative outfall designs. The basic CORMIX methodology relies on the assumption of steady ambient conditions. However, recent versions also contain special routines for the application to highly unsteady environments, such as tidal reversal conditions, in which transient recirculation and pollutant build-up effects can occur.

In addition, several post-processing options are available. These are CORJET (the Cornell Buoyant Jet Integral Model) for the detailed analysis of the near-field behavior of buoyant jets, FFLOCATR (the Far-Field Plume Locator) for the far-field delineation of discharge plumes in non-uniform river or estuary environments, and CMXGRAPH, a graphics package for plume plotting.

Several factors provided the original impetus for system development including: (a) the considerable complexity of mixing processes in the aquatic environment, resulting from the great diversity of discharge and site conditions and requiring advanced knowledge in a specialized field of hydrodynamics; (b) the failure of previously existing models (e.g. the U.S. EPA plume models (4) originally developed for municipal discharges in deep coastal waters) to adequately predict often routine discharge situations, especially for more shallow inland sites; (c) the issuance in 1985 by the U.S. EPA of additional guidelines (1) for the permitting of toxic aqueous discharges, placing yet another burden on both applicants and regulators in delineating special zones for the initial mixing of these substances; and (d) the availability of new computer methods, so-called expert systems, for making accessible to the user, within a simple personal computing environment, the expert's knowledge and experience in dealing with complex engineering problems.

Four separate publications (5,6,7,8) describe the scientific basis for the CORMIX system and demonstrate comparison and validation with field and laboratory data. The results of these works are summarized in the peer-reviewed literature (9,10,11,12,13,14,15,16,17). The CORMIX systems approach and its performance relative to the earlier U.S. EPA plume models in the context of estuarine applications is also described in EPA's technical guidance manual for performing waste load allocations in estuaries (3).

EPA's established policy is to make the CORMIX system freely available to all potential users through its modeling software distribution facility at the U.S. EPA Center for Environmental Assessment Modeling (CEAM) in Athens, Georgia. Some of the CORMIX subsystems have been available to the industrial and regulatory user communities since December 1989 when distribution of CORMIX1 was commenced by Cornell University for the purpose of identifying subtle programming errors through application to actual mixing zone analysis problems by a controlled users group. After this testing was deemed complete, CEAM commenced the distribution of CORMIX1 in November 1990. A similar approach was used to introduce CORMIX2 which began CEAM distribution in October 1991. In 1992, CORMIX1, CORMIX2, and CORMIX3 were integrated a single program and distributed by USEPA-CEAM as CORMIX Version 2.1 as of 1993.

Additional development of the post-processor modules, including plume graphics, the jet-integral model, and the far-field locator, were added to the system and distributed as CORMIX Version 3.0 as of 1994.

This manual describes the operation of a revised version, including a special routine for unsteady tidal applications, denoted as CORMIX Version 3.1 that has been distributed by Cornell as of June 1995. A slightly updated Version 3.2 will be distributed by USEPA-CEAM as of September 1996.

The objectives of this user's guide are as follows: (a) to provide a comprehensive description of the CORMIX system; (b) to provide guidance for assembly and preparation of required input data for all three subsystems as well as the post-processor models; (c) to delineate ranges of applicability of the subsystems; (d) to provide guidance for the interpretation and graphical display of system output; and (e) to illustrate practical system application through several case studies.

This manual is organized to meet the informational needs of two distinctly different groups of readers: 1) personnel in environmental management positions desiring an overview of the CORMIX systems capabilities, and 2) technical staff needing assistance in actual applications. Chapter II provides a summary of the physical processes of effluent mixing, as well as an overview of the regulatory background and practice on mixing zone applications. The general features of the CORMIX system are explained in Chapter III including summaries of: (a) predictive capabilities and limitations, (b) overall system structure and method of processing information, (c) user interaction, and (d) individual computational elements. Detailed guidance on the preparation and entry of input data, as required by the three CORMIX subsystems, is given in Chapter IV. Chapter V provides a description of system output, containing descriptive, quantitative, and graphical information on the predicted effluent flow. Chapter VI describes the background, input and output features of the CORJET jet integral model and the far-field plume locator program FFLOCATR. The closing remarks in Chapter VII contain information on system availability and user support, and on possible future developments and enhancements.

Appendices to this guide present four case studies on the application of all three CORMIX subsystems and its post-processor models. These are adapted from actual situations and illustrate the complete input requirements and output capabilities of the system. In addition, some of the assumptions on data schematization, problem simplification, and output interpretation, and construction graphical displays are discussed in a context typical of many mixing zone model applications.

II Background: Mixing Processes and Mixing Zone Regulations

When performing design work and predictive studies on effluent discharge problems, it is important to clearly distinguish between the physical aspects of **hydrodynamic mixing processes** that determine the effluent fate and distribution, and the administrative construct of **mixing zone regulations** that intend to prevent any harmful impact of the effluent on the aquatic environment and associated uses.

2.1 Hydrodynamic Mixing Processes

The mixing behavior of any wastewater discharge is governed by the interplay of ambient conditions in the receiving water body and by the discharge characteristics.

The **ambient conditions** in the receiving water body, be it stream, river, lake, reservoir, estuary or coastal waters, are described by the water body's geometric and dynamic characteristics. Important geometric parameters include plan shape, vertical cross-sections, and bathymetry, especially in the discharge vicinity. Dynamic characteristics are given by the velocity and density distribution in the water body, again primarily in the discharge vicinity. In many cases, these conditions can be taken as steady-state with little variation because the time scale for the mixing processes is usually of the order of minutes up to perhaps one hour. In some cases, notably tidally influenced flows, the ambient conditions can be highly transient and the assumption of steady-state conditions may be inappropriate. In this case, the effective dilution of the discharge plume may be reduced relative to that under steady state conditions.

The **discharge conditions** relate to the geometric and flux characteristics of the submerged outfall installation. For a single port discharge the port diameter, its elevation above the bottom and its orientation provide the geometry; for multiport diffuser installations the arrangement of the individual ports along the diffuser line, the orientation of the diffuser line, and construction details represent additional geometric features; and for surface discharges the cross-section and orientation of the flow entering the ambient watercourse are important. The **flux characteristics** are given by the effluent discharge flow rate, by its momentum flux and by its buoyancy flux. The buoyancy flux represents the effect of the relative density difference between the effluent discharge and ambient conditions in combination with the gravitational acceleration. It is a measure of the tendency for the effluent flow to rise (i.e. **positive buoyancy**) or to fall (i.e. **negative buoyancy**).

The hydrodynamics of an effluent continuously discharging into a receiving water body can be conceptualized as a mixing process occurring in two separate regions. In the first region, the initial jet characteristics of momentum flux, buoyancy flux, and outfall geometry influence the jet trajectory and mixing. This region will be referred to as the **"near-field"**, and encompasses the buoyant jet flow and any surface, bottom or terminal layer interaction. In this near-field region, outfall designers can usually affect the initial mixing characteristics through appropriate manipulation of design variables.

As the turbulent plume travels further away from the source, the source characteristics become less important. Conditions existing in the ambient environment will control trajectory and dilution of the turbulent plume through buoyant spreading motions and passive diffusion due to ambient turbulence. This region will be referred to here as the **"far-field"**. It is stressed at this point that the distinction between near-field and far-field is made purely on hydrodynamic grounds. It is unrelated to any regulatory mixing zone definitions.

2.1.1 Near-Field Processes

Three important types of near-field processes are submerged buoyant jet mixing, boundary interactions and surface buoyant jet mixing as described in the following paragraphs.

Submerged Buoyant Jet Mixing: The effluent flow from a submerged discharge port provides a velocity discontinuity between the discharged fluid and the ambient fluid causing an intense shearing action. The shearing flow breaks rapidly down into a turbulent motion. The width of the zone of high turbulence intensity increases in the direction of the flow by incorporating ("entraining") more of the outside, less turbulent fluid into this zone. In this manner, any internal concentrations (e.g. fluid momentum or pollutants) of the discharge flow become diluted by the entrainment of ambient water. Inversely, one can speak of the fact that both fluid momentum and pollutants become gradually diffused into the ambient field.

The initial velocity discontinuity may arise in different fashions. In a **"pure jet"** (also called "momentum jet" or "non-buoyant jet"), the initial momentum flux in the form of a high-velocity injection causes the turbulent mixing. In a **"pure plume,"** the initial buoyancy flux leads to local vertical accelerations which then lead to turbulent mixing. In the general case of a **"buoyant jet"** (also called a "forced plume"), a combination of initial momentum flux and buoyancy flux is responsible for turbulent mixing.

Thus, buoyant jets are characterized by a narrow turbulent fluid zone in which vigorous mixing takes place. Furthermore, depending on discharge orientation and direction of buoyant acceleration, curved trajectories are generally established in a stagnant uniform-density environment as illustrated in Figure 2.1a.

Buoyant jet mixing is further affected by ambient currents and density stratification. The role of **ambient currents** is to gradually deflect the buoyant jet into the current direction as illustrated in Figure 2.1b and thereby induce additional mixing. The role of ambient **density stratification** is to counteract the vertical acceleration within the buoyant jet leading ultimately to trapping of the flow at a certain level. Figure 2.1c shows a typical buoyant jet shape at the trapping or terminal level.

Finally, in case of multiport diffusers, the individual round buoyant jets behave independently until they interact, or merge, with each other at a certain distance from the efflux ports. After **merging**, a two-dimensional buoyant jet plane is formed as illustrated in Figure 2.1d. Such plane buoyant jets resulting from a multiport diffuser discharge in deep water can be further affected by ambient currents and by density stratification as discussed in the preceding paragraph.

Boundary Interaction Processes and Near-Field Stability: Ambient water bodies always have vertical boundaries. These include the water surface and the bottom, but in addition, "internal boundaries" may exist at pycnoclines. **Pycnoclines** are layers of rapid density change. Depending on the dynamic and geometric characteristics of the discharge flow, a variety of interaction phenomena can occur at such boundaries, particularly where flow trapping may occur.

In essence, boundary interaction processes provide a transition between the buoyant jet mixing process in the near-field, and between buoyant spreading and passive diffusion in the far-field. They can be gradual and mild, or abrupt leading to vigorous transition and mixing processes. They also can significantly influence the stability of the effluent discharge conditions.

The assessment of **near-field stability,** i.e. the distinction of stable or unstable conditions, is a key aspect of effluent dilution analyses. It is especially important for understanding the behavior of the two-dimensional plumes resulting from multiport diffusers, as shown by some examples in Figure 2.2. **"Stable discharge"** conditions, usually occurring for a combination of strong buoyancy, weak momentum and deep water, are often referred to as **"deep water"** conditions (Figures 2.2a,c). **"Unstable discharge"** conditions, on the other hand, may be considered synonymous to **"shallow water"** conditions (Figure 2.2b,d). Technical discussions on discharge stability are presented elsewhere (18,19).

A few important examples of boundary interaction for a single round buoyant jet are illustrated in Figure 2.3. If a buoyant jet is bent-over by a cross-flow, it will gradually approach the surface, bottom or terminal level and will undergo a smooth transition with little additional mixing impingement point can take on one of the following forms: (a) If the flow has sufficient buoyancy it will ultimately form a stable layer at the **surface** (Figure 2.3b). In the presence of **weak** ambient flow this will lead to an upstream intrusion against the ambient current. (b) If the buoyancy of the effluent flow is weak or its momentum very high, unstable recirculation phenomena can occur in the discharge vicinity (Figure 2.3c). This local recirculation leads to re-entrainment of already mixed water back into the buoyant jet region. (c) In the intermediate case, a combination of localized vertical mixing and upstream spreading may result (Figure 2.3d).

Another type of interaction process concerns submerged buoyant jets discharging in the vicinity of the water bottom into a stagnant or flowing ambient. Two types of dynamic interaction processes can occur that lead to rapid attachment of the effluent plume to the water bottom as illustrated in Figure 2.4. These are wake attachment forced by the receiving water's crossflow or **Coanda attachment** forced by the entrainment demand of the effluent jet itself. The latter is due to low pressure effects as the jet **periphery** is close to the water bottom.

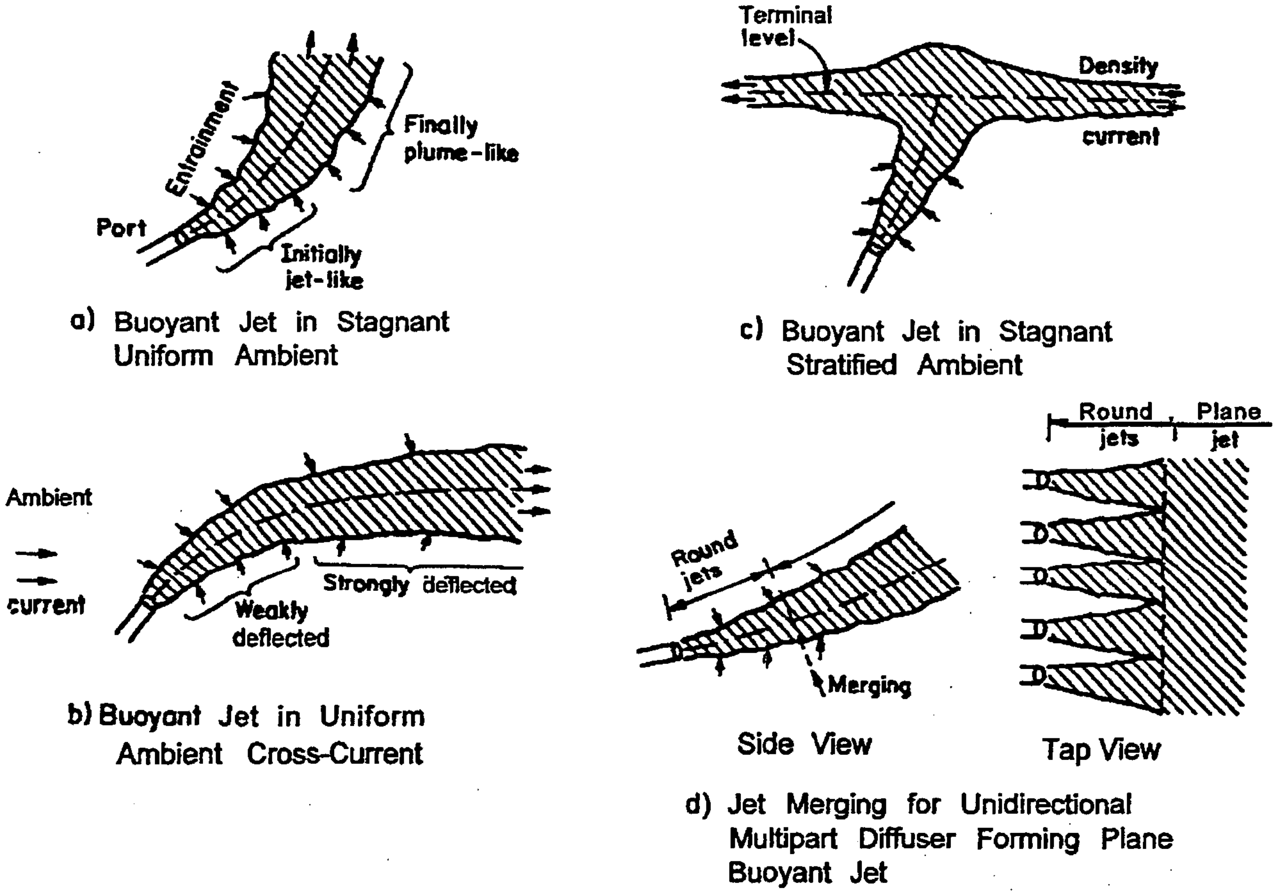
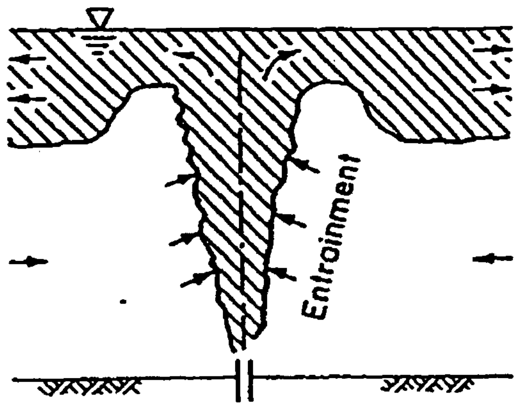
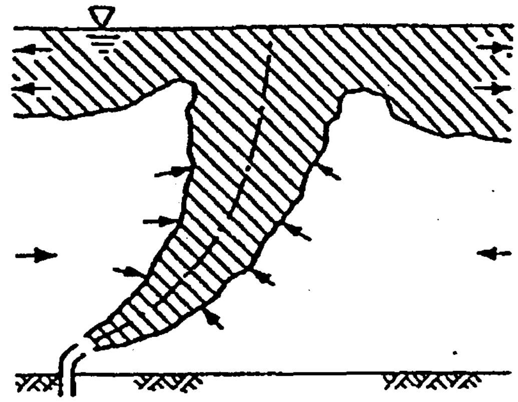


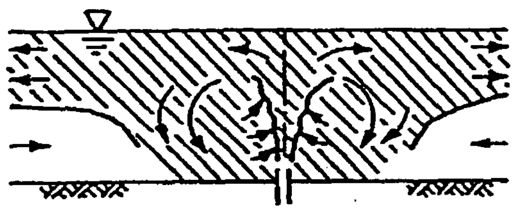
Figure 2.1: Typical buoyant jet mixing flow patterns under different ambient conditions



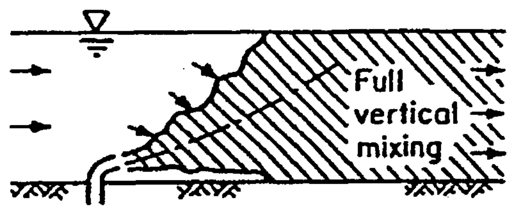
a) Deep Water, High Buoyancy, Vertical: Stable Near-Field



c) Deep Water, High Buoyancy, Near-Horizontal: Stable Near-Field

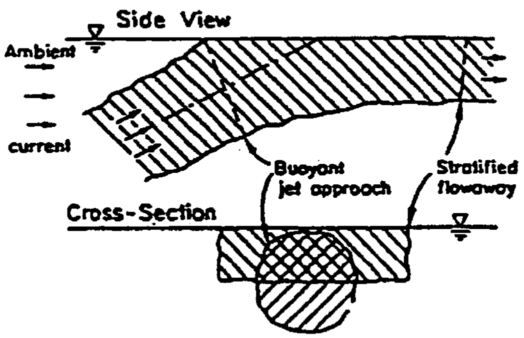


b) Shallow Water, Low Buoyancy, Vertical: Unstable Near-Field with Local Mixing and Restratification

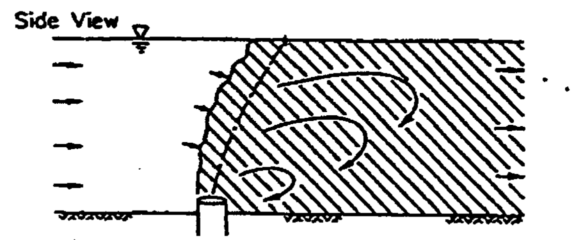


d) Shallow Water, Low Buoyancy, Near-Horizontal: Unstable Near-Field with Full Vertical Mixing

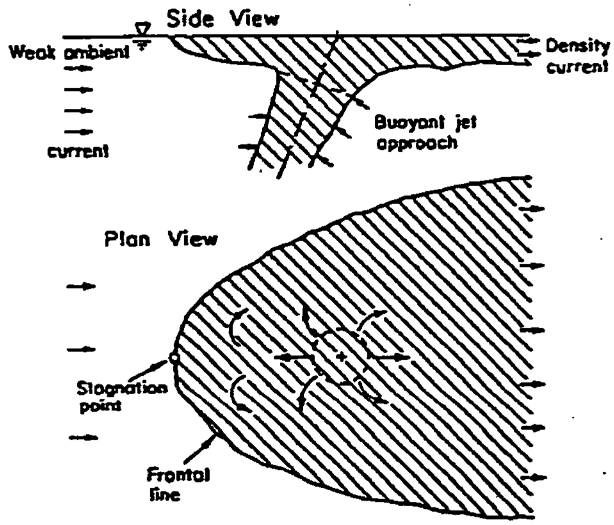
Figure 2.2: Examples of near-field stability and instability conditions for submerged discharges in limited water depth



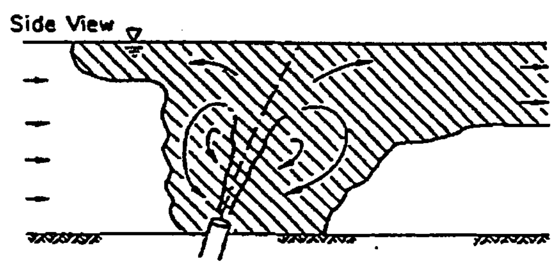
a) Gradual Surface Approach (Near-Horizontal)



c) Surface Impingement with Full Vertical Mixing in Shallow Water



b) Surface Impingement with Buoyant Upstream Spreading



d) Surface Impingement with Local Vertical Mixing, Buoyant Upstream Spreading and Restratification

Figure 2.3: Examples of boundary interactions for submerged jets in finite depth

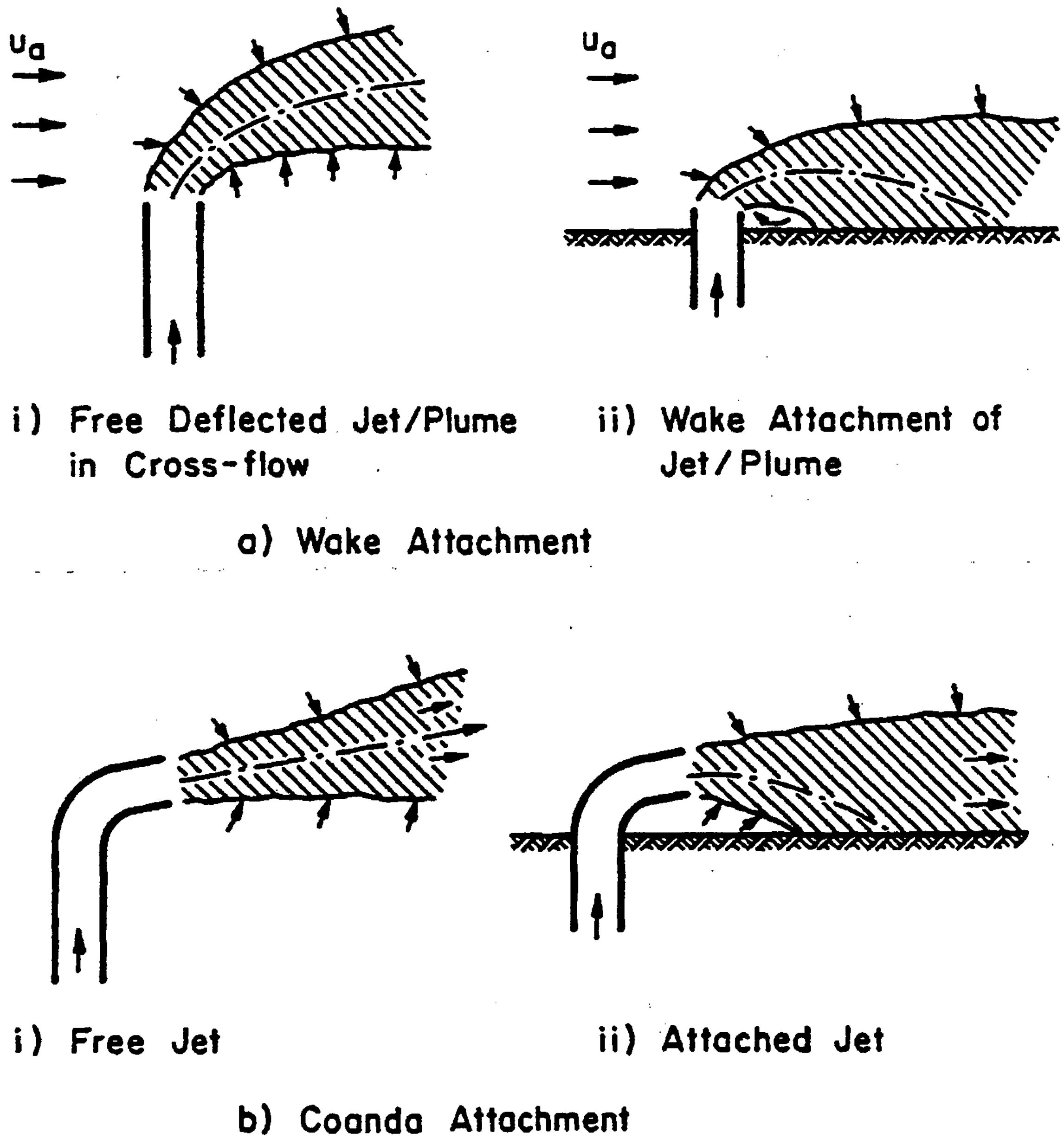
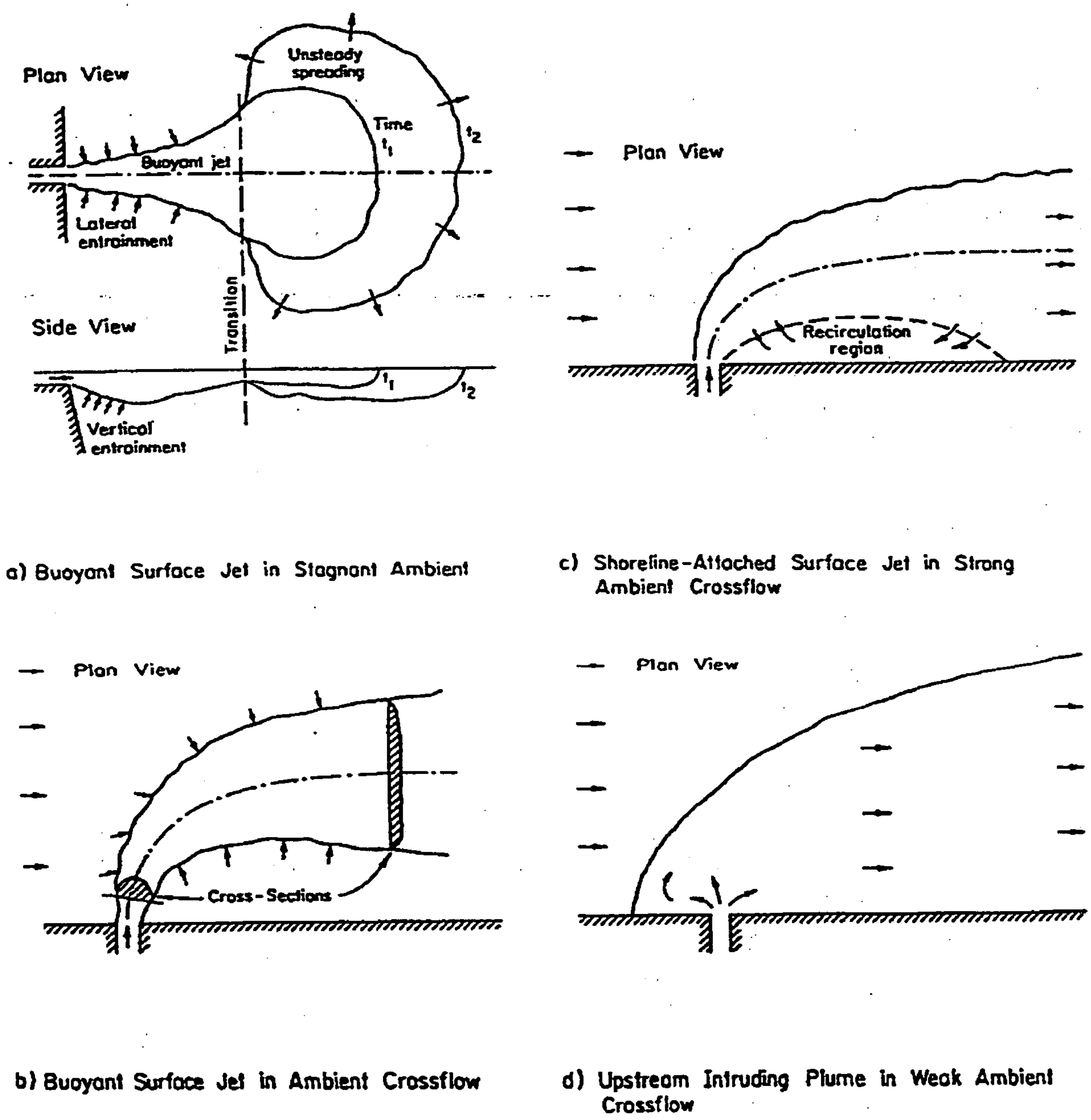


Figure 2.4: Examples of wake (crossflow induced) attachment and Coanda attachment conditions for jets discharging near boundaries

Surface Buoyant Jet Mixing: Positively buoyant jets discharged horizontally along the water surface from a laterally entering channel or pipe (Figure 2.5) bear some similarities to the more classical submerged buoyant jet. For a relatively short initial distance, the effluent behaves like a momentum jet spreading both laterally and vertically due to turbulent mixing. After this stage, vertical entrainment becomes inhibited due to buoyant damping of the turbulent motions, and the jet experiences strong lateral spreading. During stagnant ambient conditions, ultimately a reasonably thin layer may be formed at the surface of the receiving water; that layer can undergo the transient buoyant spreading motions depicted in Figure2.5a.



a) Buoyant Surface Jet in Stagnant Ambient

b) Buoyant Surface Jet in Ambient Crossflow

c) Shoreline-Attached Surface Jet in Strong Ambient Crossflow

d) Upstream Intruding Plume in Weak Ambient Crossflow

2.5: Typical buoyant surface jet mixing flow patterns under stagnant or flowing ambient conditions

In the presence of ambient crossflow, buoyant surface jets may exhibit any one of following three types of flow features: They may form a weakly deflected jet that does not interact with the shoreline (Figure 2.5b). When the crossflow is strong, they may attach to the downstream boundary forming a shore-hugging plume (Figure 2.5c). When a high discharge buoyancy flux combines with a weak crossflow, the buoyant spreading effects can be so strong that an upstream intruding plume is formed that also stays close to the shoreline (Figure 2.5d).

Intermediate-Field Effects for Multiport Diffuser Discharges: Some multiport diffuser installations induce flows in shallow water which extend beyond the strict near-field region. The resulting plumes are sometimes referred to as the "intermediate-field" (18) because they interact with the receiving water at distances that are substantially greater than the water depth; the order of magnitude of the water depth is typically used to define the dimensions of the near-field region. Intermediate fields may occur when a multiport diffuser represents a large source of momentum with a relatively weak buoyancy effect. Such a diffuser will have an unstable near-field with shallow water conditions. For certain diffuser geometries (e.g. unidirectional & staged diffuser types; see Section V) strong motions can be induced in the shallow water environment in the form of vertically mixed currents that laterally entrain ambient water and may extend over long distances before they re-stratify or dissipate their momentum.

Another type of interaction process concerns submerged buoyant jets discharging in the vicinity of the water bottom into a stagnant or flowing ambient. Two types of dynamic interaction processes can occur that lead to rapid attachment of the effluent plume to the water bottom as illustrated in Figure 2.4. These are **wake attachment** forced by the receiving water's crossflow or **Coanda attachment** forced by the entrainment demand of the effluent jet itself. The latter is due to low pressure effects as the jet periphery is close to the water bottom.

2.1.2 Far-Field Processes

Far-field mixing processes are characterized by the longitudinal advection of the mixed effluent by the ambient current velocity.

Buoyant Spreading Processes: These are defined as the horizontally transverse spreading of the mixed effluent flow while it is being advected downstream by the ambient current. Such spreading processes arise due to the buoyant forces caused by the density difference of the mixed flow relative to the ambient density. They can be effective transport mechanisms that can quickly spread a mixed effluent laterally over large distances in the transverse direction, particularly in cases of strong ambient stratification. In this situation, effluent of considerable vertical thickness at the terminal level can collapse into a thin but very wide layer unless this is prevented by lateral boundaries. If the discharge is non-buoyant, or weakly buoyant, and the ambient is unstratified, there is no buoyant spreading region in the far-field, only a passive diffusion region.

Depending on the type of near-field flow and ambient stratification, several types of buoyant spreading may occur. These include: (a) spreading at the water surface, (b) spreading at the bottom, (c) spreading at a sharp internal interface (pycnocline) with a density jump, or (d) spreading at the terminal level in continuously stratified ambient fluid. As an example, the definition diagram and structure of surface buoyant spreading processes somewhat downstream of the discharge in unstratified crossflow is shown in Figure 2.6.

The laterally spreading flow behaves like a density current and entrains some ambient fluid in the "head region" of the current. During this phase, the mixing rate is usually relatively small, the layer thickness may decrease, and a subsequent interaction with a shoreline or bank can impact the spreading and mixing processes.

Passive Ambient Diffusion Processes: The existing turbulence in the ambient environment becomes the dominating mixing mechanism at sufficiently large distances from the discharge point. In general, the passively diffusing flow grows in width and in thickness until it interacts

The strength of the ambient diffusion mechanism depends on a number of factors relating mainly to the geometry of the ambient shear flow and the amount of ambient stratification. In the context of classical diffusion theory (20), gradient diffusion processes in the bounded flows of rivers or narrow estuaries can be described by constant diffusivities in the vertical and horizontal direction that depend on turbulent intensity and on channel depth or width as the length scales. In contrast, wide "unbounded" channels or open coastal areas are characterized by plume size dependent diffusivities leading to accelerating plume growth described, for example, by the "4/3 law" of diffusion. In the presence of a stable ambient stratification, the vertical diffusive mixing is generally strongly damped.

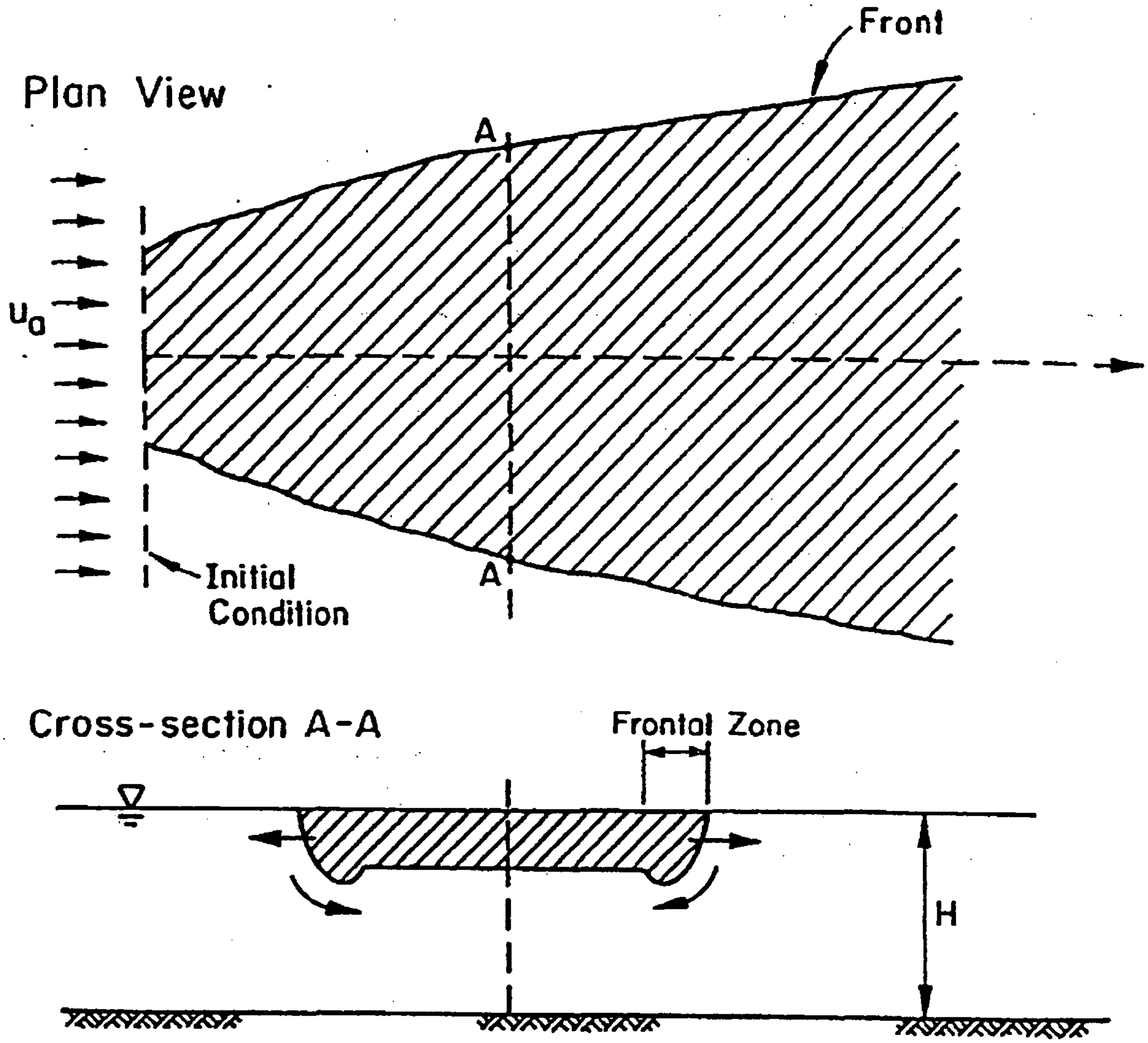


Figure 2.6: Buoyant spreading processes downstream of the near-field region (example of spreading along the water surface)

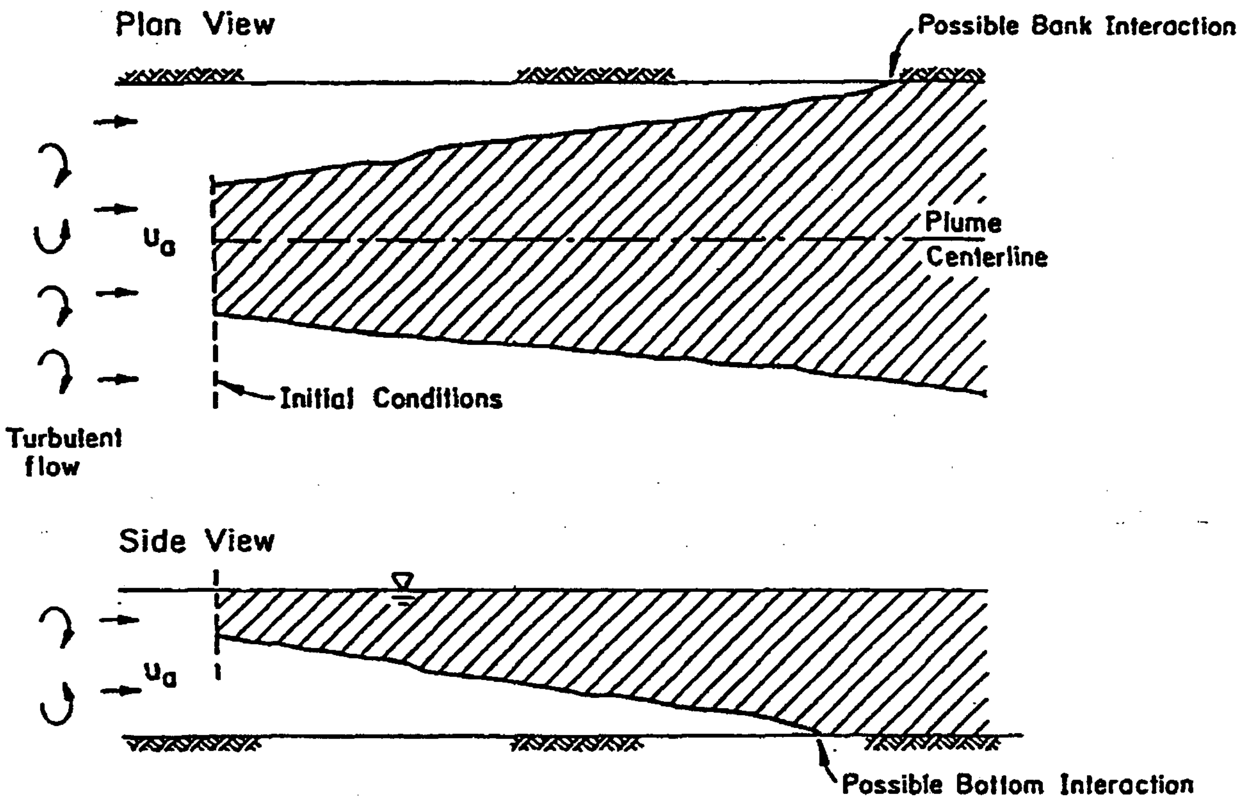


Figure 2.7: Passive ambient diffusion process with advection in the far-field

2.2 Mixing Zone Regulations

The discharge of waste water into a water body can be considered from two vantage points regarding its impact on ambient water quality. On a larger scale, seen over the entire receiving water body, care must be taken that water quality conditions that protect designated beneficial uses are achieved. This is the realm of the general waste load allocation (WLA) procedures and models.

On a local scale, or in the immediate discharge vicinity, additional precautions must be taken to insure that high initial pollutant concentrations are minimized and constrained to small zones, areas, or volumes. The generic definition of these zones, commonly referred to as "**mixing zones**", is embodied in federal water quality regulations and often cited in the regulations of permit granting authorities. As stated previously, mixing zones are administrative constructs that are independent of hydrodynamic mixing processes.

2.2.1 <u>Legal Background</u>

The Clean Water Act of 1977 defines five general categories of pollutants. These are: (a) conventional, (b) nonconventional, (c) toxics, (d) heat, and (e) dredge and fill spoil. The Act distinguishes between new and existing sources for setting effluent standards. Pollutants designated as "conventional" would be "generally those pollutants that are naturally occurring, biodegradable, oxygen demanding materials and solids. In addition, compounds which are not toxic and which are similar in characteristics to naturally occurring, biodegradable substances are to be designated as conventional pollutants for the purposes of the provision." Examples of conventional pollutants are: biochemical oxygen demand (BOD), total suspended solids, and fecal coliform bacteria. Pollutants designated as "nonconventional" would be "those which are not toxic or conventional", and some examples are: chemical oxygen demand (COD), fluoride, and ammonia. "Toxic" pollutants are those that cause harmful effects, either acute or chronic, at very low concentrations; examples of some designated toxic substances are: nickel, chloroform, or benzidine.

2.2.2 Mixing Zone Definitions

The mixing zone is defined as an **"allocated impact zone"** where numeric water quality criteria can be exceeded as long as acutely toxic conditions are prevented. A mixing zone can be thought of as a limited area or volume where the initial dilution of a discharge occurs (21). Water quality standards apply at the boundary of the mixing zone, not within the mixing zone itself. The U.S. EPA and its predecessor agencies have published numerous documents giving guidance for determining mixing zones. Guidance published by U.S. EPA in the 1984 Water Quality Standards Handbook (21) supersedes these sources.

In setting requirements for mixing zones, U.S. EPA (22) requires that "the area or volume of an individual zone or group of zones be limited to an area or volume as small as practicable that will not interfere with the designated uses or with the established community of aquatic life in the segment for which the uses are designated," and the shape be "a simple configuration that is easy to locate in the body of water and avoids impingement on biologically important areas," and "shore hugging plumes should be avoided."

The U.S. EPA rules for mixing zones recognize the State has discretion whether or not to adopt a mixing zone and to specify its dimensions. The U.S. EPA allows the use of a mixing zone in permit applications except where one is prohibited in State regulations. A previous review (5) of individual State mixing zone policies (1,22) found that 48 out of 50 States make use of a mixing zone in some form; the exceptions are Arizona and Pennsylvania. State regulations dealing with streams or rivers generally limit mixing zone widths or cross-sectional areas, and allow lengths to be determined on a case by case basis.

In the case of lakes, estuaries and coastal waters, some states specify the surface area that can be affected by the discharge. The surface area limitation usually applies to the underlying water column and benthic area. In the absence of specific mixing zone dimensions, the actual shape and size is determined on a case-by-case basis.

Special mixing zone definitions have been developed for the discharge of municipal wastewater into the coastal ocean, as regulated under Section 301(h) of the Clean Water Act (23). Frequently, these same definitions are used also for industrial and other discharges into coastal waters or large lakes, resulting in a plurality of terminology. For those discharges, the mixing zone was labeled as the **"zone of initial dilution"** in which rapid mixing of the waste stream (usually the rising buoyant fresh water plume within the ambient saline water) takes place. EPA requires that the "zone of initial dilution" be a regularly shaped area (e.g. circular or rectangular) surrounding the discharge structure (e.g. submerged pipe or diffuser line) that encompasses the regions of high (exceeding standards) pollutant concentrations under design conditions (23). In practice, limiting boundaries defined by dimensions equal to the water depth measured horizontally from any point of the discharge structure are accepted by the EPA provided they do not violate other mixing zone restrictions (23).

2.2.3 Special Mixing Zone Requirements for Toxic Substances

The U.S. EPA maintains two water quality criteria for the allowable concentration of toxic substances: a criterion maximum concentration

(CMC) to protect against acute or lethal effects; and a criterion continuous concentration (CCC) to protect against chronic effects (1). The CMC value is greater than or equal to the CCC value and is usually more restrictive. The CCC must be met at the edge of the same regulatory mixing zone specified for conventional and nonconventional discharges.

Lethality to passing organisms within the mixing zone can be prevented in one of four ways:

The first alternative is to meet the CMC criterion within the pipe itself.

The second alternative is to meet the CMC within a short distance from the outfall. If dilution of the toxic discharge in the ambient environment is allowed, a **toxic dilution zone (TDZ)**, which is usually more restrictive than the legal mixing zone for conventional and nonconventional pollutants, may be used. The revised 1991 Toxics TSD document (1) recommends for new discharges a minimum exit velocity of 3 meters per second (10 feet per second) in order to provide sufficiently rapid mixing that would minimize organism exposure time to toxic material. The TSD does not set a requirement in this regard, recognizing that the restrictions listed in the following paragraph can in many instances also be met by other designs, especially if the ambient velocity is large.

As the third alternative, the outfall design must meet the most restrictive of the following geometric restrictions for a TDZ:

— The CMC must be met within 10% of the distance from the edge of the outfall structure to the edge of the regulatory mixing zone in any spatial direction.

— The CMC must be met within a distance of 50 times the discharge length scale in any spatial direction. The discharge length scale is defined as the square-root of the cross-sectional area of any discharge outlet. This restriction is intended to ensure a dilution factor of at least 10 within this distance under all possible circumstances, including situations of severe bottom interaction and surface interaction.

— The CMC must be met within a distance of 5 times the local water depth in any horizontal direction. The local water depth is defined as the natural water depth (existing prior to the installation of the discharge outlet) prevailing under mixing zone design condition (e.g. low flow for rivers). This restriction will prevent locating the discharge in very shallow environments or very close to shore, which would result in significant surface and bottom concentrations (1).

A fourth alternative is to show that a drifting organism would not be exposed more than 1-hour to average concentrations exceeding the CMC.

2.2.4 Current Permitting Practice on Mixing Zones

It is difficult to generalize the actual practice in implementing the mixing zone regulations, given the large number and diverse types of jurisdictions and permit-granting authorities involved. By and large, however, current procedure falls into one of the following approaches, or may involve a combination thereof.

(i) The mixing zone is defined by some numerical dimension, as discussed above. The applicant must then demonstrate that the existing or proposed discharge meets all applicable standards for conventional pollutants or for the CCC of toxic pollutants at the edge of the specified mixing zone.

(ii) No numerical definition for a mixing zone may apply. In this case a mixing zone dimension may be proposed by the applicant. To do so the applicant generally uses actual concentration measurements for existing discharges, dye dispersion tests or model predictions to show at what plume distance, width, or region, the applicable standard will be met. The applicant may then use further ecological or water use-oriented arguments to demonstrate that the size of that predicted region provides reasonable protection. The permitting authority may evaluate that proposal, or sometimes pursue its own independent proposal for a mixing zone.

This approach resembles a negotiating process with the objective of providing optimal protection of the aquatic environment consistent with other uses.

As regards the acute, or CMC, criterion for toxic pollutants, the spatial restrictions embodied in the Toxics TSD document (1) call for very specific demonstrations of how the CMC criterion is met at the edge of the "toxic dilution zone". Again, field tests for existing discharges or predictive models may be used.

2.2.5 Relationship Between Actual Hydrodynamic Processes and Mixing Zone Dimensions

The spatial requirements in mixing zone regulations are not always correlated with the actual hydrodynamic processes of mixing. With few exceptions, the toxic dilution criteria apply to the near-field of most discharges since the TDZ criteria (2) are spatially highly restrictive. The regular mixing zone boundaries, however, may be located in the near-field or the far-field of the actual effluent discharge flow since they are administratively determined by the permit-granting authority. Thus, the analyst must have tools at his disposal with the capability to address both the near and far-field situations.

III General Features of the CORMIX System

This section provides a general description of common features of CORMIX. CORMIX Version 3.1 has three different subsystem modules for diverse discharge conditions. The subsystems are CORMIX1, CORMIX2, and CORMIX3 for the analysis of submerged single port, submerged multiport, and buoyant surface outfall configurations, respectively. Furthermore, two post-processor models CORJET, a near-field jet integral model, and FFLOCATR, a far-field plume locator in non-uniform channels, are included. The following two sections give a detailed guidance for developing the required input data and for understanding program output. Reference is made throughout this document to CORMIX Version 3.1 dated June 1995 or Version 3.2 dated September 1996; other versions may differ somewhat.

3.1 Overview

The CORMIX system represents a robust and versatile computerized methodology for predicting both the qualitative features (e.g. flow classification) and the quantitative aspects (e.g. dilution ratio, plume trajectory) of the hydrodynamic mixing processes resulting from different discharge configurations and in all types of ambient water bodies, including small streams, large rivers, lakes, reservoirs, estuaries, and coastal waters. The methodology: (a) has been extensively verified by the developers through comparison of simulation results to available field and laboratory data on mixing processes (5,6,7,8), (b) has undergone independent peer review in journal proceedings (9,10,11,12,13, 14,15,16,17) and (c) is equally applicable to a wide range of problems from a simple single submerged pipe discharge into a small stream with rapid cross-sectional mixing to a complicated multiport diffuser installation in a deeply stratified coastal water.

System experience suggests that CORMIX1 applies to better than 95% of submerged single-port designs, CORMIX2 to better than 80% of multiport diffusers, and CORMIX3 to better than 90% of surface discharges. Lack of applicability is usually given by highly non-uniform ambient flow conditions that are prone to locally recirculating flows. Other non-applicable cases may arise to complicated discharge geometries in which case CORMIX advises the user not to proceed with the analysis. Whenever the model is applicable extensive comparison with available field and laboratory data has shown that the CORMIX predictions on dilutions and concentrations, with associated plume geometries, are accurate to within ± 50 % (standard deviation).

The methodology provides answers to questions that typically arise during the application of mixing zone regulations for both conventional and toxic discharges. More importantly, this is accomplished by utilizing the customary approaches often used in evaluating and implementing mixing zones, thereby providing a common framework for both applicants and regulatory personnel to arrive at a consensus view of the available dilution and plume trajectory for the site and effluent discharge characteristics.

The methodology also provides a way for personnel with little or no training in hydrodynamics to investigate improved design solutions for aquatic discharge structures. To limit misuse, the system contains limits of applicability that prevent the simulation of situations for which no safe predictive methodology exists, or for discharge geometries that are undesirable from a hydrodynamic viewpoint. Furthermore, warning labels, data screening mechanisms, and alternative design recommendations are furnished by the system. The system is not fool proof, however, and final results should always be examined for reasonableness.

Finally, CORMIX is an educational tool that intends to make the user more knowledgeable and appreciative about effluent discharge and mixing processes. The system is not simply a black box that produces a final numerical or graphical output, but contains an interactive menu of user guidance, help options, and explanatory material of the relevant physical processes. These assist users in understanding model predictions and exploring the sensitivity of model predictions to assumptions.

3.2 Capabilities and Major Assumptions of the Three Subsystems and the Post-Processor Models

3.2.1 CORMIX Subsystems

CORMIX1 predicts the geometry and dilution characteristics of the effluent flow resulting from a **submerged single port diffuser discharge,** of arbitrary density (positively, neutrally, or negatively buoyant) and arbitrary location and geometry, into an ambient receiving water body that may be stagnant or flowing and have ambient density stratification of different types.

CORMIX2 applies to three commonly used types of **submerged multiport diffuser discharges** under the same general effluent and ambient conditions as CORMIX1. It analyzes unidirectional, staged, and alternating designs of multiport diffusers and allows for arbitrary alignment of the diffuser structure within the ambient water body, and for arbitrary arrangement and orientation of the individual ports. For complex hydrodynamic cases, CORMIX2 uses the "equivalent slot diffuser" concept and thus neglects the details of the individual jets issuing from each diffuser port and their merging process, but rather assumes that the flow arises from a long slot discharge with equivalent dynamic characteristics. Hence, if details of the effluent flow behavior in the immediate diffuser vicinity are needed, an additional CORMIX1 simulation for an equivalent partial effluent flow may be recommended.

CORMIX3 analyzes **buoyant surface discharges** that result when an effluent enters a larger water body laterally, through a canal, channel, or near-surface pipe. In contrast to CORMIX1 and 2, it is *limited to positively or neutrally buoyant effluents.* Different discharge geometries and orientations can be analyzed including flush or protruding channel mouths, and orientations normal, oblique, or parallel to the bank.

Additional major assumptions include the following:

— All subsystems require that the actual cross-section of the water body be described as a rectangular straight uniform channel that may be bounded laterally or unbounded. The ambient velocity is assumed to be uniform within that cross-section.

— In addition to a uniform ambient density possibility, CORMIX allows for three generic types of ambient stratification profiles to be used for the approximation of the actual vertical density distribution (see Section 4.3).

— All CORMIX subsystems are in principle **steady-state models,** however recent developments (beginning with Version 3.1) allow the analysis of **unsteady mixing in tidal environments.**

— All CORMIX systems can predict mixing for both conservative and first-order decay processes, and can simulate heat transfer from thermal plumes.

3.2.2 Post-Processor Models CORJET and FFLOCATR

CORJET, the Cornell Buoyant Jet Integral Model, is a **buoyant jet integral model** that predicts the jet trajectory and dilution characteristics of a single round jet or of a series of merging jets from a multiport diffuser with arbitrary discharge direction and positive, neutral or negative buoyancy in a general ambient environment. The ambient conditions can be highly non-uniform with both ambient current magnitude, current direction, and density a function of vertical distance. In general, CORJET can be used as an enhancement to the near-field predictions provided by CORMIX1 or 2 in order to investigate local details that have been simplified within the CORMIX representation. The major limitation of CORJET lies in the assumption of an *infinite receiving water body,* similar to all other available jet integral type models. Thus, CORJET should only be used after an initial CORMIX classification has shown that the single or multiple port discharge is indeed of the deep water type, i.e. hydrodynamically stable, without boundary interactions.

FFLOCATR, the Far-Field Plume Locator, uses the **cumulative discharge method** to delineate the CORMIX predicted far-field plume within the actual irregular (meandering or winding) river or estuary channel geometry with uneven distribution of the ambient flow.

3.3 System Processing Sequence and Structure

The general CORMIX layout appears in Figure 3.1, which shows the overall structure and the execution sequence of the program elements. The system has overall common data input features for the three different discharge elements. During program execution, the elements are loaded automatically and sequentially by the system. Each element provides user interaction and prompting in response to displayed information. This may somewhat extend the total time required for a single CORMIX session, but has offsetting benefit of allowing the user to gain process knowledge and insight on design sensitivity.

The user has numerous options with the **Main Menu** at start-up. Option 1 is to start a new CORMIX session. Option 2 is to re-run and modify a former case. Option 3 is to simply re-display (without new computation) results of a former design case. Option 4 is to use the Post-Processor, which includes the CORJET near-field jet integral model, the FFLOCATR far-field locator, and the plume display graphics which will be discussed in Section V of this document. Option 5 is the file manager which lists all files from previous simulations. Option 6 is to set/change CORMIX system speed. Here the user can select REGULAR CORMIX, complete with detailed queries and user help, or FAST-CORMIX, which has terse questions and limited user help. Option 7 contains system information and reference material. Option 7 is to quit the CORMIX system and return to DOS.

The common program elements of CORMIX are composed of DATIN, PARAM, CLASS, HYDRO, and SUM (Figure 3.1). DATIN is the program element for the entry of data and initialization of other program elements. PARAM uses the input data to compute a number of important physical parameters and length scales, as precursor to CLASS which performs the hydrodynamic classification of the given discharge/ambient situation into one of many possible generic flow configurations. HYDRO performs the actual detailed numerical prediction of the effluent plume characteristics. Finally, SUM summarizes the results from the classification and prediction, interprets them as regards mixing zone regulations, suggests design alternatives, and allows sensitivity analysis to be conveniently conducted using the current input data. At this point the **iteration menu** allows the user to perform an iteration with different ambient/discharge/regulatory conditions, or start a new design case, or make use of the post-processor options.

Due to its diverse programming requirements, CORMIX is written in two programming languages: VP-Expert, an "expert systems shell", and Fortran. The former is powerful in knowledge representation and logical reasoning, while the latter is adept at mathematical computations. Program elements DATIN, PARAM, CLASS, and SUM are written exclusively in VP-Expert. HYDRO is written in VP-Expert, but uses three Fortran executables HYDRO1, 2 and 3 for the actual detailed computation of plume characteristics. Finally, C++ is used in the specially developed graphics package CMXGRAPH.

3.4 CORMIX Data Input Features

All data is entered interactively in response to the CORMIX system prompts generated by the data input program element DATIN. DATIN queries the user for a complete specification of the physical environment of the discharge, as well as the applicable regulatory considerations for the situation undergoing analysis. A CORMIX session commences with questions on four topics which are asked sequentially in this order: site/case descriptions, ambient conditions, discharge characteristics, and regulatory mixing zone definitions. Data entry is entirely guided by the system and the available advice menu options provide expanded descriptions of the questions, if clarification is needed.

Chapter IV provides complete details on input specification for the three CORMIX discharge subsystems. Chapter VI deals with the input features of the post-processor models CORJET and FFLOCATR.

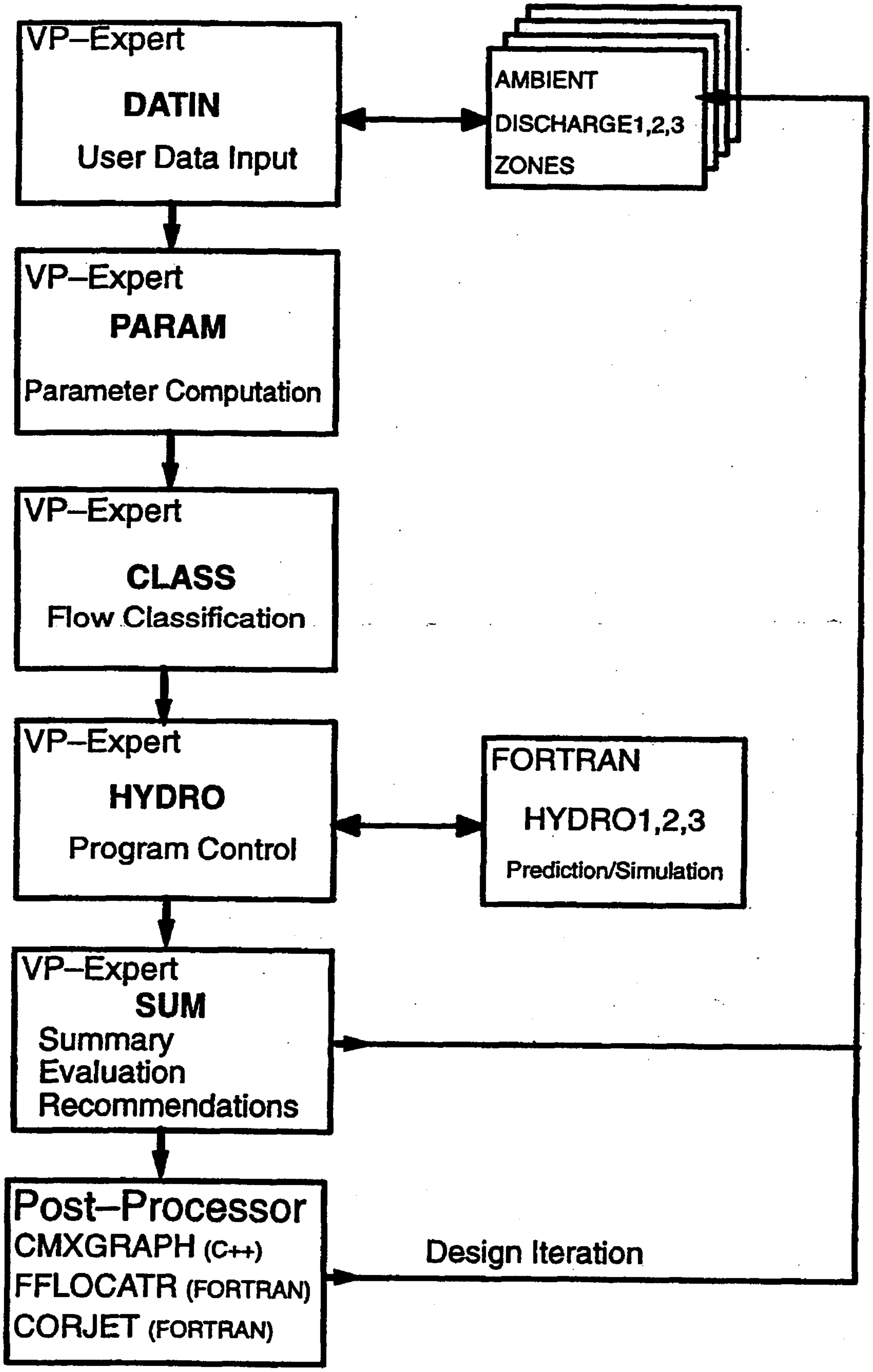


Figure 3.1: CORMIX system elements and processing sequence

3.5 Logic Elements of CORMIX: Flow Classification

To make predictions of an effluent discharge's dilution and plume trajectory, CORMIX typically combines the solutions of several simple flow patterns to provide a complete analysis from the efflux location all the way into the far-field.

The logic processing elements of CORMIX identify which solutions should be combined to provide the complete analysis. This process, called **flow classification**, develops a generic qualitative description of the discharge flow and is based on known relationships between flow patterns and certain calculated physical parameters.

PARAM is the program element that computes relevant physical parameters including: the various length scales, fluxes, and other values needed for the execution of other program elements. Length scales are calculated measures of the length of dynamic influence of various physical processes (see Chapters IV and V).

At the heart of CORMIX is a flow classification system contained in the program element CLASS. It provides a rigorous and robust expert knowledge base that carefully distinguishes among the many hydrodynamic flow patterns that a discharge may exhibit. As examples, these possibilities include discharge plumes attaching to the bottom, plumes vertically mixing due to instabilities in shallow water, plumes becoming trapped internally due to density stratification, and plumes intruding upstream against the ambient current due to buoyancy, and many others. Theoretically based hydrodynamic criteria using length scale analysis and empirical knowledge from laboratory and field experimentation, are applied in a systematic fashion to identify the most appropriate flow classification for a particular analysis situation. For all three subsystems, a total of about 80 generic flow configurations or classes can be distinguished.

The classification procedure of CORMIX is based on technical principles and has been verified by the developers through repeated testing and data comparison. It has also undergone independent peer review and the four documentation manuals (5,6,7,8) give the detailed scientific background for the classification scheme, in form of a number of criteria. The actual criteria constants are listed in the technical reports with comments on their sources and degree of reliability. Experienced users, especially those involved in research applications, may want to inspect these data values contained in the source code and occasionally vary some constant values within certain limits in order to examine improved prediction fits with available high-quality data. Extreme caution must be exercised when doing that as some values are interdependent; furthermore, if changes are made, they should be carefully documented.

When CLASS has executed, a description of the particular flow class is available to the user in the form of on-screen or hardcopy computer output; these description are also contained in the documentation reports (5,6,7). It is recommended that the novice or intermediate user review these to gain an appreciation of the involved hydrodynamic mixing processes.

3.6 Simulation Elements of CORMIX: Flow Prediction

Once a flow has been classified, CORMIX assembles and executes a sequence of appropriate hydrodynamic simulation modules in the program element HYDRO1, 2 or 3. HYDRO consists of: (a) control programs or "protocols" for each hydrodynamic flow classification and (b) a large number of subroutines or "simulation modules" corresponding to the particular flow processes, and their associated spatial regions, that occur within a given flow classification. The simulation modules are based on buoyant jet similarity theory, buoyant jet integral models, ambient diffusion theory, and stratified flow theory, and on simple dimensional analysis, as described elsewhere (5,6,7,8). The basic tenet of the simulation methodology is to arrange a sequence of relatively simple simulation modules which, when executed together, predict the trajectory and dilution characteristics of a complex flow. Each of the simulation models uses the final values of the previous module as "initial conditions".

3.7 CORMIX Output Features: Design Summary and Iterations

In addition to the narrative feedback during user input, the CORMIX system provides three types of output on-screen or in print: a) CORMIX Session Report that is a narrative summary, mostly for regulatory evaluation, of all discharge input data and global plume features, including compliance with mixing zone regulations, b) CORMIX1, 2 or 3 Prediction File that is a detailed listing of all plume properties as predicted by the Fortran program, and c) CMXGRAPH Plots representing plan, side, and trajectory views and concentration distribution of the predicted plume.

3.7.1 CORMIX Session Report

SUM is the final program element that summarizes the hydrodynamic simulation results for the case under consideration. The output in the CORMIX Session Report is arranged in four groups:

(1) Site summary gives the site identifier information, discharge and ambient environment data, and discharge length scales.

(2) Hydrodynamic simulation and mixing zone summary lists conditions at the end of the near-field region (NFR), regulatory mixing zone (RMZ) conditions, toxic dilution zone (TDZ) conditions, region of interest (ROI) conditions, upstream intrusion information, bank attachment locations, and a passive diffusion mixing summary. Users should be cognizant of the four major zone definitions, and associated acronyms, introduced above and defined as follows:

> **Near-Field Region (NFR):** The NFR is simply the zone of strong initial mixing, corresponding to the "near-field" processes discussed in Chapter II. It has no regulatory implication whatsoever. However, the information on size and mixing conditions at the edge of the NFR is given as a useful guide to the discharge designer because mixing in the NFR is usually sensitive to design conditions, and therefore somewhat controllable. A notable exception is the effluent discharge into very shallow flow-limited streams where the actual discharge port design detail may have little bearing on instream concentrations.
>
> **Regulatory Mixing Zone (RMZ):** The RMZ corresponds to either: (1) the applicable mixing zone regulation with specified size dimensions, or (2) a preliminary proposal for a mixing zone (see Section 2.2.4 (ii)).
>
> **Toxic Dilution Zone (TDZ):** The TDZ corresponds to the EPA's definition of where toxic chemical concentrations may exceed the CMC value (see Section 2.2.3).
>
> **Region of Interest (ROI):** The ROI is a user defined region of the receiving water body where mixing conditions are to be analyzed. It is specified as the maximum analysis distance in the direction of mixed effluent flow and is particularly important when legal mixing zone restrictions do not exist or when information over a larger area is of interest.

(3) Data analysis section presents further details on toxic dilution zone criteria, regulatory mixing zone criteria, stagnant ambient environment information, and region of interest criteria.

(4) Design recommendations section contains design suggestions in three general areas for improving initial dilution. These include: (a) geometry variations in discharge port design, (b) sensitivity to ambient conditions, and (c) process variations in discharge flow characteristics. The user is given guidance on the potential changes in mixing conditions from varying parameter values within these groups.

Finally, SUM is also used as an interactive loop to guide the user back to DATIN to alter design variables and perform sensitivity studies. Different options for iteration exist on the **iteration menu** depending on what input data changes are to be made. The importance of performing an ample number of CORMIX iterations cannot be sufficiently stressed. To obtain a design that adequately meets water quality and engineering construction objectives, it is necessary to get a feel for the physical situation and its sensitivity to design changes through repeated system use.

3.7.2 CORMIX1, 2 or 3 Prediction File

The CORMIX1, 2 or 3 Prediction File is a detailed listing of all simulation input data as well as the predicted plume properties (plume shapes and concentration distributions) arranged by the individual flow modules that form part of the simulation. Additional information, such as encounter of local mixing zone regulations, plume contact with bottom or shoreline, etc., are listed in the output. Detailed output features are discussed in Chapter V.

3.7.3 CMXGRAPH Plots

The post-processing graphics package CMXGRAPH can be exercised flexibly by the user at different stages: directly after a CORMIX case prediction for an initial evaluation of the design case, or later to inspect or prepare plots for an earlier design case, or outside the CORMIX system to plot any plume predicted by CORMIX or CORJET. The user can view different views of the plume, with scaling and zooming possibilities. Finally, hardcopy printouts can be prepared through a direct print-screen option or by writing to a Postscript file. Details of the graphics feature are discussed in Chapter V.

3.8 Post-Processor Models CORJET and FFLOCATR: Input and Output Features

The near-field jet integral model CORJET and the far-field plume locator model FFLOCATR can be exercised both within the CORMIX system, with guided input data assembly, or separately, with a simple Fortran input file. In both cases, only limited data are needed. Chapter VI provides a detailed discussion of the data requirements.

The output from these models is displayed on-screen or as a printed file. Furthermore, CORJET output can also be plotted with the CMXGRAPH program (see Section 5.3).

3.9 Equipment Requirements, System Installation and Run Times

The minimum recommended hardware configuration required for CORMIX is an IBM-DOS compatible microcomputer with: (a) a minimum of 550Kb of available RAM memory, (b) approximately 3Mb of hard disk space, (c) DOS 3.3 or higher operating system, and (d) a minimum 80386 with math co-processor to provide acceptable performance, especially with plume graphics display. The system will run on systems with less advanced processors, however simulation times can be long.

The RAM memory requirement of CORMIX may present an obstacle to many users because the configuration requirements of many commercial applications packages and the installation of memory resident software, or running DOS from windows, frequently reduce available RAM memory to less than 550Kb. The amount of available RAM memory can be determined with the DOS command CHKDSK. Although there are numerous approaches for increasing the size of a computer's available RAM memory, the simplest way is "boot" the computer from a floppy "system" disk that contains no AUTOEXEC.BAT or CONFIG.SYS files which consume additional memory. This should be done just prior to beginning an analysis session since it will temporary disable programs that consume RAM memory. The CONFIG.SYS file should allow the number of open files to be set to at least 20 by including the line statement "files=20". At the completion of the analysis session, the computer should be "booted" from the hard drive to restore normal operations. A bootable floppy system disk can be created with the DOS command FORMAT a:/S.

The CORMIX must be installed on a hard disk drive. The directory structure of CORMIX (Table 3.1) is fixed; it gets set up during the installation process; and it consists of a subsystem root directory, called "CORMIX", and six sub-directories. Complete installation instructions are available with the CORMIX distribution diskette.

Depending on computer configuration, a typical CORMIX session for one discharge/ambient condition may take less than 5 minutes for an Pentium-based computer to about 20 minutes for an 80286-based computer if all necessary input data is at hand. In some unusual cases (such as attached flow classes, e.g. H1A5) the numerical simulation routines in HYDROn may take up to 10 minutes to converge on Pentium-based systems.

Table 3.1
Directory Structure

CORMIX
Version 3.1 June 1995, Version 3.2 September 1996

Directory Name	Comments
CORMIX	system root directory; contains VP-Expert system files, the knowledge base program CORMIX.kmp or kbs (system driver), and the start-up batch file CMX.bat, and several other batch files to be used for starting up CORJET, CMXGRAPH, and FFLOCATR when used independently
CORMIX\DATA	contains cache "fact" files exported from knowledge base programs
CORMIX\EXE	contains Fortran hydrodynamic simulation programs HYDROn and file manipulation programs (*.exe)
CORMIX\KBS	contains all knowledge base programs (*.kmp or *.kbs)
CORMIX\POST	contains three post-processor programs CORJET, CMXGRAPH, and FFLOCATR
CORMIX\POST\CJ	contains CORJET numerical prediction files (fn.CJT) and graphical postscript files (fn.Pvn, where v = view type, and n = 0 to 9)
CORMIX\POST\FF	contains FFLOCATR cumulative discharge input data files (*.FFI) and prediction files (fn.FFX)
CORMIX\SIM	contains simulation results (Fortran files "fn.CXn", where n = 1,2,3, and fn = user designated filenames) and graphical postscript files (fn.Pvn, where v = view type, and n = 0 to 9)
CORMIX\SIM\CXn	contains simulation data files for each subsystem n (cache files "fn.CXC" and record keeping file "summary")
CORMIX\TEXT	contains all user-requested advice files and flow descriptions (*.txt)

IV CORMIX Data Input

4.1 General Aspects of Interactive Data Input

All CORMIX data input occurs interactively in response to system prompts and is entirely guided by the system. The user is automatically prompted for a complete specification of: site/case descriptions, ambient conditions, discharge characteristics, and regulatory definitions. The data for each of these four topical areas are called **input data sequences** herein. Questions are asked in plain English. Advice menu options within the program are available to provide help on how to prepare and enter data values when clarification of the system prompts is needed. The contents of these are also available in the documentation reports (5,6,7).

Regular CORMIX versus FAST-CORMIX: Upon in its initial installation the CORMIX system speed is set to "Regular CORMIX". In this mode the user will see detailed input questions with ample explanations for each variable. Also there will be opportunities to consult advice sections. It is recommended that the *novice user* employ this mode for about a dozen or so CORMIX sessions until he/she has become thoroughly familiar with the system. The *advanced user* can switch to the "FAST-CORMIX" mode in which only short questions are asked, thereby greatly accelerating data input and compacting it on screen. Certain advice section are not available. The differences are illustrated in the following:

Examples of three questions asked in **Regular CORMIX:**

1)
```
Do you want detailed ADVICE on how to specify the ambient density
stratification?
      [no] [yes]
```

2)
```
Can the ambient density be considered 'UNIFORM' throughout the water column,
or
is there a 'NON-UNIFORM' vertical density stratification?
As practical guideline, uniformity can be assumed if the vertical density
variation between top and bottom is limited to 0.1 kg/m^3 or the  temperature
variation to 1 degC.
      [uniform] [non-uniform]
```

3)
```
What is the WIDTH of the channel in the vicinity of the discharge (m)?
```

Corresponding questions in **FAST-CORMIX:**

1) <Question not asked>

2)
```
AMBIENT DENSITY?
      [uniform] [non-uniform]
```

3)
```
Channel WIDTH (m)?
```

Data can be entered in an **open format** without concern for letter case or decimal placement. The only constraint is that <u>the following characters may not be entered</u> in response to any question:

+ = { } , < > ' " / \ ;

The system checks data entries for consistency with question type (e.g. an alphabetic character for water depth), obvious physical errors (e.g. a negative length), possible inconsistencies with previous entries (e.g. an angular value implying that a port points directly back to the shoreline) and situations outside the ranges of model applicability. Inconsistency with question type and obvious physical errors require immediate re-entry while possible inconsistencies with previous entries lead to a warning label and the opportunity for later correction. Entries specifying situations outside the ranges of model applicability usually require the re-entry of the entire data segment.

Warning: No attempt should be made to alter input data by manipulating any of the data files that are used by the HYDROn Fortran programs and execute these programs separately without using the VP-Expert segments DATIN, PARAM, and CLASS. Because of the inherent error and compatibility checking of input data within these program segments, unreliable prediction may result if they are by-passed!

As discussed in Chapter III, data input occurs in three or four program segments that load automatically. At the end of each data sequence (usually of the order of 5 to 20 items long) the entire sequence is displayed and the user is requested to accept or not accept the sequence. If it is not accepted, i.e. an error has been made, the user has another opportunity for entering the sequence. If an error is detected earlier there is no way of correcting immediately, it is best then to give a short answer (e.g. the value of 1) to all remaining questions and thus quickly move to the end of the sequence for the re-start opportunity.

Due to the similarity of data entry, a common description is given for all input data sequences, except discharge data to which a separate subsection for each CORMIXn subsystem is devoted below. Further guidance on data specification can be obtained from examining the case studies in the Appendices and from the documentation manuals (5,6,7). Following the discussion of input data sequences, units of measure conversion factors and checklists for input preparation are presented.

All the data input requirements of CORMIX are included in the **Checklist for Data Preparation** (see following page) that can be photocopied by the reader for future multiple use. The checklist aids in the assembly and preparation of this data prior to beginning an analysis to verify that all necessary data are available.

4.2 Site/Case Identifier Data

The first input data sequence determines basic information needed for the program to operate. These include: a two-part identifier for labeling output and a computer file name.

It is necessary to specify three site/case labels that facilitate the rapid identification of printed output and aid in good record-keeping. The system provides for one label called SITE NAME (e.g. Blue River), another called DESIGN CASE (e.g. 7Q10-low-flow, or High-velocity-port).

The user needs to supply a DOS-compatible FILE NAME, up to eight characters long, and without extension (e.g. sdif7q10). CORMIX will use that user-specified file name *fn*, and create, transfer, or store intermediate or final data files with that same file name, but with different extensions. The most important of these are the two output data files, SIM*fn*.CXn and SIM\CXn*fn*.CXC, where n = 1, 2 or 3, which are discussed further in Chapter V.

4.3 Ambient Data

Ambient conditions are defined by the geometric and hydrographic conditions in the vicinity of the discharge. Due to the significant effect of boundary interactions on mixing processes, the ambient data requirements for the **laterally bounded** and **unbounded** analysis situations are presented separately in the discussions below. CORMIX analyses, as all mixing zone evaluations, are usually carried out under the assumption of **steady-state** ambient conditions. Even though the actual water environment is never in a true steady-state, this assumption is usually adequate since mixing processes are quite rapid relative to the time scale of hydrographic variations. In highly **unsteady tidal reversing flows** the assumption is no longer valid and significant concentration build-up can occur. CORMIX will assess this situation and compute some re-entrainment effects on plume behavior. The data requirements for that purpose are discussed in the Section 4.3.3. Following are discussions on ambient

CHECKLIST FOR DATA PREPARATION

CORMIX – CORNELL MIXING ZONE EXPERT SYSTEM -- Version 3.00-3.20

SITE Name ____________________ Date:
Design CASE ____________________ Prepared by:
DOS FILE NAME ____________________ (w/o extension)

AMBIENT DATA: Water body is bounded/unbounded
Water body depth ______ m If bounded: Width ______ m
Depth at discharge ______ m Appearance 1/2/3
If steady: Ambient flowrate ______ m^3/s or: Ambient velocity ______ m/s

If tidal: Tidal period ______ hr Max. tidal velocity ______ m/s
At time ______ hr before/at/after slack Tidal velocity at this time ______ m/s

Manning's n ______ or: Darcy-Weisbach f ______
Wind speed ______ m/s
Density data: UNITS: Density...kg/m^3 / Temperature...°C
Water body is fresh/salt water If fresh: Specify as density/temp. values
If uniform: Average density/temp. ______

If stratified: Density/temp. at surface ______
Stratification type A/B/C Density/temp. at bottom ______
If B/C: Pycnocline height ______ m If C: Density/temp. jump ______

DISCHARGE DATA: Specify geometry for CORMIX1 or 2 or 3

SUBMERGED SINGLE PORT DISCHARGE – CORMIX1
Nearest bank is on left/right Distance to nearest bank ______ m
Vertical angle THETA ______ ° Horizontal angle SIGMA ______ °
Port diameter ______ m or: Port area ______ m^2
Port height ______ m

SUBMERGED MULTIPORT DIFFUSER DISCHARGE – CORMIX2
Nearest bank is on left/right Distance to one endpoint ______ m
Diffuser length ______ m to other endpoint ______ m
Total number of openings ______ m Port height ______ m
Port diameter ______ m with contraction ratio ______
Diffuser arrangement/type unidirectional / staged / alternating or vertical
Alignment angle GAMMA ______ ° Horizontal angle SIGMA ______ °
Vertical angle THETA ______ ° Relative orientation BETA ______ °

BUOYANT SURFACE DISCHARGE – CORMIX3
Discharge located on left/right bank Configuration flush/protruding/co-flowing
Horizontal angle SIGMA ______ ° If protruding: Dist. from bank ______ m
Depth at discharge ______ m Bottom slope ______ °
If rectangular Width ______ m or: If circular Diameter ______ m
discharge channel: Depth ______ m pipe: Bottom invert depth ______ m

Effluent: Flow rate ______ m^3/s or: Effluent velocity ______ m/s
Effluent density ______ kg/m^3 or: Effluent temperature ______ °C
Heated discharge? yes/no If yes: Heat loss coefficient ______ W/m^2,°C
Concentration units ______ Effluent concentration ______
Conservative substance? yes/no If no: Decay coefficient ______ /day

MIXING ZONE DATA:
Is effluent toxic? yes/no If yes: CMC ______ CCC ______
WQ stand./conventional poll.? yes/no If yes: value of standard ______
Any mixing zone specified? yes/no If yes: distance ______ m or width ______ % or m
or area ______ % or m^2

Region of interest ______ m Grid intervals for display ______ density specification and on wind effects.

CORMIX requires that the actual cross-section of the ambient water body be described by a rectangular channel that may be bounded laterally or unbounded. Furthermore, that channel is assumed to be uniform in the downstream direction, following the mean flow of the actual water body that may be non-uniform or meandering. The process of describing a receiving water body's geometry with a rectangular cross-section is herein called **schematization.**

Additional aids exist for the CORMIX user for interpreting plume behavior in the far-field of actual non-uniform (winding or meandering) flows in rivers or estuaries (see Section 6.2 for the post-processor option FFLOCATR).

The first step towards specifying the ambient conditions is to determine whether a receiving water body should be considered "bounded" or "unbounded." To do this, as well as answer other questions on the ambient geometry, it is usually necessary to have access to cross-sectional diagrams of the water body. These should show the area normal to the ambient flow direction at the discharge site and at locations further downstream. If the water body is constrained on both sides by banks such as in rivers, streams, narrow estuaries, and other narrow watercourses, then it should be considered "bounded." However, in some cases the discharge is located close to one bank or shore while the other bank is for practical purposes very far away. When interaction of the effluent plume with that other bank or shore is impossible or unlikely, then the situation should be considered "unbounded." This would include discharges into wide lakes, wide estuaries, and coastal areas.

4.3.1 Bounded Cross-Section

Both geometric (bathymetric) and hydrographic (ambient discharge) data should be used for defining the appropriate rectangular cross-section. This schematization may be quite evident for well-channeled and regular rivers or artificial channels. For highly irregular cross-sections, it may require more judgment and perhaps several iterations of the analysis to get a better feel on the sensitivity of the results to the assumed cross-sectional shape.

In any case, the user is advised to consider the following comments:

a) Be aware that a particular flow condition such as a river discharge is usually associated with a certain water surface elevation or "stage." Data for a stage-discharge relationship is normally available from a USGS office; otherwise it can be obtained from a separate hydraulic analysis or from field measurements.

In the simplest case of a river flow, if river depth is known for a certain flow condition (subscript 1 in the following) corresponding perhaps to the situation at the time of a field study, then the depth for a given design (e.g. low) flow (subscript 2) can be predicted from Manning's equation

$$HA_2 = HA_1 \left[\frac{QA_2}{QA_1} \right]^{\frac{3}{5}}$$

in which QA is the ambient river flow and HA the mean ambient depth. This approach assumes that the both the ambient width and frictional characteristics of the channel (i.e. Manning's n) remain approximately the same during such a stage change.

b) For the given stage/river discharge combination to be analyzed, assemble plots showing the cross-sections at the discharge and several downstream locations. Examine these to determine an "equivalent rectangular cross-sectional area." Very shallow bank areas or shallow floodways may be neglected as unimportant for effluent transport. Also, more weight should be given to the cross-sections at, and close to, the discharge location since these will likely have the greatest effect on near-field processes. Figure 4.1a provides an example of the schematization process for a river or estuary cross-section.

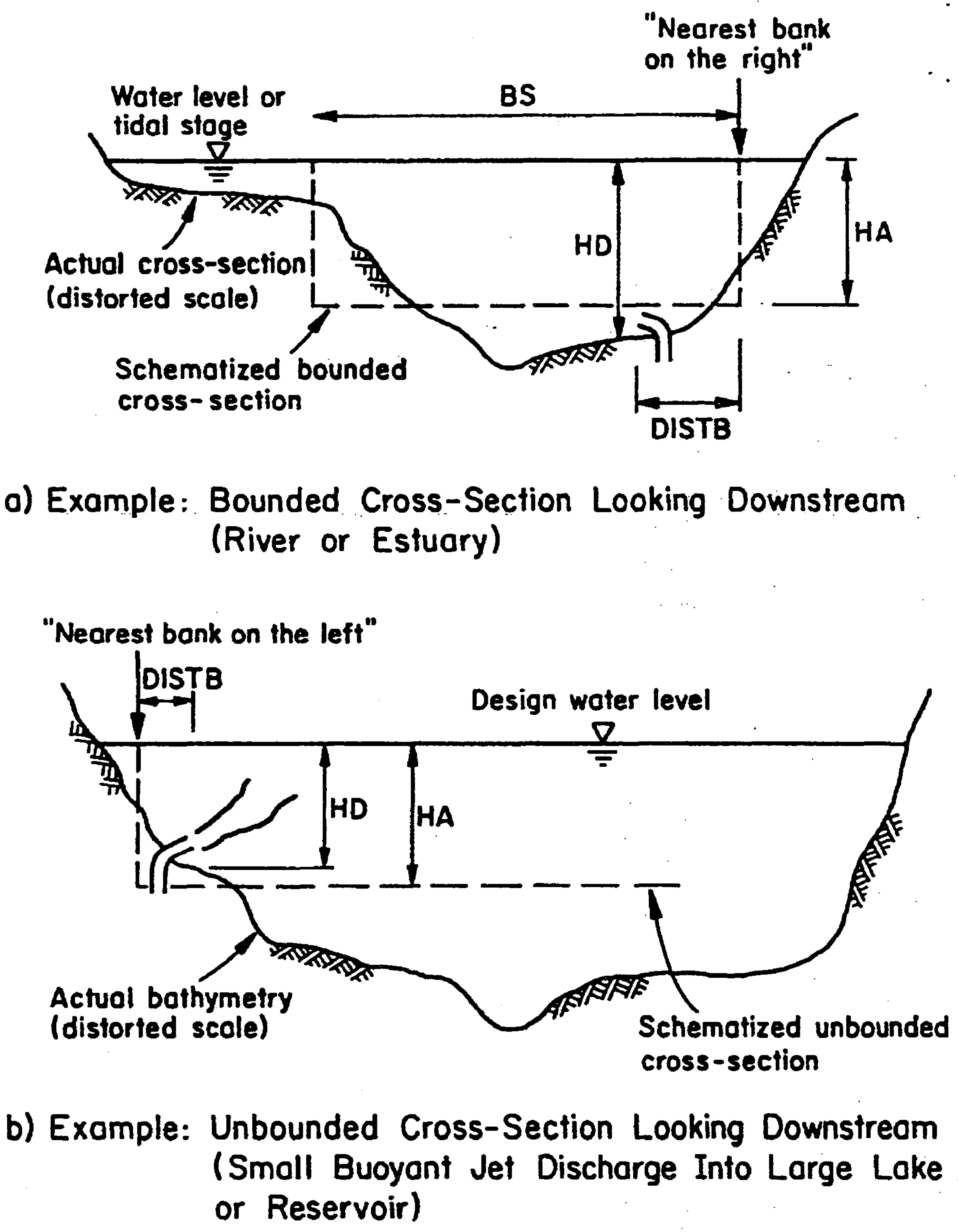


Figure 4.1: Examples of the schematization process for preparing CORMIX input data on ambient cross-sectional conditions

c) The input data values for **surface width (BS)** and **(average) depth (HA)** should be determined from the equivalent rectangular cross-sectional area. When ambient discharge and ambient velocity data are available, the reasonableness of the schematization should be checked with the continuity relation. It specifies that ambient discharge equals velocity times cross-sectional area, where the area is given by the product of average width and depth.

The discussion of the cumulative discharge method (see Section 6.2 and Figure 6.2 for an illustration) will provide further perspective on the choice of these variables.

d) CORMIX also requires specification of the **actual water depth (HD)** in the general discharge location to describe local bathymetric features. A check is built in allowing the local depth HD not to differ from the schematized average depth HA by more than +/- 30%. This restriction is included to prevent CORMIX misuse in several discharge/ambient combinations involving strongly non-uniform channels. Alternative schematizations can be explored by the user to work around the restriction. The choice for these alternatives may be influenced somewhat by the expected plume pattern. As an example, Figure 4.1b illustrates a small buoyant discharge that is located on the side slope of a deep reservoir and that is rising upward. In this situation, the correct representation of the deeper mean reservoir depth is irrelevant for plume predictions. Although the illustration is for an unbounded example, the comments on choice of HA apply here, too.

When schematizing HA and HD in highly non-uniform conditions, HD is the variable that usually influences near-field mixing, while HA is important for far-field transport and never influences the near-field.

e) The **ambient discharge (QA)** or **mean ambient velocity (UA)** may be used to specify the ambient flow condition. Depending which is specified, the program will calculate and display the other. The displayed value should be checked to see whether it is consistent with schematizations and continuity principles discussed above.

The simulation of **stagnant conditions** should usually be avoided. If zero or a very small value for ambient velocity or discharge is entered, CORMIX will label the ambient environment as stagnant. In this case, CORMIX will predict only the near-field of the discharge, since steady-state far-field processes require a mean transport velocity. Although stagnant conditions often, but not necessarily always, represent the extreme limiting case for a dilution prediction, a real water body never is truly stagnant. Therefore, a more realistic assumption for natural water bodies would be to consider a small, but finite ambient crossflow.

f) As a measure of the roughness characteristics in the channel the value of **Manning's n**, or alternatively of the **Darcy-Weisbach friction factor f**, must be specified. Friction values are useful for applications in laboratory studies. If Manning's n is given, as is preferable for field cases, CORMIX internally converts it to an f friction value using the following equation

$$f = 8g\frac{n^2}{HA^{1/3}}$$

in which g = 9.81 m/s^2.

The friction parameters influence the mixing process only in the final far-field diffusion stage, and do not have a large impact on the predictions. Generally, if these values can be estimated within +/-30%, the far-field predictions will vary by +/-10% at the most. The following list is a brief guide for specification of Manning's n values; additional details are available in hydraulics textbooks (e.g. 24).

g) The **channel appearance** can have an effect on the far field mixing by increasing turbulent diffusivity for the passive mixing process, but will not significantly affect near-field mixing. Three channel appearance types are allowed in CORMIX. Type 1 are fairly straight and uniform channels. Type 2 have moderate downstream meander with a non-uniform channel. Type 3 are strongly winding and have highly irregular downstream cross-sections.

Channel type	Manning's n
Smooth earth channel, no weeds	0.020
Earth channel, some stones and weeds	0.025
Clean and straight natural rivers	0.025 - 0.030
Winding channel, with pools and shoals	0.033 - 0.040
Very weedy streams, winding, overgrown	0.050 - 0.150
Clean straight alluvial channels (d = 75% sediment grain size in feet)	$0.031\ d^{1/6}$

4.3.2 Unbounded Cross-section

Both hydrographic and geometric information are closely linked in this case. The following comments apply:

a) From lake or reservoir elevation or tidal stage data, determine the water depth(s) for the receiving water condition to be analyzed.

b) For the given receiving water condition to be analyzed, assemble plots showing water depth as a function of distance from the shore for the discharge location and for several positions downstream along the ambient current direction.

c) If detailed hydrographic data from field surveys or from hydraulic numerical model calculations are available, determine the **"cumulative ambient discharge"** from the shore to the discharge location for the discharge cross-section. For each of the subsequent downstream cross-sections, determine the distance from the shore at which the same cumulative ambient discharge has been attained. Mark this position on all cross-sectional profiles. Examine the vertically averaged velocity and the depth at these positions to determine typical values for the **ambient depth (HA)** and **ambient velocity (UA)** input specifications. The conditions at, and close to, the discharge location should be given the most weight. The **distance from the shore (DISTB)** for the outfall location is typically specified as the cumulative ambient discharge divided by the product UA times HA.

When detailed hydrographic data are unavailable, data or estimates of the vertically averaged velocity at the discharge location can be used to specify HA, UA, and DISTB. First, determine the cumulative cross-sectional area from the shore to the discharge location for the discharge cross-section. For each of the subsequent downstream cross-sections, mark the position where the cumulative cross-sectional area has the same value as at the discharge cross-section. Then proceed as discussed in the preceding paragraph.

d) The specification of the **actual water depth at the submerged discharge location (HD)** in CORMIX1 and 2 is governed by considerations that are similar to those discussed earlier for bounded flow situations discussed above. Figure 4.1b shows an illustration of the schematization for a small buoyant discharge located on the side slope of a deep reservoir. The plume is expected to rise upward and stay close to one shore, with bottom contact and vertical mixing not expected. In this situation, no emphasis on replicating the mean reservoir depth and the actual width is necessary. However, care must still be taken to specify an ambient mean velocity that is: (a) characteristic of the actual reservoir and (b) not determined using the reduced depth assumption.

The specification of HD for CORMIX3 is dictated by the depth condition some distance offshore from the discharge exit. It does not describe the conditions immediately in front of the discharge channel exit. When in doubt, set HD simply equal to HA in the CORMIX3 case.

e) Either **Manning's n** or the **Darcy-Weisbach friction factor f** can be specified for the ambient roughness characteristics as described previously for the bounded case (see above). If the unbounded case represents a large lake or coastal area, it is often preferable to use the friction factor f. Typical f values for such open water bodies range from 0.020 to 0.030, with larger values for rougher conditions.

4.3.3 Tidal Reversing Ambient Conditions

When predictions are desired in an unsteady ambient flow field, information on the tidal cycle must be supplied. In general, estuaries or coastal waters can exhibit considerable complexity with variations in both velocity magnitude, direction and water depth. As an example, Figure 4.2 shows the time history of tidal velocities and tidal height for a mean tidal cycle at some site in Long Island Sound. The tidal height varies between mean Low Water (MLW) and Mean High water (MHW).

The tidal velocity changes its direction twice during the tidal cycle at times called slack tide. One of these times occurs near, but is not necessarily coincident with, the time MLW and is referred to as Low Water Slack (LWS). The slack period near MHW is referred to as High Water Slack (HWS). The rate reversal (time gradient of the tidal velocity) near these slack tides is of considerable importance for the concentration build-up in the transient discharge plume, as tidal reversals will reduce the effective dilution of a discharge by re-entraining the discharge plume remaining from the previous tidal cycle (8). Hence, CORMIX needs some information on the ambient design conditions relative to any of the two slack tides.

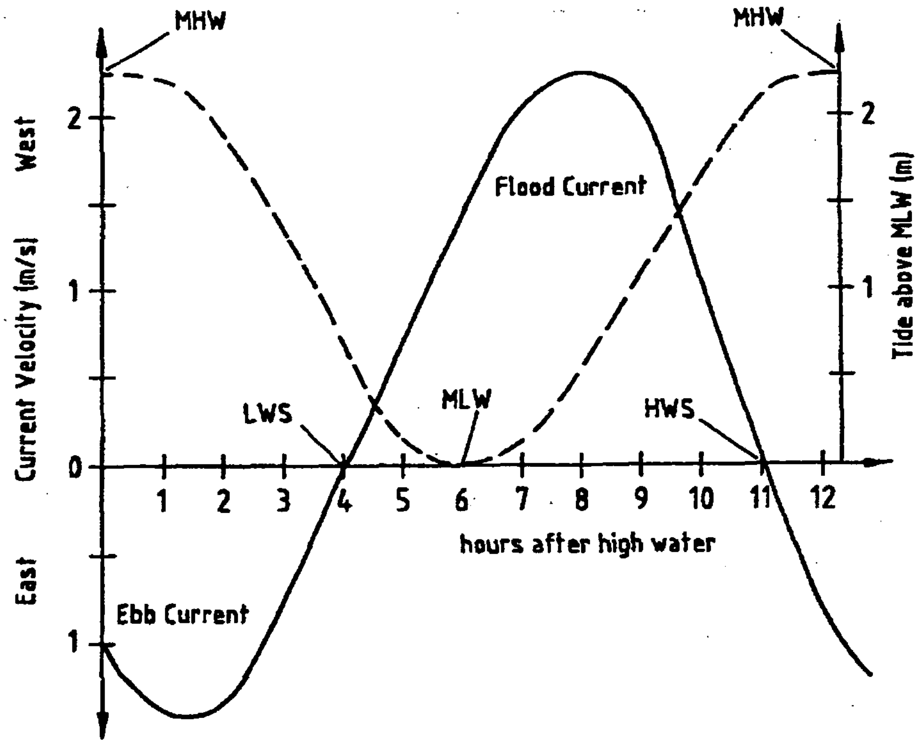


Figure 4.2: Example of tidal cycle, showing stage and velocity as a function of time after Mean High Water (MHW)

The **tidal period (PERIOD)** must be supplied; in most cases it is 12.4 hours, but in some locations it may vary slightly. The **maximum tidal velocity (UAmax)** for the location must be specified; this can usually be taken as the average of the absolute values of the two actual maxima, independent of their direction. A CORMIX design case consists then of an instantaneous ambient condition, before, at or after one of the two slack tides. Hence, the analyst must specify the **time** (in hours) **before, at, or after slack** that defines the design condition, followed by the actual **tidal ambient velocity (UA)** at that time. The ambient depth conditions are then those corresponding to that time.

In general, tidal simulations should be repeated for several time intervals (usually hourly or two-hourly intervals will suffice) before and after slack time to determine plume characteristics in unsteady ambient conditions.

Strongly unsteady conditions can also occur in other environments, such as in wind-induced current reversals in shallow lakes or coastal areas. In this case, any typical reversal period can be analyzed following an approach similar to the above.

4.3.4 Ambient Density Specification

Information about the density distribution in the ambient water body is very important for the correct prediction of effluent discharge plume behavior. CORMIX first inquires whether the ambient water is **fresh water** or **non-fresh** (i.e. brackish or saline). If the ambient water is fresh and above 4 °C, the system provides the option of entering ambient temperature data so that the ambient density values can be internally computed from an equation of state. This is the recommended option for specifying the density of fresh water, even though ambient temperature per se is not needed for the analysis of mixing conditions. In the case of salt water conditions, Figure 4.3 is included as a practical guide for specifying the density if "salinity values" in parts-per-thousand (ppt) are available for the water body. Typical open ocean salinities are in the range 33 - 35 ppt.

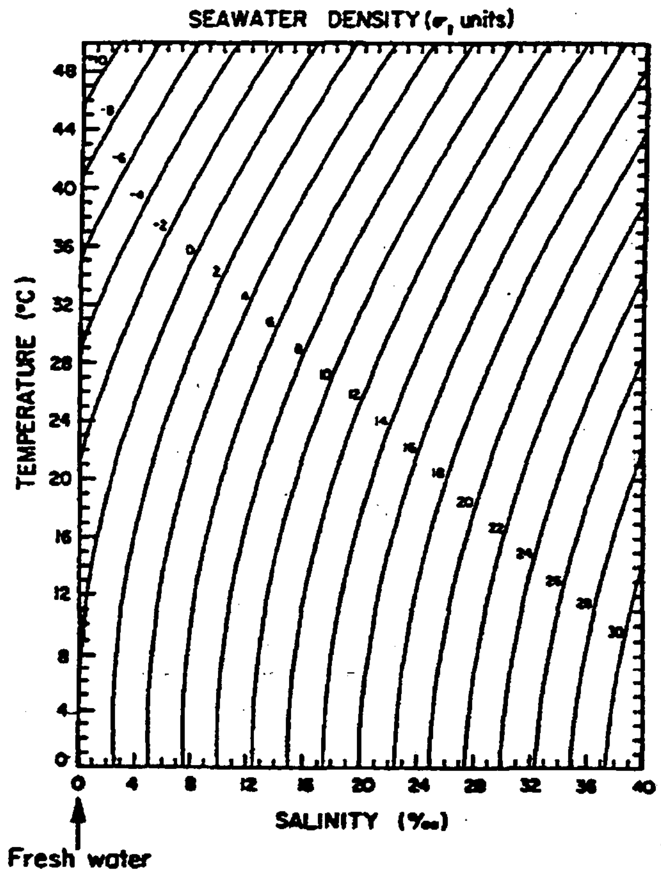
The user then specifies whether the ambient density (or temperature) can be considered as **uniform** or as **non-uniform** within the water body, and in particular within the expected plume regions. As a practical guide, vertical variation in density of less than 0.1 kg/m^3 or in temperature of less than 1 °C can be neglected. For uniform conditions, the **average ambient density** or **average temperature** must be specified.

When conditions are non-uniform, CORMIX requires that the actual measured vertical density distribution be approximated by one of three schematic stratification profile types illustrated in Figure 4.4. These are: Type A, linear density profile; Type B, two-layer system with constant densities and density jump; Type C, constant density surface layer with linear density profile in bottom layer separated by a density jump. Corresponding profile types exist for approximating a temperature distribution when it is used for specifying the density distribution.

Note: When in doubt about the specification of the ambient density values it is reasonable to first simplify as much as possible. The sensitivity of a given assumption can be explored in subsequent CORMIX simulations. Furthermore, if CORMIX indicates indeed a flow configuration (flow class) with near-field stability, additional studies with the post-processor option CORJET (see Section 6.1) can be performed to investigate *any arbitrary density distribution.*

After selecting the stratification approximation to be used, the user then enters all appropriate density (or temperature) values and **pycnocline heights (HINT)** to fully specify the profiles. The pycnocline is defined as zone or level of strong density change that separates the upper and lower layers of the water column. The program checks the density specification to insure that stable ambient stratification exists (i.e. the density at higher elevations must not exceed that at lower elevations).

Note that a dynamically correct approximation of the actua ldensity distribution should keep a balance between over-and under-estimationof the actual data similar to a best-fit in regression analysis. If simulation results indicate internal plume trapping, then it is



Density [kg/m³] = 1000.0 + σ_t

Figure 4.3: Diagram for density of seawater as a function of temperature and salinity

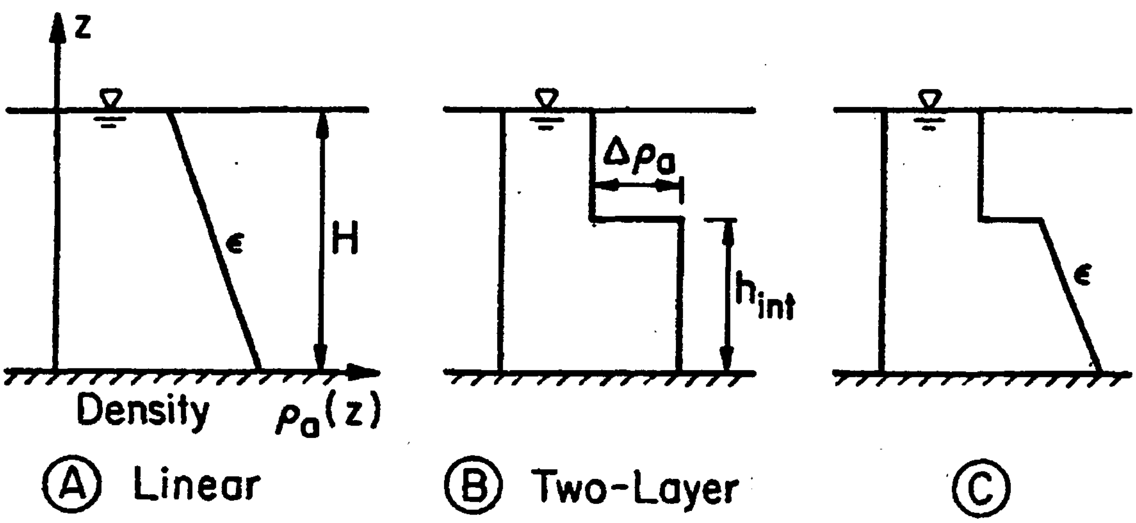


Figure 4.4: Different approximations for representing the ambient density stratification

desirable to test –through repeated use of CORMIX– different approximations (i.e. with different stratification types and/or parameter values) in order to evaluate the sensitivity of the resulting model predictions.

4.3.5 Wind speed

When specifying the **wind speed (UW)** at design conditions, it should be kept in mind that the wind is unimportant for near-field mixing, but may critically affect plume behavior in the far-field. This is especially important for heated discharges in the buoyant spreading regions. Wind speed data from adjacent meteorological stations is usually sufficient for that purpose.

The following guidelines are useful when actual measured data are not available. The typical wind speed categories measured at the 10 m level are:

- breeze (0-3 m/s)
- light wind (3-15 m/s)
- strong wind (15-30 m/s)

If field data are not available, consider using the recommended value of 2 m/s to represent conservative design conditions. An extreme low value of 0 m/s is usually unrealistic for field conditions, but useful when comparing to laboratory data. A wind speed of 15 m/s is the maximum value allowed in CORMIX.

4.4. Discharge Data: CORMIX1

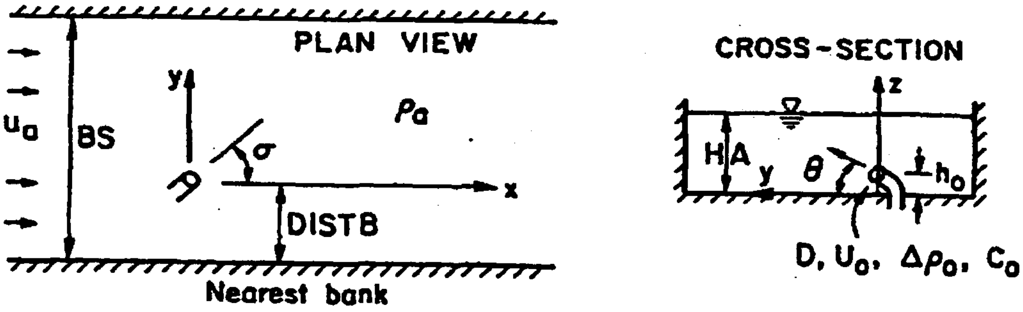
Figure 4.5a is a definition sketch giving the geometry and flow characteristics for a submerged single port discharge within the schematized cross-section.

4.4.1 Discharge Geometry

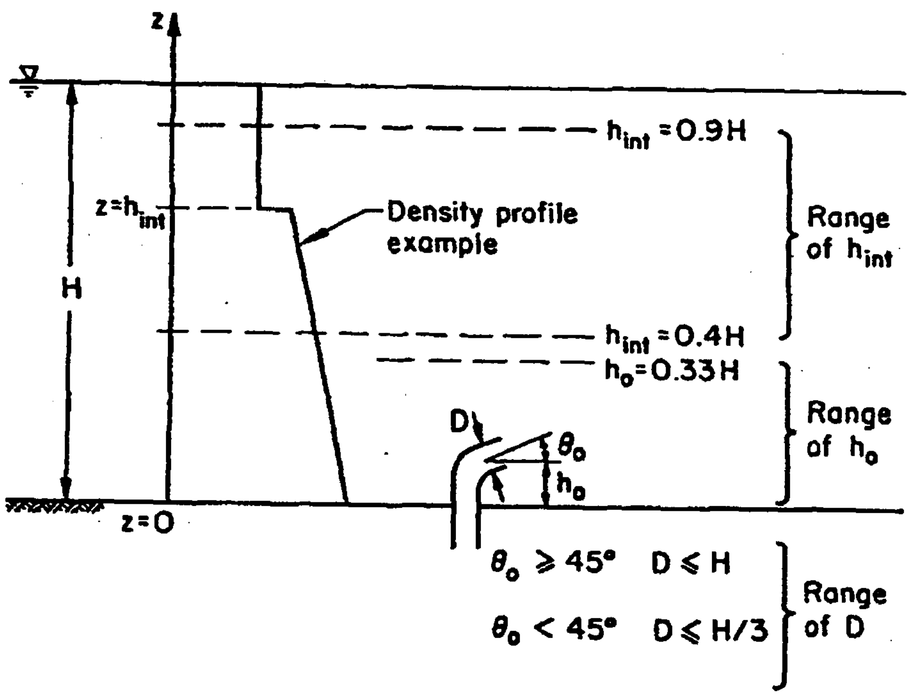
To allow the establishment of a reference coordinate system and orient the discharge to that reference, CORMIX1 requires the specification of 6 data entries. These specifications are illustrated in Figure 4.5a and include: (a) location of the **nearest bank** (i.e. left or right) as seen by an observer looking downstream in the direction of the flow, (b) **distance to the nearest bank (DISTB)**, (c) port **radius** (or **cross-sectional area** for non-circular shaped ports) (*Note:* The specification of the port dimension should account for any contraction effects that the effluent jet may experience upon leaving the port/nozzle!) , (d) **height of the port (H0)** center above the bottom, (e) **vertical angle of discharge (THETA)** between the port centerline and a horizontal plane, and (f) **horizontal angle of discharge (SIGMA)** measured counterclockwise from the ambient current direction (x-axis) to the plan projection of the port centerline. Angle THETA may range between -45° and 90°. As examples, the vertical angle is 90° for a discharge pointing vertically upward, and it is 0° for a horizontal discharge. Angle SIGMA may range between 0° and 360 °. As examples, the horizontal angle is 0° (or 360 °) when the port points downstream in the ambient flow direction, and it is 90°, when the port points to the left of the ambient flow direction.

In order to prevent an inappropriate system application, CORMIX1 checks the specified geometry for compliance with the three criteria illustrated in Figure 4.5b. These are: (a) the port height (H0) value must not exceed one-third of the local water depth (HD) value, (b) the port diameter value must not exceed HD's value for near-vertical designs, and one-third of HD's value for near-horizontal designs, and (c) the pycnocline value must be within the 40 to 90 percent range of HD's value. The port height restriction results from the fact that CORMIX1 only applies to submerged discharge applications.

In ordinary design practice, submerged implies a discharge close to the bottom, and not anywhere within the main water column or near the water surface. The port diameter restriction excludes very large discharge diameters relative to the actual water depth since these are unrealistic and/or undesirable. The distance separating the upper and lower layers of the ambient density profile type B or C is restricted in order to prevent: (a) discharges into the upper layer or (b) an unrealistically thick plume relative to a thin upper layer. For those few extreme situations that would normally be limited by the above restrictions, Section 7.4 of Doneker and Jirka (5) contains a number of hints on how to conduct these difficult analyses; only advanced users should attempt these techniques.



a) Definition Diagram CORMIX1 (Special case: HA=HD)



b) Limits of Applicability CORMIX1

Figure 4.5: CORMIX1 discharge geometry and restrictions

4.4.2 Port Discharge Flow

For discharge characteristics, CORMIX1 requires the specification of 3 data entries. These specifications include: (a) the **discharge flow rate (Q0)** or **discharge velocity (U0)**, (b) the **discharge density** or **discharge temperature** for an essentially freshwater discharge, and (c) the **discharge concentration** of the material of interest. The Q0 and U0 variables are related through the port cross-sectional area and the program computes and displays the alternate value allowing for user inspection and verification. For a freshwater discharge, discharge density can be directly related to temperature via an equation of state since the addition of any pollutant or tracer has negligible effect on density.

The specification of the pollutant in the effluent is described in Section 4.7 below.

4.5 Discharge Data: CORMIX2

A generalized definition sketch showing the geometry and flow characteristics for a typical multiport diffuser installation is provided in Figure 4.6a. Due to the great number of complexities which may rise in describing an existing or proposed diffuser design, a few definitions are introduced prior to discussing actual data requirements of CORMIX2.

A **multiport diffuser** is a linear structure consisting of many more or less closely spaced ports or nozzles which inject a series of turbulent jets at high velocity into the ambient receiving water body. These ports or nozzles may be connected to vertical risers attached to an underground pipe or tunnel or they may simply be openings in a pipe lying on the bottom.

The **diffuser line** (or axis) is a line connecting the first port or nozzle and the last port or nozzle. Generally, the diffuser line will coincide with the connecting pipe or tunnel. CORMIX2 will assume a straight diffuser line. If the actual diffuser pipe has bends or directional changes it must be approximated by a straight diffuser line.

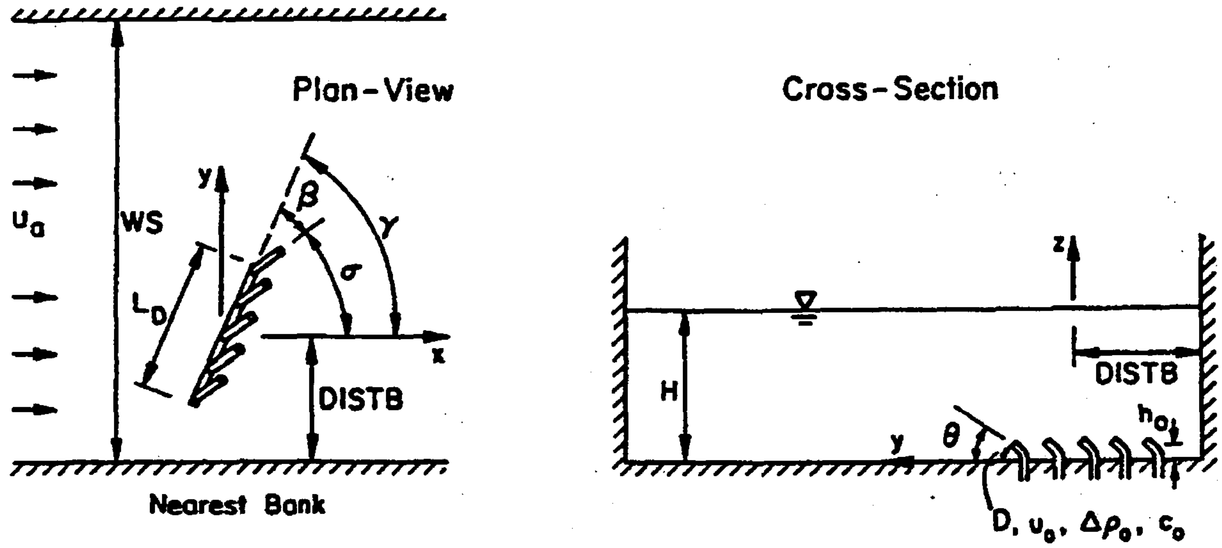
The **diffuser length** is the distance from the first to the last port or nozzle. The origin of the coordinate system used by CORMIX2 is located at the center (mid-point) of the diffuser line. The only exception is when the diffuser line starts at the shore; then the origin is located directly at the shore.

CORMIX2 can analyze discharges from the three major diffuser types used in common engineering practice. These are illustrated in Figure 4.7 and include: (a) the **unidirectional diffuser** where all ports (or nozzles) point to one side of the diffuser line and are oriented more or less normally to the diffuser line and more or less horizontally; (b) the **staged diffuser** where all ports point in one direction generally following the diffuser line with small deviations to either side of the diffuser line and are oriented more or less horizontally; and (c) the **alternating diffuser** where the ports do not point in a nearly single horizontal direction. In the latter case, the ports may point more or less horizontally in an alternating fashion to both sides of the diffuser line or they may point upward, more or less vertically.

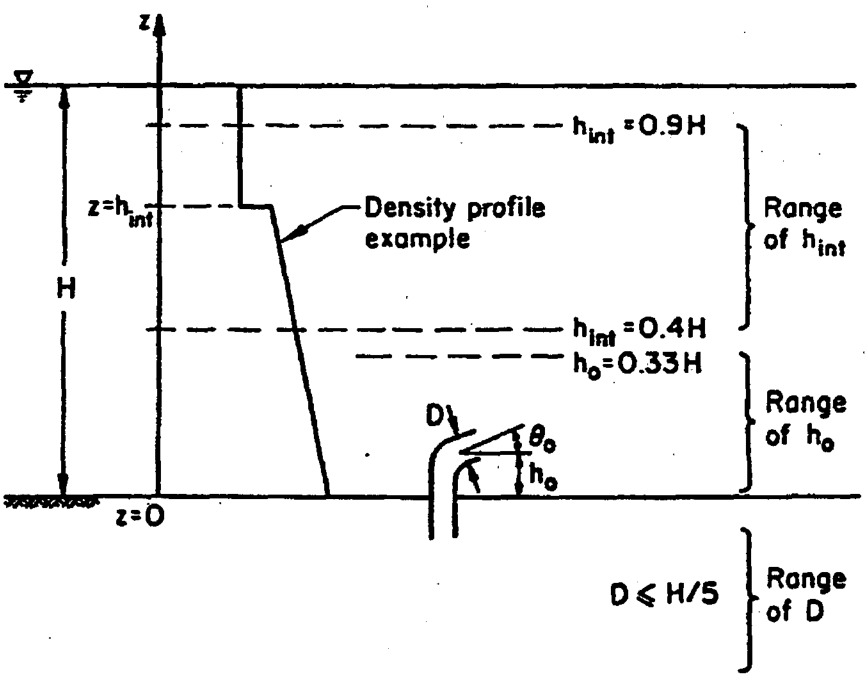
4.5.1 Diffuser Geometry

CORMIX2 assumes uniform discharge conditions along the diffuser line. This includes the local ambient receiving water depth (HD) and discharge parameters such as port size, port spacing and discharge per port, etc. If the actual receiving water depth is variable (e.g. due to an offshore slope), it should be approximated by the mean depth along the diffuser line with a possible bias to the more shallow near-shore conditions. Similarly, mean values should be used to specify variable diffuser geometry when it occurs.

To allow the establishment of a reference coordinate system and orient the discharge to that reference, CORMIX2 requires the specification of 13 data entries. These specifications are illustrated in Figure 4.6a and include: (a) location of the **nearest bank** (i.e. left or right) as seen by an observer looking downstream in the direction of the flow, (b) average **distance to the nearest bank (DISTB)**, (c) **average diameter (D0)** of the discharge ports or nozzles, (d) **contraction ratio** for the port/nozzle is required (This can range from 1 for well rounded ports --usual value-- down to 0.6 for sharp-edged orifices), (e) average



a) Definition Diagram CORMIX2



b) Limits of Applicability CORMIX2

Figure 4.6: CORMIX2 discharge geometry and restrictions

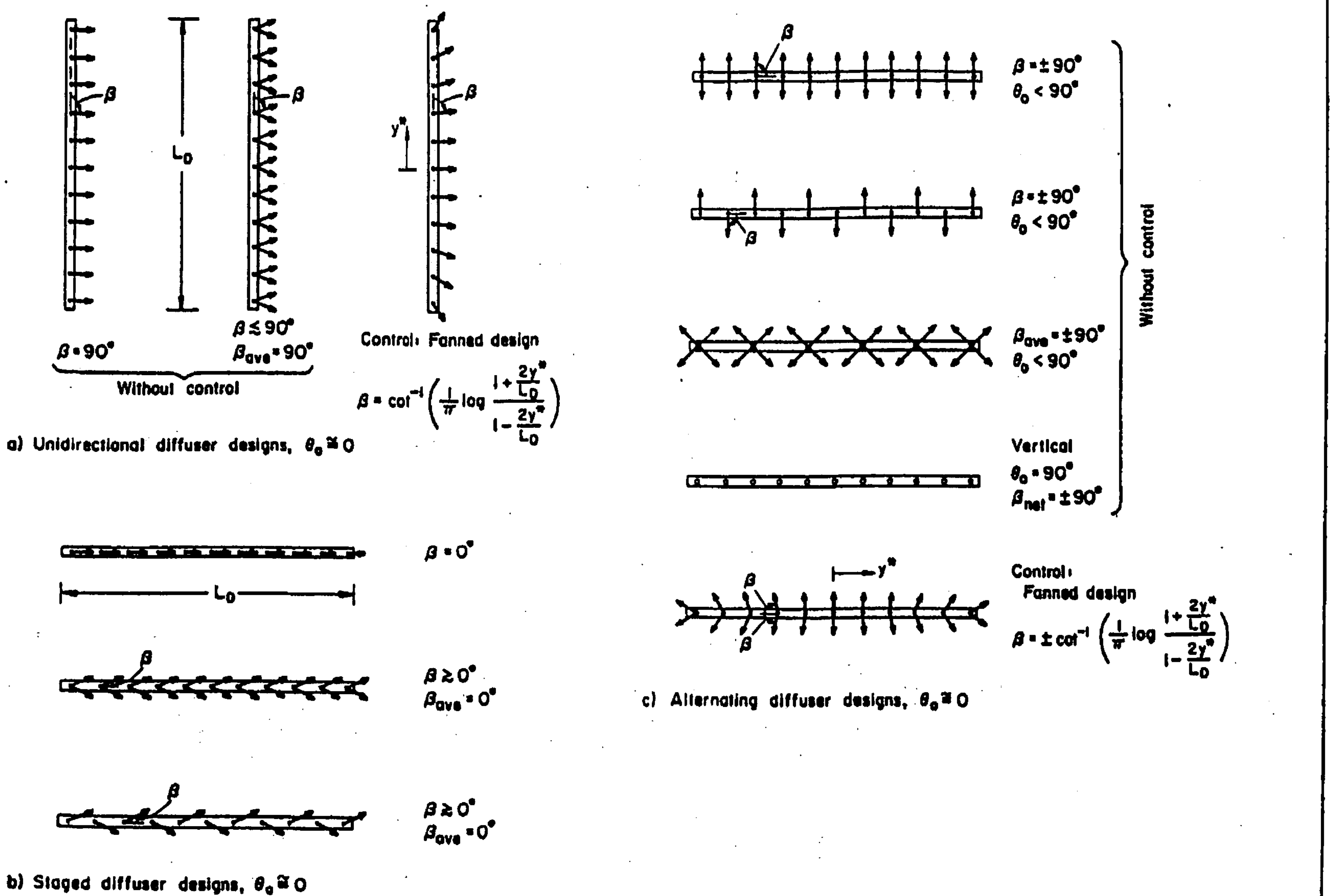


Figure 4.7: Configurations of common multiport diffuser types

height of the port centers (H0) above the bottom, (f) average **vertical angle of discharge (THETA)** between the port centerlines and a horizontal plane (-45 and 90°), (g)for the unidirectional and staged diffusers only, the average **horizontal angle of discharge (SIGMA)** measured counterclockwise from the ambient current direction (x-axis) to the plan projection of the port centerlines (0 to 360°), (h) approximate straight-line **diffuser length (LD)** between the first and last ports or risers, (I) **distance from the shore to the first and last ports or risers (YB1, YB2)** of the diffuser line, (j) number of ports or risers and the number of ports per riser if risers are present, (k) average **alignment angle (GAMMA)** measured counterclockwise from the ambient current direction (x-axis) to the diffuser axis (0 to 180 °), and (l) for the unidirectional and staged diffusers only, **relative orientation angle (BETA)** measured either clockwise or counterclockwise from the average plan projection of the port centerlines to the nearest diffuser axis (0 to 90°). Note that CORMIX2 always assumes a uniform spacing between risers or between ports, and a round port cross-sectional shape.

As examples of angle specifications, THETA is 0 degrees for a horizontal discharge and it is +90 degrees for a vertically upward discharge, SIGMA is 0 degrees (or 360°) when the ports point downstream in the ambient flow direction and it is 90 degrees when the ports point to the left of the ambient flow direction, GAMMA is 0 degrees (or 180°) for a parallel diffuser and it is 90 degrees for a perpendicular diffuser, and BETA is 0 degrees for a staged diffuser and it is 90 degrees for a unidirectional diffuser.

CORMIX2 performs a number of consistency checks to ensure the user does not make arithmetical errors when preparing and entering the above data and it also checks the specified geometry for compliance with three criteria to prevent an inappropriate system application. Figure 4.6b shows the imposed limits of system application for CORMIX2 which are: (a) the port height (H0) value must not exceed one-third of the local water depth (HD) value, (b) the port diameter value must not exceed one-fifth of HD's value, and (c) the pycnocline value must be within the 40 to 90 percent range of HD's value. The restrictions are similar to those shown in Figure 4.5b for CORMIX1 with the exception of the diameter limit for each port.

4.5.2 Diffuser Discharge Flow

For discharge characteristics, CORMIX2 requires the specification of 3 data entries. These specifications include: (a) the **total discharge flow rate (Q0)** or **discharge velocity (U0)**, (b) the **discharge density** or **discharge temperature** for an essentially freshwater discharge, and (c) the **discharge concentration** of the material of interest. The Q0 and U0 variables are related through the total cross-sectional area of all diffuser ports and the program computes and displays the alternate value allowing for user inspection and verification.

The specification of the pollutant in the diffuser effluent is described in Section 4.7 below.

4.6 Discharge Data: CORMIX3

A definition sketch for the discharge geometry and flow characteristics for a buoyant surface discharge is provided in Figure 4.8. In general, CORMIX3 allows for different types of inflow structures, ranging from simple rectangular channels to horizontal round pipes that may be located at or near the water surface. In addition, three different configurations relative to the bank are allowed as illustrated in Figure 4.9. Discharge structures can be: (a) **flush** with the bank/shore, (b) **protruding** from the bank or (c) **co-flowing** along the bank.

4.6.1 Discharge Geometry

To allow the establishment of a reference coordinate system and orient the discharge to that reference, CORMIX3 requires the specification of up to 7 data entries. These specifications are illustrated in Figure 4.8 and include: (a) location of the **nearest bank** (i.e. left or right) as seen by an observer looking downstream in the direction of the flow, (b) **discharge channel width (B0)** of the **rectangular channel**, (c)**discharge channel depth (H0)**, (d) **actual receiving water depth at the channel entry (HD0)** and (e) **bottom slope (SLOPE)** in the receiving water body in the vicinity of the discharge channel, and (f)**horizontal angle of discharge (SIGMA)** measured counterclock-wise from the ambient current direction (x-axis) to

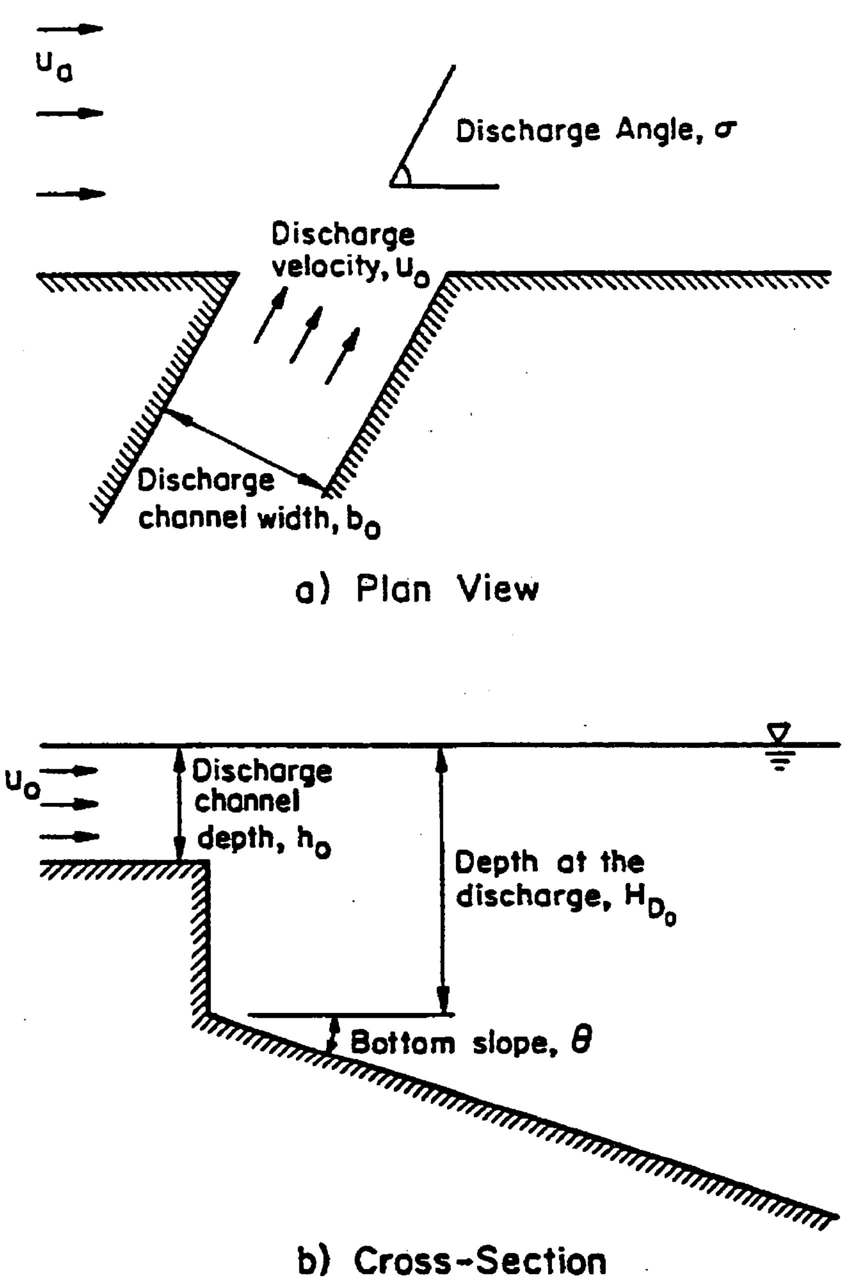
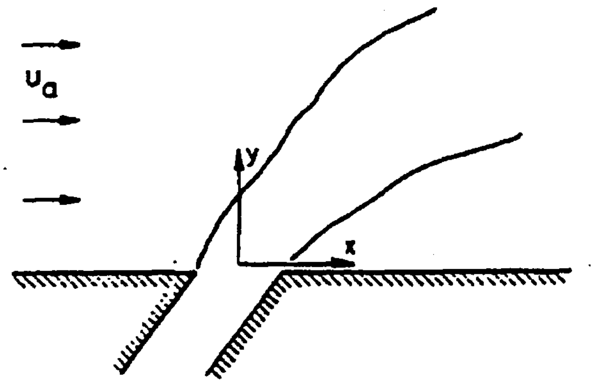
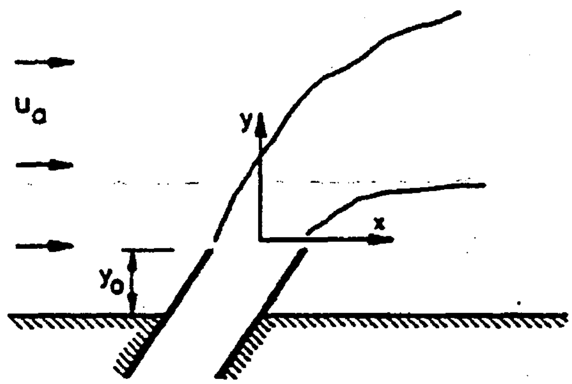


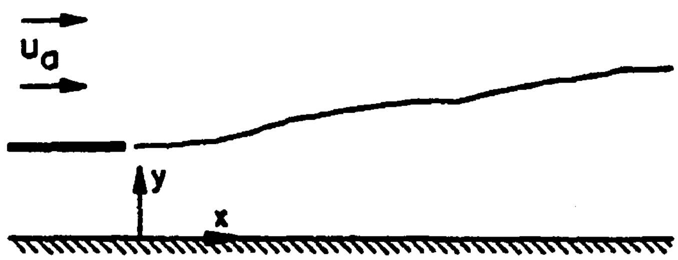
Figure 4.8: CORMIX3 discharge channel geometry



a) Discharge flush with bank



b) Protruding discharge



c) Coflowing along downstream bank

Figure 4.9: Possible CORMIX3 discharge configurations of discharge channel relative to bank/shoreline

the plan projection of the port centerline. In the case of a **circular discharge pipe**, the (b) **pipe diameter** and (c) **depth of bottom invert** below the water surface (water surface to bottom edge of pipe) must be specified, respectively. In all cases, CORMIX3 assumes the discharge is being issued horizontally.

CORMIX3 uses the variable HD0 for the actual water depth just in front of the channel exit and requires an additional specification for the receiving water bottom slope, again in front of the exit, extending into the receiving water body. These details are important for identifying cases where plume attachment to the bottom can occur.

In the case of a circular pipe discharge CORMIX3 assumes the outlet is flowing full and that it is not submerged under the water surface by more than ½ of the outlet diameter. If the discharge outlet has an odd cross-sectional shape (e.g. a pipe flowing partially full) then it should be represented schematically as a rectangular outlet of the same cross-sectional area and similar channel depth.

For open channel discharges, considerable care should be exercised when specifying discharge channel depth since this parameter is directly linked to the ambient receiving water depth (stage). This is especially important for tidal situations.

To prevent an inappropriate system application, CORMIX3 only allows for a discharge channel depth-to-width aspect ratio of 0.05 to 5. This prohibits the use of extremely oblong discharge geometry.

4.6.2 Discharge Flow

For discharge characteristics, CORMIX3 requires the specification of 3 data entries. These specifications include: (a) the **total discharge flow rate (Q0)** or **discharge velocity (U0)**, (b) the **discharge density** or **discharge temperature** for an essentially freshwater discharge, and (c) the **discharge concentration** of the material of interest. The Q0 and U0 variables are related through the channel cross-sectional area; the program computes and displays the alternate value allowing for user inspection and verification.

The discharge concentration of the material of interest (pollutant, tracer, or temperature) is defined as the excess concentration above any ambient concentration of that same material. The user can specify this quantity in any units. CORMIX1 predictions should be interpreted as computed excess concentrations in these same units. If no specific pollutant is under consideration, simply specify a discharge concentration of 100%.

4.7 Pollutant Data

CORMIX allows three types of pollutant discharges:

(a) Conservative Pollutant:
The pollutant does not undergo any decay/growth processes.

(b) Non-conservative Pollutant:
The pollutant undergoes a first order decay or growth process. One needs to specify the **coefficient of decay** (positive number) **or growth** (negative number) in units: /day (per day).

(c) Heated Discharge:
The discharge will experience heat loss to the atmosphere in cases where the plume contacts the water surface. It is necessary to specify the discharge condition in terms of *excess temperature ("delta T") above ambient in units degC*, and the **surface heat exchange coefficient** in units W/m^2,degC. Values of the heat exchange coefficient depend on ambient water temperature and wind speed. The following listing provides a guideline for the selection.

Typically, the near-field behavior is quite insensitive to the choice of these values, but it may affect the prediction results at greater distances in the far-field.

The **discharge concentration (C0)** of the material of interest (pollutant, tracer, or temperature) is defined as the *excess concentration above any ambient background concentration* of that same material. The user can specify this quantity in any **units of concentration** (e.g. mg/l, ppm, %, °C). CORMIX predictions should be interpreted as computed excess concentrations in these same units.

SURFACE HEAT EXCHANGE COEFFICIENT (W/m^2,°C)
Values for a lightly heated, natural water surface
(local excess temperatures 0 to 3 °C)

Ambient Water Temp. (°C)	Wind Speed (m/s) 0	1	2	4	6	8
5	5	10	14	24	33	42
10	5	11	16	27	38	49
15	5	12	18	31	44	59
20	5	14	21	38	52	68
25	6	16	25	45	63	82
30	6	19	30	54	76	100

Ref: "Heat Disposal in the Water Environment", E.E. Adams, D.R.F. Harleman, G.H. Jirka, and K.D. Stolzenbach, Course Notes, R.M. Parsons Laboratory, Mass. Inst. of Techn., 1981.

If no pollutant data at all is available, it is most convenient to specify C0 = 100 %.

In case of an **ambient background concentration** it is important to treat all pollutant related data items in a consistent fashion. This includes the specification of any regulatory values as discussed in Section 4.8 below.

> *Example:* suppose the actual discharge concentration for a particular pollutant is 100 mg/l, and values of CMC and CCC for the pollutant are 20 mg/l and 10 mg/l, respectively. If the background ambient concentration for the same pollutant is 4 mg/l, the data entry to CORMIX would be for the discharge concentration = 96 mg/l, for CMC = 16 mg/l, and for CCC = 6 mg/l, respectively. All concentration values listed in the diverse CORMIX output (see Chapter V) must then be interpreted accordingly, and the actual concentration values are computed by adding the background concentration value. E.g. if the CORMIX predicted value for one particular point happens to be 13.6 mg/l, then the total concentration value at that point would be 17.6 mg/l. Also, all program mixing zone messages would occur at correct regulatory concentrations because they are interpreted as excess plume concentrations above ambient.

4.8 Mixing Zone Data

The user must indicate: (a) whether EPA's toxic dilution zone (TDZ) definitions apply, (b) whether an ambient water quality standard exists, (c) whether a regulatory mixing zone (RMZ) definition exists, (d) the spatial region of interest (ROI) over which information is desired, and (e) number of locations (i.e. "grid intervals") in the ROI to display output details. Depending on the responses to the above, several additional data entries may be necessary as described in the following paragraphs.

When TDZ definitions apply, the user must also indicate the criterion maximum concentration (CMC) and criterion continuous concentration (CCC) which are intended to protect aquatic life from acute and chronic effects, respectively. CORMIX will check for compliance with: (a) the CMC standard at the edge of the TDZ and (b) the CMC standard at the edge of the RMZ, proving a RMZ was defined. See Subsection 2.2.2 for additional discussion.

When a RMZ definition exists, it can be specified by: (a) a distance from the discharge location, (b) the cross-sectional area occupied by the plume, or (c) the width of the effluent plume.

The ROI, which is a user defined region where mixing conditions are to be analyzed, is specified as the maximum analysis distance in the direction of mixed effluent flow. The level of detail for the output data within the ROI and thus, for the entire hydraulic simulation, is established by specifying the number of grid intervals that will be displayed in the output files. This parameter's allowable range is 3 to 50 and the chosen value does not affect the accuracy of the CORMIX prediction, only the amount of output detail. A low value should be specified for initial calculations to minimize printout lengths while a large value might be desirable for final predictions to give enough resolution for plotting of plume dimensions.

4.9 Units of Measure

CORMIX uses the metric system of measurement. When data values are provided to the user in English units, these must be converted to equivalent metric measures. The list at the beginning of this manual gives the five metric dimensions used by CORMIX in the left column, and on the right, their equivalents in some common English units.

Pollutant concentrations can be entered in any conventional measure such as mg/L, ppb, bacteria-count, etc.

Considering the potential accuracy of CORMIX predictions, 3 to 4 significant digits are sufficiently accurate for most input data values as suggested in the above conversion list. The only exceptions are the ambient and effluent density values. These may require 5 significant digits, especially when simulating the discharge to an ambient density-stratified receiving water body.

V CORMIX Output Features

CORMIX is a highly interactive system and conveys information to the user through qualitative descriptions and detailed quantitative numerical predictions. This output can be viewed on-screen in text mode or graphics mode, can be directed to a printer, and is stored in subdirectory CORMIX\SIM and CORMIX\SIM\CXn files. In this chapter the label n = 1, 2 or 3 designates the appropriate CORMIX subsystem.

5.1 Qualitative Output: Flow Descriptions

After completion of the input data entry sequences, the system proceeds through the program elements following the flow chart displayed in Figure 3.1. In addition to the routine operational messages provided during program execution, important qualitative information is displayed on-screen about the ongoing analysis of the given ambient/discharge case. The three general types of descriptive information provided are: (a) descriptive messages, (b) length scale computation results and (c) flow class descriptions. The paragraphs within this Section aid in the interpretation of that information.

The program elements PARAM and CLASS, in particular, provide essential information on the expected dynamic behavior of the discharge. By actively participating in the interactive process, the novice and intermediate user can derive a substantial educational benefit and a technical appreciation of the physical aspects of initial mixing processes. Although advanced users may find some of the presented material somewhat repetitive, they should still consult the length scale computation results.

5.1.1 Descriptive Messages

These messages provide both physical information and insight into the logic reasoning employed by CORMIX. Three example descriptive messages are:

```
"The effluent density (1004.5 kg/m^3) is greater than the surrounding
water density at the discharge level (997.2 kg/m^3).
Therefore, the effluent is negatively buoyant and will tend to sink
towards the bottom."

"STRONG BANK INTERACTION will occur for this perpendicular diffuser
type due to its proximity to the bank (shoreline).  The shoreline will
act as a symmetry line for the diffuser flow field.
The  diffuser  length  and  total  flow  variables  are  doubled  (or
approximately doubled, depending on the vicinity to the shoreline).
All of the following length scales are computed on that basis."

"The specified two layer ambient density stratification is dynamically
important. The discharge near field flow will be confined to the lower
layer by the ambient density stratification.
Furthermore, it may be trapped below the ambient density jump at the
pycnocline."
```

The preceding example output highlights several features of CORMIX's descriptive messages. These include: (a) conveying basic information about the involved mixing processes, (b) using a careful terminology (e.g. "..tend to sink.."), (c) describing key calculation assumptions, and (d) alerting the user to sensitive analysis conditions. In some instances, the provided information may be obvious to the user, while in others it may not, particularly for situations involving linear ambient stratification. The use of a careful terminology is necessary because messages are presented as the analysis proceeds and subsequent tests may alter, or amplify, initial results. For example, near-field instabilities, which are tested for late in the analysis, can prevent an otherwise sinking plume.

5.1.2 Length Scale Computations

The program element PARAM computes so-called **"length scales"** which represent important dynamic measures about the relative influence of certain hydrodynamic processes on effluent mixing. These calculated values are subsequently used in program element CLASS to identify the generic flow class upon which the hydraulic simulations will be based. This flow classification is accomplished through formal dynamic **length scale analysis**, which is a key aspect of the theoretical underpinnings for the CORMIX approach. The CORMIX documentation manuals (5,6,7) and related journal publications provide the theoretical background on length scale definitions and significance, their derivation from principles of dimensional analysis, and their use in the CORMIX flow classification approach.

Although flow classification is a formal process using criteria derived from theoretical studies and/or experimental data, a great deal can be deduced about the flow dynamics by comparing the calculated length scales to the actual physical measures of the ambient/discharge situation. Of greatest importance are comparison to such geometric measures as: the available water depth (HD), a pycnocline height (HINT) and the distance to the nearest bank (DISTB). The following discussion provides a brief explanation of the more important length scales and examples on how to make appropriate comparisons in a given application. Users are encouraged to make these comparisons.

a) Single port discharges: Some important length scales relating to submerged round buoyant jets (CORMIX1) are described in Table 5.1. All of these scales are defined from an interplay of the momentum and buoyancy flux quantities of the discharge with each other or with the current velocity and stratification gradient variables.

As an example, consider a vertically discharging buoyant jet into an unstratified ambient receiving water. When both calculated L_m and L_b values are substantially less than the local water depth (HD), this is an immediate indication to the user that the crossflow is very strong, leading to complete bending of the buoyant jet. If the reverse holds true, the crossflow may be so weak that its deflecting effect is negligible, and the buoyant jet will strongly interact (impinge) with the water surface. In the first instance, a situation as depicted in Figures 2.1b combined with Figure 2.1a will result, while in the second instance, a flow resembling Figures 2.2c or 2.2d may arise, depending on the relation of the two scales with each other.

As another example, consider a buoyant jet discharging into a linearly stratified ambient. If both L_m' and L_b' both larger than the pycnocline height (HINT) and even the water depth (HA), this would be an indication that the existing stratification is so weak that it will not lead to any trapping of the effluent plume within the available vertical space.

By making such comparisons, users will gradually get a good feel for the behavior of the buoyant jet, and other mixing processes within the space constraints of the ambient environment. Those interested in design can quickly gain an appreciation of the length scale measures and their sensitivity to design choices. However, there are limitations to these simplistic comparisons because the "length scales" are by no means precise measurements for the influence of the different processes. As their name implies they should be taken only as "scale" estimates. The actual CORMIX classification scheme uses formal criteria when comparing the length scale measures with the geometric constraints or each other.

b) Multiport diffusers: Some important length scales for multiport diffusers (CORMIX2) are described in Table 5.2.

To a large extent, these scales have a similar meaning for the behavior of the plane buoyant jet as the earlier ones discussed for the round buoyant jet (Table 5.1). However, they are calculated differently because the CORMIX2 system uses the "equivalent slot diffuser" concept to model the overall dynamics of the submerged multiport diffuser (Section 3.1). Except for the immediate close-up zone before the individual jets merge (Figure 2.1d) this concept is a dynamically valid and accurate representation of multiport diffuser flows (6).

Table 5.1
Length Scales for Single Port Submerged Discharges
(Used in CORMIX1 and CORMIX2)

Jet/plume transition length scale $L_M = M_o^{3/4} / J_o^{1/2}$

interpretation: For combined buoyant jet flow, the distance at which the transition from jet to plume behavior takes place in a stagnant uniform ambient.

Jet/crossflow length scale $L_m = M_o^{1/2} / u_a$

interpretation: In the presence of a crossflow, the distance of the transverse (i.e. across ambient flow) jet penetration beyond which the jet is strongly deflected (advected) by the cross flow. For a strictly co-flowing discharge ($\theta = 0$, $\sigma = 0$), the length of the region beyond which the flow is simply advected.

Plume/crossflow length scale $L_b = J_o / u_a^3$
interpretation: The vertically upward or downward flotation distance beyond which a plume becomes strongly advected by crossflow.

Jet/stratification length scale $L_m' = M_o^{1/4} / \varepsilon^{1/4}$
interpretation: In a stagnant linearly stratified ambient, the distance at which a **jet** becomes strongly affected by the stratification, leading to terminal layer formation with horizontally spreading flows.

Plume/stratification length scale $L_b' = J_o^{1/4} / \varepsilon^{3/8}$
interpretation: In a stagnant linearly stratified ambient, the distance at which a **plume** becomes strongly affected by the stratification, leading to terminal layer formation with horizontally spreading flows.

Notes: $M_o = U_o Q_o$, kinematic momentum flux
$J_o = g'_o Q_o$, kinematic buoyancy flux
$Q_o = U_o a_o$, source discharge volume flux
a_o = port area
u_a = ambient velocity
U_o = port discharge velocity
ε = ambient buoyancy gradient
g'_o = discharge buoyancy = $g(\rho_a - \rho_o)/\rho_a$

However, there are some exceptions and additional complexities to interpreting the two-dimensional slot length scales measures described in Table 5.2. In addition to the predominately two-dimensional flow behavior, some of the large scale dynamics of multiport diffusers may also be influenced by other scales depending on the overall diffuser flow pattern. A notable example is circulating motions induced in shallow receiving waters due to intermediate-field effects (Section 2.1.1). The immediate close-up zone before the individual jets merge is also not addressed by the two-dimensional length scales. Additional discussion of these and other peculiarities can be found elsewhere (6,18).

Table 5.2
Dynamic Length Scales for Multiport Diffuser (CORMIX2) in the Two-Dimensional "Slot" Discharge Representation

Slot jet/plume transition length scale $\ell_M = m_o / j_o^{2/3}$

interpretation: For combined buoyant jet flow, the distance at which the transition from jet to plume behavior takes place in a stagnant uniform ambient.

Slot jet/crossflow length scale $\ell_m = m_o / u_a^2$

interpretation: In the presence of a crossflow, the distance of the transverse (i.e. across ambient flow) jet penetration beyond which the jet is strongly deflected (advected) by the cross flow. For a strictly co-flowing discharge ($\theta = 0$, $\sigma = 0$), the length of the region beyond which the flow is simply advected.

Slot jet/stratification length scale $\ell_m' = m_o^{1/3} / \varepsilon^{1/3}$
interpretation: In a stagnant linearly stratified ambient, the distance at which a **jet** becomes strongly affected by the stratification, leading to terminal layer formation with horizontally spreading flows.

Slot plume/stratification length scale $\ell_b' = j_o^{1/3} / \varepsilon^{1/2}$
interpretation: In a stagnant linearly stratified ambient, the distance at which a **plume** becomes strongly affected by the stratification, leading to terminal layer formation with horizontally spreading flows.

Crossflow/stratification length scale $\ell_a = u_a / \varepsilon^{1/2}$
interpretation: The vertically upward or downward floatation distance beyond which a plume becomes strongly advected by crossflow.

Notes: $m_o = U_o q_o$, kinematic momentum flux per unit length
$j_o = g'_o q_o$, kinematic buoyancy flux per unit length
$q_o = U_o n a_o / L_D$, source discharge volume flux
a_o = port area
u_a = ambient velocity
U_o = port discharge velocity
ε = ambient buoyancy gradient
g'_o = discharge buoyancy = $g(\rho_a - \rho_o)/\rho_a$
n = total number of nozzles
L_D = overall diffuser length

c) Buoyant surface jets: Some important length scales that describe the near-field dynamics of buoyant surface jets discharging into unstratified receiving waters (CORMIX3) are listed in Table 5.3. These scales are defined in a similar manner to the submerged discharged cases but due to the discharge location at the surface, they have different interpretations. For example, L_m is compared to the channel width (BS) instead of the local water depth as it was in submerged case examples; if it exceeds BS, the discharge will quickly interact with the opposing bank.

Table 5.3
Dynamic Length Scales for Buoyant Surface Jets (CORMIX3) Discharging into Unstratified Receiving Water

Jet/plume transition length scale $L_M = M_o^{3/4} / J_o^{1/2}$

interpretation: For stagnant ambient conditions, the extent of the initial jet region before mixing changes over into an unsteady surface spreading motion.

Jet/crossflow length scale $L_m = M_o^{1/2} / u_a$

interpretation: The distance over which a discharging jet intrudes into the ambient cross-flow before it gets strongly deflected.

Plume/crossflow length scale $L_b = J_o / u_a^3$

interpretation: A measure of the tendency for upstream intrusion for a strongly buoyant discharge.

Notes: $M_o = U_oQ_o$, kinematic momentum flux
$J_o = g'_oU_o$, kinematic buoyancy flux
$Q_o = U_oa_o$, source discharge volume flux
a_o = channel cross-sectional area
u_a = ambient velocity
U_o = channel discharge velocity
g'_o = discharge buoyancy = $g(\rho_a - \rho_o)/\rho_a$

d) Tidal reversing flows: Additional length and time scales can be defined for unsteady flows in which the scale of influence of oscillating plume depends on the rate of velocity reversal change at slack tide (8,17). CORMIX will take the actual steady-state predictions and adjust their concentration values according to the time after reversal relative to the time scale T_u and also limit their areal applicability relative to L_u.

5.1.3 <u>Description of Flow Classes</u>

Program element CLASS, performs a rigorous classification of the given discharge/ambient situation into one of many **generic flow classes** with distinct hydrodynamic features. In a way, this amounts to identifying a general pictorial description of the expected flow configuration.

Table 5.5 lists and describes the broad categories of flow classes available in CORMIX. CORMIX1, 2 and 3, consider 35, 31 and 11 distinct flow classifications, respectively. Each flow class identification consists of an alphanumeric label corresponding to the flow category and a number (e.g. MU2). Text descriptions of the flow classes are available on-screen during the analysis and can printed from the files stored within sub-directory CORMIX\TEXT (Table 3.1). Pictorial illustrations of the flow classes can be found in <u>Appendix A</u>. As an example, Figure 5.1 shows the pictorial illustration and text description for flow class S1, a case of an effluent that becomes trapped in ambient stratification. It is strongly recommended that novice or intermediate users scrutinize these materials to gain a qualitative understanding of the effluent flow's behavior.

Table 5.4
Dynamic Length and Time Scales for Discharges into Unsteady Tidal Reversing Flows

Jet-to unsteady-crossflow length scale $L_u = \left(\frac{M_o}{|du_a/dt|} \right)^{1/3}$

interpretation: A measure of the distance of the forward propagation into the ambient flow of a discharge during the reversal episode.

Jet-to unsteady-crossflow time scale $T_u = \left(\frac{M_o}{|du_a/dt|^{1/4}} \right)^{1/6}$

interpretation: a measure of the duration over which an effluent may be considered as discharging into stagnant water while the velocity field is reversing.

Notes: $M_o = U_oQ_o$, kinematic momentum flux
$|du_a/dt|$ = time rate of reversal of ambient velocity (absolute value)

Table 5.5
Flow Class Categories and Descriptions

CORMIX1:	35 flow classes
Classes S:	Flows trapped in a layer within linear stratification.
Classes V,H:	Positively buoyant flows in a uniform density layer.
Classes NV,NH:	Negatively buoyant flows in uniform density layer.
Classes A:	Flows affected by dynamic bottom attachment.
CORMIX2 :	31 flow classes
Classes MS:	Flows trapped in a layer within linear ambient stratification.
Classes MU:	Positively buoyant flows in a uniform density layer.
Classes MNU:	Negatively buoyant flows in uniform density layer.
CORMIX3	9 flow classes
Classes FJ:	Free jet flows without near-field shoreline interaction.
Classes SA:	Shoreline-attached discharges in crossflow.

Classes WJ:	Wall jets/plumes from discharges parallel to shoreline.
Classes PL:	Upstream intruding plumes.

FLOW CLASS S1

This flow configuration is profoundly affected by the linear ambient density stratification. The predominantly jet-like flow gets trapped at some terminal (equilibrium) level. The trapping is also affected by the reasonably strong ambient crossflow. Following the trapping zone, the discharge flow forms an internal layer that is further influenced by buoyant spreading and passive diffusion.

The following flow zones exist:

1) Weakly deflected jet in crossflow: The flow is initially dominated by the effluent momentum (jet-like) and is weakly deflected by the ambient current.

2) Strongly deflected jet in crossflow: The jet has become strongly deflected by the ambient current and is slowly rising toward the trapping level.

3) Terminal layer approach: The bent-over submerged jet/plume approaches the terminal level. Within a short distance the concentration distribution becomes relatively uniform across the plume width and thickness.

*** The zones listed above constitute the NEAR-FIELD REGION in which strong initial mixing takes place. ***

4) Buoyant spreading in internal layer: The discharge flow within the internal layer spreads laterally while it is being advected by the ambient current. The plume thickness may decrease during this phase. The mixing rate is relatively small. The plume may interact with a nearby bank or shoreline.

5) Passive ambient mixing: After some distance the background turbulence in the ambient shear flow becomes the dominating mixing mechanism. The passive plume is growing in depth and in width. The plume may interact with the upper layer boundary, channel bottom and/or banks.

*** Predictions will be terminated in zone 4 or 5 depending on the definitions of the REGULATORY MIXING ZONE or the REGION OF INTEREST. ***

Figure 5.1: Example of a Flow Class Description

5.2 Quantitative Output: Numerical Flow Predictions

After execution of the detailed flow prediction in program element HYDROn, the system provides two types of detailed numerical output on effluent plume trajectory and mixing and on compliance with regulations. A concise summary is available on-screen in the final system element SUM and a detailed numerical output file is also generated for inspecting and plotting the plume's behavior after the analysis.

5.2.1 Summary Output in SUM

The self-explanatory summary output which can be displayed on-screen includes: (a) the date and time of the analysis section, (b) a complete echo of the input data, (c) the calculated flux, length scale and non-dimensional parameter values, (d) the flow classification used for predicting plume trajectory and mixing, (e) the coordinate system used in the analysis, (f) a summary of the near-field region (NFR) conditions, (g) the far-field locations where the plume becomes essentially fully mixed (i.e. uniform concentration) in the horizontal and vertical directions, (h) a summary of the toxic dilution zone (TDZ) conditions, and (i) a summary of the regulatory mixing zone (RMZ) conditions. Although the raw data used to construct this summary output is permanently stored in file 'fn'.CXC within the output sub-directory CORMIX\SIM\CXn, a hard-copy printout should be requested during the analysis session because the raw data file is unformatted and does not contain the explanatory text that is available during program execution; 'fn' is the filename specified by the user during input data entry.

The **coordinate system conventions** pertain to the origin location and axis direction. In CORMIX1 analyses, the origin is located at the bottom of the receiving water just below the discharge port center and thus, at a depth HD below the water surface. In CORMIX2 analyses, the origin is located at the bottom of the receiving water, at the midpoint of the diffuser line and thus, at a depth HD below the water surface. In CORMIX3 analyses, the origin is located at the water surface where the discharge channel centerline and receiving water shoreline intersect. The x-axis lies in the horizontal plane and points downstream in the direction following the ambient flow; the y-axis lies in the horizontal plane and points to the left as seen by an observer looking downstream along the x-axis; and the z-axis points vertically upward. Note that when the ambient current direction varies (e.g. due to reversing tidal flows), the interpretation of simulation results becomes more involved since the x-axis and the y-axis will change depending on flow direction.

In addition to the numerical predictions of the plume size, location and chemical concentration, the summary of the near-field region (NFR) conditions describes other relevant plume features such as bottom attachment, bank interaction and the degree of upstream intrusion. This information is useful for both engineering design and for determining whether important resource areas may be exposed to undesirable chemical concentrations.

In case of a toxic discharge, the summary toxic dilution zone (TDZ) conditions will indicate the location along the plume where the local concentration begins to fall below the specified CMC. CORMIX automatically checks compliance with the three geometric restrictions listed for mixing zones associated with toxics discharges under alternative 3 (see Subsection 2.3.3) and the results of these comparisons are displayed. The user can evaluate the fourth alternative by referring to travel times given at the end of each simulation module in the related output files.

When regulatory mixing zone (RMZ) criteria have been specified during input data entry, the geometric, dilution and concentration conditions at the edge of the specified or proposed RMZ are compared to these criteria and/or to the applicable CCC concentration following the practices discussed in Subsection 2.2.4. The results of these comparisons are displayed.

5.2.2 Detailed Prediction Output File 'fn'.CXn

The file 'fn'.CXn stored within sub-directory CORMIX\SIM contains the same kinds of information available in the summary output plus the detailed numerical predictions on plume geometry and mixing produced during the hydraulic simulation. Data in that file forms the basis for further analysis, inspection, evaluation, and plotting of the plume shape and trajectory. The graphics package also uses the same data to plot on-screen, and print if desired, the plume properties as explained in Section 5.2.3.

During program execution, the user has several opportunities to display on-screen or print out this file. It can also be printed at a later date by using the DOS PRINT command or any word processor. CORMIX will not erase any of the files with .CXn (or .CXC) extension that get stored in the CORMIX\SIM sub-directory. Consequently, periodic directory maintenance is recommended to remove old and superfluous files. This is best accomplished with a built-in file manager (see Main Menu) that deletes the specified files from the hard disk, but also erases their entry from the record keeping file CORMIX\SIM\CXn\summary.

The 'fn'.CXn file is a FORTRAN output file generated by the HYDROn prediction program. As is typical of many FORTRAN outputs, its display features are terse with tight format control and data items labeled in symbolic form only (e.g. "Q0" for discharge flow rate). Complete output file examples can be inspected in Appendices B, C and D.

All three CORMIXn subsystems produce a 'fn'.CXn output file with common appearance and features as described in the following paragraphs.

a) Lead-in information: The output starts (and ends) with a "111...111", "222...222", or "333...333" banner line to accentuate which subsystem has been used. The date and time of the analysis session and all important input data are the next items in the file. These are subsequently followed by the calculated length scale values, non-dimensional numbers of interest to the specialist, the flow class identification, and the coordinate system is displayed.

b) Prediction results for each flow "module": As was mentioned previously in Subsection 3.6, the CORMIX prediction methodology utilizes a number of **simulation modules** that are executed sequentially and that correspond to the different flow processes and associated spatial regions which occur within a given flow class. The 'fn".CXn output reflects that sequence and is a arranged in output blocks for each module.

Each simulation module has a "MODnxx" label where "n" is 1, 2, or 3 corresponding to CORMIXn, and "xx" is a two-digit identification number. The two general types of modules are continuous flow and control volume.

The **continuous flow module** type describes the continuous evolution of a flow region along a trajectory. Depending on the number of grid intervals specified by the user, information on plume geometry, flow, and mixing information along the plume trajectory may be available for a few or many water body locations.

Figure 5.2 provides examples of typical output from continuous flow modules. The annotations along the right margin illustrate important features of the output format. Figure 5.2a was taken from a CORMIX1 simulation output file and shows an example of a submerged jet region module (MOD110, equivalent to CORJET). The output contains labeling information on the module, and explanatory notes on profile definitions. It also gives a numerical list on the predictions, first repeating the final values from the preceding flow module and then one line for each user-specified grid interval. This information gives the x-y-z position of the jet/plume centerline, the dilution (S) and concentration (C) at the centerline, and the jet width (B).

Dilution (S) is defined as the ratio of the initial concentration (at the discharge port) to the concentration at a given location, irrespective of any decay or growth effects if specified for a non-conservative pollutant. However, **concentration** (C) will include any first-order effects for non-conservative pollutants. Dilution (S) given by CORMIX for submerged jet or plume regions is the minimum centerline dilution for the jet/plume. The control volume and buoyant spreading modules give bulk dilutions, which are equivalent to flux-averaged dilutions for these regions. If a flux-averaged dilution S_f is desired for submerged jet or plume regions, the ratio of flux-average to minimum centerline dilution S_f/S = 1.7 and 1.3, for single-port round and multiport plane discharges, respectively.

```
-----------------------------------------------------------------------------
BEGIN CORJET (MOD110): JET/PLUME NEAR-FIELD MIXING REGION
 Jet/plume transition motion in weak crossflow.
  Zone of flow establishment:              THETAE=      0.00  SIGMAE=     277.06
  LE    =       3.39  XE    =       0.21  YE    =      -3.38  ZE    =       1.00
 Profile definitions:
   B = Gaussian 1/e (37%) half-width, normal to trajectory
   S = hydrodynamic centerline dilution
   C = centerline concentration (includes reaction effects, if any)
        X          Y        Z         S       C          B
      0.00       0.00     1.00       1.0 0.100E+03   0.76
      0.21      -3.38     1.00       1.0 0.100E+03   0.76
      0.90      -7.41     4.11       1.8 0.562E+02   1.13
      1.55      -9.36     9.07       3.3 0.300E+02   1.59
      2.23     -10.55    14.27       5.4 0.186E+02   2.10
      2.95     -11.39    19.56       7.9 0.127E+02   2.63
      3.72     -12.02    24.85      10.8 0.928E+01   3.16
 Cumulative travel time =           18. sec
END OF CORJET (MOD110): JET/PLUME NEAR-FIELD MIXING REGION
-----------------------------------------------------------------------------
```

a) Submerged buoyant jet module

```
-----------------------------------------------------------------------------     BEGIN MOD341:
BUOYANT AMBIENT SPREADING                                               Profile definitions:
   BV = top-hat thickness, measured vertically
   BH = top-hat half-width, measured horizontally from bank/shoreline
   S  = hydrodynamic average (bulk) dilution
   C  = average (bulk) concentration (includes reaction effects, if any)
  Plume Stage 1 (not bank attached):
        X          Y        Z         S       C          BV         BH
      1.93       -.82     0.00       8.4  .884E+00     .03        .58
      2.07       -.82     0.00       8.5  .869E+00     .03        .62
      2.20       -.82     0.00       8.6  .856E+00     .03        .65
 ** WATER QUALITY STANDARD OR CCC HAS BEEN FOUND **
 The pollutant concentration in the plume falls below water quality standard
   or CCC value of  .850E+00 in the current prediction interval.
 This is the spatial extent of concentrations exceeding the water quality
   standard or CCC value.
      2.34       -.82     0.00       8.8  .844E+00     .03        .68
      2.48       -.82     0.00       8.9  .833E+00     .03        .71
      2.62       -.82     0.00       9.0  .822E+00     .03        .74
      2.76       -.82     0.00       9.1  .811E+00     .03        .77
      2.89       -.82     0.00       9.2  .801E+00     .03        .80
      2.96       -.82     0.00       9.3  .796E+00     .03        .82
 Cumulative travel time =           95. sec
-----------------------------------------------------------------------------   Plume is ATTACHED
to LEFT  bank/shore.
   Plume width is now determined from LEFT  bank/shore.
 Plume Stage 2 (bank attached):
        X          Y        Z         S       C          BV         BH
      2.96        .00     0.00       9.3  .796E+00     .03        .82
     16.05        .00     0.00      31.3  .237E+00     .03       2.59
     29.13        .00     0.00      96.8  .764E-01     .06       3.77
     42.22        .00     0.00     220.7  .335E-01     .10       4.76
     55.31        .00     0.00     411.4  .180E-01     .16       5.64
     68.39        .00     0.00     675.3  .110E-01     .23       6.45
     81.48        .00     0.00    1017.8  .727E-02     .31       7.20
     94.56        .00     0.00    1443.5  .513E-02     .40       7.91
    101.11        .00     0.00    1688.9  .438E-02     .45       8.26
 Cumulative travel time =         3367. sec
 END OF MOD341: BUOYANT AMBIENT SPREADING
-----------------------------------------------------------------------------
```

b) Far-field flow module (example of buoyant spreading with bank contact)

Figure 5.2: Examples of continuous flow modules within CORMIX

The **cumulative travel time** (T) is given at the end of each simulation module. The travel time can be used to assess the applicability of the steady-state predictions given by CORMIX to time scales appropriate for the particular application.

Another example of a continuous flow module output is shown in Figure 5.2b. It was abstracted from a CORMIX simulation output file and shows predictions for the far-field process of buoyant ambient spreading (Figure 2.6). Although it is terse, the output file values and commentary generally provide a complete picture of flow conditions. In this example output (Figure 5.2b), evidence of this completeness includes: (a) the prediction output is separated in two stages corresponding to before and after bank interaction, respectively; due to the typical oblong cross-section of the plume in this stage, width dimensions for the vertical and lateral extent are given and defined; the coordinates for the upper and lower boundaries of the plume are listed as a convenience for plotting; and the system searches for criteria that apply to mixing zone regulations and when a criterion is satisfied, a remark gets inserted in the output list at the appropriate spatial position. (Note: The length dimensions in Figure 5.2b are small as they relate to a laboratory simulation.)

Some mixing flow processes are so complicated that no mechanistically-based mathematical description of them is presently available in state-of-the-art science. Those processes are best analyzed with **control volume modules** as shown in Figure 5.3.

In the control volume modeling approach, the outflow values for a region are computed as a function of the inflow values and are based on conservation principles.

An output example for control volumes modules is illustrated in Figure 5.3. It is taken from a CORMIX1 simulation output file and gives predictions for a flow case corresponding to an unstable near-field (Figure 2.2c). Note that a separate listing of inflow variables and outflow variables is given with appropriate explanations. The tabular listing of plume shape is based on an interpolation routine using a generic plume shape for these upstream intruding motions, rather than a detailed computation.

c) Numerous other supplementary messages on plume behavior (e.g. bottom attachment, bank contact, etc.) and on possible model restrictions (e.g. ambient dilution limitations in a flow-restricted river) are contained in the output as warranted; Figures 5.2 and 5.3 provide but a few examples of these user aids.

5.3 Graphical Output: Display and Plotting of Plume Features Using CMXGRAPH

5.3.1 Access to CMXGRAPH

CMXGRAPH is a specially developed graphics package, written in C++, for the display and plotting of CORMIX (and also CORJET, see Section 6.2) predicted effluent plumes. It uses the prediction files 'fn'.CXn that are stored in the directory CORMIX\SIM, and plots plume features based on the numerical and narrative information contained in these files.

The graphics system can be accessed in different ways:

(1) Use within CORMIX: Different access modes exist here.

> (1a) The user can display the plume graphics immediately after the actual prediction and *before the file information is stored.* This is useful for an initial inspection and evaluation of results.
> (1b) It can be accessed at an end of the prediction after the file has been stored, by entering the Post-Processor option in the Iteration Menu.
> (1c) It can be accessed on earlier existing files by directly choosing the Post-Processor option in the Main Menu.

(2) Use outside CORMIX:

The graphics system can be invoked directly by typing:

> cmxgraph (or simply: cg) *filename*
> where *filename* (including path and extension) is any prediction file generated by CORMIX or by CORJET.

```
---------------------------------------------------------------------------
BEGIN MOD132: LAYER BOUNDARY IMPINGEMENT/UPSTREAM SPREADING

  Vertical angle of layer/boundary impingement     =     79.65 deg
  Horizontal angle of layer/boundary impingement   =    324.93 deg


 UPSTREAM INTRUSION PROPERTIES:
        Upstream intrusion length                  =     328.95 m
        X-position of upstream stagnation point    =    -325.23 m
        Thickness in intrusion region              =       0.55 m
        Half-width at downstream end               =     470.97 m
        Thickness at downstream end                =       0.70 m

 In this case, the upstream INTRUSION IS VERY LARGE, exceeding 10 times
   the local water depth.

 This may be caused by a very small ambient velocity, perhaps in
   combination with large discharge buoyancy.

  Control volume inflow:

      X        Y        Z        S        C        B
     3.72   -12.02   24.85    10.8 0.928E+01   3.16

 Profile definitions:

   BV = top-hat thickness, measured vertically
   BH = top-hat half-width, measured horizontally in Y-direction
   ZU = upper plume boundary (Z-coordinate)
   ZL = lower plume boundary (Z-coordinate)
   S  = hydrodynamic average (bulk) dilution
   C  = average (bulk) concentration (includes reaction effects, if any)

      X        Y        Z        S        C        BV       BH       ZU       ZL
   -325.23  -12.02    28.00  9999.9 0.000E+00   0.00     0.00    28.00    28.00
   -313.94  -12.02    28.00    46.5 0.215E+01   0.13    66.61    28.00    27.87
   -258.63  -12.02    28.00    19.3 0.519E+01   0.31   161.78    28.00    27.69
   -203.31  -12.02    28.00    14.5 0.688E+01   0.40   218.89    28.00    27.60
   -148.00  -12.02    28.00    12.5 0.802E+01   0.47   263.91    28.00    27.53
    -92.68  -12.02    28.00    11.4 0.878E+01   0.52   302.30    28.00    27.48
    -37.37  -12.02    28.00    10.9 0.919E+01   0.54   336.34    28.00    27.46
     17.95  -12.02    28.00    11.0 0.913E+01   0.55   367.24    28.00    27.45
     73.26  -12.02    28.00    14.4 0.694E+01   0.59   395.73    28.00    27.41
    128.58  -12.02    28.00    19.1 0.522E+01   0.65   422.30    28.00    27.35
    183.89  -12.02    28.00    22.0 0.455E+01   0.68   447.30    28.00    27.32
    239.21  -12.02    28.00    23.2 0.431E+01   0.70   470.97    28.00    27.30
 Cumulative travel time =         3037. sec

END OF MOD132: LAYER BOUNDARY IMPINGEMENT/UPSTREAM SPREADING
---------------------------------------------------------------------------
```

Figure 5.3: Example of control volume flow module

As mentioned, numerous flow features (as evidenced by the different flow classes) can occur. It is difficult to develop a robust graphics package that operates safely for all of these possibilities. The CMXGRAPH system has been widely tested, but occasional crashes can occur for rare flow module combinations and then only for certain plot types. Should a crash occur and the direct access mode (1a), listed above, has been used then the current file information will be lost. In those cases, it is safer to *first save the current session file data* and then exercise the graphics system.

5.3.2 Use of CMXGRAPH

The graphics system has a self-explanatory screen interface as shown in Figure 5.4. The menu is controlled by the **keyboard** alone by typing the letters that appear in capital on the menu buttons, or by user the four cursor keys when in zoom mode.

The **GRAPHICS MENU COMMANDS** are as follows:

Help — an advice section is available listing the same information as given here

Quit — exits the graphics system

There exist FIVE PLOT TYPES:

Plan — generates a plan view of plume (x-y), as seen from above *(entry option)*

Side — generates a side view of plume (x-z), as seen by an observer looking from the bank/shore

Traj — generates a side view along trajectory of plume. The view is stretched out along the actually curving centerline trajectory.

c-X — generates a plot of concentration on the plume centerline plotted against downstream distance x

c-D — generates a plot of concentration on the plume centerline plotted against distance along the plume trajectory

The user can CONTROL the plume VIEW:

Near — displays the near-field region only ; useful for close-up details *(entry option)*

Full — displays the complete near- and far-field regions (i.e. the entire prediction results)

SHOW/HIDE FEATURES can be exercised to display additional information:

Labels — puts identifier labels (site/case information) on top of plot *(entry option)*

Wqual — displays information on regulatory mixing regulations (TDZ, RMZ, ...) on the plot; this is displayed by dotted lines where particular regulations are encountered.

Module shows boundaries of prediction modules

ZOOM/SCALE CONTROL allows control of plot details:

Zoom allows the user to enlarge any RECTANGULAR SECTION of the current plot; this is accomplished by:
– Use CURSOR Control keys to move cursor (up,down,left,right)

– Cursor SPEED can be modified by typing any number: 1(slowest),2,.. to 0(fastest)
– Press RETURN when first corner of desired rectangle has been reached
– Move cursor to find opposite corner and press RETURN to fix opposite corner

sKale allows the user to FIX SCALE distortion of current plot. The current scale is displayed in a window on the menu bottom (see Figure 5.4).
– Type in desired distortion at the prompt All subsequent versions of the plot (including zooms will be fixed at this scale distortion.
– Use the sKale button again, to release the scale distortion.

Bkup back-up to earlier zoomed/scaled versions of current plot

Esc exit from zoom/scale mode (also Quit or repeated Bkup can be used to exit)

Several PRINT OPTIONS are available:

pfile writes the current plot to a POSTSCRIPT FILE for later printing. The file can be edited and/or printed later using any compatible software (including public domain software, such as Ghostscript).

– Each print file is stored as \"*filename*.Pvn\" where:

filename = CORMIX or CORJET assigned filename,
Pvn = file extension indicating a Postscript file,
v = P, S, T, X or D, for one of the five view types,
n = 0 to 9, increasing file number.

– If the total file number for a particular view type exceeds the maximum of ten (10), the first file in the series will be erased and replaced by the new file.

psCrn allows a PRINT SCREEN action of the current plot

– The plot is first recreated without the menu interface and plot border.

– Then use the Shift-PrintScreen buttons, to print the plot on-line.
Important: The PRINTER must have been initialized for GRAPHICS MODE with the DOS command: \"graphics [type] /r\" where: [type] = type of printer (e.g.: color4, laserjetii).

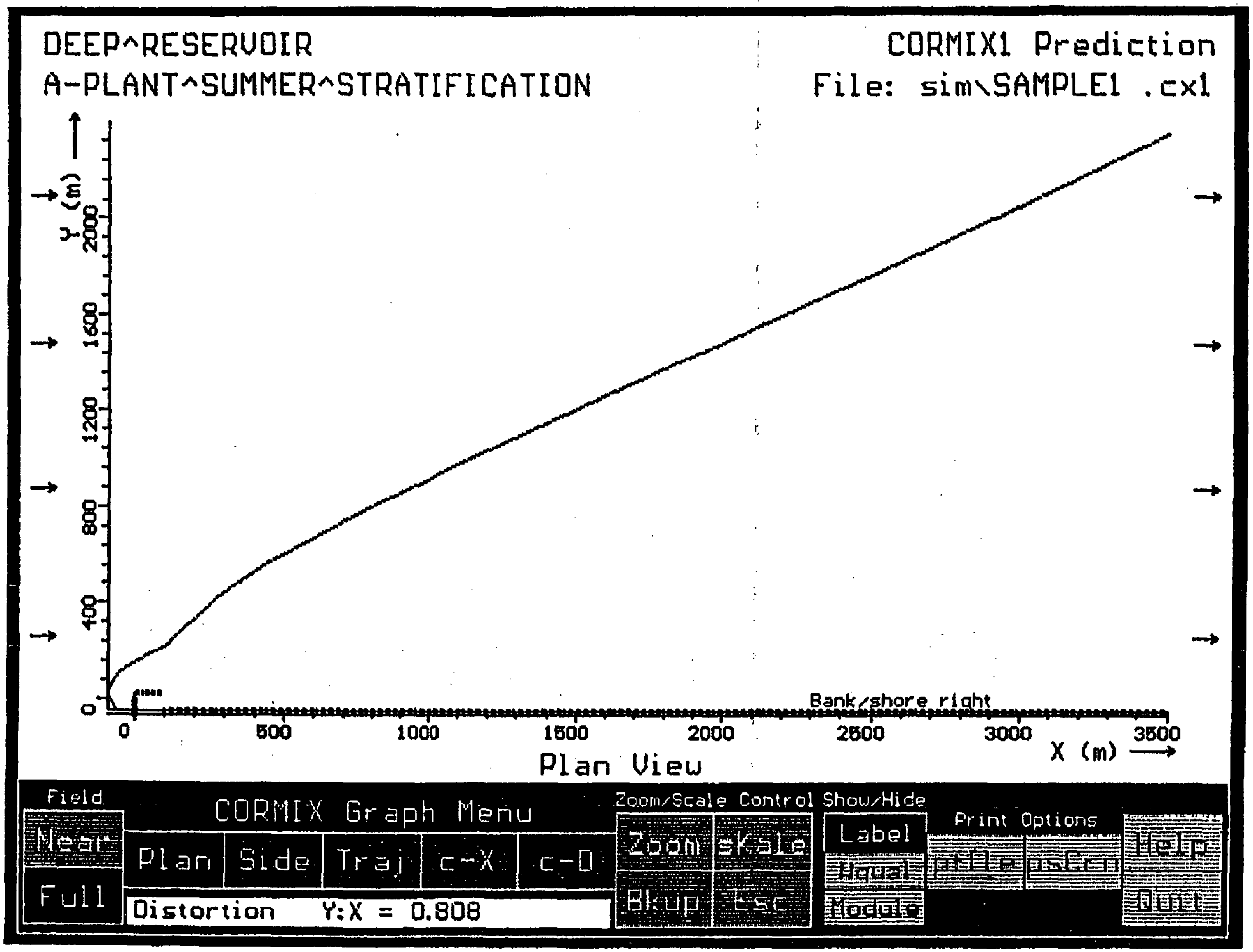


Figure 5.4 CMXGRAPH interface with menu options including example plot

The case study materials in the Appendices show some of the possibilities that can be exercised in the graphics display the plume features described in the *fn*.CXn output files. As shown above, the plume is characterized by its centerline trajectory, dilution, and width values. For understanding added detail in the plume cross-section, it is important to keep in mind the different concentration distributions and meanings of "plume width". These are explained in the supplemental statements at the beginning of each flow module (see Figures 5.2 and 5.3). Also, Figure 5.5 may be useful for further illustration. It gives the cross-sectional distribution of concentration for many of the commonly occurring plume cross-sections in the various regions predicted by the CORMIXn subsystems.

In some instances, users may desire to plot concentration isolines for the predicted plume shapes. The information contained in the HYDROn output file for each module and the definitions shown in Figure 5.5 are sufficient to construct such plots. In particular, in submerged plume or passive mixing regions having a Gaussian distribution, the following formula can be used

$$c(n) = c_c e^{-(\frac{n}{b})^2}$$

where c(n) is the lateral concentration, n is the coordinate position measured tranversely away from the centerline, c_c is the centerline concentration, e is the natural logarithm base, and b is the local plume half-width. However, this equation can not be used to plot concentration isolines in the control volume or buoyant spreading regions because they are defined with a top-hat or uniform concentration profile and not a Gaussian distribution.

By and large, all CORMIXn predictions are continuous from module to module satisfying the conservation of mass, momentum and energy principles. Occasionally, some *mismatches in plume width* can occur as a consequence of enforcing these principles. Most of these will be barely noticeable with the usual plotting resolution and they can usually be safely ignored. Some of the mismatches or discontinuities can be kept to a minimum by *specifying a large number for the grid intervals* (see Section 4.9) to increase the resolution of the CORMIX prediction. This is especially useful for the final simulations on a particular design case.

In addition, when bottom attachment or bank interaction occurs, the plume trajectory is assumed to (and simulation predictions do) shift suddenly to the boundary. In actuality, that shift would be much more gradual and this should be considered when interpreting the results of the CMXGRAPH plots or, alternatively, when plotting plume features by hand.

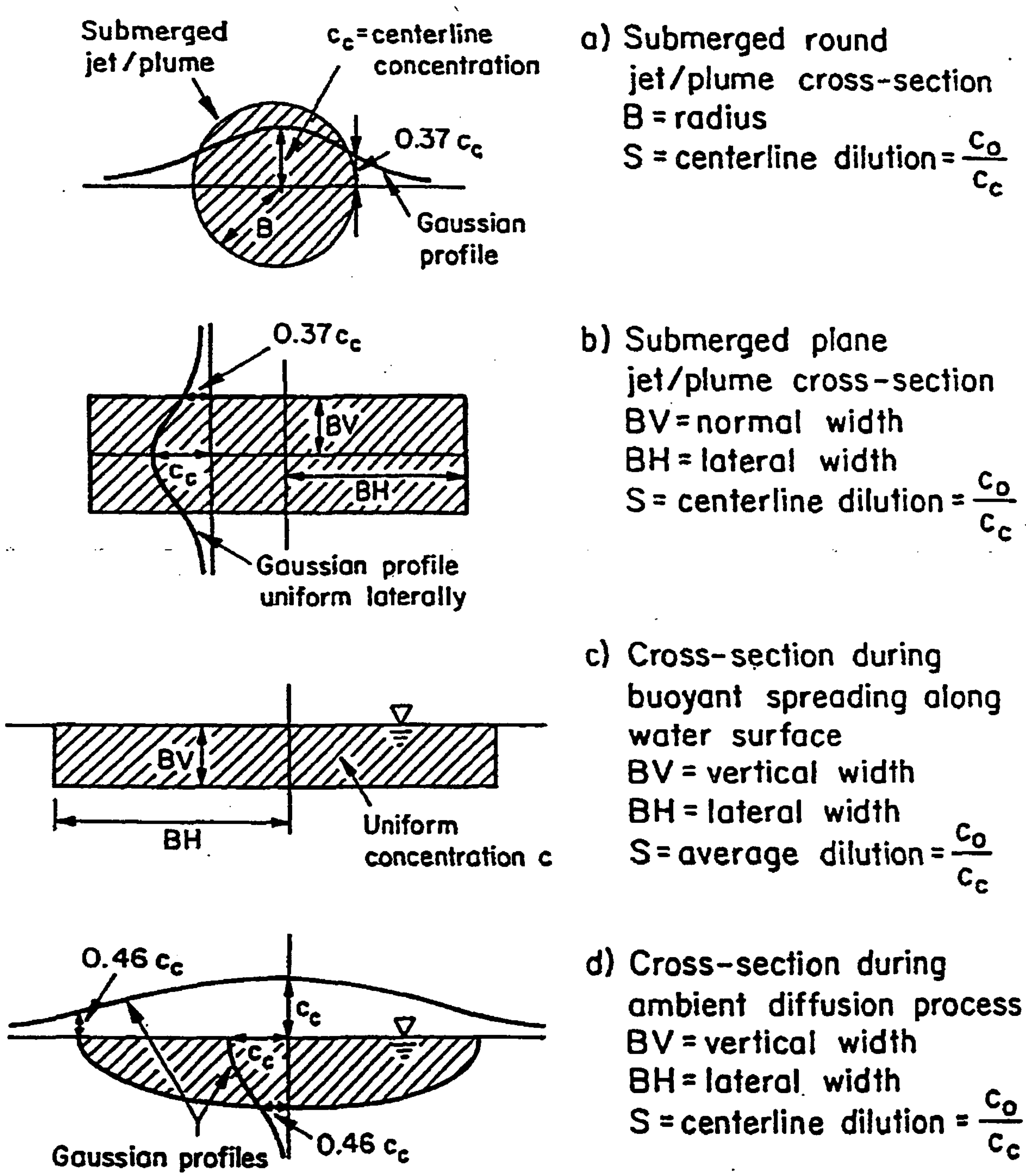


Figure 5.5: Cross-sectional distributions of CORMIX predicted jet/plume sections

VI Post-Processor Models CORJET and FFLOCATR: Input and Output Features

The CORMIX system contains three post-processor options which be accessed directly from within the system or independently outside of CORMIX. In either case, the post-processor options provide additional enhancements to CORMIX in terms of plume display, and more detailed computation of near- and far-field plume features.

The first of the options, the graphics package CMXGRAPH, has already been described in Section 5.3. The second option is CORJET, the Cornell Buoyant Jet Integral Model, for the detailed analysis of the near-field behavior of buoyant jets. FFLOCATR, the Far-Field Plume Locator, for the far-field delineation of discharge plumes in non-uniform river or estuary environments is the third option. The latter two are described in this chapter.

6.1 CORJET: The Cornell Buoyant Jet Integral Model

6.1.1 General Features

CORJET is a Fortran model that solves the three-dimensional jet integral equations for submerged buoyant jets –either **a single round jet or interacting multiple jets in a multiport diffuser**– in a highly arbitrary ambient environment. The ambient/discharge conditions include an arbitrary discharge direction, positive, neutral or negative discharge buoyancy, an arbitrary stable density distribution, and a non-uniform ambient velocity distribution with magnitude and direction as a function of vertical position.

Figure 6.1 displays these general characteristics for the case of a single port. In case of the multiport diffuser all the discharge port/nozzles point in the same direction (unidirectional or staged design) and the diffuser line can have an arbitrary alignment angle relative to the ambient current (for definitions see Section 4.5.1).

The detailed theoretical basis for CORJET can be found in the documentation report (8) on recent CORMIX system enhancements. CORJET is a type of a jet integral model whose original development in a two-dimensional framework and for a round jet only was first reported in the peer-reviewed literature by Jirka and Fong (25). Detailed verification studies with various experimental data sources have been reported (8,26).

In jet integral models the hydrodynamic equations governing the conservation of mass and momentum, and of other quantities as pollutant mass, density deficit, temperature and/or salinity, are solved step-wise along the general curved jet trajectory. The solution yields values of the trajectory position itself and of the centerline concentrations of these quantities, while the actual cross-sectional distribution is fixed a priori (mostly as a Gaussian distribution) in these models. Literally several dozen such model developments have been reported in the literature over the last thirty years or so of research on these mixing phenomena. Most of these developments differ (i) in the degree of simplifying assumptions on the ambient/discharge characteristics (e.g. two-dimensional trajectories or uniform ambient conditions only), and (ii) in the type of closure that is made to specify the turbulent growth and entrainment behavior in these jets under a variety of forcing conditions. Thus, some of these models can be demonstrated to be unduly limited for practical applications, and others to be clearly invalid in certain limiting regimes of plume behavior.

Whenever a jet integral model is reasonably general in its formulation <u>and</u> has been validated through experimental data comparison under a number of conditions it can be considered a useful prediction tool for near-field plume analysis. For practical purposes, all the models that meet the above conditions, in fact, differ little in their prediction results. The deviation among model results is usually less than the scatter in experimental data that is used for their verification. This holds true also for CORJET as well as another jet integral model,

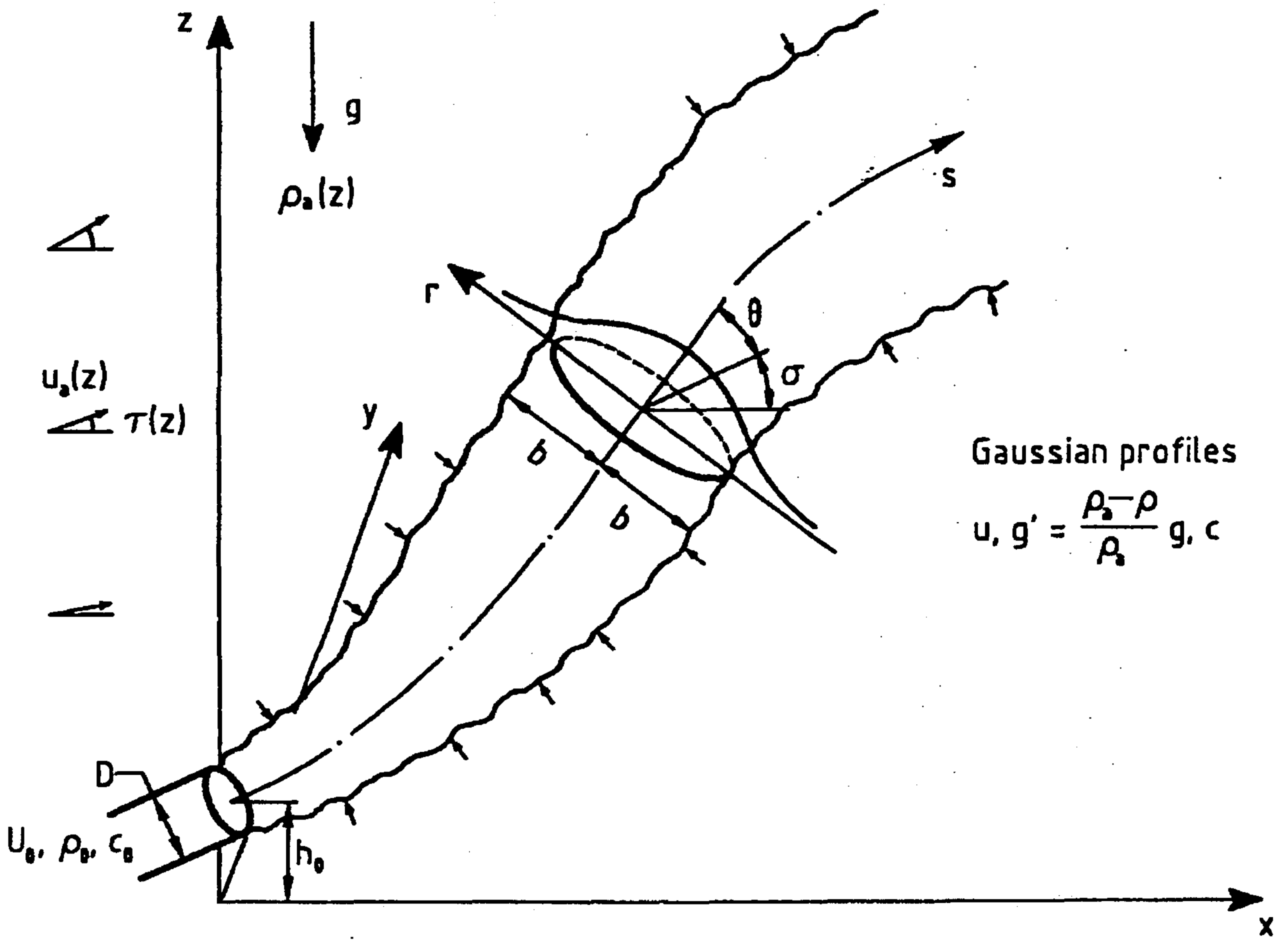


Figure 6.1: General three-dimensional trajectory of submerged buoyant jet in ambient flow with arbitrary density and velocity distribution: Case of a single round jet

(27), that has current USEPA support and distribution.

Both CORJET and PLUMES, although they differ in their internal formulation and closure assumptions, have a wide generality in discharge/ambient conditions and a reasonable verification base for a variety of conditions. They can deal with three-dimensional trajectories, with positive, neutral or negative discharge buoyancy, with conditions of reversible buoyancy (so-called nascent conditions in freshwater systems due to the density maximum at 4°C, requiring use of the full non-linear equation of state), with first-order pollutant decay, with variable stable ambient density, and with sheared non-uniform ambient currents, and with the merging of multiple port diffuser plumes. Three specialized features that the PLUMES model cannot deal with are a variable current direction at different levels, arbitrary diffuser alignments (with the extreme of a fully parallel alignment, $\gamma = 0°$ in Figure 4.6), and applications to atmospheric plumes (using the concept of potential temperature and density).

Jet integral models, such as CORJET and

PLUMES, appear as useful and efficient tools for the rapid analysis of the near-field mixing of aqueous discharges. They require fairly little input data and are numerically efficient. However, their inherent limitations must be kept in mind.

All **jet integral models,** including CORJET, **assume an infinite receiving water body,** without any boundary effects due to limiting dimensions vertically (surface, bottom, or pycnocline) or laterally (banks or shore). Thus, they do not deal with such hydrodynamic effects as jet attachment and near-field instabilities that are so prevalent in many aqueous discharge plumes as emphasized in Section 2.1.1. Furthermore, they are **near-field models only** and do not give predictions on what happens to the entire mixing zone that may often cover larger distances (see Section 2.2.5).

In summary, jet integral models **if used alone** and by an inexperienced analyst are **not a safe methodology for mixing zone analysis.** They become safe only when used in conjunction with a more comprehensive analysis using the full CORMIX system. Therefore, in case of engineering design applications, **CORJET should be employed after prior use of the expert system CORMIX has indicated that the buoyant jet will not experience any instabilities due to shallow water or due to attachment to boundaries.**

In fact, the CORMIX system has built in several safeguards and warning statements to the user as explained below. When used in that context CORJET becomes a highly useful addition to the CORMIX system that can provide considerable additional detail and sensitivity analysis in the immediate near-field of the discharge plume.

6.1.2 Access to CORJET

CORJET, like the other post-processor options such as the graphics system (Section 5.3.1), can be accessed in different ways:

(1) Use within CORMIX:

(1a) It can be accessed at an end of the prediction after the file has been stored, by entering the Post-Processor option in the Iteration Menu.

(1b) It can be accessed on earlier existing files by directly choosing the Post-Processor option in the Main Menu.

In either case, once the CORJET option is chosen the user must first specify whether a CORMIX1 or 2 simulation should be analyzed for the near-field with CORJET. Then the CORMIX1 or 2 filename in the CORMIX\SIM directory must be specified. CORJET will run automatically using the input data of the given CORMIX data file.

(2) Use outside CORMIX:

CORJET can be invoked directly by typing:

corjet (or simply: cj) *filename*

where *filename* (including path and extension) is any specially prepared input data file (see following section). Alternatively if one types:

corjet (or simply: cj)

the model will prompt the user for the input data filename.

6.1.3 CORJET Input Data File

This section for data preparation applies only if CORJET is run independently from the CORMIX system as discussed above. The **checklist** given on the following page is useful for data assembly prior to input data entry.

In this case, the Fortran model CORJET reads input data file with *filename* that is user-specified with arbitrary name, extension and directory. For user convenience it is recommended that all such files be kept in the special directory CORMIX\POST\CJ.

The input data file is a Fortran-readable file that is read in open format, that is all pertinent data values are arranged on a line and separated by one or more open spaces. The file consists of five data blocks, each of which must be lead in by two dummy lines that are not read. Table 6.1 gives an example of a data file in which the dummy lines are indicated by the # sign.

Table 6.1
Example of an input data file for CORJET

```
#CORJET INPUT FILE
#Title line (50 characters max.):
Case2: SINGLE PORT, STRATIFIED, VARIABLE CURRENT
#Fluid (1=water,2=air), Density option (1=calculate,2=specify directly):
#Fluid (½):   Density option (½):   Ambient levels (1-10):
1             1                      3
#Ambient conditions (if d.o.=1, fill in TA+SA; if 2, fill in RHOA):
#Level ZA     TA     SA     RHOA   UA     TAUA
1      0.     12.    30.           0.5    0.
2      5.     15.    29.5          0.8    0.
3      15.    20.    28.           1.2    0.
#Discharge conditions (T0+S0, or RHO0 as above; if NOPEN=1: set LD=0,ALIGN=0):
#NOPEN D0    H0    U0    THETA0 SIGMA0 C0    KD    T0    S0    RHO0   LD    ALIGN
1      0.5   0.    3.0   45.    45.    100.  0.    30.   0.           0.    0.
#Program control:
#ZMAX  ZMIN  DISMAX NPRINT
30.    0.    200.   10
```

The **required input data values** (all in SI units) are discussed in the following. The definition of these values is entirely consistent with those for CORMIX (in particular, see Section 4.4 and 4.5 for discharge conditions).

Block 1: Identifier

LABEL: Any descriptive label/text (should not exceed 50 characters, so that it does not get truncated on the graphics plots)

Block 2: Fluid and density specification

IFLUID: 1 (water) or 2 (air, for atmospheric applications)

IDENOP: 1: in case of water: Density will be calculated from specified temperature and/or salinity In case of air: Potential density will be calculated from potential temperature assuming dry adiabatic conditions

2: Density values will be specified directly

LEVAMB: Number of levels for which ambient conditions are given (1 to 10)

Block 3: Ambient Conditions (specify LEVAMB lines)

LEV: Level number (increasing from 1 to LEVAMB)

ZA: Specify vertical level (z-coordinate) (m)

TA : if IFLUID=1(water): Temperature at ZA (degC) *(omit if IDENOP=2)*
if IFLUID=2(air): Potential temperature at ZA (degC) *(omit if IDENOP=2)*

SALA: Salinity at ZA (ppt) *(omit if IDENOP=2 or if IFLUID=2)*

RHOA: if IFLUID=1: Density at ZA (kg/m^3) *(omit if IDENOP=1)*
if IFLUID=2: Potential density at ZA (kg/m^3) *(omit if IDENOP=1)*

UA: Ambient velocity (speed) at ZA (m/s)

TAUA: Angle of ambient velocity vector measured CCW from x-axis (deg) (set = 0. unless velocity distribution in vertical is skewed, i.e. spiral-type)

Block 4: Discharge Conditions

NOPEN: 1: if SINGLE PORT DISCHARGE (i.e. 1 opening)
>= 3: number of openings (ports) for MULTIPORT DIFFUSER

D0: Port diameter (m) (should include contraction effects if any)

H0: Port center height above x-y plane (m)

U0: Jet exit velocity (m/s)

THETA0: Vertical angle of discharge (deg)

CHECKLIST FOR DATA PREPARATION

CORJET – CORNELL BUOYANT JET INTEGRAL MODEL– Version 4.10

DOS File Name:

Date:
Prepared by:

Label:

Fluid/Density:

Fluid: 1 (water) 2 (air)

Density specificaton: 1 (via temp./sal.) 2 (direct)

Number of ambient levels: (1 to 10)

Ambient Data:

Level No.	Elevation (m)	Temperature (°C)	Salinity (ppt)	Density (kg/m³)	Velocity (m/s)	Angle of velocity (deg)

Discharge Conditions:

Number of openings: (=1 for single port s.p.)		Port diameter (m)	Height above origin (m)	Exit velocity (m/s)	Vertical angle (deg)	Horizontal angle (deg)
Discharge conc. (any units)	Coefficient of decay (/s)	Discharge temp. (°C)	Discharge salinity (ppt)	Discharge density (kg/m³)	Diffuser length (m) (= 0. if s.p.)	Alignment angle (deg) (= 0. if s.p.)

Program Control:

Max. vertical distance (m):

Min. vertical distance (m):

Max. distance along trajectory (m):

Print intervals: (best 5 to 10)

SIGMA0: Horizontal angle of discharge axis measured CCW from x-axis (deg)
Examples: 0. = co-flow, 90. or 270. = cross-flow, 180. = counterflow
C0: Discharge concentration (any units that need not be specified)
KD: Coefficient of substance decay [negative value if growth] (/s)
T0: Discharge temperature (degC) *(omit if IDENOP=2)*
S0: Discharge salinity (ppt) *(omit if IDENOP=2 OR IF IFLUID=2)*
RHO0: Discharge density (kg/m^3) *(omit if IDENOP=1)*
LD: Diffuser length (m) (set = 0. [non-blank] if NOPEN=1)
ALIGN: Diffuser alignment angle (deg) measured CCW from x-axis (set = 0. if NOPEN=1)
Examples: 0. = parallel diffuser, 90. = perpendicular diffuser

Block 4: Program Control
ZMAX: Maximum vertical coordinate of interest (m)
ZMIN: Minimum vertical coordinate of interest (m)
ZMAX and ZMIN are cutoffs for + and - buoyancy, respectively!
DISMAX: Maximum distance of interest along trajectory (m)
NPRINT: Print intervals (any positive number less than 100; recommended value 5 to 10; does not affect accuracy of computation!)

Note on density specification: It is important to note the mutual exclusivity for the indirect or direct density specification as listed above. Omit the values (i.e. leave blank spaces) depending on the value of the IDENOP parameter. This can be seen in the preceding example data file. Up to 10 ambient levels can be specified for density and velocity distribution. This is sufficient to replicate complicated observed ambient profiles. CORJET performs internal **consistency checks** to test whether the specified density distribution is statically stable.

The **coordinate system** in CORJET can, in principle be taken as consistent with the CORMIX1 and 2 conventions (Section 5.2.1), i.e. the origin at the bottom of the receiving water body. (In fact, this convention is exercised whenever CORJET is run from within CORMIX.) However, since CORJET does not recognize the dynamic effect of the presence of the actual bottom boundary it is often convenient to set the origin at the center of the discharge port. In that case the port height H0 must be entered as 0.0. x points horizontally in the downstream direction, y laterally across in the horizontal plane, and z vertically upward. In the rare case when the ambient velocity distribution is skewed in the vertical, the definition of the x direction is best made by the direction of the ambient velocity at the level of origin (then TAUA is 0.0 at that level!), but any other convention is possible, too, and can be implemented by the choice of the TAUA value at the level of origin.

The CORMIX system contains upon its installation several **CORJET case studies** (see also Appendix E) that are installed as CORMIX\POST\CJ\case*.inp. It is recommended to copy one or more of these files and use the copy for constructing any future input data file.

6.1.4 CORJET Output Features

Regardless of the access mode (within or outside of CORMIX) CORJET has two output mechanisms, a numerical output file and a graphical display by means of CMXGRAPH.

(a) CORJET Output File:

(a.1) Use within CORMIX:

The output file gets stored as CORMIX\POST\CJ*fn*.CJX where *fn* is the CORMIX1 or 2 filename that has been specified during the data entry. This file can be viewed on-screen or printed within CORMIX.

A typical CORJET output file generated in this access mode is shown in Table 6.2 below corresponding to the input example presented above. The header information starts with the banner 'JJJ' and then echoes all the pertinent data that had been supplied to CORMIX and had been picked up for the CORJET simulation. The underlying CORMIX1 or 2 **flow class** is listed. If one of the **unstable or bottom-attaching** flow classes is encountered in this access mode, then **CORJET will not provide any predictions** since a pure jet integral model would not be **applicable.**

The tabular listing (see Table 6.2) gives the plume values along the trajectory. CORJET will cut off at a vertical level ZMAX that is equal to the water depth at discharge or ZMIN = 0.0 (for negatively buoyant cases) equal to the water body bottom. In neither case does it compute the actual boundary approach or impingement processes (as does the more complete CORMIX model in which some CORJET elements are, in fact, integrated, starting with Version 3.0). The interpretation of data values in this tabular listing is consistent with that for CORMIX1 or 2 (see Section 5.2.2).

Table 6.2
Example of CORJET output file when accessed within CORMIX

```
CORJET PREDICTION FILE:
JJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJ
CORJET:  CORNELL BUOYANT JET INTEGRAL MODEL          Version 4.0, March 1995
---------------------------------------------------------------------------
FILE NAME:                 cormix\post\cj\SAMPLE1.CJX
 Label/identifier:         A-PLANT^SUMMER^STRATIFICATION
 Time of CORJET run:        4/12/96--18:40:19
NEAR-FIELD DATA values for earlier CORMIX1  prediction (metric):
 Site name/label:          DEEP^RESERVOIR
 Design case:              A-PLANT^SUMMER^STRATIFICATION
 FILE NAME:                cormix\sim\SAMPLE1 .CX1
 Time of CORMIX run:       06/24/95--22:29:54
 HD     =      30.50  UA     =         .01  CUNITS= PPM
 STRCND=    C         density stratified environment
 RHOAS =     996.21  RHOAB =     999.61  HINT   =      15.50  DRHOJ =      2.181
 FLOCLS=    S3
Corresponding CORJET ambient conditions:
   LEV      ZA      RHOA      UA     TAUA
    1        .00   999.61     .01      .00
    2      14.75   998.39     .01      .00
    3      16.25   996.21     .01      .00
    4      30.50   996.21     .01      .00
  Pycnocline thickness has been set to 1/10 of upper layer thickness.
Discharge conditions (metric):  SINGLE PORT
   D0       H0        U0   THETA0 SIGMA0     C0       KD     RHO0
   .254     .60      3.02  10.00  90.00 .35E+04 .00E+00  998.21
Program control:
   ZMAX     ZMIN    DISMAX  NPRINT
   30.50      .00 1525.00      10
Flux variables (based on ambient at discharge level):
 Q0     =  .153E+00  M0     =  .462E+00  J0     =  .203E-02  GP0    =  .133E-01
Length scales (m) and parameters:
 LQ     =        .23  LM     =      12.44  Lm     =      45.31  Lb     =     601.53
 Lmp    =       4.88  Lbp    =       3.06
 FR0    =      52.01  R      =     201.31
---------------------------------------------------------------------------
CORJET PREDICTION:                  Stepsize =    .2251  Printout every  10 steps
 Single jet/plume:
    X       Y       Z      Sc       Cc        B  |   DIST   Save     Gpc    Flc
    .00     .00     .60    1.0  .350E+04    .13  |    .00    1.0  .13E-01 52.01
    .01    1.23     .82    1.0  .350E+04    .13  |   1.25    1.4  .16E-01 95.03
    .04    3.45    1.22    2.5  .142E+04    .37  |   3.50    4.2  .50E-02 33.42
    .11    5.65    1.65    4.1  .852E+03    .62  |   5.75    7.0  .25E-02 21.98
    .22    7.85    2.13    5.8  .607E+03    .87  |   8.00    9.8  .12E-02 19.01
    .35   10.04    2.65    7.4  .471E+03   1.12  |  10.25   12.6  .32E-03 25.46
    .44   11.13    2.92    8.3  .423E+03   1.25  |  11.38   14.0 -.59E-04 50.81
 Level of buoyancy reversal in stratified ambient.
    .53   12.22    3.19    9.1  .384E+03   1.37  |  12.50   15.4 -.40E-03 16.80
    .74   14.40    3.68   10.8  .325E+03   1.63  |  14.76   18.2 -.97E-03  8.35
    .99   16.61    4.06   12.4  .282E+03   1.88  |  17.01   21.0 -.13E-02  5.70
   1.28   18.83    4.20   14.1  .248E+03   2.14  |  19.26   23.8 -.13E-02  4.61
   1.31   19.05    4.20   14.3  .245E+03   2.17  |  19.48   24.1 -.13E-02  4.56
 Maximum jet height has been reached.
   1.62   21.05    4.05   15.9  .220E+03   2.40  |  21.51   26.8 -.99E-03  4.54
   1.99   23.23    3.63   17.8  .196E+03   2.66  |  23.76   30.0 -.34E-03  6.68
   2.19   24.31    3.37   18.8  .187E+03   2.80  |  24.89   31.6  .27E-04 22.15
 Terminal level in stratified ambient has been reached.      PROGRAM STOPS!
---------------------------------------------------------------------------
END OF CORJET PREDICTION:          Total number of integration steps =   106
JJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJ
```

The main usefulness of CORJET when run in this mode lies in the short and separate display of the near-field buoyant jet only. In some cases, the pertinent regulatory constraints may be limited to that region.

(a.2) Use outside of CORMIX:

The output file gets stored as *filename*.OUT in the same directory for which the user had specified the input file (see Section 6.1.2(2)). This file can be viewed on-screen or printed using any text processor.

The CORJET output file corresponding to the input data file of Table 6.1 is listed in Table 6.3. The lead-in data provide an echo of the input data and then lists the calculated length scale and non-dimensional numbers controlling the mixing process.

Table 6.3
Example of CORJET output file

```
CORJET PREDICTION FILE:
JJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJ
CORJET:  CORNELL BUOYANT JET INTEGRAL MODEL           Version 4.0, March 1995
-----------------------------------------------------------------------------
FILE NAME:                 post\cj\case2.OUT
 Label/identifier:         Case2: SINGLE PORT, STRATIFIED, VARIABLE CURRENT
 Time of CORJET run:        4/10/96--19:28: 6

Ambient conditions:        No. of levels: 3   Fluid: Water   Density option: 1
   LEV      ZA        TA        SA    RHOA        UA     TAUA
    1       .00     12.00    30.00 1022.71       .50      .00
    2      5.00     15.00    29.50 1021.74       .80      .00
    3     15.00     20.00    28.00 1019.43      1.20      .00
Discharge conditions (metric):  SINGLE PORT
   DO       HO        UO   THETAO SIGMAO     CO       KD       TO      SO      RHOO
   .500     .00     3.00   45.00  45.00 .10E+03  .00E+0    30.0      .0   995.65
Program control:
   ZMAX     ZMIN   DISMAX  NPRINT
  30.00      .00   200.00     10
Flux variables (based on ambient at discharge level):
 Q0    =  .589E+00  M0    =  .177E+01  J0    =  .153E+00  GP0    =  .259E+00
 QT0   =  .106E+02  QS0   = -.177E+02
Length scales (m) and parameters:
 LQ    =       .44  LM    =      3.92  Lm    =      2.66  Lb     =     1.22
 Lmp   =      5.61  Lbp   =      6.71
 FR0   =      8.33  R     =      6.00
Zone of flow establishment (m):
 LE    =      1.30  XE    =       .75  YE    =       .62  ZE     =      .86
 THETAE=     38.34  SIGMAE=     34.00  GAMMAE=     49.43
-----------------------------------------------------------------------------
CORJET PREDICTION:              Stepsize =     .2659  Printout every  10 steps
 Single jet/plume:
    X        Y       Z      Sc        Cc       B  |  DIST    Save     Gpc    dTc dSALc
    .00      .00     .00    1.0  .100E+03    .25 |    .00    1.0  .26E+00 18.0-30.0
    .75      .62     .86    1.0  .100E+03    .25 |   1.30    1.4  .27E+00 20.8-34.7
   2.81     1.50    2.27    3.0  .334E+02    .64 |   3.96    4.6  .83E-01  5.2 -9.9
   5.22     1.96    3.28    5.7  .176E+02    .94 |   6.62    8.3  .42E-01  2.1 -5.1
   7.74     2.22    4.07    8.4  .118E+02   1.16 |   9.27   12.1  .26E-01   .8 -3.3
  10.31     2.40    4.74   11.2  .890E+01   1.34 |  11.93   15.8  .18E-01   .1 -2.4
  12.90     2.52    5.32   14.0  .716E+01   1.49 |  14.59   19.5  .13E-01  -.3 -1.9
  15.51     2.61    5.84   16.6  .601E+01   1.62 |  17.25   23.2  .96E-02  -.6 -1.5
  18.12     2.68    6.31   19.2  .520E+01   1.74 |  19.91   26.7  .70E-02  -.8 -1.2
  20.75     2.73    6.74   21.7  .460E+01   1.84 |  22.57   30.0  .50E-02 -1.0 -1.0
  23.38     2.78    7.13   24.1  .414E+01   1.93 |  25.23   33.3  .34E-02 -1.1   -.8
  26.01     2.82    7.48   26.4  .379E+01   2.01 |  27.89   36.3  .21E-02 -1.3   -.6
  28.65     2.85    7.80   28.5  .351E+01   2.08 |  30.54   39.1  .10E-02 -1.4   -.5
  31.29     2.88    8.09   30.4  .329E+01   2.14 |  33.20   41.6  .15E-03 -1.5   -.4
  31.82     2.89    8.14   30.8  .325E+01   2.15 |  33.73   42.1 -.13E-04 -1.5   -.4
 Terminal level in stratified ambient has been reached.        PROGRAM STOPS!
-----------------------------------------------------------------------------
END OF CORJET PREDICTION:        Total number of integration steps =     123
JJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJ
```

The actual tabular listing of the numerical output is divided in two halves by a vertical line. The left half lists data exactly in the same fashion as a CORMIX1 or 2 prediction file (see Section 5.2.2). The right half gives additional detailed information on the following variables:

DIST:	distance (m) along the jet trajectory
Save:	average (bulk) dilution, defined on the basis of total volume flux within the jet relative to the initial volume flux (discharge)
Gpc:	centerline buoyant acceleration (m/s^2)
dTc:	centerline temperature difference relative to local ambient temperature (°C) *(if IDENOP = 1)*
dSALc:	centerline salinity difference relative to local ambient salinity (ppt) *(if IDENOP = 1)*
Flc:	local densimetric Froude number *(if IDENOP = 2)*

In this mode CORJET becomes an important engineering tool for **design sensitivity analysis** –and also for research purposes– to evaluate the behavior of the near-field processes to some of the ambient/discharge details, some of which had to be simplified (schematized) within the CORMIX approach. The user can learn to understand through repeated use of CORJET that plume mixing can indeed often be represented by simple linear, or even uniform, approximations to the ambient density structure.

Again, it is emphasized that CORJET when used alone is not a safe prediction methodology because of the limiting assumption of infinite receiving water. For that reason an alert is printed at the end of each CORJET output file:

```
Note: CORJET has been used outside the
      CORMIX system, assuming unlimited
      receiving water.
      Carefully examine all results for
      possible boundary effects due to
      surface, bottom, or lateral
      boundaries.
```

Previous application of CORMIX assures a careful examination of the interaction of the discharge with boundaries has been accomplished.

(b) Graphics display and plotting of CORJET results:

The graphical display and plotting of the CORJET prediction results by means of CMXGRAPH is similar to that of CORMIX results as described in Section 5.3.

The graphics package can be invoked in either access mode (within or outside of CORMIX) immediately after the computation or independently on any existing CORJET output file that has been computed earlier. Thus, **CMXGRAPH has been configured to deal with both CORMIX prediction files and CORJET output files.**

6.2 FFLOCATR: The Far-Field Plume Locator

6.2.1 General Features

Although the main emphasis of CORMIX is on the near-field mixing behavior of discharges it can also be used for providing plume predictions at larger distances in the far-field provided the flow is not highly irregular with pronounced recirculating zones and eddies in the ambient flow.

The CORMIX predicted far-field always applies to a rectangular schematized cross-section with a straight uniform channel (see Sections 4.3.1 and 4.3.2). The FFLOCATR is a simple method for interpreting the schematized CORMIX far-field plumes within the actual flow patterns in natural rivers and estuaries. This procedure, based on the cumulative discharge method, is illustrated in Figure 6.2.

The **cumulative discharge method**, first proposed by Yotsukura and Sayre (28; see also 19,20), is a convenient approach of dealing with lateral mixing in natural irregular (but not highly irregular with recirculating zones!) channels. In such channel geometry the passive far-field plume that is vertically mixed, or approaches vertical mixing, will be positioned around the "streamline", or more precisely the "cumulative discharge line", that passes through the plume

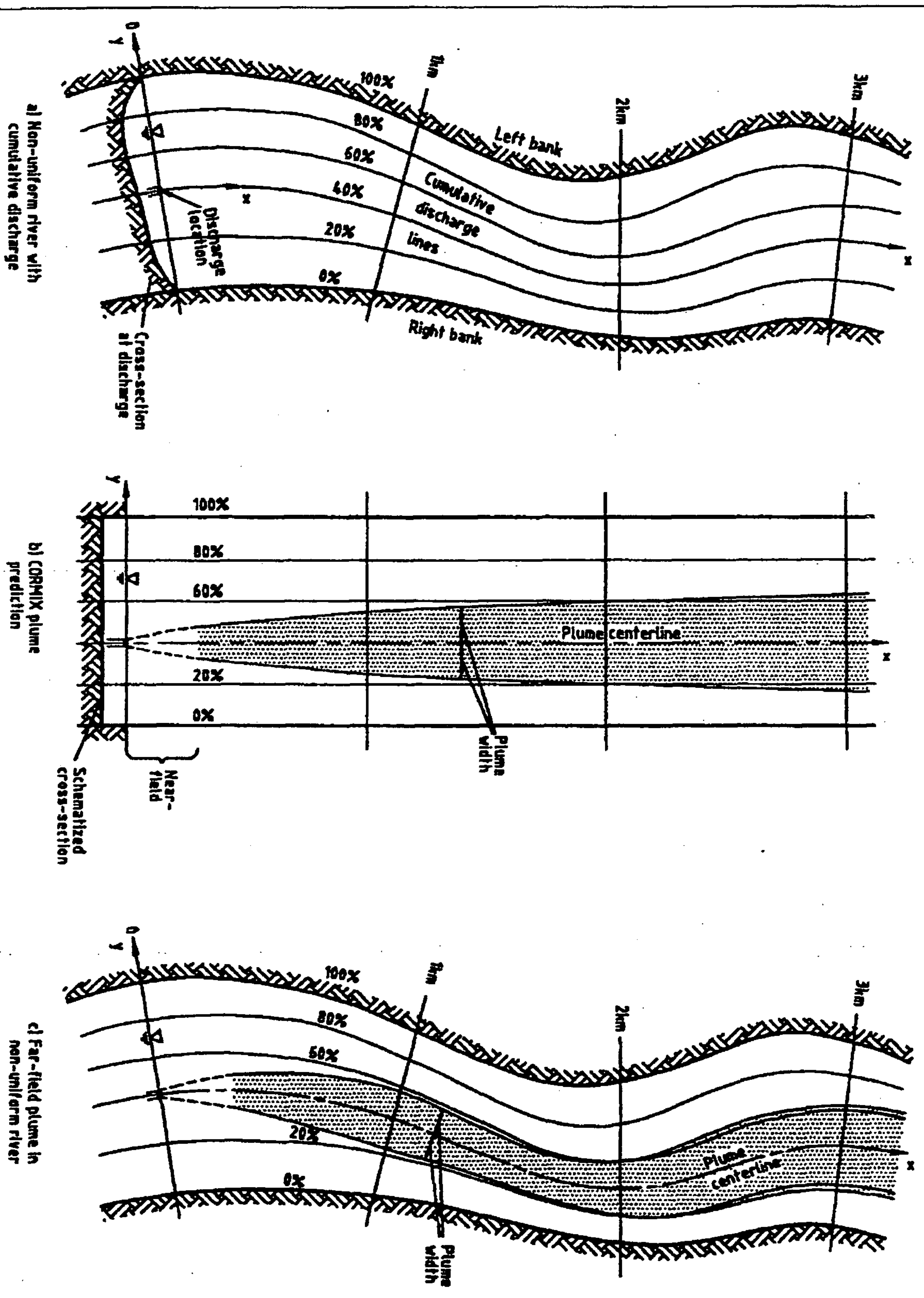


Figure 6.2: Illustration of the cumulative discharge method for translating the CORMIX predicted far field plume to the actual flow characteristics in winding irregular rivers or estuaries

center when it enters the far-field. Lateral spreading around this line occurs by lateral turbulent diffusion and can be enhanced buoyancy induced processes.

Looking downstream at a particular cross-section (see Figure 6.2a) the cumulative discharge $q(y)$ is defined as

$$q(y') = \int_0^{y'} \overline{u_a}(y')\, H(y')\, dy'$$

in which y' is the lateral coordinate pointing from the right bank to the left across the flow (y' differs from y as defined in CORMIX whose origin is at the discharge location), H is the local depth, and $\overline{u_a}$ is the depth-averaged local velocity. When the above equation is integrated across the full channel width B_s then the total discharge will result $Q_a = q(B_s)$. Hence, if the local values $q(y')$ are divided by Q_a the results can be presented in normalized form as the cumulative discharge lines ranging from 0% at the right bank to 100% at the left bank. The full distribution of such cumulative discharge lines in a river or estuary gives an appearance of the overall flow pattern that is important for pollutant transport. Closely spaced discharge lines are mostly indicative of areas of large depth and higher velocities as they occur in the outside portion of river bends or meanders (as sketched in Figure 6.2a).

In the CORMIX schematization of ambient flow characteristics and channel cross-section it is, in fact, useful to keep in mind the cumulative transport aspects of the ambient flow as remarked in Section 4.3.1 and 4.3.2. Thus, the uniform CORMIX flow field with the constant depth laterally is indeed conforming to a cumulative discharge distribution with equally spaced discharge lines, as indicated in Figure 6.2b. It is then conceptually straightforward to translate the CORMIX plume prediction back to the actual flow distribution by calculating and plotting the plume boundaries within the given cumulative discharge lines as shown in Figure 6.3c. The actual plume pattern may then show some surprising features such as strong "shifting back and forth" between opposing banks and an apparent "thinning' of the plume width. These realistic plume features are simply dictated by the non-uniform flow field.

Further technical details on the FFLOCATR model can be found in the report on CORMIX enhancements (8).

6.2.2 Access to FFLOCATR

FFLOCATR can also be accessed in different ways:

(1) Use within CORMIX:

(1a) It can be accessed at an end of the prediction after the file has been stored, by entering the Post-Processor option in the Iteration Menu.

(1b) It can be accessed on earlier existing files by directly choosing the Post-Processor option in the Main Menu.

In either case, once the FFLOCATR option is chosen the user must first specify whether a CORMIX1, 2 or 3 simulation should be interpreted for the far-field with FFLOCATR. Then the CORMIX filename in the CORMIX\SIM directory must be specified. Finally, the user must specify the name of the cumulative discharge input data file, or if that does not yet exist, the user can first create such file by entering data on the cumulative discharge distribution at several cross-sections.

(2) Use outside CORMIX:

FFLOCATR can be invoked directly by typing the command line with three arguments:

fflocatr CORMIXn *fn* POST\FF*cumdata*.FFI

(alternatively, ffl can be typed instead of fflocatr) where CORMIXn, n = 1, 2 or 3, specifies which earlier CORMIX simulation should be analyzed for the far-field, *fn* (without path and extension) is the name of the CORMIX prediction file in the CORMIX\SIM directory, and *cumdata* (with directory designation POST\FF and fixed extension FFI) is the cumulative discharge input data file (see following section) existing in directory CORMIX\POST\FF.

Alternatively if one types:

fflocatr (or simply: ffl)

without the three arguments, the model will prompt the user for the file information.

6.2.3 FFLOCATR Cumulative Discharge Input Data File

In general, it is more convenient to construct the *cumdata*.FFI file outside of CORMIX and store it in the CORMIX\POST\FF directory. This option is described first.

(a) Input Data File Prepared Outside of CORMIX:

FFLOCATR is a Fortran program and reads the *cumdata*.FFI file in open format. An example is shown in Table 6.4 (corresponding to the test case discussed in Appendix B).

Table 6.4
Example of a cumulative discharge input data file for FFLOCATR

```
SHALLOW RIVER CUMULATIVE DISCHARGE          (applies to Sample2)
Number of Cross-sections (XS):
3
XS 'Label-' Dist.  10%   20%   30%   40%   50%   60%   70%   80%   90%   100%
<> <------> <----> <---> <---> <---> <---> <---> <---> <---> <---> <---> <--->
1  'STA1'   30.5   6.1   12.2  15.9  20.7  27.5  33.6  58.0  76.3  82.4  88.5
2  'STA2'   152.5  9.2   16.8  21.4  24.4  27.5  33.6  36.6  39.7  54.9  79.3
3  'STA3'   305.   18.3  33.6  39.3  45.8  48.8  51.9  54.0  56.4  61.0  67.1
```

The **required input data values** (SI units) are:

Line 1: Any descriptive label.
Line 2: <dummy line; not read>
Line 3: NUMXS = Number of cross-sections (1 to 10) for which discharge data values will be entered
Line 4: <dummy line useful for formatting subsequent data; not read>
Line 5: <dummy line useful for formatting subsequent data; not read>
Lines 6ff: NUMXS lines must be entered, each containing the following data:
- XS = number of cross-section, numbered sequentially beginning with 1
- STALAB = arbitrary label for cross-section, bracketed by apostrophes ' with maximum total length of 10 characters (e.g. 'RM595' standing for river mile 595)
- YCD = 10 values, representing the position of the cumulative discharge line (m) measured from the right bank, beginning with the 10% line, incrementing by 10%, and ending with the 100% line. The 100% line is also equal to the channel width at that cross-section.

Consistency checks are performed on each data file to make sure that the entered values YCD are monotonically increasing. Essentially two methods can be used for obtaining the values for the cumulative discharge positions YCD in specific cases:

1) On the basis of detailed **stream-gaging surveys**, for example using the standard methods employed by the U.S. Geological Survey. This is the preferable approach for small to medium streams or rivers.

2) Using the results of detailed **numerical models** for the flow distribution in open channel flow. This is preferable for larger rivers or estuaries.

The primary application for FFLOCATR is for **bounded channels** such as streams, rivers or estuaries. The model will not execute when it encounters a CORMIX file for a design case involving an unbounded ambient flow.

Nevertheless, it may sometimes be useful to provide a detailed far-field plume delineation also for **unbounded flow situations**, such as coastal areas or lakes. This can be done when detailed hydrographic data or numerical model predictions describing the flow distribution in the near-shore where the plume may be located are available. A CORMIX simulation can then be re-run specifying a "bounded channel" with a width equal to some arbitrary bounding offshore streamline. The YCD data can then be specified relative to the value of that chosen streamline. FFLOCATR will thus predict the far-field plume location in the irregular coastal zone (assuming recirculating eddies do not exist in the flow).

(b) Input Data File Prepared Within CORMIX:

The user can generate the data file with exactly the same data structure as discussed above also within CORMIX. The system will prompt the user for the individual data items (up to 10 cross-sections can be entered) and then for a *cumdata* filename. The file will then be stored automatically in directory CORMIX\POST\FF with extension FFI.

6.2.4 FFLOCATR Output Features

FFLOCATR generates an output file CORMIX\POST\FF*fn*.FFX indicating that the far-field plume prediction for the CORMIX design case *fn* has been interpreted under the actual far-field flow distribution. This file can be inspected on-screen when in CORMIX or externally with any text processor, and can be printed out. No graphics plotting option exists for this file.

As an example, Table 6.5 on the next page shows the output file that combines the cumulative discharge input data of Table 6.4 with the CORMIX2 plume predictions that are part of Appendix B. The output file preceded by the banner 'FFF' consists of three parts. The first part lists some of the underlying CORMIX data including file information. The second part echoes the complete cumulative discharge input data file.

The actual results of the FFLOCATR translation routine are given in the third part. For each of the specified cross-sections (stations) the output file lists the station label, the downstream distance, and the position of plume center, left edge and right edge, respectively, each measured from the right bank, and the local centerline dilution and concentration. Data of this kind can then readily be used to prepare plots of far-field plumes superimposed on maps of the actual flow field. This last step has been illustrated in Figure 6.2c.

It should be understood that the plume centerline in the far-field does not necessarily coincide with the cumulative discharge line that passes through the offshore discharge location (as has been illustrated in Figure 6.2 where a co-flowing discharge had been assumed). The plume centerline can shift because of near-field processes, as in case of a cross-flowing discharge, or if bank interaction occurs in the far-field, causing the centerline to shift to one bank/shore.

Table 6.5
Example of FFLOCATR output file

```
FFLOCATR RESULTS FILE:
FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
FFLOCATR:  FAR-FIELD PLUME LOCATOR                      Version 1.0, March 1994
-----------------------------------------------------------------------------
Output FILE NAME:          POST\FF\SAMPLE2.FFX
 Time of FFLOCATR run:     1995/ 6/ 2-- 8:54:38

-----------------------------------------------------------------------------
FAR-FIELD DATA values from earlier CORMIX2 prediction:
 FILE NAME:                SIM\SAMPLE2.cx2
 Site name/label:          B-PLANT^SHALLOW-RIVER
 Design case:              LOW-FLOW^7Q10
 Time of CORMIX2 run:      09/20/94--15:24:11

Channel characteristics (metric):
 BS     =     50.00  HA     =        .30  UA     =        .54
 BANK  =   right     DISTB =      20.00
 STRCND=   U         uniform density environment

Pollutant data:
 CO     =    100.00  CUNITS=    PERCENT

-----------------------------------------------------------------------------
CUMULATIVE DISCHARGE DATA (m):
 FILE NAME:                POST\FF\SH-RIVER.ffi
 Data label:               SHALLOW RIVER CUMULATIVE DISCHARGE
 Number of XS:             3
XS'Label-'  Dist.  10%   20%   30%   40%   50%   60%   70%   80%   90%  100%
1 'STA1  '   30.5  6.10 12.20 15.90 20.70 27.50 33.60 58.00 76.30 82.40 88.00
2 'STA2  '  152.5  9.20 16.80 21.40 24.40 27.50 33.60 36.60 39.70 54.90 79.00
3 'STA3  '  305.0 18.30 33.60 39.30 45.80 48.80 51.90 54.00 56.40 61.00 67.00

-----------------------------------------------------------------------------
FAR-FIELD PLUME PROPERTIES (m):
 XS  'Label-' Distance      Left      Plume      Right    Dilution     Conc.
 #           downstream     edge    centerline   edge
  1  'STA1  '    30.50     27.50      20.70     13.28       30.1     .332E+01
  2  'STA2  '   152.50     27.50      24.40     17.80       31.4     .318E+01
  3  'STA3  '   305.00     48.80      45.80     34.32       33.0     .303E+01
-----------------------------------------------------------------------------
END OF FFLOCATR:  FAR-FIELD PLUME LOCATOR
FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
```

VII Closure

7.1 Synopsis

The Cornell Mixing Zone Expert System (CORMIX) is a series of software subsystems for the analysis, prediction, and design of aqueous toxic or conventional pollutant discharges into diverse water bodies. The major emphasis is on the geometry and dilution characteristics of the initial mixing zone including compliance with regulatory constraints. The system also predicts the behavior of the discharge plume at larger distances in the far-field.

The highly user-interactive CORMIX system is implemented on IBM-PC compatible microcomputers and consists of three subsystems. These are: CORMIX1 for submerged single port discharges, CORMIX2 for submerged multiport diffuser discharges and CORMIX3 for buoyant surface discharges. The basic CORMIX methodology relies on the assumption of steady ambient conditions. However, recent versions also contain special routines for the application to highly unsteady environments, such as tidal reversal conditions, in which transient recirculation and pollutant build-up effects can occur.

In addition, two post-processing models are linked to the CORMIX system, but can also be used independently. These are CORJET (the Cornell Buoyant Jet Integral Model) for the detailed analysis of the near-field behavior of buoyant jets, and FFLOCATR (the Far-Field Plume Locator) for the far-field delineation of discharge plumes in non-uniform river or estuary environments.

This user's manual gives a comprehensive and uniform description of all three CORMIX subsystems; it provides advice for assembly and preparation of required input data; it delineates ranges of applicability of the three subsystems; it provides instruction for the interpretation and graphical display of system output; and it illustrates practical system application through several case studies.

7.2 System and Documentation Availability

The CORMIX system programs can be obtained from:

U.S. EPA - Center for Environmental
Assessment Modeling (CEAM)
Environmental Research Laboratory
960 College Station Road
Athens, GA 30605-2700 USA
Tel. 706-546-3549 (or FTS 250-3590)
Fax:706-546-3402
E-mail: ceam@athens.ath.epa.gov

As of the release of this manual (late 1996) the following versions of CORMIX are available: CORMIX Version2.1 (1993, without graphics and post-processor features) and Version3.1 (August 1996, as described in this report). The models can be obtained by mail or over the electronic bulletin board operated by CEAM. Information on program installation and computer configuration are also provided by CEAM. The ftp address is:

ftp://ftp.epa.gov/epa_ceam/wwwhtml/ceamhome.htm

The distribution versions of CORMIX contain only the executable code of the FORTRAN programs HYDROn; they do not include the source code. The source code can be requested separately by writing to CEAM at U.S. EPA-ERL and giving the reason for code inspection and possible manipulation. The full code, while made up of simple individual modules, is complex with multiple interdependencies; only experienced research personnel should attempt this work when engaged in comparison of model predictions to new field or laboratory data.

The technical documentation reports(5,6,7,8) are available as U.S. EPA and NITS publications, and have also been issued as technical reports of the DeFrees Hydraulics Laboratory.

7.3 User Support

Technical and scientific support for CORMIX under contract from the USEPA is provided by:

Dr. Robert L. Doneker
Department of Environmental Science and Engineering
Oregon Graduate Institute
PO Box 91000
Portland, OR 97291-1000
Tel. 503-690-4053, Fax. 503-690-1273
email: doneker@ese.ogi.edu

This includes assistance on problems of system installation and execution, and advice on the specification of input data as well as interpretation of CORMIX output.

Any high-quality field or laboratory data on effluent mixing processes is a valuable asset for any future development or updates on CORMIX. Transmittal of such data to the following address will be greatly appreciated:

Prof. Gerhard H. Jirka
Institute for Hydromechanics
University of Karlsruhe
PO Box 6380
D-76128 Karlsruhe, GERMANY
Tel. (49) 721/608-2200, Fax. (49) 721/66-16-86

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Appendix A

Flow Classification Diagrams for the Three CORMIX Subsystems

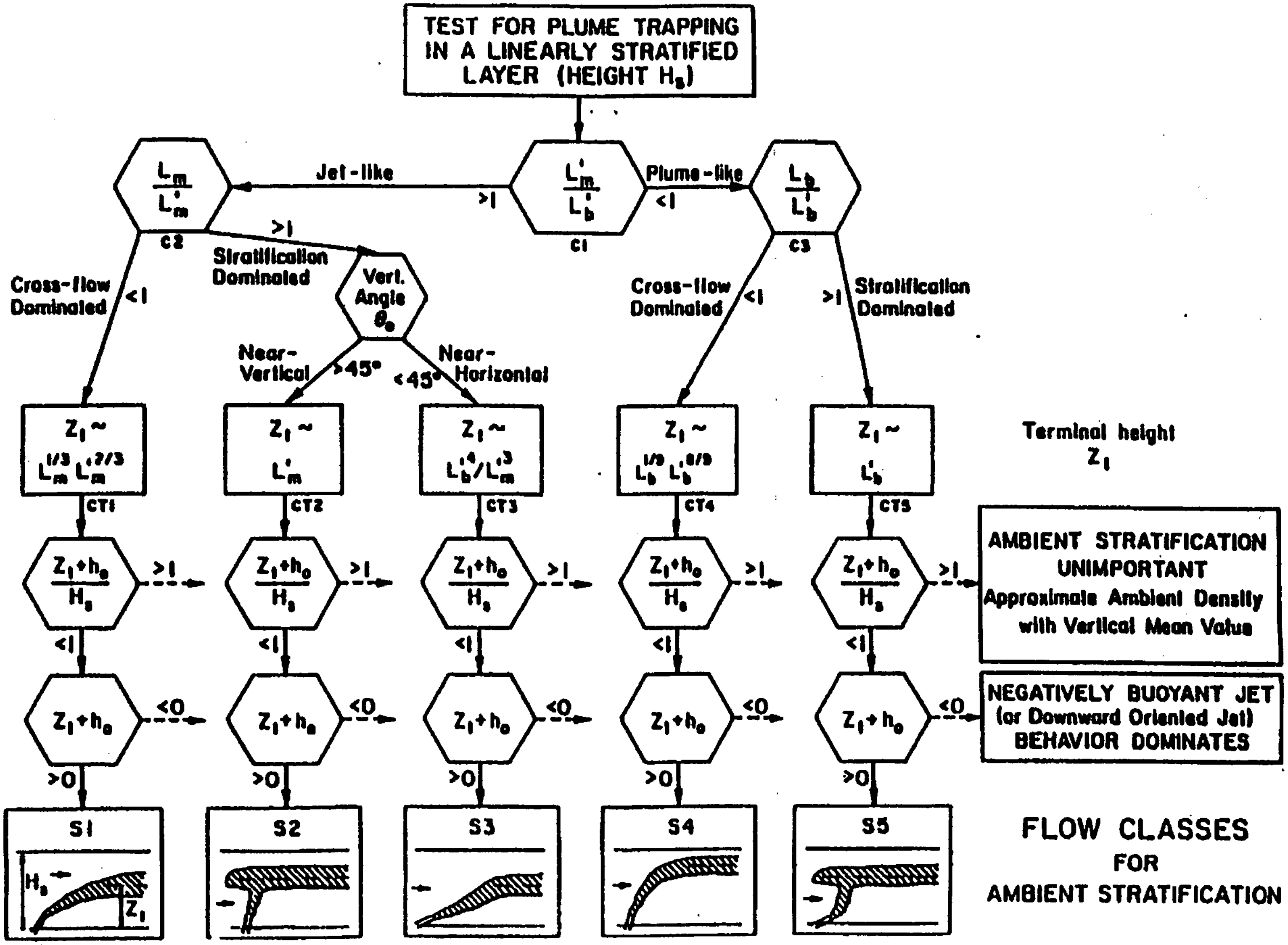


Figure A.1: CORMIX1 Classification: Assessment of ambient density stratification and different flow classes for internally trapped

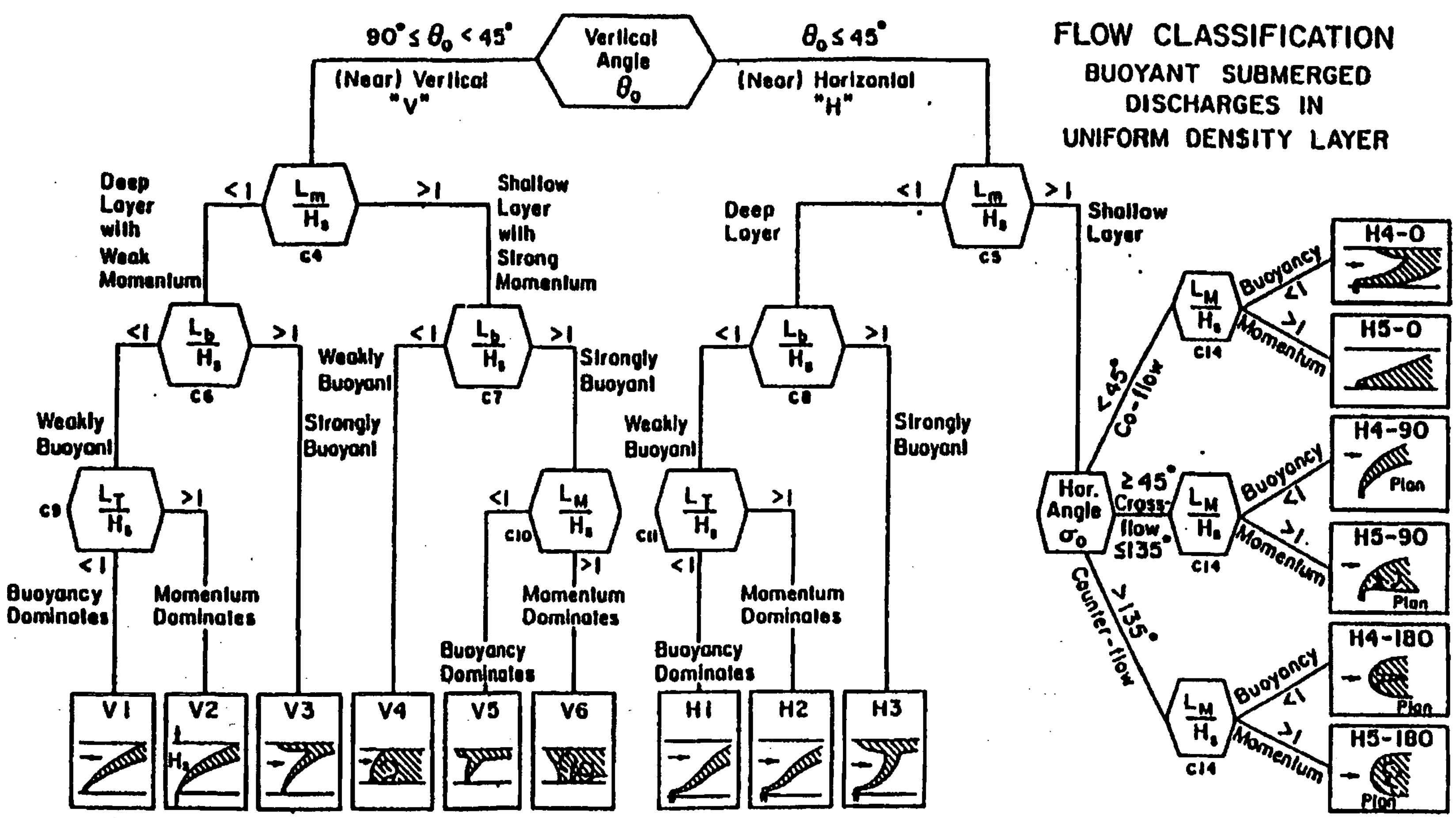


Figure A.2: CORMIX1 Classification: Behavior of positively buoyant discharges in uniform ambient layer flow

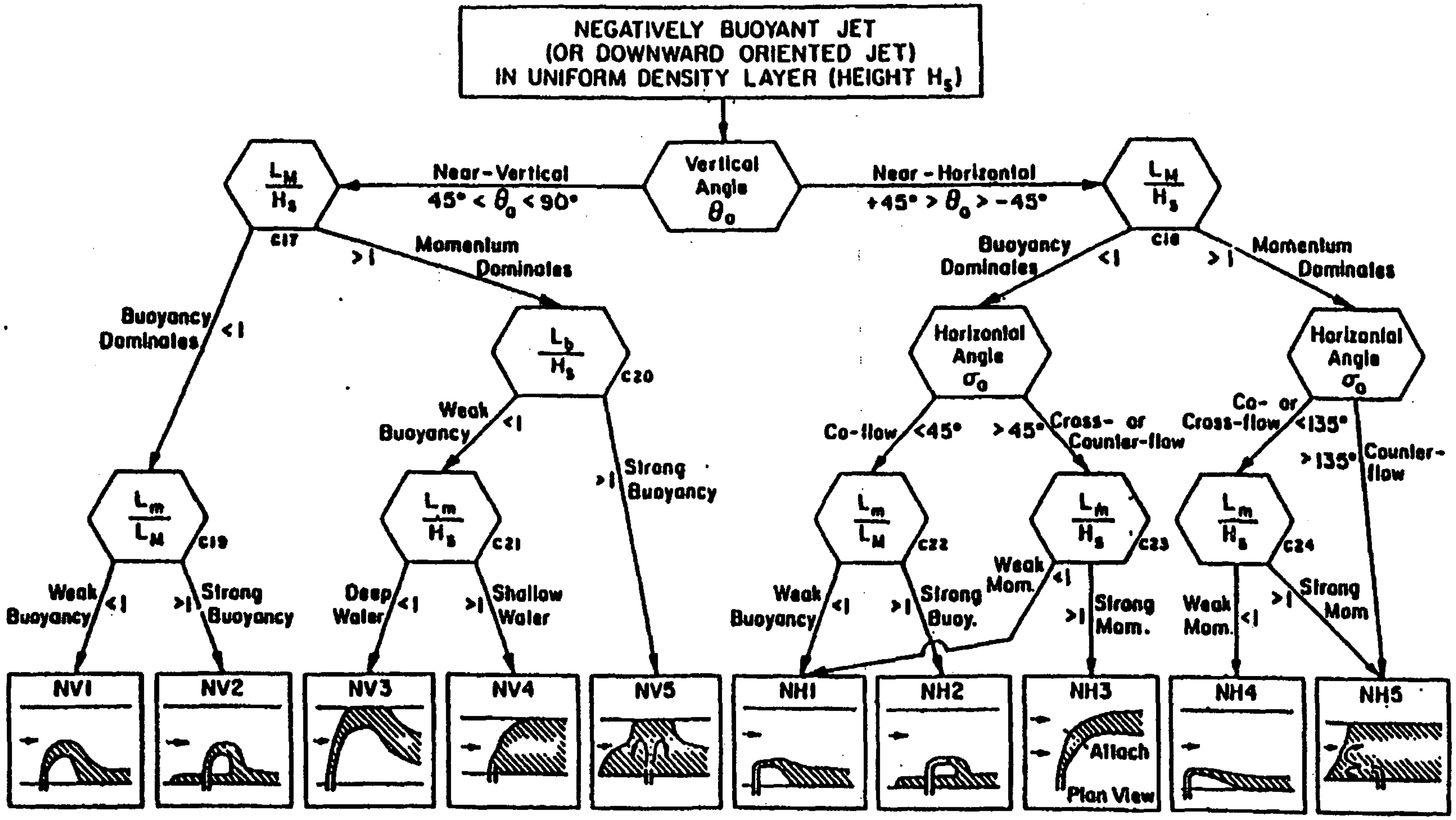


Figure A.3: CORMIX1 Classification: Behavior of negatively buoyant discharges in uniform layer flow (Flow Classes NV and NH)

CLASSIFICATION BOTTOM ATTACHMENT

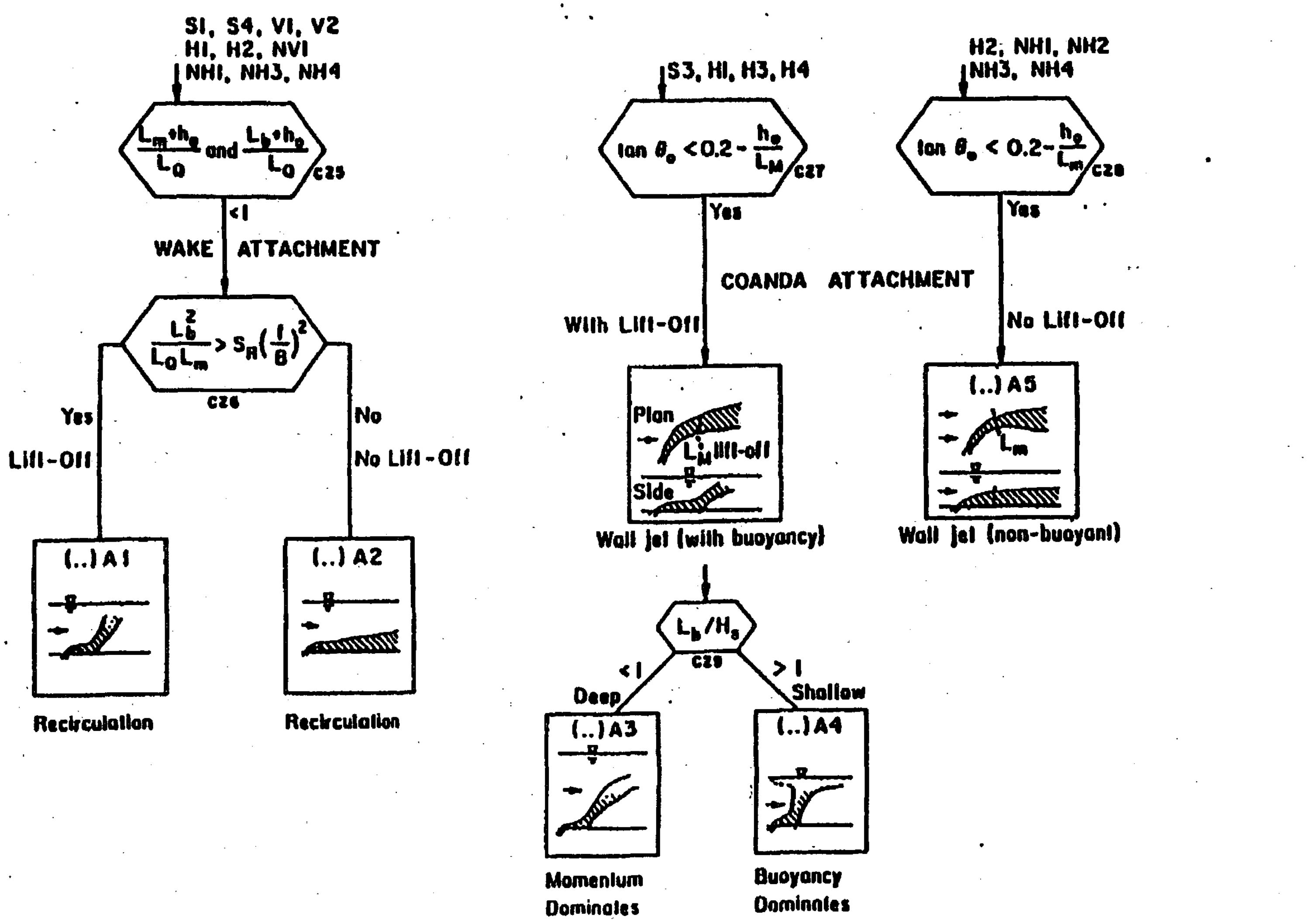


Figure A.4: CORMIX1 Classification: Dynamic bottom attachment of discharge due to wake or Coanda attachment

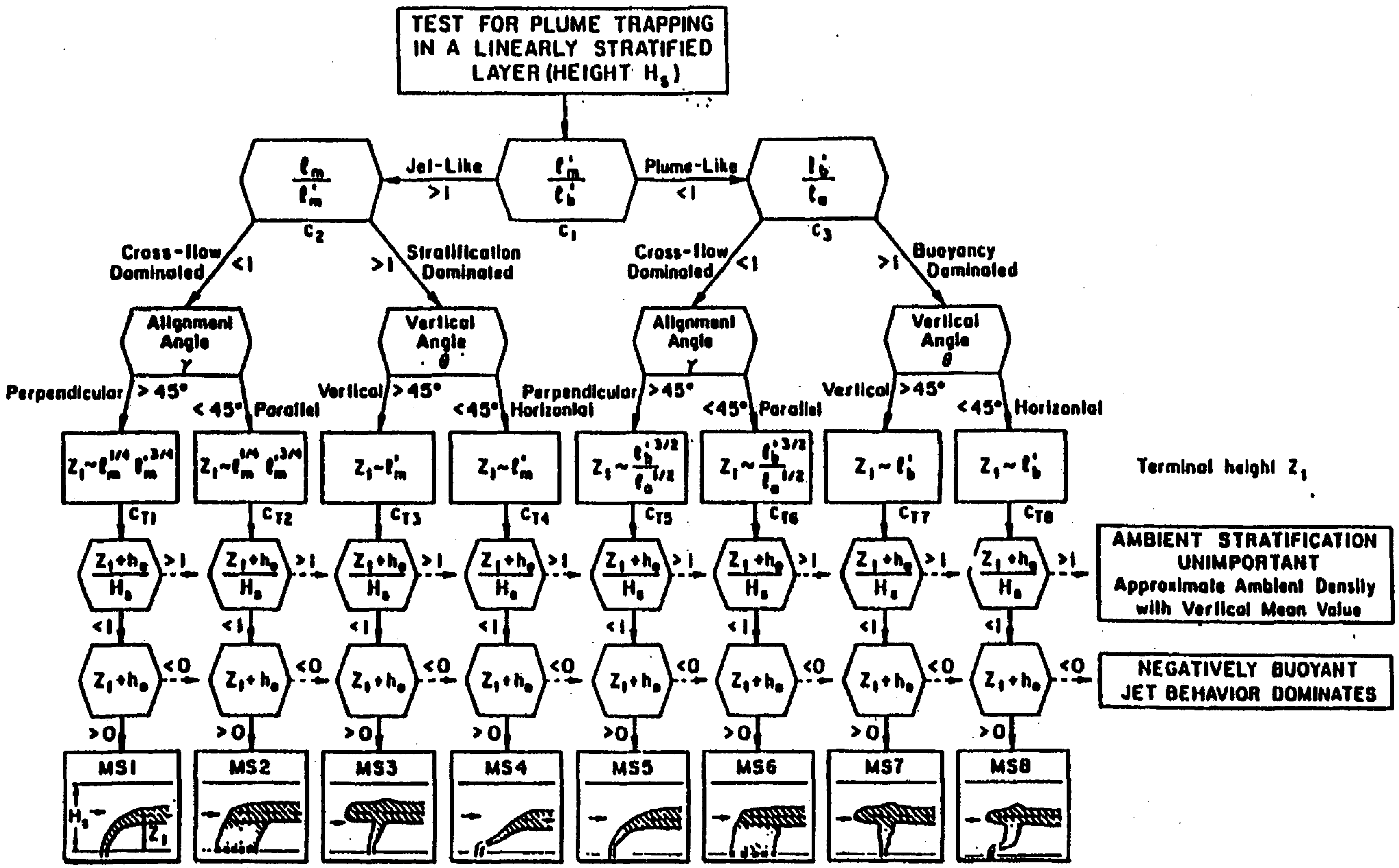


Figure A.5: CORMIX2 Classification: Assessment of ambient density stratification and different flow classes for internally trapped

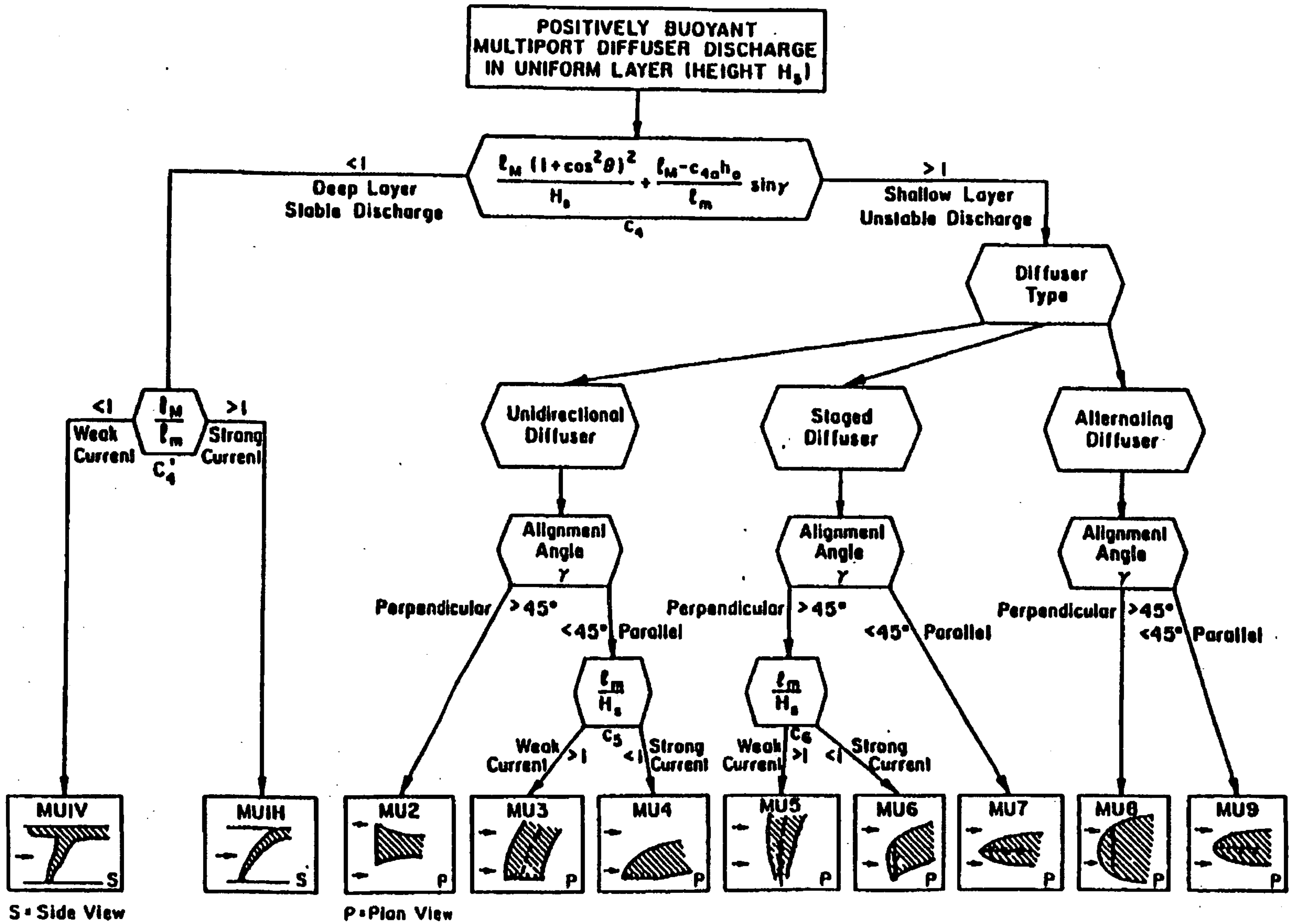


Figure A.6: CORMIX2 Classification: Behavior of positively buoyant multiport diffuser discharges in uniform ambient layer flow

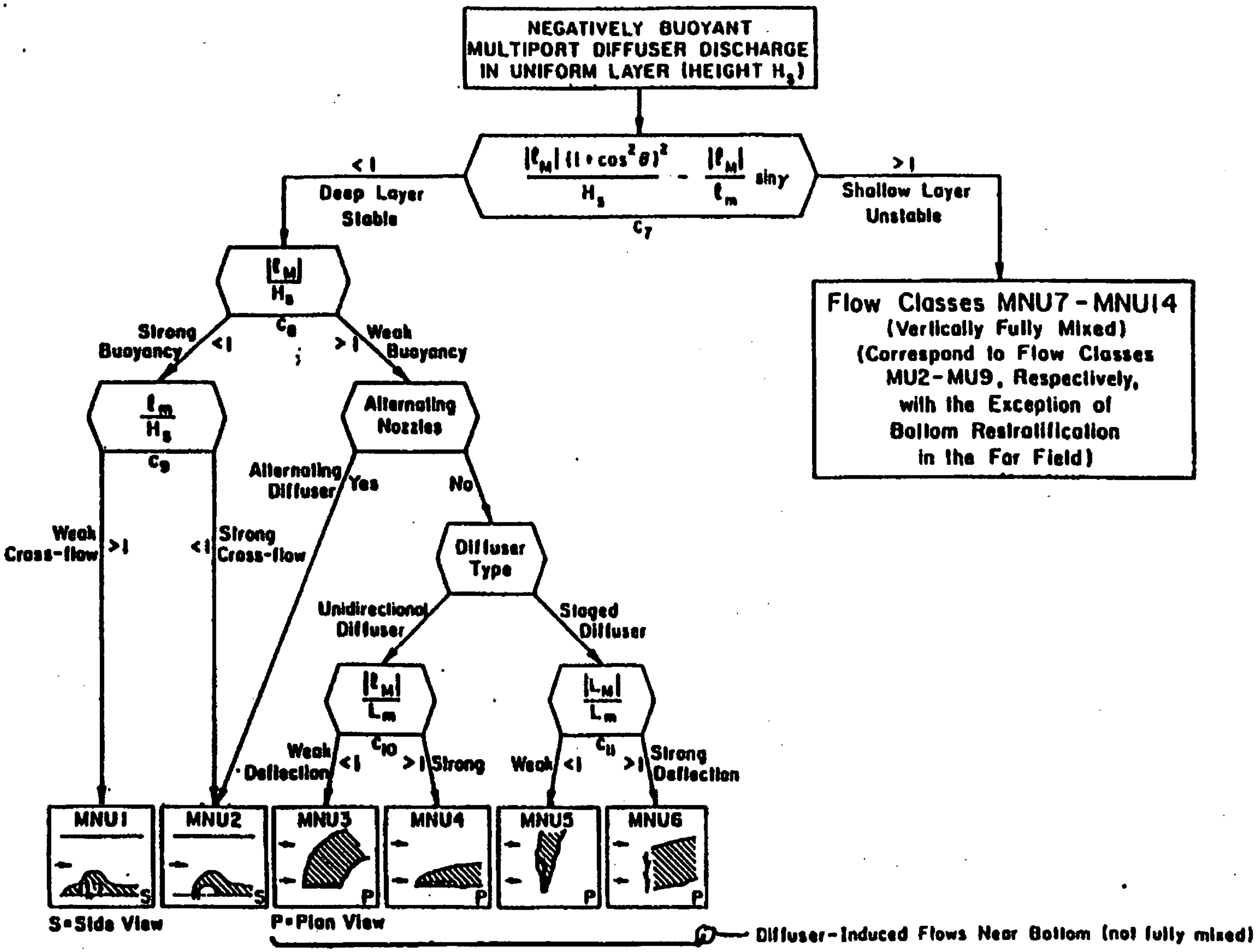


Figure A.7: CORMIX2 Classification: Behavior of negatively buoyant multiport diffuser discharges in uniform ambient layer flow

FLOW CLASSIFICATION FOR BUOYANT SURFACE DISCHARGES

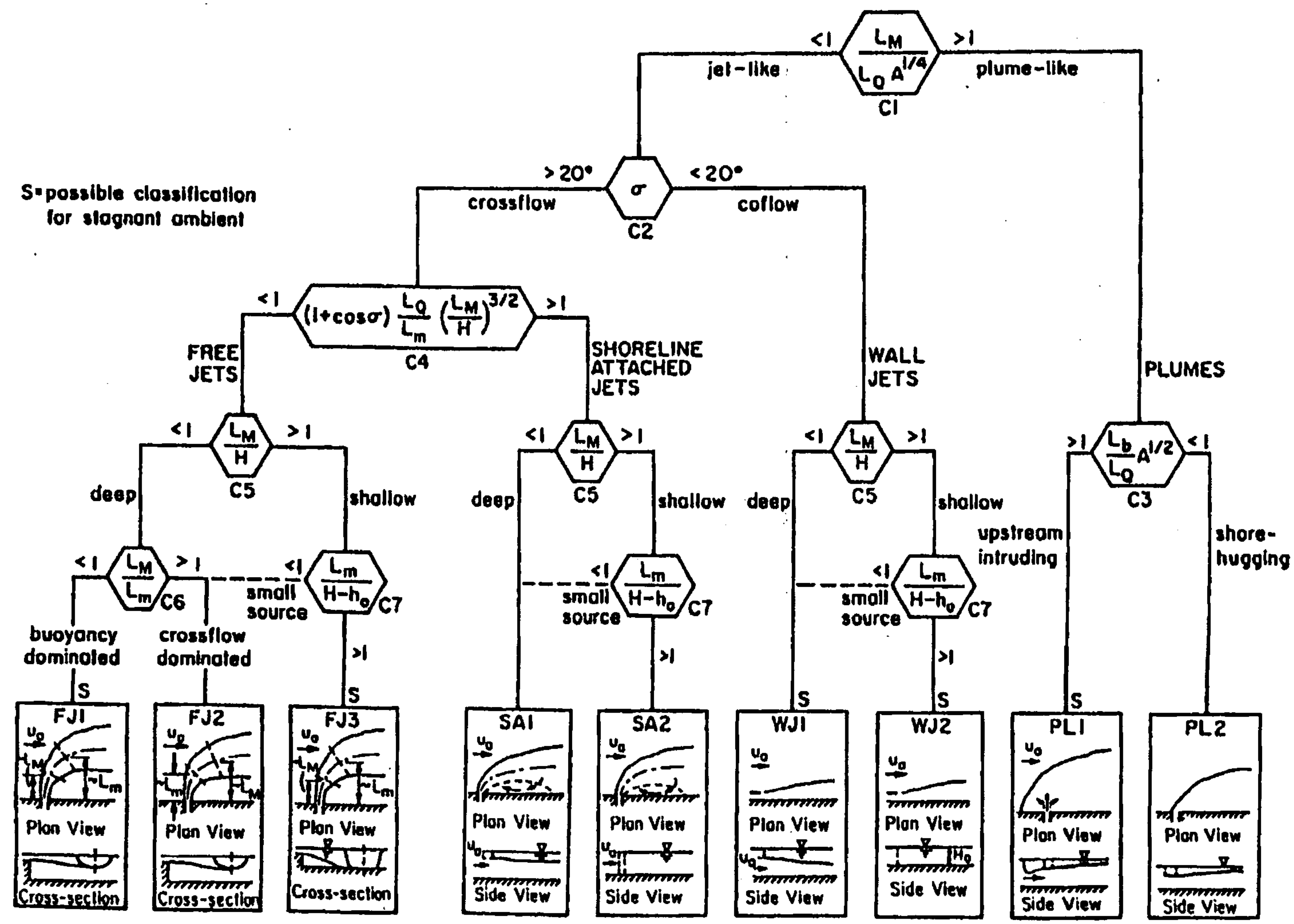


Figure A.8: CORMIX3 Classification: Assessment of buoyant surface discharges as free jets, shoreline-attached jets, wall jets, or

Appendix B
CORMIX1: Submerged Single Port Discharge in a Deep Reservoir

This case study illustrates the application of CORMIX1 to the prediction of the effluent from a small manufacturing plant into a large and deep stratified reservoir.

B.1 Problem Statement

A manufacturing plant (A-Plant) is discharging its effluent into an adjacent deep reservoir. The plant design flowrate is 3.5 mgd (≈ 0.15 m^3/s). The effluent contains heavy metal at a concentration of 3500 ppb, and is released at a temperature of 68 °F (= 20 °C). The density of the effluent at this low concentration can be considered equivalent to freshwater.

The existing reservoir has been formed by flooding a river valley. The reservoir length is about 60 miles. The water level in the reservoir is fluctuating depending on the release operation at the downstream dam with its hydropower installation. During summer conditions, the reservoir level is typically at an elevation of 710 ft above sea level. This results in a reservoir width of about 4000 ft (≈ 1200 m) and a maximum depth of 310 ft (≈ 95 m) at the discharge location. The mean river flow into the reservoir during the summer low-flow conditions is about 18,540 cfs (≈ 525 m^3/s). The typical temperature of the inflowing river water is 55 °F (≈ 13 °C).

Figure B.1 shows the local bathymetry (as obtained from a USGS map) in the vicinity of the proposed discharge. Since the discharge is very small relative to the reservoir size and the ambient flowrate, it is expected that mostly local conditions will be important, and not overall reservoir dimensions. (Note: Any such conjecture has to be verified against the final simulation results, and adjustments have to be made if needed.)

Temperature data as a function of depth obtained from field measurements in the center of the reservoir show a significant temperature stratification (see Figure B.2), as is typical for such deep reservoirs during summer conditions. The stratification can be expected to be horizontally uniform and therefore similar conditions will hold at the discharge site. Also, the river inflow is colder than the surface layer of the stratified reservoir. The reservoir has a selective withdrawal structure at the dam, therefore it can be expected that the river water will flow predominantly in a vertically limited layer, that may extend from a depth of about 35 m to the surface. The velocity of that flow is estimated at about 1.5 cm/s (≈ 0.015 m/s), given the 35 m thick layer and an about 1000 m width at that elevation. (Note: More detailed hydrodynamic investigations, using available models for stratified reservoir dynamics, can be used to obtain more precise estimates of the velocity field. Generally, however, it cannot be assumed that the velocity in stratified reservoirs is given by the simple average of the flowrate divided by the cross-sectional area.)

The proposed discharge location on the side slope of the cross-section is also shown in Figure B.1: a submerged single port discharge at an elevation of 610 ft above sea level, i.e. at a local depth of 100 ft (≈ 30.5 m) below the surface, is proposed in the initial design phase. The port diameter is 10 in (≈ 0.254 m) and is located 2 ft (≈ 0.6 m) above the local bottom. The discharge is pointing offshore and is angled upward at 10 °.

The discharge is subject to State mixing zone regulations whereby the mixing zone width is less than 10% of the width of the water body. Furthermore, the heavy metal in the effluent is considered toxic with CMC and CCC limits of 1200 and 600 ppb, respectively.

B.2 Problem Schematization and Data Preparation

Figure B.3 is the data checklist that summarizes the CORMIX1 input for the present problem. The ambient water body has been characterized as unbounded in line with the expectation that the discharge plume will be small

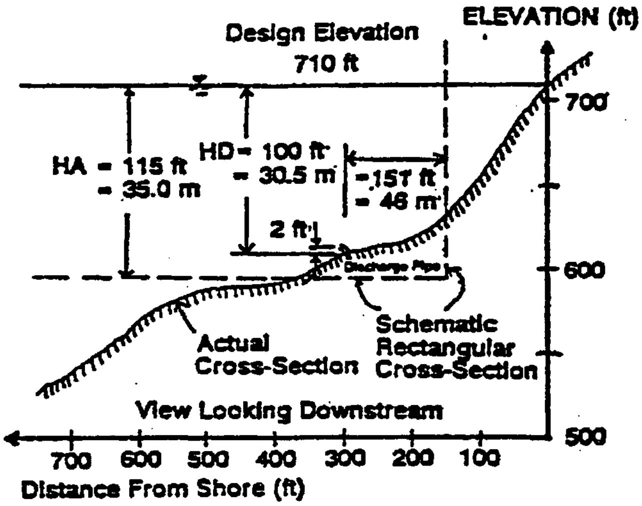


Figure B.1: Local details of Deep Reservoir cross-section and CORMIX1 schematization

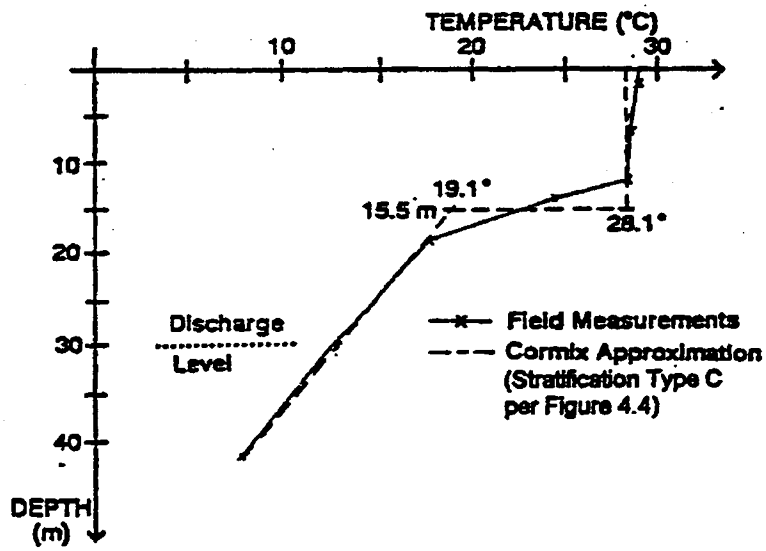


Figure B.2: Temperature field data as a function of depth and CORMIX1 representation of Type C temperature profile

CHECKLIST FOR DATA PREPARATION

CORMIX – CORNELL MIXING ZONE EXPERT SYSTEM – Version 3.1,3.2

SITE Name	A-Plant Deep Reservoir	Date:	
Design CASE	Summer Stratification	Prepared by:	GHJ
DOS FILE NAME	Sample 1 (w/o extension)		

AMBIENT DATA:

Water body depth	35.0 m	Water body is	~~bounded~~/unbounded
Depth at discharge	30.5 m	If bounded: Width	- m
		Appearance	~~1/2/3~~
If steady: Ambient flowrate	- m³/s or:	Ambient velocity	0.015 m/s
If tidal: Tidal period	hr	Max. tidal velocity	m/s
At time ___ hr before/at/after slack:		Tidal velocity at this time	- m/s
Manning's n	0.02 or:	Darcy-Weisbach f	-
Wind speed	2 m/s		
Density data:		UNITS: Density...kg/m³ / Temperature...°C	
Water body is	fresh/~~salt~~ water	If fresh: Specify as	~~density~~/temp. values
If uniform:		Average density/temp.	
If stratified:		~~Density~~/temp. at surface	28.1
Stratification type	~~A/B~~/C	~~Density~~/temp. at bottom	11.0
If B/C: Pycnocline height	15.5 m	If C: ~~Density~~/temp. jump	9.0

DISCHARGE DATA: Specify geometry for CORMIX1 or 2 or 3

SUBMERGED SINGLE PORT DISCHARGE – CORMIX1

Nearest bank is on	~~left~~/right	Distance to nearest bank	46.0 m
Vertical angle THETA	10 °	Horizontal angle SIGMA	90 °
Port diameter	0.254 m or:	Port area	- m²
Port height	0.6 m		

~~**SUBMERGED MULTIPORT DIFFUSER DISCHARGE – CORMIX2**~~

Nearest bank is on	left/right	Distance to one endpoint	m
Diffuser length	m	to other endpoint	m
Total number of openings	m	Port height	m
Port diameter	m with	contraction ratio	
Diffuser arrangement/type	unidirectional / staged / alternating or vertical		
Alignment angle GAMMA	°	Horizontal angle SIGMA	°
Vertical angle THETA	°	Relative orientation BETA	°

~~**BUOYANT SURFACE DISCHARGE – CORMIX3**~~

Discharge located on	left/right bank	Configuration	flush/protruding/co-flowing
Horizontal angle SIGMA	°	If protruding: Dist. from bank	m
Depth at discharge	m	Bottom slope	°
If rectangular Width	m or:	If circular Diameter	m
discharge channel: Depth	m	pipe: Bottom invert depth	m

Effluent: Flow rate	0.153 m³/s or:	Effluent velocity	- m/s
Effluent density	- kg/m³ or:	Effluent temperature	20.0 °C
Heated discharge?	~~yes~~/no	If yes: Heat loss coefficient	- W/m²,°C
Concentration units	ppb	Effluent concentration	3500
Conservative substance?	yes/~~no~~	If no: Decay coefficient	- /day

MIXING ZONE DATA:

Is effluent toxic?	yes/~~no~~	If yes: CMC 1200	CCC 600
WQ stand./conventional poll.?	~~yes~~/no	If yes: value of standard	-
Any mixing zone specified?	yes/~~no~~	If yes: distance - m	or width 120 % or m
			or area - % or m²
Region of interest	3500 m	Grid intervals for display	20

Figure B.3: Data preparation checklist for A-Plant Deep Reservoir design case study using CORMIX1 in size relative to the reservoir width. Furthermore, since (1) the discharge elevation is well above the lowest point of the reservoir and (2) the plume is expected to rise toward the surface, the ambient water depth is taken as 150 ft (≈35.0 m) only.

The depth at the discharge corresponds to the local depth at the discharge location. Because of the sloping bank from the discharge to the near shoreline, the distance to bank (46 m) corresponds to one-half of the actual distance from the outlet to the shoreline at the water surface. The ambient velocity corresponds to the estimate made above for the stratified water body. A Manning's n of 0.02 describes the smooth bottom.

Density data is simply entered via the temperature values of the fresh water body. A Stratification Type C is chosen to describe the actual temperature profile.

The discharge data values summarize the discharge situation as described above. Finally, the mixing zone specifications include a width value of 120 m, corresponding to 10 % of the actual width of 1200 m. Information is desired over about one mile (≈ 1600 m) which represents the region of interest (ROI) limitation.

B.3 CORMIX1 Session and Results

If desired by the user, CORMIX1 provides a summary of the data as they are entered, and then a full record of the simulation sequence and final results. This session summary report is shown in Table B.1. Of particular interest to the user are the evaluations in program element PARAM and CLASS. Note, that the computed length scales L_m' and $_bL'$ are quite small, indicating that the jet or plume will be trapped quickly by the ambient stratification; thus, this is the first numerical indication that the near-field jet/plume will indeed be small relative to the reservoir. The ambient flow related scales L_m and L_b are quite large, indicating that the ambient velocity is very weak. The resulting flow class S3 is dominated by the ambient stratification; the plume will be limited to the lower layer of the stratification. The user should also consult the description of flow class S3 that is available during the CORMIX1 session (not reproduced here). The detailed plume properties are computed in program element HYDRO, and are displayed in the Fortran CORMIX1 prediction file (see Table B.2, discussed in more detail further below).

Many important features of the plume prediction are summarized in program element SUM of the session record (see Table B.1). Notably, all aspects pertaining to mixing zone regulations are contained in that summary. For example, it can be seen quickly from that summary that the present discharge configuration meets all three toxic dilution zone (TDZ) criteria and also the regulatory mixing zone (RMZ) limitation. Obviously, other ambient conditions and discharge variations should be considered in additional simulations before a design such as this should be deemed fully satisfactory.

B.4 Graphical Displays of Detailed Plume Predictions

As for most engineering studies it is desirable to produce graphical displays for visualization of the predicted results. The data contained in the CORMIX1 prediction file (Table B.2) form the basis for such plots. Unfortunately, it is often difficult to display all plume features in one single plot because the plume may contain a lot of near-field details while extending over large distances into the far-field. A short examination of Table B.2 proves that point: The plume gets quickly trapped within a very limited near-field but with considerable mixing (see MOD110 = CORJET of the CORMIX1 prediction). Yet after that the plume extends over large distances into the far-field forming a wide thin layer within the stratified reservoir (see MOD142).

Using the graphics package CMXGRAPH, two plots have been prepared to display the jet/plume side view in the near-field, using distorted and undistorted 1:1 scales, respectively, (Figure B.4) and the plan view in the near-field and larger scale far-field (Figure B.5) of the effluent plume. Figure B.4 shows the initial trajectory of the slightly upward curved jet that rises to maximum level of 4.29 m and then gets trapped at an elevation of 3.44 m above the local bottom. In the trapping stage the jet undergoes a complicated transition (MOD137) to the horizontally spreading layer. CORMIX1 predicts

Table B.1
CORMIX Session Report for A-Plant discharge into Deep Reservoir with summer stratification

```
CORMIX SESSION REPORT:
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
                 CORMIX: CORNELL MIXING ZONE EXPERT SYSTEM
                     CORMIX v.3.10          June 1995
SITE NAME/LABEL:                     Sample 1
  DESIGN CASE:                       Summer Stratification
  FILE NAME:                         SAMPLE1
Using subsystem CORMIX1:             Submerged Single Port Discharges
  Start of session:                  08/25/96--16:37:01
****************************************************************************
SUMMARY OF INPUT DATA:
----------------------------------------------------------------------------
AMBIENT PARAMETERS:
  Cross-section                                = unbounded
  Average depth                      HA        =           35 m
  Depth at discharge                 HD        =         30.5 m
  Ambient velocity                   UA        =         .015 m/s
  Darcy-Weisbach friction factor     F         =       0.0096
    Calculated from Manning's n                =          .02
  Wind velocity                      UW        =            2 m/s
Stratification Type                  STRCND    = C
  Surface temperature                          =         28.1 degC
  Bottom temperature                           =         11.0 degC
  Temperature below thermocline                =        19.10 degC
  Calculated FRESH-WATER DENSITY values:
  Surface density                    RHOAS     =     996.2053 kg/m^3
  Bottom density                     RHOAB     =     999.6071 kg/m^3
  Stratification height              HINT      =         15.5 m (pycnocline level)
  Density below pycnocline           RHOAP     =     998.3866 kg/m^3
----------------------------------------------------------------------------
DISCHARGE PARAMETERS:                Submerged Single Port Discharge
  Nearest bank                                 = right
  Distance to bank                   DISTB     =          46. m
  Port diameter                      D0        =         .254 m
  Port cross-sectional area          A0        =       0.0506 m^2
  Discharge velocity                 U0        =         3.01 m/s
  Discharge flowrate                 Q0        =         .153 m^3/s
  Discharge port height              H0        =           .6 m
  Vertical discharge angle           THETA     =           10 deg
  Horizontal discharge angle         SIGMA     =          90. deg
  Discharge temperature (freshwater)           =         20.0 degC
    Corresponding density            RHO0      =     998.2051 kg/m^3
  Density difference                 DRHO      =       1.3548 kg/m^3
  Buoyant acceleration               GP0       =        .0133 m/s^2
  Discharge concentration            C0        =         3500 PPB
  Surface heat exchange coeff.       KS        =            0 m/s
  Coefficient of decay               KD        =            0 /s
----------------------------------------------------------------------------
DISCHARGE/ENVIRONMENT LENGTH SCALES:
  LQ  =      0.22 m        Lm  =      45.31 m        Lb  =      602.57 m
  LM  =     12.42 m        Lm' =       4.94 m        Lb' =        3.11 m
----------------------------------------------------------------------------
NON-DIMENSIONAL PARAMETERS:
  Port densimetric Froude number     FR0       =        51.96
  Velocity ratio                     R         =       201.30
----------------------------------------------------------------------------
MIXING ZONE / TOXIC DILUTION ZONE / AREA OF INTEREST PARAMETERS:
  Toxic discharge                              = yes
  CMC concentration                  CMC       =            1200 PPB


  CCC concentration                  CCC       =             600 PPB
  Water quality standard                       = given by CCC value
  Regulatory mixing zone                       = yes
  Regulatory mixing zone specification         = width
  Regulatory mixing zone value                 =          120 m (m^2 if area)
  Region of interest                           =      3500.00 m
****************************************************************************
HYDRODYNAMIC CLASSIFICATION:
  *------------------------*
  | FLOW CLASS   =      S3 |
  *------------------------*
  The specified ambient density stratification is important, the discharge
  near field flow is confined to the lower layer by the ambient density
  stratification.
  Applicable layer depth = lower layer depth =          15.5 m
****************************************************************************
MIXING ZONE EVALUATION (hydrodynamic and regulatory summary):
----------------------------------------------------------------------------
X-Y-Z Coordinate system:
  Origin is located at the bottom below the port center:
           46. m from the right bank/shore.
  Number of display steps NSTEP = 20 per module.
```

```
-----------------------------------------------------------------------------
NEAR-FIELD REGION (NFR) CONDITIONS :
Note: The NFR is the zone of strong initial mixing.  It has no regulatory
  implication.  However, this information may be useful for the discharge
  designer because the mixing in the NFR is usually sensitive to the
  discharge design conditions.
  Pollutant concentration at edge of NFR =          98.2267 PPB
  Dilution at edge of NFR                =         35.6
  NFR Location:                        x =         98.19 m
    (centerline coordinates)           y =         24.63 m
                                       z =          3.43 m
  NFR plume dimensions:       half-width =        191.86 m
                               thickness =           .94 m
-----------------------------------------------------------------------------
Buoyancy assessment:
  The effluent density is less than the surrounding ambient water
  density at the discharge level.
  Therefore, the effluent is POSITIVELY BUOYANT and will tend to rise towards
  the surface.
-----------------------------------------------------------------------------
Stratification assessment:
  The specified ambient density stratification is dynamically important.
  The discharge near field flow is trapped within the linearly stratified
  ambient density layer.
-----------------------------------------------------------------------------
UPSTREAM INTRUSION SUMMARY:
Plume exhibits upstream intrusion due to low ambient velocity or strong
  discharge buoyancy.
  Intrusion length                        =         90.24 m
  Intrusion stagnation point              =        -87.98 m
  Intrusion thickness                     =          1.29 m
  Intrusion half width at impingement     =        191.86 m
  Intrusion half thickness at impingement =           .94 m
************************ TOXIC DILUTION ZONE SUMMARY ************************
Recall: The TDZ corresponds to the three (3) criteria issued in the USEPA
  Technical Support Document (TSD) for Water Quality-based Toxics Control,
  1991 (EPA/505/2-90-001).
  Criterion maximum concentration (CMC)  =             1200 PPB


  Corresponding dilution                  =          2.9
The CMC was encountered at the following plume position:
  Plume location:                      x =           .05 m
    (centerline coordinates)           y =          3.93 m
                                       z =          1.31 m
  Plume dimensions:           half-width =           .10 m
                               thickness =           .10 m
 CRITERION 1: This location is within 50 times the discharge length scale of
              Lq =        0.22 m.
 +++++ The discharge length scale TEST for the TDZ has been SATISFIED. ++++++

 CRITERION 2: This location is within 5 times the ambient water depth of
              HD =          30.5 m.
 ++++++++++ The ambient depth TEST for the TDZ has been SATISFIED.+++++++++++

 CRITERION 3: This location is within one tenth the distance of the extent
              of the Regulatory Mixing Zone of          98.19 m downstream.
 +++++ The Regulatory Mixing Zone TEST for the TDZ has been SATISFIED. ++++++

 The diffuser discharge velocity is equal to         3.01 m/s.
   This exceeds the value of 3.0 m/s recommended in the TSD.

 *** All three CMC criteria for the TDZ are SATISFIED for this discharge. ***
********************** REGULATORY MIXING ZONE SUMMARY ***********************
The plume conditions at the boundary of the specified RMZ are as follows:
  Pollutant concentration                 =         98.226660 PPB
  Corresponding dilution                  =         35.6
  Plume location:                       x =         98.19 m
    (centerline coordinates)            y =         24.63 m
                                        z =          3.43 m
  Plume dimensions:            half-width =        191.86 m
                                thickness =           .94 m
At this position, the plume is CONTACTING the RIGHT bank.
Furthermore, the CCC for the toxic pollutant has indeed been met
  within the RMZ. In particular:
The CCC was encountered at the following plume position:
The CCC for the toxic pollutant was encountered at the following
  plume position:
  CCC                                     =              600 PPB
  Corresponding dilution                  =          5.8
  Plume location:                       x =           .21 m
    (centerline coordinates)            y =          7.82 m
                                        z =          2.12 m
  Plume dimensions:            half-width =           .10 m
                                thickness =           .10 m
********************* FINAL DESIGN ADVICE AND COMMENTS **********************
REMINDER: The user must take note that HYDRODYNAMIC MODELING by any known
  technique is NOT AN EXACT SCIENCE.
Extensive comparison with field and laboratory data has shown that the
  CORMIX predictions on dilutions and concentrations (with associated
  plume geometries) are reliable for the majority of cases and are accurate
  to within about +-50% (standard deviation).
As a further safeguard, CORMIX will not give predictions whenever it judges
  the design configuration as highly complex and uncertain for prediction.
*****************************************************************************
DESIGN CASE:                      Summer Stratification
FILE NAME:                        SAMPLE1
Subsystem CORMIX1:                Submerged Single Port Discharges
END OF SESSION/ITERATION:         08/26/96--05:37:41
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
```

Table B.2
CORMIX1 Prediction File for A-Plant discharge into Deep Reservoir with summer stratification

```
CORMIX1 PREDICTION FILE:
111111111111111111111111111111111111111111111111111111111111111111111111111
                     CORNELL MIXING ZONE EXPERT SYSTEM
Subsystem CORMIX1:                                        Subsystem version:
 Submerged Single Port Discharges           CORMIX_v.3.1_________June_1995
---------------------------------------------------------------------------
---------------------------------------------------------------------------
CASE DESCRIPTION
 Site name/label:          DEEP^RESERVOIR
 Design case:              A-PLANT^SUMMER^STRATIFICATION
 FILE NAME:                cormix\sim\SAMPLE1 .cx1
 Time of Fortran run:      06/24/95--22:29:54

ENVIRONMENT PARAMETERS (metric units)
 Unbounded section
 HA     =    35.00 HD     =     30.50
 UA     =     .015 F      =      .010 USTAR = .5200E-03
 UW     =    2.000 UWSTAR= .2198E-02
 Density stratified environment
 STRCND=  C        RHOAM =  997.6240
 RHOAS =  996.2053 RHOAB =  999.6072  RHOAH0=  999.5599  E      = .7730E-03
 DRHOJ =    2.1813 HINT  =     15.50  ES     = .2153E-02

DISCHARGE PARAMETERS (metric units)
 BANK  =  RIGHT    DISTB =     46.00
 D0    =      .254 A0    =      .051 H0     =       .60
 THETA =     10.00 SIGMA =     90.00
 U0    =     3.020 Q0    =      .153        = .1530E+00
 RHO0  =  998.2051 DRHO0 = .1355E+01  GP0    = .1329E-01
 C0    = .3500E+04 CUNITS=  PPB
 IPOLL =  1        KS    = .0000E+00  KD     = .0000E+00

FLUX VARIABLES (metric units)
 Q0    = .1530E+00 M0    = .4620E+00  J0     = .2034E-02  SIGNJ0=      1.0
 Associated length scales (meters)
 LQ    =       .23 LM    =     12.43  Lm     =     45.31  Lb    =    602.57
                                      Lmp    =      4.94  Lbp   =      3.12

NON-DIMENSIONAL PARAMETERS
 FR0   =     51.96 R     =    201.30

FLOW CLASSIFICATION
 111111111111111111111111111111111111111111
 1  Flow class (CORMIX1)        =    S3     1
 1  Applicable layer depth HS =    15.50  1
 111111111111111111111111111111111111111111

MIXING ZONE / TOXIC DILUTION / REGION OF INTEREST PARAMETERS
 C0    = .3500E+04 CUNITS=  PPM
 NTOX  =  1        CMC   = .1200E+04  CCC    =  CSTD
 NSTD  =  1        CSTD  = .6000E+03
 REGMZ =  1
 REGSPC=  2        XREG  =       .00  WREG   =    120.00  AREG  =       .00
 XINT  =   3500.00 XMAX  =   3500.00

X-Y-Z COORDINATE SYSTEM:
   ORIGIN is located at the bottom and below the center of the port:
       46.00 m  from the RIGHT bank/shore.
   X-axis points downstream, Y-axis points to left, Z-axis points upward.
NSTEP = 20 display intervals per module
---------------------------------------------------------------------------
---------------------------------------------------------------------------
BEGIN MOD101: DISCHARGE MODULE

       X        Y        Z        S        C        B
      .00      .00      .60      1.0  .350E+04     .13

END OF MOD101: DISCHARGE MODULE
---------------------------------------------------------------------------
---------------------------------------------------------------------------
BEGIN CORJET (MOD110): JET/PLUME NEAR-FIELD MIXING REGION
```

```
Jet-like motion in linear stratification with weak crossflow.

 Zone of flow establishment:              THETAE=     10.00  SIGMAE=      89.45
  LE     =      1.25  XE     =        .01  YE     =      1.23  ZE     =        .82

 Profile definitions:
   B = Gaussian 1/e (37%) half-width, normal to trajectory
   S = hydrodynamic centerline dilution
   C = centerline concentration (includes reaction effects, if any)

        X          Y         Z         S        C          B
       .00        .00       .60      1.0  .350E+04      .13
       .01       1.23       .82      1.0  .350E+04      .14
       .02       2.30      1.01      1.7  .205E+04      .26
       .04       3.48      1.23      2.6  .136E+04      .39
** CMC HAS BEEN FOUND **
 The pollutant concentration in the plume falls below CMC value of  .120E+04
   in the current prediction interval.
 This is the extent of the TOXIC DILUTION ZONE.
       .08       4.67      1.45      3.5  .101E+04      .53
       .13       5.97      1.72      4.4  .790E+03      .67
       .18       7.14      1.97      5.3  .658E+03      .80
** WATER QUALITY STANDARD OR CCC HAS BEEN FOUND **
 The pollutant concentration in the plume falls below water quality standard
   or CCC value of  .600E+03 in the current prediction interval.
 This is the spatial extent of concentrations exceeding the water quality
   standard or CCC value.
       .24       8.32      2.24      6.2  .564E+03      .94
       .32       9.49      2.52      7.1  .493E+03     1.07
       .40      10.65      2.81      8.0  .437E+03     1.21
       .49      11.82      3.10      8.9  .393E+03     1.34
       .60      12.99      3.39      9.8  .357E+03     1.48
       .71      14.15      3.66     10.7  .328E+03     1.61
       .84      15.33      3.90     11.6  .303E+03     1.75
       .98      16.51      4.09     12.4  .281E+03     1.89
      1.13      17.70      4.23     13.3  .262E+03     2.03
      1.27      18.77      4.29     14.2  .247E+03     2.15
  Maximum jet height has been reached.
      1.45      19.96      4.27     15.1  .232E+03     2.29
      1.63      21.15      4.16     16.1  .218E+03     2.43
      1.83      22.32      3.97     17.1  .205E+03     2.57
      2.04      23.48      3.72     18.1  .193E+03     2.71
      2.26      24.63      3.44     19.1  .183E+03     2.85
  Terminal level in stratified ambient has been reached.
 Cumulative travel time =           63. sec

END OF CORJET (MOD110): JET/PLUME NEAR-FIELD MIXING REGION
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD137: TERMINAL LAYER INJECTION/UPSTREAM SPREADING

 UPSTREAM INTRUSION PROPERTIES:
        Maximum elevation of jet/plume rise      =       7.64 m
        Layer thickness in impingement region    =       1.29 m
        Upstream intrusion length                =      90.24 m
        X-position of upstream stagnation point  =     -87.99 m
        Thickness in intrusion region            =       1.29 m
        Half-width at downstream end             =     191.87 m
        Thickness at downstream end              =        .95 m

  Control volume inflow:
        X          Y         Z         S        C          B
      2.26      24.63      3.44     19.1  .183E+03     2.85

 Profile definitions:
   BV = top-hat thickness, measured vertically
   BH = top-hat half-width, measured horizontally in Y-direction
   ZU = upper plume boundary (Z-coordinate)
   ZL = lower plume boundary (Z-coordinate)
   S  = hydrodynamic average (bulk) dilution
   C  = average (bulk) concentration (includes reaction effects, if any)

       X          Y         Z        S        C          BV        BH        ZU        ZL
    -87.99      24.63      3.44   9999.9  .000E+00      .00       .00      3.44      3.44
    -84.26      24.63      3.44     75.2  .465E+02      .33     27.13      3.60      3.27
    -66.02      24.63      3.44     31.3  .112E+03      .79     65.91      3.83      3.04
```

-47.77	24.63	3.44	23.8	.147E+03	1.04	89.17	3.96	2.92
-29.53	24.63	3.44	20.8	.169E+03	1.19	107.51	4.03	2.84
-11.28	24.63	3.44	19.4	.180E+03	1.28	123.15	4.07	2.80
6.96	24.63	3.44	19.3	.181E+03	1.29	137.02	4.08	2.79
25.21	24.63	3.44	22.5	.155E+03	1.22	149.61	4.05	2.82
43.45	24.63	3.44	27.7	.126E+03	1.11	161.21	3.99	2.88
61.70	24.63	3.44	32.1	.109E+03	1.02	172.04	3.95	2.93
79.95	24.63	3.44	34.4	.102E+03	.97	182.22	3.92	2.95
98.19	24.63	3.44	35.6	.982E+02	.95	191.87	3.91	2.96

Cumulative travel time = 6459. sec

END OF MOD137: TERMINAL LAYER INJECTION/UPSTREAM SPREADING

** End of NEAR-FIELD REGION (NFR) **

In this design case, the discharge is located CLOSE TO BANK/SHORE.
Some boundary interaction occurs at end of near-field.
This may be related to a design case with a very LOW AMBIENT VELOCITY.
The dilution values in one or more of the preceding zones may be too high.
Carefully evaluate results in near-field and check degree of interaction.

Consider locating outfall further away from bank or shore.
In the next prediction module, the plume centerline will be set
to follow the bank/shore.
** REGULATORY MIXING ZONE BOUNDARY is within the Near-Field Region (NFR) **

BEGIN MOD142: BUOYANT TERMINAL LAYER SPREADING

Plume is ATTACHED to RIGHT bank/shore.
Plume width is now determined from RIGHT bank/shore.

Profile definitions:
BV = top-hat thickness, measured vertically
BH = top-hat half-width, measured horizontally in Y-direction
ZU = upper plume boundary (Z-coordinate)
ZL = lower plume boundary (Z-coordinate)
S = hydrodynamic average (bulk) dilution
C = average (bulk) concentration (includes reaction effects, if any)

Plume Stage 2 (bank attached):

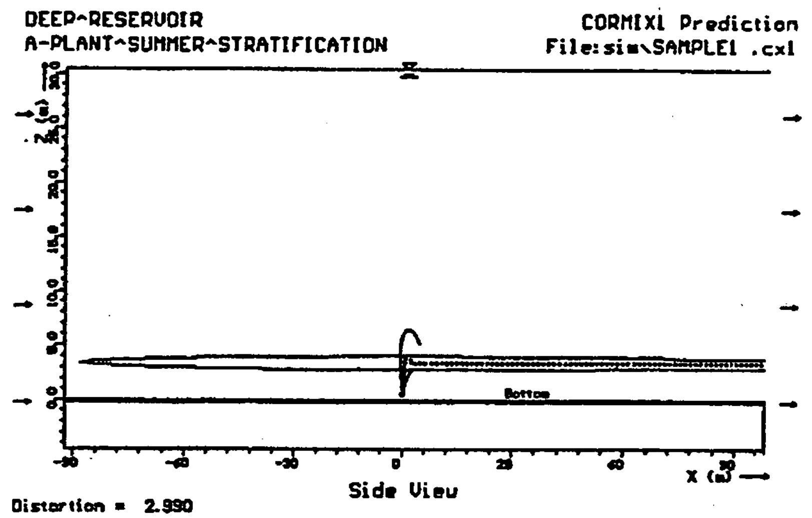
X	Y	Z	S	C	BV	BH	ZU	ZL
98.19	-46.00	3.44	35.6	.982E+02	1.38	262.50	4.13	2.74
268.28	-46.00	3.44	42.7	.820E+02	.93	468.27	3.90	2.97
438.37	-46.00	3.44	48.4	.722E+02	.81	609.62	3.84	3.03
608.46	-46.00	3.44	54.7	.640E+02	.77	728.17	3.82	3.05
778.55	-46.00	3.44	61.7	.568E+02	.75	836.14	3.81	3.06
948.64	-46.00	3.44	69.2	.505E+02	.75	938.66	3.81	3.06
1118.73	-46.00	3.44	77.3	.453E+02	.76	1038.24	3.82	3.06
1288.82	-46.00	3.44	85.9	.408E+02	.77	1136.20	3.82	3.05
1458.91	-46.00	3.44	94.8	.369E+02	.78	1233.26	3.83	3.04
1629.00	-46.00	3.44	104.0	.336E+02	.80	1329.86	3.84	3.04
1799.10	-46.00	3.44	113.6	.308E+02	.81	1426.23	3.84	3.03
1969.19	-46.00	3.44	123.4	.284E+02	.83	1522.53	3.85	3.02
2139.28	-46.00	3.44	133.5	.262E+02	.84	1618.85	3.86	3.02
2309.37	-46.00	3.44	143.8	.243E+02	.86	1715.24	3.86	3.01
2479.46	-46.00	3.44	154.4	.227E+02	.87	1811.74	3.87	3.00
2649.55	-46.00	3.44	165.2	.212E+02	.88	1908.37	3.88	2.99
2819.64	-46.00	3.44	176.2	.199E+02	.90	2005.12	3.88	2.99
2989.73	-46.00	3.44	187.4	.187E+02	.91	2102.02	3.89	2.98
3159.82	-46.00	3.44	198.7	.176E+02	.92	2199.06	3.90	2.98
3329.91	-46.00	3.44	210.3	.166E+02	.93	2296.24	3.90	2.97
3500.00	-46.00	3.44	222.1	.158E+02	.95	2393.56	3.91	2.96

Cumulative travel time = 233246. sec

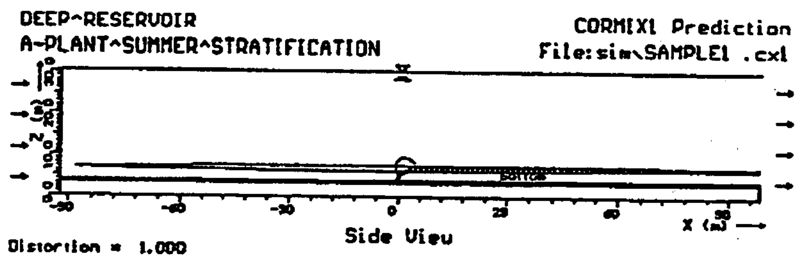
Simulation limit based on maximum specified distance = 3500.00 m.
This is the REGION OF INTEREST limitation.

END OF MOD142: BUOYANT TERMINAL LAYER SPREADING

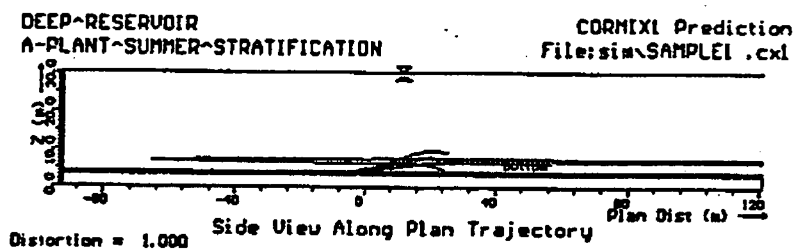
CORMIX1: Submerged Single Port Discharges End of Prediction File
1111111111111111111111111111111111111111111111111111111111111111111111111



(a)

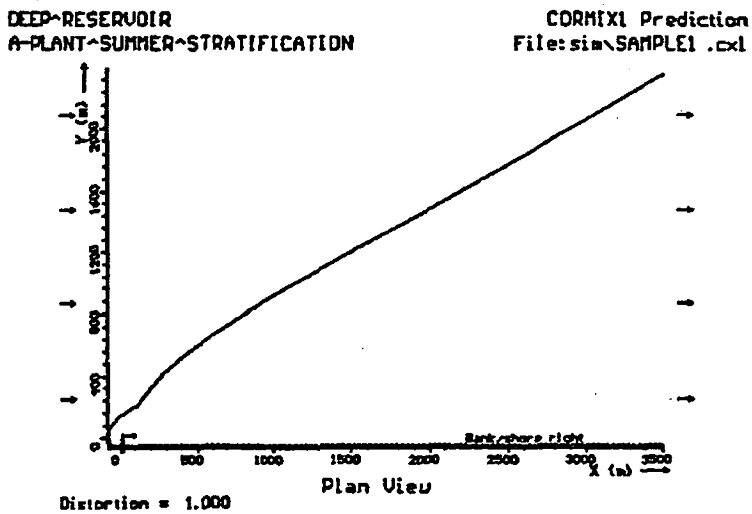


(b)

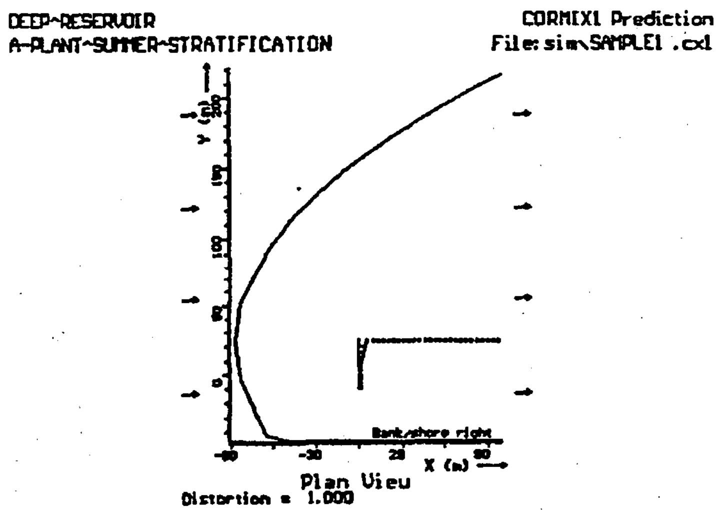


(c)

Figure B.4: Different side views of near-field jet/plume discharge in stratified reservoir. a) distorted unscaled view, b) view with fixed undistorted scale, and c) undistorted view along trajectory (in the x-y plane).



(a)



(b)

Figure B.5: Plan view of diffuser plume in a) complete field (near- and far), and b) near-field only. (Note: since in this simulation the discharge was schematized as an unbounded cross-section, the resulting plume would actually contact far shoreline when the plume width exceeds the actual cross-section width of 1000 m. This occurs when BH ≅ 1000 m at x ≅ 1000 m downstream as shown in view a). Thus, if plume concentration data were required after far shoreline contact, a bounded cross-section would need to be specified (BS = 1000) in a new simulation.

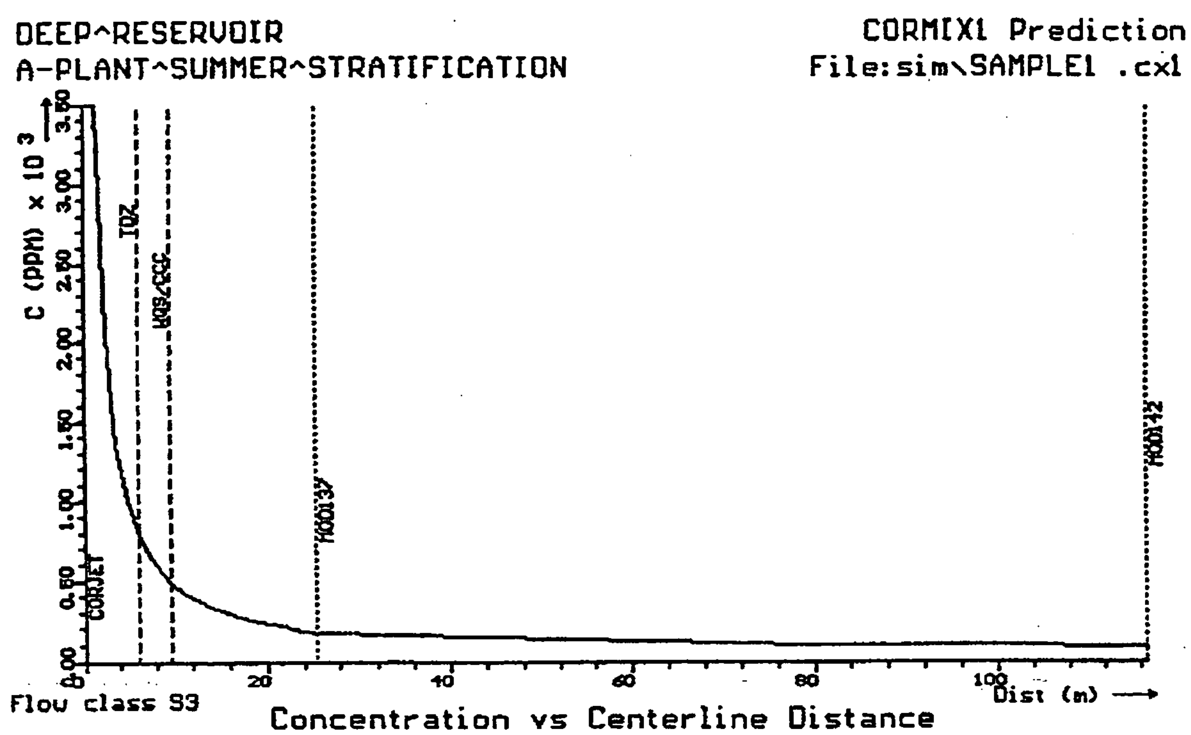


Figure B.6: Concentration distribution as a function of distance along plume centerline

a few parameters such as the upstream intrusion length, downstream width, and shape of the intrusion. As indicated in Figure B.5, reasonable transition boundaries can be assumed to provide smooth transitions to the far-field processes.

The side and plan views show the wide and thin layer that forms as the plume collapses laterally within the ambient stratification while it is advected by the weak ambient flow.

Some discontinuity in the predicted plume dimensions occurs in the transition from the control volume (MOD137) describing upstream spreading to the continuous prediction for ambient buoyant spreading (MOD142). The cause for this discontinuity is the simultaneous interaction of the plume with the channel boundary that occurs within MOD137. CORMIX1 detects such complicated simultaneous processes and warns the user who then can compensate by providing reasonable, mass-conserving transitions.

It is also possible to include concentration values, e.g. along the centerline, in plots of this type. This has not been done in these figures in order not to overload them. Alternatively, the concentration distribution following the centerline of the plume is plotted in Figure B.6. The rapid drop-off within the initial buoyant jet region is evident. Also, the thresholds for all water quality parameters and module boundaries have been exercised in the plot. Hence, the locations where the CMC (i.e. TDZ) and CCC values are met have been indicated.

B.5 Details of Buoyant Jet Near-field Mixing

The CORJET model option can be employed if further details within the very initial buoyant jet motion are desired. This option can be exercised internally at the conclusion of the CORMIX design case by choosing the post-processor. The CORJET output corresponding to this has already been shown as an example in

Section 6.1, namely as Table 6.2. That output agrees well with that listed in Table B.2.

More importantly, CORJET could also be used separately to examine different approximations to the ambient density profile and/or velocity distribution. The reader is encouraged to explore this approach, following the procedures explained in Section 6.1 and illustrated in Appendix E.

Appendix C
CORMIX1 and 2: Submerged Single Port Discharge and Multiport Diffuser in a Shallow River

The design modification of an existing (hypothetical situation) discharge from a plant into a shallow river is considered in this case study. This affords an opportunity to demonstrate the joint use of CORMIX and of a dye field study in order to analyze an existing effluent plume from a single port discharge and to suggest a design conversion to a multiport diffuser with improved mixing characteristics.

C.1 Problem Statement

An industrial plant (B-Plant) is currently discharging its effluent into an adjacent shallow river. The design flowrate is quite small at 2.1 mgd (≈ 0.092 m^3/s). The river is about 200 to 300 ft wide at the discharge location and the following downstream reach. Water depth is, of course, dependent on the river discharge that is seasonally variable. An examination of available streamflow records (USGS data) suggests a 7Q10 low flow discharge of 285 cfs (≈ 8.06 m^3/s).

Recent water quality studies in the discharge reach performed during low flow summer conditions have shown occasional coloration problems in the discharge plume that seem to be related to inadequate mixing characteristics of the present submerged single port discharge. For that reason the plant operator is considering an improvement of the discharge structure.

C.2 Existing Single Port Discharge: Dye Field Study and CORMIX1 Comparison

An initial field study was conducted in order (1) to measure the geometric and hydraulic characteristics of the discharge reach with special emphasis on the first 1000 ft downstream, and (2) to determine plume concentrations by means of a dye injection into the plant effluent.

Figure C.1 shows the plan geometry of the discharge reach. River cross-sections were determined by depth measurements at several stations as indicated. For example, Figure C.2 gives the cross-section at the discharge location. All cross-sections exhibit quite some non-uniformity as is typical for a gently meandering alluvial (gravel) river. The indicated water level corresponds to the river discharge of 840 cfs (≈ 23.7 m^3/s) that was measured during the field survey using the usual USGS stream-gaging methods. The ambient temperature at this flowrate was 20 °C. The discharge pipe (diameter = 8 in ≈ 0.2 m) is located about 95 ft from the right bank, and is pointing in the downstream direction.

In order to obtain a detailed description of the flow field in the river, reach discharge measurements were conducted at several more downstream stations (200, 400, 750, and 1000 ft, respectively). Figure C.1 includes the cumulative discharge isolines, expressed in % of the total discharge as measured from the right bank, for the reach. These lines provide a useful indication of the mean flow pattern in such a winding river for subsequent interpretation of observed plume features (see also comments on cumulative discharge method in Section 6.2).

A dye test was carried out by continuously discharging a fluorescein dye solution into the plant effluent. The dye concentration exiting the discharge pipe was 560 ppb with a temperature of 22 °C. Dye concentration were measured at the transects indicated in Figure C.1, and have been plotted in Figure C.3 as a function of distance from the right bank. The observed concentration profiles show decreasing peak (maximum) values with increasing downstream distances. Observations indicated a vertically mixed plume at all locations. In the display of Figure C.3 the plume centerline position is clearly shifting relative to the right bank, and the plume width occasionally appears to slightlycontract in width.

An initial CORMIX1 evaluation was carried out to ascertain its applicability in this somewhat

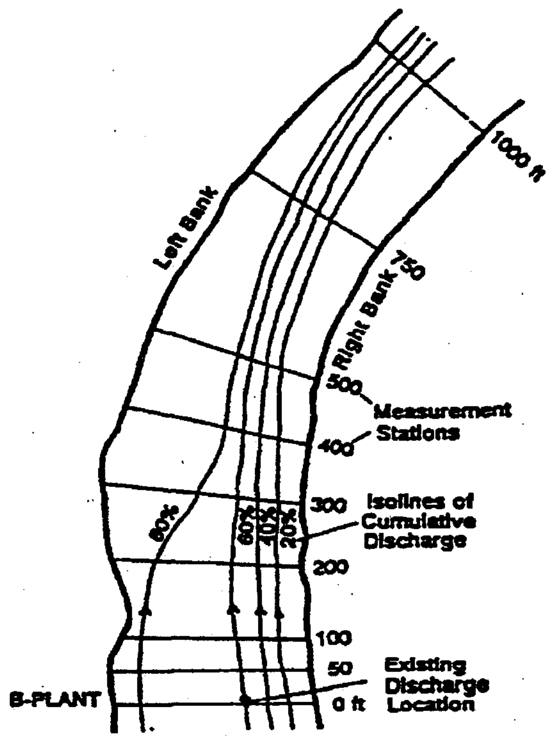


Figure C.1: Plan view of downstream reach of Shallow River with cumulative discharge measurement stations and distribution

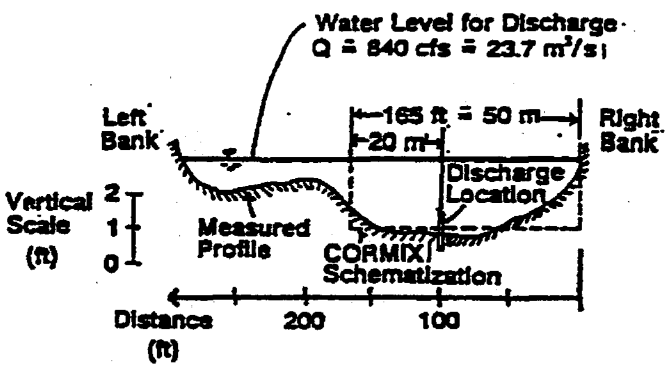


Figure C.2: River cross-section at discharge location

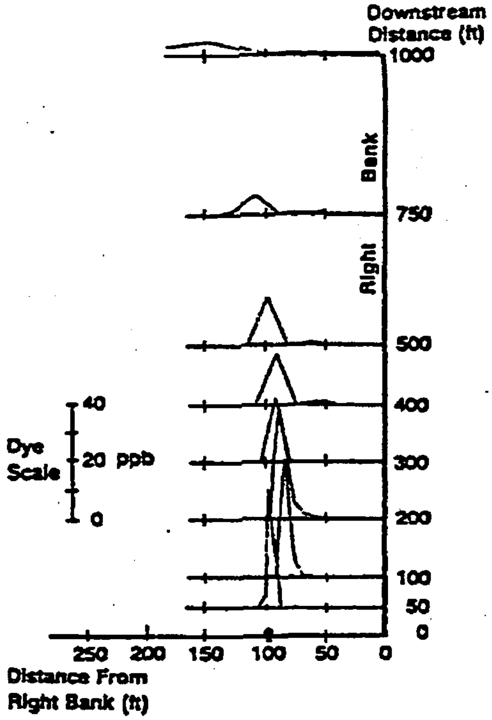


Figure C.3: Measured dye concentration plotted as a function of distance from right bank

irregular flow environment. For this purpose, the cross-section was schematized as a rectangular cross-section putting emphasis on the depth conditions around the discharge location. The average and local depths at this flow rate are both 1.9 ft or (» 0.6 m).

Information from the cumulative discharge data was used. Note that the cumulative discharge data shows the discharge located at the 60 % line, i.e. it is hydraulically closer to the left bank, while it appears geographically closer to the right! This is reflected in the schematization: Within the 165 ft (» 50 m) wide rectangular channel, the discharge is located 20 m from the left bank. The roughness of the slightly winding, but otherwise clean natural channel has been specified by a Manning's n value of 0.03.

Figure C.4 is the data checklist prepared for the CORMIX1 session, while Table C.1 represents the detailed CORMIX1 Prediction File (the session report is not given here). CORMIX1 predicts that the plume gets rapidly mixed over the shallow depth, and is primarily influenced by far-field mixing processes, a feature that is quite consistent with observations. The dye concentration distribution predicted by CORMIX1 in the schematic rectangular channel are plotted in Figure C.5 and show a much more regular mixing pattern than the earlier Figure C.3. However, matters can be readily reconciled when both field data and CORMIX1 predictions are interpreted as a function of **cumulative discharge** (for example by means of the far-field post-processor FFLOCATR, although the details of the FFLOCATR application are not shown herein).

This has been done in Figure C.6 where both distributions are directly superposed on the cumulative discharge pattern. The agreement is excellent. This entire procedure points out the need for high-quality field data if detailed interpretations and predictions of discharge plumes are desired.

C.3 Proposed Multiport Diffuser Discharge Under 7Q10 flow Conditions: CORMIX2 Predictions

The following strategy is pursued in order

CHECKLIST FOR DATA PREPARATION

CORMIX -- CORNELL MIXING ZONE EXPERT SYSTEM -- Version 3.1,3.2

SITE Name: Shallow River — Date:
Design CASE: Dye Test — Prepared by: GHJ
DOS FILE NAME: Dye 1 (w/o extension)

AMBIENT DATA:
Water body depth 0.6 m — Water body is bounded/unbounded
Depth at discharge 0.6 m — If bounded: Width 50 m
If steady: Ambient flowrate 23.7 m³/s or: Ambient velocity - m/s — Appearance 1/2/3

If tidal: Tidal period ____ hr — Max. tidal velocity ____ m/s
At time ____ hr before/at/after slack: Tidal velocity at this time ____ m/s

Manning's n 0.03 or: Darcy-Weisbach f -
Wind speed 2 m/s
Density data: — UNITS: Density...kg/m³ / Temperature...°C
Water body is fresh/salt water — If fresh: Specify as density/temp. values
If uniform: — Average density/temp. 20.0

If stratified: — Density/temp. at surface ____
Stratification type A/B/C — Density/temp. at bottom ____
If B/C: Pycnocline height ____ m — If C: Density/temp. jump ____

DISCHARGE DATA: — Specify geometry for CORMIX1 or 2 or 3

SUBMERGED SINGLE PORT DISCHARGE -- CORMIX1
Nearest bank is on left/right — Distance to nearest bank 20.0 m
Vertical angle THETA 0 ° — Horizontal angle SIGMA 0 °
Port diameter 0.2 m or: Port area - m²
Port height 0.15 m

SUBMERGED MULTIPORT DIFFUSER DISCHARGE -- CORMIX2
Nearest bank is on left/right — Distance to one endpoint ____ m
Diffuser length ____ m — to other endpoint ____ m
Total number of openings ____ m — Port height ____ m
Port diameter ____ m with contraction ratio ____
Diffuser arrangement/type unidirectional / staged / alternating or vertical
Alignment angle GAMMA ____ ° — Horizontal angle SIGMA ____ °
Vertical angle THETA ____ ° — Relative orientation BETA ____ °

BUOYANT SURFACE DISCHARGE -- CORMIX3
Discharge located on left/right bank — Configuration flush/protruding/co-flowing
Horizontal angle SIGMA ____ ° — If protruding: Dist. from bank ____ m
Depth at discharge ____ m — Bottom slope ____ °
If rectangular Width ____ m or: If circular Diameter ____ m
discharge channel: Depth ____ m — pipe: Bottom invert depth ____ m

Effluent: Flow rate 0.092 m³/s or: Effluent velocity - m/s
Effluent density - kg/m³ or: Effluent temperature 22.0 °C
Heated discharge? yes/no — If yes: Heat loss coefficient - W/m²,°C
Concentration units ppb — Effluent concentration 560
Conservative substance? yes/no — If no: Decay coefficient - /day

MIXING ZONE DATA:
Is effluent toxic? yes/no — If yes: CMC - CCC -
WQ stand./conventional poll.? yes/no — If yes: value of standard -
Any mixing zone specified? yes/no — If yes: distance - m or width - % or m
or area - % or m²

Region of interest 1000 m — Grid intervals for display 20

Figure C.4: Data preparation checklist for Shallow River dye test evaluation and verification using CORMIX1

Table C.1
CORMIX1 Prediction File for dye test in Shallow River

```
CORMIX1 PREDICTION FILE:
1111111111111111111111111111111111111111111111111111111111111111111111111111
                      CORNELL MIXING ZONE EXPERT SYSTEM
Subsystem CORMIX1:                                        Subsystem version:
 Submerged Single Port Discharges          CORMIX_v.3.10__________June_1995
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
CASE DESCRIPTION
 Site name/label:          Shallow^River
 Design case:              Dye^Test
 FILE NAME:                cormix\sim\dye1    .cx1
 Time of Fortran run:      04/14/96--11:03:24

ENVIRONMENT PARAMETERS (metric units)
 Bounded section
 BS    =     50.00 AS    =     30.00 QA    =     23.70  ICHREG= 2
 HA    =       .60 HD    =       .60
 UA    =      .790 F     =      .084 USTAR = .8081E-01
 UW    =     2.000 UWSTAR= .2198E-02
 Uniform density environment
 STRCND= U          RHOAM =  998.2051

DISCHARGE PARAMETERS (metric units)
 BANK  =  LEFT      DISTB =     20.00
 D0    =      .200 A0    =      .031 H0    =       .15
 THETA =       .00 SIGMA =       .00
 U0    =     2.929 Q0    =      .092       = .9200E-01
 RHO0  =  997.7714  DRHO0 = .4337E+00 GP0   = .4260E-02
 C0    = .5600E+03  CUNITS=  ppb
 IPOLL =  1         KS    = .0000E+00 KD    = .0000E+00

FLUX VARIABLES (metric units)
 Q0    = .9200E-01  M0    = .2694E+00 J0    = .3920E-03  SIGNJ0=      1.0
 Associated length scales (meters)
 LQ    =       .18  LM    =     18.89 Lm    =       .66  Lb    =       .00
                                      Lmp   =  99999.00  Lbp   =  99999.00

NON-DIMENSIONAL PARAMETERS
 FR0   =    100.31  R     =      3.70

FLOW CLASSIFICATION
 111111111111111111111111111111111111111111
 1  Flow class (CORMIX1)        =    H5-0   1
 1  Applicable layer depth HS =       .60   1
 111111111111111111111111111111111111111111

MIXING ZONE / TOXIC DILUTION / REGION OF INTEREST PARAMETERS
 C0    = .5600E+03  CUNITS=  ppb
 NTOX  =  0
 NSTD  =  0
 REGMZ =  0
 XINT  =   1000.00  XMAX  =   1000.00

X-Y-Z COORDINATE SYSTEM:
   ORIGIN is located at the bottom and below the center of the port:
       20.00 m  from the LEFT  bank/shore.
   X-axis points downstream, Y-axis points to left, Z-axis points upward.
NSTEP = 20 display intervals per module
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD101: DISCHARGE MODULE

 COANDA ATTACHMENT immediately following the discharge.

       X         Y        Z        S       C         B
      .00       .00      .00      1.0  .560E+03     .14

END OF MOD101: DISCHARGE MODULE
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN CORJET (MOD110): JET/PLUME NEAR-FIELD MIXING REGION

 Bottom-attached jet motion.
```

Profile definitions:
B = Gaussian 1/e (37%) half-width, normal to trajectory
Half wall jet, attached to bottom.
S = hydrodynamic centerline dilution
C = centerline concentration (includes reaction effects, if any)

X	Y	Z	S	C	B
.00	.00	.00	1.0	.560E+03	.10
1.05	.00	.00	1.2	.483E+03	.16
2.10	.00	.00	1.7	.337E+03	.21
3.15	.00	.00	2.1	.263E+03	.26
4.21	.00	.00	2.6	.216E+03	.29
5.26	.00	.00	3.0	.185E+03	.32
6.31	.00	.00	3.4	.163E+03	.35
7.36	.00	.00	3.8	.146E+03	.38
8.41	.00	.00	4.2	.132E+03	.40
9.46	.00	.00	4.6	.121E+03	.42
10.51	.00	.00	5.0	.112E+03	.44
11.56	.00	.00	5.3	.105E+03	.46
12.62	.00	.00	5.7	.983E+02	.48
13.67	.00	.00	6.0	.927E+02	.50
14.72	.00	.00	6.4	.878E+02	.51
15.77	.00	.00	6.7	.834E+02	.53
16.82	.00	.00	7.0	.795E+02	.55
17.87	.00	.00	7.4	.761E+02	.56
18.92	.00	.00	7.7	.729E+02	.57
19.97	.00	.00	8.0	.701E+02	.59
21.03	.00	.00	8.3	.675E+02	.60

Cumulative travel time = 14. sec

END OF CORJET (MOD110): JET/PLUME NEAR-FIELD MIXING REGION

BEGIN MOD133: LAYER BOUNDARY IMPINGEMENT/FULL VERTICAL MIXING

Control volume inflow:

X	Y	Z	S	C	B
21.03	.00	.00	8.3	.675E+02	.60

Profile definitions:
BV = layer depth (vertically mixed)
BH = top-hat half-width, in horizontal plane normal to trajectory
ZU = upper plume boundary (Z-coordinate)
ZL = lower plume boundary (Z-coordinate)
S = hydrodynamic average (bulk) dilution
C = average (bulk) concentration (includes reaction effects, if any)

X	Y	Z	S	C	BV	BH	ZU	ZL
20.43	.00	.60	8.3	.675E+02	.00	.00	.60	.60
20.55	.00	.60	8.3	.675E+02	.60	.11	.60	.00
20.67	.00	.60	8.3	.675E+02	.60	.15	.60	.00
20.79	.00	.60	8.3	.675E+02	.60	.19	.60	.00
20.91	.00	.60	8.3	.675E+02	.60	.22	.60	.00
21.03	.00	.60	8.3	.675E+02	.60	.24	.60	.00
21.15	.00	.60	8.8	.637E+02	.60	.27	.60	.00
21.27	.00	.60	9.9	.568E+02	.60	.29	.60	.00
21.39	.00	.60	10.8	.517E+02	.60	.31	.60	.00
21.51	.00	.60	11.4	.493E+02	.60	.33	.60	.00
21.63	.00	.60	11.6	.482E+02	.60	.35	.60	.00

Cumulative travel time = 15. sec

END OF MOD133: LAYER BOUNDARY IMPINGEMENT/FULL VERTICAL MIXING

BEGIN MOD153: VERTICALLY MIXED PLUME IN CO-FLOW

Phase 1: Vertically mixed, Phase 2: Re-stratified

Phase 1: The plume is VERTICALLY FULLY MIXED over the entire layer depth.
This flow region is INSIGNIFICANT in spatial extent and will be by-passed.

Phase 2: The flow has RESTRATIFIED at the beginning of this zone.

This flow region is INSIGNIFICANT in spatial extent and will be by-passed.

```
END OF MOD153: VERTICALLY MIXED PLUME IN CO-FLOW
-----------------------------------------------------------------------------
** End of NEAR-FIELD REGION (NFR) **

 The initial plume WIDTH values in the next far-field module will be
  CORRECTED by a factor  3.25 to conserve the mass flux in the far-field!
 The correction factor is quite large because of the small ambient velocity
   relative to the strong mixing characteristics of the discharge!
   This indicates localized RECIRCULATION REGIONS and internal hydraulic JUMPS.
 Flow appears highly UNSTEADY and prediction results are UNRELIABLE!
-----------------------------------------------------------------------------
BEGIN MOD141: BUOYANT AMBIENT SPREADING

 Discharge is non-buoyant or weakly buoyant.
   Therefore BUOYANT SPREADING REGIME is ABSENT.

END OF MOD141: BUOYANT AMBIENT SPREADING
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD161: PASSIVE AMBIENT MIXING IN UNIFORM AMBIENT

  Vertical diffusivity (initial value)    =  .970E-02 m^2/s
  Horizontal diffusivity (initial value) =  .242E-01 m^2/s

 The passive diffusion plume is VERTICALLY FULLY MIXED at beginning of region.

 Profile definitions:
   BV = Gaussian s.d.*sqrt(pi/2) (46%) thickness, measured vertically
      = or equal to layer depth, if fully mixed
   BH = Gaussian s.d.*sqrt(pi/2) (46%) half-width,
        measured horizontally in Y-direction
   ZU = upper plume boundary (Z-coordinate)
   ZL = lower plume boundary (Z-coordinate)
   S  = hydrodynamic centerline dilution
   C  = centerline concentration (includes reaction effects, if any)

 Plume Stage 1 (not bank attached):
        X          Y         Z        S       C          BV        BH        ZU        ZL
      21.63       .00       .60     11.6  .482E+02     .60      1.12      .60       .00
      70.55       .00       .60     25.3  .222E+02     .60      2.44      .60       .00
     119.47       .00       .60     33.8  .166E+02     .60      3.26      .60       .00
     168.39       .00       .60     40.5  .138E+02     .60      3.92      .60       .00
     217.30       .00       .60     46.3  .121E+02     .60      4.48      .60       .00
     266.22       .00       .60     51.5  .109E+02     .60      4.98      .60       .00
     315.14       .00       .60     56.1  .998E+01     .60      5.43      .60       .00
     364.06       .00       .60     60.5  .926E+01     .60      5.84      .60       .00
     412.98       .00       .60     64.5  .869E+01     .60      6.23      .60       .00
     461.90       .00       .60     68.3  .820E+01     .60      6.60      .60       .00
     510.81       .00       .60     71.9  .779E+01     .60      6.95      .60       .00
     559.73       .00       .60     75.3  .744E+01     .60      7.28      .60       .00
     608.65       .00       .60     78.5  .713E+01     .60      7.59      .60       .00
     657.57       .00       .60     81.7  .686E+01     .60      7.90      .60       .00
     706.49       .00       .60     84.7  .661E+01     .60      8.19      .60       .00
     755.41       .00       .60     87.6  .639E+01     .60      8.47      .60       .00
     804.33       .00       .60     90.4  .619E+01     .60      8.74      .60       .00
     853.24       .00       .60     93.2  .601E+01     .60      9.01      .60       .00
     902.16       .00       .60     95.8  .584E+01     .60      9.27      .60       .00
     951.08       .00       .60     98.4  .569E+01     .60      9.52      .60       .00
    1000.00       .00       .60    101.0  .555E+01     .60      9.76      .60       .00
 Cumulative travel time =        1249. sec

 Simulation limit based on maximum specified distance =   1000.00 m.
   This is the REGION OF INTEREST limitation.

END OF MOD161: PASSIVE AMBIENT MIXING IN UNIFORM AMBIENT
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
CORMIX1: Submerged Single Port Discharges             End of Prediction File
11111111111111111111111111111111111111111111111111111111111111111111111111111
```

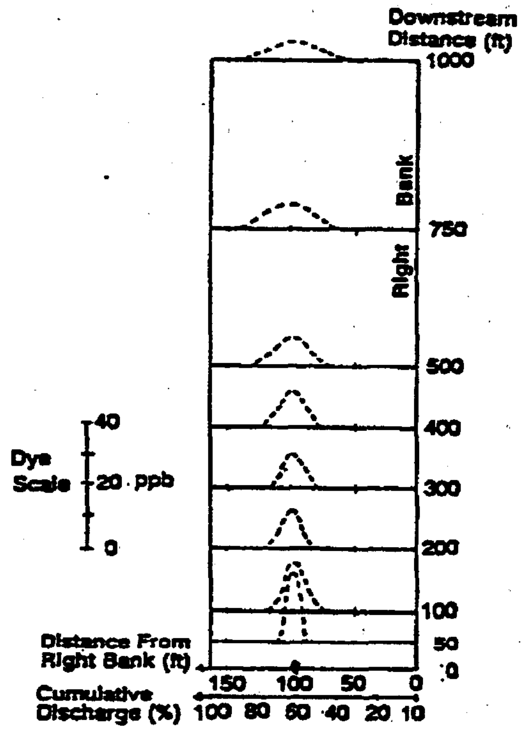


Figure C.5: Dye concentrations predicted by CORMIX1 plotted as a function of distance from right bank in schematized channel

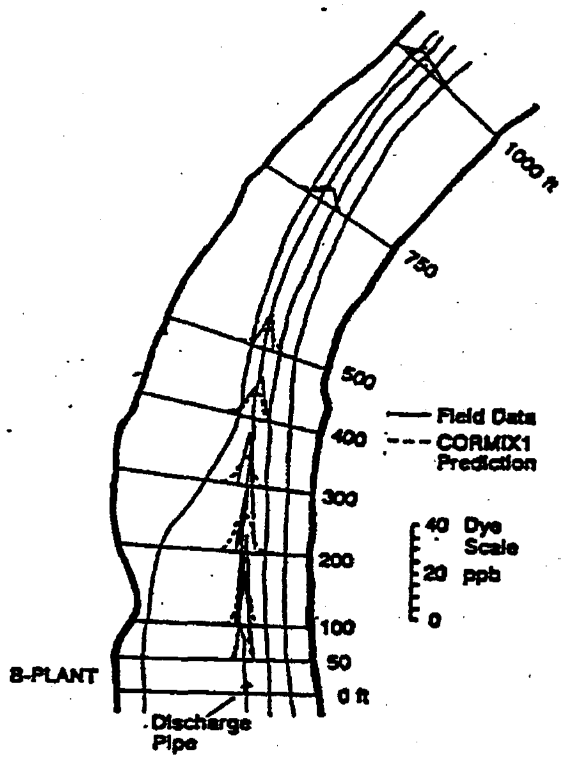


Figure C.6: Comparison of measured field dye distribution and CORMIX1 predictions within cumulative discharge pattern to improve the near-field mixing characteristics of the existing discharge: (1) Utilization of a multiport diffuser to increase the initial entrainment of ambient water into the multiple effluent jets, and (2) shifting of the discharge location toward the right bank to delay the contact with the left shoreline that -with the present installation- seems to occur at a downstream distance of 1000 ft.

The design study is carried out for the low flow ambient condition given by the 7Q10 discharge (285 cfs ≈ 8.1 m^3/s) as is typical for water quality studies on riverine sites. Temperatures of the discharge and ambient and channel roughness is assumed unchanged. The new local and average depth for this flowrate is calculated to be ≈ 0.3 m from the formula given in Section 4.3.1.

State water quality regulations call for a demonstration of plume concentrations at the edge of a mixing zone that is limited to one fourth (1/4) of the river width. With an average river width of 250 ft, this corresponds to a width limitation of 250/4 ≈ 62 ft (≈ 19 m). (Note: The actual width limitation must be handled within the schematized cross-sections as specified. For the schematic channel width of 50 m this represents a 19/50 = 38% width limitation specification as used in CORIMX2.)

Obviously, a number of design solutions, with different diffuser configurations and locations, need to be investigated. One of several feasible solutions is presented in the following: A 15 m (≈ 49 ft) long diffuser consisting of 7 nozzles is installed in perpendicular, co-flowing arrangement centered at the 40% cumulative discharge position. (Note: In the actual coordinate position, this corresponds to a distance of about 70 ft from the right bank; see Figure C.1.) The nozzle diameter is 2.5 in (≈ 0.0635 m).

The CORMIX2 simulation is summarized in Figure C.7 (data preparation checklist), Table C.2 (session report), and Table C.3 (prediction file).

Inspection of the session record and prediction file shows that the plume becomes rapidly mixed over the very shallow water depth. Furthermore, a high initial dilution of 29.8 is attained in a short region (labeled the "acceleration zone", MOD271) following the high velocity multiport discharge. These results are plotted in Figure C.8 using the graphics package CMXGRAPH. In order to illustrate the capabilities of the graphics program these plots include (a) the un-scaled plan view as it first appears on screen, (b) a re-scaled plan view that is undistorted (1:1) to show the actual long and narrow plume shape and river stretch, and (c) a side view of the near-field only with 1:2 vertical distortion. The user should explore the manifold features of the graphics package.

Obviously, predicted plan plume shapes should be interpreted with the **cumulative discharge method.** The far-field plume locator FFLOCATR (Section 6.2) is designed for exactly that purpose. The two data files examples in Section 6.2 (input: Table 6.4, output: Table 6.5) are, in fact, applications for the present design case. Hence, the results of Table 6.5 when plotted on the river plan view with the cumulative discharge isolines are shown in Figure C.9 and exhibit realistic plume shapes. After the rapid initial mixing in the near-field the plume is growing only very slowly in the far-field (MOD261). At the 1000 ft transect, the plume stays clear of the left bank.

The concentration distribution along the plume centerline is plotted in Figure C.10 for the near-field only, as very slow additional mixing occurs at larger distances (see Table C.3). As regards the **regulatory mixing zone (RMZ)** the prediction results indicate that it will be encountered at a considerable distance downstream, at about 354 m (≈ 1200 ft), i.e. outside the region plotted in Figure C.10. The dilution at that location is 33.5, corresponding to a local centerline concentration value of 3.0 %.

Finally, it is illuminating to compare the performance of the proposed multiport diffuser design with the existing single port situation, both under 7Q10 low flow. This is also included in Figure C.10 by plotting the plume centerline concentrations. (Note: The data sheet, session record, and output file for this CORMIX1 application are omitted for space reasons.) Clearly, the multiport design achieves much more rapid initial mixing by capturing more of the ambient entrainment flow as the diffuser is spread over portion of the river width. Figure C.10 also includes an additional CORMIX1 prediction for a single plume out of the 7-nozzle arrangement to provide more detail in the near-field; the user has been prompted by several messages within CORMIX2 to perform this additional prediction.

CHECKLIST FOR DATA PREPARATION

CORMIX – CORNELL MIXING ZONE EXPERT SYSTEM – Version 3.1,3.2

SITE Name: B-Plant Shallow River — Date:
Design CASE: Low Flow 7Q10 — Prepared by: GHJ
DOS FILE NAME: Sample 2 (w/o extension)

AMBIENT DATA:

Water body depth	0.3 m	Water body is	~~bounded/unbounded~~ bounded
Depth at discharge	0.3 m	If bounded: Width	50 m
If steady: Ambient flowrate	8.1 m³/s or:	Appearance	1/2/3
		Ambient velocity	- m/s
If tidal: Tidal period	hr	Max. tidal velocity	m/s
At time ___ hr before/at/after slack:		Tidal velocity at this time	m/s
Manning's n	0.03 or:	Darcy-Weisbach f	-
Wind speed	2 m/s		
Density data:		UNITS: Density...kg/m³ / Temperature...°C	
Water body is	fresh/~~salt~~ water	If fresh: Specify as	~~density~~/temp. values
If uniform:		Average ~~density~~/temp.	20.0
If stratified:		Density/temp. at surface	
Stratification type	A/B/C	Density/temp. at bottom	
If B/C: Pycnocline height	m	If C: Density/temp. jump	

DISCHARGE DATA: Specify geometry for CORMIX1 or 2 or 3

~~SUBMERGED SINGLE PORT DISCHARGE – CORMIX1~~

Nearest bank is on	left/right	Distance to nearest bank	m
Vertical angle THETA	°	Horizontal angle SIGMA	°
Port diameter	m or:	Port area	m²
Port height	m		

SUBMERGED MULTIPORT DIFFUSER DISCHARGE – CORMIX2

Nearest bank is on	~~left~~/right	Distance to one endpoint	12.5 m
Diffuser length	15 m	to other endpoint	27.5 m
Total number of openings	7 m	Port height	0.09 m
Port diameter	0.0635 m with	contraction ratio	1.0
Diffuser arrangement/type	unidirectional /~~staged~~ /~~alternating or vertical~~		
Alignment angle GAMMA	90 °	Horizontal angle SIGMA	0 °
Vertical angle THETA	0 °	Relative orientation BETA	90 °

~~BUOYANT SURFACE DISCHARGE – CORMIX3~~

Discharge located on	left/right bank	Configuration ~~flush/protruding/co-flowing~~	
Horizontal angle SIGMA	°	If protruding: Dist. from bank	m
Depth at discharge	m	Bottom slope	°
If rectangular Width	m or:	If circular Diameter	m
discharge channel: Depth	m	pipe: Bottom invert depth	m

Effluent: Flow rate	0.092 m³/s or:	Effluent velocity	- m/s
Effluent density	- kg/m³ or:	Effluent temperature	22.0 °C
Heated discharge?	~~yes~~/no	If yes: Heat loss coefficient	- W/m²,°C
Concentration units	%	Effluent concentration	100
Conservative substance?	yes/~~no~~	If no: Decay coefficient	- /day

MIXING ZONE DATA:

Is effluent toxic?	~~yes~~/no	If yes: CMC -	CCC -
WQ stand./conventional poll.?	~~yes~~/no	If yes: value of standard	-
Any mixing zone specified?	yes/~~no~~	If yes: distance - m	or width 38 % ~~or m~~
			or area - % or m²
Region of interest	1000 m	Grid intervals for display	20

Figure C.7: Data preparation checklist for Shallow River design case for multiport diffuser using CORMIX2

Table C.2
CORMIX Session Report for B-Plant discharge into Shallow River with multiport diffuser

```
CORMIX SESSION REPORT:
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
                 CORMIX: CORNELL MIXING ZONE EXPERT SYSTEM
                     CORMIX v.3.10             June 1995
SITE NAME/LABEL:                    B-PLANT SHALLOW-RIVER
  DESIGN CASE:                      LOW-FLOW 7Q10
  FILE NAME:                        SAMPLE2
Using subsystem CORMIX2:            Submerged Multiport Diffuser Discharges
  Start of session:                 06/24/95--22:35:06
**************************************************************************
SUMMARY OF INPUT DATA:
--------------------------------------------------------------------------
AMBIENT PARAMETERS:
  Cross-section                             = bounded
  Width                             BS      =         50.0 m
  Channel regularity                ICHREG  = 2
  Ambient flowrate                  QA      =          8.1 m^3/s
  Average depth                     HA      =         0.30 m
  Depth at discharge                HD      =         0.30 m
  Ambient velocity                  UA      =       0.5400 m/s
  Darcy-Weisbach friction factor    F       =       0.1054
    Calculated from Manning's n             =         0.03
  Wind velocity                     UW      =            2 m/s
Stratification Type                 STRCND  = U
  Surface temperature                       =         20.0 degC
  Bottom temperature                        =         20.0 degC
  Calculated FRESH-WATER DENSITY values:
  Surface density                   RHOAS   =     998.2051 kg/m^3
  Bottom density                    RHOAB   =     998.2051 kg/m^3
--------------------------------------------------------------------------
DISCHARGE PARAMETERS:               Submerged Multiport Diffuser Discharge
  Diffuser type                     DITYPE  = unidirectional perpendicular
  Diffuser length                   LD      = 15.0 m
  Nearest bank                              = right
  Diffuser endpoints                YB1     =      12.5 m;    YB2 =     27.5 m
  Number of openings                NOPEN   =            7
  Spacing between risers/openings   SPAC    =         2.50 m
  Port/Nozzle diameter              D0      =       0.0635 m
  Equivalent slot width             B0      =       0.0014 m
  Total area of openings            A0      =       0.0031 m^2
  Discharge velocity                U0      =         4.14 m/s
  Total discharge flowrate          Q0      =        0.092 m^3/s
  Discharge port height             H0      =         0.09 m
  Nozzle arrangement                BETYPE  = unidirectional without fanning
  Diffuser alignment angle          GAMMA   =           90 deg
  Vertical discharge angle          THETA   =            0 deg
  Horizontal discharge angle        SIGMA   =            0 deg
  Relative orientation angle        BETA    =           90 deg
  Discharge temperature (freshwater)        =         22.0 degC
    Corresponding density           RHO0    =     997.7714 kg/m^3
  Density difference                DRHO    =       0.4336 kg/m^3
  Buoyant acceleration              GP0     =        .0043 m/s^2
  Discharge concentration           C0      =          100 PERCENT
  Surface heat exchange coeff.      KS      =            0 m/s
  Coefficient of decay              KD      =            0 /s
--------------------------------------------------------------------------
FLUX VARIABLES PER UNIT DIFFUSER LENGTH:
  Discharge (volume flux)           q0      =     0.006133 m^2/s
  Momentum flux                     m0      =     0.025452 m^3/s^2
  Buoyancy flux                     j0      =     0.000026 m^3/s^3
--------------------------------------------------------------------------
DISCHARGE/ENVIRONMENT LENGTH SCALES :
  lq  =       0.00 m        lm  =        0.08 m         lM  =       28.80 m
  lm' =    99999.0 m        lb' =     99999.0 m         la  =     99999.0 m
  (These refer to the actual discharge/environment length scales.)
--------------------------------------------------------------------------
NON-DIMENSIONAL PARAMETERS:
  Slot Froude number                FR0     =     1653.66
  Port/nozzle Froude number         FRD0    =      252.28
  Velocity ratio                    R       =        7.68
--------------------------------------------------------------------------
MIXING ZONE / TOXIC DILUTION ZONE / AREA OF INTEREST PARAMETERS:
  Toxic discharge                           = no
  Water quality standard specified          = no
  Regulatory mixing zone                    = yes
  Regulatory mixing zone specification      = width
  Regulatory mixing zone value              =           19 m (m^2 if area)
  Region of interest                        =      1000.00 m
```

```
*****************************************************************************
HYDRODYNAMIC CLASSIFICATION:
 *------------------------*
 | FLOW CLASS  =    MU2 |
 *------------------------*
 This flow configuration applies to a layer corresponding to the full water
 depth at the discharge site.
 Applicable layer depth = water depth =          0.30 m
*****************************************************************************
MIXING ZONE EVALUATION (hydrodynamic and regulatory summary):
-----------------------------------------------------------------------------
X-Y-Z Coordinate system:
 Origin is located at the bottom below the port center:
           20 m from the right bank/shore.
 Number of display steps NSTEP = 20 per module.
-----------------------------------------------------------------------------
NEAR-FIELD REGION (NFR) CONDITIONS :
Note: The NFR is the zone of strong initial mixing.  It has no regulatory
 implication.  However, this information may be useful for the discharge
 designer because the mixing in the NFR is usually sensitive to the
 discharge design conditions.
 Pollutant concentration at edge of NFR =          3.3538 PERCENT
   (centerline coordinates)          y =          .00 m
                                     z =          .30 m
 NFR plume dimensions:       half-width =         6.73 m
                             thickness =          .30 m
-----------------------------------------------------------------------------
Buoyancy assessment:
 The effluent density is less than the surrounding ambient water
 density at the discharge level.
 Therefore, the effluent is POSITIVELY BUOYANT and will tend to rise towards
 the surface.
-----------------------------------------------------------------------------
Near-field instability behavior:
 The diffuser flow will experience instabilities with full vertical mixing
 in the near-field.
 There may be benthic impact of high pollutant concentrations.
-----------------------------------------------------------------------------
FAR-FIELD MIXING SUMMARY:
 Plume becomes vertically fully mixed ALREADY IN NEAR-FIELD at        7.50 m
 downstream and continues as vertically mixed into the far-field.
*********************** TOXIC DILUTION ZONE SUMMARY ***********************
No TDZ was specified for this simulation.
********************* REGULATORY MIXING ZONE SUMMARY **********************
The plume conditions at the boundary of the specified RMZ are as follows:
 Pollutant concentration              =          2.955534 PERCENT
 Corresponding dilution               =          33.8
 Plume location:                    x =        384.55 m
   (centerline coordinates)         y =          .00 m
                                    z =          .30 m
 Plume dimensions:        half-width =          9.50 m
                           thickness =          .30 m
********************* FINAL DESIGN ADVICE AND COMMENTS ********************
CORMIX2 uses the TWO-DIMENSIONAL SLOT DIFFUSER CONCEPT to represent
 the actual three-dimensional diffuser geometry.  Thus, it approximates
 the details of the merging process of the individual jets from each
 port/nozzle.
In the present design, the spacing between adjacent ports/nozzles
 (or riser assemblies) is somewhat greater (in the range between
 three times to ten times) the local water depth.  It is unlikely
 that sufficient lateral interaction of adjacent jets will
 occur in the near-field.  However, the individual jets/plumes may merge
 soon after in the intermediate-field or in the far-field.

CORMIX2 may have LIMITED APPLICABILITY for this discharge situation.
 The results may be somewhat unrealistic in the near-field (minimum
 dilution may be overpredicted), but appear to be applicable for the
 intermediate- and far-field processes.
The user is advised to use a subsequent CORMIX1 (single port discharge)
 analysis, using discharge data for an individual diffuser jet/plume,
 in order to compare to the present near-field prediction.
-----------------------------------------------------------------------------
REMINDER:  The user must take note that HYDRODYNAMIC MODELING by any known
 technique is NOT AN EXACT SCIENCE.
Extensive comparison with field and laboratory data has shown that the
 CORMIX predictions on dilutions and concentrations (with associated
 plume geometries) are reliable for the majority of cases and are accurate
 to within about +-50% (standard deviation).
As a further safeguard, CORMIX will not give predictions whenever it judges
 the design configuration as highly complex and uncertain for prediction.
*****************************************************************************
DESIGN CASE:                    LOW-FLOW 7Q10
FILE NAME:                      SAMPLE2
Subsystem CORMIX2:              Submerged Multiport Diffuser Discharges
END OF SESSION/ITERATION:       04/14/96--11:16:37
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
```

Table C.3
CORMIX2 Prediction File for B-Plant discharge into Shallow River with multiport diffuser

```
CORMIX2 PREDICTION FILE:
22222222222222222222222222222222222222222222222222222222222222222222222222222
                    CORNELL MIXING ZONE EXPERT SYSTEM
Subsystem CORMIX2:                                       Subsystem version:
 Submerged Multiport Diffuser Discharges     CORMIX_v.3.00__________July_1994
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
CASE DESCRIPTION
 Site name/label:         B-PLANT^SHALLOW-RIVER
 Design case:             LOW-FLOW^7Q10
 FILE NAME:               cormix\sim\SAMPLE2 .cx2
 Time of Fortran run:     06/24/95--22:36:15

ENVIRONMENT PARAMETERS (metric units)
 Bounded section
 BS     =      50.00 AS     =      15.00 QA     =       8.10 ICHREG= 2
 HA     =        .30 HD     =        .30
 UA     =       .540 F      =       .105 USTAR = .6199E-01
 UW     =      2.000 UWSTAR= .2198E-02
 Uniform density environment
 STRCND= U           RHOAM =  998.2051

DIFFUSER DISCHARGE PARAMETERS (metric units)
 Diffuser type:      DITYPE= unidirectional_perpendicular
 BANK   = RIGHT      DISTB =      20.00 YB1    =     12.50 YB2    =      27.50
 LD     =      15.00 NOPEN =   7        SPAC   =      2.50
 DO     =       .064 AO    =       .003 HO     =       .09
 Nozzle/port arrangement:  unidirectional_without_fanning
 GAMMA =      90.00 THETA =        .00 SIGMA =        .00 BETA   =      90.00
 UO     =      4.150 QO    =       .092        = .9200E-01
 RHOO   =   997.7714 DRHOO = .4337E+00 GPO    = .4260E-02
 CO     = .1000E+03 CUNITS= PERCENT
 IPOLL = 1          KS    = .0000E+00 KD     = .0000E+00

FLUX VARIABLES - PER UNIT DIFFUSER LENGTH (metric units)
 q0     = .6133E-02 m0    = .2545E-01 j0     = .2613E-04 SIGNJ0=       1.0
 Associated 2-d length scales (meters)
 lQ=B   =       .001 lM    =      28.81 lm     =       .09
 lmp    =   99999.00 lbp   =   99999.00 la     =   99999.00

FLUX VARIABLES - ENTIRE DIFFUSER (metric units)
 Q0     = .9200E-01 M0    = .3818E+00 J0     = .3920E-03
 Associated 3-d length scales (meters)
 LQ     =        .15 LM    =      24.53 Lm     =      1.14 Lb     =        .00
                                        Lmp    =  99999.00 Lbp    =   99999.00

NON-DIMENSIONAL PARAMETERS
 FR0    =    1653.66 FRD0  =     252.28 R      =      7.68
 (slot)              (port/nozzle)

FLOW CLASSIFICATION
 222222222222222222222222222222222222222222
 2 Flow class (CORMIX2)        =   MU2    2
 2 Applicable layer depth HS =        .30 2
 222222222222222222222222222222222222222222

MIXING ZONE / TOXIC DILUTION / REGION OF INTEREST PARAMETERS
 CO     = .1000E+03 CUNITS= PERCENT
 NTOX   = 0
 NSTD   = 0
 REGMZ = 1
 REGSPC= 2           XREG  =        .00 WREG   =     19.00 AREG   =        .00
 XINT   =    1000.00 XMAX  =    1000.00

X-Y-Z COORDINATE SYSTEM:
   ORIGIN is located at the bottom and the diffuser mid-point:
       20.00 m  from the RIGHT bank/shore.
   X-axis points downstream, Y-axis points to left, Z-axis points upward.
NSTEP = 20 display intervals per module
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD201: DIFFUSER DISCHARGE MODULE
```

Due to complex near-field motions: EQUIVALENT SLOT DIFFUSER (2-D) GEOMETRY

Profile definitions:
BV = Gaussian 1/e (37%) half-width, in vertical plane normal to trajectory
BH = top-hat half-width, in horizontal plane normal to trajectory
S = hydrodynamic centerline dilution
C = centerline concentration (includes reaction effects, if any)

X	Y	Z	S	C	BV	BH
.00	.00	.09	1.0	.100E+03	.00	7.50

END OF MOD201: DIFFUSER DISCHARGE MODULE

BEGIN MOD271: ACCELERATION ZONE OF UNIDIRECTIONAL CO-FLOWING DIFFUSER

In this laterally contracting zone the diffuser plume becomes VERTICALLY FULLY MIXED over the entire layer depth (HS = .30m).
Full mixing is achieved after a plume distance of about five layer depths from the diffuser.

Profile definitions:
BV = layer depth (vertically mixed)
BH = top-hat half-width, in horizontal plane normal to trajectory
S = hydrodynamic average (bulk) dilution
C = average (bulk) concentration (includes reaction effects, if any)

X	Y	Z	S	C	BV	BH
.00	.00	.09	1.0	.100E+03	.00	7.50
.38	.00	.09	11.2	.894E+01	.08	7.39
.75	.00	.10	15.4	.649E+01	.15	7.30
1.13	.00	.10	18.6	.536E+01	.23	7.22
1.50	.00	.10	21.4	.468E+01	.30	7.15
1.88	.00	.11	23.8	.420E+01	.30	7.09
2.25	.00	.11	26.0	.385E+01	.30	7.04
2.63	.00	.11	28.0	.358E+01	.30	6.99
3.00	.00	.11	29.8	.335E+01	.30	6.95
3.38	.00	.12	29.8	.335E+01	.30	6.91
3.75	.00	.12	29.8	.335E+01	.30	6.87
4.13	.00	.12	29.8	.335E+01	.30	6.84
4.50	.00	.13	29.8	.335E+01	.30	6.82
4.88	.00	.13	29.8	.335E+01	.30	6.80
5.25	.00	.13	29.8	.335E+01	.30	6.78
5.63	.00	.14	29.8	.335E+01	.30	6.76
6.00	.00	.14	29.8	.335E+01	.30	6.75
6.38	.00	.14	29.8	.335E+01	.30	6.74
6.75	.00	.14	29.8	.335E+01	.30	6.74
7.13	.00	.15	29.8	.335E+01	.30	6.74
7.50	.00	.15	29.8	.335E+01	.30	6.73

Cumulative travel time = 11. sec

END OF MOD271: ACCELERATION ZONE OF UNIDIRECTIONAL CO-FLOWING DIFFUSER

BEGIN MOD251: DIFFUSER PLUME IN CO-FLOW

Phase 1: Vertically mixed, Phase 2: Re-stratified

Phase 1: The diffuser plume is VERTICALLY FULLY MIXED over the entire layer depth.
This flow region is INSIGNIFICANT in spatial extent and will be by-passed.

Phase 2: The flow has RESTRATIFIED at the beginning of this zone.

This flow region is INSIGNIFICANT in spatial extent and will be by-passed.

END OF MOD251: DIFFUSER PLUME IN CO-FLOW

** End of NEAR-FIELD REGION (NFR) **

The initial plume WIDTH values in the next far-field module will be CORRECTED by a factor 1.24 to conserve the mass flux in the far-field!

BEGIN MOD241: BUOYANT AMBIENT SPREADING

Discharge is non-buoyant or weakly buoyant.
Therefore BUOYANT SPREADING REGIME is ABSENT.

END OF MOD241: BUOYANT AMBIENT SPREADING

BEGIN MOD261: PASSIVE AMBIENT MIXING IN UNIFORM AMBIENT

Vertical diffusivity (initial value)   = .372E-02 m^2/s
Horizontal diffusivity (initial value) = .930E-02 m^2/s

The passive diffusion plume is VERTICALLY FULLY MIXED at beginning of region.

Profile definitions:
BV = Gaussian s.d.*sqrt(pi/2) (46%) thickness, measured vertically
= or equal to layer depth, if fully mixed
BH = Gaussian s.d.*sqrt(pi/2) (46%) half-width,
measured horizontally in Y-direction
ZU = upper plume boundary (Z-coordinate)
ZL = lower plume boundary (Z-coordinate)
S = hydrodynamic centerline dilution
C = centerline concentration (includes reaction effects, if any)

Plume Stage 1 (not bank attached):

X	Y	Z	S	C	BV	BH	ZU	ZL
7.50	.00	.30	29.8	.335E+01	.30	8.37	.30	.00
57.13	.00	.30	30.4	.329E+01	.30	8.53	.30	.00
106.75	.00	.30	30.9	.323E+01	.30	8.68	.30	.00
156.38	.00	.30	31.5	.318E+01	.30	8.83	.30	.00
206.00	.00	.30	32.0	.313E+01	.30	8.98	.30	.00
255.63	.00	.30	32.5	.308E+01	.30	9.13	.30	.00
305.25	.00	.30	33.0	.303E+01	.30	9.27	.30	.00
354.88	.00	.30	33.5	.298E+01	.30	9.42	.30	.00

** REGULATORY MIXING ZONE BOUNDARY **
In this prediction interval the TOTAL plume width meets or exceeds
the regulatory value =   19.00 m.
This is the extent of the REGULATORY MIXING ZONE.

X	Y	Z	S	C	BV	BH	ZU	ZL
404.50	.00	.30	34.0	.294E+01	.30	9.56	.30	.00
454.13	.00	.30	34.5	.290E+01	.30	9.69	.30	.00
503.75	.00	.30	35.0	.286E+01	.30	9.83	.30	.00
553.38	.00	.30	35.5	.282E+01	.30	9.96	.30	.00
603.00	.00	.30	36.0	.278E+01	.30	10.10	.30	.00
652.63	.00	.30	36.4	.275E+01	.30	10.23	.30	.00
702.25	.00	.30	36.9	.271E+01	.30	10.36	.30	.00
751.88	.00	.30	37.3	.268E+01	.30	10.48	.30	.00
801.50	.00	.30	37.8	.265E+01	.30	10.61	.30	.00
851.13	.00	.30	38.2	.262E+01	.30	10.73	.30	.00
900.75	.00	.30	38.7	.259E+01	.30	10.86	.30	.00
950.38	.00	.30	39.1	.256E+01	.30	10.98	.30	.00
1000.00	.00	.30	39.5	.253E+01	.30	11.10	.30	.00

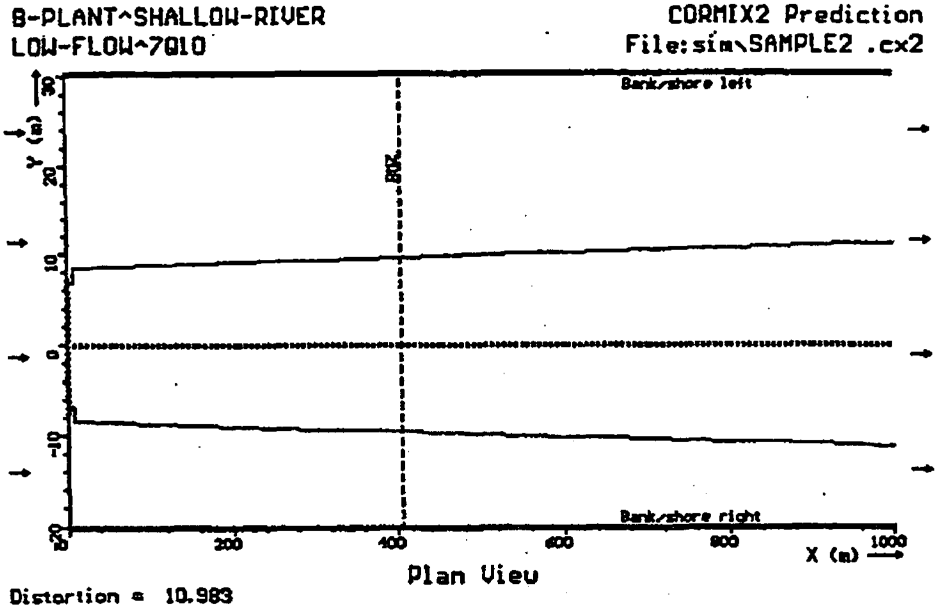
Cumulative travel time =   1828. sec

Simulation limit based on maximum specified distance =   1000.00 m.
This is the REGION OF INTEREST limitation.

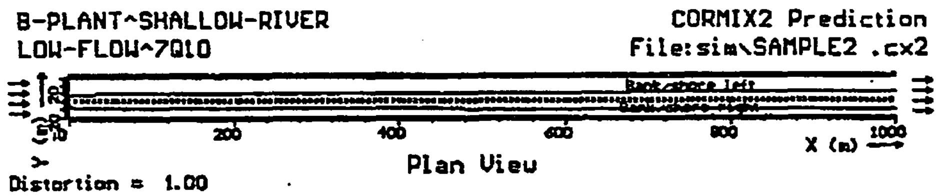
END OF MOD261: PASSIVE AMBIENT MIXING IN UNIFORM AMBIENT

Because of the fairly LARGE SPACING between adjacent risers/nozzles/ports,
the above results may be unreliable in the immediate near-field of
the diffuser.
A SUBSEQUENT APPLICATION OF CORMIX1 IS RECOMMENDED to provide more detail
for one of the individual jets/plumes in the initial region
before merging.

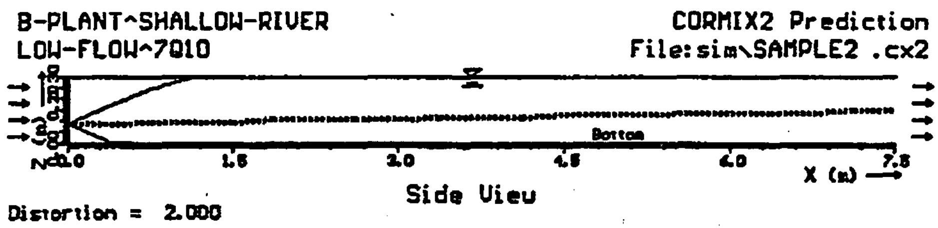
CORMIX2: Submerged Multiport Diffuser Discharges   End of Prediction File
22222222222222222222222222222222222222222222222222222222222222222222222222



(a)



(b)



(c)

Figure C.8: CORMIX2 prediction for B-Plant multiport diffuser discharge in Shallow River. Examples of different graphics plots: a) Plan view over entire reach, b) equivalent undistorted plan view, and c) side view of near-field only.

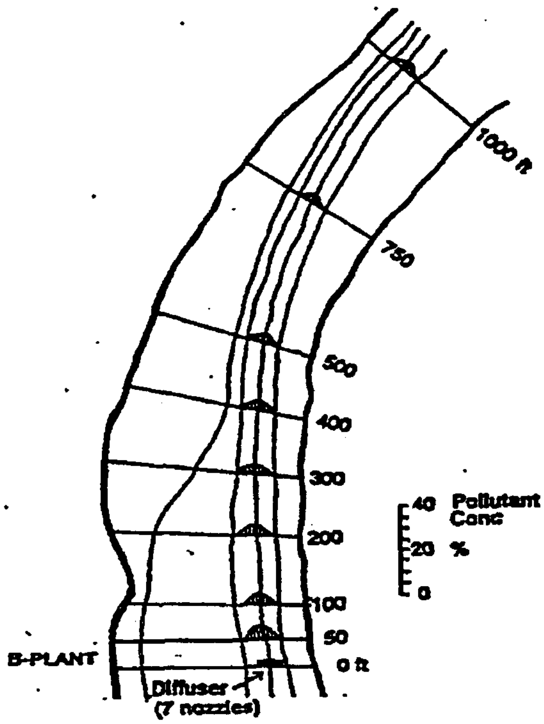


Figure C.9: Results of cumulative discharge interpretation of CORMIX2 prediction for B-Plant multiport diffuser discharge in Shallow River

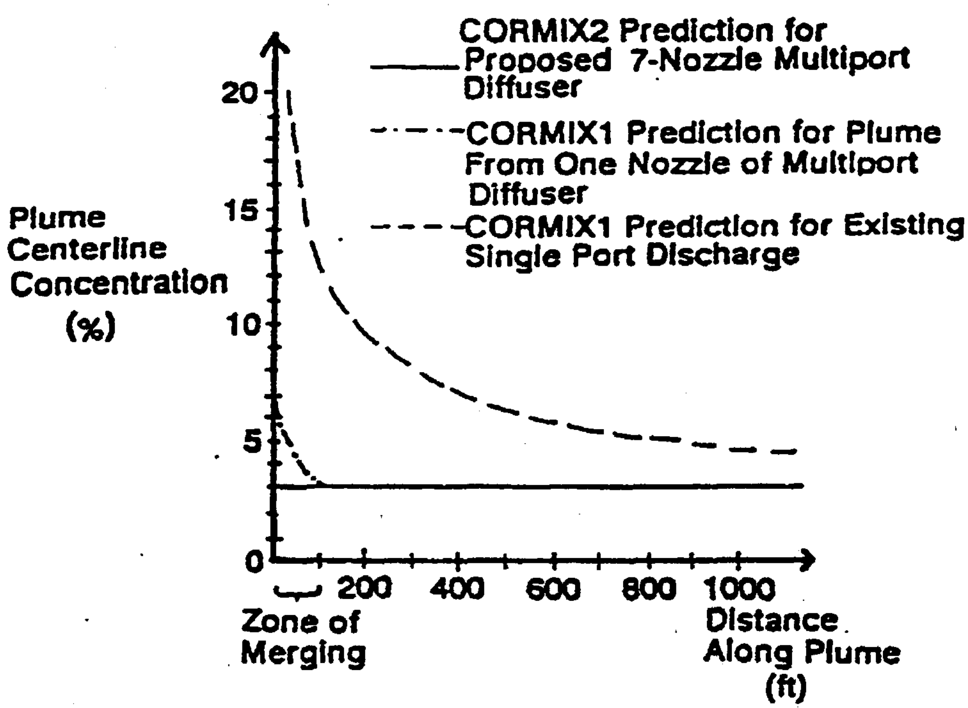


Figure C.10: Predicted plume centerline concentrations for multiport diffuser design (CORMIX1) in comparison to single port design (CORMIX2)

Appendix D
CORMIX3: Buoyant Surface Discharge In An Estuary

Estuarine conditions are characterized by highly variable ambient conditions during the tidal cycle. This case study provides a short application example for a buoyant surface discharge from a large manufacturing plant discharging its process water into an estuary.

D.1 Problem Statement

A manufacturing plant (C-Plant) is using process water at a capacity of 2.2 m^3/s ($\approx$ 50 mgd). The process water is essentially fresh water with a discharge temperature of 20.0 °C and contains copper at a concentration of 80 µg/l.

The plant is located at the shore of an estuary. Figure D.1 shows the bottom bathymetry at the plant location; two transects have been measured and show a relatively rapid drop-off from the MSL line to a depth of about 5 m below MSL. It is proposed to build a discharge channel with a bottom elevation of about 1.0 m below MSL and a width of 2.0 m. Thus, given the tidal variation at the discharge location indicated in Figure D.1, the actual channel depth will vary from a maximum of about 1.8 m at MHW to a minimum of about 0.5 at MLW, with corresponding adjustments in the discharge velocity.

Figure D.2 shows data from oceanographic field surveys near the discharge site with ambient velocity variations from about +0.7 m/s for flood tide and to about -0.7 m/s for ebb tide. Figure D.2 also shows the tidal elevation variations from -.7 m above MLW at ebb to +1.1 m above MLW at flood. The estuary has brackish water with mean salinity of about 26 ppt, yielding a density of about 1018 kg/m^3 (see Figure 4.3 as an aid).

State regulations specify a mixing zone of about 250 m extending in any direction from the discharge point. The CMC and CCC values for copper are 25 and 15 µg/l, respectively.

D.2 Steady State Simulation (for reference)

Although it is to be expected that the surface discharge plume for this situation will be quite variable in appearance and mixing characteristics due to the tidal reversal, a steady state simulation will be performed to illustrate the basic CORMIX3 application in a time invariant ambient receiving water. Furthermore, this simulation will be used as a basis for comparison in the next selection, where tidal CORMIX simulations are appropriately performed in order to determine the time evolution in this highly unsteady environment.

Assume that the conditions one hour after low water slack tide (t = 11.7 h) represent that in a large steady river (see condition (b), Figure D.2). This design condition is represented by a water level 0.35 m below MSL and an ambient velocity of 0.22 m/s. As shown in Figure D.1, the ambient water body is schematized as unbounded, with an average depth of 6 m at MSL, a local depth of 2.5 m at MSL (1.5 m below the discharge channel mouth), and a bottom slope of 11°.

Figure D.3 presents the input data checklist and Table D.1 shows the CORMIX3 prediction file (the session report is omitted here for brevity) for the steady state reference condition one hour after low water slack (LWS). The shallow discharge channel (depth of 0.65 m) produces a relatively weak free jet (flow class FJ1). After only 4.5 m offshore distance, the initial jet momentum is overwhelmed by the high discharge buoyancy, and forms a surface plume which is weakly deflected by the ambient crossflow (MOD313). In this region, buoyant forces rapidly thin and spread the plume horizontally. Both the CCC and CMC are met within this region, (and also within the regulatory mixing zone) as is displayed by CORMIX in the prediction file. The plume then becomes strongly deflected (MOD323) and finally contacts the shoreline some 1560 m downstream. The plume then becomes attached to the shoreline, and spreads through passive ambient diffusion and weak buoyant forces (MOD341), until the end of the region of interest (2000 m). Figure D.4 shows the above behavior.

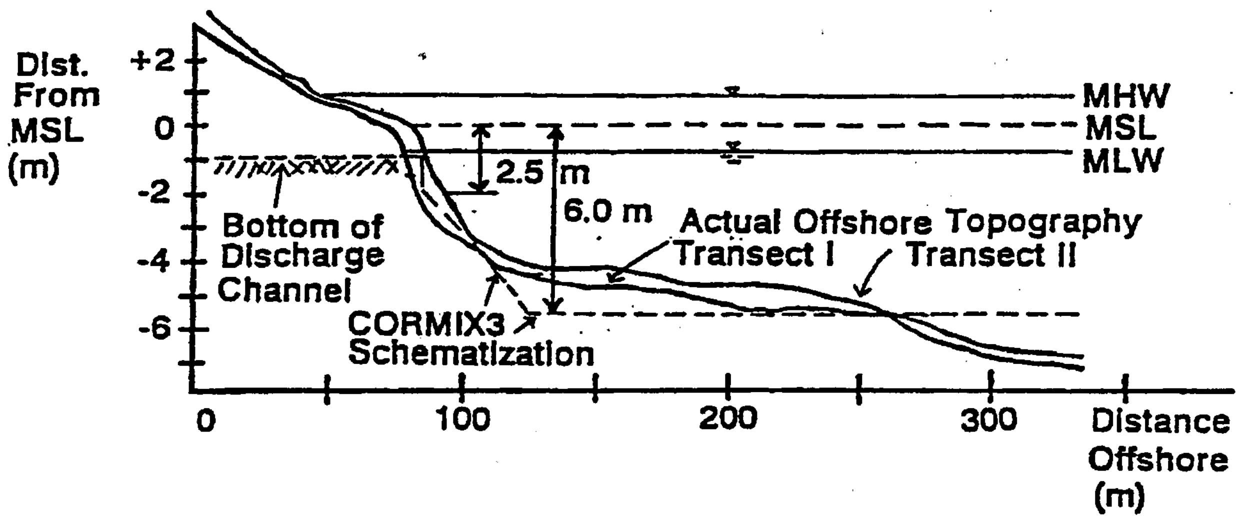


Figure D.1: Bathymetric conditions in Estuary in vicinity of C-Plant surface discharge

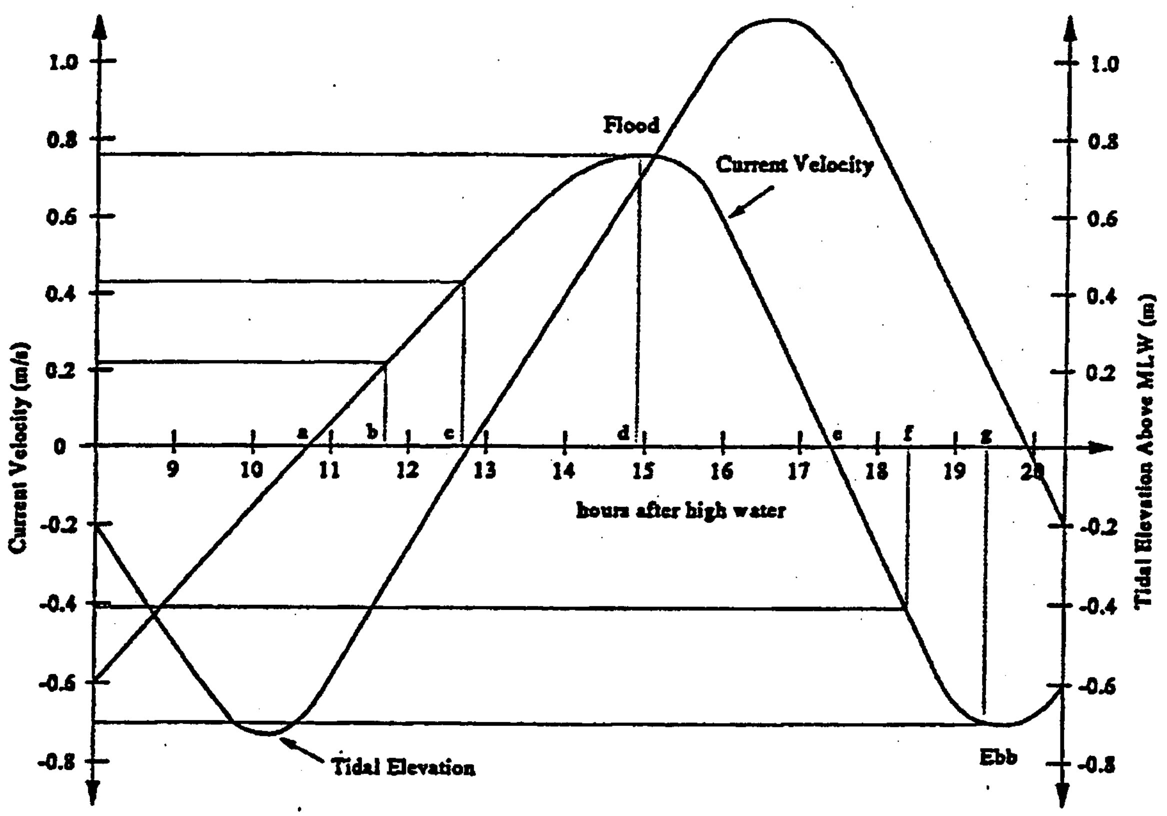


Figure D.2: Oceanographic data for Estuary showing tidal elevation and current. A complete tidal analysis might include simulations for all time instances labeled a to g.

CHECKLIST FOR DATA PREPARATION

CORMIX – CORNELL MIXING ZONE EXPERT SYSTEM – Version 3.10

SITE Name C-Plant Estuary — Date:
Design CASE Steady State - 1 hr. after slack — Prepared by: RLD
DOS FILE NAME Sample1 (w/o extension)

AMBIENT DATA:

Water body depth	5.65 m	Water body is	bounded/unbounded
Depth at discharge	5.65 m	If bounded: Width	____ m
		Appearance	1/2/3x
If steady: Ambient flowrate	____ m³/s or:	Ambient velocity	0.22 m/s
If tidal: Tidal period	____ hr	Max. tidal velocity	____ m/s
At time ____ hr before/at/after slack:		Tidal velocity at this time	____ m/s
Manning's n	____ or:	Darcy-Weisbach f	0.025
Wind speed	2 m/s		
Density data:		UNITS: Density...kg/m³ / Temperature...°C	
Water body is	fresh/salt water	If fresh: Specify as	density/temp. values
If uniform:		Average density/temp.	1018.0
If stratified:		Density/temp. at surface	____
Stratification type	A/B/C	Density/temp. at bottom	____
If B/C: Pycnocline height	____ m	If C: Density/temp. jump	____

DISCHARGE DATA: Specify geometry for CORMIX1 or 2 or 3

SUBMERGED SINGLE PORT DISCHARGE – CORMIX1

Nearest bank is on	left/right	Distance to nearest bank	____ m
Vertical angle THETA	____ °	Horizontal angle SIGMA	____ °
Port diameter	____ m or:	Port area	____ m²
Port height	____ m		

SUBMERGED MULTIPORT DIFFUSER DISCHARGE – CORMIX2

Nearest bank is on	left/right	Distance to one endpoint	____ m
Diffuser length	____ m	to other endpoint	____ m
Total number of openings	____ m	Port height	____ m
Port diameter	____ m with	contraction ratio	____
Diffuser arrangement/type	unidirectional / staged / alternating or vertical		
Alignment angle GAMMA	____ °	Horizontal angle SIGMA	____ °
Vertical angle THETA	____ °	Relative orientation BETA	____ °

BUOYANT SURFACE DISCHARGE – CORMIX3

Discharge located on	left/right bank	Configuration	flush/protruding/co-flowing
Horizontal angle SIGMA	90 °	If protruding: Dist. from bank	____ m
Depth at discharge	2.15 m	Bottom slope	11 °
If rectangular Width	2 m or:	If circular Diameter	____ m
discharge channel: Depth	0.65 m	pipe: Bottom invert depth	____ m

Effluent: Flow rate	2.2 m³/s or:	Effluent velocity	____ m/s
Effluent density	- kg/m³ or:	Effluent temperature	22 °C
Heated discharge?	yes/no	If yes: Heat loss coefficient	- W/m²,°C
Concentration units	mug-p-L	Effluent concentration	80
Conservative substance?	yes/no	If no: Decay coefficient	____ /day

MIXING ZONE DATA:

Is effluent toxic?	yes/no	If yes: CMC 25	CCC 15
WQ stand./conventional poll.?	yes/no	If yes: value of standard	____
Any mixing zone specified?	yes/no	If yes: distance 250 m	or width - % or m
			or area - % or m²
Region of interest	2000 m	Grid intervals for display	20

Figure D.3: Data preparation checklist for CORMIX3 steady-state simulation for C-Plant estuary discharge

Table D.1
CORMIX3 Prediction Steady-Sate Prediction File for Surface Buoyant Discharge

```
CORMIX3 PREDICTION FILE:
333333333333333333333333333333333333333333333333333333333333333333333333333
                       CORNELL MIXING ZONE EXPERT SYSTEM
Subsystem CORMIX3:                                          Subsystem version:
 Buoyant Surface Discharges                  CORMIX_v.3.10_________June_1995
---------------------------------------------------------------------------
---------------------------------------------------------------------------
CASE DESCRIPTION
 Site name/label:            C-PLANT^ESTUARY
 Design case:                STEADY^SIMULATION^ONE^HOUR^AFTER^SLACK
 FILE NAME:                  cormix\sim\SAMPLE3 .cx3
 Time of Fortran run:        06/24/95--22:32:20

ENVIRONMENT PARAMETERS (metric units)
 Unbounded section
HA    =       5.65  HD     =        5.65
UA    =       .220  F      =        .025 USTAR = .1230E-01
UW    =      2.000  UWSTAR= .2198E-02
 Uniform density environment
 STRCND= U          RHOAM = 1018.0000

DISCHARGE PARAMETERS (metric units)
 BANK  =  RIGHT     DISTB =          .00  Configuration: flush_discharge
 SIGMA =      90.00 HDO    =        2.15  SLOPE =       11.00
 Rectangular channel geometry:
 BO    =      2.000 HO     =        .650 AO     = .1300E+01  AR    =       .325
 UO    =      1.692 QO     =       2.200        = .2200E+01
 RHOO  =   998.2051 DRHOO = .1979E+02 GPO    = .1907E+00
 CO    = .8000E+02 CUNITS=  MUG-P-L
 IPOLL =  1         KS     = .0000E+00 KD     = .0000E+00

FLUX VARIABLES (metric units)
 QO    = .2200E+01  MO     = .3723E+01 JO     = .4195E+00
 Associated length scales (meters)
 LQ    =      1.14  LM     =        4.14 Lm     =       8.77 Lb    =      39.40

NON-DIMENSIONAL PARAMETERS
 FRO   =      3.62  FRCH   =        4.80 R      =       7.69

FLOW CLASSIFICATION
 3333333333333333333333333333333333333333
 3  Flow class (CORMIX3)       =    FJ1   3
 3  Applicable layer depth HS =     5.65  3
 3333333333333333333333333333333333333333

MIXING ZONE / TOXIC DILUTION / REGION OF INTEREST PARAMETERS
 CO    = .8000E+02  CUNITS= MUG-P-L
 NTOX  =  1         CMC    = .2500E+02 CCC    = CSTD
 NSTD  =  1         CSTD   = .1500E+02
 REGMZ =  1
 REGSPC=  1         XREG   =      250.00 WREG   =       .00  AREG  =        .00
 XINT  =    2000.00 XMAX   =     2000.00

X-Y-Z COORDINATE SYSTEM:
    ORIGIN is located at the WATER SURFACE and at center of discharge
      channel/outlet:        .00 m  from the RIGHT bank/shore.
    X-axis points downstream
    Y-axis points to left as seen by an observer looking downstream
    Z-axis points vertically upward (in CORMIX3, all values Z = 0.00)
NSTEP = 20 display intervals per module
---------------------------------------------------------------------------
        TRJBUO     TRJATT     TRJBND     TRJNBY     TRJCOR     DILCOR
C        3.401      1.000      1.000      1.000      3.400      1.000
---------------------------------------------------------------------------
BEGIN MOD301: DISCHARGE MODULE

 Efflux conditions:
        X          Y          Z         S          C          BV        BH
       .00        .00       0.00       1.0    .800E+02      .65       1.00

END OF MOD301: DISCHARGE MODULE
```

```
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD302: ZONE OF FLOW ESTABLISHMENT

  Control volume inflow:
      X        Y       Z        S       C        BV       BH
     .00      .00    0.00      1.0  .800E+02    .65     1.00

 Profile definitions:
   BV = Gaussian 1/e (37%) vertical thickness
   BH = Gaussian 1/e (37%) horizontal half-width, normal to trajectory
   S = hydrodynamic centerline dilution
   C = centerline concentration (includes reaction effects, if any)

  Control volume outflow:
      X        Y       Z        S       C        BV       BH
     .13     4.11    0.00      1.4  .576E+02   1.09     1.41
 Cumulative travel time =          2. sec

END OF MOD302: ZONE OF FLOW ESTABLISHMENT
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD311: WEAKLY DEFLECTED JET (3-D)

 Surface JET into a crossflow

 Profile definitions:
   BV = Gaussian 1/e (37%) vertical thickness
   BH = Gaussian 1/e (37%) horizontal half-width, normal to trajectory
   S = hydrodynamic centerline dilution
   C = centerline concentration (includes reaction effects, if any)

      X        Y       Z        S       C        BV       BH
     .13     4.11    0.00      1.4  .576E+02   1.28     1.65
     .13     4.14    0.00      1.4  .575E+02   1.28     1.66
     .13     4.16    0.00      1.4  .574E+02   1.28     1.66
     .13     4.18    0.00      1.4  .573E+02   1.28     1.66
     .13     4.20    0.00      1.4  .572E+02   1.29     1.66
     .14     4.23    0.00      1.4  .571E+02   1.29     1.67
     .14     4.25    0.00      1.4  .570E+02   1.29     1.67
     .14     4.27    0.00      1.4  .569E+02   1.29     1.67
     .14     4.29    0.00      1.4  .568E+02   1.30     1.67
     .15     4.32    0.00      1.4  .567E+02   1.30     1.68
     .15     4.34    0.00      1.4  .566E+02   1.30     1.68
     .15     4.36    0.00      1.4  .565E+02   1.30     1.68
     .15     4.38    0.00      1.4  .564E+02   1.30     1.68
     .15     4.41    0.00      1.4  .563E+02   1.31     1.69
     .16     4.43    0.00      1.4  .562E+02   1.31     1.69
     .16     4.45    0.00      1.4  .561E+02   1.31     1.69
     .16     4.47    0.00      1.4  .560E+02   1.31     1.69
     .16     4.50    0.00      1.4  .559E+02   1.32     1.70
     .17     4.52    0.00      1.4  .558E+02   1.32     1.70
     .17     4.54    0.00      1.4  .558E+02   1.32     1.70
     .17     4.56    0.00      1.4  .557E+02   1.32     1.70
 Cumulative travel time =          3. sec

END OF MOD311: WEAKLY DEFLECTED JET (3-D)
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD313: WEAKLY DEFLECTED PLUME

 Surface PLUME into a crossflow

 Profile definitions:
   BV = Gaussian 1/e (37%) vertical thickness
   BH = Gaussian 1/e (37%) horizontal half-width, normal to trajectory
   S = hydrodynamic centerline dilution
   C = centerline concentration (includes reaction effects, if any)

      X        Y       Z        S       C        BV       BH
     .17     4.56    0.00      1.4  .557E+02   1.32     1.70
     .41     6.86    0.00      2.3  .343E+02    .82     4.48
     .67     9.16    0.00      2.9  .279E+02    .66     6.76
** CMC HAS BEEN FOUND **
 The pollutant concentration in the plume falls below CMC value of  .250E+02
   in the current prediction interval.
 This is the extent of the TOXIC DILUTION ZONE.
```

.96	11.46	0.00	3.3	.244E+02	.58	8.88
1.28	13.76	0.00	3.6	.220E+02	.52	10.93
1.62	16.05	0.00	4.0	.202E+02	.48	12.95
1.99	18.35	0.00	4.3	.188E+02	.45	14.94
2.38	20.65	0.00	4.5	.177E+02	.42	16.93
2.80	22.95	0.00	4.8	.167E+02	.40	18.92
3.25	25.25	0.00	5.0	.159E+02	.38	20.91
3.72	27.54	0.00	5.3	.152E+02	.36	22.90

** WATER QUALITY STANDARD OR CCC HAS BEEN FOUND **

The pollutant concentration in the plume falls below water quality standard or CCC value of .150E+02 in the current prediction interval.

This is the spatial extent of concentrations exceeding the water quality standard or CCC value.

4.22	29.84	0.00	5.5	.146E+02	.35	24.90
4.75	32.14	0.00	5.7	.140E+02	.33	26.92
5.30	34.44	0.00	5.9	.135E+02	.32	28.93
5.87	36.74	0.00	6.1	.131E+02	.31	30.96
6.48	39.03	0.00	6.3	.126E+02	.30	33.00
7.11	41.33	0.00	6.5	.123E+02	.29	35.05
7.76	43.63	0.00	6.7	.119E+02	.28	37.11
8.44	45.93	0.00	6.9	.116E+02	.28	39.18
9.15	48.23	0.00	7.1	.113E+02	.27	41.25
9.88	50.52	0.00	7.2	.110E+02	.26	43.34

Cumulative travel time = 248. sec

END OF MOD313: WEAKLY DEFLECTED PLUME

BEGIN MOD323: STRONGLY DEFLECTED PLUME

Profile definitions:
BV = top-hat thickness,measured vertically
BH = top-hat half-width, measured horizontally in Y-direction
S = hydrodynamic average (bulk) dilution
C = average (bulk) concentration (includes reaction effects, if any)

X	Y	Z	S	C	BV	BH
9.88	50.52	0.00	7.2	.110E+02	.26	43.34
84.15	123.86	0.00	7.5	.107E+02	.23	60.96
158.42	154.39	0.00	7.8	.103E+02	.22	77.07
232.69	176.11	0.00	8.1	.985E+01	.22	92.39

** REGULATORY MIXING ZONE BOUNDARY **

In this prediction interval the plume distance meets or exceeds the regulatory value = 250.00 m.

This is the extent of the REGULATORY MIXING ZONE.

306.96	193.50	0.00	8.6	.934E+01	.22	107.24
381.23	208.23	0.00	9.1	.876E+01	.23	121.77
455.50	221.14	0.00	9.8	.815E+01	.25	136.02
529.77	232.70	0.00	10.7	.750E+01	.26	150.02
604.04	243.21	0.00	11.7	.685E+01	.28	163.77
678.31	252.88	0.00	12.9	.621E+01	.30	177.26
752.58	261.87	0.00	14.3	.560E+01	.32	190.49
826.84	270.29	0.00	15.9	.504E+01	.34	203.46
901.11	278.21	0.00	17.7	.452E+01	.36	216.17
975.38	285.70	0.00	19.7	.406E+01	.39	228.65
1049.65	292.82	0.00	21.9	.365E+01	.41	240.91
1123.92	299.61	0.00	24.4	.328E+01	.44	252.95
1198.18	306.11	0.00	27.1	.295E+01	.47	264.79
1272.45	312.34	0.00	30.0	.267E+01	.50	276.45
1346.72	318.34	0.00	33.1	.241E+01	.54	287.93
1420.99	324.11	0.00	36.5	.219E+01	.57	299.25
1495.25	329.69	0.00	40.1	.199E+01	.61	310.43

Cumulative travel time = 7000. sec

END OF MOD323: STRONGLY DEFLECTED PLUME

** End of NEAR-FIELD REGION (NFR) **

BEGIN MOD341: BUOYANT AMBIENT SPREADING

Profile definitions:
BV = top-hat thickness,measured vertically
BH = top-hat half-width, measured horizontally from bank/shoreline
S = hydrodynamic average (bulk) dilution
C = average (bulk) concentration (includes reaction effects, if any)

Plume Stage 1 (not bank attached):

X	Y	Z	S	C	BV	BH
1495.25	329.69	0.00	40.1	.199E+01	.63	319.79
1498.55	329.69	0.00	40.3	.199E+01	.63	320.29
1501.84	329.69	0.00	40.5	.198E+01	.63	320.79
1505.13	329.69	0.00	40.6	.197E+01	.63	321.29
1508.42	329.69	0.00	40.8	.196E+01	.63	321.79
1511.72	329.69	0.00	41.0	.195E+01	.64	322.29
1515.01	329.69	0.00	41.1	.195E+01	.64	322.78
1518.30	329.69	0.00	41.3	.194E+01	.64	323.28
1521.59	329.69	0.00	41.5	.193E+01	.64	323.78
1524.89	329.69	0.00	41.6	.192E+01	.64	324.27
1528.18	329.69	0.00	41.8	.191E+01	.64	324.77
1531.47	329.69	0.00	42.0	.191E+01	.65	325.27
1534.77	329.69	0.00	42.1	.190E+01	.65	325.76
1538.06	329.69	0.00	42.3	.189E+01	.65	326.26
1541.35	329.69	0.00	42.5	.188E+01	.65	326.75
1544.64	329.69	0.00	42.6	.188E+01	.65	327.25
1547.94	329.69	0.00	42.8	.187E+01	.65	327.74
1551.23	329.69	0.00	43.0	.186E+01	.65	328.23
1554.52	329.69	0.00	43.2	.185E+01	.66	328.73
1557.81	329.69	0.00	43.3	.185E+01	.66	329.22
1561.11	329.69	0.00	43.5	.184E+01	.66	329.71

Cumulative travel time = 7299. sec

Plume is ATTACHED to RIGHT bank/shore.
Plume width is now determined from RIGHT bank/shore.

Plume Stage 2 (bank attached):

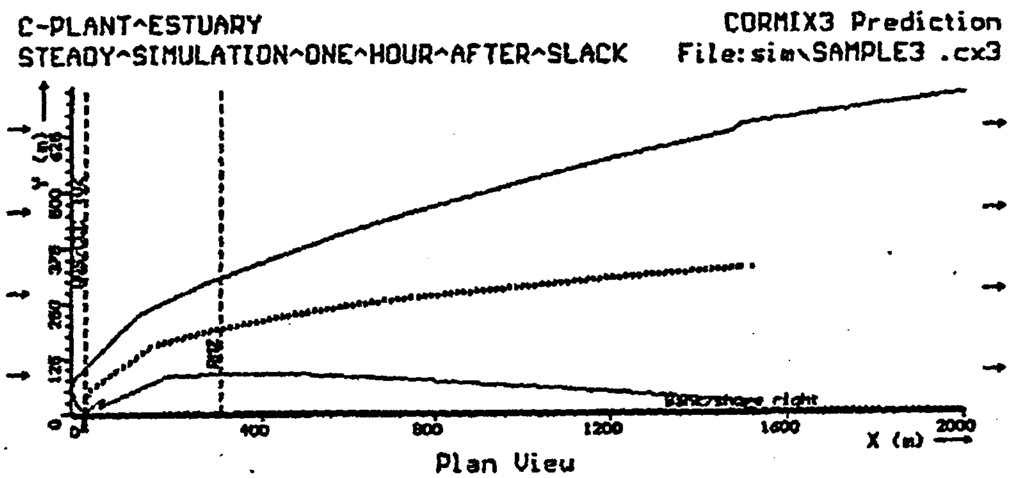
X	Y	Z	S	C	BV	BH
1561.11	.00	0.00	43.5	.184E+01	.66	659.39
1583.05	.00	0.00	44.6	.179E+01	.67	662.33
1605.00	.00	0.00	45.7	.175E+01	.69	665.27
1626.94	.00	0.00	46.8	.171E+01	.70	668.21
1648.89	.00	0.00	48.0	.167E+01	.71	671.16
1670.83	.00	0.00	49.1	.163E+01	.73	674.11
1692.78	.00	0.00	50.3	.159E+01	.74	677.06
1714.72	.00	0.00	51.4	.156E+01	.76	680.01
1736.66	.00	0.00	52.6	.152E+01	.77	682.97
1758.61	.00	0.00	53.8	.149E+01	.78	685.92
1780.55	.00	0.00	55.0	.146E+01	.80	688.88
1802.50	.00	0.00	56.2	.142E+01	.81	691.83
1824.44	.00	0.00	57.4	.139E+01	.83	694.79
1846.39	.00	0.00	58.6	.136E+01	.84	697.75
1868.33	.00	0.00	59.9	.134E+01	.85	700.71
1890.28	.00	0.00	61.1	.131E+01	.87	703.67
1912.22	.00	0.00	62.4	.128E+01	.88	706.62
1934.17	.00	0.00	63.6	.126E+01	.90	709.58
1956.11	.00	0.00	64.9	.123E+01	.91	712.54
1978.05	.00	0.00	66.2	.121E+01	.93	715.50
2000.00	.00	0.00	67.5	.118E+01	.94	718.46

Cumulative travel time = 9294. sec

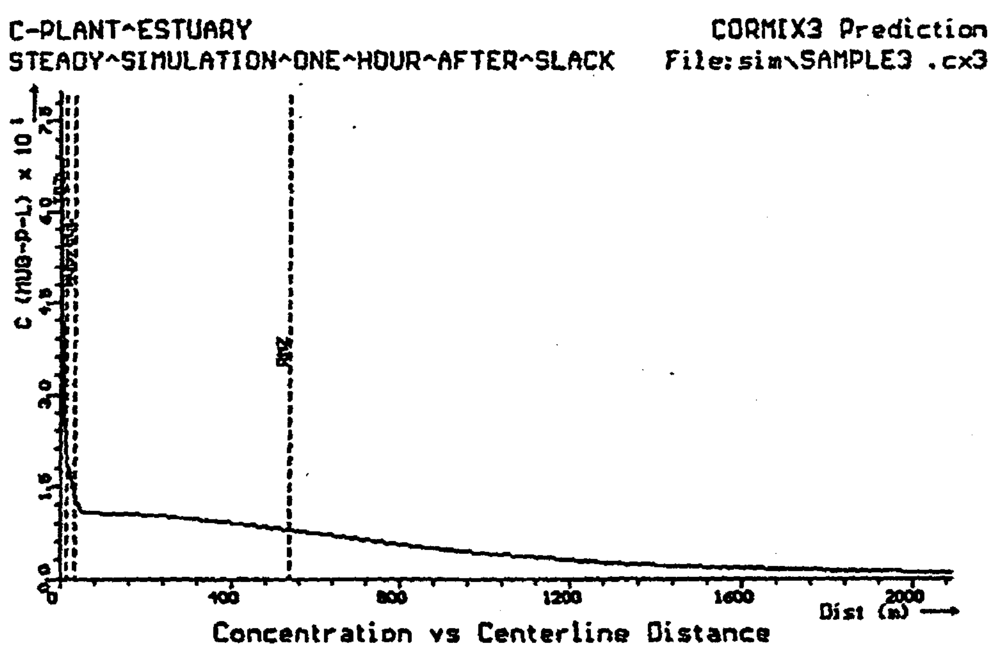
Simulation limit based on maximum specified distance = 2000.00 m.
This is the REGION OF INTEREST limitation.

END OF MOD341: BUOYANT AMBIENT SPREADING

CORMIX3: Buoyant Surface Discharges End of Prediction File
33333333333333333333333333333333333333333333333333333333333333333333333333



(a)



(b)

Figure D.4: CORMIX3 prediction of surface discharge from C-Plant into Estuary using a steady-state simulation. a) Plume shape in near- and far-field, and b) concentration along plume centerline.

D.3 Detailed Tidal Simulations

A high variation in both ambient velocity and tidal elevation occurs during the tidal episode shown in Figure D.2. The changing water height produces a discharge velocity which varies from 0.61 m/s (at high water slack) to 2.2 m/s (at low water slack). When combined with the large buoyancy flux, this produces flows which change from momentum dominated jets to highly buoyant plumes in a short period of time. Simultaneously, the time-variant ambient velocity (which ranges from stagnant to 0.75 m/s) produces flows which are free and unattached at slack tide, yet become strongly shore-hugging at maximum flood or ebb currents.

In such highly time-variant ambient conditions, it is recommended that several CORMIX predictions be performed at **critical tidal conditions** throughout a reversal episode. These critical tidal conditions are identified as:

1) *Shortly after slack tide*: Effects of re-entrainment of discharge from the previous half-cycle are greatest. However, the flow is evolving rapidly in time, causing CORMIX tidal predictions to be limited in spatial extent. Several predictions should be made at hourly or half hourly intervals following the reversal.

2) *Maximum flood and ebb currents*: These represent extremes of along-shore extent and shoreline interaction. Re-entrainment will be less important at these times.

For the present scenario, it is suggested that up to seven simulations be performed at the times indicated on Figure D.2 by the letters a-g. In the following section, a detailed simulation is performed corresponding to time b, one hour after slack tide. The results are contrasted for that case to the steady-state assumption simulated in the preceding.

D.4 Tidal simulation one hour after slack tide

A detailed example of the tidal simulation capability of CORMIX is presented in this section, using conditions corresponding to those in Section D.2 (see Figure D.2, time b). To perform a CORMIX tidal simulation, four additional pieces of data are required:

1) the tidal period (usually 12.4 hours for a semi-diurnal tidal cycle)
2) the time of simulation (in hours relative to slack tide)
3) the ambient velocity at the time of simulation
4) the maximum velocity which occurs during the tidal cycle

From this data, CORMIX calculates the rate of reversal (du_a/dt) and related unsteady length scales (L_u, T_u, $[L_m]_{min}$, see Table 5.4), and determines the spatial extent of CORMIX applicability and the re-entrainment and build-up caused by the reversal of ambient current. (Note: If a simulation is performed at slack tide, then the time of simulation is t = 0 h, and the ambient velocity is set to u_a = 0 m/s.) However, in order to calculate the reversal rate, CORMIX requires input of the ambient velocity at an other time near reversal (for example, at one hour before or after slack tide). This information is only used to determine the limit of spatial applicability for the slack tide simulation.

For this application, the time of simulation is one hour after slack tide. The ambient velocity at this time is u_a = 0.22 m/s, and the ambient and discharge channel depths are the same as in Section D.2. The maximum ambient velocity during the tidal cycle is 0.75 m/s. For this simulation, the data preparation checklist is given in Figure D.5.

Table D.2 lists the CORMIX session report and Table D.3 the CORMIX3 prediction file for this tidal application. Two important consequences are evident when comparing Table D.3 and Table D.1 (corresponding steady-state simulation): 1) a concentration build-up in the near-field, and 2) the termination of the plume prediction after some distance. The latter distance is the region over which a reasonably steady-state plume can establish itself within the time-varying tidal environment. The theoretical background for these procedures is given in the report on recent CORMIX enhancements (8).

CHECKLIST FOR DATA PREPARATION

CORMIX – CORNELL MIXING ZONE EXPERT SYSTEM – Version 3.1,3.2

SITE Name: C-Plant Estuary — Date:
Design CASE: Tidal simulation 1 hr after slack — Prepared by: GHJ
DOS FILE NAME: Sample 3T (w/o extension)

AMBIENT DATA:

Water body depth	5.65 m	Water body is	~~bounded~~/unbounded
Depth at discharge	5.65 m	If bounded: Width	- m
If steady: Ambient flowrate	- m³/s or:	Appearance	~~NDS~~
		Ambient velocity	- m/s
If tidal: Tidal period	12.4 hr	Max. tidal velocity	0.75 m/s
At time 1.0 hr ~~before~~/at/after slack:		Tidal velocity at this time	0.22 m/s
Manning's n	- or:	Darcy-Weisbach f	0.025
Wind speed	2 m/s		
Density data:		UNITS: Density...kg/m³ / Temperature...°C	
Water body is	~~fresh~~/salt water	If fresh: Specify as	density/~~temp.~~ values
If uniform:		Average density/~~temp.~~	1018.0
If stratified:		Density/temp. at surface	
Stratification type	A/B/C	Density/temp. at bottom	
If B/C: Pycnocline height	m	If C: Density/temp. jump	

DISCHARGE DATA: Specify geometry for CORMIX1 or 2 or 3

~~SUBMERGED SINGLE PORT DISCHARGE – CORMIX1~~

Nearest bank is on	left/right	Distance to nearest bank	m
Vertical angle THETA	°	Horizontal angle SIGMA	°
Port diameter	m or:	Port area	m²
Port height	m		

~~SUBMERGED MULTIPORT DIFFUSER DISCHARGE – CORMIX2~~

Nearest bank is on	left/right	Distance to one endpoint	m
Diffuser length	m	to other endpoint	m
Total number of openings	m	Port height	m
Port diameter	m with	contraction ratio	
Diffuser arrangement/type	unidirectional / staged / alternating or vertical		
Alignment angle GAMMA	°	Horizontal angle SIGMA	°
Vertical angle THETA	°	Relative orientation BETA	°

BUOYANT SURFACE DISCHARGE – CORMIX3

Discharge located on	~~left~~/right bank	Configuration	flush/~~protruding/co-flowing~~
Horizontal angle SIGMA	90 °	If protruding: Dist. from bank	- m
Depth at discharge	2.15 m	Bottom slope	11 °
If rectangular Width	2.0 m or:	If circular Diameter	- m
discharge channel: Depth	0.65 m	pipe: Bottom invert depth	- m

Effluent: Flow rate	2.20 m³/s or:	Effluent velocity	- m/s
Effluent density	- kg/m³ or:	Effluent temperature fresh	22.0 °C
Heated discharge?	~~yes~~/no	If yes: Heat loss coefficient	- W/m²,°C
Concentration units	mug-p-L	Effluent concentration	80
Conservative substance?	yes/~~no~~	If no: Decay coefficient	- /day

MIXING ZONE DATA:

Is effluent toxic?	yes/~~no~~	If yes: CMC 25	CCC 15
WQ stand./conventional poll.?	~~yes~~/no	If yes: value of standard	-
Any mixing zone specified?	yes/~~no~~	If yes: distance 250 m	or width - % or m; or area - % or m²
Region of interest	2000 m	Grid intervals for display	10

Figure D.5: Data preparation checklist for C-Plant discharge into Estuary design case for unsteady tidal conditions using CORMIX3

Table D.2
CORMIX Session Report for C-Plant discharge into Estuary with unsteady tidal conditions

```
CORMIX SESSION REPORT:
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
                 CORMIX: CORNELL MIXING ZONE EXPERT SYSTEM

SITE NAME/LABEL:              C-PLANT ESTUARY
  DESIGN CASE:                TIDAL SIMULATION ONE HOUR AFTER SLACK
  FILE NAME:                  SAMPLE3T
Using subsystem CORMIX3:      Buoyant Surface Discharges
  Start of session:           06/24/95--22:33:33
****************************************************************************
SUMMARY OF INPUT DATA:
----------------------------------------------------------------------------
AMBIENT PARAMETERS:
  Cross-section                          = unbounded
  Average depth                 HA       =          5.65 m
  Depth at discharge            HD       =          5.65 m
  Darcy-Weisbach friction factor F       =          .025
  Wind velocity                 UW       =             2 m/s
TIDAL SIMULATION at time        Tsim     =             1 hours
  Instantaneous ambient velocity UA      =           .22 m/s
  Maximum tidal velocity        UaMAX    =           .75 m/s
  Rate of tidal reversal        dUA/dt   =        0.2200 (m/s)/hour
  Period of reversal            T        =          12.4 hours
Stratification Type             STRCND   = U
  Surface density               RHOAS    =          1018 kg/m^3
  Bottom density                RHOAB    =          1018 kg/m^3
----------------------------------------------------------------------------
DISCHARGE PARAMETERS:           Buoyant Surface Discharge
  Discharge located on                   = right bank/shoreline
  Discharge configuration                = flush discharge
  Distance from bank to outlet  DISTB    =           0.0 m
  Discharge angle               SIGMA    =            90 deg
  Depth near discharge outlet   HD0      =          2.15 m
  Bottom slope at discharge     SLOPE    =            11 deg
  Rectangular discharge:
    Discharge cross-section area A0      =        1.3000 m^2
    Discharge channel width     B0       =             2 m
    Discharge channel depth     H0       =           .65 m
    Discharge aspect ratio      AR       =          0.32
  Discharge flowrate            Q0       =      2.199990 m^3/s
  Discharge velocity            U0       =          1.69 m/s
  Discharge temperature (freshwater)     =            20 degC
    Corresponding density       RHO0     =      998.2051 kg/m^3
  Density difference            DRHO     =       19.7948 kg/m^3
  Buoyant acceleration          GP0      =         .1907 m/s^2
  Discharge concentration       C0       =                80 MUG-P-L
  Surface heat exchange coeff.  KS       =             0 m/s
  Coefficient of decay          KD       =             0 /s
----------------------------------------------------------------------------
DISCHARGE/ENVIRONMENT LENGTH SCALES:
  LQ  =       1.14 m       Lm  =       8.77 m         Lb  =       39.39 m
  LM  =       4.13 m
UNSTEADY TIDAL SCALES:
  Tu  =     0.2228 hours   Lu  =      39.34 m         Lmin=        2.57 m
----------------------------------------------------------------------------
NON-DIMENSIONAL PARAMETERS:
  Densimetric Froude number     FR0      =          3.62 (based on LQ)
  Channel densimetric Froude no. FRCH    =          4.80 (based on H0)
  Velocity ratio                R        =          7.69
----------------------------------------------------------------------------
MIXING ZONE / TOXIC DILUTION ZONE / AREA OF INTEREST PARAMETERS:
  Toxic discharge                        = yes
  CMC concentration             CMC      =                25 MUG-P-L
  CCC concentration             CCC      =                15 MUG-P-L
  Water quality standard                 = given by CCC value
  Regulatory mixing zone                 = yes
  Regulatory mixing zone specification   = distance
  Regulatory mixing zone value           =           250 m (m^2 if area)
  Region of interest                     =       3500.00 m
****************************************************************************
HYDRODYNAMIC CLASSIFICATION:
  *------------------------*
  | FLOW CLASS  =     FJ1  |
  *------------------------*
****************************************************************************
MIXING ZONE EVALUATION (hydrodynamic and regulatory summary):
----------------------------------------------------------------------------
X-Y-Z Coordinate system:
  Origin is located at water surface and at centerline of discharge channel:
          0.0 m from the right bank/shore.
  Number of display steps NSTEP = 20 per module.
```

```
-----------------------------------------------------------------------------
NEAR-FIELD REGION (NFR) CONDITIONS :
Note: The NFR is the zone of strong initial mixing.  It has no regulatory
  implication.  However, this information may be useful for the discharge
  designer because the mixing in the NFR is usually sensitive to the
  discharge design conditions.
  Pollutant concentration at edge of NFR =            .0000 MUG-P-L
  Dilution at edge of NFR                =            .0
  NFR Location:                        x =            .00 m
    (centerline coordinates)           y =            .00 m
                                       z =            .00 m
  NFR plume dimensions:       half-width =            .00 m
                               thickness =            .00 m
-----------------------------------------------------------------------------
UNSTEADY TIDAL ASSESSMENT:
  Because of the unsteadiness of the ambient current during the tidal
  reversal, CORMIX predictions have been TERMINATED at:
                                       x =      282.05 m
                                       y =      187.66 m
                                       z =         .00 m
  For this condition AFTER TIDAL REVERSAL, mixed water from the previous
  half-cycle becomes re-entrained into the near field of the discharge,
  increasing pollutant concentrations compared to steady-state predictions.
  A pool of mixed water formed at slack tide will be advected downstream
  in this phase.
************************ TOXIC DILUTION ZONE SUMMARY ************************
Recall: The TDZ corresponds to the three (3) criteria issued in the USEPA
  Technical Support Document (TSD) for Water Quality-based Toxics Control,
  1991 (EPA/505/2-90-001).
  Criterion maximum concentration (CMC)  =              25 MUG-P-L
  Corresponding dilution                 =         3.2
The CMC was encountered at the following plume position:
  Plume location:                      x =         1.04 m
    (centerline coordinates)           y =        12.05 m
                                       z =          .00 m
  Plume dimensions:           half-width =         9.41 m
                               thickness =          .56 m
 CRITERION 1: This location is within 50 times the discharge length scale of
              Lq =       1.14 m.
 +++++ The discharge length scale TEST for the TDZ has been SATISFIED. ++++++

 CRITERION 2: This location is within 5 times the ambient water depth of
              HD =          5.65 m.
 ++++++++++ The ambient depth TEST for the TDZ has been SATISFIED.+++++++++++

 CRITERION 3: This location is within one tenth the distance of the extent
              of the Regulatory Mixing Zone of        250.00 m downstream.
 +++++ The Regulatory Mixing Zone TEST for the TDZ has been SATISFIED. ++++++

 The diffuser discharge velocity is equal to         1.69 m/s.
   This is below the value of 3.0 m/s recommended in the TSD.

 *** All three CMC criteria for the TDZ are SATISFIED for this discharge. ***
********************** REGULATORY MIXING ZONE SUMMARY **********************
The plume conditions at the boundary of the specified RMZ are as follows:
  Pollutant concentration                =     17.960500 MUG-P-L
  Corresponding dilution                 =         4.4
  Plume location:                      x =       250.00 m
    (centerline coordinates)           y =       176.10 m
                                       z =          .00 m
  Plume dimensions:           half-width =        95.88 m
                               thickness =          .21 m
At this position, the plume is NOT IN CONTACT with any bank.
However, the CCC for the toxic pollutant has not been met within the RMZ.
  In particular:
The CCC was encountered at the following plume position:
The CCC for the toxic pollutant was encountered at the following
  plume position:
  CCC                                    =              15 MUG-P-L
  Corresponding dilution                 =         5.3
  Plume location:                      x =         6.02 m
    (centerline coordinates)           y =        37.32 m
                                       z =          .00 m
  Plume dimensions:           half-width =        31.48 m
                               thickness =          .30 m
********************* FINAL DESIGN ADVICE AND COMMENTS **********************
REMINDER: The user must take note that HYDRODYNAMIC MODELING by any known
  technique is NOT AN EXACT SCIENCE.
Extensive comparison with field and laboratory data has shown that the
  CORMIX predictions on dilutions and concentrations (with associated
  plume geometries) are reliable for the majority of cases and are accurate
  to within about +-50% (standard deviation).
As a further safeguard, CORMIX will not give predictions whenever it judges
  the design configuration as highly complex and uncertain for prediction.
*****************************************************************************
DESIGN CASE:                      TIDAL SIMULATION ONE HOUR AFTER SLACK
FILE NAME:                        SAMPLE3T
Subsystem CORMIX3:                Buoyant Surface Discharges
END OF SESSION/ITERATION:         04/14/96--11:24:13
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
```

Table D.3
CORMIX3 Prediction File for C-Plant discharge into Estuary with unsteady tidal conditions

```
CORMIX3 PREDICTION FILE:
33333333333333333333333333333333333333333333333333333333333333333333333333
                      CORNELL MIXING ZONE EXPERT SYSTEM
Subsystem CORMIX3:                                       Subsystem version:
 Buoyant Surface Discharges                 CORMIX_v.3.10_________June_1995
---------------------------------------------------------------------------
---------------------------------------------------------------------------
CASE DESCRIPTION
 Site name/label:          C-PLANT^ESTUARY
 Design case:              TIDAL^SIMULATION^ONE^HOUR^AFTER^SLACK
 FILE NAME:                cormix\sim\SAMPLE3T.cx3
 Time of Fortran run:      06/24/95--22:34:03

ENVIRONMENT PARAMETERS (metric units)
 Unbounded section
 HA     =      5.65  HD    =      5.65
 Tidal Simulation at TIME =      1.000 h
 PERIOD=    12.40 h UAmax =       .750 dUa/dt=       .220 (m/s)/h
 UA     =       .220 F     =       .025 USTAR = .1230E-01
 UW     =      2.000 UWSTAR= .2198E-02
 Uniform density environment
 STRCND=  U          RHOAM = 1018.0000

DISCHARGE PARAMETERS (metric units)
 BANK  =  RIGHT      DISTB =        .00  Configuration: flush_discharge
 SIGMA =     90.00  HD0    =       2.15  SLOPE =      11.00
 Rectangular channel geometry:
 B0     =     2.000 H0     =       .650 A0     = .1300E+01  AR    =      .325
 U0     =     1.692 Q0     =      2.200        = .2200E+01
 RHO0   =  998.2051 DRHO0  = .1979E+02 GP0     = .1907E+00
 C0     = .8000E+02 CUNITS=  MUG-P-L
 IPOLL  =  1         KS    = .0000E+00 KD      = .0000E+00

FLUX VARIABLES (metric units)
 Q0     = .2200E+01  M0    = .3723E+01 J0      = .4195E+00
 Associated length scales (meters)
 LQ     =      1.14  LM    =      4.14 Lm      =      8.77 Lb     =     39.40
 Tidal:              Tu    =    .2229 h Lu     =    39.347 Lmin   =     2.573

NON-DIMENSIONAL PARAMETERS
 FR0    =      3.62  FRCH  =      4.80 R       =      7.69

FLOW CLASSIFICATION
 333333333333333333333333333333333333333333
 3  Flow class (CORMIX3)      =     FJ1    3
 3  Applicable layer depth HS =     5.65   3
 333333333333333333333333333333333333333333

MIXING ZONE / TOXIC DILUTION / REGION OF INTEREST PARAMETERS
 C0      = .8000E+02  CUNITS=  MUG-P-L
 NTOX    =  1         CMC    = .2500E+02 CCC     = CSTD
 NSTD    =  1         CSTD   = .1500E+02
 REGMZ   =  1
 REGSPC=  1           XREG   =    250.00 WREG    =       .00  AREG   =       .00
 XINT    =   2500.00  XMAX   =   3500.00

X-Y-Z COORDINATE SYSTEM:
    ORIGIN is located at the WATER SURFACE and at center of discharge
      channel/outlet:         .00 m  from the RIGHT bank/shore.
    X-axis points downstream
    Y-axis points to left as seen by an observer looking downstream
    Z-axis points vertically upward (in CORMIX3, all values Z = 0.00)
NSTEP = 20 display intervals per module
---------------------------------------------------------------------------
        TRJBUO    TRJATT    TRJBND    TRJNBY    TRJCOR    DILCOR
C        3.401     1.000     1.000     1.000     3.400     1.000
---------------------------------------------------------------------------
BEGIN MOD301: DISCHARGE MODULE

 Efflux conditions:
       X         Y        Z         S        C         BV        BH
      .00       .00      0.00      1.0   .800E+02     .65      1.00
```

END OF MOD301: DISCHARGE MODULE

BEGIN MOD302: ZONE OF FLOW ESTABLISHMENT

Control volume inflow:

X	Y	Z	S	C	BV	BH
.00	.00	0.00	1.0	.800E+02	.65	1.00

Profile definitions:
BV = Gaussian 1/e (37%) vertical thickness
BH = Gaussian 1/e (37%) horizontal half-width, normal to trajectory
S = hydrodynamic centerline dilution
C = centerline concentration (includes reaction effects, if any)

Control volume outflow:

X	Y	Z	S	C	BV	BH
.13	4.11	0.00	1.4	.586E+02	1.09	1.41

Cumulative travel time = 2. sec

END OF MOD302: ZONE OF FLOW ESTABLISHMENT

BEGIN MOD311: WEAKLY DEFLECTED JET (3-D)

Surface JET into a crossflow

Profile definitions:
BV = Gaussian 1/e (37%) vertical thickness
BH = Gaussian 1/e (37%) horizontal half-width, normal to trajectory
S = hydrodynamic centerline dilution
C = centerline concentration (includes reaction effects, if any)

X	Y	Z	S	C	BV	BH
.13	4.11	0.00	1.4	.586E+02	1.28	1.65
.13	4.14	0.00	1.4	.585E+02	1.28	1.66
.13	4.16	0.00	1.4	.584E+02	1.28	1.66
.13	4.18	0.00	1.4	.583E+02	1.28	1.66
.13	4.20	0.00	1.4	.582E+02	1.29	1.66
.14	4.23	0.00	1.4	.581E+02	1.29	1.67
.14	4.25	0.00	1.4	.580E+02	1.29	1.67
.14	4.27	0.00	1.4	.580E+02	1.29	1.67
.14	4.29	0.00	1.4	.579E+02	1.30	1.67
.15	4.32	0.00	1.4	.578E+02	1.30	1.68
.15	4.34	0.00	1.4	.577E+02	1.30	1.68
.15	4.36	0.00	1.4	.576E+02	1.30	1.68
.15	4.38	0.00	1.4	.575E+02	1.30	1.68
.15	4.41	0.00	1.4	.574E+02	1.31	1.69
.16	4.43	0.00	1.4	.573E+02	1.31	1.69
.16	4.45	0.00	1.4	.572E+02	1.31	1.69
.16	4.47	0.00	1.4	.571E+02	1.31	1.69
.16	4.50	0.00	1.4	.571E+02	1.32	1.70
.17	4.52	0.00	1.4	.570E+02	1.32	1.70
.17	4.54	0.00	1.4	.569E+02	1.32	1.70
.17	4.56	0.00	1.4	.568E+02	1.32	1.70

Cumulative travel time = 3. sec

END OF MOD311: WEAKLY DEFLECTED JET (3-D)

BEGIN MOD313: WEAKLY DEFLECTED PLUME

Surface PLUME into a crossflow

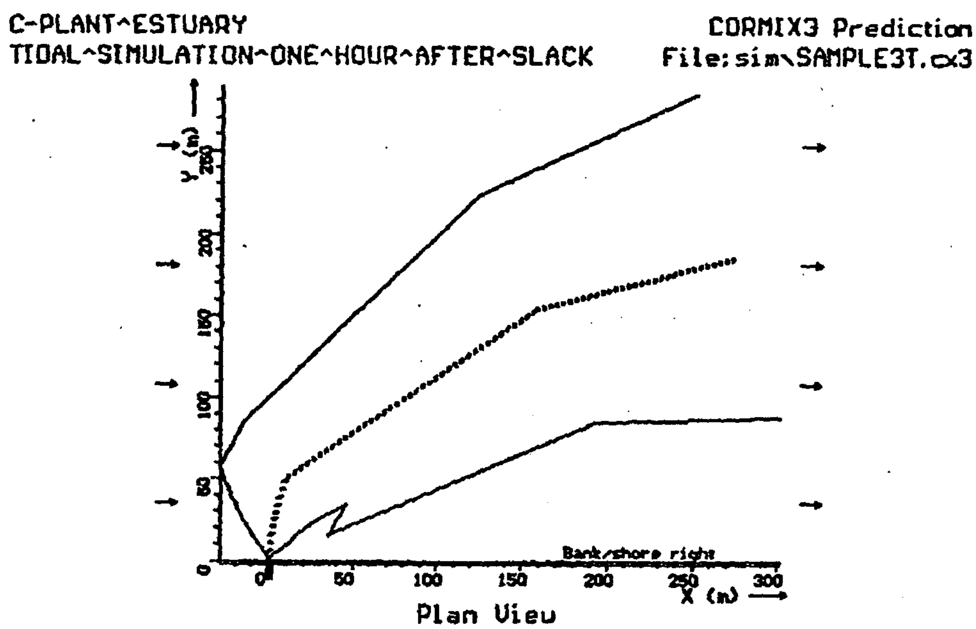
Profile definitions:
BV = Gaussian 1/e (37%) vertical thickness
BH = Gaussian 1/e (37%) horizontal half-width, normal to trajectory
S = hydrodynamic centerline dilution
C = centerline concentration (includes reaction effects, if any)

X	Y	Z	S	C	BV	BH
.17	4.56	0.00	1.4	.568E+02	1.32	1.70
.41	6.86	0.00	2.3	.354E+02	.82	4.48
.67	9.16	0.00	2.8	.291E+02	.66	6.76
.96	11.46	0.00	3.1	.256E+02	.58	8.88

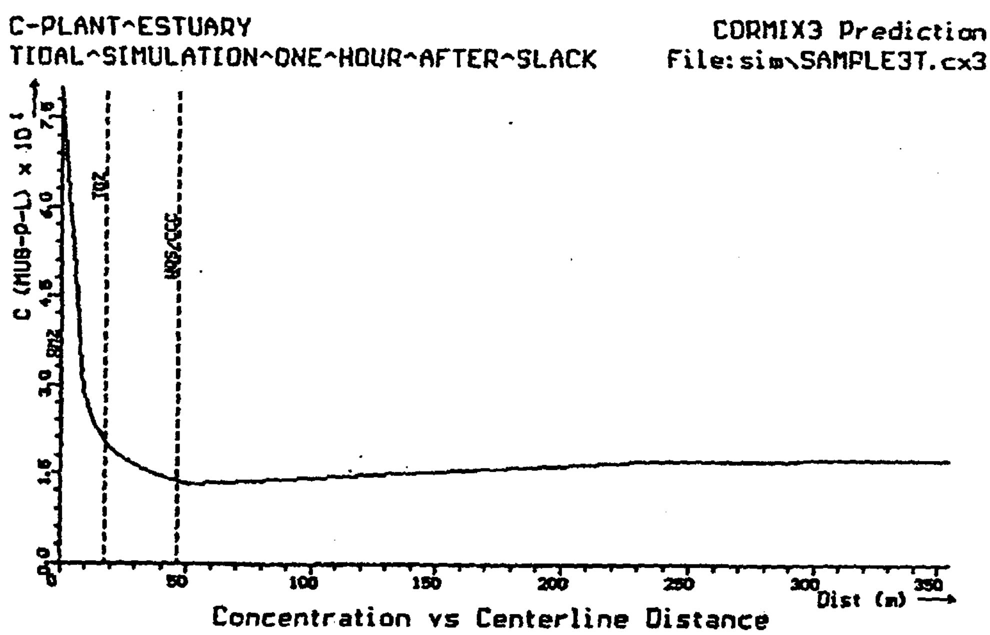
** CMC HAS BEEN FOUND **
The pollutant concentration in the plume falls below CMC value of .250E+02

```
  in the current prediction interval.
 This is the extent of the TOXIC DILUTION ZONE.
      1.28    13.76    0.00     3.4  .233E+02    .52     10.93
      1.62    16.05    0.00     3.7  .216E+02    .48     12.95
      1.99    18.35    0.00     3.9  .203E+02    .45     14.94
      2.38    20.65    0.00     4.2  .192E+02    .42     16.93
      2.80    22.95    0.00     4.4  .184E+02    .40     18.92
      3.25    25.25    0.00     4.5  .176E+02    .38     20.91
      3.72    27.54    0.00     4.7  .170E+02    .36     22.90
      4.22    29.84    0.00     4.9  .164E+02    .35     24.90
      4.75    32.14    0.00     5.0  .159E+02    .33     26.92
      5.30    34.44    0.00     5.2  .155E+02    .32     28.93
      5.87    36.74    0.00     5.3  .151E+02    .31     30.96
** WATER QUALITY STANDARD OR CCC HAS BEEN FOUND **
 The pollutant concentration in the plume falls below water quality standard
   or CCC value of  .150E+02 in the current prediction interval.
 This is the spatial extent of concentrations exceeding the water quality
   standard or CCC value.
      6.48    39.03    0.00     5.4  .147E+02    .30     33.00
      7.11    41.33    0.00     5.6  .144E+02    .29     35.05
      7.76    43.63    0.00     5.7  .141E+02    .28     37.11
      8.44    45.93    0.00     5.8  .138E+02    .28     39.18
      9.15    48.23    0.00     5.9  .136E+02    .27     41.25
      9.88    50.52    0.00     6.0  .134E+02    .26     43.34
 Cumulative travel time =        248. sec

END OF MOD313: WEAKLY DEFLECTED PLUME
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD323: STRONGLY DEFLECTED PLUME

 Profile definitions:
   BV = top-hat thickness,measured vertically
   BH = top-hat half-width, measured horizontally in Y-direction
   S  = hydrodynamic average (bulk) dilution
   C  = average (bulk) concentration (includes reaction effects, if any)

      X         Y        Z        S        C        BV       BH
     9.88     50.52    0.00     6.0  .134E+02    .26     43.34
    84.15    123.86    0.00     4.9  .163E+02    .23     60.96
   158.42    154.39    0.00     4.6  .174E+02    .22     77.07
   232.69    176.11    0.00     4.5  .178E+02    .22     92.39
 ** REGULATORY MIXING ZONE BOUNDARY **
 In this prediction interval the plume distance meets or exceeds
   the regulatory value =   250.00 m.
 This is the extent of the REGULATORY MIXING ZONE.
   282.05    187.67    0.00     4.5  .177E+02    .22    102.26
 Cumulative travel time =        1485. sec

 CORMIX prediction has been TERMINATED at last prediction interval.
   Limiting distance due to TIDAL REVERSAL has been reached.

END OF MOD323: STRONGLY DEFLECTED PLUME
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
CORMIX3: Buoyant Surface Discharges                      End of Prediction File
33333333333333333333333333333333333333333333333333333333333333333333333333333
```

The results of the tidal simulations are shown graphically in Figure D.6. The most obvious difference in the tidal CORMIX prediction at this time is that the maximum predicted downstream distance is limited to 275 m in the x-direction. Furthermore, a significant increase in the pollutant concentration (copper) is observed at the edge of the RMZ (compare Figure D.4b and D.6b at a distance of 250 m downstream) in the tidal application as a result of tidal re-entrainment. As a result, the copper concentration at the RMZ is 18 µg/L as opposed to 10 µg/L for the steady state simulation, which exceeds the CCC at this distance.



(a)



(b)

Figure D.6: CORMIX3 prediction of surface discharge from C-Plant into Estuary using a unsteady tidal simulation. a) Plume shape in near-field only (prediction is terminated after this region), and b) concentration along plume centerline.

Appendix E
Two Applications of CORJET

Two case studies are presented here illustrating the application of the post-processing model included within CORMIX, namely CORJET, the Cornell buoyant jet integral model. As discussed in Section 6.1 is an important tool for predicting additional details within the near-field of a submerged discharge. Both case studies are included in the normal CORMIX installation package.

It is repeated here that CORJET, as any jet integral model, if used alone and by an inexperienced analyst, is **not a safe methodology for mixing zone analysis.** It is advised to use it only in conjunction with the more comprehensive CORMIX system. Therefore, in case of engineering design applications, **CORJET should be employed after prior use of the expert system CORMIX has indicated that the buoyant jet will not experience any instabilities due to shallow water or due to attachment to boundaries.**

E.1 Submerged multiport diffuser in deep water

A short diffuser consisting of 11 ports and a total length of 20 m is discharging fresh water at a temperature of 30 °C into the stratified coastal ocean. The diffuser ports are each 0.5 m in diameter and well-rounded in their internal hydraulic design so that no further exit flow contraction will occur. The nozzles are oriented with a vertical angle of 45 ° upward and a horizontal angle of 45 ° pointing into the ambient crossflow (see multiport diffuser definition diagram, Figures 4.6 and 4.7). The diffuser has an alignment of 60 ° with respect to the ambient current. The discharge flow has a concentration of 100 % of some conservative substance.

Detailed measurements in the water column give the distribution of temperature, salinity and current velocity as a function of vertical distance. The current at each level flows in the same direction, i.e. along the coastline. The water depth at the discharge location is of the order of 30 m.

The CORJET data preparation checklist for this design case is given as Figure E.1. Density data is specified in this case via temperature and salinity. The program computes internally the actual density distribution using the full (UNESCO) equation of state. It should be noted that in case of multiple ambient levels CORJET assumes outside the specified range (e.g. above 15 m in this case) that the data are linearly continued from the last specified interval. If uniform ambient conditions exist only a single level must be specified.

The port height H0 in the input data specification is set to 0.0 m; thus, the coordinate system is conveniently set at the discharge height. Another value for the actual height above the water bottom could be used too, but remember that CORJET, as all integral models, does not compute actual bottom interaction effects (see Section 6.1.1). A maximum computation height of 30 m and distance of 200 m is specified to stop the computation. The number of print intervals is set to 10, in order to provide sufficient detail.

A prior application of CORMIX (using a linear density approximation Type A) has shown that a stable multiport diffuser flow class MS results for this case. The reader is encouraged to ascertain that! Thus, CORJET is indeed applicable for this case.

Table E.1 shows the input data file as prepared externally using a line editor. The CORJET prediction file is shown in Table E.2. The file echoes the input data, but also lists the computed density values, and all important parameters and non-dimensional numbers. Note that all parameters and scales are referenced to the values of ambient conditions <u>at the level of discharge</u>. The second half of the output table gives the predicted plume conditions.

CHECKLIST FOR DATA PREPARATION

CORJET – CORNELL BUOYANT JET INTEGRAL MODEL-- Version 4.1

DOS File Name: CASE5MPD.INP **Date:** 4/12/96
Prepared by: GHJ

Label: Case 5: MULTIPORT DIFFUSER, STRATIFIED, VARIABLE CURRENT

Fluid/Density:

Fluid: 1 (water) ~~2 (air)~~ Density specification: 1 (via temp./sal.) ~~2 (direct)~~ Number of ambient levels: 3 (1 to 10)

Ambient Data:

Level No.	Elevation (m)	Temperature (°C)	Salinity (ppt)	Density (kg/m³)	Velocity (m/s)	Angle of velocity (deg)
1	0	12.0	30.0	-	0.5	0
2	5	15.0	29.5	-	0.8	0
3	15	20.0	28.0	-	1.2	0

Discharge Conditions:

Number of openings: (=1 for single port s.p.)	Port diameter (m)	Height above origin (m)	Exit velocity (m/s)	Vertical angle (deg)	Horizontal angle (deg)
11	0.5	0.0	3.0	45.0	45.0

Discharge conc. (any units)	Coefficient of decay (/s)	Discharge temp. (°C)	Discharge salinity (ppt)	Discharge density (kg/m³)	Diffuser length (m) (= 0. if s.p.)	Alignment angle (deg) (= 0. if s.p.)
100	0	30.0	0.0	-	20.0	60.

Program Control:

Max. vertical distance (m): 30.0 Min. vertical distance (m): 0.0 Max. distance along trajectory (m): 200.0 Print intervals: (best 5 to 10) 10

Figure E.1: Data preparation checklist for CORJET simulation of multiport diffuser discharge into stratified coastal waters with arbitrary velocity distribution

Table E.1
CORJET input data file for multiport diffuser discharge into stratified coastal waters

```
#CORJET INPUT FILE
#Title line (50 characters max.):
Case5: MULTIPORT DIFFUSER: STRATIFIED, VARIABLE CURRENT
#Fluid (1=water,2=air), Density option (1=calculate,2=specify directly):
#Fluid (½):   Density option (½):   Ambient levels (1-10):
1             1                      3
#Ambient conditions (if d.o.=1, fill in TA+SA; if 2, fill in RHOA):
#Level ZA    TA     SA     RHOA    UA     TAUA
1      0.    12.    30.            0.5    0.
2      5.    15.    29.5           0.8    0.
3      15.   20.    28.            1.2    0.
#Discharge conditions (T0+S0, or RHO0 as above; if NOPEN=1: set LD=0,ALIGN=0):
#NOPEN D0    H0    U0     THETA0 SIGMA0 C0     KD    T0     S0    RHO0   LD    ALIGN
11     0.5   0.    3.0    45.    45.    100.   0.    30.    0.           20.   60.
#Program control:
#ZMAX  ZMIN  DISMAX NPRINT
30.    0.    200.   10
```

Table E.2
CORJET prediction file for multiport diffuser discharge into stratified coastal waters

```
CORJET PREDICTION FILE:
JJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJ
CORJET:  CORNELL BUOYANT JET INTEGRAL MODEL          Version 4.1, April 1996
----------------------------------------------------------------------------
FILE NAME:                  post\cj\case5mpd.OUT
 Label/identifier:          Case5: MULTIPORT DIFFUSER: STRATIFIED, VARIABLE CU
 Time of CORJET run:          4/13/96--15:56:58

Ambient conditions:         No. of levels: 3   Fluid: Water   Density option: 1
   LEV      ZA        TA        SA    RHOA       UA     TAUA
    1        .00     12.00    30.00 1022.71      .50      .00
    2       5.00     15.00    29.50 1021.74      .80      .00
    3      15.00     20.00    28.00 1019.43     1.20      .00

Discharge conditions (metric):  For each port:
   D0       H0        U0   THETA0 SIGMA0     C0        KD      T0      S0      RHO0
   .500     .00      3.00  45.00  45.00 .10E+03 .00E+0    30.0      .0   995.65
 MULTIPORT DIFFUSER conditions:
   NOPEN    LD        SPAC  ALIGN    Q0total
    11     20.00      2.00  60.00     6.480 = .6480E+01

Program control:
   ZMAX     ZMIN    DISMAX  NPRINT
   30.00     .00   200.00     10

Flux variables (based on ambient at discharge level):   For each port:
 Q0    =  .589E+00  M0    =  .177E+01  J0    =  .153E+00 GP0   =  .259E+00
 QT0   =  .106E+02  QS0   = -.177E+02
 For multiport diffuser (per unit length):
 q0    =  .324E+00  m0    =  .972E+00  j0    =  .841E-01

Length scales (m) and parameters:    For each port:
 LQ    =       .44  LM    =       3.92  Lm    =       2.66  Lb    =       1.22
 Lmp   =      5.61  Lbp   =       6.71
 For multiport diffuser (per unit length):
 lQ=B  =      .108  lM    =       5.07  lm    =       3.89  lq*   =        .74
 lmp   =      8.16  lbp   =      10.37
 FR0   =      8.33  FR02  =      17.92  Fa    =       1.14  R     =       6.00
 (port)             (2-D slot)
Zone of flow establishment (m):
 LE    =      1.30  XE    =        .75  YE    =        .62  ZE    =        .86
 THETAE=     38.34  SIGMAE=      34.00  GAMMAE=      49.43

----------------------------------------------------------------------------
CORJET PREDICTION:              Stepsize =    .2659  Printout every  10 steps
 Individual jet/plumes before merging:
    X        Y        Z      Sc       Cc        B  |  DIST    Save     Gpc   dTc dSALc
    .00      .00      .00    1.0  .100E+03    .25 |    .00    1.0  .26E+00 18.0-30.0
    .75      .62      .86    1.0  .100E+03    .25 |   1.30    1.4  .27E+00 20.8-34.7
   2.80     1.50     2.27    3.0  .333E+02    .64 |   3.96    4.6  .83E-01  5.2 -9.9
 Merging of individual jet/plumes to form plane jet/plume:
```

Horizontal jet/plume half-width BH = B + 10.00

4.26	1.78	2.85	4.5	.223E+02	.82	5.55	6.6	.54E-01	3.1	-6.5
5.31	1.84	3.01	6.3	.159E+02	.90	6.62	6.4	.38E-01	2.1	-4.7
7.96	1.88	3.22	7.4	.136E+02	1.09	9.27	7.5	.32E-01	1.6	-3.9
10.61	1.89	3.41	8.4	.118E+02	1.27	11.93	8.6	.28E-01	1.3	-3.4
13.26	1.89	3.59	9.5	.105E+02	1.45	14.59	9.7	.24E-01	1.1	-3.0
15.91	1.89	3.77	10.6	.940E+01	1.63	17.25	10.7	.21E-01	.8	-2.7
18.57	1.89	3.94	11.7	.852E+01	1.81	19.91	11.8	.19E-01	.6	-2.4
21.22	1.89	4.11	12.8	.779E+01	1.99	22.57	12.9	.17E-01	.5	-2.2
23.88	1.89	4.27	13.9	.717E+01	2.17	25.23	14.0	.15E-01	.3	-2.0
26.53	1.89	4.43	15.1	.664E+01	2.34	27.89	15.1	.14E-01	.2	-1.8
29.18	1.89	4.58	16.2	.619E+01	2.51	30.54	16.1	.13E-01	.1	-1.7
31.84	1.89	4.73	17.2	.580E+01	2.68	33.20	17.2	.12E-01	.0	-1.6
34.49	1.89	4.87	18.3	.545E+01	2.85	35.86	18.2	.11E-01	-.1	-1.5
37.15	1.89	5.01	19.4	.515E+01	3.02	38.52	19.3	.97E-02	-.2	-1.4
39.80	1.89	5.15	20.5	.488E+01	3.18	41.18	20.3	.89E-02	-.2	-1.3
42.46	1.89	5.28	21.5	.464E+01	3.34	43.84	21.4	.82E-02	-.3	-1.2
45.11	1.89	5.41	22.6	.443E+01	3.49	46.50	22.4	.75E-02	-.3	-1.1
47.77	1.89	5.53	23.6	.424E+01	3.64	49.15	23.4	.69E-02	-.4	-1.0
50.43	1.89	5.65	24.6	.407E+01	3.79	51.81	24.3	.63E-02	-.4	-1.0
53.08	1.89	5.77	25.6	.391E+01	3.94	54.47	25.3	.58E-02	-.5	-.9
55.74	1.89	5.88	26.5	.377E+01	4.08	57.13	26.2	.54E-02	-.5	-.9
58.39	1.89	5.99	27.5	.364E+01	4.22	59.79	27.1	.49E-02	-.6	-.8
61.05	1.89	6.09	28.4	.352E+01	4.35	62.45	28.0	.45E-02	-.6	-.8
63.71	1.89	6.20	29.3	.342E+01	4.48	65.11	28.9	.42E-02	-.6	-.7
66.36	1.89	6.29	30.1	.332E+01	4.61	67.77	29.7	.38E-02	-.7	-.7
69.02	1.89	6.39	31.0	.323E+01	4.73	70.42	30.5	.35E-02	-.7	-.7
71.68	1.89	6.48	31.8	.315E+01	4.85	73.08	31.3	.32E-02	-.7	-.6
74.34	1.89	6.57	32.6	.307E+01	4.96	75.74	32.1	.29E-02	-.8	-.6
76.99	1.89	6.65	33.3	.300E+01	5.07	78.40	32.8	.27E-02	-.8	-.6
79.65	1.89	6.74	34.1	.293E+01	5.17	81.06	33.5	.24E-02	-.8	-.6
82.31	1.89	6.81	34.8	.287E+01	5.27	83.72	34.2	.22E-02	-.9	-.5
84.97	1.89	6.89	35.5	.282E+01	5.37	86.38	34.9	.20E-02	-.9	-.5
87.62	1.89	6.96	36.1	.277E+01	5.46	89.03	35.5	.18E-02	-.9	-.5
90.28	1.89	7.03	36.7	.272E+01	5.54	91.69	36.1	.16E-02	-.9	-.5
92.94	1.89	7.09	37.3	.268E+01	5.62	94.35	36.6	.14E-02	-.9	-.5
95.60	1.89	7.16	37.8	.264E+01	5.70	97.01	37.1	.12E-02	-1.0	-.4
98.26	1.89	7.22	38.3	.261E+01	5.77	99.67	37.6	.11E-02	-1.0	-.4
100.91	1.89	7.27	38.8	.258E+01	5.83	102.33	38.1	.93E-03	-1.0	-.4
103.57	1.89	7.33	39.2	.255E+01	5.89	104.99	38.5	.80E-03	-1.0	-.4
106.23	1.89	7.38	39.6	.252E+01	5.95	107.65	38.9	.67E-03	-1.0	-.4
108.89	1.89	7.43	40.0	.250E+01	6.00	110.30	39.2	.56E-03	-1.1	-.4
111.55	1.89	7.47	40.3	.248E+01	6.04	112.96	39.5	.45E-03	-1.1	-.4
114.20	1.89	7.51	40.6	.246E+01	6.08	115.62	39.8	.35E-03	-1.1	-.4
116.86	1.89	7.55	40.8	.245E+01	6.11	118.28	40.0	.26E-03	-1.1	-.3
119.52	1.89	7.59	41.0	.244E+01	6.13	120.94	40.2	.17E-03	-1.1	-.3
122.18	1.89	7.62	41.1	.243E+01	6.15	123.60	40.3	.94E-04	-1.1	-.3
124.84	1.89	7.65	41.2	.243E+01	6.16	126.26	40.3	.23E-04	-1.1	-.3
125.90	1.89	7.66	41.2	.243E+01	6.15	127.32	40.3	-.35E-05	-1.1	-.3

Terminal level in stratified ambient has been reached. PROGRAM STOPS!

END OF CORJET PREDICTION: Total number of integration steps = 475

JJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJ

Note: CORJET has been used outside the CORMIX system, assuming unlimited receiving water. Carefully examine all results for possible boundary effects due to surface, bottom, or lateral boundaries!

The CORJET program when called within the normal CORMIX installation after its execution automatically links to the graphics package CMXGRAPH so the user can inspect the predicted plume, rather than looking at the output file. Many graphics options (see Section 5.3) exist to fully evaluate the plume geometry and concentration distributions. Three examples of graphics output are shown in Figures E.2 and E.3.

Figure E.2 shows the plan view, side view, and side view along the trajectory, respectively, of the plume, all with a plot scale fixed to 1:1, i.e. undistorted. All these figures have been produced with the Postscript-file print option (I) of CMXGRAPH (in contrast to all the figures in Appendices B to D that were made with the screen print (C) option). Such an undistorted is always preferable for the viewer of such plots in order to get an unbiased picture of the mixing pattern. Note the merging of the individual jets in the plan view. Figure E.3 gives the concentration distribution along the plume centerline trajectory, showing the rapid drop-off in this jet mixing process.

E.2 Smoke plume in stratified atmosphere with skewed wind velocity

As mentioned in Section 6.1 CORJET is also applicable for atmospheric conditions in which case the concept of potential density based on the perfect gas equation with adiabatic conditions is employed. Furthermore, the wind conditions in the lower atmospheric boundary layer with its greater freedom laterally often has a skewed velocity distribution with different wind directions at different levels above the ground. This is the topic of this case study.

An industrial chimney with a height of 40 m above ground discharges hot gases at a temperature of 200 °C into the atmosphere. The discharge has a diameter of 3 m and an exit velocity of 10 m/s. A discharge concentration of 100 % exists for a fairly rapidly decaying substance with a decay rate of 1 per 10 min or 0.0028 /s.

Typical measurements, for example using a tracked rising balloon, give the distribution of temperature and wind velocity as a function of height above the ground. This is shown in the CORJET data preparation checklist given as Figure E.4. Density data is specified in this case as air temperature, the program will convert density inputs internally to potential density as a function of temperature. The wind velocity vector with increasing height deviates increasingly from the direction at ground level. In this example the coordinate system has been set at ground level so that the chimney (i.e."port") height is equal to 40 m.

Table E.3 shows the input data file for this case, while Table E.4 is the CORJET prediction file. The file echoes the input data, but also lists the potential density values, and all important parameters and non-dimensional numbers.

Predicted plume properties are shown graphically as Figures E.5 and E.6. Figure E.5 shows the plan view and the side view, respectively, of the plume, both with a plot scale fixed to 1:1, i.e. undistorted. The plan view shows that the plume follows the variable direction of the wind as it rises to higher levels.

Figure E.6 gives the concentration distribution along the plume centerline trajectory. The added effect of plume decay would be discernible only in the detailed output file (Table E.4) where the centerline concentration is not merely the inverse of the hydrodynamic centerline dilution (the effect of pure mixing) but lower because of the internal chemical decay effect.

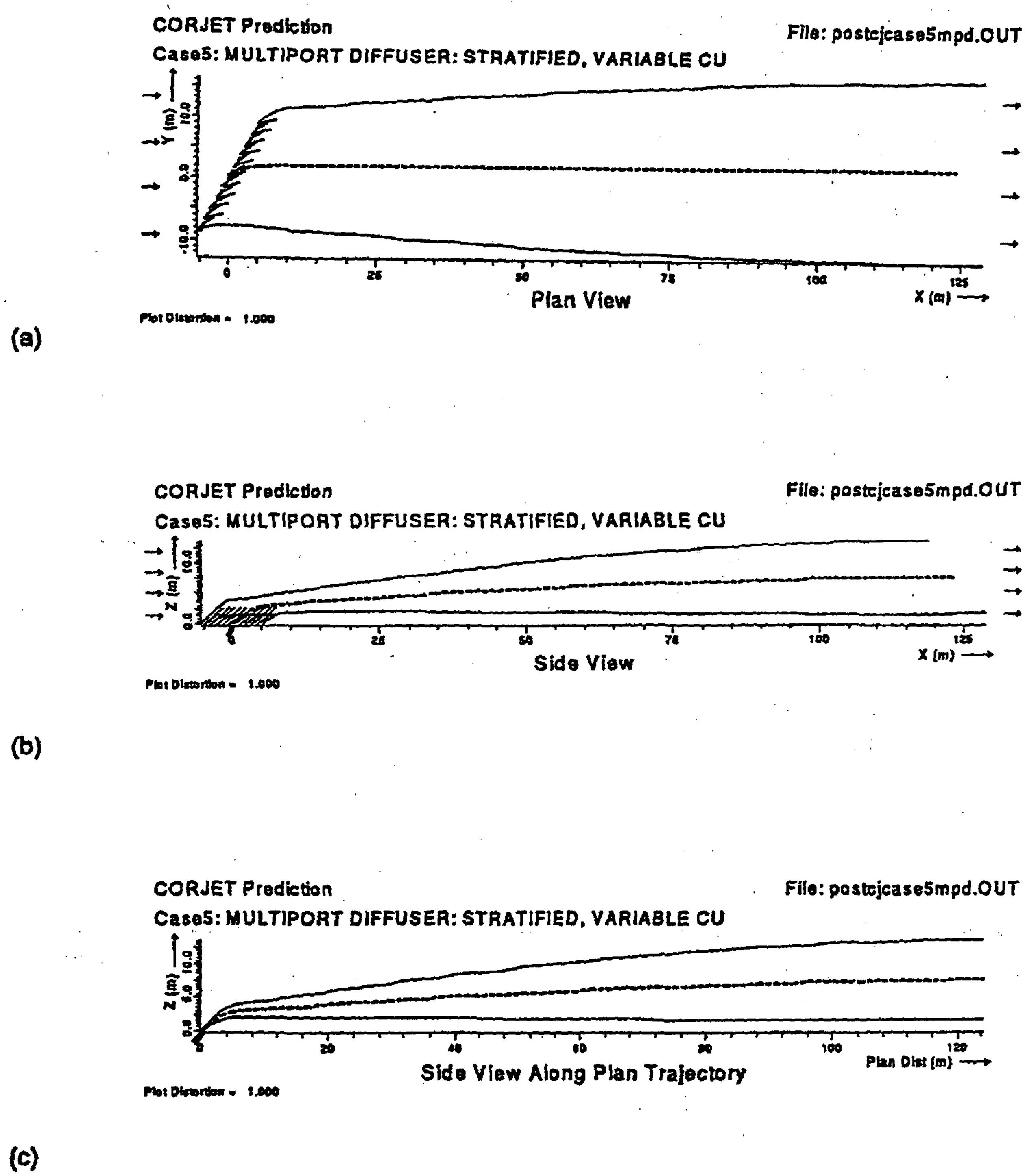


Figure E.2: CORJET prediction for multiport diffuser discharge into stratified coastal waters as plotted with graphics package. a) Plan view, b) side view, and c) side view along trajectory both with plot scale fixed at 1:1 (undistorted).

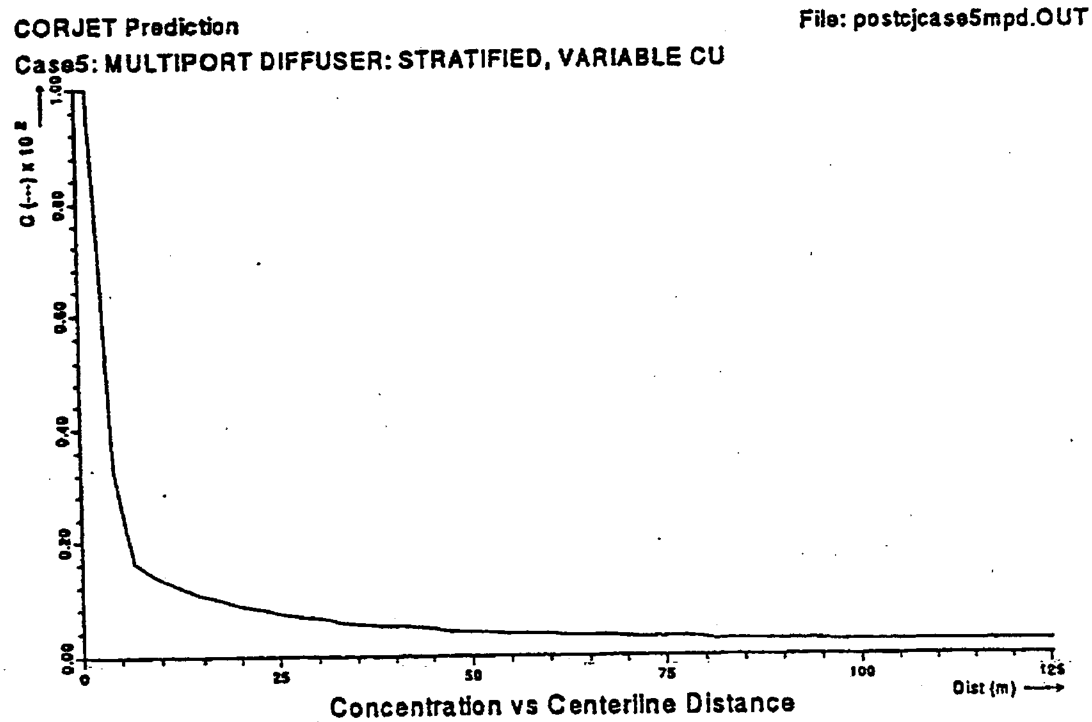


Figure E.3: CORJET prediction for multiport diffuser discharge into stratified coastal waters as plotted with graphics package. Concentration along centerline trajectory.

CHECKLIST FOR DATA PREPARATION

CORJET – CORNELL BUOYANT JET INTEGRAL MODEL– Version 4.1

DOS File Name: CASE3AIR.INP

Date: 4/12/96
Prepared by: GHJ

Label: Case 3: CHIMNEY, STRATIFIED AIR, VARIABLE WIND

Fluid/Density:

Fluid: ~~1 (water)~~ 2 (air)

Density specification: 1 (via temp.~~(ask)~~) ~~2 (direct)~~

Number of ambient levels: 4 (1 to 10)

Ambient Data:

Level No.	Elevation (m)	Temperature (°C)	Salinity (ppt)	Density (kg/m³)	Velocity (m/s)	Angle of velocity (deg)
1	0	12.0	-	-	2.0	0
2	50	12.0	-	-	5.0	15
3	100	12.5	-	-	6.0	25
4	200	13.0	-	-	6.5	30

Discharge Conditions:

Number of openings: (=1 for single port s.p.)	Port diameter (m)	Height above origin (m)	Exit velocity (m/s)	Vertical angle (deg)	Horizontal angle (deg)
1	3.0	40.0	10.0	90.0	0.0

Discharge conc. (any units)	Coefficient of decay (/s)	Discharge temp. (°C)	Discharge salinity (ppt)	Discharge density (kg/m³)	Diffuser length (m) (= 0. if s.p.)	Alignment angle (deg) (= 0. if s.p.)
100	0.0028	200.	-	-	0.0	0.0

Program Control:

Max. vertical distance (m): 200 Min. vertical distance (m): 0 Max. distance along trajectory (m): 1000 Print intervals: (best 5 to 10) 30

Figure E.4: Data preparation checklist for CORJET simulation of chimney discharge into stratified atmosphere with skewed wind velocity distribution

Table E.3
CORJET input data file for chimney discharge into stratified atmosphere with skewed wind

```
#CORJET INPUT FILE
#Title line (50 characters max.):
Case3: CHIMNEY, STRATIFIED AIR, VARIABLE WIND
#Fluid (1=water,2=air), Density option (1=calculate,2=specify directly):
#Fluid (1/2):    Density option (1/2):    Ambient levels (1-10):
2                1                        4
#Ambient conditions (if d.o.=1, fill in TA+SA; if 2, fill in RHOA):
#Level ZA     TA     SA     RHOA   UA     TAUA
1      0.     12.0                 2.0    0.
2      50.    12.0                 5.0    15.
3      100.   12.5                 6.0    25
4      200.   13.0                 6.5    30.
#Discharge conditions (T0+S0, or RHO0 as above; if NOPEN=1: set LD=0,ALIGN=0):
#NOPEN D0   H0   U0    THETA0 SIGMA0 C0    KD    T0    S0   RHO0  LD   ALIGN
1      3.0  40.  10.0  90.    0.     100.  .0028 200.             0.   0.
#Program control:
#ZMAX  ZMIN  DISMAX NPRINT
200.   0.    1000.  30
```

Table E.4
CORJET prediction file for chimney discharge into stratified atmosphere with skewed wind

```
CORJET PREDICTION FILE:
JJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJ
CORJET:  CORNELL BUOYANT JET INTEGRAL MODEL          Version 4.1, April 1996
---------------------------------------------------------------------------
FILE NAME:                 post\cj\case3air.OUT
 Label/identifier:         Case3: CHIMNEY, STRATIFIED AIR, VARIABLE WIND
 Time of CORJET run:        4/13/96--16:12:15

Ambient conditions:        No. of levels: 4    Fluid: Air      Density option: 1
   LEV      ZA        TA       SA     RHOA      UA     TAUA
    1        .00     12.00     .00     1.24     2.00     .00
    2      50.00     12.00     .00     1.24     5.00   15.00
    3     100.00     12.50     .00     1.24     6.00   25.00
    4     200.00     13.00     .00     1.23     6.50   30.00

Discharge conditions (metric):  SINGLE PORT
    D0       H0       U0   THETA0 SIGMA0    C0      KD      T0       S0      RHO0
   3.000  40.00    10.00  90.00     .00 .10E+03 .28E-0  200.0      .0       .75

Program control:
   ZMAX     ZMIN   DISMAX  NPRINT
  200.00     .00 1000.00      30

Flux variables (based on ambient at discharge level):
 Q0    =  .707E+02  M0    =  .707E+03  J0     =  .275E+03  GP0    =  .390E+01
 QT0   =  .133E+05  QS0   =  .000E+00

Length scales (m) and parameters:
 LQ    =       2.66  LM    =      8.26  Lm     =       6.04  Lb     =       3.23
 Lmp   =      11.97  Lbp   =     14.42
 FR0   =       2.92  R     =      2.27
Zone of flow establishment (m):
 LE    =        .00  XE    =       .00  YE     =        .00  ZE     =      40.00
 THETAE=      41.69  SIGMAE=     12.00  GAMMAE=      41.69
---------------------------------------------------------------------------
CORJET PREDICTION:              Stepsize =    .6042  Printout every  30 steps
 Single jet/plume:
     X        Y       Z       Sc       Cc       B  |  DIST    Save    Gpc   dTc dSALc
    .00      .00   40.00     1.0  .100E+03  1.50|     .00    1.0  .39E+01188.0   .0
    .00      .00   40.00     1.0  .100E+03  1.50|     .00    1.4  .41E+01204.4   .0
  15.18     3.42   49.21     4.5  .221E+02  3.53|   18.13    6.6  .12E+01 41.6   .0
  31.38     7.54   56.20     9.6  .104E+02  5.18|   36.25   13.8  .63E+00 19.5   .0
  47.86    12.09   62.22    15.8  .634E+01  6.64|   54.38   22.5  .39E+00 11.8   .0
  64.47    16.97   67.60    22.7  .440E+01  7.96|   72.51   32.2  .27E+00  8.1   .0
```

81.13	22.13	72.51	30.3	.330E+01	9.18	90.64	42.8	.20E+00	6.0	.0
97.83	27.54	77.06	38.4	.260E+01	10.30	108.76	54.0	.16E+00	4.7	.0
114.52	33.18	81.30	47.0	.213E+01	11.36	126.89	65.8	.13E+00	3.8	.0
131.21	39.03	85.29	55.9	.179E+01	12.35	145.02	78.1	.11E+00	3.1	.0
147.88	45.08	89.05	65.1	.154E+01	13.29	163.15	90.7	.90E-01	2.6	.0
164.52	51.31	92.63	74.5	.134E+01	14.18	181.27	103.7	.77E-01	2.3	.0
181.14	57.72	96.03	84.2	.119E+01	15.02	199.40	116.9	.67E-01	2.0	.0
197.71	64.29	99.27	94.0	.106E+01	15.83	217.53	130.4	.58E-01	1.7	.0
214.26	71.02	102.38	103.9	.963E+00	16.60	235.66	144.1	.52E-01	1.5	.0
230.77	77.88	105.37	113.8	.879E+00	17.35	253.78	157.8	.47E-01	1.4	.0
247.25	84.85	108.25	123.7	.808E+00	18.06	271.91	171.7	.42E-01	1.2	.0
263.71	91.92	111.04	133.8	.747E+00	18.75	290.04	185.6	.39E-01	1.1	.0
280.14	99.07	113.75	143.9	.695E+00	19.42	308.17	199.6	.35E-01	1.0	.0
296.56	106.30	116.39	154.1	.649E+00	20.07	326.29	213.7	.32E-01	.9	.0
312.96	113.58	118.96	164.4	.608E+00	20.71	344.42	228.0	.30E-01	.9	.0
329.34	120.93	121.47	174.7	.572E+00	21.33	362.55	242.3	.27E-01	.8	.0
345.70	128.34	123.91	185.1	.540E+00	21.93	380.67	256.7	.25E-01	.7	.0
362.05	135.79	126.30	195.6	.511E+00	22.52	398.80	271.1	.23E-01	.7	.0
378.39	143.29	128.64	206.1	.485E+00	23.10	416.93	285.7	.22E-01	.6	.0
394.72	150.83	130.92	216.6	.462E+00	23.66	435.06	300.2	.20E-01	.6	.0
411.03	158.41	133.16	227.2	.440E+00	24.21	453.18	314.8	.19E-01	.5	.0
427.33	166.03	135.35	237.8	.421E+00	24.75	471.31	329.5	.17E-01	.5	.0
443.62	173.69	137.49	248.4	.403E+00	25.28	489.44	344.1	.16E-01	.5	.0
459.90	181.39	139.58	259.0	.386E+00	25.80	507.57	358.8	.15E-01	.4	.0
476.17	189.11	141.64	269.6	.371E+00	26.31	525.69	373.5	.14E-01	.4	.0
492.43	196.87	143.65	280.3	.357E+00	26.80	543.82	388.1	.13E-01	.4	.0
508.68	204.66	145.62	290.9	.344E+00	27.29	561.95	402.7	.12E-01	.3	.0
524.92	212.48	147.54	301.4	.332E+00	27.76	580.08	417.3	.11E-01	.3	.0
541.15	220.33	149.43	312.0	.321E+00	28.23	598.20	431.9	.10E-01	.3	.0
557.37	228.20	151.28	322.5	.310E+00	28.68	616.33	446.4	.95E-02	.3	.0
573.58	236.11	153.10	333.0	.300E+00	29.13	634.46	460.9	.88E-02	.3	.0
589.79	244.03	154.87	343.5	.291E+00	29.57	652.59	475.2	.81E-02	.2	.0
605.98	251.98	156.61	353.8	.283E+00	30.00	670.71	489.6	.74E-02	.2	.0
622.17	259.96	158.31	364.2	.275E+00	30.42	688.84	503.8	.68E-02	.2	.0
638.36	267.96	159.98	374.4	.267E+00	30.83	706.97	517.9	.63E-02	.2	.0
654.53	275.98	161.61	384.6	.260E+00	31.23	725.09	532.0	.57E-02	.2	.0
670.69	284.03	163.21	394.8	.253E+00	31.62	743.22	545.9	.52E-02	.2	.0
686.85	292.09	164.77	404.8	.247E+00	32.01	761.35	559.7	.47E-02	.1	.0
703.01	300.18	166.30	414.8	.241E+00	32.39	779.48	573.4	.42E-02	.1	.0
719.15	308.28	167.79	424.6	.235E+00	32.76	797.60	587.0	.38E-02	.1	.0
735.29	316.41	169.25	434.4	.230E+00	33.12	815.73	600.4	.34E-02	.1	.0
751.42	324.56	170.68	444.1	.225E+00	33.47	833.86	613.8	.30E-02	.1	.0
767.54	332.72	172.08	453.6	.220E+00	33.82	851.99	626.9	.26E-02	.1	.0
783.66	340.90	173.44	463.1	.216E+00	34.16	870.11	639.9	.22E-02	.1	.0
799.77	349.10	174.77	472.5	.212E+00	34.49	888.24	652.8	.18E-02	.1	.0
815.88	357.32	176.07	481.7	.208E+00	34.81	906.37	665.5	.15E-02	.0	.0
831.98	365.55	177.34	490.8	.204E+00	35.13	924.50	678.0	.12E-02	.0	.0
848.07	373.80	178.57	499.8	.200E+00	35.43	942.62	690.3	.87E-03	.0	.0
864.16	382.07	179.78	508.6	.197E+00	35.73	960.75	702.5	.57E-03	.0	.0
880.24	390.35	180.95	517.4	.193E+00	36.03	978.88	714.5	.29E-03	.0	.0
896.32	398.65	182.09	525.9	.190E+00	36.31	997.01	726.2	.15E-04	.0	.0
897.39	399.20	182.17	526.5	.190E+00	36.33	998.21	727.0	-.19E-05	.0	.0

Terminal level in stratified ambient has been reached. PROGRAM STOPS!

END OF CORJET PREDICTION: Total number of integration steps = 1653

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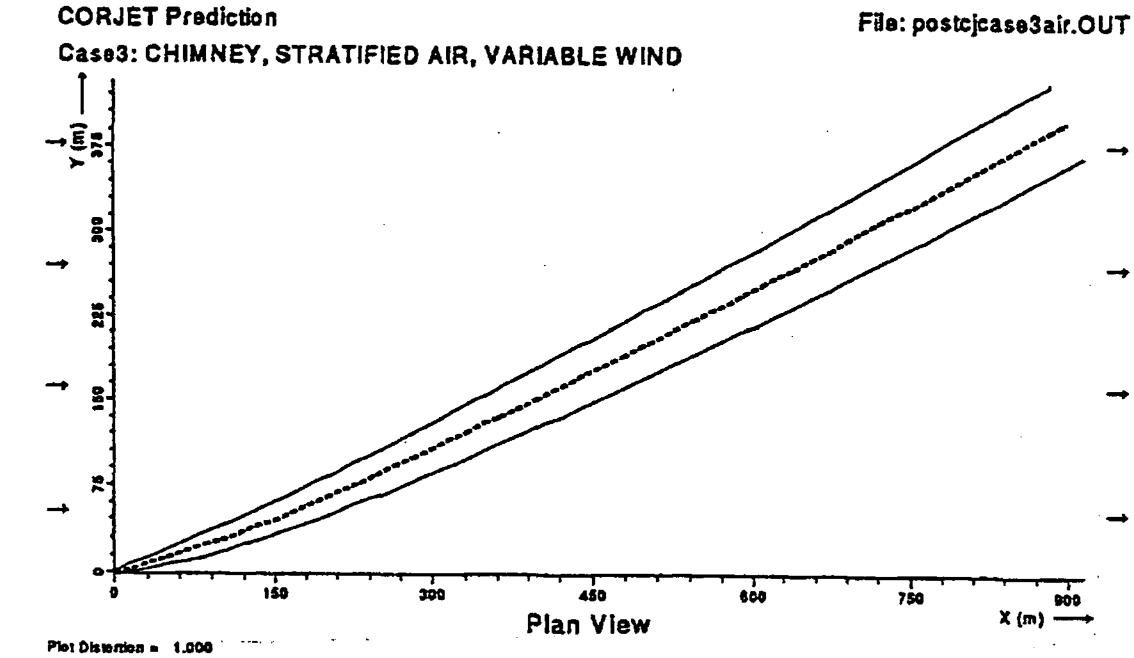
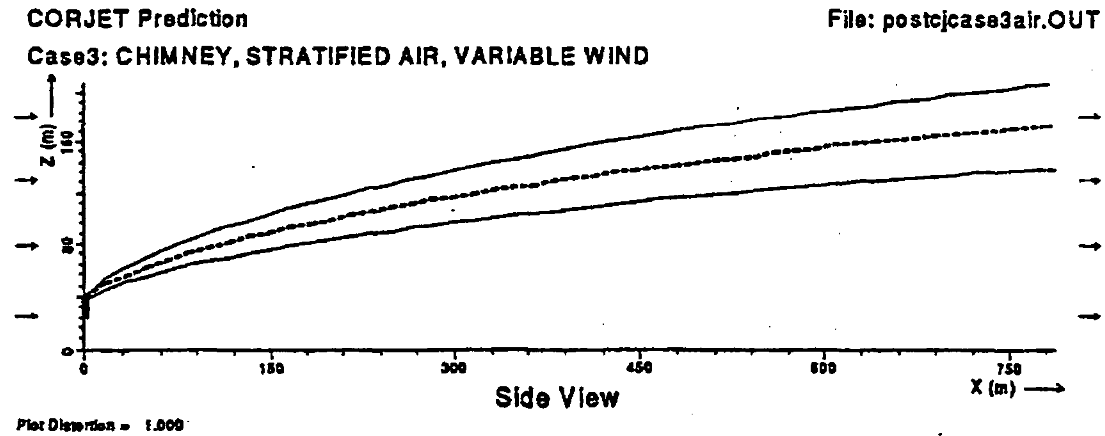


(a)



(b)

Figure E.5: CORJET prediction for chimney discharge into stratified atmosphere with skewed wind profile as plotted with graphics package. a) Plan view, and b) side view along trajectory both with plot scale fixed at 1:1 (undistorted).

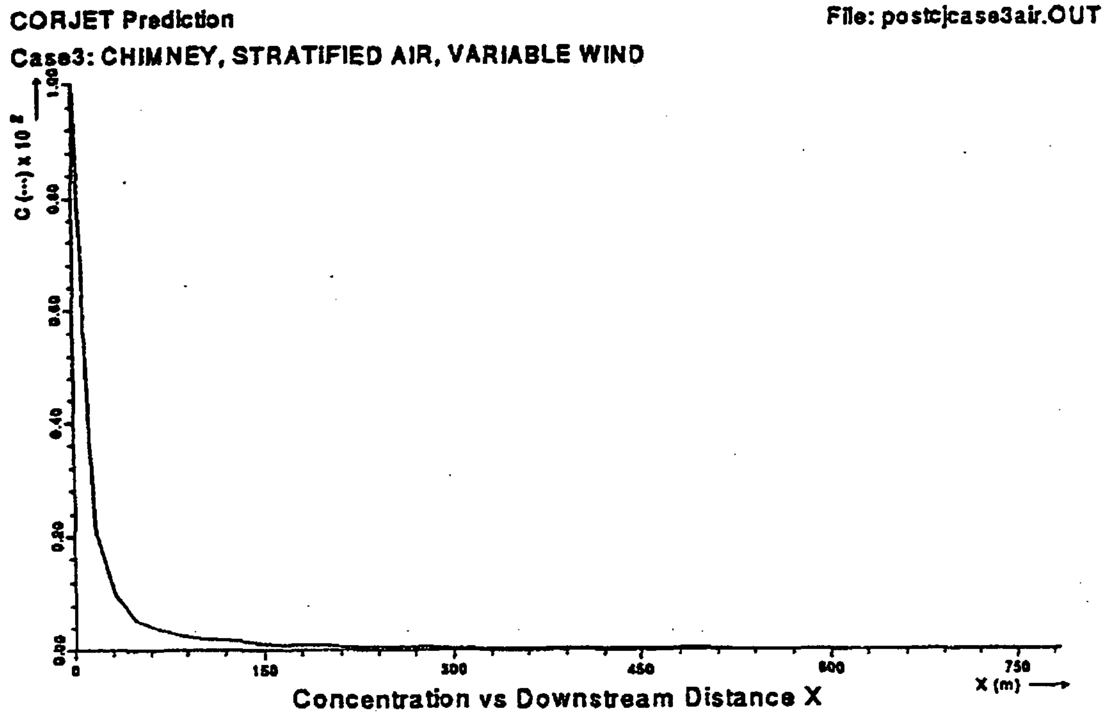


Figure E.6: CORJET prediction for chimney discharge into stratified atmosphere with skewed wind profile as plotted with graphics package. Concentration along centerline trajectory.