NUREG-1054

Simplified Analysis for Liquid Pathway Studies

U.S. Nuclear Regulatory Commission

Office of Nuclear Reactor Regulation

R. Codell

NOTICE

Availability of Reference Materials Cited in NRC Publications

Most documents cited in NRC publications will be available from one of the following sources:

1. The NRC Public Document Room, 1717 H Street, N.W.
   Washington, DC 20555
2. The NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission,
   Washington, DC 20555
3. The National Technical Information Service, Springfield, VA 22161

Although the listing that follows represents the majority of documents cited in NRC publications, it is not intended to be exhaustive.

Referenced documents available for inspection and copying for a fee from the NRC Public Document Room include NRC correspondence and internal NRC memoranda; NRC Office of Inspection and Enforcement bulletins, circulars, information notices, inspection and investigation notices; Licensee Event Reports; vendor reports and correspondence; Commission papers; and applicant and licensee documents and correspondence.

The following documents in the NUREG series are available for purchase from the NRC/GPO Sales Program: formal NRC staff and contractor reports, NRC-sponsored conference proceedings, and NRC booklets and brochures. Also available are Regulatory Guides, NRC regulations in the *Code of Federal Regulations*, and *Nuclear Regulatory Commission Issuances.*

Documents available from the National Technical Information Service include NUREG series reports and technical reports prepared by other federal agencies and reports prepared by the Atomic Energy Commission, forerunner agency to the Nuclear Regulatory Commission.

Documents available from public and special technical libraries include all open literature items, such as books, journal and periodical articles, and transactions. *Federal Register* notices, federal and state legislation, and congressional reports can usually be obtained from these libraries.

Documents such as theses, dissertations, foreign reports and translations, and non-NRC conference proceedings are available for purchase from the organization sponsoring the publication cited.

Single copies of NRC draft reports are available free, to the extent of supply, upon written request to the Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

Copies of industry codes and standards used in a substantive manner in the NRC regulatory process are maintained at the NRC Library, 7920 Norfolk Avenue, Bethesda, Maryland, and are available there for reference use by the public. Codes and standards are usually copyrighted and may be purchased from the originating organization or, if they are American National Standards, from the American National Standards Institute, 1430 Broadway, New York, NY 10018.

GPO Printed copy price: $5.00

NUREG-1054

Simplified Analysis for Liquid Pathway Studies

Manuscript Completed: December 1983
Date Published: August 1984

R. Codell*

Division of Engineering
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

*Currently with the Office of Nuclear Material Safety and Safeguards

ABSTRACT

The analysis of the potential contamination of surface water via groundwater contamination from severe nuclear accidents is routinely calculated during licensing reviews. This analysis is facilitated by the methods described in this report, which is codified into a BASIC language computer program, SCREENLP. This program performs simplified calculations for groundwater and surface water transport and calculates population doses to potential users of the contaminated water irrespective of possible mitigation methods. The results are then compared to similar analyses performed using data for the generic sites in NUREG-0440, "Liquid Pathway Generic Study," to determine if the site being investigated would pose any unusual liquid pathway hazards.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

Symbol	Definition	Dimension	Example
A_d	drainage basin area	L^2	ft^2
A,B	coefficients in equation .		
B_{if}	bioaccumulation factor for radionuclide i in finfish	$(T^{-1}/M)/(T^{-1}/L^3)$	(mCi/kg)/(mCi/ℓ)
B_{is}	bioaccumulation factor for radionuclide i in shellfish	$(T^{-1}/M)/(T^{-1}/L^3)$	(mCi/kg)/(mCi/ℓ)
BAF_{i1}	bioaccumulation factor for radionuclide i for finfish	$(T^{-1}/M)/(T^{-1}/L^3)$	(mCi/kg)/(mCi/ℓ)
BAF_{i2}	bioaccumulation factor for radionuclide i for shellfish	$(T^{-1}/M)/(T^{-1}/L^3)$	(mCi/kg)/(mCi/ℓ)
C_{ipj}	concentration of radionuclide i in segment j caused by pathway p	-	-
d	effective water depth in coastal model	L	m
d_{1j}	average depth of water layer in water body segment j	L	ft
d_{2j}	average depth of sediment in water body segment	L	ft

LIST OF SYMBOLS (Continued)

Symbol	Definition	Dimension	Example
D_{ij}	effective dilution of radionuclide i in water body segment j	T/L^3	sec/ft^3
D_p	population dose for the p^{th} exposure pathway	$FL/(F/L/T^2)$	person-rem
DF_i	dose factor for ingestion of radionuclide i	$FL/(F/L/T^2)/T^{-1}$	mrem/pCi
DF_{ip}	dose factor for exposure pathway p from radionuclide i	-	-
DF_{si}	dose factor for standing on contaminated ground	$(FL/(F/(L/T^2))/T)/T^{-1}/L^2$	$(mrem/hr)/(mCi/m^2)$
E	fraction of fish that is ingested	-	-
F_{gi}	fraction of released radionuclide i that passes the groundwater barrier	-	-
F_{pi}	transmittal factor for radionuclide i in pathway p	-	-
F_{si}	fraction of radionuclide i entering the sump or suppression pool water	-	-

LIST OF SYMBOLS (Continued)

Symbol	Definition	Dimension	Example
F_{Ti}	transmittal factor for radionuclide i between source and affected population		
G_b	usage rate of beach	T/L	person-hr/linear meter of beach
$G_1(x,y)$	annual average finfish catch density at x, y	$F/L^2/T$	kg/ha/yr
$G_2(x,y)$	annual average shellfish catch density at x, y	$F/L^2/T$	kg/ha/yr
h	water table thickness	L	ft
h_o	maximum thickness of lens	L	ft
H	aquifer thickness at the sink	L	ft
k	hydraulic conductivity (permeability)	L/T	ft/yr
K	transfer coefficient between water and beach deposits	L^3/FT	ℓ/km-yr
K_d	equilibrium coefficient of sediment	L^3/F	ml/gm
K_{di}	equilibrium distribution coefficient of radionuclide i	L^3/F	ml/gm

LIST OF SYMBOLS (Continued)

Symbol	Definition	Dimension	Example
K_f	coefficient for direct transfer from water to bottom sediment	L/T	ft/yr
L	distance from top of hill, or groundwater divide, to surface water body	L	ft
L_1	distance from source to sink	L	ft
m	groundwater gradient	L/L	ft (rise)/ft (run)
M	number of radionuclides	-	-
M_d	number of days in record	T	day
M_i	quantity of radionuclide i entering ground	T^{-1}	Ci
	also core inventory of radionuclide i	T^{-1}	Ci
M_{si}	quantity of radionuclide i present in core at time of meltdown	T^{-1}	Ci
n	total porosity of soil	-	-
n_e	effective porosity	-	-
N	number of segments in water body	-	-

LIST OF SYMBOLS (Continued)

Symbol	Definition	Dimension	Example
P_{dj}	population drawing drinking water from segment j	-	number of people
P_{pj}	population affected by the liquid release in segment j	-	number of people
P_{sj}	population using shoreline and beaches in segment j	-	number of people
q_j	freshwater flowrate in river segment j	L^3/T	ft^3/sec
q	annual average stream flow	L^3/T	ft^3/yr
q_i	daily flowrate for day i	L^3/T	ft^3/sec
$\bar{q}^R$	reciprocal average flowrate	L^3/T	ft/sec
R	recharge to water table	$L^3/T/L^2$	$(ft^3/yr)/ft^2$
R_d	retardation coefficient	-	-
R_{di}	retardation coefficient of radionuclide i	-	-
s	slope of impermeable layer	L/L	ft/ft
S	source strength	-	Ci/day
S_j	salinity in estuary segment j	-	parts per thousand

LIST OF SYMBOLS (Continued)

Symbol	Definition	Dimension	Example
S_s	salinity of seawater	-	parts per thousand
$t_{\frac{1}{2},i}$	half-life of radionuclide i	T	yr
T	groundwater travel time	T	yr
U	coastal drift current	L/T	m/day
U_d	average annual drinking water consumption	L^3/T	ℓ/yr
U_{jf}	edible finfish catch in segment j	F/T	kg/yr
U_{js}	annual edible shellfish catch in segment j	F/T	kg/yr
U_{pj}	usage factor for pathway p in segment j	-	-
U_s	annual average usage rate of beaches per capita	T/T	hr/yr
v_j	sedimentation rate in reservoir j	L/T	ft/yr
V_j	volume of river segment j	L^3	ft^3
W	shore-width factor	-	-
x	linear distance ordinate	L	ft

LIST OF SYMBOLS (Continued)

Symbol	Definition	Dimension	Example
x_1, y_1	spatial integration limits for coastal zone	L	m
y	offshore distance ordinate	L	m
α, β	coefficients in Equation 24	-	-
γ_f	specific gravity of freshwater	-	-
γ_s	specific gravity of saltwater	-	-
δ	relative buoyancy of freshwater in seawater	-	-
ε	sediment efficiency (effectiveness factor)	-	-
λ	radioactive decay coefficient, 0.693/half-life	1/T	1/yr
λ_i	decay constant for radionuclide i	1/T	1/yr
ρ	sediment density	F/L^3	gm/ml
ρ_b	bulk density of soil	F/L^3	gm/ml
ρ_s	effective density of shoreline deposits	F/L^2	kg/km^2
τ_i	time constant for erosion of radionuclide i on beach	T	yr

LIST OF SYMBOLS (Continued)

Symbol	Definition	Dimension	Example
χ	dilution calculated from equation	T/L^3	day/m^3
$\chi(x,y)$	dilution calculated in offshore zone at x, y	T/L^3	day/m^3
$(\langle q \rangle)_L$	long-term arithmetic mean flowrate	L^3/T	ft^3/sec
$\langle q_i \rangle$	arithmetic mean flow for year i	L^3/T	ft^3/sec
$\bar{q}_i^R$	reciprocal mean flow for year i	L^3/T	ft^3/sec

SIMPLIFIED ANALYSIS FOR LIQUID PATHWAY STUDIES

1 INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC), as part of its environmental review of nuclear power plant applications, is required to consider the consequences and probabilities of a range of accidents involving the release of radionuclides to the environment (interim rulemaking issue) (Federal Register, June 30, 1980). The accident studies usually consider atmospheric releases in the greatest detail, but releases to the hydrosphere are also considered.

Several pathways for radionuclide release to the hydrosphere are possible:

(1) Releases directly to surface water through normal channels of water flow at the site: Such releases (e.g., accidental routing of small quantities of radwaste to the circulating water) are possible, but are generally minor. Large releases are not likely to occur through this pathway.

(2) Atmospheric release: Radionuclides released to the atmosphere could be deposited to the land and water surface, thereby contaminating surface water and groundwater. There is reason to believe that this is one of the more likely pathways of water contamination following an accident involving major airborne releases; in general, however, the consequences of the liquid pathway contamination would be relatively small compared with the direct air pathway contamination (Codell, 1983).

(3) Contamination of the groundwater under the reactor by a major release of molten core debris and highly contaminated water following basemat melt-through. Surface water could become contaminated because of the migration of the groundwater in the direction of the nearest water body.

Of the three liquid pathways, only the groundwater route is evaluated for the environmental review because it is a unique pathway not covered by the atmospheric analyses and is potentially important.

The analysis of contamination through groundwater is potentially very complicated. Instead of a detailed analysis of groundwater contamination, a simplified procedure is used based on a comparison of the site under evaluation with generic sites presented in the Liquid Pathway Generic Study (LPGS) (NUREG-0440). The LPGS is an evaluation of the consequences of core-melt-accident releases from a floating nuclear plant and several generic land-based plants. This study was undertaken because it was recognized that the floating nuclear plant lacked the isolation of the soil and rock under land-based plants and thereby posed a potentially serious risk in the event of a basemat penetration. The analyses in the LPGS occupied the time and efforts of a significant number of staff and contractor personnel.

It would be unreasonable to repeat the LPGS calculations for each of the reviewed plants because of the large expenditure of staff resources that would be required. Instead, population doses for uninterdicted releases to the groundwater from the plant are calculated by a collection of simplified mathematical techniques incorporated into a BASIC language screening computer program called "SCREENLP" and compared with doses calculated in a similar fashion for the LPGS generic base case sites. This approach allows the staff to determine how the site under consideration compares with the sites considered in the LPGS in terms of potential risk. The reasons for choosing the simplified approach include:

(1) A core-melt accident is extremely unlikely. In the event of a core-melt accident with containment breaching, the airborne pathway consequences are likely to greatly exceed liquid pathway consequences.

(2) A more detailed analysis would require a substantial commitment of staff time and effort.

(3) Many of the parameters needed for a more detailed analysis are not well known.

(4) It is not clear that a more detailed quantitative analysis would aid decisionmaking more than this simplified quantitative method.

(5) Isolation of the source or interdiction of the liquid pathways following a core-melt accident is likely.

This evaluation presents the methodology used by the NRC staff for quantifying the risk from liquid pathway consequences of a core-melt accident at land-based light-water nuclear power plants. Included are the necessary details from the LPGS and the methods, equations, and other important information to carry out the evaluation. The method is facilitated by an extensively documented interactive BASIC language computer program, which prompts the user for all of the necessary input data. The use of the program and examples applied to all of the LPGS cases are presented in Section 5.

Use of the dose values calculated from information in the LPGS as a basis for comparison in this evaluation should not be construed as indicating they are acceptable. These doses are used as a basis because they were calculated using conservative values of parameters for typical land-based plants. The evaluation, therefore, results in a determination of whether the plant being evaluated poses significantly different liquid pathway risks than a typical plant at a similar setting.

Most of the balance of this report describes the use of the SCREENLP model for performing liquid pathway calculations. The program is given in Appendix C.

2 BACKGROUND SUMMARY OF ANALYSES IN LIQUID PATHWAY GENERIC STUDY

2.1 Introduction

The LPGS includes evaluations of consequences from several accident scenarios for six land-based plants. The reactor was considered to be a typical Westinghouse pressurized-water reactor (PWR) with an ice condenser containment and a thermal power rating of 3,425 MWt, similar to the Reactor Safety Study PWR (WASH-1400). A core-melt accident is assumed to release core debris to the ground in the form of a molten mass that passes through the reactor building basemat.

A series of analytical models were used to calculate the releases to the groundwater, the travel of the contamination through the groundwater, the dispersal of the contamination in the pathways, and the resultant doses to man. Doses were calculated for a population and for the maximum exposed individual.

2.2 Sites

All nuclear power plants currently operating or under construction are generally situated in one of six settings:

(1) beside a large river (e.g., River Bend)
(2) beside a small river (e.g., Summer)
(3) near a Great Lake (e.g., Zion)
(4) near an estuary (e.g., Salem)
(5) on the ocean coast (e.g., Diablo Canyon)
(6) on a site not near a surface water body, that is, a dry site (e.g., Palo Verde)

2.3 Groundwater Pathway

All land-based sites evaluated in the LPGS were assumed to be 1,500 ft from the shoreline and to have a groundwater travel time of 0.61 year. Retardation factors chosen for strontium and cesium were 9.2 and 83, respectively.

2.4 Surface Water Transport

Dispersion and transport of released radionuclides in the surface water were patterned after those at actual sites on real bodies of water, which are considered to be typical of a large range of power plant sites. The large-river site was patterned after the characteristics of the lower Mississippi River. The small-river site was patterned after the characteristics of the Clinch-Tennessee-Ohio-Mississippi River. The estuary site was based on the characteristics of the Delaware River estuary. The Great Lakes site was based on the characteristics of Lake Ontario. The dry site was considered to be located on the Snake River Plain aquifer in Idaho.

The coastal site was studied separately by Offshore Power Systems and was considered to have dispersion parameters typical of those of a wide variety of coastal locations.

2.5 Usage Factors

Usage factors for pathways were average usage rates for the United States and were not necessarily associated with usage rates typical of the surface water bodies on which the dispersion models were based. Aquatic food usage in the various water bodies was calculated by dividing long-term total harvests for the entire United States by the total surface area of those water bodies. Shoreline usage was compiled in a similar manner by taking total U.S. shoreline usage and dividing by the total number of shoreline miles of waterways. Drinking water statistics were derived from information on average numbers of water users as a function of distances downstream from sites. Details on the water body dispersion and usage rates are given in Section 4 of this report and in the LPGS.

3 METHODOLOGY FOR LIQUID PATHWAYS SCREENING MODEL

3.1 Introduction

Liquid pathway models have been incorporated into a computer program called "SCREENLP." The models utilize subsets of models from the Liquid Pathway Generic Study (LPGS). The SCREENLP program analyzes the potential contamination of surface water via the groundwater pathway resulting from a severe nuclear reactor core-melt accident (Class 9) and calculates a "surrogate" population dose resulting from three potential basic dose sources. These sources are drinking water, finfish and shellfish ingestion, and shoreline exposure. The calculated site-specific dose values are available to be compared with the generic site dose values that were calculated in a similar manner using LPGS parameters. This comparison provides the basis for determining if the site under study would pose an unusual liquid pathway hazard. The generic sites (land-based) are categorized in the four basic environments: river, Great Lakes, estuary, and coastal. The dry site, that is, one located far away from a surface-water body, is not covered by the SCREENLP model.

The following sections describe the parts of the liquid pathway screening model and how they are used in the framework of the SCREENLP computer program listed in Appendix C.

3.2 Source Term

The source term for the SCREENLP program describes the quantity of radionuclides that can escape the reactor and enter the groundwater. For population dose without interdiction, it is possible to make several preliminary conclusions that simplify the analysis:

(1) Population dose is proportional only to the quantity of the radionuclides entering the groundwater.

(2) Population dose is independent of the rate of release of the radionuclide to the groundwater.

(3) Nearly all of the population dose would be caused by the radioisotopes Sr-90, Cs-134, and Cs-137. All others can be ignored with only a small error.

(4) The largest population dose would be caused by the sump water release scenario for pressurized-water reactors (PWRs).* All other cases have much smaller consequences and can be ignored in comparison.

The SCREENLP program uses the following source term:

$$M_i = M_{si} F_{si} \tag{1}$$

where M_i is the quantity of radionuclide i entering the ground, M_{si} is the quantity of radionuclide i present in the core at the time of meltdown, and F_{si} is the fraction of radionuclide i that enters the sump or suppression pool water and is therefore readily available for groundwater transport.

The quantities M_{si} and F_{si} used in the screening model were taken from the LPGS, Table A8, and are presented in Table 3.1. The SCREENLP computer program has an option to change these values if desired.

Table 3.1 Source term for liquid pathways screening model

Nuclide	Inventory M_{si} (curie)	Sump release fraction F_{si}
Sr-90	6.1×10^6	0.24
Cs-134	2.1×10^7	1.0
Cs-137	8.6×10^6	1.0

Source: NUREG-0440, Table A8.

---

*The staff also includes in this general category any releases of contaminated suppression pool water in the case of boiling-water reactors (BWRs).

3.3 Groundwater Transport

Radionuclides released to the ground must be transported in the groundwater before they can affect users. Transport in the ground depends on advection by flowing groundwater, dispersion in the ground, and sorption of the radionuclide by the rock or soil. For the present population dose calculations, only the fractional quantity of the released radionuclide i passing the groundwater barrier F_{gi} is important. The total quantity passing strongly depends on the groundwater travel time, retardation, and half-life of the radionuclide, and is only weakly dependent on dispersion parameters for the ranges of characteristic values likely to be encountered. Therefore, dispersion in groundwater was not considered in the SCREENLP program.

The fraction of released radionuclides passing the groundwater barrier F_{gi} can be evaluated in several ways:

(1) Input F_{gi} for each radionuclide directly.

(2) Calculate F_{gi} from the groundwater travel time and retardation coefficient.

(3) Use travel time calculated from Darcy's law (slope and permeability).

(4) Use travel time calculated from water balance on sloping land surface.

(5) Use travel time calculated from a freshwater-lens water balance in coastal environments.

These options are included in the computer program and are described in detail below.

(1) Groundwater Treatment Option 1 - "Enter Groundwater Transmittal Factors"

This option is self-explanatory. The groundwater passage function F_{gi} is input for Sr-90, Cs-134, and Cs-137.

(2) Groundwater Treatment Option 2 - "Enter Travel Time Through Ground"

With this option, the groundwater travel time and retardation factors are input, and the fraction of the radionuclide passing to surface water is calculated with the equation

$$F_{gi} = \exp\left(-\frac{0.693TR_{di}}{t_{\frac{1}{2}i}}\right) \qquad (2)$$

where T = groundwater travel time
R_{di} = retardation coefficient of radionuclide i
$t_{\frac{1}{2}i}$ = half-life of radionuclide i

The terms R_{di} are either entered directly, or are calculated by the equation

$$R_{di} = 1 + \frac{\rho_b K_{di}}{n} \qquad (3)$$

where ρ_b = bulk density of the soil, gm/ml
K_{di} = equilibrium distribution coefficient of radionuclide i on the soil, ml/gm
n = total porosity of the soil

The data necessary to calculate R_{di} should be gathered from the field whenever possible. Appendix A contains useful tables of data from textbook sources that can be used if no other data are available; however, values at the conservative ends of the ranges should be chosen. The choice of entering or calculating R_{di} is presented for Options 3, 4, and 5 as well.

Example 1 - Groundwater Treatment Option 2: The groundwater travel time is 2 years. Calculate the transmittal factor for K_d = 2 ml/gm for strontium, K_d = 6 ml/gm for cesium, ρ_b = 2 gm/ml, and $n = 0.2$.

Solution: The liquid pathways screening program is demonstrated for the present example in Figure 3.1.

```
************************

GROUNDWATER TREATMENT OPTIONS
1.ENTER GR.WTR TRANSMITTAL FACTORS
  FOR SR90,CS134,CS137
2.ENTER TRAVEL TIME THROUGH GROUND
3.CALC TRAVEL TIME FROM DARCYS LAW
4.CALC TRAVEL TIME FROM RECHARGE
   TO WATER TABLE
5.CALC TRAVEL TIME IN FRESHWATER
   LENS FOR COASTAL ENVIRONMENT
ENTER OPTION NUMBER
? 2

INPUT TRAVEL TIME FOR GROUNDWATER,YRS
? 2.0
ENTER 1 TO INPUT RD FACTORS
ENTER 2 TO CALC RD FACTORS
? 2
ENTER KD(ML/GM) FOR SR AND CS
? 2.0,6.0
ENTER BULK DENSITY OF SOIL(GM/ML) AND TOTAL POROSITY
? 2.0,0.2
RETARDATION FACTORS
SR90 =          21
CS137 AND CS134 =              61
GROUNDWATER PASSAGE FACTORS
SR90 =          .377736
CS134 =         2.02467E-17
CS137 =         6.02402E-02
GRNDWATER TRANSMISSION FACTORS
FOR LPGS WERE
SR90 = .87802
CS134 = 1.1897E-7
CS137 = .31164
RATIO OF PRESENT SITE GROUNDWATER
TRANSMITTAL FACTORS TO LPGS'S
SR90 =          .430213
CS134 =         1.71481E-10
CS137 =         .193301

****************************
```

Figure 3.1 Groundwater Treatment Option 2 - example

(3) Groundwater Treatment Option 3 - "Calculate Travel Time From Slope - Permeability"

This option allows the computation of the travel time T from Darcy's law:

$$T = \frac{L_1 n_e}{mk} \tag{4}$$

where L_1 = distance from the source to the sink, ft
n_e = effective porosity
m = groundwater gradient, ft/ft
k = hydraulic conductivity (permeability), ft/yr

The slope m is usually estimated as the difference between water table or ground surface height at the release point and the river stage or surface water mean elevation divided by the lateral distance between them L_1. Coefficients n_e and k should be site specific whenever possible. Ranges of these coefficients in typical materials are given in Appendix B.

Once travel time is computed, the program continues with the calculation for R_{di} as in Option 2.

Example 2 - Groundwater Treatment Option 3: Compute the travel time for a distance of 500 ft, slope of 0.005, hydraulic conductivity of 200 ft/yr and effective porosity of 0.015.

Solution: Groundwater Treatment Option 3 is demonstrated in Figure 3.2.

(4) Groundwater Treatment Option 4 - "Calculate Travel Time From Recharge to Water Table"

This option computes travel time using the solution of a differential equation describing the balance between infiltration of rainwater and groundwater flow

```
************************

GROUNDWATER TREATMENT OPTIONS
1.ENTER GR.WTR TRANSMITTAL FACTORS
  FOR SR90,CS134,CS137
2.ENTER TRAVEL TIME THROUGH GROUND
3.CALC TRAVEL TIME FROM DARCYS LAW
4.CALC TRAVEL TIME FROM RECHARGE
  TO WATER TABLE
5.CALC TRAVEL TIME IN FRESHWATER
  LENS FOR COASTAL ENVIRONMENT
ENTER OPTION NUMBER
? 3

ENTER DISTANCE FROM
 SOURCE TO WATER BODY, FEET
? 500
ENTER PERMEABILITY,FT/YR? 200.0
ENTER EFFECTIVE POROSITY? .015
ENTER SLOPE TOWARD WATER BODY FT/FT? .005
GROUNDWATER SPEED,FT/YR       66.6666
TRAVEL TIME,YR =              7.5
ENTER 1 TO INPUT RD FACTORS
ENTER 2 TO CALC RD FACTORS
? 2
ENTER KD(ML/GM) FOR SR AND CS
? 2.0,6.0
ENTER BULK DENSITY OF SOIL(GM/ML) AND TOTAL POROSITY
? 2.0,0.2
RETARDATION FACTORS
SR90 =           21
CS137 AND CS134 =             61
GROUNDWATER PASSAGE FACTORS
SR90 =           .025969
CS134 =          2.50503E-63
CS137 =          2.6581E-05
GRNDWATER TRANSMISSION FACTORS
FOR LPGS WERE
SR90 = .87802
CS134 = 1.1897E-7
CS137 = .31164
RATIO OF PRESENT SITE GROUNDWATER
TRANSMITTAL FACTORS TO LPGS'S
SR90 =           2.95768E-02
CS134 =          2.12165E-56
CS137 =          8.5294E-05

****************************
```

Figure 3.2 Groundwater Treatment Option 3 - example in the direction of the sink, as shown in Figure 3.3. Referring to this figure, the differential equation that expresses the shape of the water table is (Bear, 1979):

$$\frac{dh}{dx} + s = -\frac{Rx}{hk} \tag{5}$$

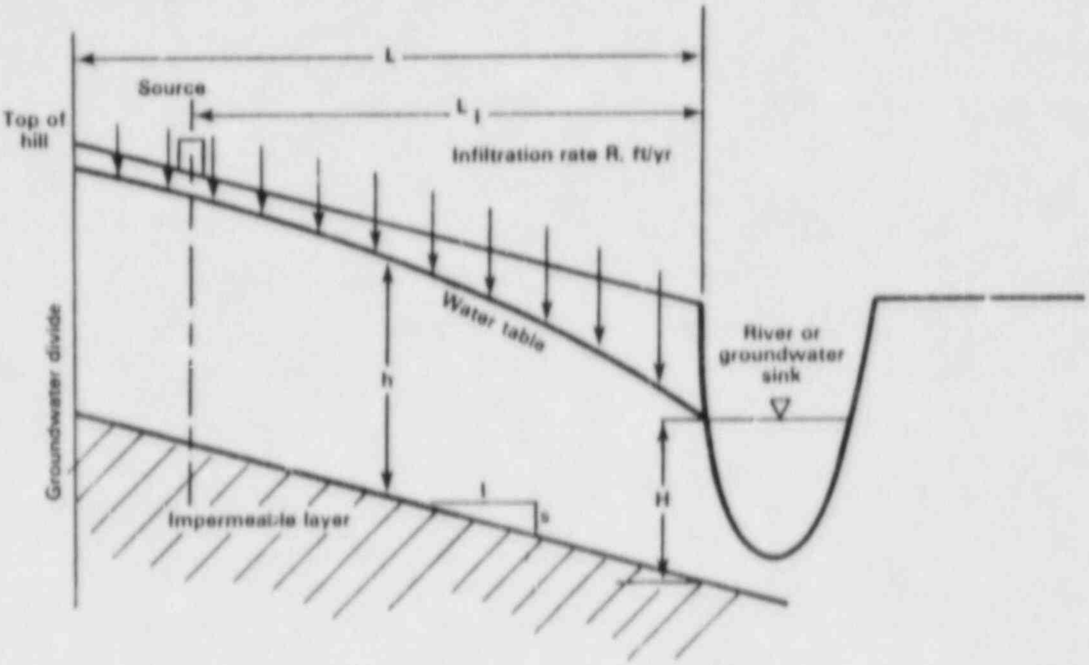


Figure 3.3 Water table on a sloping plane

where h = water table thickness, ft

x = linear distance from the groundwater high, ft

s = slope of the impermeable layer, ft/ft

R = recharge to the water table, $(ft^3/yr)/ft^2$

k = hydraulic conductivity ft/yr

The boundary condition on Equation 5 is

$$h = H \text{ at } x = L \tag{6}$$

where H is the aquifer thickness at the sink, and L is the distance from the top of the hill (assumed to be the groundwater divide) to the sink (e.g., river).

Equation 5 is solved numerically for h using a second-order Runge-Kutta integration method, integrating from $x = L$ to $x = 0$. Travel time is simultaneously calculated by the numerical integration of the equation:

$$T = \int_{x=L}^{x=L_1} \frac{hn_e}{Rx}\, dx \tag{7}$$

where L_1 is the distance from the sink to the source.

It is important to check that the water table does not exceed the land surface elevation, because the position of the actual land surface is not taken into account in this computation. If h exceeds the allowable thickness, this is an indication that the parameters of the model were improperly chosen; for example, hydraulic conductivity was too low, recharge was too high, or ground surface was saturated and a portion of the recharge ran off.

As with all other models, site-specific data should be used whenever available. Appendix A contains ranges of data for typically encountered materials.

At the completion of Option 4, the program continues with the calculation for R_{di} as in Option 2.

Example 3 - Groundwater Treatment Option 4: Referring to Figure 3.4, calculate the travel time to the river for the following parameters:

$L = 4{,}000$ ft
$L_1 = 1{,}000$ ft
$n_e = 0.075$
$k = 500$ ft/yr
$H = 150$ ft
$R = 0.5$ ft/yr
$S = 0.02$

Solution: The solution to this problem is shown in Figure 3.4.

```
************************

GROUNDWATER TREATMENT OPTIONS
1.ENTER GR.WT. TRANSMITTAL FACTORS
  FOR SR90,CS134,CS137
2.ENTER TRAVEL TIME THROUGH GROUND
3.CALC TRAVEL TIME FROM DARCYS LAW
4.CALC TRAVEL TIME FROM RECHARGE
  TO WATER TABLE
5.CALC TRAVEL TIME IN FRESHWATER
  LENS FOR COASTAL ENVIRONMENT
ENTER OPTION NUMBER
? 4

ENTER DIST FROM TOP OF
 HILL TO SINK,FT
? 4000
ENTER DISTANCE FROM
 SOURCE TO SINK ,FT
? 1000
ENTER THICKNESS OF SATURATED
 LAYER AT SINK,FT
? 150
ENTER RECHARGE,FT/YR
? .5
INPUT HYDRAULIC COND,FT/YR
? 500
INPUT SLOPE OF LAND>0
? .02
INPUT EFFECTIVE POROSITY
? .075
TRAVEL TIME ,YEARS =            6.56703
MAXIMUM MOUND THICKNESS,FT =                  153.023
WARNING!!! - BE SURE THAT MOUND
THICKNESS DOESN'T EXCEED MAX
 AQUIFER THICKNESS
ENTER 1 TO INPUT RD FACTORS
ENTER 2 TO CALC RD FACTORS
```

Figure 3.4 Groundwater Treatment Option 4 - example

(5) Groundwater Treatment Option 5 - "Calculate Travel Time in Freshwater Lens for Coastal Environment"

This option is a variation of the uniform recharge case presented in Groundwater Treatment Option 4 above, but for seacoasts or islands. Rainwater infiltrating the ground floats on the denser seawater forming a freshwater lens as depicted in Figure 3.5. This phenomenon is also known as the

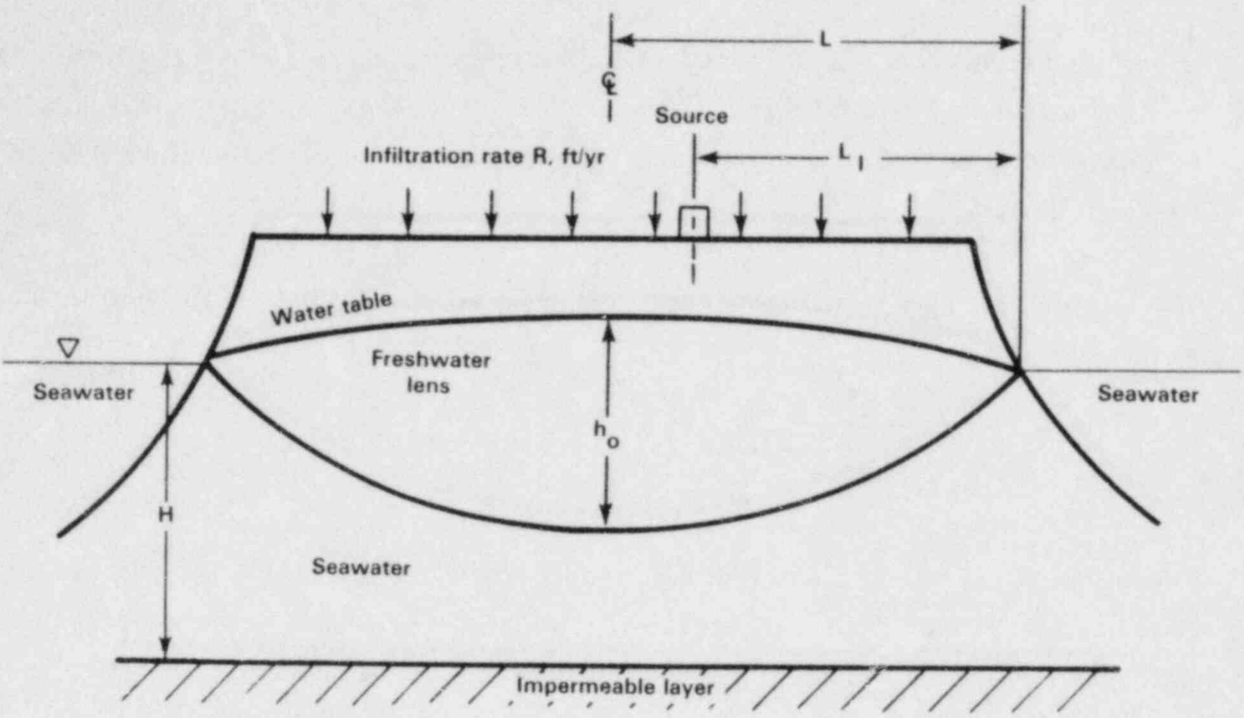


Figure 3.5 Uniform recharge to a freshwater lens

Ghyben-Herzberg approximation (Bear, 1979). The travel time from the source to the coast using this approximation can be estimated to be

$$T = \tau(L) - \tau(L - L_1) \tag{8}$$

where $\tau(x) = n_e \sqrt{\frac{1 + \delta}{Rk}} \; \{\sqrt{L^2 - x^2} - L \ln (\frac{L + \sqrt{L^2 - x^2}}{x})\}$

where n_e = effective porosity
R = recharge to water table, (ft³/yr)/ft² (see Section 4.3)
k = hydraulic conductivity, ft/yr
L = distance from center of island to shoreline, ft
L_1 = distance from source to shoreline, ft

The factor δ is the relative buoyancy of freshwater and is expressed

$$\delta = \frac{\gamma_f}{\gamma_s - \gamma_f} \tag{10}$$

where γ_s is the specific gravity of saltwater and γ_f is the specific gravity of freshwater. Typically from seawater, $\delta = 40$, and this value is fixed in the computer program. Calculations for R_{di} proceed as in Option 2 once travel time has been estimated.

The maximum thickness of the lens h_o occurs at the island center and is expressed

$$h_o = (1 + \delta)\ L \sqrt{\frac{R}{(1 + \delta)k}} \tag{11}$$

The maximum thickness must not be greater than the thickness of the water-bearing layer. If it is, coefficients such as recharge and permeability may have been improperly chosen, or the ground may be saturated. In some cases freshwater would displace saltwater over part of the flow path. In such cases, the travel time is likely to lie somewhere between those calculated by Option 4 and Option 5.

Example 4 - Groundwater Treatment Option 5, Uniform Recharge on a Barrier Island: Referring to Figure 3.5, calculate the travel time from the source to the ocean for the following parameters:

$R = 0.6$ ft/yr
$n_e = 0.03$
$k = 6{,}000$ ft/yr
$L = 3{,}000$ ft
$L_1 = 2{,}400$ ft
$H = 300$ ft

Solution: The solution is shown in Figure 3.6.

3.4 Surface Water Dilution

Population doses from the postulated releases are proportional to the long-term average concentrations in the affected portions of the receiving waters. The

```
************************

GROUNDWATER TREATMENT OPTIONS
1.ENTER GR.WTR TRANSMITTAL FACTORS
  FOR SR90,CS134,CS137
2.ENTER TRAVEL TIME THROUGH GROUND
3.CALC TRAVEL TIME FROM DARCYS LAW
4.CALC TRAVEL TIME FROM RECHARGE
  TO WATER TABLE
5.CALC TRAVEL TIME IN FRESHWATER
  LENS FOR COASTAL ENVIRONMENT
ENTER OPTION NUMBER
? 5

ENTER EFFECTIVE POROSITY
? .03
ENTER HYDRAULIC COND,FT/YR
? 6000
ENTER DISTANCE FROM CENTER
OF LENS TO SEA,FT
? 3000
ENTER DISTANCE FROM SOURCE
 TO SEA, FT
? 2400
ENTER RECHARGE,FT/YR
? .6
TR.TIME,YEARS=                   12.6075
MAX MOUND HT,FT=                 192.094

WARNING!!! - BE SURE TO CHECK
THAT MOUND HT DOESN'T EXCEED THICKNESS
OF AQUIFER. IF SO VALUES CHOSEN MAY BE INAPPROPRIATE
ENTER 1 TO INPUT RD FACTORS
ENTER 2 TO CALC RD FACTORS
```

Figure 3.6 Groundwater Treatment Option 5 - example

computer program has several options for dealing with surface water dilution. These include (1) reading the dilution directly (sec/ft^3), (2) calculating the dilution in rivers, lakes, and estuaries for each radionuclide based on sediment interaction in addition to dilution, (3) calculating the dilution in estuaries from the observed salinity profile, and (4) using a coastal dispersion model. All of the LPGS cases are considered to be covered by these four options, although somewhat different models were used in NUREG-0440. Each surface water dilution option is described below.

(1) Surface Water Treatment Option 1 - "Read in Dilutions"

In this option, dilution in each segment is considered to be proportional only to the flowrate in that segment. The dilutions are read in directly as the reciprocal of the flowrate, sec/ft^3. The LPGS large-river base case example uses this option and is presented in Section 5.

(2) Surface Water Treatment Option 2 - "Calculate Nuclide-Specific Dilutions From Sediment Loads in Rivers or Lakes"

In this option, the steady-state concentration in each river, lake, or estuary segment is calculated on the basis of the effects of sediment interactions.

Sediment scavenging is an important mechanism for removing radionuclides, particularly cesium, from the water.

The water body is considered to be partitioned into completely mixed segments. The concentration of each radionuclide in each segment is calculated on the basis of the input values of flowrate, sediment load, water depth, sediment depth, equilibrium coefficient, sediment density, half-life, and direct transfer coefficient.

Dilution of radionuclide i in segment j is defined by Equation 1:

$$D_{ij} = D_{ij-1} q_{j-1} V_j \left(\lambda_{2ij} - \lambda_{1ij} \lambda_{3ij} / \lambda_{4ij}\right) \tag{12}$$

where $(D_{io}q_o)$ is defined as unity, and

$$\lambda_{1ij} = \frac{K_f}{d_{1j}K_{di}} \tag{13}$$

$$\lambda_{2ij} = \frac{q_j}{V_j} + \lambda_i + \frac{\varepsilon v_j K_{di}}{d_{1j}} + \frac{K_f}{d_{1j}} \tag{14}$$

$$\lambda_{3ij} = \frac{\varepsilon v_j K_{di} + K_f}{d_{2j}} \tag{15}$$

$$\lambda_{4ij} = \lambda_i + \frac{\varepsilon v_j}{d_{2j}} + \frac{K_f}{d_{2j}K_{di}} \tag{16}$$

q_{j-1} = flow from previous segment
V_j = volume of j^{th} segment
K_f = coefficient for direct transfer between the water and bottom sediment
K_{di} = equilibrium coefficient of the nuclide i in sediment, ml/gm
ε = sediment efficiency
d_{1j} = average depth of the water layer in water body j
d_{2j} = average depth of the sediment layer in water body j
λ_i = radioactive decay coefficient of nuclide i, 0.693/half-life, yr^{-1}
v_j = sedimentation rate in reservoir j, ft/yr

Site-specific data should be used whenever possible.

The LPGS small-river base case uses Surface Water Treatment Option 2 and is presented in Section 5. Note that the LPGS estuary base case also uses Surface Water Treatment Option 2.

(3) Surface Water Treatment Option 3 - "Calculate Dilutions From Salinity Profile in Estuary"

This option is used to calculate dilution in an estuary where the salinity as a function of distance is known. The dilution of radionuclide i in segment j is calculated from a mass balance equation:

$$D_{ij} = (1 - S_j/S_s)/q_j \tag{17}$$

where S_j = salinity in estuary segment j, parts per thousand
S_s = seawater salinity, parts per thousand
q_j = freshwater flowrate in that segment, ft^3/sec

Example 5 - Surface Water Treatment Option 3 - Estuary: Calculate the dilutions in an estuary that is represented by three segments as shown in Figure 3.7.

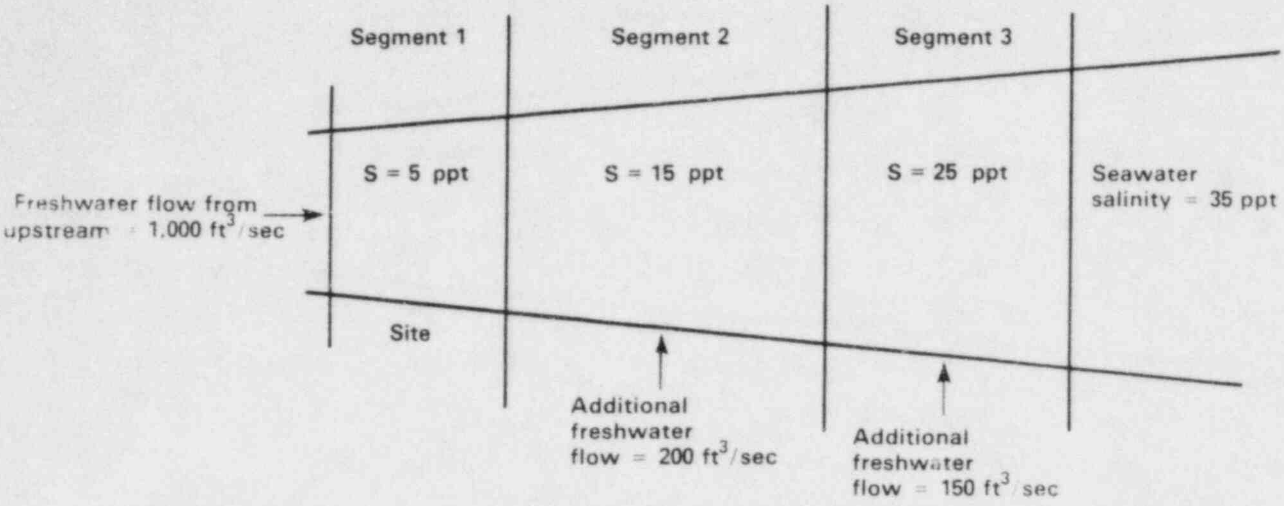


Figure 3.7 Representation of estuary

From Figure 3.7, the freshwater throughput is 1,000, 1,200, and 1,350 ft^3/sec for Segments 1, 2, and 3, respectively. The solution is shown in Figure 3.8.

```
**********************

DILUTION FACTOR OPTIONS
1.READ IN DILUTIONS
2.CALCULATE NUCLIDE SPECIFIC DIL
  FROM SED LOADS IN RIVER OR LAKES
3.CALC DILUTIONS FROM SALINITY
  PROFILE IN ESTUARY
ENTER OPTION NUMBER
? 3

ENTER SEAWATER SALINITY,PPT
? 35
ENTER SALINITY IN EACH SEGMENT,PPT
AND FRESHWATER THRUPUT,CFS
SEGMENT 1 ? 5,1000

DILUTION IN SEGMENT =        8.57143E-04
SEGMENT 2 ? 15,1200

DILUTION IN SEGMENT =        4.76191E-04
SEGMENT 3 ? 25,1350

DILUTION IN SEGMENT =        2.1164E-04

**************************
```

Figure 3.8 Surface Water Treatment Option 3 - example

3.5 Models for Exposures to the Population

3.5.1 Introduction

Population dose is calculated from three pathways: drinking water, aquatic food, and shoreline exposure; pathways other than these are considered negligible contributors to dose. Screening analyses show that over 90% of the population dose from liquid pathways comes from the three radionuclides Sr-90, Cs-134, and Cs-137; therefore, other radionuclides are neglected in the analysis.

The present dose models have been derived from the models in the LPGS. Population dose D_p is calculated for the p^{th} exposure pathway by the formula

$$D_p = \sum_{j=1}^{N} P_{pj} \sum_{i=1}^{M} DF_{ip} F_{pi} \int_o^t C_{ipj}\, dt \qquad (18)$$

where N = number of segments in water body

P_{pj} = population in segment j affected by the liquid release

M = number of radionuclides

DF_{ip} = dose factor for exposure pathway p from radionuclide i

F_{pi} = transmittal factor for radionuclide i in pathway p

C_{ipj} = concentration of radionuclide i in segment j caused by pathway p

Population dose is evaluated for an infinite time after the release, assuming no interdiction. The concentration of radionuclide i in the surface water would vary with time and would depend on the inventory of radionuclide i in the core M_{si}, the fraction escaping the reactor F_{si}, the fraction escaping the ground F_{gi}, and the dilution and removal mechanisms in the surface water body.

The integral of concentration in Equation 18 for infinite time reduces to:

$$\left.\int_o^t C_{ipj}\, dt\right|_{t \to \infty} = M_{si} F_{si} F_{gi} D_{ij} \qquad (19)$$

where D_{ij} is the factor accounting for dilution and removal of radionuclide i in segment j of the water body. The infinite time population dose for pathway p can therefore be stated as:

$$\text{Dose} = \sum_{j=1}^{N} P_{pj}\, U_{pj} \sum_{i=1}^{M} DF_{ip}\, M_{si}\, F_{si}\, F_{gi}\, D_{ij}\, F_{pi} \tag{20}$$

where U_{pj} = usage rate of contaminated water for pathway p in segment j.

The subsequent paragraphs describe the application of Equation 20 for the various situations likely to be encountered.

3.5.2 Drinking Water Pathway

For the annual cumulative dose in the case of drinking water, Equation 20 reduces to

$$\text{Dose} = \sum_{j=1}^{N} P_{dj}\, U_{d} \sum_{i=1}^{M} DF_{i}\, M_{si}\, F_{si}\, F_{gi}\, D_{ij}\, F_{Ti} \tag{21}$$

where P_{dj} = population drawing drinking water from segment j
U_d = average annual drinking water consumption (use 730 ℓ/yr)
DF_i = dose factor for ingestion of radionuclide i (0.186×10^{-2}, 1.21×10^{-4}, and 0.714×10^{-4} mrem per picocurie for Sr-90, Cs-134, and Cs-137, respectively)
D_{ij} = effective dilution of radionuclide i in segment j
F_{Ti} = water treatment passage factor for radionuclide i (0.2 for Sr and 0.9 for Cs in LPGS)

3.5.3 Aquatic Food Pathway

For aquatic food, the finfish and shellfish doses are calculated. Equation 20 reduces to

$$\text{Dose} = \sum_{j=1}^{N} \sum_{i=1}^{M} DF_{i}\, M_{si}\, F_{si}\, F_{gi}\, D_{ij} \cdot (B_{is}\, U_{js} + B_{if}\, U_{jf})\, E \tag{22}$$

where DF_i = dose factor for ingestion of radionuclide i

B_{is} = bioaccumulation factor for radionuclide i in shellfish, (mCi/kg)/(mCi/ℓ)

U_{js} = annual edible shellfish catch in segment j

B_{if} = bioaccumulation factor for radionuclide i in finfish, (mCi/kg)/(mCi/ℓ)

U_{jf} = annual edible finfish catch in segment j

E = fraction of fish that is ingested (LPGS used 0.50)

3.5.4 Shoreline Exposure Pathway

For the population dose to people using the beaches and shorelines, Equation 20 reduces to

$$\text{Dose} = \sum_{j=1}^{N} P_{sj}\, U_s \sum_{i=1}^{M} DF_{si}\, W\, K\, \tau_i\, D_{ij}\, M_i\, F_{si}\, F_{gi}\, \rho_s \qquad (23)$$

where P_{sj} = number of people using shoreline and beaches in segment j

U_s = annual average usage rate of beaches per capita, hr/yr

DF_{si} = dose factor for standing on contaminated ground, (mrem/hr)/(mCi/m^2)

K = transfer coefficient between water and beach deposits, 631 ℓ/kg-yr

τ_i = time constant for erosion of radionuclide i on beach, yr

$$\tau_i = \frac{A}{\lambda_i + \alpha} + \frac{B}{\lambda_i + \beta} \qquad (24)$$

where $\lambda_i = 0.693/t_{\frac{1}{2}}$

ρ_s = effective density of shoreline deposits = 40 kg/m^2

The term W is the shore-width factor, which accounts for the effective width of shorelines for different bodies of water. The terms α, β, A, and B are factors that account for the residence time of radionuclides on shore. The shoreline deposition model differs from the LPGS model, which does not account for erosion of the radionuclides from the shoreline. The present model is derived from NUREG/CR-1596 and was adopted because it represents a considerable improvement over the original LPGS model. Table 3.2 gives the values of a, β, A, B, and W for the various water bodies.

Table 3.2 Factors for shoreline model

Water body	W	α, yr^{-1}	β, yr^{-1}	A	B
River	0.2	1.406	7.702×10^{-3}	0.63	0.37
Great Lakes	0.3	1.406	7.702×10^{-3}	0.63	0.37
Estuary	1.0	1.406	7.702×10^{-3}	0.05	0.95
Sea coast	0.5	16.867	1.406	0.9	0.1

Source: NUREG/CR-1596

3.6 Coastal Site Population Dose Model

The dose model for coastal sites is treated separately from the other models in the computer program. This part of the original LPGS evaluation was performed mainly by Offshore Power Systems, and the model of Offshore Power Systems Topical Report 22A60 is largely incorporated in the present computer program.

The dispersion from a steady-state source emanating from the shoreline into the open ocean moving at velocity U parallel to shore is expressed as

$$\chi = \frac{1}{zd(\pi U p(x))^{1/2}} \exp\left(- \frac{Uy^2}{4p(x)}\right) e^{-\left(\frac{\lambda_i x}{U}\right)} \quad \text{day/m}^3 \tag{25}$$

$$\text{where } p(x) = \frac{1.91 \cdot 10^5}{U^{1.34}} x^{2.34} + p(0) \quad \text{m}^3\text{/day} \tag{26}$$

where d = effective water depth, m

U = longshore drift current, m/day

y = offshore distance, m

λ_i = decay constant for radionuclide i

x = longshore distance, m

p(0) = base value of p at x = 0 (taken as 1.85×10^7 m^3/day in the present case)

Only the aquatic food and shoreline dose are calculated for the coastal site because there are no users of drinking water that could be affected. Seafood catch is tabulated in discrete zones as a function of offshore distance. The water is divided into rectangular blocks downcurrent and off shore from the coast. Equation 25 is used to calculate the concentration at the center of each block, which is then multiplied by the fish catch in that block and summed. Population dose is then calculated by the formula:

$$\text{Dose} = \sum_{k=1}^{2} \int_{o}^{x_1} \int_{o}^{y_1} \chi(x,y)\, G_k(x,y)\, dx\, dy \sum_{i=1}^{3} M_i\, F_{gi}\, F_{si}\, DF_i\, BAF_{ik} \tag{27}$$

where x_1, y_1 = spatial limits of offshore dose model, m
χ = dilution calculated from Equation 25, day/m^3
$G_1(x,y)$ = annual average finfish catch density at x,y, kg/ha/yr
$G_2(x,y)$ = annual average shellfish catch density at x,y, kg/ha/yr
M_i = core inventory of radionuclide i, Ci
F_{gi} = groundwater passage factor of radionuclide i
F_{si} = sump water factor of radionuclide i
DF_i = dose factor for ingestion of radionuclide i, mrem/pCi
BAF_{i1} = bioaccumulation factor for radionuclide i for finfish, (mCi/kg)/(mCi/ℓ).
BAF_{i2} = bioaccumulation factor for radionuclide i for shellfish, (mCi/kg)/(mCi/ℓ)

The radioactive decay term is left out of the calculations because it would make the integral in Equation 27 nuclide dependent, and for the radionuclides considered would make a negligible difference in calculated dose.

Population dose from shoreline exposure is calculated from the downcurrent dilution predicted by Equation 25 at y = 0, and the shoreline usage rate in person-hours per linear meter of beach:

$$\text{Dose} = \left(\int_{o}^{x_1} \chi(x, y = 0)\,dx \right) \sum_{i=1}^{3} M_i\, F_{gi}\, F_{si}\, DF_{si}\, G_b\, W\, \tau_i \tag{28}$$

where $\chi(x,y = 0)$ = dilution at the shoreline, day/m^3

DF_{si} = dose factor for standing on irradiated ground, (mCi/hr)/(pCi/m^2)

G_b = usage rate of beach, person-hr/linear meter of beach

W = shore-width factor (0.5 for coastal site)

τ_i = time constant for erosion of radionuclide i on beach, yr (defined by Equation 24)

and the other terms are as previously defined.

The coastal model is illustrated in the LPGS coastal site example presented in Section 5.

4 OPERATION OF COMPUTER PROGRAM

4.1 Introduction

The liquid pathway computer program is an interactive BASIC program, which prompts the user for all necessary information. Figure 4.1 gives a flow diagram of the major computational units in the program. Appendix C contains a listing of the BASIC program as it appears on the NRC Data General MV 8000.

4.2 Classification of Sites

Sites are classified "small river," large river," "Great Lakes," "estuarine," "coastal," or "dry" (although there is no provision in the present program for dry sites). In many cases the distinction between types of sites is unclear, because rivers feed the Great Lakes and all rivers become estuaries, which flow into the sea. The site characterization, therefore, is somewhat subjective.

Although it would be possible to consider river bodies linked together (e.g., river → estuary → coastal), this is generally not necessary. As a rule, large- or small-river sites should also include the estuarine sections, but there is no need to consider the subsequent coastal sections because of the relatively high dilution once the estuaries enter coastal waters. For cases where the rivers enter the Great Lakes, the downstream users as far as the St. Lawrence River terminus should be included, although population statistics for drinking water and fish catch for the Great Lakes themselves will generally dominate the population dose. Coastal sites are often located in barrier island settings such as Oyster Creek, which is on Barnegat Bay. These sites have the characteristics of both estuaries and oceans, and the affected environment of both settings should be considered.

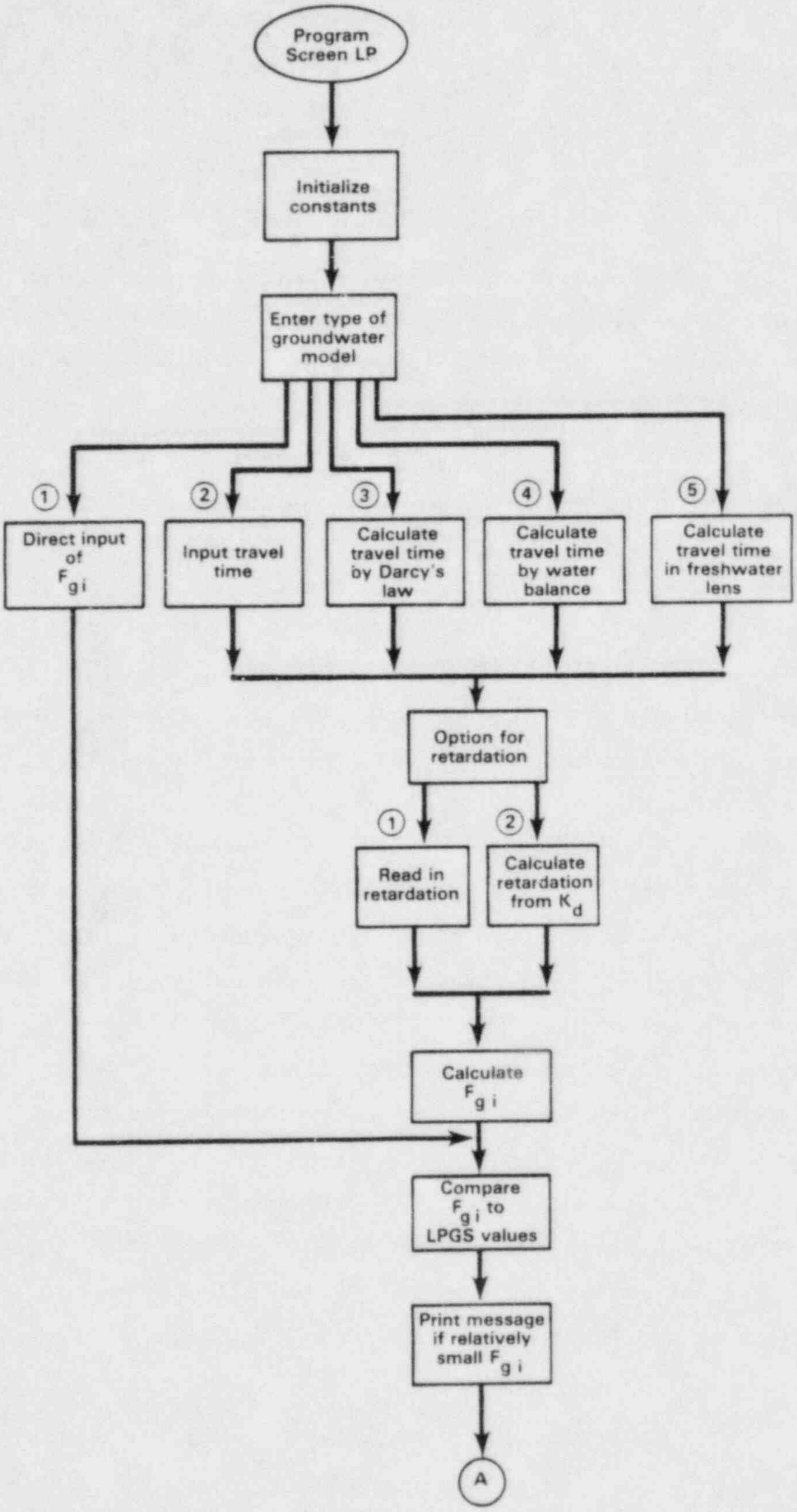


Figure 4.1 Flowchart of liquid pathways program

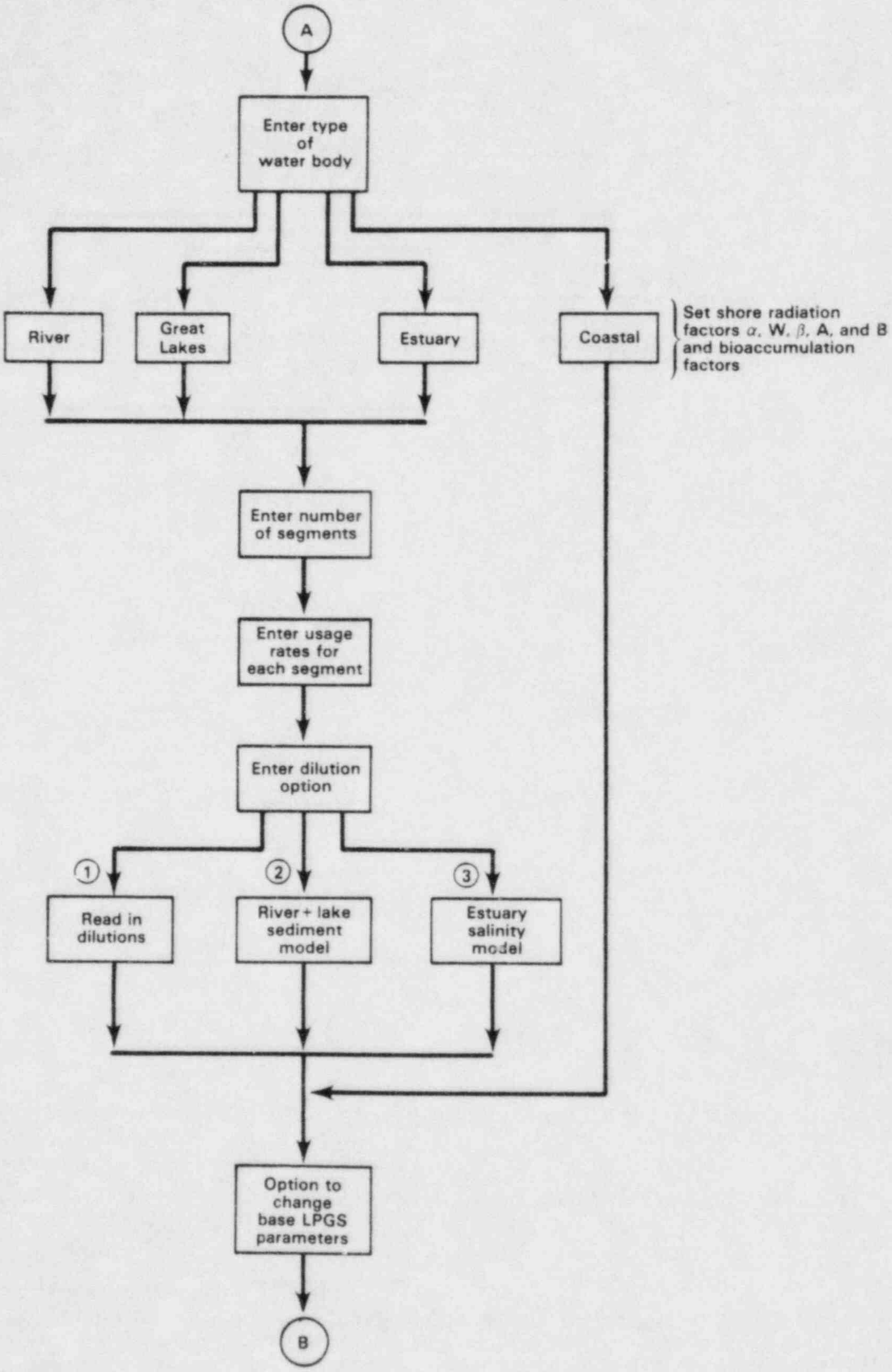


Figure 4.1 (Continued)

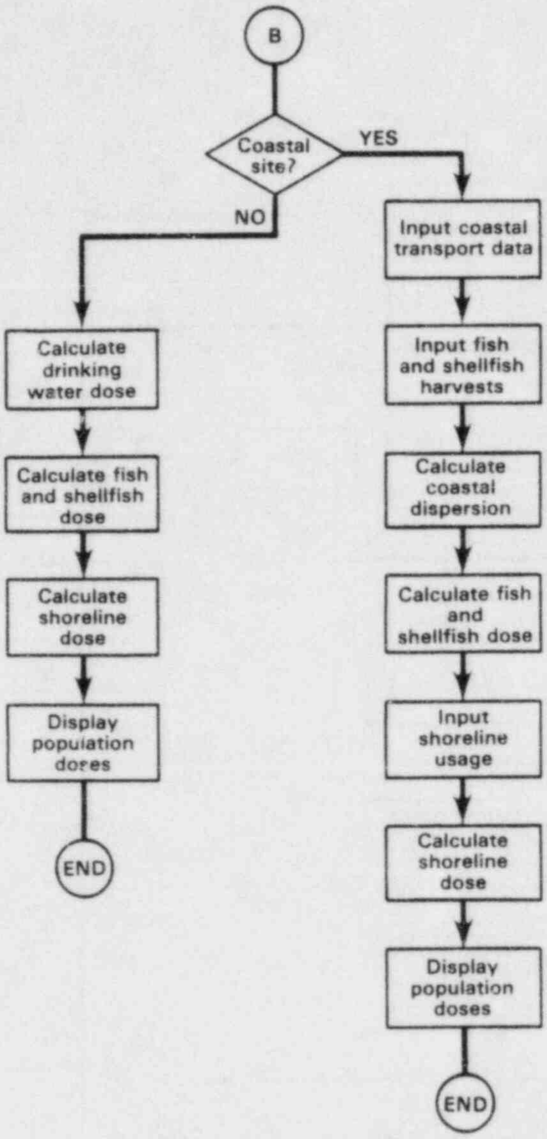


Figure 4.1 (Continued)

4.3 Selection of Data for Site-Specific Evaluations

Three types of data must be compiled for liquid pathways dose evaluations:

(1) groundwater transport data, e.g., travel time, equilibrium distribution coefficient

(2) surface water transport data, e.g., flowrates, sedimentation rates, salinity

(3) usage data, e.g., drinking water users, shoreline recreations users, fish catch

The data needs for the groundwater transport portion of the analysis are the same for all sites. The surface water transport and usage data are generally different for each type of site.

4.3.1 Groundwater Transport Data

There are five options for calculating the groundwater transport passage factor F_{gi} in the liquid pathways program. Each option has different data needs:

Groundwater Treatment Option 1 - The groundwater passage factor F_{gi} for each radionuclide is input directly.

Data Need:
F_{gi} for Sr-90, Cs-134, and Cs-137

Groundwater Treatment Option 2 - The groundwater travel time T is input directly. F_{gi} for each radionuclide is calculated from the retardation coefficient, which is either input directly or calculated from the equilibrium distribution coefficient k_d, porosity n, and bulk density ρ_b.

Data Needs:
Travel time T, yr, and either

(1) retardation coefficients R_d for Sr and Cs (dimensionless) or

(2) k_d - distribution coefficient for Sr and Cs, ml/gm
ρ_b - bulk density, gm/ml
n - total porosity (dimensionless)

Groundwater Treatment Option 3 - Travel time T is calculated by Darcy's law.

Data Needs:
m - slope of water table, ft/ft

k - hydraulic conductivity of soil, ft/yr
Remainder of data in Option 2

Groundwater Treatment Option 4 - Travel time T is calculated by water balance.

Data Needs:

H - thickness of water-bearing layer at stream, ft
L_2 - distance from stream to top of hill (or groundwater divide), ft
L_1 - distance from stream to source, ft
R - recharge rate, ft/yr
k - hydraulic conductivity, ft/yr
m - slope of land surface, ft/ft
n_e - effective porosity (dimensionless)
Remainder of data in Option 2

Groundwater Treatment Option 5 - Travel time T is calculated by water balance in freshwater lens.

Data Needs:

n_e - effective porosity (dimensionless)
k - hydraulic conductivity, ft/yr
L_3 - distance from center of island (or groundwater divide) to sea, ft
L_1 - distance from source to sea, ft
R - recharge rate, ft/yr
Remainder of data in Option 2

Sources of Groundwater Data

Groundwater data should be collected from actual site information whenever possible. Parameters such as hydraulic conductivity and porosity can be taken from onsite well pumping tests available at most sites. Aquifer thicknesses and properties of aquifer materials should also be available from drilling logs and are usually presented in Sections 2.4 and 2.5 of the Safety Analysis Report for nuclear power plants. Retardation data are rarely available at sites, with a few exceptions such as Hanford, Washington (WPPSS Nuclear Project, Units 1 and 2). Estimation of retardation must frequently be based on scanty information. Hydrogeologic data and equilibrium distribution coefficients for typical materials are presented in Appendix B, but must be generalized for site conditions only with extreme caution. Data on distribution coefficients for cesium and strontium for example are given for crushed rock and cannot generally be applied to fractured rock. Small values of k_d should be chosen conservatively if site data are not certain. The most conservative assumption is, of course, that $R_d = 1$ (no retardation).

Estimating Recharge

Groundwater Treatment Options 4 and 5 require estimates of groundwater recharge to the water table. Recharge estimates can be made in several ways. Both simple analytical (Thornthwaite and Mather, 1957) and complicated numerical methods (Gupta et al., 1978) exist to balance precipitation versus evaporation, transpiration from plants, and infiltration.

Estimates of recharge can be made from regional aquifer recharge figures compiled in various local, State, and Federal reports. Surface water flowing in streams and rivers comes almost entirely from two sources: surface runoff and groundwater seepage during periods of precipitation or snowmelt, and groundwater seepage alone in fair weather. The fair-weather river and stream flows, being almost all groundwater, can be used to estimate recharge. Methods of estimating these flows can be found in standard hydrology references (Chow, 1964).

A method of estimating recharge, which will generally give conservatively high results, is to determine the ratio of annual stream flow Q (ft^3/yr) and the surface area A_d of the streams catchment basin (ft^2)

$$R = Q/A_d \qquad ft/yr \tag{28}$$

This procedure overestimates R because both runoff and base flow are included in Q. Both flowrate and basin areas can be found in U.S. Geological Survey (1973) regional records.

The most conservative estimate of recharge is, of course, that R = annual rainfall depth.

Example 6 - Estimating Recharge: Estimate recharge to the water table from stream gage records in a nearby stream.

Drainage area of basin = 200 mi^2
Annual average discharge = 101 ft^3/sec

Solution: The conservative recharge rate calculated from Equation 28 would be

$$R = \frac{101\ \text{ft}^3/\text{sec}}{200\ \text{mi}^2} \cdot \frac{86{,}400\ \text{sec}}{\text{day}} \cdot \frac{365\ \text{days}}{\text{year}} \cdot \frac{\text{mi}^2}{(5{,}280\ \text{ft})^2} = 0.57\ \text{ft/yr}$$

4.3.2 Surface Water Dilution Data

There are four surface water body options. Each option has different data needs.

Surface Water Treatment Option 1 - Read dilutions directly. Simply input the reciprocal of effective flowrate in each section of the water body, sec/ft^3.

Data Need:
q_j - flowrate leaving each section, ft^3/sec

Surface Water Treatment Option 2 - Calculate nuclide-specific dilution from sediment load data in rivers, lakes, or estuaries.

Data Needs:
For each segment:
q_k - flowrate leaving each segment, ft^3/sec
V_j - volume of segment, ft^3
d_{1j} - average depth of segment, ft
d_{2j} - average sediment depth, ft

For all segments together:

k_d - sediment radionuclide distribution coefficient, ml/gm

k_f - direct transfer factor, ft/yr

ε - sediment efficiency adjustment factor (dimensionless)

ρ - sediment density, gm/ml

v - sedimentation rate, ft/yr

Surface Water Treatment Option 3 - Calculate dilution in estuary from freshwater flow and salinity profile.

Data Needs:

S_s - seawater salinity, parts per thousand

For each segment:

q_j - freshwater flowing through segment (total of upstream flow and local input). ft^3/sec

S_j - salinity in center of segment, parts per thousand

Surface Water Treatment Option 4 - Use coastal model.

Data Needs:

U - drift current parallel to shore, m/day

b - effective water depth, m

N - number of offshore regions for seafood catch

dx - length of longshore increment, km

nx - number of longshore increments

Estimating Flowrates

For Surface Water Treatment Options 1 and 2, the flowrate chosen should be the reciprocal average flowrate rather than the annual average flowrate. In many cases, the annual average flowrate seriously overestimates the dilution and is not conservative. The reciprocal average flowrate is defined as

$$\bar{q}^R = M_d \left(\sum_{i=1}^{M_d} \frac{1}{q_i} \right)^{-1} \qquad (29)$$

where M_d = number of days in the record
q_i = daily flowrate for day i

The reciprocal average flowrate emphasizes drought flows and is more representative of long-term average dilution than the arithmetic mean flowrate, which emphasizes flood flows. Appendix A gives operating instructions for the FLOWAV computer program, which uses the U.S. Geological Survey's WATSTORE hydrologic data base system to calculate $\bar{q}^R$ from daily flowrates.

Estimating Characteristics of Sediment

Sedimentation data for the Surface Water Treatment Option 2 surface water model were gathered from literature values. Ranges of values typical of various water bodies and references are given in Table 4.1. Neglecting sediment effects would lead to conservative dose predictions.

Sediment coefficients for the LPGS small-river case were taken from extensive studies of the Clinch and Tennessee Rivers for which real data were available (Oak Ridge National Laboratory, 1967; personal communication from U.S. Geological Survey). Sedimentation rate v was derived by dividing the annual estimated sediment load in each segment by the surface area of that segment. The sediment effectiveness factor $\varepsilon = 0.1$ was adjusted to give the best fit of sediment concentration between the model and prototype data. These data are presented in the LPGS small-river base case given in Section 5.

4.3.3 Pathway Usage Rates

Usage rates for the three pathways, drinking water, aquatic food consumption, and shoreline exposure, are required for each run. Most of this information is available in the Safety Analysis Report and Environmental Report for the site. Section 4.3 and Appendix D of the LPGS give generic values for fish consumption used in the study and the bases for choosing these values.

Table 4.1 Literature values of sediment properties

Parameter	Water body or case	Range	Reference
v - sedimentation rate	River	0.61-1.28 cm/yr (Clinch and Tennessee Rivers)	USGS, 1977
	Estuary	2.6 cm/yr (Monsweage Bay) 0.5-0.8 cm/yr (Chesapeake Bay)	Churchill, 1976 Schubel, 1969
	Lake	0.03-0.08 cm/yr (Great Lakes and other lakes)	Lerman, 1971; Lerman and Brunskill, 1971; Lerman and Taniguchi, 1971
d - sedimentation depth	LPGS river, lake, estuary cases	10 cm	
	Lake	8-11 cm (Great Lakes)	Lerman, 1971; Churchill, 1976
	Estuary	10 cm	
k_f - direct transfer		0.4 m/yr	Lerman and Brunskill, 1971; Booth, 1975
k_d	LPGS estuary case	Sr, 350 ml/gm Cs, 500 ml/gm	Duursma and Gross, 1971; Duursma, 1973; Nishiwaki, 1973; Booth, 1975; Churchill, 1976; Seymour, 1977; Onishi, 1981
	LPGS river case	Sr, 1,200 ml/gm Cs, 42,500 ml/gm	ORNL, 1967; Booth, 1975
	LPGS Great Lakes case	Sr, 1,200 ml/gm Cs, 13,500 ml/gm	Booth, 1975
ε - sediment efficiency	LPGS small-river case	0.1	Based on fit to data in Clinch River
	LPGS Great Lakes case	1.0	ORNL, 1967

The direct exposure pathway was estimated from average usage per unit surface area of the water body and is also presented in Section 4.3 and Appendix D of the LPGS.

Drinking water use in the LPGS is presented as the average number of users as a function of distance downstream from the plant. Table 4.3.1 of the LPGS presents the river and stream average water usages. The number of drinking water users on the Great Lakes is tabulated in Table 4.3.3 of the LPGS.

Table 4.2 summarizes the pathway usage rates analyzed in the LPGS. Values for usage presented in this table should be used for the site only in cases where necessary site-specific data are lacking.

4.3.4 Data Worksheet

As an aid in running the program, a detailed worksheet is provided in Figure 4.2. This worksheet should be completed with the necessary data for the chosen options and will assist the user in preparing inputs for the program at run time.

Table 4.2 Liquid pathway usage rates used in LPGS

Liquid pathway usage and location	Value
Drinking Water[1]	
River sites, km from site	
0-16	4,300 users
16-32	28,000 users
32-80	45,000 users
80-160	67,000 users
160-320	110,000 users
320-640	260,000 users
640-1300	100,000 users
Great Lakes	
Lake Superior	0.26×10^6 users
Lake Michigan	11×10^6 users
Lake Huron	0.71×10^6 users
Lake Erie	9.5×10^6 users
Lake Ontario	1.9×10^6 users
Seafood Consumption[2]	
Rivers	
Recreational finfish	4.5 kg/ha/yr (4 lb/acre/yr)
Commercial finfish	2.3 kg/ha/yr (2 lb/acre/yr)
Shellfish	0
Lakes	
Recreational finfish	5.6 kg/ha/yr (5 lb/acre/yr)
Commercial finfish	0.6 kg/ha/yr (0.5 lb/acre/yr)
Estuaries	
Recreational finfish	93 kg/ha/yr
Commercial finfish	11 kg/ha/yr
Recreational shellfish	22 kg/ha/yr
Commercial shellfish	29 kg/ha/yr
Coastal sites	
0-5 km off shore	
Commercial	70 kg/ha/yr
Recreational	49 kg/ha/yr
5-19 km off shore	
Commercial	7.3 kg/ha/yr
Recreational	0
19-80 km off shore	
Commercial	1.1 kg/ha/yr
Recreational	0
Direct Exposure	
Rivers	1 user-hr/ha-day (0.5 user-hr/(water) acre day)
Lakes	0.5 user-hr/ha-day (0.25 user-hr/(water) acre day)
Estuaries	1 user-hr/ha-day (0.5 user-hr/(water) acre day)
Coastal sites	68,750 user-hr/yr/linear kilometer of beach

[1] Rivers and lakes only.

[2] On basis of water surface area.

A. Title of run #, to 60 characters

B. Groundwater transport options (all sites)
(1 = enter groundwater transmittal directly, 2 = enter travel time, 3 = Darcy's law, 4 = water balance, 5 = freshwater lens)

Groundwater Treatment Option 1 (enter groundwater transmittal factors)

a. Sr-90 = __________

b. Cs-134 = __________

c. Cs-137 = __________

Groundwater Treatment Option 2 (enter travel time)

T = __________ yr

Groundwater Treatment Option 3 (Darcy's law)

a. Distance from source to sink = __________ ft

b. Hydraulic conductivity = __________ ft/yr

c. Effective porosity = __________

d. Slope = __________ ft/ft

Groundwater Treatment Option 4 - Recharge to Water Table

a. Distance from top of hill to sink = __________ ft

b. Distance from source to sink = __________ ft

c. Thickness of saturated layer at sink = __________ ft

d. Recharge to water table = __________ $(ft^3/yr)/ft^2$

Figure 4.2 Data worksheet for liquid pathways program

e. Hydraulic conductivity = __________ ft/yr

f. Slope of land = __________ ft/ft (must be greater than zero)

g. Effective porosity = __________

C. For Groundwater Treatment Options 2, 3, 4, and 5 only
Option for inputting or calculating retardation
(1 = input R_d, 2 = calculate R_d)

1. Input R_d

   a. Sr = __________

   b. Cs = __________

2. Calculate R_d

   a. K_d for Sr = __________ ml/gm

   b. K_d for Cs = __________ ml/gm

   c. Soil bulk density = __________ gm/ml

   d. Total porosity of soil = __________

D. Type of water body (1 = river, 2 = Great Lake, 3 = estuary, 4 = coastal)

____

E. Number of segments in water body, up to 30 (river, Great Lakes, or estuary cases only)

____

F. For each segment (river, Great Lakes, and estuary only)

Figure 4.2 (Continued)

Segment	Drinking water, users	Finfish catch, lb	Shellfish catch, lb	Shoreline, user-hours
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				

G. Surface water dilution option for rivers, Great Lakes, and estuaries only (1 = read in dilution, 2 = sediment model, 3 = estuary salinity model)

____

____

Surface Water Treatment Option 1 (read in dilutions) - up to 30 segments

Segment	Dilution, sec/ft^3
1.	
2.	
3.	
4.	
5.	
6.	
7.	
8.	
9.	
10.	

Figure 4.2 (Continued)

Surface Water Treatment Option 2 (sediment model)

a. k_d for Sr = __________ ml/gm

b. k_d for Cs = __________ ml/gm

c. k_f (was 1.3 ft/yr in LPGS) = ____________ ft/yr

d. ε (was 0.1 for LPGS river, 1.0 for LPGS lake) = __________

e. Sediment depth (was 0.33 ft in LPGS river and lake) = __________ ft

f. Sediment density (was 2.0 gm/ml) = __________ gm/ml

g. For each river segment up to 30 segments, enter:

Segment	Flowrate leaving, ft^3/sec	Volume,* ft^3	Depth, ft	Sedimentation rate ft/yr
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				

Surface Water Treatment Option 3 (salinity model)

a. Seawater salinity = __________ ppt

b. For each segment up to 30 segments, enter:

---

*Between upstream and downstream limits of segment at mean river stage.

Figure 4.2 (Continued)

Segment	Salinity, ppt	Freshwater throughput, ft^3/sec
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		

H. Change basic data used in LPGS case? (all sites - optional) (1 = bioaccumulation factors, 2 = core inventory, 3 = sump release fractions, 4 = water treatment factors, 5 = edible fish portion, 6 = no more changes)

____

____

1. Bioaccumulation factors for Sr = __________ and Cs = __________

   (default values: Sr = 5, Cs = 400 freshwater, Sr = 2, Cs = 40 saltwater)

2. Core inventory for

   Sr-90 = __________ Ci (default = 6.1 x 10^6 Ci)

   Cs-134 = __________ Ci (default = 2.1 x 10^7 Ci)

   Cs-137 = __________ Ci (default = 8.6 x 10^6 Ci)

3. Sump water release fractions for

   Sr-90 = __________ (default = 0.24)

   Cs-134 = __________ (default = 1.0)

   Cs-137 = __________ (default = 1.0)

Figure 4.2 (Continued)

4. Water treatment factors (freshwater sites only) for Sr = __________

and Cs = __________

(default = 0.2 for Sr, 0.9 for Cs)

5. Edible fish portion = __________

(default = 0.5)

6. No more changes

I. Coastal dispersion model only

1. Drift current parallel to shore (used 4,320 m/day in LPGS) =

__________ m/day

2. Effective depth (used 10 m in LPGS) = __________ m

3. Number of offshore regions = __________

4. For each region (up to 10 regions):

Region	Width, km	Finfish catch, kg/ha/yr	Shellfish catch, kg/ha/yr
1.			
2.			
3.			
4.			
5.			

5. Number of longshore increments = __________ (up to 200)
(typically 200)

6. Length of each longshore increment = __________ km
(typically 1 km)

7. Shoreline use = __________ user-hr/linear kilometer of beach/yr
(was 68,760 user-hr/linear kilometer/yr in LPGS)

Figure 4.2 (Continued)

5 BASE CASE EXAMPLES

In this section, the liquid pathways program will be rerun for the base cases presented in the LPGS (NUREG-0440). The purpose of these runs is twofold:

(1) The capabilities of the program will be demonstrated for typical cases.

(2) The surrogate population doses for the LPGS cases will be determined by comparison with other cases for which the program will be run.

5.1 Groundwater Transport - All Cases

For all land-based sites in the LPGS except the dry site, the travel time for groundwater between the reactor and the surface water was 0.61 yr. The retardation factors R_d were 9.2 for strontium and 83 for cesium. Groundwater Treatment Option 2 will therefore be used in all cases.

5.2 Large-River Site

The large-river site is assumed to include a 100-mi reach of a river patterned after the Mississippi River. Usage rates for the river are 100,000 drinking water users and 150,000 lb round weight (as caught) of fish catch per year, of which 50% is considered edible. No shellfish catch was considered. Shoreline usage is estimated to be 4.6 million user-hr/yr (Section 4.3.3.1, NUREG-0440).

The flowrate for dilution in the river taken from Table 4.2.1 of the LPGS is 490,200 ft^3/sec.

The run is set up in one section because no space-dependent data are given. The river segment is 2,100 ft wide and 100 mi long. No sedimentation is assumed. Depth for this segment was not given, but assuming a nominal 30-ft depth, the volume of the segment would be 3.3×10^{10} ft^3. The residence time of water in the segment, $V/q = 0.82$ day, is far smaller than the half-lives of the radionuclides evaluated. In this case, the dilutions can be calculated directly from the flowrate:

$$\text{Dilution} = 1/Q = 2.14 \times 10^{-6}$$

and are the same for Sr-90, Cs-134, and Cs-137.

The inputs and outputs of the program are shown in Figure 5.1.

5.3 Small-River Site

The river model is based on the Clinch-Tennessee-Ohio Mississippi River system for hydrologic properties, but usage rates are generic values compiled from average usage rates for U.S. rivers. Data inputs for running the computer program are presented in Table 5.1.

In the original LPGS, the river system was considered to be a series of reservoirs in the Clinch and Tennessee River segments in which sediment scavenging plays an active role in reducing concentrations. In the Ohio and Mississippi River segments, sediment scavenging was not considered to be important.

The present model evaluates the river in 13 segments, using the river model with sediment (Surface Water Treatment Option 2). Parameters for the Tennessee River portions of the model were determined from U.S. Department of Agriculture references (Dendy and Champion, 1973), since the sediment effects depend on these parameters. In the Ohio and Mississippi River segments, however, sediment effects were assumed to be unimportant; therefore, no accurate determination of river dimensions was necessary.

The original LPGS evaluation was based on flowrates that were taken from a single year of flowrate data, and chosen to fall between the arithmetic mean and the reciprocal mean flow. All hydrologic parameters for the small-river site are given in Table 5.1.

```
LIQUID PATHWAY PROGRAM
US NUCLEAR REGULATORY COMMISSION
R CODELL NOV 4,1983

ENTER NAME OF SITE AND TITLE
? LPGS LARGE RIVER BASE CASE

************************

GROUNDWATER TREATMENT OPTIONS
1.ENTER GR.WTR TRANSMITTAL FACTORS
  FOR SR90,CS134,CS137
2.ENTER TRAVEL TIME THROUGH GROUND
3.CALC TRAVEL TIME FROM DARCYS LAW
4.CALC TRAVEL TIME FROM RECHARGE
  TO WATER TABLE
5.CALC TRAVEL TIME IN FRESHWATER
  LENS FOR COASTAL ENVIRONMENT
ENTER OPTION NUMBER
? 2

INPUT TRAVEL TIME FOR GROUNDWATER,YRS
? 0.61
ENTER 1 TO INPUT RD FACTORS
ENTER 2 TO CALC RD FACTORS
? 1
INPUT RD FOR SR AND CS
? 9.2,83
GROUNDWATER PASSAGE FACTORS
SR90 =         .87802
CS134 =         1.1807E-07
CS137 =        .31164
GRNDWATER TRANSMISSION FACTORS
FOR LPGS WERE
SR90 = .87802
CS134 = 1.1897E-7
CS137 = .31164
RATIO OF PRESENT SITE GROUNDWATER
TRANSMITTAL FACTORS TO LPGS'S
SR90 =          1
CS134 =        .999997
CS137 =        .999998

****************************

ENTER TYPE OF WATER BODY:
1.RIVER    2.GREAT LAKES
3.ESTUARY  4.COASTAL
? 1
ENTER NUMBER OF SEGMENTS IN WATER BODY
? 1
ENTER NUMBER OF DRINKING WATER USERS,
FINFISH CATCH, POUNDS,
SHELLFISH CATCH,POUNDS
AND SHORELINE USER HOURS IN EACH SEGMENT
SEGMENT 1 ? 100000,150000,0,4.6E6

**********************
```

Figure 5.1 LPGS large-river base case

```
DILUTION FACTOR OPTIONS
1.READ IN DILUTIONS
2.CALCULATE NUCLIDE SPECIFIC DIL
  FROM SED LOADS IN RIVER OR LAKES
3.CALC DILUTIONS FROM SALINITY
  PROFILE IN ESTUARY
ENTER OPTION NUMBER
? 1

*****************************************************

ENTER DILUT.FOR SR90,CS134,CS137 IN EACH SEG
SEGMENT 1 ? 2.04E-6,2.04E-6,2.04E-6

**************************

CHANGE LPGS BASE PARAMETERS?
CHANGE:
1.BIOACCUMULATION FACTORS
2.CORE INVENTORY
3.SUMP RELEASE FRACTION
4.WATER TREATMENT FACTOR
5.EDIBLE FISH PORTION
6.NO MORE CHANGES
SELECT OPTION NUMBER
? 6

*****************************************************


*************************
CALCULATED POPULATION DOSES
*************************

DRINKING WATER DOSE, PERSON REMS
SR90 =          79789.9
CS134 =         4.50552E-02
CS137 =         28737.7
TOT DRINK WTR DOSE =          108528       PERSON REMS

AQUATIC FOOD INGESTION DOSE IN PERSON REMS

SR90 =          923.153
CS134 =         9.26719E-03
CS137 =         5910.91
TOTAL FISH INGESTION DOSE =                    6834.08       PERSON REMS

SHORELINE EXPOSURE DOSE,PERSON REMS

SR90 =          0
CS134 =         2.38842E-03
CS137 =         7457.13
TOTAL SHORELINE EXPOSURE =   7457.13       PERSON REMS

TOTAL POPULATION DOSE FOR LPGS
COMPARISON =   122819        PERSON REMS

STOP at 02760
```

Figure 5.1 (Continued)

Table 5.1 Physical parameters for small-river site

Segment name	Q, flowrate leaving, ft^3/sec	V, volume, ft^3	d, average depth, ft	v,* sediment velocity, ft/yr	Drinking water users	Finfish catch, lb/yr	Shoreline, user-hr/yr
White Oak Creek to mouth of Clinch River	1,761	6.14E8**	30.41	0.035	4,300	2.8E3	6.38E4
Watts Bar Lake	26,385	2.58E10	30.41	0.035	28,000	2.36E5	5.77E6
Chicamauga Lake	32,573	2.15E10	21.03	0.042	102,000	2.14E5	5.22E6
Hales Bar Lake	34,247	6.5E9	21.03	0.042	61,000	0	0
Guntersville Lake	40,000	4.66E10	15.81	0.0249	194,000	4.11E5	1.0E7
Wheeler Lake	45,045	4.63E10	15.81	0.02	161,000	4.07E5	9.93E6
Wilson Lake	46,512	2.83E10	42.13	0.035	15,000	9.39E5	2.28E6
Pickwick Lake	50,000	4.84E10	25.82	0.026	70,000	2.61E5	6.35E6
Kentucky Lake	58,824	1.24E11	12.62	0.036	105,000	9.71E5	2.37E7
Kentucky Dam to Ohio River Junction	58,824	7.98E9	33	0	5,000	3.37E4	8.26E5
Ohio River Junction to Memphis	176,991	3.03E9	33	0	5,000	1.28E4	5.57E4
Memphis to Vicksburg	393,701	8.09E10	33	0	50,000	3.43E5	8.36E6
Below Vicksburg	490,196	6.71E10	33	0	45,000	2.84E5	6.94E6

*Calculated as the average sediment accumulation in water body, ft^3/yr, divided by the water body surface area, ft^2.

**6.14E8 = 6.14×10^8, etc.

NOTE: Other parameters are:
k_d = 1,200 for Sr; k_d = 42,500 for Cs; k_f = 1.3 ft/yr; sediment depth d_2 = 0.33 ft; sediment efficiency ε = 0.1

Usage Rate

Usage rates for the small-river site are generic values based on averages for U.S. rivers. Drinking water use is given in the LPGS as a function of downstream distance from the site. Aquatic food harvest is given in the LPGS as a function of surface area and is a total of 2.55×10^6 lb round weight (of which 50% is edible) distributed according to the surface area of the various reaches of the water body. No shellfish catch was considered in this case.

Shoreline usage is based on the reservoir surface area and a generic usage rate of 1 user-hr/ha-day/yr, and is presented in Table 5.1 for the reservoir segments.

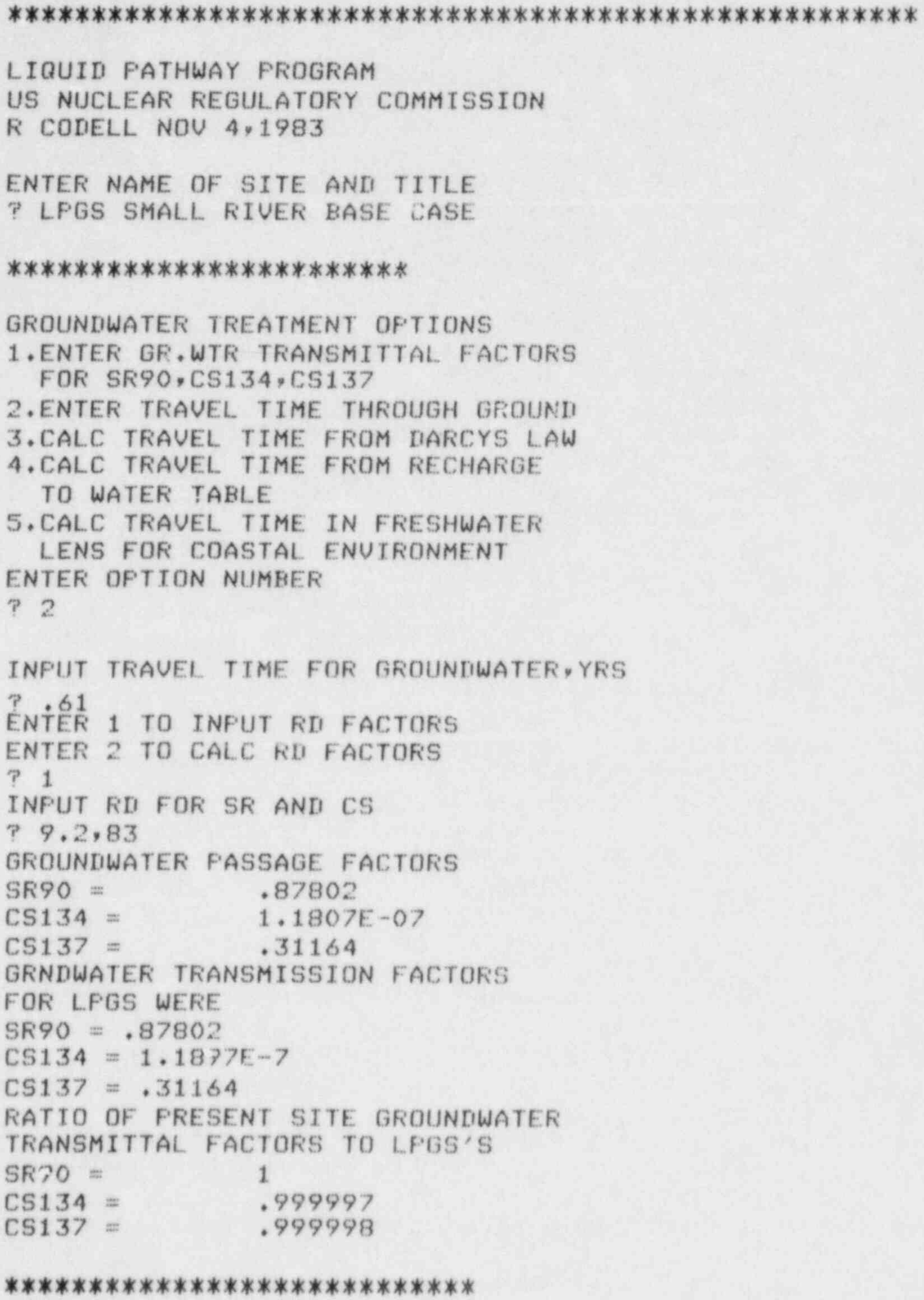
The output for this case is shown in Figure 5.2.

5.4 Great Lakes Site

The Great Lakes site in the LPGS was modeled taking near-shore dispersion as well as mixing throughout the entire lake into account. The study found, however, that the largest contribution to population dose resulted from long-term concentration uniformly distributed throughout the lake, which is adequately expressed by the mixed tank-reservoir model incorporated in the present model.

The LPGS lake site is patterned after Lake Ontario, which is the last lake in the series of the five Great Lakes. Hydrologic and water-use parameters for this model are given in Table 5.2.

Because the LPGS lake (Lake Ontario) is the last lake in the series, the model is set up for a single segment. The output for this case is shown in Figure 5.3. It should be noted that if any of the other Great Lakes were to be evaluated, the model should be set up with more than one segment to consider the lakes that are downstream in the series.



```
*******************************************************

LIQUID PATHWAY PROGRAM
US NUCLEAR REGULATORY COMMISSION
R CODELL NOV 4,1983

ENTER NAME OF SITE AND TITLE
? LPGS SMALL RIVER BASE CASE

************************

GROUNDWATER TREATMENT OPTIONS
1.ENTER GR.WTR TRANSMITTAL FACTORS
  FOR SR90,CS134,CS137
2.ENTER TRAVEL TIME THROUGH GROUND
3.CALC TRAVEL TIME FROM DARCYS LAW
4.CALC TRAVEL TIME FROM RECHARGE
  TO WATER TABLE
5.CALC TRAVEL TIME IN FRESHWATER
  LENS FOR COASTAL ENVIRONMENT
ENTER OPTION NUMBER
? 2

INPUT TRAVEL TIME FOR GROUNDWATER,YRS
? .61
ENTER 1 TO INPUT RD FACTORS
ENTER 2 TO CALC RD FACTORS
? 1
INPUT RD FOR SR AND CS
? 9.2,83
GROUNDWATER PASSAGE FACTORS
SR90 =          .87802
CS134 =         1.1807E-07
CS137 =         .31164
GRNDWATER TRANSMISSION FACTORS
FOR LPGS WERE
SR90 = .87802
CS134 = 1.1877E-7
CS137 = .31164
RATIO OF PRESENT SITE GROUNDWATER
TRANSMITTAL FACTORS TO LPGS'S
SR90 =          1
CS134 =         .999997
CS137 =         .999998

****************************
```

Figure 5.2 LPGS small-river base case

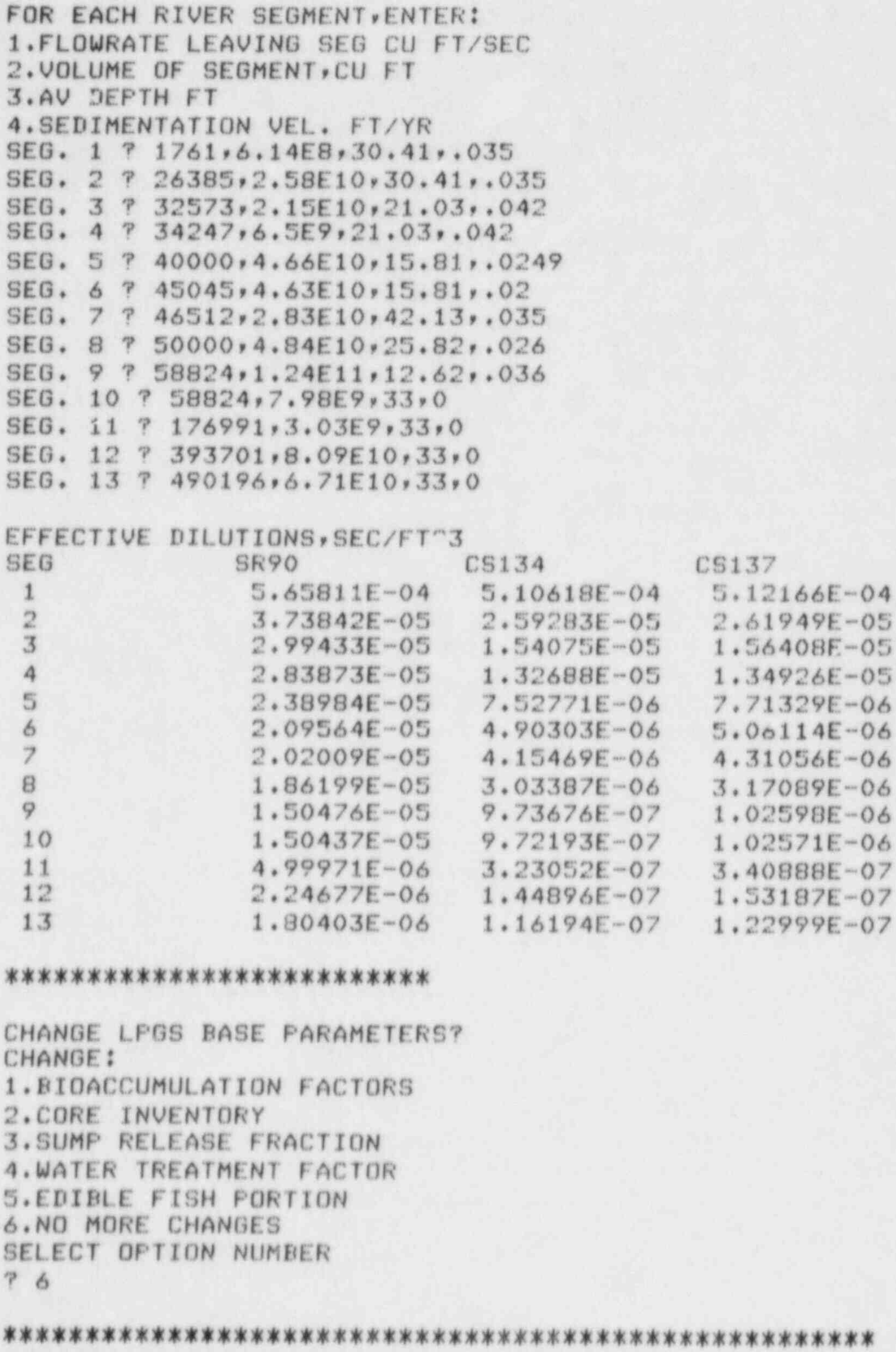
```
ENTER TYPE OF WATER BODY:
1.RIVER    2.GREAT LAKES
3.ESTUARY  4.COASTAL
? 1
ENTER NUMBER OF SEGMENTS IN WATER BODY
? 13
ENTER NUMBER OF DRINKING WATER USERS,
FINFISH CATCH, POUNDS,
SHELLFISH CATCH,POUNDS
AND SHORELINE USER HOURS IN EACH SEGMENT
SEGMENT 1 ? 4300,2800,0,6.38E4
SEGMENT 2 ? 28000,2.36E5,0,5.77E6
SEGMENT 3 ? 102000,2.14E5,0,5.22E6
SEGMENT 4 ? 61000,0,0,0
SEGMENT 5 ? 194000,4.11E5,0,1.0E7
SEGMENT 6 ? 161000,4.07E5,0,9.93E6
SEGMENT 7 ? 15000,9.39E5,0,2.29E6
SEGMENT 8 ? 70000,2.61E5,0,6.35E6
SEGMENT 9 ? 105000,9.71E5,0,2.37E7
SEGMENT 10 ? 5000,3.37E4,0,8.26E5
SEGMENT 11 ? 5000,1.28E4,0,5.57E4
SEGMENT 12 ? 50000,3.43E5,0,8.36E6
SEGMENT 13 ? 45000,2.84E5,0,6.94E6

**********************

DILUTION FACTOR OPTIONS
1.READ IN DILUTIONS
2.CALCULATE NUCLIDE SPECIFIC DIL
  FROM SED LOADS IN RIVER OR LAKES
3.CALC DILUTIONS FROM SALINITY
  PROFILE IN ESTUARY
ENTER OPTION NUMBER
? 2

ENTER KD FOR SR AND CS IN SED,ML/GM
? 1200,42500
ENTER KF COEFFICIENT
(WAS 1.3 FT/YR IN LPGS)
? 1.3
ENTER SED EFFICIENCY
? 0.1
ENTER SEDIMENT DEPTH IN
RESERVOIR SEGMENTS,FT
? .33
ENTER SEDIMENT DENSITY,GM/CC
? 2
```

Figure 5.2 (Continued)



```
FOR EACH RIVER SEGMENT,ENTER:
1.FLOWRATE LEAVING SEG CU FT/SEC
2.VOLUME OF SEGMENT,CU FT
3.AV DEPTH FT
4.SEDIMENTATION VEL. FT/YR
SEG. 1 ? 1761,6.14E8,30.41,.035
SEG. 2 ? 26385,2.58E10,30.41,.035
SEG. 3 ? 32573,2.15E10,21.03,.042
SEG. 4 ? 34247,6.5E9,21.03,.042
SEG. 5 ? 40000,4.66E10,15.81,.0249
SEG. 6 ? 45045,4.63E10,15.81,.02
SEG. 7 ? 46512,2.83E10,42.13,.035
SEG. 8 ? 50000,4.84E10,25.82,.026
SEG. 9 ? 58824,1.24E11,12.62,.036
SEG. 10 ? 58824,7.98E9,33,0
SEG. 11 ? 176991,3.03E9,33,0
SEG. 12 ? 393701,8.09E10,33,0
SEG. 13 ? 490196,6.71E10,33,0

EFFECTIVE DILUTIONS,SEC/FT^3
SEG           SR90           CS134          CS137
 1             5.65811E-04    5.10618E-04    5.12166E-04
 2             3.73842E-05    2.59283E-05    2.61949E-05
 3             2.99433E-05    1.54075E-05    1.56408E-05
 4             2.83873E-05    1.32688E-05    1.34926E-05
 5             2.38984E-05    7.52771E-06    7.71329E-06
 6             2.09564E-05    4.90303E-06    5.06114E-06
 7             2.02009E-05    4.15469E-06    4.31056E-06
 8             1.86199E-05    3.03387E-06    3.17089E-06
 9             1.50476E-05    9.73676E-07    1.02598E-06
 10            1.50437E-05    9.72193E-07    1.02571E-06
 11            4.99971E-06    3.23052E-07    3.40888E-07
 12            2.24677E-06    1.44896E-07    1.53187E-07
 13            1.80403E-06    1.16194E-07    1.22999E-07

*************************

CHANGE LPGS BASE PARAMETERS?
CHANGE:
1.BIOACCUMULATION FACTORS
2.CORE INVENTORY
3.SUMP RELEASE FRACTION
4.WATER TREATMENT FACTOR
5.EDIBLE FISH PORTION
6.NO MORE CHANGES
SELECT OPTION NUMBER
? 6

*****************************************************
```

Figure 5.2 (Continued)

```
*************************
CALCULATED POPULATION DOSES
*************************

DRINKING WATER DOSE, PERSON REMS
SR90 =         7.72711E+06
CS134 =        1.75544
CS137 =        1.13821E+06
TOT DRINK WTR DOSE =          8.86532E+06  PERSON REMS

AQUATIC FOOD INGESTION DOSE IN PERSON REMS

SR90 =         227651
CS134 =        .656989
CS137 =        428659
TOTAL FISH INGESTION DOSE =                 656310       PERSON REMS

SHORELINE EXPOSURE DOSE,PERSON REMS

SR90 =         0
CS134 =        .112312
CS137 =        357740
TOTAL SHORELINE EXPOSURE =    357740       PERSON REMS

TOTAL POPULATION DOSE FOR LPGS
COMPARISON =   9.87937E+06  PERSON REMS

STOP at 02760
```

Figure 5.2 (Continued)

Table 5.2 Hydrologic and water-use parameters for LPGS Great Lakes site

Parameter	Value
Volume V	5.78×10^{13} ft^3
Flowrate Q	2.34×10^5 ft^3/sec
Sediment velocity v*	1.64×10^{-3} ft/yr
Sediment density	2 gm/ml
k_d for Sr	1,200 ml/gm
k_d for Cs	13,500 ml/gm
Lake depth d_1	98.4 ft
Sediment depth d_2	0.33 ft
Direct transfer coefficient k_f	1.31 ft/yr
Sediment efficiency ε	1.0
Drinking water users	2.0×10^6
Aquatic food catch	
Finfish only, round weight alive	2.75×10^7 lb
Shoreline usage	4.4×10^8 user-hr/yr

*Calculated as the increase in sediment depth per year.

```
******************************************************

LIQUID PATHWAY PROGRAM
US NUCLEAR REGULATORY COMMISSION
R CODELL NOV 4,1983

ENTER NAME OF SITE AND TITLE
? LPGS GREAT LAKES BASE CASE

************************

GROUNDWATER TREATMENT OPTIONS
1.ENTER GR.WTR TRANSMITTAL FACTORS
  FOR SR90,CS134,CS137
2.ENTER TRAVEL TIME THROUGH GROUND
3.CALC TRAVEL TIME FROM DARCYS LAW
4.CALC TRAVEL TIME FROM RECHARGE
  TO WATER TABLE
5.CALC TRAVEL TIME IN FRESHWATER
  LENS FOR COASTAL ENVIRONMENT
ENTER OPTION NUMBER
? 2

INPUT TRAVEL TIME FOR GROUNDWATER,YRS
? .61
ENTER 1 TO INPUT RD FACTORS
ENTER 2 TO CALC RD FACTORS
? 1
INPUT RD FOR SR AND CS
? 9.2,83
GROUNDWATER PASSAGE FACTORS
SR90 =          .87802
CS134 =         1.1807E-07
CS137 =         .31164
GRNDWATER TRANSMISSION FACTORS
FOR LPGS WERE
SR90 = .87802
CS134 = 1.1897E-7
CS137 = .31164
RATIO OF PRESENT SITE GROUNDWATER
TRANSMITTAL FACTORS TO LPGS'S
SR90 =          1
CS134 =         .999997
CS137 =         .999998

****************************
```

Figure 5.3 LPGS Great Lakes base case

```
ENTER TYPE OF WATER BODY:
1.RIVER    2.GREAT LAKES
3.ESTUARY  4.COASTAL
? 2
ENTER NUMBER OF SEGMENTS IN WATER BODY
? 1
ENTER NUMBER OF DRINKING WATER USERS,
FINFISH CATCH, POUNDS,
SHELLFISH CATCH,POUNDS
AND SHORELINE USER HOURS IN EACH SEGMENT
SEGMENT 1 ? 2.0E6,2.75E7,0,4.4E8

**********************

DILUTION FACTOR OPTIONS
1.READ IN DILUTIONS
2.CALCULATE NUCLIDE SPECIFIC DIL
  FROM SED LOADS IN RIVER OR LAKES
3.CALC DILUTIONS FROM SALINITY
  PROFILE IN ESTUARY
ENTER OPTION NUMBER
? 2

ENTER KD FOR SR AND CS IN SED,ML/GM
? 1200,13500
ENTER KF COEFFICIENT
(WAS 1.3 FT/YR IN LPGS)
? 1.3
ENTER SED EFFICIENCY
? 1
ENTER SEDIMENT DEPTH IN
RESERVOIR SEGMENTS,FT
? .33
ENTER SEDIMENT DENSITY,GM/CC
? 2

FOR EACH RIVER SEGMENT,ENTER:
1.FLOWRATE LEAVING SEG CU FT/SEC
2.VOLUME OF SEGMENT,CU FT
3.AV DEPTH FT
4.SEDIMENTATION VEL. FT/YR
SEG. 1 ? 2.34E5,5.78E13,98.4,1.64E-3

EFFECTIVE DILUTIONS,SEC/FT^3
SEG           SR90          CS134          CS137
 1             2.71268E-06   6.02385E-07   8.92227E-07

**************************
```

Figure 5.3 (Continued)

```
CHANGE LPGS BASE PARAMETERS?
CHANGE:
1.BIOACCUMULATION FACTORS
2.CORE INVENTORY
3.SUMP RELEASE FRACTION
4.WATER TREATMENT FACTOR
5.EDIBLE FISH PORTION
6.NO MORE CHANGES
SELECT OPTION NUMBER
? 6

*****************************************************


*************************
CALCULATED POPULATION DOSES
*************************

DRINKING WATER DOSE, PERSON REMS
SR90 =         2.12201E+06
CS134 =        .266084
CS137 =        251378
TOT DRINK WTR DOSE =         2.37339E+06  PERSON REMS

AQUATIC FOOD INGESTION DOSE IN PERSON REMS

SR90 =         225053
CS134 =        .501688
CS137 =        473960
TOTAL FISH INGESTION DOSE =                699013       PERSON REMS

SHORELINE EXPOSURE DOSE,PERSON REMS

SR90 =         0
CS134 =        .101191
CS137 =        467954
TOTAL SHORELINE EXPOSURE =   467954       PERSON REMS

TOTAL POPULATION DOSE FOR LPGS
COMPARISON =   3.54035E+06  PERSON REMS

STOP at 02760
```

Figure 5.3 (Continued)

5.5 Estuary Site

The LPGS estuary site was loosely patterned after the Delaware River and used a model that accounted for the interaction of sediment. The study concluded that sediment effects in the estuary site were not large.

The present computer program does not incorporate the original LPGS model because the staff now concludes that it was unrealistic. The original LPGS model probably underestimated shoreline and swimming population dose because of the assumption that the water and sediment were in equilibrium at all times. This assumption did not affect the dose calculations for aquatic food dose as severely because it also increased the residence time. The models of choice for evaluating surface water transport and dilution are Surface Water Treatment Options 2 or 3 of the computer program. Surface Water Treatment Option 2 treats surface water transport in the estuary as if it were a river with sediment scavenging, but coefficients for the estuary case would probably be different from those for a river. Surface Water Treatment Option 3 calculates dilution in estuaries on the basis of observed salinity profiles and does not consider sediment scavenging.

The LPGS base estuary case will be evaluated using Surface Water Treatment Option 2, using one segment and the parameters of the original LPGS evaluation, which are presented in Table 5.3. Output of this run is shown in Figure 5.4. Data used in this evaluation are taken from Table 4.1.

5.6 Coastal Site

The coastal site case was set up and run as presented in Offshore Power Systems Topical Report 22A60, Revision 1. Input parameters for this case are given in Table 5.4. Output for this case is presented in Figure 5.5. No shellfish catch was assumed.

Table 5.3 Parameters for LPGS estuary site

Parameter	Value
Flowrate Q	13,000 ft^3/sec
Volume V	1.1×10^{11} ft^3
Cross section A	160,000 ft^2
Effective water depth d_1	33 ft
Effective sediment depth d_2	0.33 ft
Sedimentation velocity v	0.025 ft/yr
Sediment density ρ	2 gm/ml
k_d for Sr	350 ml/gm
k_d for Cs	500 ml/gm
Aquatic food catch*	
Finfish	2.33×10^7 lb
Shellfish	1.12×10^7 lb
Shore usage	2.6×10^8 user-hr/yr
Sediment efficiency ε	1.0

*Bioaccumulation factors for saltwater apply. 50% edible portion.

```
****************************************************

LIQUID PATHWAY PROGRAM
US NUCLEAR REGULATORY COMMISSION
R CODELL NOV 4,1983

ENTER NAME OF SITE AND TITLE
? LPGS ESTUARY BASE CASE

***********************

GROUNDWATER TREATMENT OPTIONS
1.ENTER GR.WTR TRANSMITTAL FACTORS
  FOR SR90,CS134,CS137
2.ENTER TRAVEL TIME THROUGH GROUND
3.CALC TRAVEL TIME FROM DARCYS LAW
4.CALC TRAVEL TIME FROM RECHARGE
  TO WATER TABLE
5.CALC TRAVEL TIME IN FRESHWATER
  LENS FOR COASTAL ENVIRONMENT
ENTER OPTION NUMBER
? 2

INPUT TRAVEL TIME FOR GROUNDWATER,YRS
? .61
ENTER 1 TO INPUT RD FACTORS
ENTER 2 TO CALC RD FACTORS
? 1
INPUT RD FOR SR AND CS
? 9.2,83
GROUNDWATER PASSAGE FACTORS
SR90 =          .87802
CS134 =         1.1807E-07
CS137 =         .31164
GRNDWATER TRANSMISSION FACTORS
FOR LPGS WERE
SR90 = .87802
CS134 = 1.1897E-7
CS137 = .31164
RATIO OF PRESENT SITE GROUNDWATER
TRANSMITTAL FACTORS TO LPGS'S
SR90 =          1
CS134 =         .999997
CS137 =         .999998

***************************
```

Figure 5.4 LPGS estuary base case

```
ENTER TYPE OF WATER BODY:
1.RIVER    2.GREAT LAKES
3.ESTUARY  4.COASTAL
? 3
ENTER NUMBER OF SEGMENTS IN WATER BODY
? 1
ENTER NUMBER OF DRINKING WATER USERS,
FINFISH CATCH, POUNDS,
SHELLFISH CATCH,POUNDS
AND SHORELINE USER HOURS IN EACH SEGMENT
SEGMENT 1 ? 0,2.33E7,1.12E7,2.6E7

**********************

DILUTION FACTOR OPTIONS
1.READ IN DILUTIONS
2.CALCULATE NUCLIDE SPECIFIC DIL
  FROM SED LOADS IN RIVER OR LAKES
3.CALC DILUTIONS FROM SALINITY
  PROFILE IN ESTUARY
ENTER OPTION NUMBER
? 2

ENTER KD FOR SR AND CS IN SED,ML/GM
? 350,500
ENTER KF COEFFICIENT
(WAS 1.3 FT/YR IN LPGS)
? 1.3
ENTER SED EFFICIENCY
? 1
ENTER SEDIMENT DEPTH IN
RESERVOIR SEGMENTS,FT
? .33
ENTER SEDIMENT DENSITY,GM/CC
? 2

FOR EACH RIVER SEGMENT,ENTER:
1.FLOWRATE LEAVING SEG CU FT/SEC
2.VOLUME OF SEGMENT,CU FT
3.AV DEPTH FT
4.SEDIMENTATION VEL. FT/YR
SEG. 1 ? 13000,1.1E11,33,.025

EFFECTIVE DILUTIONS,SEC/FT^3
SEG             SR90          CS134          CS137
 1               6.68402E-05   5.93431E-05   6.34775E-05
```

Figure 5.4 (Continued)

```
**************************

CHANGE LPGS BASE PARAMETERS?
CHANGE:
1.BIOACCUMULATION FACTORS
2.CORE INVENTORY
3.SUMP RELEASE FRACTION
4.WATER TREATMENT FACTOR
5.EDIBLE FISH PORTION
6.NO MORE CHANGES
SELECT OPTION NUMBER
? 6

*****************************************************


*************************
CALCULATED POPULATION DOSES
*************************

DRINKING WATER DOSE, PERSON REMS
SR90 =         0
CS134 =        0
CS137 =        0
TOT DRINK WTR DOSE =          0           PERSON REMS

AQUATIC FOOD INGESTION DOSE IN PERSON REMS

SR90 =         1.09131E+07
CS134 =        5.44553
CS137 =        3.71532E+06
TOTAL FISH INGESTION DOSE =                 1.46284E+07  PERSON REMS

SHORELINE EXPOSURE DOSE,PERSON REMS

SR90 =         0
CS134 =        3.85898
CS137 =        1.62608E+07
TOTAL SHORELINE EXPOSURE =    1.62608E+07  PERSON REMS

TOTAL POPULATION DOSE FOR LPGS
COMPARISON =   3.08892E+07  PERSON REMS

STOP at 02760
```

Figure 5.4 (Continued)

Table 5.4 Parameters for LPGS coastal site

Parameter	Value
Drift current U	4,320 m/day
Effective depth d	10 m
Aquatic food catch	
0-5 km off shore (5 km wide)	120 kg/ha/yr
5-19 km off shore (14 km wide)	7.3 kg/ha/yr
19-80 km off shore (61 km wide)	1.1 kg/ha/yr
Shellfish catch	0
Shoreline usage	68,750 person-hr/yr/linear kilometer of beach
Length of beach downcurrent	160 km

```
************************************************ ****

LIQUID PATHWAY PROGRAM
US NUCLEAR REGULATORY COMMISSION
R CODELL NOV 4,1983

ENTER NAME OF SITE AND TITLE
? LPGS COASTAL SITE BASE CASE

************************

GROUNDWATER TREATMENT OPTIONS
1.ENTER GR.WTR TRANSMITTAL FACTORS
  FOR SR90,CS134,CS137
2.ENTER TRAVEL TIME THROUGH GROUND
3.CALC TRAVEL TIME FROM DARCYS LAW
4.CALC TRAVEL TIME FROM RECHARGE
  TO WATER TABLE
5.CALC TRAVEL TIME IN FRESHWATER
  LENS FOR COASTAL ENVIRONMENT
ENTER OPTION NUMBER
? 2

INPUT TRAVEL TIME FOR GROUNDWATER,YRS
? .61
ENTER 1 TO INPUT RD FACTORS
ENTER 2 TO CALC RD FACTORS
? 1
INPUT RD FOR SR AND CS
? 9.2,83
GROUNDWATER PASSAGE FACTORS
SR90 =          .87802
CS134 =         1.1807E-07
CS137 =         .31164
GRNDWATER TRANSMISSION FACTORS
FOR LPGS WERE
SR90 = .87802
CS134 = 1.1897E-7
CS137 = .31164
RATIO OF PRESENT SITE GROUNDWATER
TRANSMITTAL FACTORS TO LPGS'S
SR90 =          1
CS134 =         .999997
CS137 =         .999998

***************************

ENTER TYPE OF WATER BODY:
1.RIVER    2.GREAT LAKES
3.ESTUARY  4.COASTAL
? 4

*************************
```

Figure 5.5 LPGS coastal base case

```
CHANGE LPGS BASE PARAMETERS?
CHANGE:
1.BIOACCUMULATION FACTORS
2.CORE INVENTORY
3.SUMP RELEASE FRACTION
4.WATER TREATMENT FACTOR
5.EDIBLE FISH PORTION
6.NO MORE CHANGES
SELECT OPTION NUMBER
? 6

*****************************************************

INPUT DRIFT CURRENT,M/D(LPGS=4320)
? 4320
INPUT EFF.DEPTH,M(LPGS=10)
? 10
INPUT NO OF OFFSHORE REGIONS
? 3
FOR EACH REGION INPUT:
1.WIDTH OF REGION,KM
2.FINFISH CATCH,KG/HA/YR
3.SHELLFISH CATCH,KG/HA/YR
REGION 1 ? 5,120,0
REGION 2 ? 14,7.3,0
REGION 3 ? 61,1.1,0
INPUT NUMBER OF LONGSHORE INCREMENTS<=200
? 160
INPUT LONGSHORE INCREMENT,KM
? 1
*********************************************************
NOTE: MAY TAKE A MINUTE
*********************************************************
WORKING ON REGION              1
WORKING ON REGION              2
WORKING ON REGION              3
AQUATIC FOOD INGESTION DOSE PERSON REM

SR90 =          205645
CS134 =         .516098
CS137 =         329184
TOTAL FISH INGESTION DOSE =
 534829        PERSON REMS
INPUT SHORELINE USE,USER-HOURS PER LINEAR KILOMETER OF BEACH
? 68750
SHORELINE DOSE IN PERSON REMS

SR90 =          0
CS134 =         5.59147E-03
CS137 =         2360.07
TOTAL SHORELINE POPULATION DOSE =
 2360.07        PERSON REMS

TOTAL POPULATION DOSE FOR LPGS COMPARISON =
 537189         PERSON REMS

STOP at 05890
```

Figure 5.5 (Continued)

6 CONCLUSION

The procedure and computer program described in the preceding sections greatly facilitate the analysis of comparative liquid pathway consequences for site evaluations. Each site under review should be evaluated with the given procedure. Surrogate population doses for the given site should be compared with the surrogate population doses for the generic sites evaluated in Section 5 of this report. The surrogate population doses for the generic sites are summarized in Table 6.1.

The population dose for the site being studied should be compared with that for the LPGS generic site most closely resembling it. In addition, the groundwater travel time in the studied site should be reported because it bears on the conclusion about possible interdiction of contaminated groundwater.

Table 6.1 Summary of surrogate population doses* for LPGS base cases

Generic site	Drinking water dose, rem	Seafood ingestion dose, rem	Shoreline exposure, rem	Total, rem
Large river	1.08×10^5	6.83×10^3	7.457×10^3	1.228×10^5
Small river	8.865×10^6	6.563×10^5	3.577×10^5	9.88×10^6
Great Lakes	2.34×10^6	6.369×10^5	4.066×10^5	3.540×10^6
Estuary	0	1.463×10^7	1.626×10^8	1.772×10^8
Coastal	0	5.348×10^5	2.36×10^3	5.372×10^5

*These doses should not be accepted at face value, but should be used only for comparison with other sites.

7 REFERENCES

Bear J., Hydraulics of Groundwater, McGraw Hill, New York, 1979.

Booth, R. S., "A System Analysis Model for Calculating Radionuclide Transport Between Receiving Water and Bottom Sediment," Report No. ORNL-TM-4751, Oak Ridge National Laboratory, Oak Ridge, Tenn., Apr. 1975.

Chow V. T., Handbook of Applied Hydrology, McGraw-Hill, New York, 1964.

Churchill, J. H., "Measurement and Computer Modeling of the Distribution of Nuclear Reactor Discharge Radionuclides in the Estuarine Sediment Near the Maine Yankee Atomic Power Plant in Wiscasset Maine," Masters Thesis, Physics Department, University of Maine, Orono, Dec. 1976.

Codell, R. B., Testimony Before Atomic Safety and Licensing Board in Matter of Indian Point Units 2 and 3, Jan. 1983, White Plains, N.Y.

Dendy, F. E., and W. A. Champion, "Summary of Reservoir Sediment Deposition Surveys Made in the United States Through 1970," Misc. Pub. No. 1266, U.S. Department of Agriculture, Washington, D.C., July 1973.

Duursma, E. K., "Specific Activity of Radionuclides Sorbed by Marine Sediments in Relation to the Stable Element Composition," in Radioactive Contamination of the Marine Environment, International Atomic Energy Agency, Vienna, Austria, 1973.

---, and M. G. Gross, "Marine Sediments and Radioactivity," Chapter 6, in Radioactivity in the Marine Environment, National Academy of Sciences, Washington, D.C., 1971.

Gupta, S. K., K. Tanji, D. Nielson, J. Biggar, C. Simmons, and J. MacIntyre, "Field Simulation of Soil-Water Movement With Crop Water Extraction," Water Science and Engineering Paper No. 4013, Department of Land, Air and Water Resources, University of California, Davis, 1978.

Lerman, A., "Transport of Radionuclides in Sediments," in *Proceedings of the Third National Symposium on Radioecology*, Vol. 2, Oak Ridge National Laboratory, Oak Ridge, Tenn., Conf. 710501-p2, May 10-12, 1971.

---, and G. J. Brunskill, "Migration of Major Constituents From Lake Sediments Into Lake Water and its Bearing on Lake Composition," *Limnology and Oceanography*, 16(6):880-890, Nov. 1971.

---, and H. Taniguchi, "Strontium-90 and Cesium-137 in Water and Deep Sediments of the Great Lakes," in *Proceedings of the Third National Symposium on Radioecology*, Vol. 1, Oak Ridge National Laboratory, Oak Ridge, Tenn., Conf. 710501-p1, May 10-12, 1971.

Nishiwaki, Y., Y. Kimura, Y. Honda, H. Morishima, T. Koga, Y. Miyaguchi, and H. Kawai, "Behavior and Distribution of Radioactive Substances in Coastal and Estuarine Waters, in *Radioactive Contamination of the Marine Environment*, International Atomic Energy Agency, Vienna, Austria, 1973.

Oak Ridge National Laboratory, "Comprehensive Report on the Clinch River Study," Report No. ORNL-4035, Oak Ridge, Tenn., Apr. 1967.

Offshore Power Systems, "OPS Liquid Pathway Generic Study," Topical Report 22A60, Jacksonville, Fla., June 1977; Rev. 1, Aug. 1977.

Schubel, J. R., "Distribution and Transportation of Suspended Sediment in Upper Chesapeake Bay," Technical Report No. 60, Chesapeake Bay Institute, Johns Hopkins University, Baltimore, Md., Nov. 1969.

Seymour, A. H., and W. R. Schell, "Distribution Coefficients for Transuranic Elements in Aquatic Environments," Annual Progress Report from the University of Washington, Seattle, Wash., to the U.S. Nuclear Regulatory Commission, May 1977.

Thornthwaite, C.W., and J. Mather, "Instructions for Computing Potential Evapotranspiration and the Water Balance," in Publications in Climatology, Vol. 10, No. 3, Laboratory of Climatology, Centerton N.J., 1957.

U.S. Atomic Energy Commission, WASH-1400 (now NUREG-75/014), "Reactor Safety Study - An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants," Oct. 1975.

U.S. Geological Survey, "Surface Water Supply of the United States," Geological Survey Water Supply Paper 2117, U.S. Department of the Interior, Washington, D.C., 1973.

U. S. Nuclear Regulatory Commission, "Nuclear Power Plant Accident Considerations Under the National Environmental Policy Act of 1969," Federal Register, Vol. 45, No. 118, June 13, 1980, pp. 40101-40104.

---, NUREG-0440, "Liquid Pathway Generic Study: Impacts of Accidental Radioactive Releases to the Hydrosphere From Floating and Land-Based Nuclear Power Plants," Feb. 1978.

---, NUREG/CR-1322, "Critical Review: Radionuclide Transport, Sediment Transport and Water Quality Mathematical Modeling and Radionuclide Absorption/Desorption Mechanisms," Y. Onishi, R. J. Serne, E. M. Arnold, C. E. Cowan, and F. L. Thompson, Jan. 1981.

---, NUREG/CR-1596, "The Consequences From Liquid Pathways After a Reactor Meltdown Accident," S. J. Niemczyk, June 1981.

APPENDIX A

RUNNING WATSTORE DATA BASE SYSTEM TO CALCULATE DILUTION FLOWRATES

TABLE OF CONTENTS

LIST OF FIGURES

TABLE

A.1 INTRODUCTION

A computer program, FLOWAV, has been written by the author (R. Codell) to assist the user in calculating dilutions for rivers that have flow-recording gages included in the U.S. Geological Survey (USGS, 1975) WATSTORE data base. The program uses the daily values file to calculate yearly and long-term mean and reciprocal average flowrates. The output of the program must frequently be interpreted by a procedure to account for recent modifications of the watershed such as urbanization, forest clearing, and regulation by dams. The procedure for running the program and interpreting the data will be explained and demonstrated by example.

A.2 RUNNING FLOWAV

To run the flow-averaging program FLOWAV, the following information is needed:

(1) an active WATSTORE account on the USGS headquarters computer
(2) river gage numbers and State codes
(3) backfile tape numbers for the States in which the gages are located

River gage numbers are available in USGS publications (USGS, 1979). Backfile tapes are the tapes containing the long-term daily value files. The tapes are updated at approximately 6-month intervals, at which time the tape numbers change. The only reliable way of knowing the correct tape numbers is to generate the WATSTORE MESSAGE file printout before submitting the FLOWAV job.

The procedure to generate the WATSTORE MESSAGE file printout, which contains the correct backfile tape numbers and other information on the WATSTORE system, is demonstrated in Figure A.1. A portion of the output from this run, showing the backfile tape numbers, is shown in Figure A.2. A list of State codes is shown in Table A.1.

```
 *RELAY  PUNCH RF
(Job card goes here)
/*ROUTE  PRINT RM1246
//*THIS RUN FOR R CODELL FTS492-8117
//PROCLIB DD DSN=WRD.PROCLIB,DISP=SHR
// EXEC MESSAGE,PRINT=WRD02
/*
//
$$$
```

Figure A.1 WATSTORE MESSAGE job

The FLOWAV program is run by submitting a card deck containing the necessary WATSTORE information to retrieve the information on the desired river gaging stations and processing the information with a FORTRAN computer program. Figure A.3 illustrates the deck setup for two gages on the Missouri River: Sioux City Iowa, gage 06486000, and Omaha Nebraska, gage 06610000. Because the gages are in two different States, two tapes must be requested. From Table A.1, Iowa is State code 19 and Nebraska is State code 31. At the time that this run was made, the corresponding backfile tape numbers from Figure A.2 were 115621 and 115626. The comments in parentheses on the right of each line in Figure A.3 are for the sake of explanation only and are not punched on the cards.

Partial output of the run, for gage 06486000 only, is presented in Figure A.4.

A.3 INTERPRETING OUTPUT FROM PROGRAM

The long-term average reciprocal flowrate can be read from Figure A.4, in the next-to-last column of the tabular data labeled "TOT REC FL." This column is the total average reciprocal flowrate from the beginning of the record to the year listed in Column 1.

The two graphs plotted in Figure A.4 point to an interesting phenomenon. As is often the case, the flow characteristics of rivers are altered by such phenomena as diversion, watershed alteration (e.g., deforestation, urbanization), and regulation by dams. Regulation of rivers has the effect of increasing the

```
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$$$                                                           $$$
$$$    MESSAGES, NOTES, AND NEWS FROM DATASET MEMBER WRD02    $$$
$$$                                                           $$$
$$$             DATE OF FOLLOWING MESSAGE = 830809            $$$
$$$                                                           $$$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$

*******************************************************************
     THE FOLLOWING MAGNETIC TAPES NOW CONTAIN THE LATEST INFORMATION
     FOR THE DAILY VALUES BACKFILE.  THE DAILY VALUES BACKFILE CONTAINS
     ALL DATA FROM BEGINNING OF RECORD THROUGH THE 1981 WATER YEAR THAT
     WAS ENTERED INTO THE FILE BEFORE AUGUST 04, 1983 @09.19.31.78.
*******************************************************************
   WATSTORE DAILY VALUES BACKFILE (6250 BPI) TAPE -- AUGUST 09, 1983
    TAPE                     BEGINNING                    ENDING
     NO                        STATE                       STATE
                               CODE                         CODE
   115609                      01                           02
-------------------------------------------------------------------
   115610                      04                           05
-------------------------------------------------------------------
   115611                      06                           06(11147070)
-------------------------------------------------------------------
   115612                      06(11147500)                 06(11381990)
-------------------------------------------------------------------
   115613                      06(11382000)                 06
-------------------------------------------------------------------
   115614                      08                           08
-------------------------------------------------------------------
   115615                      09                           12(02311600)
-------------------------------------------------------------------
   115616                      12(02312000)                 12
-------------------------------------------------------------------
   115617                      13                           13
-------------------------------------------------------------------
   115618                      15                           15
-------------------------------------------------------------------
   115619                      16                           16
-------------------------------------------------------------------
   115620                      17                           18
-------------------------------------------------------------------
   115621                      19                           20
-------------------------------------------------------------------
   115622                      21                           23
-------------------------------------------------------------------
   115623                      24                           26
-------------------------------------------------------------------
   115624                      27                           28
-------------------------------------------------------------------
   115625                      29                           30
-------------------------------------------------------------------
   115626                      31                           33
-------------------------------------------------------------------
   115627                      34                           35
-------------------------------------------------------------------
```

Figure A.2 Partial output of WATSTORE MESSAGE run

```
   115628                        36                        36
-----------------------------------------------------------------
   115629                        37                        38
-----------------------------------------------------------------
   115630                        39                        40
-----------------------------------------------------------------
   115631                        41                        41
-----------------------------------------------------------------
   115632                        42                        42
-----------------------------------------------------------------
   115633                        44                        47
-----------------------------------------------------------------
   115634                        48                        48(08116700)
-----------------------------------------------------------------
   115635                        48(08117200)              49
-----------------------------------------------------------------
   115636                        50                        51
-----------------------------------------------------------------
   115637                        53                        53
-----------------------------------------------------------------
   115638                        54                        55
-----------------------------------------------------------------
   115639                        56                        97


*****************************************************************
   DAILY VALUE BACKFILE TAPE USERS ARE REMINDED THAT TAPES MUST BE
   USED BY THE ORDER OF STATE CODES AND NOT NUMERICALLY.
*****************************************************************
```

Figure A.2 (Continued)

Table A.1 State codes for backfile tapes

State	Code	State	Code
Alabama	01	Missouri	29
Alaska	02	Montana	30
Arizona	04	Nebraska	31
Arkansas	05	Nevada	32
California	06	New Hampshire	33
Colorado	08	New Jersey	34
Connecticut	09	New Mexico	35
Delaware	10	New York	36
District of		North Carolina	37
Columbia	11	North Dakota	38
Florida	12	Ohio	39
Georgia	13	Oklahoma	40
Hawaii	15	Oregon	41
Idaho	16	Pennsylvania	42
Illinois	17	Rhode Island	44
Indiana	18	South Carolina	45
Iowa	19	South Dakota	46
Kansas	20	Tennessee	47
Kentucky	21	Texas	48
Louisiana	22	Utah	49
Maine	23	Vermont	50
Maryland	24	Virginia	51
Massachusetts	25	Washington	53
Michigan	26	West Virginia	54
Minnesota	27	Wisconsin	55
Mississippi	28	Wyoming	56

```
/*RELAY  PUNCH RE2
    (JOB CARD GOES HERE    )
/*ROUTE  PRINT RMT246
//*THIS RUN FOR R CODELL FTS492-8117
//PROCLIB DD DSN=WRD.PROCLIB,DISP=SHR
/*SETUP     115626/H
// EXEC     DVRETR,VOL1=115626,VOL2=115621,AGENCY=USGS
//HDR.SYSIN DD  *
M3
R00060
D       06486000           ****USGS GAGE AT SIOUX CITY***
D       06610000           ****USGS GAGE AT OMAHA********
/*
//  EXEC FTG1CLG
//FORT.SYSIN DD *
C    PROGRAM FLOWAV   AV AND RECIPROCAL FOR USGS WATSTORE DATA


      (REST OF FORTRAN PROGRAM GOES HERE)


      END
/*
//GO.FT10F001 DD DSN=+BKREC,DISP=(OLD,PASS),
//     DCB=(RECFM=FB,LRECL=1656,BLKSIZE=11592)
//GO.SYSIN DD *

/*
//
$$$
/*EOF
```

Figure A.3 Sample FLOWAV Run

ratio of the reciprocal mean to the arithmetic mean flow because drought-and-flood flows are evened out. Urbanization may have the opposite effect because of the loss of absorbency in the watershed. In either case, the current or projected state of the river should be used in all dilution calculations. The following procedure is one method for taking the current or projected state of the river into account:

```
                        STATION                                  PARA-                     NO                                         CONTRIB.
FILE  STATE  AGENCY  IDENTIFICATION     CROSS      SAMPLING     METER          STAT       VALUE       DIST   COUNTY   DRAINAGE       DRAINAGE
TYPE   CODE   CODE       NUMBER        SECTION       DEPTH       CODE   YEAR   CODE     INDICATOR     CODE    CODE      AREA           AREA

  R     19    USGS    06486000        999999.000 999999.000       60   1929      3    999999.000     19      193   314600.00          0.0



                                                                      HYDROLOGIC  RTV                 STATION LOCATOR
                                                   WELL                  UNIT     SEQ BEG  SITE  LAT-      LONG-   SEQ  GEOLOGIC
         STATION NAME OR LOCAL WELL NUMBER        DEPTH         DATUM    CODE      NO  MO  CODE  ITUDE     ITUDE   NO   UNIT CODE

MISSOURI RIVER AT SIOUX CITY, IOWA             -99993.00     1056.98 10230001      1  10    SW   422910 0962447 00

        YEAR       MIN FLOW    MAX FLOW       NDAYS      YR AV FL     YR REC FL TOT DYS      TOT AV FL   TOT REC FL   RATIO
      (ALL FLOWRATES IN CFS)

        1929        7200.00   178000.00        365       34877,34     19327,56      365      34877,34     19327,56     1,8045
        1930        6100.00    83800.00        365       25490,96     17580,99      730      30184,13     18412,95     1,4499
        1931        5510.00    53600.00        365       15703,86     12802,23     1095      25357,37     16065,94     1,2266
        1939        6800.00   166000.00        365       25330,22     16686,72     1460      25350,57     16216,77     1,5180
        1940        3100.00    52400.00        366       15549,02     10493,35     1826      23385,96     14618,59     1,4818
        1941        3900.00   120000.00        365       19932,03     12687,58     2191      22810,57     14257,11     1,5710
        1942        2920.00   126000.00        365       29253,09     15240,18     2556      23730,57     14389,66     1,9195
        1943        6000.00   208000.00        365       34986,85     18465,36     2921      25137,12     14797,80     1,8947
        1944       10200.00   178300.00        366       39689,89     25833,83     3287      26757,53     15536,84     1,5364
        1945       12000.00   111400.00        365       30472,87     23886,13     3652      27128,86     16099,28     1,2758
        1946        3300.00    87200.00        365       24936,71     17834,14     4017      26929,67     16242,86     1,3983
        1947        3520.00   172000.00        365       37879,18     21052,19     4382      27841,71     16557,93     1,7993
        1948        7400.00   110000.00        366       38474,86     25222,16     4748      28661,37     17008,31     1,5254
        1949        3700.00   177000.00        365       34691,78     22665,08     5113      29091,86     17316,84     1,5306
        1950        3800.00   219000.00        365       36708,22     18925,44     5478      29599,34     17415,48     1,9396
        1951        4000.00   149000.00        365       37833,42     24132,53     5843      30113,70     17723,64     1,5677
        1952        6800.00   438000.00        366       47245,37     27057,73     6209      31123,56     18091,53     1,7461
        1953        7000.00   105000.00        365       31283,01     22258,13     6574      31132,41     18281,54     1,4055
        1954        8000.00    49500.00        365       24868,22     20675,20     6939      30802,90     18393,56     1,2028
        1955        6200.00    36500.00        365       22246,98     17188,66     7304      30375,34     18329,35     1,2943
        1956        8100.00    36500.00        366       23642,76     17348,02     7670      30054,07     18280,01     1,3629
        1957        6000.00    35400.00        365       19770,93     14542,92     8035      29586,95     18069,09     1,3595
        1958        4000.00    35400.00        365       20148,38     15346,55     8400      29176,82     17930,86     1,3129
        1959        6500.00    33000.00        365       20608,19     16109,05     8765      28820,00     17846,82     1,2793
        1960        6800.00    95100.00        366       21387,46     15195,94     9131      28522,07     17722,89     1,4074
        1961        3500.00    32100.00        365       20681,89     16211,50     9496      28228,41     17659,61     1,2881
        1962        3000.00    71000.00        365       20028,57     13149,14     9861      27924,87     17438,20     1,5232
        1963        5000.00    33200.00        365       21208,22     14914,35    10226      27685,12     17333,50     1,4220
        1964        5830.00    35200.00        366       21759,10     15166,74    10592      27480,34     17248,36     1,4347
        1965        6000.00    35200.00        365       22654,82     16711,45    10957      27319,57     17229,92     1,3556
        1966       13000.00    37400.00        365       27418,36     25678,02    11322      27322,74     17414,62     1,0678
        1967        5000.00    36900.00        365       26430,57     20302,65    11687      27294,87     17492,34     1,3018
        1968        9780.00    38300.00        366       28250,71     25255,09    12053      27323,88     17657,14     1,1186
```

Figure A.4 Sample FLOWAV output

```
1969        6240.00     76400.00       365        34271.29     27731.97    12418        27528.08     17647.73      1.2358
1970        9000.00     51200.00       365        33514.79     29279.43    12783        27699.00     18048.95      1.1447
1971       13500.00     69800.00       365        38320.27     32122.66    13146        27993.86     18271.17      1.1929
1972       14500.00     55700.00       366        40745.08     35677.95    13514        28339.18     18515.83      1.1420
1973       19300.00     54100.00       365        32230.14     30108.05    13879        28441.51     18705.23      1.0705
1974       13000.00     40000.00       365        28109.04     26170.06    14244        28432.98     18842.96      1.0741
1975        8000.00     64200.00       365        35476.16     28759.00    14609        28608.95     19006.70      1.2336
1976       12000.00     66200.00       366        39686.06     36010.63    14975        28879.67     19228.61      1.1021
1977        9000.00     38900.00       365        29498.36     27183.69    15340        28894.39     19363.44      1.0851
1978       10400.00     61200.00       365        33923.29     27646.64    15705        29011.26     19499.22      1.2270
1979       15000.00     57600.00       365        38330.14     33993.99    16070        29222.91     19689.91      1.1276
1980       13800.00     43500.00       366        31490.16     29339.64    16436        29273.40     19835.18      1.0733
1981       11000.00     40500.00       365        28541.64     25273.25    16801        29257.50     19928.34      1.1293
1982       10000.00     35300.00       365        26122.19     23190.65    17166        29190.83     19988.12      1.1264
1983       23700.00     50100.00       332        34553.31     33515.88    17498        29292.57     20142.38      1.0310
```

Figure A.4 (Continued)

YEARLY(1) AND CUM(2),SECFT AV FLOWS FOR MISSOURI RIVER AT SIOUX CITY, IOWA

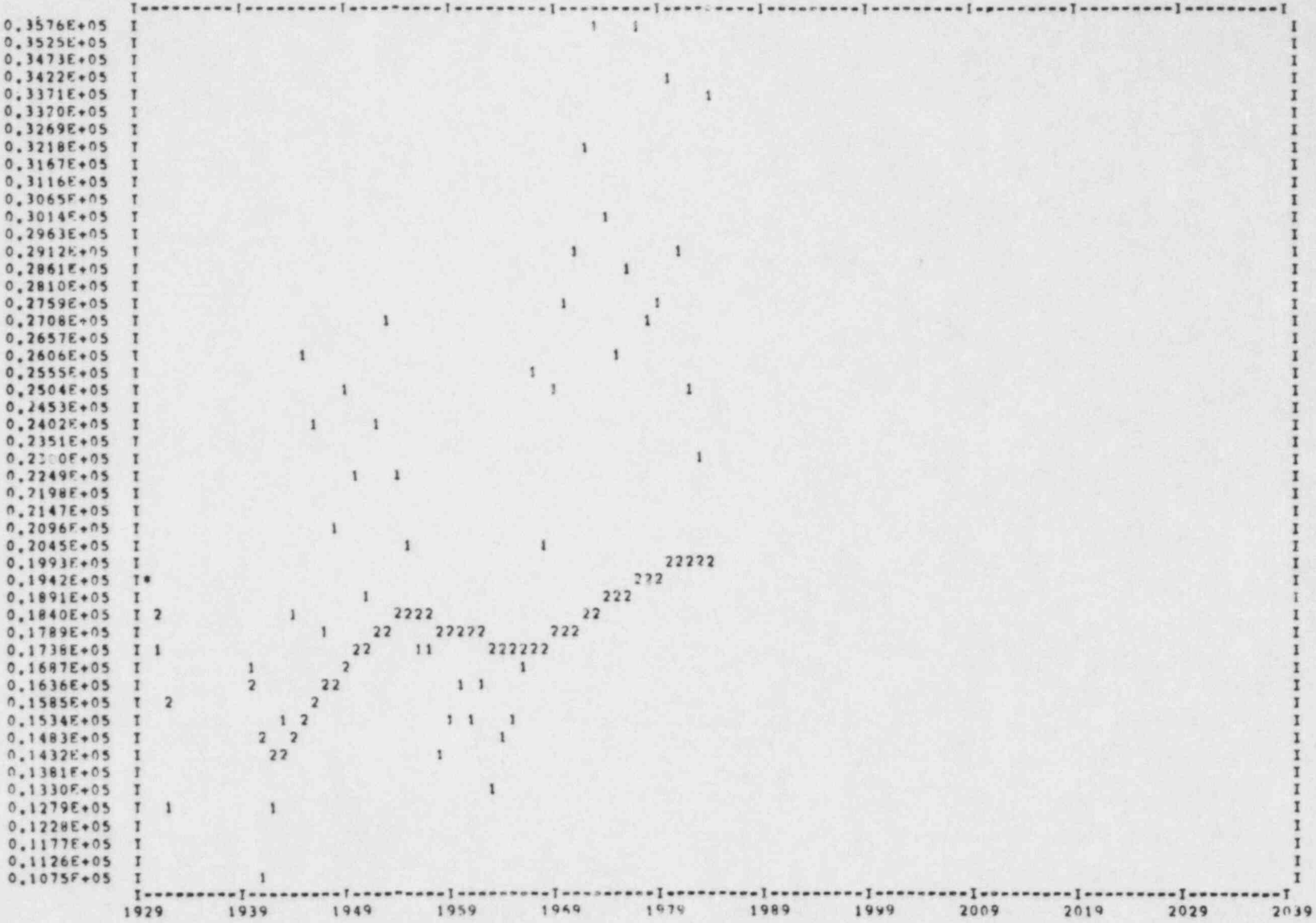


Figure A.4 (Continued)

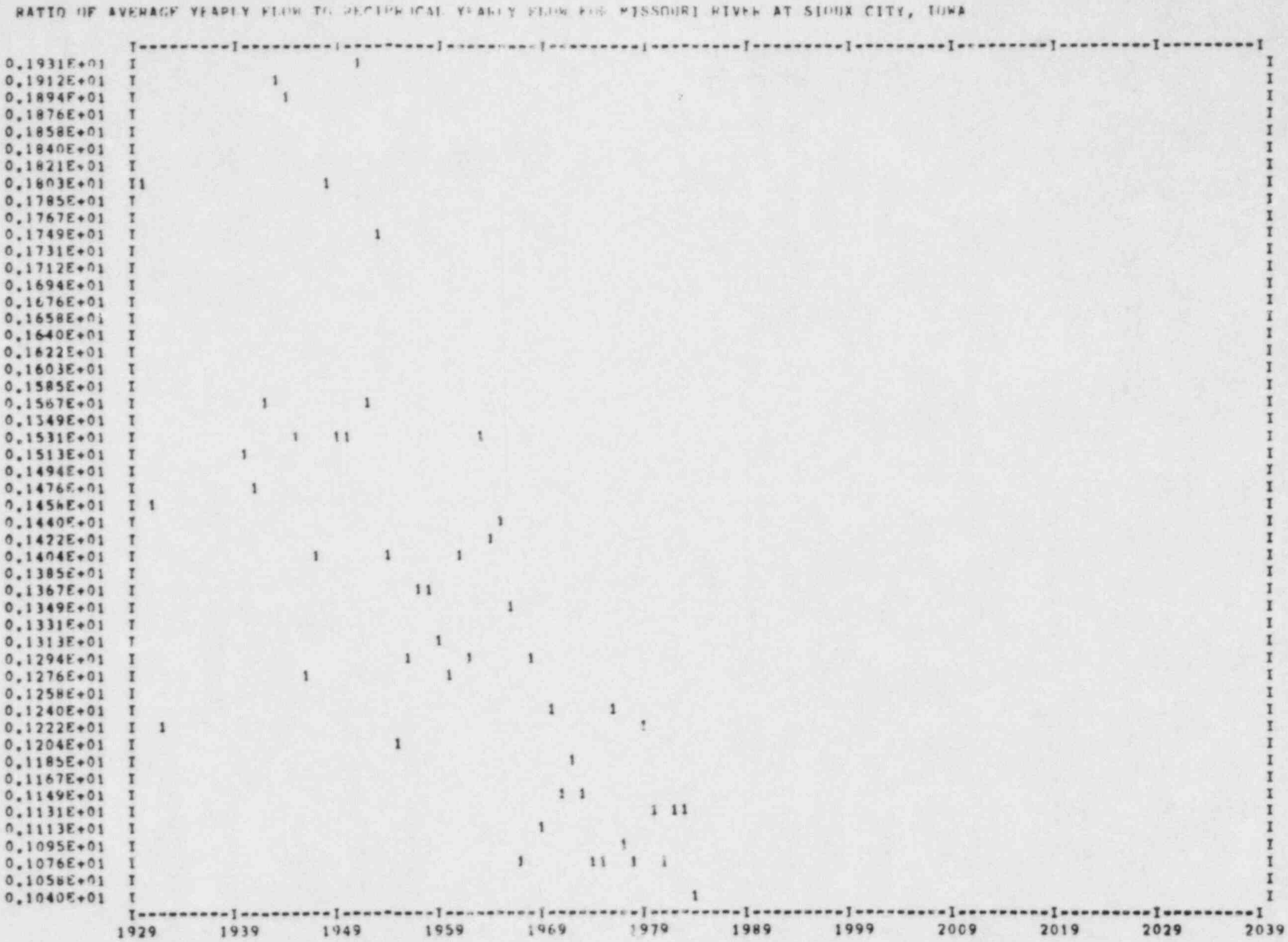


Figure A.4 (Continued)

(1) Calculate long-term arithmetic average flowrate $(\langle q \rangle)_L$ from the total flowrate record in the river (with appropriate adjustments for reservoir filling).

(2) Calculate the current or projected modern ratio $(\langle q \rangle / \bar{q}^R)_M$ from the modern record, which reflects the current or projected state of regulation of the river basin. This is done by calculating the mean and reciprocal mean flowrate manually from the yearly values printed in the program.

(3) Estimate $\bar{q}^R$ for the current or projected state of the river by

$$\bar{q}^R = \frac{(\langle q \rangle)_L}{(\langle q \rangle / \bar{q}^R)_M} \tag{A.1}$$

For example, in the Missouri River at Sioux City, the long-term mean flowrate $(\langle q \rangle)_L$ from 1929 to 1982 was about 29,191 ft^3/sec (Figure A.4, column labeled "TOT AV FL"). The average volumes of the major reservoirs that were closed between 1952 and 1964 (USGS, 1973) were added to the average flowrate and increased the long-term mean flowrate to about 30,500 ft^3/sec.

All transients from the filling of the major reservoirs seem to have subsided by the end of the 1960s. In the 13-year period 1970 to 1982, the arithmetic mean and reciprocal mean flows were calculated:

$$(\langle q \rangle)_M = \frac{1}{13} \sum_{i=1970}^{1982} \langle q_i \rangle = 33,537 \tag{A.2}$$

$$(\bar{q}^R)_M = 13 / \sum_{i=1970}^{1982} \frac{1}{\bar{q}_i^R} = 28,718 \tag{A.3}$$

where $\langle q_i \rangle$ is the arithmetic mean flow for year i and $\bar{q}_i^R$ is the reciprocal mean flow for year i.

The ratio $(\langle q\rangle/\bar{q}^R)_M$ is determined, therefore, to be 33,537.4/28,718.2 = 1.17. The modern value of $\bar{q}^R$ adjusted for regulation is, therefore, 30,500/1.17 = 26,068 ft^3/sec

This value is significantly larger than $(\bar{q}^R)_L$ of about 19,988 ft^3/sec calculated from the total record up to and including 1982 (Figure A.4, column labeled "TOT REC FL"). Of course, $(\bar{q}^R)_L$ would give a more conservative estimate of time-averaged concentration.

The "FLOWAV " program is listed in Figure A.5.

A.4 REFERENCES

U.S. Geological Survey, "Surface Water Supply of the United States, 1966-1970, Part 6, Missouri River Basin," Geological Survey Water Supply Paper 2117, U.S. Department of the Interior, Washington, D.C., 1973.

---, "WATSTORE User's Guide," Open File Report 79-426, U.S. Department of the Interior, Washington, D.C., Aug. 1975.

---, "Catalog of Information on Water Data - Index to Water Data Acquisition," U.S. Department of the Interior, Office of Water Data Coordination, Reston, Va., 1979.

```
C     PROGRAM FLOWAV   AV AND RECIPROCAL FOR USGS WATSTORE DATA
C    R CODELL    USNRC   JULY,1981
      INTEGER*2 RSV1,FORMT,STATE,DVRDIS,DVRSIT,DVRSEQ,BEGMO,WTYR,
     1SCODE,DVRSEN,DVRMON,ENDMO,DVRSV3(19)
      INTEGER    PCODE,DVRHOC,D,DVRDAT
      DIMENSION IMO(12)
      REAL STATSV(5)
      DIMENSION DVRNSV(12)
      DIMENSION Y3(200)
      REAL STATON(5),XSEC,DEPTH,NOVAL,DAILY(31,12),DVRSV2,DVRCTY,
     1DVRNAM(12),DVRDRN,DVRCDA,DVRWD,         OUTPUT(12)
      DOUBLE PRECISION AGENCY,DVRLAT,DVRLON,DVRGUN,DATUM
      DIMENSION IX(200),Y1(200),Y2(200)
C     READ DAILY VALUE FILE ON TAPE UNIT 10
C    READ IPUNCH FROM CARD. IF EQ 0 NOPUNCH, IF NE 0 PUNCH CARD FOR EACH YEAR
      READ(5,601) IPUNCH
  601 FORMAT(I5)
      WRITE(6,7)
C     GET FIRST STATION NAME
      READ(10,40) RSV1,FORMT,STATE,AGENCY,STATSV
      BACKSPACE 10
  353 CONTINUE
      KNTR=0
      SYRRT=1.0E-30
      SYRT=1.0E-30
      NDTOT=0
    1 READ (10,40,END=50) RSV1,FORMT, STATE,AGENCY,STATON,XSEC,DEPTH,
     1PCODE,WTYR,SCODE,NOVAL,DAILY,DVRSV2,DVRDIS,DVRCTY,DVRNAM,DVRDRN,
     1DVRCDA,DVRWD,DVRDAT,DVRHOC,DVRSEQ,DVRMON,DVRSIT,DVRLAT,DVRLON,
     1DVRSEN,DVRGUN,DVRSV3
   40 FORMAT (2A1,A2,A5,5A3,2A4,A4,2A2,A4,200A4,172A4,A3,A2,A3,12A4,3A4,
     1     A4,A4,2A2,A2,A6,A7,A2,A8,19A1)
C     CHECK TO SEE IF STATION NAME HAS CHANGED
      DO 350 I=1,5
      IF(STATSV(I).NE.STATON(I)) GOTO 351
  350 CONTINUE
      GOTO 352
C    NEW STATION FILE
  351 BACKSPACE 10
      DO 355 I=1,5
 355  STATSV(I)=STATON(I)
  487 CONTINUE
C     IF TOTAL YEARS GT 110 PLOT ONLY LAST 110 YEARS
      NSTRT=1
      IF(KNTR.GT.110) NSTRT=KNTR-110
      WRITE(6,420) DVRNSV
  420 FORMAT(1H1,10X,'YEARLY(1) AND CUM(2),RECIP AV FLOWS FOR ',12A4,/)
      CALL PLOT(IX,Y1,Y2,KNTR,2,NSTRT)
      WRITE(6,421) DVRNSV
      CALL PLOT(IX,Y3,Y2,KNTR,1,NSTRT)
      GOTO 353
  352 CONTINUE
      BEGMO=DVRMON
      ENDMO=BEGMO-1
      IF(BEGMO.EQ.1) ENDMO=BEGMO-1
      CALL CONVRT(DVRDAT,DATUM)
      KNTR=KNTR+1
      IF(KNTR.GT.1) GOTO 200
      WRITE(6,2) FORMT,STATE,AGENCY,STATON,XSEC,DEPTH,PCODE,WTYR,SCODE,
     1NOVAL,DVRDIS,DVRCTY,DVRDRN,DVRCDA
      WRITE(6,3) DVRNAM,DVRWD,DATUM,DVRHOC,DVRSEQ,DVRMON,DVRSIT,DVRLAT
     1,DVRLON,DVRSEN,DVRGUN
      DO 700 I=1,12
```

Figure A.5 Listing of program FLOWAV

```
  108 FORMAT(I4,F10.3,F10.2,I3,2F10.2,I5,2F9.2,F9.4)
      GOTO 1
   50 NSTRT=1
      IF(KNTR.GT.110) NSTRT=KNTR-110
      WRITE(6,420) DVRNSV
      CALL PLOT(IX,Y1,Y2,KNTR,2,NSTRT)
      WRITE(6,421) DVRNSV
      CALL PLOT(IX,Y3,Y2,KNTR,1,NSTRT)
  421 FORMAT(1H1,5X, 'RATIO OF AVERAGE YEARLY FLOW TO RECIPROCAL YEARLY
     1FLOW FOR ',12A4,/)
      STOP
    2 FORMAT (1H1,24X,7HSTATION,28X,5HPARA-,20X,2HNO,31X,8HCONTRIB./
     1 57H FILE  STATE  AGENCY  IDENTIFICATION    CROSS    SAMPLING,
     2 3X,5HMETER,8X,4HSTAT,6X,5HVALUE, 5X,
     3 33HDIST  COUNTY  DRAINAGE   DRAINAGE/19H TYPE   CODE   CODE,
     4 6X,6HNUMBER,8X,7HSECTION,5X,5HDEPTH, 4X,4HCODE, 3X,
     5 57HYEAR  CODE    INDICATOR   CODE   CODE       AREA       AREA
     6//,3X,A1,4X,A2,4X,A5,2X,5A3,1X,F10.3,1X,F10.3,2X,I5,2X,I4,2X,I5,
     73X,F11.4,3X,A2,4X,A3,2X,F9.2,3X,F9.2)
    3 FORMAT(///69X,43HHYDROLOGIC  RTV              STATION LOCATOR/
     1 52X,4HWELL, 16X, 4HUNIT, 5X,19HSEQ BEG  SITE  LAT-, 4X,
     2 20HLONG-  SEQ  GEOLOGIC/ 8X, 13HSTATION NAME ,
     3 20HOR LOCAL WELL NUMBER,10X,5HDEPTH, 8X, 5HDATUM, 3X, 4HCODE,6X,
     4 43HNO  MO  CODE  ITUDE   ITUDE  NO   UNIT CODE// 1X,
     512A4,1X,F9.2,F10.2,      I9,4X,I2,2X,I2,3X ,A2,3X,A7,A8,A2,3X,A8,/)
    7 FORMAT(1H1,2X,' AVERAGE AND RECIPROCAL AVERAGE FOR YEARLY AND TOTA
     1L CUMULATIVE FLOWRATES-WATSTORE DATA',/2X,'R CODELL USNRC 7/81',/)
  107 FORMAT(1H0,T8,'YEAR',T18,'MIN FLOW',T30,'MAX FLOW',T43,'NDAYS',
     1 T52,'YR AV FL',T64,'YR REC FL',T74,'TOT DYS',T86,'TOT AV FL',
     2 T98,'TOT REC FL',T110,'RATIO',T120, '1/YR REC FL',/)
  104 FORMAT( 5X,I6,2X,2F12.2,2X,I6,2X,2F12.2,2X,I6,2X,2F12.2,F10.4,
     1 E12.4)
      END
      SUBROUTINE CONVRT(IDATUM,DATUM)
C     THIS SUBROUTINE CONVERTS A FIXED DECIMAL(7,2) NUMBER
C    TO A DOUBLE PRECISION FLOATING POINT NUMBER
      DOUBLE PRECISION DATUM,SIGN
      DATUM=0.00
      ICOMP=0
      IF(IDATUM .LT. 0)ICOMP=1
      SIGN=1.00
C   PEAL OFF SIGN   D=13=MINUS   C=12=POSITIVE
      IJ=IDATUM/16-ICOMP
       IK=IJ*16
      IL=IDATUM-IK
      IF(IL .EQ. 13)SIGN=-1.00
      DO 10 I=1,7
C   PEAL OFF EACH HEX DIGIT STARTING FROM THE RIGHT
      IDATUM=IJ
      IJ=IDATUM/16-ICOMP
      IK=IJ*16
      IL=IDATUM-IK
      DATUM=DATUM+IL*10.**(I-3)
   10 CONTINUE
      DATUM=DATUM*SIGN
      RETURN
      END
```

Figure A.5 (Continued)

```
  700 DVRNSV(I)=DVRNAM(I)
      IF(IPUNCH.EQ.0) GOTO 600
      PUNCH 110,DVRNAM
      PUNCH 109,STATON,DVRDRN,DVRCDA,DVRLAT,DVRLON
  600 CONTINUE
  110 FORMAT(12A4)
  109 FORMAT(5A3,2F12.1,2X,A7,2X,A8)
      WRITE(6,107)
  200 CONTINUE
      II=0
      DO 4 I=BEGMO,12
      II=II+1
    4 IMO(II)=I
      IF(BEGMO.EQ.1) GOTO 66
      DO 5 I=1,ENDMO
      II=II+1
    5 IMO(II)=I
   66 CONTINUE
      SYR=0
      SYRR=0
      NDAYS=0
      FMAX=-1.0E12
      FMIN=1.0E12
      DO 101 D=1,31
      DO 102 I=1,12
      FLOW=DAILY(D,IMO(I))
      IF(FLOW .EQ. NOVAL) GO TO 102
      IF(FLOW .LE. 0.0)GO TO 102
      IF(FLOW.GT.FMAX) FMAX=FLOW
      IF(FLOW.LT.FMIN) FMIN=FLOW
C     ACCUMULATE AVERAGE AND RECIP AVERAGE FLOWS
      NDAYS=NDAYS+1
      SYR=SYR+FLOW
      SYRR=SYRR+1.0/FLOW
  102 CONTINUE
  101 CONTINUE
      FLOWR=0
      AFLOW=0
      IF(NDAYS.LE.0) GOTO 1501
      FLOWR=NDAYS/SYRR
      AFLOW=SYR/NDAYS
 1501 CONTINUE
      NDTOT=NDTOT+NDAYS
      SYRT=SYRT+SYR
      SYRRT=SYRRT+SYRR
      FLOWRT=0
      AFLOWT=0
      IF(NDTOT.LE.0) GOTO 1500
      FLOWRT=NDTOT/SYRRT
      AFLOWT=SYRT/NDTOT
 1500 CONTINUE
      RATIO=AFLOW/FLOWR
      RFLOWR=1.0/(FLOWR+1.0E-20)
      WRITE(6,104) WTYR,FMIN,FMAX,NDAYS,AFLOW,FLOWR,NDTOT,AFLOWT,
     1 FLOWRT,RATIO,RFLOWR
      IX(KNTR)=WTYR
      Y1(KNTR)=FLOWR
      Y2(KNTR)=FLOWRT
      Y3(KNTR)=RATIO
      IF(IPUNCH.EQ.0) GOTO 1
      PUNCH 108,WTYR,FMIN,FMAX,NDAYS,AFLOW,FLOWR,NDTOT,AFLOWT,
     1 FLOWRT,RATIO
```

Figure A.5 (Continued)

```
      SUBROUTINE PLOT(IX,Y1,Y2,NYEARS,NVARS,NSTRT)
C     PRINTER PLOTTER FOR USGS PROGRAM
C     R CODELL AUG 1981
C   IX IS ARRAY OF DATES IN YEARS
C   Y1 IS FIRST INDEPENDENT VARIABLE
C   Y2 IS SECOND INDEPENDENT VARIABLE
C   NYEARS IS NUMBER OF POINTS IN ARRAY - MUST BE LE DIMENSIONS
C   NVARS IS THE NUMBER OF ARRAYS PLOTTED - ONE OR TWO
C   NSTRT IS STARTING POINT IN ARRAY FOR PLOTTING
      DIMENSION IX(1),Y1(1),Y2(1),IDATE(200)
      DIMENSION L(110,50)
      DATA IBL,ICHAR1,ICHAR2/1H ,1H1,1H2/
      DATA ICHAR3/1H*/
      DO 1 I=1,110
      DO 1 J=1,50
 1    L(I,J)=IBL
C     CALCULATE RANGE OF PLOTTED VARIABLES
      NEND=NSTRT+NYEARS
      YMIN=1.0E30
      YMAX=-1.0E30
      DO 3 I=1,NYEARS
      IF(Y1(I) .GT. YMAX)YMAX=Y1(I)
      IF(Y1(I) .LT. YMIN)YMIN=Y1(I)
      IF(NVARS .EQ. 1)GO TO 3
      IF(Y2(I) .GT. YMAX)YMAX=Y2(I)
      IF(Y2(I) .LT. YMIN)YMIN=Y2(I)
 3    CONTINUE
      DY=(YMAX-YMIN)/50.0
      IDATE(1)=1
      J=1
      DO 4 I=2,NYEARS
    4 IDATE(I)=IX(I+NSTRT-1)-IX(NSTRT)+1
C     FILL IN PLOTTER ARRAY
      DO 5 I=1,NYEARS
      IXPLT=IDATE(I)
      IF(IXPLT .GT. 110)IXPLT=110
      IF(IXPLT.LT.1) IXPLT=1
      IY1=(Y1(I+NSTRT-1)-YMIN)/DY+1
      IF(IY1 .GT. 50)IY1=50
      IF(NVARS .EQ. 1)GO TO 7
      IY2=(Y2(I+NSTRT-1)-YMIN)/DY+1
      IF(IY2 .GT. 50)IY2=50
 6    IF(IY1 .NE. IY2)GO TO 8
      L(IXPLT,IY1)=ICHAR3
      GOTO 5
 8    L(IXPLT,IY2)=ICHAR2
 7    L(IXPLT,IY1)=ICHAR1
 5    CONTINUE
C     PLOT GRAPH
      WRITE(6,12)
      DO 9 K=1,50
      I=50-K+1
      YPLT=(I-1)*DY+.5*DY+YMIN
 9    WRITE(6,10) YPLT,(L(J,I),J=1,110)
   10 FORMAT(2X,E13.4,2X,1HI,110A1,1HI)
      J1=IX(NSTRT)
      J2=J1+110
      WRITE(6,12)
      WRITE(6,11) (J,J=J1,J2,10)
 12   FORMAT(17X,1HI,11(10H---------I))
   11 FORMAT(16X,11(I4,6X),I4)
      RETURN
      END
```

Figure A.5 (Continued)

APPENDIX B

TEXTBOOK DATA FOR GROUNDWATER TRANSPORT

TABLE OF CONTENTS

LIST OF TABLES

B.1 POROSITY AND EFFECTIVE POROSITY

Tables B.1 and B.2 give representative values of porosity and effective porosity of aquifer materials.

B.2 PERMEABILITY

The permeabilities of a range of porous aquifer materials are presented in Table B.3.

B.3 DISTRIBUTION COEFFICIENTS

Distribution coefficients for strontium and cesium for a range of geologic materials are presented in Tables B.4 and B.5.

Table B.1 Typical values of porosity of aquifer materials

Aquifer material	Number of analyses	Range	Arithmetic mean
Igneous rocks			
Weathered granite	8	0.34-0.57	0.45
Weathered gabbro	4	0.42-0.45	0.43
Basalt	94	0.03-0.35	0.17
Sedimentary materials			
Sandstone	65	0.14-0.49	0.34
Siltstone	7	0.21-0.41	0.35
Sand (fine)	245	0.25-0.53	0.43
Sand (coarse)	26	0.31-0.46	0.39
Gravel (fine)	38	0.25-0.38	0.34
Gravel (coarse)	15	0.24-0.36	0.28
Silt	281	0.34-0.51	0.45
Clay	74	0.34-0.57	0.42
Limestone	74	0.07-0.56	0.30
Metamorphic rocks			
Schist	18	0.04-0.49	0.38

Source: D. B. McWhorter and D. K. Sunada, Ground-Water Hydrology and Hydraulics, Water Resources Publications, Fort Collins, Colo., 1977. Reprinted with permission.

Table B.2 Typical values of effective porosity of aquifer materials

Aquifer material	Number of analyses	Range	Arithmetic mean
Sedimentary materials			
Sandstone (fine)	47	0.02-0.40	0.21
Sandstone (medium)	10	0.12-0.41	0.27
Siltstone	13	0.01-0.33	0.12
Sand (fine)	287	0.01-0.46	0.33
Sand (medium)	297	0.16-0.46	0.32
Sand (coarse)	143	0.18-0.43	0.30
Gravel (fine)	33	0.13-0.40	0.28
Gravel (medium)	13	0.17-0.44	0.24
Gravel (coarse)	9	0.13-0.25	0.21
Silt	299	0.01-0.39	0.20
Clay	27	0.01-0.18	0.06
Limestone	32	0-0.36	0.14
Wind-laid materials			
Loess	5	0.14-0.22	0.18
Eolian sand	14	0.32-0.47	0.38
Tuff	90	0.02-0.47	0.21
Metamorphic rocks			
Schist	11	0.22-0.33	0.26

Source: D. B. McWorter and D. K. Sunada, Ground-Water Hydrology and Hydraulics, Water Resources Publications, Fort Collins, Colo., 1977. Reprinted with permission.

Table B.3 Typical values of permeability or hydraulic conductivity of porous materials

Aquifer material	Number of analyses	Range (cm/sec)	Arithmetic mean	
			(cm/sec)	(ft/yr)
Igneous rocks				
Weathered granite	7	$(3.3\text{-}52) \times 10^{-4}$	1.65×10^{-3}	1.71×10^{3}
Weathered gabbro	4	$(0.5\text{-}3.8) \times 10^{-4}$	1.89×10^{-4}	1.96×10^{3}
Basalt	93	$(0.2\text{-}4{,}250) \times 10^{-8}$	9.45×10^{-6}	9.78×10^{0}
Sedimentary materials				
Sandstone (fine)	20	$(0.5\text{-}2{,}270) \times 10^{-6}$	3.31×10^{-4}	3.42×10^{2}
Siltstone	8	$(0.1\text{-}142) \times 10^{-8}$	1.9×10^{-7}	1.97×10^{-1}
Sand (fine)	159	$(0.2\text{-}1.89) \times 10^{-4}$	2.88×10^{-3}	2.98×10^{3}
Sand (medium)	255	$(0.9\text{-}567) \times 10^{-4}$	1.42×10^{-2}	1.47×10^{4}
Sand (coarse)	158	$(0.3\text{-}6{,}610) \times 10^{-4}$	5.20×10^{-2}	5.38×10^{4}
Gravel	40	$(0.3\text{-}31.2) \times 10^{-1}$	4.03×10^{-1}	4.17×10^{5}
Silt	39	$(0.09\text{-}7{,}090) \times 10^{-7}$	2.83×10^{-5}	2.93×10^{1}
Clay	19	$(0.1\text{-}47) \times 10^{-8}$	9×10^{-8}	9.31×10^{-2}
Metamorphic rocks				
Schist	17	$(0.002\text{-}1{,}130) \times 10^{-6}$	1.9×10^{-4}	1.97×10^{2}

Source: D. B. McWorther and D. K. Sunada, Ground-Water Hydrology and Hydraulics, Water Resources Publications, Fort Collins, Colo., 1977. Reprinted with permission.

Table B.4 Distribution coefficients for strontium and cesium

Condition	K_d (ml/gm) Sr	Cs
Basalt, 32-80 mesh, prepared groundwater	16-135	792-9,520
Quartz sand, pH 7.7	1.7-3.8	22-314
Granodiorite, 100-200 mesh, prepared groundwater	4-9	8-9
Granodiorite, 0.5-1 mm, prepared groundwater	11-23	1,030-1,810
Hanford sediments	50	300
Tuff	45-75	800-1,000
Dolomite, 200 mesh, brine, pH 6.7	∼1	∼1-15
Dolomite, 200 mesh, simulated groundwater, pH 7.9	3-5	7-125
Clay, 20-45 mesh, brine, pH 6.8	<1	<1-9
Clay, 20-45 mesh, simulated groundwater, pH 7.7	3-45	30-120
Polyhalite, 200 mesh, brine, pH 6.8	5-22	<1
Sandstone, 200 mesh, brine, pH 7.0	<1	14-16
Sandstone, 200 mesh, simulated groundwater, pH 7.7	1-5	130-140
Basalt, 0.5-4 mm, 300 ppm total dissolved solids (TDS)	220	39
Basalt, 0.5-4 mm, 300 ppm TDS	1,220	280
Basalt, 0.5-4 mm, seawater	1.1	6.5
Soil, pH 6.8	143-282	617-1,053
Tuff. 100-200 mesh, prepared groundwater	2,070-3,480	12,000-17,800
Soils	19-43	189-420
Tuff, chimney rubble, groundwater	400	5,000-8,000
Soils, calcium groundwater	9.4-71	250-1,000
Tuff, >0.4 mm, prepared groundwater	260	1,020
Carbonate, >4 mm, prepared groundwater	9.9	13.5
Granite, >4 mm, groundwater	1.7	34.3
Shaley siltstone, >4 mm, well water	8.32	309
Sandstone, >4 mm, well water	1.37	102
Salt, >4 mm, saturated saltwater	0.19	0.027
Alluvium, 0.5-4 mm, groundwater	48-2,454	121-3,165
Sands	13-43	100
Basalt, fractured in situ measurements	3	--
Dolomite, 100-325 mesh, distilled water, pH 8.3	5.6-12.4	110-2,656
Dolomite, 100-325 mesh, brine, pH 6.5-6.9	-0.8-1.0	-0.3-0.3
Limestone, 100-170 mesh, distilled water, pH 8.3	9.0-13.0	6,540-7,518
Limestone, 100-170 mesh, brine, pH 6.5-6.9	-0.4-0.9	-0.8-0.2
Sandstone, 100-170 mesh, distilled water, pH 8.3	22-37.5	12,195-18,567
Sandstone, 100-325 mesh, distilled water, pH 8.3	12.0-19.2	5,248-6,855
Sandstone, 100-170 mesh, brine, pH 6.5-6.9	-0.3-1.1	-0.1-0.5
Sandstone, 100-325 mesh, brine, pH 6.5-6.9	-0.5-0.7	-0.3-0.8
Dolomite, 4,000 ppm TDS	5-14	--
Tuff	400	--

Source: U.S. Nuclear Regulatory Commission, NUREG/CR-0912, "Geosciences Data Base Handbook for Modeling a Nuclear Waste Repository," D. Isherwood, Vols. 1 and 2, 1981.

Table B.5 Strontium and cesium distribution coefficients from controlled sample program

	K_d(ml/gm)		
Laboratory*	Sr	Cs	Condition
ANL	5.4 ± 0.3	65 ± 2	Limestone, 20-50 mesh, with synthetic equilibrated groundwater, pH 8.2 ± 0.2, equilibrated with atmospheric O_2, solid/solution = 1 g/15 ml
AECL	1.8 ± 0.5	1.3 ± 0.4	
LASL	1.4 ± 0.2	88 ± 1	
LBL	2.4 ± 0.1	49 ± 5	
LLL	2.7 ± 0.5	60 ± 30	
ORNL-I	5.9 ± 0.2	227 ± 14	
ORNL-II	9.3 ± 2.4	663 ± 61	
PNL	14.9 ± 4.6	880 ± 160	
RHO	13.4 ± 0.6	6.8 ± 0.6	
ANL	0.18 ± 0.01	0.14 ± 0.01	Limestone, 20-50 mesh, with synthetic Waste Isolation Pilot Plant (WIPP) #B brine, pH 6.5 ± 0.5, equilibrated with atmospheric O_2, solid/solution = 1 g/15 ml
AECL	4.2 ± 1.6	0.2 ± 0.4	
LASL	0.1 ± 0.2	-0.12 ± 0.12	
LBL	0.1 ± 0.1	0.16 ± 0.9	
LLL	0.9 ± 0.4	0.5 ± 0.5	
ORNL-I	1.0 ± 0.1	0.6 ± 0.3	
ORNL-II	0.9 ± 0.1	0.1 ± 0.3	
PNL	3.4 ± 0.3	3.3 ± 0.1	
RHO	8.0 ± 1.2	0.04 ± 0.03	
ANL	68 ± 17	401 ± 21	Basalt, 20-50 mesh, with synthetic equilibrated groundwater, pH 7.7-8.2, equilibrated with atmospheric O_2, solid/solution = 1 g/15 ml
AECL	41 ± 6	31 ± 2	
LASL	81 ± 1	265 ± 4	
LBL	55 ± 2	296 ± 10	
LLL	45 ± 1	290 ± 70	
ORNL-I	89 ± 5	380 ± 5	
ORNL-II	93 ± 6	453 ± 12	
PNL	92 ± 3	380 ± 70	
RHO	73 ± 4	255 ± 7	
ANL	0.05 ± 0.005	1.48 ± 0.05	Basalt, 20-50 mesh, with synthetic WIPP #B brine, pH 7.7-8.2, equilibrated with atomspheric O_2, solid/solution = 1 g/15 ml
AECL	2.9 ± 0.4	1.4 ± 0.4	
LASL	0.2 ± 0.2	0.6 ± 0.2	
LBL	0.1 ± 0.1	1.52 ± 0.04	
LLL	0.0	1.6 ± 0.1	
ORNL-I	0.7 ± 0.3	2.2 ± 0.2	
ORNL-II	0.4 ± 0.1	1.79 ± 0.01	
PNL	3.6 ± 0.8	4.6 ± 0.3	
RHO	0.23 ± 0.02	0.95 ± 0.13	

*ANL	Argonne National Laboratory
AECL	Atomic Energy of Canada, Limited
LASL	Los Alamos Scientific Laboratory
LBL	Lawrence Berkeley Laboratory
LLL	Lawrence Livermore Laboratory
ORNL	Oak Ridge National Laboratory (ORNL-I and ORNL-II are two independent groups at ORNL)
PNL	Battelle Pacific Northwest Laboratory
RHO	Rockwell Hanford Operations

Source: U.S. Nuclear Regulatory Commission, NUREG/CR-0912, "Geosciences Data Base Handbook for Modeling a Nuclear Waste Regulatory," D. Isherwood, Vols. 1 and 2, 1981.

APPENDIX C

LISTING OF LIQUID PATHWAY PROGRAM "SCREENLP"

```
00100 REM LPGS PROGRAM R CODELL 9/14/83
00110 PRINT "*********************************************************"
00120 PRINT
00130 PRINT "LIQUID PATHWAY PROGRAM"
00140 PRINT "US NUCLEAR REGULATORY COMMISSION"
00150 PRINT "R CODELL NOV 4,1983"
00160 PRINT
00170 PRINT "ENTER NAME OF SITE AND TITLE"
00180 INPUT T$
00190 DIM D(3,3),U(30,4),Z(3,30)
00200 REM DOSE FACTORS FOR DRINKING WATER
00210 REM MILLIREM/PICOCURIE
00220 READ D(1,1),D(1,2),D(1,3)
00230 DATA .186E-2,1.21E-4,.714E-4
00240 REM READ IN DOSE FACTORS FOR FISH INGESTION FROM SR90,CS134,CS137
00250 REM MILLIREMS/PICOCURIE
00260 READ D(2,1),D(2,2),D(2,3)
00270 DATA .186E-2,1.21E-4,.714E-4
00280 REM READ IN DOSE FACTORS FOR SHORELINE EXP,SR90,CS134,CS137
00290 REM MILLIREM/HR/PCI/SQ.M
00300 READ D(3,1),D(3,2),D(3,3)
00310 DATA 0,1.2E-8,4.2E-9
00320 REM READ IN DECAY CONSTANTS FOR SR90,CS134,CS137 1/YR
00330 READ L(1),L(2),L(3)
00340 DATA .02318,.31507,.023028
00350 REM CORE INVENTORIES FOR LPGS CASE
00360 READ M(1),M(2),M(3)
00370 DATA 6.1E6,2.1E7,8.6E6
00380 REM SUMP FRACTIONS FOR LPGS CASE
00390 READ S(1),S(2),S(3)
00400 DATA .24,1.0,1.0
00410 REM WATER TREATMENT PASSING FACTOR FROM LPGS
00420 READ T(1),T(2),T(3)
00430 DATA .2,.9,.9
00440 REM BIOACCUMULATION FACTOR FOR FRESH WATER FOR SR90,CS134,CS137
00450 READ B(1),B(2),B(3)
00460 DATA 5.0,400.0,400.0
00470 REM SHELLFISH FRESH WATER BAF
00480 READ B(4),B(5),B(6)
00490 DATA 100,1000,1000
00500 REM EDIBLE PORTION OF FISH
00510 LET E8=.5
00520 REM OPTIONS FOR GROUNDWATER TRANSPORT
00530 PRINT
00540 PRINT "*************************"
00550 PRINT
00560 PRINT "GROUNDWATER TREATMENT OPTIONS"
00570 PRINT "1.ENTER GR.WTR TRANSMITTAL FACTORS"
00580 PRINT "  FOR SR90,CS134,CS137"
00590 PRINT "2.ENTER TRAVEL TIME THROUGH GROUND"
00600 PRINT "3.CALC TRAVEL TIME FROM DARCYS LAW"
00610 PRINT "4.CALC TRAVEL TIME FROM RECHARGE"
00620 PRINT "  TO WATER TABLE"
00630 PRINT "5.CALC TRAVEL TIME IN FRESHWATER"
00640 PRINT "  LENS FOR COASTAL ENVIRONMENT"
00650 PRINT "ENTER OPTION NUMBER"
00660 INPUT N4
00670 ON N4 GOTO 03490, 03540, 03870, 04030, 04550
00680 PRINT "GRNDWATER TRANSMISSION FACTORS"
00690 PRINT "FOR LPGS WERE"
00700 PRINT "SR90 = .87802"
```

```
00710 PRINT 'CS134 = 1.1897E-7'
00720 PRINT 'CS137 = .31164'
00730 LET R1=A(1)/.87802
00740 LET R2=A(2)/1.1807E-07
00750 LET R3=A(3)/.31164
00760 PRINT 'RATIO OF PRESENT SITE GROUNDWATER'
00770 PRINT 'TRANSMITTAL FACTORS TO LPGS'S'
00780 PRINT 'SR90 = ',R1
00790 PRINT 'CS134 = ',R2
00800 PRINT 'CS137 = ',R3
00810 LET R4=.001
00820 IF R1<R4 AND R2<R4 AND R3<R4 THEN PRINT 'CONSIDER STOPPING HERE'
00830 PRINT
00840 PRINT '****************************'
00850 PRINT
00860 PRINT 'ENTER TYPE OF WATER BODY:'
00870 PRINT '1.RIVER     2.GREAT LAKES'
00880 PRINT '3.ESTUARY  4.COASTAL'
00890 INPUT N3
00900 ON N3 GOTO 00910, 01000, 01090, 01180
00910 REM RIVER SITE
00920 REM SHORE WIDTH FACTOR
00930 LET F5=.2
00940 REM SHORELINE EROSION FACTORS
00950 LET A4=.63
00960 LET B4=.37
00970 LET A5=1.406
00980 LET B5=.007702
00990 GOTO 01260
01000 REM GREAT LAKES SITE
01010 REM SHORE WIDTH FACTOR
01020 LET F5=.3
01030 REM SHORELINE EROSION FACTORS
01040 LET A4=.63
01050 LET B4=.37
01060 LET A5=1.406
01070 LET B5=.007702
01080 GOTO 01260
01090 REM ESTUARY SITE
01100 REM SHORE WIDTH FACTOR
01110 LET F5=1
01120 REM SHORE WIDTH FACTORS
01130 LET A4=.05
01140 LET B4=.95
01150 LET A5=1.406
01160 LET B5=.007702
01170 GOTO 01260
01180 REM OCEAN SITE
01190 REM SHORE WIDTH FACTOR
01200 LET F5=.5
01210 REM SHORELINE EROSION FACTORS
01220 LET A4=.9
01230 LET B4=.1
01240 LET A5=16.867
01250 LET B5=1.406
01260 REM RELAXATION TIMES FOR SHORELINE EXPOSURE
01270 FOR I=1 TO 3
01280   LET H(I)=A4/(L(I)+A5)+B4/(L(I)+B5)
01290 NEXT I
01300 IF N3<3 THEN 01340
01310 READ B(1),B(2),B(3),B(4),B(5),B(6)
01320 DATA 2,40,40,20,25,25
```

```
01330 IF N3=4 THEN 01680
01340 PRINT "ENTER NUMBER OF SEGMENTS IN WATER BODY"
01350 INPUT N1
01360 PRINT "ENTER NUMBER OF DRINKING WATER USERS,"
01370 PRINT "FINFISH CATCH, POUNDS,"
01380 PRINT "SHELLFISH CATCH,POUNDS"
01390 PRINT "AND SHORELINE USER HOURS IN EACH SEGMENT"
01400 FOR I=1 TO N1
01410   PRINT "SEGMENT";I;
01420   INPUT U(I,1),U(I,2),U(I,4),U(I,3)
01430 NEXT I
01440 REM OPTIONS FOR DILUTION CALCULATIONS
01450 PRINT
01460 PRINT "**********************"
01470 PRINT
01480 PRINT "DILUTION FACTOR OPTIONS"
01490 PRINT "1.READ IN DILUTIONS"
01500 PRINT "2.CALCULATE NUCLIDE SPECIFIC DIL"
01510 PRINT "  FROM SED LOADS IN RIVER OR LAKES"
01520 PRINT "3.CALC DILUTIONS FROM SALINITY"
01530 PRINT "  PROFILE IN ESTUARY"
01540 PRINT "ENTER OPTION NUMBER"
01550 INPUT N2
01560 ON N2 GOSUB 01580, 02770, 03330
01570 GOTO 01680
01580 REM READ IN DILUTIONS
01590 PRINT
01600 PRINT "*****************************************************"
01610 PRINT
01620 PRINT "ENTER DILUT.FOR SR90,CS134,CS137 IN EACH SEG"
01630 FOR I=1 TO N1
01640   PRINT "SEGMENT";I;
01650   INPUT Z(1,I),Z(2,I),Z(3,I)
01660 NEXT I
01670 RETURN
01680 REM MENU FOR DATA CHANGES
01690 PRINT
01700 PRINT "**************************"
01710 PRINT
01720 PRINT "CHANGE LPGS BASE PARAMETERS?"
01730 PRINT "CHANGE:"
01740 PRINT "1.BIOACCUMULATION FACTORS"
01750 PRINT "2.CORE INVENTORY"
01760 PRINT "3.SUMP RELEASE FRACTION"
01770 PRINT "4.WATER TREATMENT FACTOR"
01780 PRINT "5.EDIBLE FISH PORTION"
01790 PRINT "6.NO MORE CHANGES"
01800 PRINT "SELECT OPTION NUMBER"
01810 INPUT N7
01820 PRINT
01830 PRINT "*****************************************************"
01840 PRINT
01850 ON N7 GOTO 01860, 01950, 01990, 02030, 02070, 02110
01860 PRINT "INPUT FINFISH BAF FOR SR AND CS"
01870 PRINT "OLD VALUES WERE ",B(1),B(2)
01880 INPUT B(1),B(2)
01890 LET B(3)=B(2)
01900 PRINT "INPUT SHELLFISH BAF FOR SR AND CS"
01910 PRINT "OLD VALUES WERE",B(4),B(5)
01920 INPUT B(4),B(5)
01930 LET B(6)=B(5)
```

```
01940 GOTO 01730
01950 PRINT "INPUT CORE INVENTORY FOR SR90,CS134,CS137"
01960 PRINT "OLD VALUES =",M(1),M(2),M(3),"CI"
01970 INPUT M(1),M(2),M(3)
01980 GOTO 01730
01990 PRINT "INPUT SUMP RELEASE FACTORS FOR SR90,CS134,CS137"
02000 PRINT "OLD VALUES=",S(1),S(2),S(3)
02010 INPUT S(1),S(2),S(3)
02020 GOTO 01730
02030 PRINT "INPUT WAT.TREAT PASSING FACTORS FOR SR90,CS134,CS137"
02040 PRINT "OLD VALUES  = ",T(1),T(2),T(3)
02050 INPUT T(1),T(2),T(3)
02060 GOTO 01730
02070 PRINT "INPUT PORTION OF FISH THAT IS EATEN"
02080 PRINT "OLD VALUE = ",E8
02090 INPUT E8
02100 GOTO 01730
02110 REM CALCULATE DOSES
02120 IF N3=4 THEN 05000
02130 REM CONVERSION FOR DR.WATER
02140 LET C5=730*1.E+12*.001/(28.3*86400*365)
02150 REM DRINKING WATER DOSE
02160 DIM Y(4,4)
02170 FOR I=1 TO 3
02180   LET Y(I,1)=0
02190   FOR J=1 TO N1
02200     LET Y(I,1)=Y(I,1)+M(I)*S(I)*A(I)*T(I)*D(1,I)*U(J,1)*Z(I,J)*C5
02210   NEXT J
02220 NEXT I
02230 PRINT
02240 PRINT "*************************"
02250 PRINT "CALCULATED POPULATION DOSES"
02260 PRINT "*************************"
02270 PRINT
02280 PRINT "DRINKING WATER DOSE, PERSON REMS"
02290 PRINT "SR90 = ",Y(1,1)
02300 PRINT "CS134 = ",Y(2,1)
02310 PRINT "CS137 = ",Y(3,1)
02320 LET Y(4,1)=Y(1,1)+Y(2,1)+Y(3,1)
02330 PRINT "TOT DRINK WTR DOSE = ",Y(4,1),"PERSON REMS"
02340 REM FIN AND SHELL FISH INGESTION DOSE
02350 REM CONVERSION FOR FISH
02360 LET C6=1.E+12/(28.3*1000*2.22*365*86400)
02370 REM CORRECT FOR EDIBLE PORTION OF FISH
02380 LET C6=C6*E8
02390 FOR I=1 TO 3
02400   LET Y(I,2)=0
02410   FOR J=1 TO N1
02420     LET C8=U(J,2)*B(I)+U(J,4)*B(I+3)
02430     LET Y(I,2)=Y(I,2)+M(I)*S(I)*A(I)*D(2,I)*C8*Z(I,J)*C6
02440   NEXT J
02450 NEXT I
02460 PRINT
02470 PRINT "AQUATIC FOOD INGESTION DOSE IN PERSON REMS"
02480 PRINT
02490 PRINT "SR90 = ",Y(1,2)
02500 PRINT "CS134 = ",Y(2,2)
02510 PRINT "CS137 = ",Y(3,2)
02520 LET Y(4,2)=Y(1,2)+Y(2,2)+Y(3,2)
02530 PRINT "TOTAL FISH INGESTION DOSE = ",Y(4,2),"PERSON REMS"
02540 REM SHORELINE EXPOSURE
```

```
02550 REM CONVERSION FOR SHORELINE EXP
02560 LET C7=631*40*1.E+12/(28.3*86400*365*1000)
02570 FOR I=1 TO 3
02580   LET Y(I,3)=0
02590   FOR J=1 TO N1
02600     LET Y(I,3)=Y(I,3)+M(I)*S(I)*A(I)*D(3,I)*U(J,3)*H(I)*Z(I,J)*C7*F5
02610   NEXT J
02620 NEXT I
02630 PRINT
02640 PRINT "SHORELINE EXPOSURE DOSE,PERSON REMS"
02650 PRINT
02660 PRINT "SR90 = ",Y(1,3)
02670 PRINT "CS134 = ",Y(2,3)
02680 PRINT "CS137 = ",Y(3,3)
02690 LET Y(4,3)=Y(1,3)+Y(2,3)+Y(3,3)
02700 PRINT "TOTAL SHORELINE EXPOSURE = ",Y(4,3),"PERSON REMS"
02710 REM TOTAL DOSE
02720 LET Y9=Y(4,1)+Y(4,2)+Y(4,3)
02730 PRINT
02740 PRINT "TOTAL POPULATION DOSE FOR LPGS"
02750 PRINT "COMPARISON = ",Y9,"PERSON REMS"
02760 STOP
02770 REM DILUTION IN RIVERS AND LAKES WITH SED
02780 PRINT
02790 PRINT "ENTER KD FOR SR AND CS IN SED,ML/GM"
02800 INPUT R(1),R(2)
02810 LET R(3)=R(2)
02820 DIM K(9)
02830 PRINT "ENTER KF COEFFICIENT"
02840 PRINT "(WAS 1.3 FT/YR IN LPGS)"
02850 INPUT K1
02860 PRINT "ENTER SED EFFICIENCY"
02870 INPUT K2
02880 PRINT "ENTER SEDIMENT DEPTH IN"
02890 PRINT "RESERVOIR SEGMENTS,FT"
02900 INPUT K(8)
02910 PRINT "ENTER SEDIMENT DENSITY,GM/CC"
02920 INPUT K3
02930 FOR I=1 TO 3
02940   LET R(I)=R(I)*K3
02950 NEXT I
02960 PRINT
02970 PRINT "FOR EACH RIVER SEGMENT,ENTER:"
02980 PRINT "1.FLOWRATE LEAVING SEG CU FT/SEC"
02990 PRINT "2.VOLUME OF SEGMENT,CU FT"
03000 PRINT "3.AV DEPTH FT"
03010 PRINT "4.SEDIMENTATION VEL. FT/YR"
03020 FOR I=1 TO N1
03030   PRINT "SEG.";I;
03040   INPUT K(5),K(6),K(7),V1
03050   REM CONVERT FLOW TO CU FT/YR
03060   LET K(5)=K(5)*365*86400
03070   FOR J=1 TO 3
03080     LET K(1)=K1/(K(7)*R(J))
03090     LET K(2)=K(5)/K(6)+L(J)+K2*V1*R(J)/K(7)+K1/K(7)
03100     LET K(3)=(K2*V1*R(J)+K1)/K(8)
03110     LET K(4)=L(J)+K2*V1/K(8)+K1/(K(8)*R(J))
03120     IF I>1 THEN 03150
03130     LET W9=1
03140     GOTO 03160
03150     LET W9=Z(J.I-1)*Q1
```

```
03160      LET Z(J,I)=W9/(K(6)*(K(2)-K(1)*K(3)/K(4)))
03170    NEXT J
03180    LET Q1=K(5)
03190 NEXT I
03200 REM CONVERT DIL TO SEC/CU FT
03210 FOR I=1 TO N1
03220   FOR J=1 TO 3
03230     LET Z(J,I)=Z(J,I)*365*86400
03240   NEXT J
03250 NEXT I
03260 PRINT
03270 PRINT "EFFECTIVE DILUTIONS,SEC/FT^3"
03280 PRINT "SEG","SR90","CS134","CS137"
03290 FOR I=1 TO N1
03300   PRINT I,Z(1,I),Z(2,I),Z(3,I)
03310 NEXT I
03320 RETURN
03330 REM
03340 PRINT
03350 PRINT "ENTER SEAWATER SALINITY,PPT"
03360 INPUT S5
03370 PRINT "ENTER SALINITY IN EACH SEGMENT,PPT"
03380 PRINT "AND FRESHWATER THRUPUT,CFS"
03390 FOR I=1 TO N1
03400   PRINT "SEGMENT";I;
03410   INPUT S4,Q5
03420   LET Z(1,I)=(1-S4/S5)/Q5
03430   LET Z(2,I)=Z(1,I)
03440   LET Z(3,I)=Z(1,I)
03450   PRINT
03460   PRINT "DILUTION IN SEGMENT =",Z(1,I)
03470 NEXT I
03480 RETURN
03490 REM READ IN GROUNDWATER PASSAGE FACTORS
03500 PRINT
03510 PRINT "INPUT FRACTIONS OF SR90,CS134,CS137"
03520 INPUT A(1),A(2),A(3)
03530 GOTO 00680
03540 REM A CALCULATED FROM TRAVEL TIME
03550 PRINT
03560 PRINT "INPUT TRAVEL TIME FOR GROUNDWATER,YRS"
03570 INPUT T1
03580 REM OPTION TO CALC OR INPUT RD
03590 PRINT "ENTER 1 TO INPUT RD FACTORS"
03600 PRINT "ENTER 2 TO CALC RD FACTORS"
03610 INPUT I5
03620 IF I5<>1 THEN 03670
03630 PRINT "INPUT RD FOR SR AND CS"
03640 INPUT R(1),R(2)
03650 LET R(3)=R(2)
03660 GOTO 03790
03670 REM CALCULATE RD
03680 PRINT "ENTER KD(ML/GM) FOR SR AND CS"
03690 INPUT R(1),R(2)
03700 LET R(3)=R(2)
03710 PRINT "ENTER BULK DENSITY OF SOIL(GM/ML) AND TOTAL POROSITY"
03720 INPUT D5,P5
03730 FOR I=1 TO 3
03740   LET R(I)=1+D5*R(I)/P5
03750 NEXT I
03760 PRINT "RETARDATION FACTORS"
```

```
03770 PRINT 'SR90 = ',R(1)
03780 PRINT 'CS137 AND CS134 = ',R(2)
03790 FOR I=1 TO 3
03800   LET A(I)=EXP(-L(I)*T1*R(I))
03810 NEXT I
03820 PRINT 'GROUNDWATER PASSAGE FACTORS'
03830 PRINT 'SR90 = ',A(1)
03840 PRINT 'CS134 = ',A(2)
03850 PRINT 'CS137 = ',A(3)
03860 GOTO 00680
03870 REM TRAVEL TIME FROM SLOPE-HYDRAULIC CONDUCTIVITY
03880 PRINT
03890 PRINT 'ENTER DISTANCE FROM'
03900 PRINT ' SOURCE TO WATER BODY, FEET'
03910 INPUT X1
03920 PRINT 'ENTER HYDRAULIC CONDUCTIVITY,FT/YR';
03930 INPUT P1
03940 PRINT 'ENTER EFFECTIVE POROSITY';
03950 INPUT N5
03960 PRINT 'ENTER SLOPE TOWARD WATER BODY FT/FT';
03970 INPUT S1
03980 LET U1=S1*P1/N5
03990 LET T1=X1/U1
04000 PRINT 'GROUNDWATER SPEED,FT/YR',U1
04010 PRINT 'TRAVEL TIME,YR = ',T1
04020 GOTO 03580
04030 REM RECHARGE RECHARGE ON A SLOPED WATER TABLE
04040 REM CALCULATE MOUND HT AND TRAVEL TIME
04050 REM H2=THICKNESS OF LAYER AT STREAM,FT
04060 REM L2=DIST STREAM TO TOP OF HILL
04070 REM L1=DIST STREAM TO SOURCE
04080 REM N=INFILTRATION FT/YR
04090 REM P1=HYDRAULIC CONDUCTIVITY FT/YR
04100 REM S1=SLOPE OF HILL
04110 REM N5=EFFECTIVE POROSITY
04120 PRINT
04130 PRINT 'ENTER DIST FROM TOP OF'
04140 PRINT ' HILL TO SINK,FT'
04150 INPUT L2
04160 PRINT 'ENTER DISTANCE FROM'
04170 PRINT ' SOURCE TO SINK ,FT'
04180 INPUT L1
04190 PRINT 'ENTER THICKNESS OF SATURATED'
04200 PRINT ' LAYER AT SINK,FT'
04210 INPUT H2
04220 PRINT 'ENTER RECHARGE,FT/YR'
04230 INPUT N
04240 PRINT 'INPUT HYDRAULIC CONDUCTIVITY,FT/YR'
04250 INPUT P1
04260 PRINT 'INPUT SLOPE OF LAND'
04270 INPUT S1
04280 PRINT 'INPUT EFFECTIVE POROSITY'
04290 INPUT N5
04300 LET X=L2
04310 LET X1=L2
04320 LET T1=0
04330 LET H1=H2
04340 LET D1=L1/100
04350 FOR I=1 TO 100
04360   GOSUB 04520
04370   LET X1=X-D1
```

```
04380   LET H1=H2+F*D1
04390   LET F1=F
04400   GOSUB 04520
04410   LET X=X1
04420   LET H2=(F+F1)*D1/2+H2
04430   LET H1=H2
04440   LET T1=T1+D1/(N*(X+.5*D1)/(H2*N5))
04450 NEXT I
04460 PRINT 'TRAVEL TIME ,YEARS = ',T1
04470 PRINT 'MAXIMUM MOUND THICKNESS,FT = ',H2
04480 PRINT 'WARNING!!! - BE SURE THAT MOUND '
04490 PRINT 'THICKNESS DOESN'T EXCEED MAX'
04500 PRINT ' AQUIFER THICKNESS'
04510 GOTO 03580
04520 REM FUNCTION OF INTEGRAL
04530 LET F=N*X1/(P1*H1)-S1
04540 RETURN
04550 REM RECHARGE IN FRESHWATER LENS
04560 REM R CODELL 5/13/83
04570 REM INPUT NE,RECHARGE,K,L,L1,L2,DENSITY DIFF-CALC T
04580 REM N5=EFFECTIVE POROSITY,R=RECHARGE FT/YEAR
04590 REM P1=HYDRAULIC CONDUCTIVITY, FT/YEAR
04600 REM L3=DIST TO GNDWTR HIGH
04610 PRINT
04620 PRINT 'ENTER EFFECTIVE POROSITY'
04630 INPUT N5
04640 PRINT 'ENTER HYDRAULIC CONDUCTIVITY,FT/YR'
04650 INPUT P1
04660 PRINT 'ENTER DISTANCE FROM CENTER'
04670 PRINT 'OF LENS TO SEA,FT'
04680 INPUT L3
04690 PRINT 'ENTER DISTANCE FROM SOURCE'
04700 PRINT ' TO SEA, FT'
04710 INPUT L1
04720 PRINT 'ENTER RECHARGE,FT/YR'
04730 INPUT R5
04740 REM FOR FRESHWATER-SALTWATER
04750 LET D1=40
04760 REM SINK ASSUMED AT SHORELINE
04770 LET L2=0
04780 LET A1=L3
04790 LET X=L3-L2
04800 GOSUB 04960
04810 LET T2=T4
04820 LET X=L3-L1
04830 GOSUB 04960
04840 LET T1=T4
04850 LET T3=T2-T1
04860 REM MAX MOUND HEIGHT
04870 LET H1=(1+D1)*L3*SQR(R5/((1+D1)*P1))
04880 PRINT 'TR.TIME,YEARS=',T3
04890 PRINT 'MAX MOUND HT,FT=',H1
04900 PRINT
04910 PRINT 'WARNING!!! - BE SURE TO CHECK'
04920 PRINT 'THAT MOUND HT DOESN'T EXCEED THICKNESS'
04930 PRINT 'OF AQUIFER. IF SO VALUES CHOSEN MAY BE INAPPROPRIATE'
04940 LET T1=T3
04950 GOTO 03580
04960 LET C=SQR(A1^2-X^2)
04970 LET T4=N5/SQR(P1*R5)*(C-A1*LOG((A1+C)/X))
04980 LET T4=T4*SQR(1+D1)
04990 RETURN
```

```
05000 REM ROUTINE FOR COASTAL FISH DOSE
05010 DIM P(200),Q(200)
05020 PRINT 'INPUT DRIFT CURRENT,M/D(LPGS=4320)'
05030 INPUT U1
05040 PRINT 'INPUT EFFECTIVE DEPTH,M(LPGS=10)'
05050 INPUT D1
05060 PRINT 'INPUT NO OF OFFSHORE REGIONS'
05070 INPUT N1
05080 PRINT 'FOR EACH REGION INPUT:'
05090 PRINT '1.WIDTH OF REGION,KM'
05100 PRINT '2.FINFISH CATCH,KG/HA/YR'
05110 PRINT '3.SHELLFISH CATCH,KG/HA/YR'
05120 FOR I=1 TO N1
05130   PRINT 'REGION';I;
05140   INPUT W(I),G(I),O(I)
05150 NEXT I
05160 PRINT 'INPUT NUMBER OF LONGSHORE INCREMENTS<=200'
05170 INPUT M3
05180 PRINT 'INPUT LONGSHORE INCREMENT,KM'
05190 INPUT D3
05200 PRINT '**********************************************************'
05210 PRINT 'NOTE: MAY TAKE A MINUTE'
05220 PRINT '**********************************************************'
05230 LET C1=1/(D1*SQR(3.14159*U1))
05240 LET C2=-U1/4
05250 LET C3=191900/U1^1.34
05260 LET P1=18500000
05270 REM GENERATE P(X) TABLES
05280 FOR I=1 TO M3
05290   LET P2=C3*((I-.5)*D3*1000)^2.34+P1
05300   LET P(I)=C1/SQR(P2)
05310   LET Q(I)=C2/P2
05320 NEXT I
05330 LET S1=0
05340 LET S2=0
05350 REM INT CONC*FISH IN SEGS
05360 LET Y1=0
05370 FOR K1=1 TO N1
05380   PRINT 'WORKING ON REGION',K1
05390   LET Y2=Y1+W(K1)
05400   REM INTEGRATION INCREMENT
05410   LET D2=W(K1)/5
05420   LET D6=D2*D3
05430   FOR J=1 TO 5
05440     LET Y3=Y1+(J-.5)*D2
05450     LET Y6=Y3^2*1000000
05460     FOR I=1 TO M3
05470       LET G6=P(I)*EXP(Q(I)*Y6)*D6
05480       LET S1=S1+G6*G(K1)
05490       LET S2=S2+G6*O(K1)
05500     NEXT I
05510   NEXT J
05520   LET Y1=Y2
05530 NEXT K1
05540 REM KG/CU M
05550 FOR I=1 TO 3
05560   LET Y(I,2)=S1*M(I)*S(I)*A(I)*D(2,I)*B(I)*273973
05570   LET Y(I,2)=Y(I,2)+S2*M(I)*S(I)*A(I)*D(2,I)*B(I+3)*273973
05580 NEXT I
05590 PRINT 'AQUATIC FOOD INGESTION DOSE PERSON REM'
05600 PRINT
```

```
05610 PRINT "SR90 =",Y(1,2)
05620 PRINT "CS134 =",Y(2,2)
05630 PRINT "CS137 =",Y(3,2)
05640 LET Y(4,2)=Y(1,2)+Y(2,2)+Y(3,2)
05650 PRINT "TOTAL FISH INGESTION DOSE ="
05660 PRINT Y(4,2),"PERSON REMS"
05670 REM SHORELINE DOSE
05680 PRINT "INPUT SHORELINE USE,USER-HOURS PER LINEAR KILOMETER OF BEACH"
05690 INPUT G1
05700 LET S2=0
05710 FOR I=1 TO M3
05720   LET S2=S2+P(I)*D3
05730 NEXT I
05740 FOR I=1 TO 3
05750   LET Y(I,3)=S2*G1*F5*M(I)*S(I)*A(I)*D(3,I)*69150000*H(I)
05760 NEXT I
05770 PRINT "SHORELINE DOSE IN PERSON REMS"
05780 PRINT
05790 PRINT "SR90 = ",Y(1,3)
05800 PRINT "CS134 = ",Y(2,3)
05810 PRINT "CS137 = ",Y(3,3)
05820 LET Y(4,3)=Y(2,3)+Y(3,3)
05830 PRINT "TOTAL SHORELINE POPULATION DOSE = "
05840 PRINT Y(4,3)," PERSON REMS"
05850 PRINT
05860 LET Y(4,4)=Y(4,2)+Y(4,3)
05870 PRINT "TOTAL POPULATION DOSE FOR LPGS COMPARISON = "
05880 PRINT Y(4,4)," PERSON REMS"
05890 STOP
05900 END
```

NRC FORM 335
(6-83)

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

1. REPORT NUMBER (Assigned by TIDC, add Vol. No., if any)
NUREG-1054

2. Leave blank

3. TITLE AND SUBTITLE
Simplified Analysis for Liquid Pathway Studies

4. RECIPIENT'S ACCESSION NUMBER

5. DATE REPORT COMPLETED

MONTH	YEAR
December	1983

6. AUTHOR(S)
Richard B. Codell

7. DATE REPORT ISSUED

MONTH	YEAR
August	1984

8. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Division of Engineering
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, DC 20555

9. PROJECT/TASK/WORK UNIT NUMBER

10. FIN NUMBER

11. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Same as 8 above

12a. TYPE OF REPORT

12b. PERIOD COVERED (Inclusive dates)

13. SUPPLEMENTARY NOTES
Computer Program available from author

14. ABSTRACT (200 words or less)

The analysis of the potential contamination of surface water via groundwater contamination from severe nuclear accidents is routinely calculated during licensing reviews. This analysis is facilitated by the methods described in this report, which is codified into a BASIC language computer program, SCREENLP. This program performs simplified calculations for groundwater and surface water transport and calculates population doses to potential users of the contaminated water irrespective of possible mitigation methods. The results are then compared to similar analyses performed using data for the generic sites in NUREG-0440, "Liquid Pathway Generic Study", to determine if the site being investigated would pose any unusual liquid pathway hazards.

15a. KEY WORDS AND DOCUMENT ANALYSIS
Liquid Pathways
Risk analysis
Groundwater
Surface water
Transport

15b. DESCRIPTORS

16. AVAILABILITY STATEMENT
Unlimited

17. SECURITY CLASSIFICATION
(This report)
Unclassified

18. NUMBER OF PAGES

19. SECURITY CLASSIFICATION
(This page)
Unclassified

20. PRICE
$

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

120555078877 1 IAN
US NRC
ADM-DIV OF TIDC
POLICY & PUB MGT BR-PDR NUREG
W-501
WASHINGTON DC 20555