V. Environmental Setting

V. ENVIRONMENTAL SETTING

A. GENERAL OVERVIEW

The cultural and natural history of the Hudson River has been studied and described by individuals and institutions with diverse interests and opinions since the beginning of recorded history in America. There is a wealth of information and data to describe the environmental setting for the proposed action; this chapter summarizes this information, highlighting and describing in detail those aspects of the environment that are potentially influenced by the action.

Information from many sources has been reviewed and included; however, the bulk of the data used to describe the biology, chemistry, and physical processes of the Hudson River come from the monitoring program developed in consultation with the DEC over the past 12 years. The sampling design, equipment, and standard operating procedures for all aspects of the monitoring studies have been described in detail in annual reports (see Appendix V-1). A synopsis of the program is included in Appendix V-2. For the reader's convenience key elements of the program are summarized as appropriate in the sections on biological and chemical characteristics.

Few water bodies have been the subject of sampling and evaluation over a multiyear period. The major deterrents to accumulating usable multiyear data are year-to-year inconsistencies in sampling and analysis protocols. All sampling and analyses are described in detail in the references listed in Appendix V-1. To control bias introduced by changes, even inadvertent, in standard procedures, the Hudson River Utilities Monitoring Program was the subject of an extensive, documented, quality control and assurance program. The components of the QA/QC program and its results are described in Young et al. 1992.

The effects of the proposed action, beneficial as well as potentially detrimental, will occur within a complex physical and cultural context. This general overview describes this context, with emphasis on the history of the Hudson River, a history that is closely related to the natural resources of the estuary and the many competing uses man makes of the resources.

1. Geography

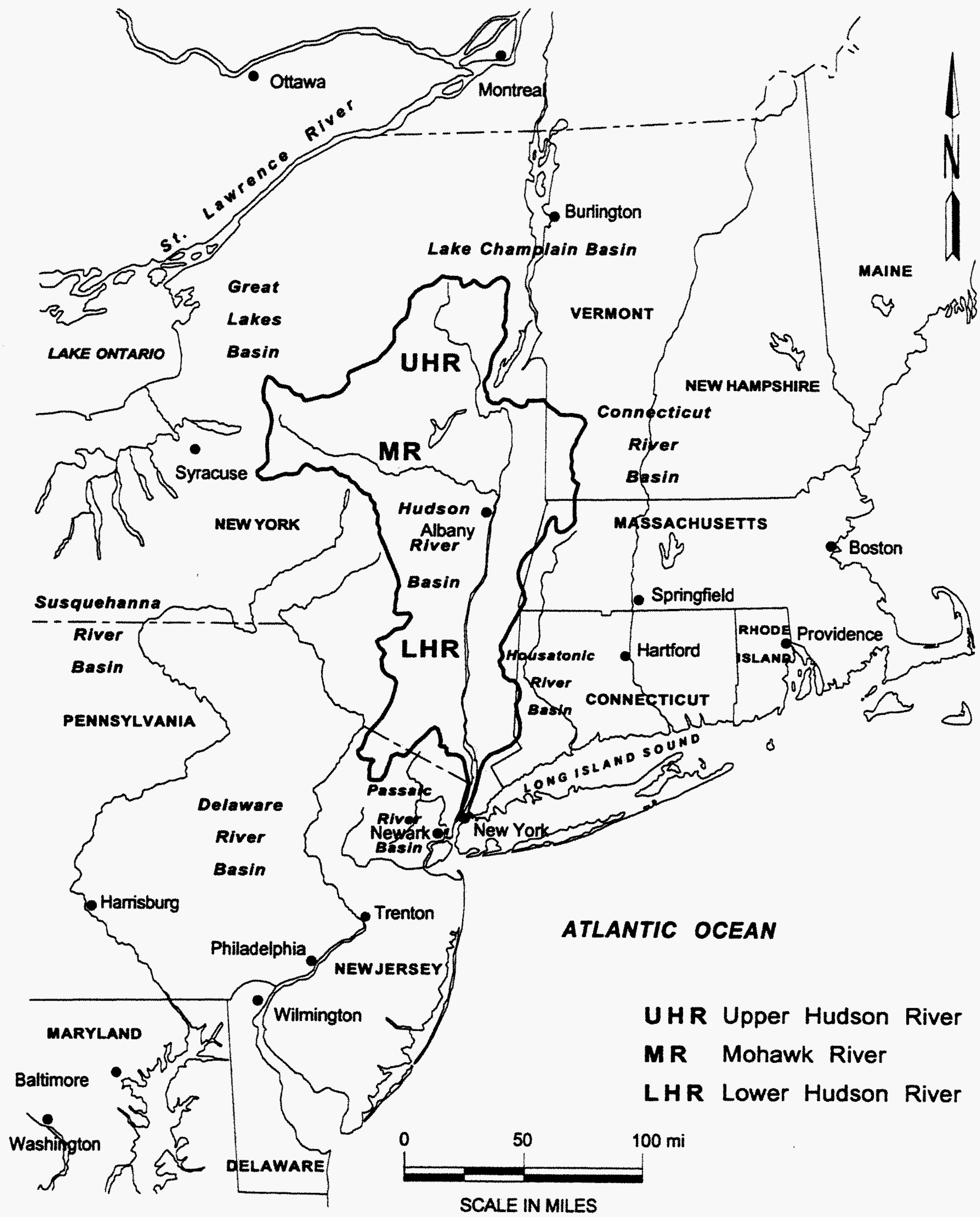
The Hudson-Mohawk river basin is located in the eastern part of New York State and covers an area of 13,366 square miles. Most of the watershed lies within the east-central part of the state; small portions, however, extend into Vermont, Massachusetts, Connecticut, and New Jersey (Figure V-1). The watershed is one of five major drainage basins within New York State and the only one that includes a major estuary. The basin is bounded on the north by the St. Lawrence and Lake Champlain drainage basins; on the east by the Connecticut and Housatonic river basins and the Connecticut coastal area; on the west by the Delaware, Susquehanna, Oswego, and Black river basins; and on the south by the basins of small streams tributary to the Hudson River in New York Harbor.

The Hudson-Mohawk basin can be divided into three principal subbasins: (1) the upper Hudson and the (2) Mohawk river subbasins, which drain into (3) the lower Hudson sub-basin. The upper Hudson and Mohawk River subbasins are primary sources of the freshwater flows into the lower Hudson. Approximately 35% of the drainage area is from the upper Hudson subbasin, about 26% from the Mohawk subbasin (Table V-1). The lower 60 miles of the Hudson River below Newburgh, New York, contain only 10% of the watershed.

The 315-mile-long Hudson River originates at Lake Tear-of-the-Clouds on the south-west slope of Mt. Marcy in the Adirondack Mountains. From its source the river flows 87 miles in a south-southeast direction to its confluence with the Sacandaga River near river mile (RM) 228. At this point the river flows east to Hudson Falls (RM 198) where it again turns south. Near RM 156 the Mohawk River joins the Hudson. Two miles farther downriver is the Federal Dam at Troy (RM 154), which creates a physical barrier between the upper and lower Hudson River. The Federal Dam prevents any tidal influence or fluctuations in the upper basin and marks the upper limit of the Hudson River estuary. The upper river basin covers 4627 square miles. From its source to Troy Dam the river drops 1810 ft, an average of about 12 ft per mile.

The Mohawk River has its source in the hills near the boundaries of Lewis and Oneida counties of New York and drains 3462 square miles. The river flows in a southerly direction to Rome, then in a generally east-southeast direction to its confluence with the Hudson at Cohoes, New York. The river falls from 1800 ft at its source to 14.3 ft at Cohoes over its course of 155 miles; the average drop is 13 ft per mile.

The lower Hudson River commences below the junction of the Mohawk and upper Hudson rivers at Troy above Green Island and flows south to its discharge into New York Bay. All



Source: Abood 1992

Figure V-1. Hudson River basin.

TABLE V-1

DRAINAGE AREAS OF HUDSON-MOHAWK RIVER SYSTEM

WATERSHED	AREA (mi^2)	% OF TOTAL
Upper Hudson	4,627	34.6
Mohawk River	3,462	25.9
Lower Hudson above Green Island	8,090	60.5
Above Newburgh	12,000	89.7
Entire Hudson River	13,366	100.0

Adapted from Abood et al. (1992) and McFadden (1977).

of this section of the river is tidal. Not including the upper Hudson and Mohawk river basins, the lower Hudson basin drains an area of approximately 5277 square miles and is essentially a flooded valley with very little gradient. Over its 154-mile course below the dam to its mouth, the river drops approximately 5 ft, an average of 0.4 in. per mile.

2. Physiography

a. Glacial Influences

The physiographic features of the Hudson River Valley were shaped by the geologic forces of the last ice age. The Wisconsin ice sheet reached Long Island and across northern New Jersey. With its movement from the north, it carried vast quantities of rock, which it dropped as it receded. This debris ranged from clay particles to very large boulders that had been scoured or had broken loose from their native rocks. The entire watershed is covered with this layer of glacial drift.

As the glacier receded and the developing Great Lakes opened up, various outlets for the lakes were formed; the Mohawk-Hudson Valley was the eastern outlet (Flint 1957; Clayton 1967). Glaciation deepened the channel of the Hudson River through the Hudson Highlands. Borings made during construction of the Catskill aqueduct indicated that the gorge was cut to 768 ft below present sea level (Schuberth 1968); boulders and other glacial debris subsequently filled the canyon to its present maximum depth of approximately 180 ft. The channel above and below the Highlands was not excavated as deeply, but was still partially filled with drift materials as the glacier receded. The clay and other fine sediments in the glacial drift covering the region still contribute much suspended material to its streams.

b. Topography

The Hudson River watershed comprises a diverse set of topographic features that influence the Hudson River estuary. Within the basin 48% of the terrain is mountainous, 2% is lakes and water bodies, and about 50% is rolling hills and lower-elevation river valley. Johnsen (1966) and Sanders (1974) give a more complete description of the physiographic features of the basin.

The most prominent physiographic features of the Hudson-Mohawk basin are the Adirondack Mountains, the Mohawk Valley, the Catskill Mountains, the Hudson Valley, and the Hudson Highlands. The Adirondacks cover a large part of north-central New York between Lake Champlain and Lake Ontario. The southern part of the region, drained by the upper Hudson River, contains some of the highest mountains in the eastern United States, including Mt. Marcy (5344 ft), Algonquin Peak (5114 ft), Mt. Skylight (4920 ft), and Mt. Haystack (4918 ft). The relief in the southern Adirondacks is about 4000 ft.

The Mohawk River Valley, which is used principally for agriculture, occupies an east-west belt of rolling hills between Albany and Rome, New York. Since the 19th century, the Mohawk River has been used as the New York Barge Canal and is no longer free-flowing. The relief of the area is low, ranging to a few hundred feet, with maximum elevations of about 1000 ft.

The elevation of the Catskill Mountains ranges to approximately 4200 ft, and relief of 3000 ft is common. The northern part of the Catskills in the Hudson watershed is drained principally by Schoharie Creek, a tributary of the Mohawk River; the southern Catskills are drained by the Rondout and Esopus creeks, tributaries of the lower Hudson.

The Hudson River Valley from Hudson Falls south to Newburgh, including the Wallkill River drainage from northern New Jersey, lies in a narrow segment of the Great Valley of the Valley and Ridge Physiographic Province (Fenneman 1938) and is primarily agricultural. Elevations are low, with valley floors <500 ft and ridge tops generally <1000 ft.

Covering a very small part of the watershed (<1%) are the low but rugged Highlands across the lower Hudson River. Elevations range from 1200 to 1400 ft. Although relief is commonly 500 to 800 ft, where the Hudson River cuts through the Highlands at sea level, relief can reach >1000 ft.

Several reservoirs and numerous lakes are located within the Hudson basin. The Sacandaga and Indian Lake reservoirs are the two major reservoirs controlling flow in the upper Hudson River. The Hinckley, Delta, and Schoharie reservoirs are located in the Mohawk River basin. The Ashokan Reservoir, which receives water from the Schoharie, provides water to the New York City public water supply system. Other major reservoir systems within the basin include 12 reservoirs and lakes in the Croton River system and four in the lower Hudson and upper Delaware basins.

Most of the natural lakes within the Hudson basin are found in the northernmost region. Among the largest are Saratoga, Schroon, Pleasant, and Piseco lakes. Other lakes and ponds are small and typically located near the headwaters of streams.

3. Climate

The Hudson River basin lies within the temperate region of the northern hemisphere. As is typical of temperate zones, there is considerable seasonal variation in climatological characteristics. The climate of the region is strongly influenced by its position on the eastern side of the continent, which provides a large land mass to influence the prevailing air movement patterns; by the Great Lakes, which lie to the northwest; by the variation in elevation within the basin; and by proximity to the Atlantic Ocean at the southern extreme.

a. Air Temperature

Mean annual air temperatures within the basin vary from approximately 40°F near the northern end of the basin (Stillwater Reservoir station) to 55°F at the southern end (New York City, Central Park) (Table V-2). The difference in annual means at these locations reflects the substantial differences in latitude and elevation and the moderating influence of the Atlantic Ocean and heat island effect at the New York City station. Monitoring stations at intermediate locations display a pattern of annual mean temperatures that might be expected because of the gradient in these factors. As latitude, elevation, and distance from the ocean decrease, mean annual temperatures increase.

Seasonal temperature patterns at all stations show annual minimums in January and maximums in July (Figure V-2). The more northern stations exhibit greater seasonal variation in monthly mean temperature (52°F at Stillwater Reservoir) than the southern stations do (45°F at New York City) due to the moderating oceanic influence in the southern part of the basin.

b. Precipitation

Annual precipitation patterns also vary within the drainage, with higher precipitation in the Adirondack and Catskill mountains (up to 60 in. per year) and in New York City, and lower precipitation in the Mohawk and Hudson Valley areas. At Stillwater Reservoir mean annual precipitation is approximately 46 in.; at Central Park mean precipitation is 44 in. (Table V-2). In areas at lower elevations than the Adirondacks, or farther from the ocean than New York City, precipitation is reduced, with Albany near the minimum at about 36 in. annually.

Seasonal fluctuations in precipitation are smaller in magnitude than fluctuations in temperature (Figure V-3). Monthly mean precipitation varies only about 1 to 1.5 in.

TABLE V-2

MEAN ANNUAL TEMPERATURE AND PRECIPITATION AT SELECTED CLIMATE MONITORING STATIONS IN THE HUDSON RIVER DRAINAGE AREA

(1951-1980)

STATION	INDEX NO.	LATITUDE	ELEVATION (ft)	MEAN TEMP. (°F)[a]	MEAN PRECIP. (in.)[a]
Stillwater Reservoir	8248	43 53'	1690	40.2	45.81
Utica Airport	8737	43 9'	712	45.8	43.44
Albany Airport	0042	42 45'	275	47.3	35.74
Poughkeepsie Airport	6820	41 38'	155	49.1	40.16
NYC Central Park	5801	40 47'	132	54.5	44.12

[a]NOAA 1991.

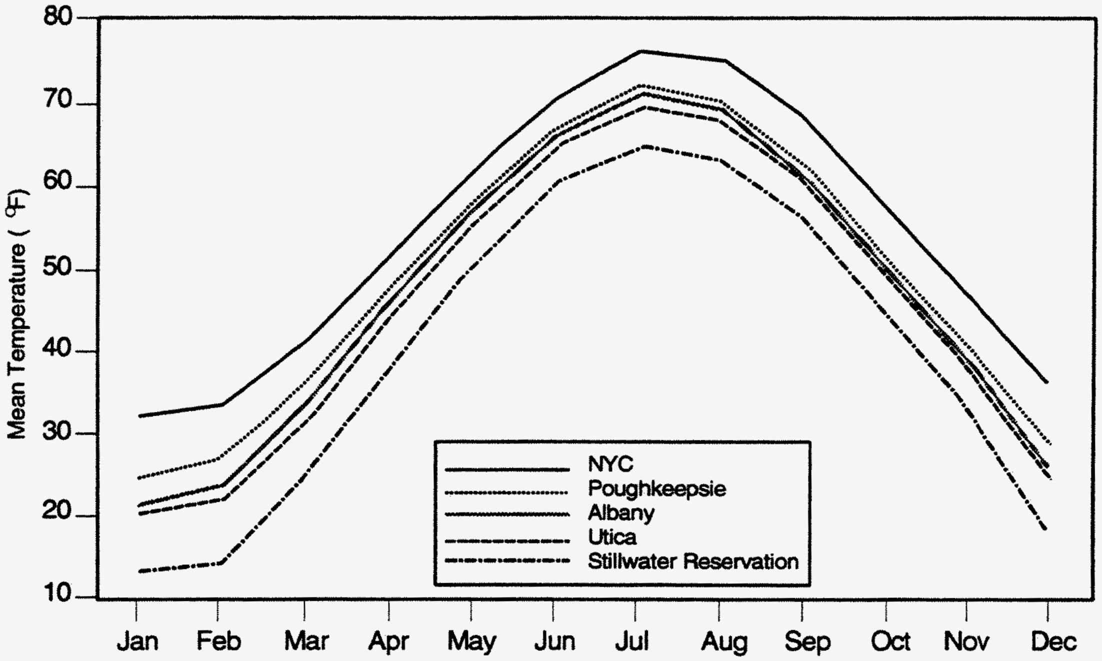


Figure V-2. Seasonal variation in monthly mean temperature at selected stations within the Hudson River drainage.

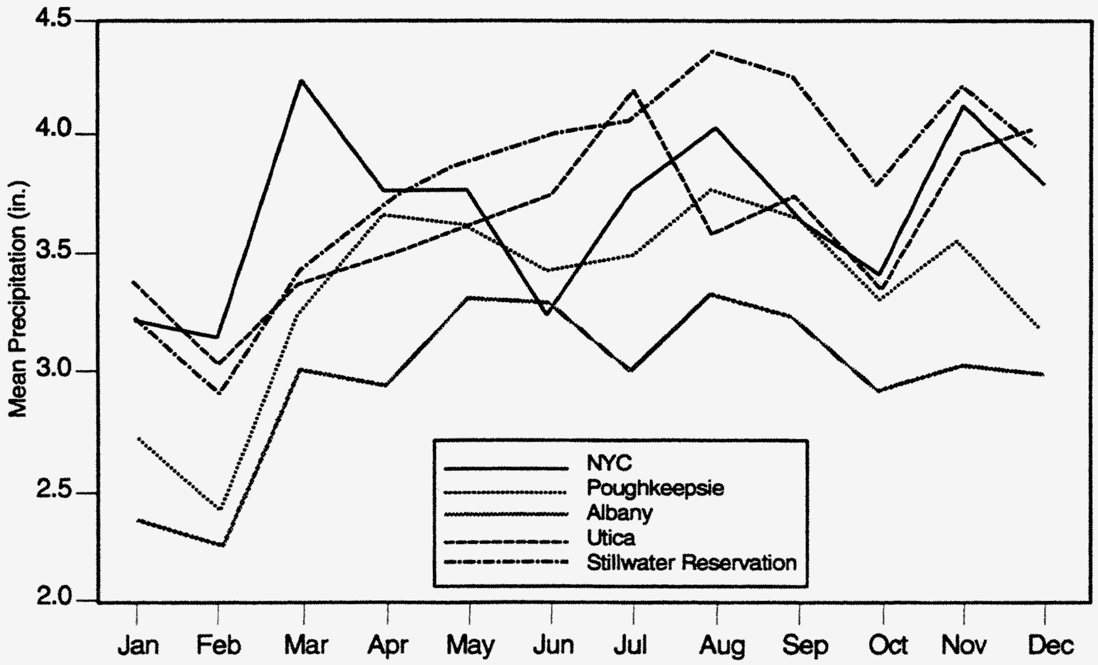


Figure V-3. Seasonal variation in monthly mean precipitation at selected stations within the Hudson River drainage.

throughout the year; extremely high or low precipitation can occur in any month, however. As is true for temperature, southerly stations exhibit a moderation because of their proximity to the ocean.

c. *Long-Term Variations*

Both temperature and precipitation can vary substantially from the 1951-1980 average values presented in Table V-2. From 1931 to 1990 mean annual temperatures in the Hudson Valley region (Division 05 for New York climatological data) have varied between 46 and 51°F, with little indication of any long-term trend or distinct cycles (Figure V-4). Similarly, there appears to be little or no trend in Hudson Valley precipitation over the last 60 years, although there does appear to be cycling between wet and dry periods (Figure V-5). The mid-1960s were particularly dry, as mean precipitation declined to about 28 in. per year; the 1970s were relatively wet, with a peak annual mean of 54 in.

4. Vegetation

a. *Climax Terrestrial Vegetation*

Northern hardwood species dominate the climax vegetation throughout New York State except for the lower Hudson Valley and the higher elevations in the Adirondacks and Catskills. Beech and sugar maple are the dominant tree species in this northern hardwood group (classified as beech-maple mesic forest by Reschke [1990]). In the warmer areas where this group is dominant, basswood, white ash, and black cherry are subdominants and white pine is common on sandy or dry soils and in abandoned fields. Red cedar, white ash, hawthorns, and black locust also invade abandoned fields; red maple is common in poorly drained areas. In the cooler areas where northern hardwoods dominate, yellow birch becomes codominant with beech and sugar maple. Hemlock is common on moist, shady slopes and in ravines. White cedar is common in abandoned fields and poorly drained areas. Alder and larch also appear in wet areas. Throughout the Hudson Highlands and Hudson Valley, the beech-maple mesic forest provides the spectacular fall colors that draw visitors from around the world.

In the lower Hudson Valley, where low elevations, warming from the Atlantic Ocean, and shelter from cold northwest winds by the Catskill Mountains result in a warmer climate than in the rest of the state, oaks are included in the dominant tree associations. Mixed pitch pine-oak forests or Appalachian oak-pine forests (classification by Reschke [1990]) are

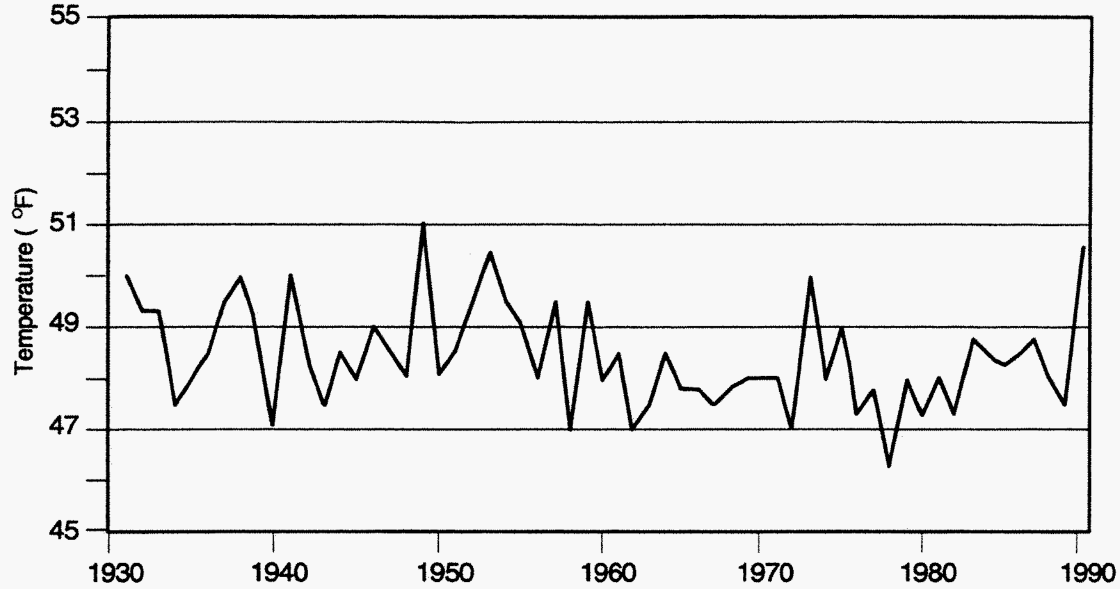


Figure V-4. Mean annual air temperature for the Hudson Valley region (Division 05) for 1931-1990.

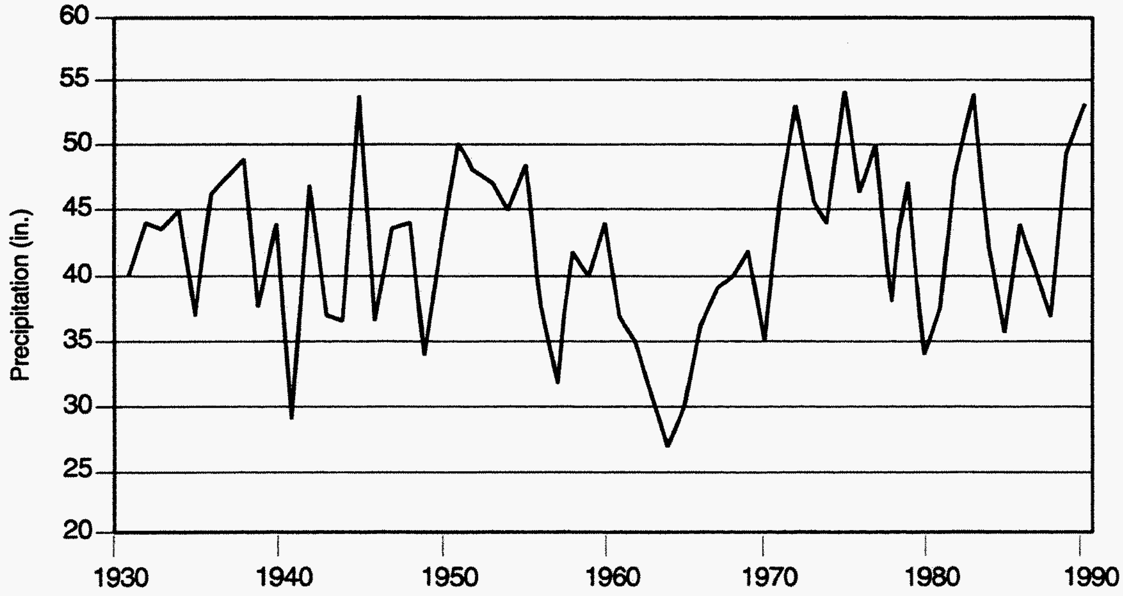


Figure V-5. Mean annual precipitation for the Hudson Valley region (Division 05) for 1931-1990.

found on the well-drained sandy soils of the glacial moraines associated with streams and tributaries in the Hudson Valley. The oaks may be one or more of the following: black, red, chestnut, white, or scarlet oak. On the cool, mid-elevation slopes of the Hudson Highlands and on the moist margins of palustrine wetlands, hemlocks may be codominant with red oaks (hemlock-northern hardwood forest). Each of these ecological communities is ranked as G4 or G5 in the Nature Conservancy's global ranking system. These rankings indicate that the vegetation community and the species associated with it are "apparently" or "demonstrably" secure throughout its range.

The chestnut-oak forests that may be found on mid-elevation slopes in the Hudson Highlands are ranked G3 or G4, indicating that it is vulnerable to extinction because of biological factors but "apparently" secure. This forest is typically dominated by chestnut and red oaks. American chestnut was a common component of this forest before the chestnut blight, but its abundance is now greatly reduced.

In the mid-Hudson Valley and upper Hudson watershed near the Hudson and Mohawk rivers, oak-dominated forests and other northern hardwoods intermingle or alternate with each other. The drier, warmer slopes (south and southwest facing) support nearly pure stands of oak or oak mixed with hickory. The cooler, wetter slopes (north and northeast facing) support the hemlock forest and northern hardwoods. At the higher elevations in the upper Hudson watershed (and in the Catskills) spruce and fir dominate the tree association.

Many factors have acted to modify the climax vegetation of the Hudson basin. Some of the more significant include logging for the lumber and pulpwood industries, deforestation to allow agriculture or human habitation, diseases such as Dutch Elm disease and chestnut blight, and insect pests such as gypsy moth caterpillar, woolly adelgid, and elongate leaf scale. Although most of the changes to this community are reversible in the long term, conversion of forests to agricultural or urban uses can cause changes to the soil structure that will prevent development of the original community type for an extremely long time.

b. Wetland and Aquatic Vegetation

Wetland vegetation in the Hudson-Mohawk basin is composed of a wide variety of types, including emergent marshes, shrub swamps, inland lake shore, pine barrens, vernal ponds, sedge meadows, fens, dwarf shrub bogs, highbush blueberry bog thickets, inland cedar swamps, and black spruce-tamarack bogs, among others (Reschke 1990). Although these communities are ecologically important, they account for only a small portion of the watershed and are not prevalent near the Hudson River estuary.

Along the Hudson estuary the community types are tidal marshes, intertidal mudflats, and subtidal aquatic beds, all of which can be either freshwater or brackish, depend-ing on their location on the river (Reschke 1990). The freshwater communities are chiefly found north of Newburgh; brackish communities are found farther south, although there is no sharp demarcation of the two types.

Common species of the freshwater tidal marshes are spatterdock, pickerelweed, arrowleaf, cattails, arrowhead, and bulrush. Arrowheads, mud plantain, and wild rice are characteristic of mudflats. Below the tidal zone the vegetation is commonly waterweed, tapegrass, naiads, and pondweed.

The brackish areas of the estuarine tidal marshes contain many of the species found in the freshwater marsh, but also more salinity-tolerant species, such as saltwater cordgrass, saltmeadow cordgrass, and spike grass. Mudflats contain arrowhead, bulrush, and tape-grass, while the subtidal aquatic beds are populated by waterweed, coontail, naiad, widgeon grass, and pondweeds.

In recent times the aquatic vegetation in the Hudson River has undergone considerable change. The trend has been toward the reduction of native plant populations, partially because of pollution but also, and more important, through displacement by the expansion of exotics.

One of the most successful invaders of the lower Hudson River has been the exotic water chestnut. A native of Europe and Asia, the water chestnut was introduced into the upper Hudson River drainage in 1884 (Hook 1985). It quickly spread and was considered a pest by the 1930s. An eradication program of hand-pulling and application of 2,4-D was initially successful in controlling the species, but laws restricting the use of this herbicide resulted in the abandonment of this program in 1975. The species rapidly regained dominance in sheltered coves and shallows as far south as Constitution Island, with isolated patches as far south as Iona Island (Schmidt and Kiviat 1988).

Another exotic that has successfully invaded the lower Hudson River is purple loose-strife. Introduced over 100 years ago, this species is now abundant in a variety of habitats. It provides no known special habitats or food for wetland biota, and it displaces the native cattails, which are excellent habitat for marsh fauna, shore birds, and migrating birds (BTIPR 1977).

Habitat alteration has also accounted for changes in aquatic vegetation. Major shoreline alterations within recorded history are attributable primarily to construction of railroad rights-of-way along the shorelines. According to Boyle (1969), bays near Tivoli and

Hudson were originally open water (nonmarshy). Construction of cause-ways partially blocked tributary inlets, thereby trapping sediment and detritus and producing new marsh areas. Similar filling is apparent in the areas of Constitution Island, Iona Island, Peekskill Bay, and Croton Point.

The shipping channel from the ocean to the Port of Albany and throughout navigable tributaries has been maintained by the Army Corps of Engineers (COE). The channel has been dredged on an as-needed basis. In some river segments dredging occurs every five years. COE is also responsible for authorizing new or maintenance dredging of waterfront facilities through its dredge permit program. The impacts of major dredging activities are evaluated in EISs prepared under the NEPA guidelines.

Croton Bay (RM 34) once supported nearly 190 acres of dense submerged aquatic vegetation (SAV), mostly native water milfoils, pondweed, and water celery. This vegetation, which undoubtedly served as an important fish nursery area, had largely disappeared by 1972 (Buckley 1992). In addition to SAV losses, more than 25 acres of cattails were lost and 40 acres of swamp rose mallow and saltmeadow cordgrass were stressed. Although there was some recovery in the late 1970s, by the early 1980s all these gains had disappeared. Vegetation losses in Croton Bay appear to have resulted from contaminated groundwater and leachate from an old landfill on Croton Point (Buckley 1992).

5. Wildlife

The distribution and abundance of terrestrial wildlife species in the Hudson Valley reflect changing land-use patterns and human attitudes toward wildlife. Habitat for wildlife has been lost to urban and suburban development and modified as former agricultural land reverts to forest. Urban environments support relatively few native species, while suburban areas can harbor relatively large populations of many common species, such as skunk, opossum, raccoon, woodchuck, and deer. Suburban environments provide sufficient space for species that have relatively small home ranges or can utilize human structures and habitats, such as parks, lawns, and roadsides. Hunting and trapping is limited or nonexistent in suburban areas, permitting some species to attain nuisance levels. Farmland has been reverting to forest for many decades, which has produced mature woodlands favored by some species. Turkey and pileated woodpecker have responded with population increases in the second growth forests.

Wildlife associated with aquatic habitats was affected by shoreline development, particularly the railroad corridor at the water's edge along much of the Hudson River. Where filling took place behind railroad embankments, wetland habitat was created, which may have offset development losses to some extent. The river is important for a wide variety of waterfowl, shorebirds, and wading birds. Among these species, mute swans, an introduced species, and the Canada goose are examples of species that have recently increased to nuisance levels.

The Hudson Valley is important to several species listed as state and/or federal endangered or threatened species or species of special concern. The peregrine falcon, which can utilize bridges and buildings for nesting, declined greatly due to pesticide contamination, but is now recovering through introductions to these former nesting sites. Bald eagles winter in the Hudson Valley and recently resumed nesting in southeastern New York. Both the peregrine falcon and bald eagle are currently included on the state and federal endangered lists. The upland ridges provide habitat for the timber rattlesnake (threatened in New York State).

The future of terrestrial wildlife in the Hudson Valley will be controlled by land management policies and practices that protect natural habitats. Parklands and preserves now represent important wildlife areas, but they may become isolated unless suitable habitat is maintained throughout the river valley. DEC's Draft *Preliminary Assessment of Wildlife Management Needs* (1989) recognized the potential of the Hudson River Greenway for providing important wildlife habitat. The Greenway could provide links between parcels of undeveloped land. Increasing public awareness of the importance of maintaining biodiversity and the habitat needs of wildlife may play an important role in the conservation of wildlife in the near future.

6. History of Human Settlement and Land Use

a. Settlement of the Valley

Human settlement of the Hudson-Mohawk River basin began approximately 11,000 years ago, shortly after the retreat of the Wisconsin stage ice sheet. The Paleo-Indians of this period were primarily dependent on the large mammals that existed in the area, but also used smaller animals, fish, and vegetable foods. Either through overhunting or changes in forage supply resulting from climatic warming, large-mammal abundance decreased in the Hudson Valley approximately 9000-6000 YBP (years before present). With their primary food source gone, the Paleo-Indians disappeared, leaving little evidence of their nomadic existence.

Evidence of human habitation is not found again for approximately 4000 years. Early Archaic Stage sites are found only near the southern fringe of the region, on Staten Island and in the Delaware Valley just north of the Water Gap. Over the next approximately 1000 years there was gradual reoccupation of the lower Hudson Valley.

By approximately 3000 YBP, use of ceramic pottery became common, which suggests a more sedentary life style. These Woodland Stage people appeared to do extensive hunting, fishing, and collecting of wild plants. Later, increasing amounts of maize, squash, gourds, and beans were cultivated. As the size of the villages grew, more and more land was cleared for agriculture, especially for maize. During the Woodland Stage 60,000-70,000 people from at least five major Indian groups occupied the area (Salwen 1976).

The Indians of the Hudson-Mohawk basin were composed of two distinct groups by the early 17th century (Rayback 1966). The Algonquins controlled the lower Hudson River and the eastern end of the Mohawk. Tribes of the Algonquin group were the Delaware, Mohicans, Wappingers, and Montauks. European colonization of the valley followed swiftly after Henry Hudson's initial explorations in 1609. By 1626 Dutch colonists were sending furs and samples of grain back to the Netherlands. The Hudson Valley was successfully settled because of its suitability for crops and agricultural practices familiar to the Dutch colonists (Meinig 1966). From 1664 until the time of the Revolution, the area was controlled largely by the British. Because the English continued the Dutch practice of conferring large parcels of land, or patents, to a few individuals, but often without clear definition of the boundaries, settlement of the region was slow. Land for settlement by people who had not obtained the land patents was either unavailable or of uncertain ownership, so that they often migrated to other colonies. Nevertheless, by 1775 the entire Hudson Valley from New York to Glens Falls and the Mohawk Valley west to Amsterdam were considered settled (Meinig 1966).

The development of steam-powered travel, canal waterways, and railways in the early 1800s permitted increased settlement in the Mohawk Valley. The Erie and Champlain canal systems and the Mohawk and Hudson railroad were the initial transportation penetrations beyond Albany. As settlement of the upper reaches of the watershed increased, industrialization also increased.

Since the proposed actions that are the subject of this EIS take place wholly within the lower Hudson River drainage, the remainder of this overview will deal primarily with the lower Hudson.

By 1910 there were approximately 1 million inhabitants in the 10 counties along the lower Hudson from Albany south, not including New York City (Table V-3). Subsequent growth was rapid. From 1910 to 1940 the population in the lower Hudson River basin expanded rapidly, to 8.9 million (including New York City). Most of the increase occurred in New York City and the counties of Rockland and Westchester. In the 1940s growth was relatively uniform along the river, ranging from 6 to 10% for the decade. Although New York City had the lowest growth rate (6%), it still accounted for most of the population increase in the region. After 1950 the New York City population remained nearly constant, while the mid-Hudson and lower counties began a period of rapid growth. Mid-Hudson counties grew by 27%; lower counties expanded by 32%. In the 1960s the mid-Hudson and lower counties continued their rapid population growth; New York City and the upper counties grew at a much slower rate. Since 1970 only the mid-Hudson counties have continued to grow rapidly, increasing from 642,000 inhabitants in 1970 to 816,000 in 1990. Upper counties have grown only about 6% in the last 20 years, the lower counties about 2%. New York City population in 1990 was about 0.5 million lower than it was during its stable period, from 1950 to 1970.

With the exception of Albany County, the upper and mid-Hudson counties have moderate population densities of 68 to 357 people per square mile. Albany County is more urban, with a mean density of 551 per square mile. These values contrast sharply with the densely populated lower region (1860 per square mile) and New York City (23,320 per square mile). The 1990 census estimated nearly 18 million inhabitants in the state and nearly 10 million in the lower Hudson basin (U.S. Bureau of the Census, 1990).

b. Land Use

The lower Hudson Valley has a wide range of land uses, from high-density urban areas to sparsely populated natural areas. The former are along the river in the cities of Albany, Troy, Hudson, Kingston, Poughkeepsie, Newburgh, Peekskill, Yonkers, and other non-riverfront cities in Westchester County. These areas contain not only residences, but also the highest concentration of industrial uses, such as manufacturing, chemical and food processing, and service-sector industries. Outside the urban areas, lower-density residential areas are common, particularly in Rockland and Westchester counties.

Along the Hudson River north of Newburgh, in the Wallkill River Valley of Orange and Ulster counties, and in the western areas of Columbia and Dutchess counties, agricultural uses are common. Dairy and horse farms are abundant, and apples, grapes, onions, and vegetables are the principal commodities of the farming sector.

TABLE V-3

POPULATION SIZES (1000s) AND PERCENT INCREASE (%) FOR LOWER HUDSON BASIN

REGION	1910	1940	1950	1960	1970	1980	1990	1990 DENSITY (No./mi²)
Upper Counties	370	413	444	494	524	538	555	223
Albany		(20)	(8)	(11)	(6)	(3)	(3)	
Rensselaer								
Greene								
Columbia								
Mid-Hudson	310	364	402	510	642	740	816	270
Ulster		(30)	(10)	(27)	(28)	(15)	(10)	
Dutchess								
Orange								
Putnam								
Lower Counties	330	648	715	946	1,124	1,126	1,140	1,860
Rockland		(117)	(10)	(32)	(19)	(0)	(1)	
Westchester								
New York City	4,767	7,455	7,892	7,782	7,896	7,072	7,323	23,320
		(66)	(6)	(-1)	(2)	(-10)	(4)	
Total	5,777	8,880	9,453	9,732	10,186	9,476	9,834	
NY State	9,114	13,479	14,830	16,782	18,241	17,558	17,990	

Source: 1990 Census of the Population, U.S. Bureau of the Census.

Due to population changes and economic factors, land-use patterns are constantly changing. As population increases, particularly in the mid-Hudson counties, additional lands are being converted to residential use. The demand for residential land, and the poor economic climate for agriculture, has led to a substantial reduction in agricultural land, not only in the Hudson Valley but across the state. Based on the 1987 Censor of Agriculture, during the period 1982 through 1987 farm acreage in the lower Hudson Valley has declined 3% per year (HRVGC 1991). Half of all reported farmland conversions in New York State resulted in subdivisions; over 60% of these occurred in Orange County. If the present rate of conversion were to continue for 35 years, the existing farmland in the lower Hudson Valley would disappear (HRVGC 1991).

A relatively large part of the lower Hudson watershed remains relatively undeveloped, except along the major highways, due to its mountainous nature. These areas include the Catskill Mountains of Greene and Ulster counties, the Shawangunk Ridge in Ulster County, and the Hudson Highlands of the four southern counties. These areas have been logged in the past, but are now generally used for outdoor recreation such as skiing and hiking. Although some large tracts are protected from development because of their status as designated parks (e.g., Palisades Interstate Park, Harriman State Park, Bear Mountain State Park, Catskill Park), smaller, privately owned lands are constantly being developed. The need for undeveloped areas has been recognized and is being protected by efforts such as the Hudson River Valley Greenway.

7. Cultural and Aesthetic Resources

Cultural resources abound in the Hudson Valley and surrounding counties. Among the most notable are many architecturally and historically significant buildings, Revolutionary War sites, museums, natural areas, recreation areas, and scenic areas.

Along the Hudson River from Saugerties to Wappingers Falls are many large estates and institutional holdings, remnants of the land grants made during colonial times. A number of houses of architectural and historic importance, including the Vanderbilt mansion, the Ogden Mills mansion, and the Franklin D. Roosevelt home, are located here. Along the riverbanks are beautifully landscaped grounds and fruit orchards. The Marlboro Mountains, Mirror Lake, and Esopus Lake are favorite recreational areas.

The Highlands region, from approximately Newburgh to Tarrytown, is one of the most scenic areas along the river. The river cuts through the gorge with the peaks of Storm King, Beacon, and Bear Mountain rising above the surrounding landscape. Palisades Interstate

Park has preserved much of this land. The Highlands region is also rich in history; locations such as Fort Montgomery, Fort Clinton, and the Stony Point Battlefield were important Revolutionary War battle sites. The scenic and historical West Point Military Academy is one of the most visited tourist attractions in southern New York.

The lower Hudson River from Tarrytown to the mouth of the river is a region of unique character. Along the western shore rise the scenic Palisades that overlook the river from High Tor to beyond the George Washington Bridge. The eastern shore is highly developed. Because of the high population density in this region and demand for recreational areas, several parks have been created. Riverfront parks are provided by the Palisades Interstate Park Commission and various municipalities. This region also includes numerous historic sites, especially in New York City.

The entire Hudson River Valley has historically had such natural beauty that it inspired a distinct genre of landscape painting known as the Hudson River School. The most famous of the Hudson River artists were Albert Bierstadt, Asher Durand, Frederic Church, and Thomas Cole, who painted scenes of the Hudson River from the Palisades to the Catskills.

To ensure the preservation of the Hudson River's scenic, historic, and cultural resources, New York State passed legislation in June 1965 that created the Hudson River Valley Scenic and Historic Corridor. This Act established a commission to formulate and oversee the "preservation, enhancement, and development of the scenic, historic, recreational, and natural resources" in a mile-wide corridor on both sides of the Hudson River. (The corridor width is extended to 2 miles for visual impact.) The commission was also charged to "encourage the full development of the commercial, industrial, agricultural, residential, and other resources" within the corridor.

In his State of the State address in 1988, Governor Mario Cuomo proposed the formation of a "Greenway" system for the Hudson River. This 170-mile system would be open to nonmotorized usage and would link "parks and protected areas, rivers and bodies of water, urban cultural parks, and historic sites and scenic settings by means including trails, waterways, and scenic highways" along the river from Cohoes (5 miles north of Albany) to lower Manhattan. Legislation authorizing this system was signed in August of 1988. The 19-member Hudson Valley Greenway Council (HVGC) that oversees the project is made up of state officials and private citizens. Initial funding was to be from private donations and the 1990 Environmental Quality Bond Act. However, with the defeat of the Bond Act, funds were obtained from a 20 per $100 increase in hotel taxes.

In 1996, with the passage of the Clean Water, Clean Air Act, funding support was restored under the Pataki Administration. In a September 17, 1998 press release, Governor Pataki announced that to date, nearly $2 million has been awarded to communities and organizations through the programs. By that time, nearly 285 miles of hiking and biking trails and 154 miles of waterway trails have been designated.

8. Recreational Resources

The lower Hudson watershed represents about 11% of the state's total land area, but more than 50% of the state's population lives within this area. There are 211 municipalities, 12 cities, 60 villages, and 139 towns in the region. There are 367 miles of water frontage, 62,318 acres of waterfront parks, and 331 miles of trails along the lower Hudson. Within the Hudson River Greenway area are 100 National Historic Landmarks and 89 Historic Districts (HRVGC 1991). A 1990 report (HTF 1990) observed: "It is now common for one short segment of a river corridor to have an industrial plant, a water works, a sewage treatment plant, a commercial center, a condominium, a park, a group of historic sites, a farm, a hunting preserve, and a wildlife sanctuary." However, the pressure for residential and recreational land dominates this competition. The broad consensus is that the lower Hudson Valley is losing open space and is falling behind in providing adequate parklands and public cultural amenities because of extensive land development and population growth. Moreover, with rising management costs, the absence of management funding, and escalating liability insurance premiums, most communities will not accept public land dedications. As a result, few river corridor parcels are becoming public property and six communities located along the lower Hudson (the towns of Livingston, Schaghticoke, and Lloyd and the villages of South Nyack, Briarcliff Manor, and Buchanan) have no public access to the river (HRVGC 1991).

As of 1990 there were 81 public and commercial boat launch and docking facilities along the lower Hudson (HRVGC 1991). Between 1982 and 1989 there was a 53% increase in the number of motorboat registrations in the lower Hudson Valley, almost double the rate for the state as a whole. This escalation in boating activity has increased the use of the existing marinas, service shops, storage areas, docks, and launches to the point where harbor crowding and the safety of all users on the river itself are becoming serious problems. Despite these restrictions on public access, the recovery of the striped bass population and the increasing abundance of largemouth bass in the Hudson River has made sport fishing a popular recreational activity in the lower Hudson Valley.

Although the development of the mid-Hudson region has increased water-related recreational activities, it has had the opposite effect on hunting and trapping. Almost all private land is posted in the lower Hudson Valley, and the amount of public land available for hunting and trapping is limited. As a result, hunting pressure has decreased on both large- and small-game populations. Larger predators, like the black bear and eastern coyote, have reentered the valley. White-tailed deer have reached nuisance densities in heavily developed counties like Westchester, and small mammals and Canada geese are flourishing throughout the lower Hudson Valley. Stocking programs have successfully returned the wild turkey to the valley and they are quite common.

Hiking, cycling, walking, and horseback riding are popular recreational activities along riverside trails. The river path from Haverstraw Beach State Park to Nyack Beach State Park is a popular walking and cycling path. Much of the Long Path along the Palisades offers spectacular views of the Hudson River. The Appalachian Trail crosses the Hudson at Bear Mountain, and there are many well-used hiking trails in the Highlands region and in the Catskill Mountains.

Several large parks and natural areas are available for biking, camping, birding, and climbing in the lower Hudson watershed. These include the Catskill, Bear Mountain, Harriman, Taconic, and Minnewaska state parks and private natural areas such as Mohonk Preserve and Black Rock Forest. These areas have received increased use due to the rapidly increasing population in the mid-Hudson region, with little increase in the amount of land available for outdoor recreation.

9. Commercial and Industrial Use

a. Overview

The types of industry in the lower Hudson Valley have changed substantially over the years. Prior to the 1900s, the dominant industries were those of the primary sector, i.e., agriculture, forestry, fishing, and mining. These gave way during the early part of the century to a progressive increase in the secondary sector, i.e., manufacturing industries such as food products, textiles, apparel, pulp and paper, chemicals, leather, stone, metal, machinery, and transportation equipment. This stage reached its zenith in the 1950s and 1960s. Since 1985, manufacturing has declined in seven of the nine counties in the lower Hudson Valley (Mid-Hudson Patterns for Progress 1992). In contrast, service industries, such as transportation, communication, public utilities, wholesale and retail trades, finance, insurance and real estate, repair, and others, have increased in all nine counties.

The Hudson River is used as a source of potable water, for waste disposal, transportation, and for cooling by industry and municipalities. At least five municipalities currently use the lower Hudson River as a source of potable water. Rohmann et al. (1987) identified 183 separate industrial and municipal discharges to the Hudson and Mohawk rivers. The greatest number of users were in the chemical industry, followed by the oil industry; paper and textile manufacturers; sand, gravel, and rock processors; power plants; and cement companies.

Chemical companies have used the river primarily for waste disposal. Their wastes include dyes, acids, bases, trace metals, vitamins, cyanides, organic materials from drug manufacture, and other chemicals. However, the implementation of stringent water quality regulations beginning in the mid-1960s has reduced the amount and kinds of wastes discharged from these facilities.

Approximately 50 bulk petroleum storage facilities are located in the Hudson River Valley. Most petroleum products are transported upriver to unloading facilities located at Hastings, Newburgh, and the Port of Albany. More than half the total tonnage moved on the river is in the form of petroleum products.

Formerly, logging and pulp and paper operations were important industries along the river. Only a few pulp and paper mills remain in operation, however, mostly above the dam at Troy. These old plants depend on the Hudson River only for raw process water. Both raw and finished products are shipped by rail or truck; these industries no longer use the river for transportation.

Most of the Hudson River Valley's mineral industries are located south of Albany. Major products include crushed and dimension stone, portland cement, lightweight aggregate, brick, sand and gravel, and emery. The location of these industries is determined not only by the location of the raw materials, but also by access to the river. A number of the larger firms barge their products to the New York metropolitan area, the principal market. Activity in these industries is responsive to trends in the construction industry.

Four private companies and one public company operate large electrical generating facilities within the valley. Electric generating facilities include hydroelectric, fossil fuel, and nuclear power plants.

At least 20 publicly owned treatment works (POTW) discharged sewage and wastewater into the Hudson River. Most of the municipal wastes receive primary and secondary treatment. A relatively small amount of sewage is attributed to discharges from pleasure boats. During the late 1960s less than 0.5% of the municipal and industrial biological oxygen demand (BOD) discharge was attributed to pleasure boaters. This contribution was further reduced by Article 33C of the New York State Conservation Law, which required holding tanks on boats and shore treatment systems.

b. Major Discharges

The Federal Water Pollution Control Act Amendments of 1972 established the National Pollutant Discharge Elimination System (NPDES). The State of New York administers the permits within its jurisdiction. Twelve facilities discharge 50 mgd or more to the Hudson River below Troy Dam (Table V-4). Seven are electric generating facilities that use river water for the cooling of condensers and other mechanical systems. The Empire State Plaza in Albany and the World Trade Center in Manhattan use river water to cool the air conditioning and heating systems that service these office complexes. The Charles Point Resource Recovery Facility uses cooling water to remove heat generated by the incinerators used on this location. The Yonkers Joint Municipal Sewage Treatment Plant and the North River Water Pollution Control Facility do not withdraw water from the river but discharge treated wastewater effluent from municipally owned treatment facilities.

i. Electric Generating Stations

(The Roseton Units 1 and 2, Indian Point Units 2 and 3, and Bowline Point Units 1 and 2 Generating Stations are described in Section IV.)

Albany Steam Station. The Albany Station is located on the west shore of the Hudson River in the town of Glenmont, approximately 12 miles south of Troy Dam. The city of Albany is 4 miles north of the plant. The Albany Station began commercial operation in 1952. It consists of four generating units, each with a maximum capacity of 100 MW. The station was coal fired until 1970 when it was converted to fuel oil. It currently can also run on natural gas.

Cooling water is drawn from the Hudson River through a shoreline intake structure. At maximum capacity 506 mgd can be circulated through the plant's condensers using the flow supplied by eight pumps. The intake structure consists of a skimmer wall extending just below mean low water and three intake openings, each measuring 11.2 by 18 ft. The average velocity at the face of the intake is calculated to be 1.3 fps. Trash racks with 3-in. spacing prevent debris and coarse materials from entering the intake. Water is directed through a common intake tunnel to traveling screens with a mesh size of 0.375 in.

The Albany Steam Station discharge is located on the surface approximately 550 ft south of the intake. It is 24 ft wide and 11 ft high. The discharge velocity at the face of the outfall is estimated to be 1.4 fps. The actual structure is oriented in a southerly direction, discharging with the normal river current at an angle to the river shoreline.

TABLE V-4

PERMITTED MAXIMUM DISCHARGES OF 50 mgd OR GREATER TO LOWER HUDSON RIVER

PERMITTEE	RM	USE	mgd
Electric Generating Stations			
Albany Steam Station	140	Cooling water	515
Danskammer Point Generating Station	71	Cooling water	457
Roseton Generating Station	69	Cooling water	926
Lovett Generating Station	41	Cooling water	496
Indian Point Stations Units. 1, 2, and 3	42	Cooling water	2800
Bowline Point Generating Station	35	Cooling water	912
59th Street Generating Station	7	Cooling water	70
Wastewater Treatment Facilities			
Yonkers Joint Municipal Sewage Treatment Facility	17	Discharge of wastewater	92
North River Water Pollution Control Facility	10	Discharge of wastewater	170
Others			
Empire State Plaza	146	Cooling water	108
Westchester Resource Recovery Plant	43	Cooling water	55
World Trade Center	1	Cooling water	94

Source: NYSDEC SPDES files, October 1992, pers. commun. E.W. Radle.

Danskammer Point Generating Station. The Danskammer Point Generating Station is located on the west bank of the Hudson River about 0.75 mile north of the Roseton Units 1 and 2 plant. The plant operates four fossil-fueled steam electric units with a normal total capacity of 494 MW. It is located on a point that protrudes into the river. Cooling water is drawn into the plant through a channel on the north end of the point and is discharged into a shallow embayment to the south.

The cooling water intake consists of trash bar racks located at the river shoreline, an intake channel, and a common intake bay from which river water is diverted through a series of vertical traveling screens into the four generating units. The trash rack is approximately 34 ft wide. The intake channel is 450 ft long, 34 ft wide, and approximately 11 ft deep. The average water velocity in the channel when all circulating pumps are operating is 1.94 fps. Each of the four units draws water through three individual traveling screens.

Cooling water flow from all four units of the Danskammer Point plant is discharged parallel to river flow through three discharge pipes located to the south of the plant. The average depth of the river at the discharge is 6 ft. This configuration creates a predominantly surface discharge plan that usually follows the western shoreline.

Lovett Generating Station. The Lovett Generating Station is located on the west bank of the Hudson River at RM 41, slightly north of Stony Point. Lovett is a fossil-fueled steam electric generating station consisting of five units: Unit 1 became operational in February 1949, Unit 2 in July 1951, Unit 3 in March 1955, Unit 4 in May 1966, and Unit 5 in April 1969. In 1987 Units 4 and 5 were converted to burn coal in addition to gas and oil. In 1995, Units 1 and 2 were decomissioned. Present net generating capacity is 443 MW.

The intakes for all units are located on the shorelines. Each intake structure is equipped with bar racks and vertical traveling screens. Traveling screens have a 0.95-cm square mesh.

The cooling water for Unit 3 discharges to the south; Unit 5 is discharged from a canal to the north. For Unit 4, cooling water is discharged at the river bottom approximately 75 m offshore to the south.

59th Street Generating Station. The 59th Street Generating Station is on the east bank of the Hudson River at RM 7, just north of the Battery. The plant has five boilers with a total electric generating capacity of 41 MW, two steam turbines, one retired in 1991 and one rated at 20 MW, and three package boilers that generate steam for delivery to customers. The three package boilers have a steam generating capacity of 330,000 lb/hr; the steam is sold for district heating and cooling. The station no longer uses river water for its service cooling water system. It uses city water instead, which it reclaims for use as boiler feedwater.

ii. Wastewater Treatment Facilities

Yonkers Joint Municipal Sewage Treatment Facility. The Yonkers facility discharges treated municipal wastewater to the Hudson River. The screening house was built in 1931 but primary treatment was not begun until 1961. Secondary treatment did not start until 1979. The current permitted volume is 92 mgd. The facility has been involved since 1987 in a major upgrade program, including pretreatment requirements, development of additional treatment capability, and studies of the facility's effluent.

North River Water Pollution Control Facility. The North River treatment plant, just below the George Washington Bridge, discharges treated wastewater up to a permitted limit of 170 mgd. Advanced preliminary treatment facilities construction began in 1983 and became operational in 1986. The secondary treatment facilities were started in 1985. Secondary treatment began in April 1991. The effluent has been tested with acute and chronic bioassay procedures. The results indicate that the discharge is in compliance with permit limitations on toxicity to aquatic organisms.

iii. Others

Empire State Plaza. Empire State Plaza uses Hudson River water (108 mgd) to provide heating and cooling for the state office complex in Albany. The shoreline intake moves water at very low velocity.

Westchester Resource Recovery Plant. The Westchester Resource Recovery plant (RESCO) is located on the east bank of the Hudson River at Peekskill, New York. The plant was constructed in 1982 for dual purposes: to incinerate waste material and to generate electric power from the heat of the waste combustion. The generating capacity is 60 MW. Condensers are cooled by once-through cooling with a permitted flow rate of 55 mgd. The cooling water intake is located approximately 750 ft offshore at a depth of 22 ft. The intake is composed of Johnson Company cylindrical v-wire screens made of copper-nickel alloy. Each screen is about 1.4 m long and 1.4 m in diameter. Four screens are mounted on T-stands approximately 1.5 m above the river bottom; the screens are oriented parallel to ambient currents. The slot openings of the mesh are 0.5 mm. Through-slot water velocity is 15 cm/s, less than the ambient current flow past the screens that flood in ebb tides. Screen surfaces can be cleaned by an air backwash that blasts the debris off screen surfaces, to be carried away by river currents.

The cooling water outfall is located 1200 ft offshore in 55 ft of water. The cooling water exits through a 12-port diffuser that is 220 ft long. The high-velocity diffuser is designed to provide rapid mixing of the thermal discharge with river flow.

World Trade Center. The World Trade Center is located on the west side of Manhattan between Vesey Street to the north and Liberty Street to the south. Cooling water (94 mgd) is drawn from the Hudson River at RM 0.7. The intake is located under a cantilevered esplanade that forms a skimmer wall with 30 ft of water below it. Approximately 100 ft eastward, bar racks screen water entering the intake pipe. The single intake pipe splits and passes through another set of bar racks (since rusted away and no longer in place). Two 0.95-cm vertical traveling screens filter water in front of a series of circulating pipes. Impinged fish and debris are removed from the traveling screens and are collected in a sluiceway pit. No provision is made to return fish and invertebrates back to the river.

Circulating water is chlorinated when temperatures of ambient river water are over 59°F, generally from April/May to mid-October. Discharged circulating water leaves the system through two pipes to a discharge canal located under the cantilevered esplanade. The canal ends at the northeast corner of the North Cove Marina.

c. *Major Intakes*

i. *Chelsea Pumping Station*

The Chelsea Pumping Station is located on the east bank of the Hudson River across from the Roseton Units 1 and 2 Generating Station. The station was constructed in 1950 in response to a water supply shortage caused by moderate drought, increased consumption of water following World War II, and delays in completing the Delaware Aqueduct System reservoir. It was designed to provide emergency supplies of water by pumping up to 100 mgd from the Hudson River into the Delaware Aqueduct at Shaft 6. The station was completed on May 1, 1951, and put on standby status. The station was not used in the 1950s; thus, it was dismantled in 1957 in accordance with the terms of its emergency operating permit.

The drought emergency of the 1960s resulted in reconstruction of the station. The new station constructed in 1966 was a duplicate of the 1950s original. The intake conduit had been left intact and the original pump and motors were repurchased and reinstalled. The pumping station has been maintained since 1966 and has been operated three times since that date. It was operated for 300 days in 1966 and 1967, then again placed on standby. On July 10, 1985, the station was reactivated until December 11, 1985. In the spring of 1989 the station was operated for two weeks to preserve the supplies in New York City's upstate reservoirs, which had been depleted during a winter of low precipitation.

Since 1985, operation of the Chelsea Pumping Station has been the subject of debate, hearing, and multiple draft environmental impact statements addressing the environmental issues associated with operation of the station. Impacts on Hudson River biota due to the operation of this station were evaluated in a DEIS prepared by Malcolm Pirnie (1986). This evaluation did not include sampling of impingement or entrainment at Chelsea; rather, data from Roseton Units 1 and 2 and Danskammer Point were used as surrogates for impacts associated with Chelsea.

The intake for the pumping station consists of a 72-in.-diameter concrete pipe that extends approximately 700 ft from the shoreline to an intake crib located at a depth of 40 ft. Water entering the pumping station is diverted to three channels, each fitted with an inclined bar rack (2-in. openings) and 0.375-in. mesh traveling screens. Impinged material is cleaned by traveling rakes and spray water. Impinged materials, including fish, are stored temporarily, then trucked off-site for disposal.

B. PHYSICAL CHARACTERISTICS OF THE ESTUARY

The physical characteristics of the estuary and its drainage basin define the limits of the biological and chemical species in the system and control the degree of mixing and interaction among species. This section describes the physical features and mechanisms of the Hudson River.

Much of the information in this section was first presented in academic publications and studies sponsored by federal agencies such as the U.S. Geological Survey (USGS) and the National Oceanic and Atmospheric Administration (NOAA). The river studies funded by the Hudson River utilities included collection of data on temperatures, tides, and sediment loads using turbidity as a surrogate. For the most part these data were collected in conjunction with biological sampling.

1. Basin Morphometry

The three-dimensional shape (morphometry) of the riverbed is the result of important habitat features such as depth, current velocity, and substrate type. Broad, shallow basins promote the settling of suspended organic matter, which feeds dense populations of bottom-dwelling organisms that in turn feed large numbers of small fish. Narrow, shallow reaches with high current flows have bottoms that are scoured clean of organic matter, resulting in coarse gravel that makes good spawning sites for some species. Tributaries often have these same physical characteristics, generating another source of spawning sites. Fast flows through deep basins generate turbulent deepwater areas where fish eggs and weakly swimming hatchlings tend to accumulate and remain in the water column, away from smothering fine sediments and predatory bottom-dwelling organisms. Shallow, shore-zone areas promote the growth of rooted plants that provide a protective and productive habitat for small fish. The following overview of the Hudson River estuary describes the major changes in the morphometry of the riverbed and identifies some of the important habitat areas within the river.

The lower Hudson River estuary is 154 miles long from the Battery to Troy Dam. For ease of discussion and to provide for equitable sampling in the Hudson River Utilities Monitoring Program, it is divided into 13 regions (Figure V-6) that extend from RM 4 to RM 152. In

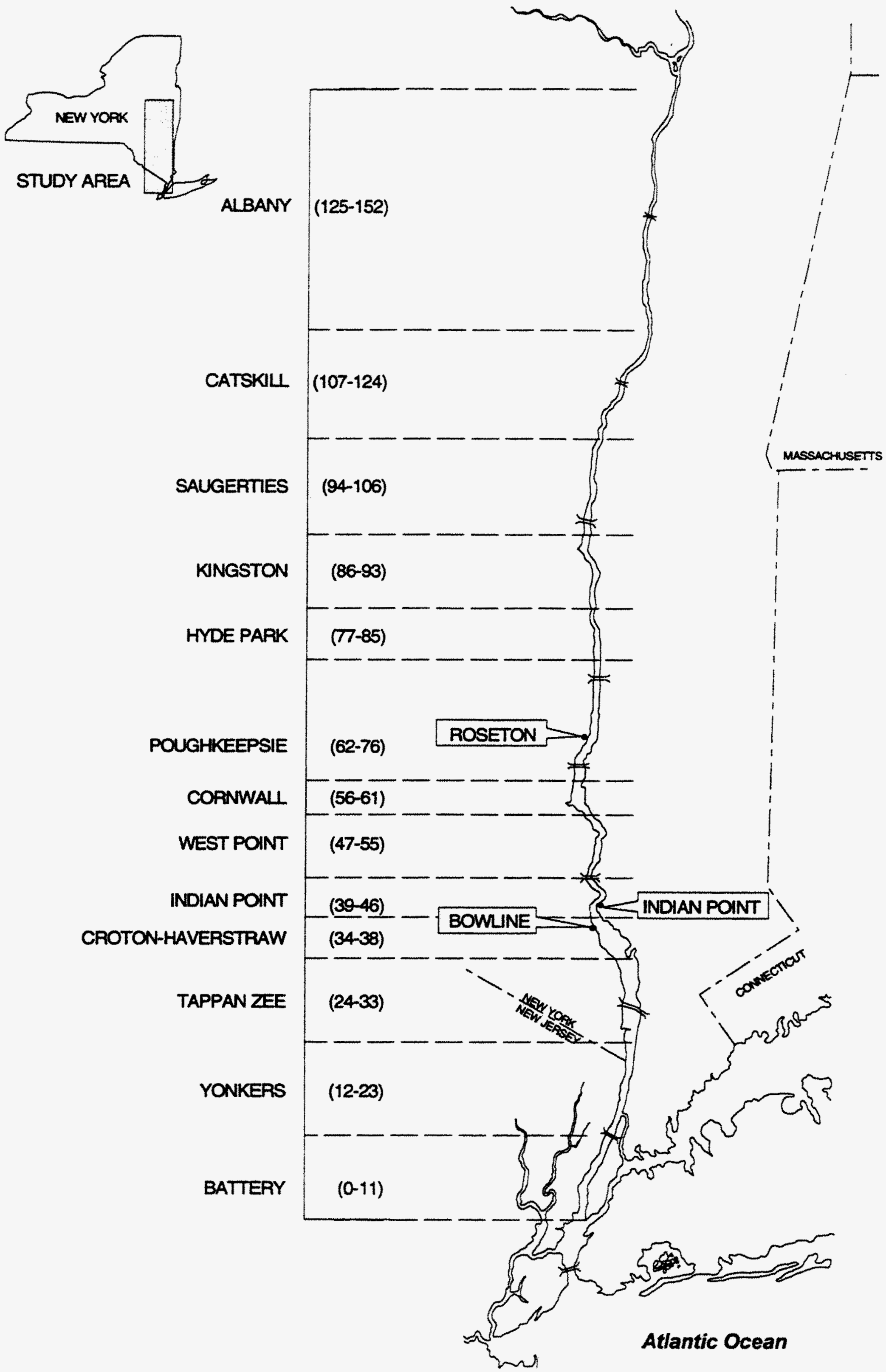


Figure V-6. The lower Hudson River estuary.

Table V-5 the river has been divided into segments of roughly comparable volume, starting at the Troy Dam. The first segment extends from RM 152 to RM 94 and includes the regions of Albany, Catskill, and Saugerties. This 59-mile reach of river is narrow and has extensive shoals and 29 tributaries. The slope of the river bottom is also greatest in this section of the lower Hudson, which means that current velocities are generally greater in this segment than in other segments.

The second segment extends from RM 93 to RM 56 and includes the regions of Kingston, Hyde Park, Poughkeepsie, and Cornwall. This reach contains a series of progressively deeper (going downriver) basins. Although the reach is about two-thirds the length of the uppermost segment, its volume is more than 1.5 times that of the uppermost segment. This is the result of the constriction formed by the Catskill Mountains to the west and the Taconic Mountains to the east that caused the glaciers to cut more deeply into the floor of the Hudson River Valley as they passed through the segment. Shallow shoreline and shoal areas are common only in the southernmost end of the reach.

The third segment of the river extends from RM 55 to RM 39 and includes several prominent points where the river bends sharply. The Hudson Highlands forced the glaciers through a narrow and tortuous path in this reach and they cut deeply into the valley floor. This is the deepest and most turbulent section of the river, greatly feared by the captains of sailing ships during colonial times. The river narrows abruptly, bends sharply, and increases dramatically in depth to over 150 ft. At the lower end of this segment, between RM 45 and RM 38, a series of progressively shallower gouges in the bedrock gives the river bottom a slanted corrugated form (much like that of an old-fashioned scrub board) as it rises to the shallows below the Hudson Highlands.

When the glaciers spilled out of the Hudson Highlands, they created a broad shallow basin. This reach is short, extending from RM 38 to RM 24, and very broad, 2.5 miles wide. This is the widest and shallowest section of the river and includes two prominent natural landmarks, Croton Point and Piermont Point. It has the most extensive shoal and shore-zone areas. This is a major deposition zone within the river and the sediments have a relatively high organic content. Biologically, it is a productive area of the river, particularly as a nursery for juvenile fish.

Below the broad, shallow basin, the Palisades again restricted the flow of the glaciers and the river narrows and deepens until it spills out into New York Harbor. The section is relatively straight, with few shoal areas or shore-zone habitats. In the lower 12 miles there is relatively little natural shoreline remaining.

TABLE V-5

HABITAT RIVER REACH VOLUMES AND NUMBER OF TRIBUTARIES ENTERING EACH REACH[a]

RIVER REACH (river miles)	TOTAL VOLUME (x 10^6 m^3)	SHOAL VOLUME[a] (x 10^6 m^3)	SHORE ZONE VOLUME[b] (x 10^6 m^3)	LENGTH (miles)	AVERAGE CROSS SECTION (m^2)	TRIBUTARIES (number)
RM 152-94	408.0	81.6	22.8	59	4,300	29
RM 93-56	647.2	25.9	12.5	38	10,600	11
RM 55-39	415.7	16.6	5.3	17	15,200	5
RM 38-24	469.5	173.7	32.5	15	19,400	3
RM 23-1	438.4	43.8	3.4	23	11,800	1

[a]Shoals - water of 20 ft or less.
[b]Shore zone - water of 10 ft or less.

2. Freshwater Flow

Freshwater flow is one of the single most important factors in determining physical, chemical, and biological processes within the estuary. The seasonal variation of freshwater discharge and the occurrence of high-flow events have an important influence on the physical/chemical processes and the distribution of aquatic life. Under low-flow conditions saline water and attendant marine species reach far upriver; under high-flow conditions fresh water and freshwater organisms reach far downstream. Sediment deposition and resuspension, mobilization of chemicals, including toxins, and the inflow of allochthonous organic detritus imported from the watershed are all influenced by freshwater flows. Under low-flow conditions the lower estuarine portion of the river is reasonably well mixed with fresh water. Under these conditions there is only an approximate 10% difference in salinity between the surface and bottom waters. Under high-flow conditions fresh water overrides the salt layer and salinity differences of up to 20% can be established (Busby and Darmer 1970).

Freshwater flow varies over the year, with maximum flows occurring primarily during March, April, and May and low freshwater flows beginning in June and continuing until November.

Under normal summer conditions about 75% of the freshwater flow enters the lower Hudson River at Troy. Flow at this location is gauged at the USGS station at Green Island. Freshwater flows reaching this point are regulated by a series of dams, locks, and water supply reservoirs in the upper Hudson and Mohawk subbasins. Over 70% of the remaining freshwater flow enters via tributaries near the upper end of the estuary (Table V-6). The major tributaries below the Federal Dam at Troy are Kinderhook Creek (RM 125), Catskill Creek (RM 113), Roeliff-Jansen Kill (RM 111), Esopus Creek (RM 103), Rondout Creek and Wallkill River (RM 92), Wappinger Creek (RM 67), and Croton River (RM 34). The remaining tributaries are generally smaller in size. The storage reservoirs in the upper basin fill during late winter and spring; thus the percentage contribution of the lower basin tributaries would be greater at this time. As most of these tributaries are ungauged and freshwater contribution cannot be measured at the mouth of the estuary because of tidal oscillations, the size of the drainage areas of the tributaries are used to estimate the contribution of these inputs. Texas Instruments (1976a.) and Abood et al. (1992) present relationships for determining the freshwater flow at Poughkeepsie and Manhattan from the Green Island flow.

TABLE V-6

MAJOR FRESHWATER TRIBUTARIES TO HUDSON RIVER BELOW TROY, NEW YORK

TRIBUTARY	RIVER MILE (km)	SHORE	DRAINAGE AREA* (mi^2)	MEAN FLOW (cfs)
Sparkill Creek	24.5 (39)	West		
Croton River	34.0 (55)	East	378	
Moodna Creek	58.0 (93)	West		
Fishkill Creek	60.0 (97)	East		
Wappinger Creek	67.0 (108)	East	208	254
Rondout Creek (+ Wallkill River)	92.0 (148)	West	1197	
Esopus Creek	103.0 (166)	West	425	588
Roeliff-Jansen Kill	111.0 (179)	East	208	
Catskill Creek	113.0 (182)	West	417	
Kinderhook Creek	122.0 (196)	East	512	
Moordener Kill	138.5 (223)	East	33	38
Normans Kill	144.0 (232)	West	168	145

Based on data from 1947 through 1997, the average annual freshwater input at Green Island is 13,527 cfs (Figure V-7). Average annual flow values are quite variable, ranging from a low of 7750 cfs in 1965 to a high of 21,311 cfs in 1976. There was a period of extreme high flows during the 1970s and a period of severe drought during the 1960s. On a seasonal basis, flows at Green Island are greatest in April, when snowmelt from the Adirondack Mountains and high precipitation occur in conjunction with saturated soil conditions (Table V-7). During this month, average flow is 30,729 cfs, with a range of 9,073 to 61,817 cfs. Flows decrease during the summer as the dry soils and vegetation absorbs more of the precipitation. By August average flow is 5673 cfs, with a range of 1,692 to 14,631 cfs. Flows increase again through the fall as vegetation growth and transpiration slow and the ground begins to freeze.

Spring freshets, tropical storms, and intense rainfalls can bring about sudden increases in flow. During these events, peak daily flows can be quite high. The maximum daily flow recorded at Green Island was 141,000 cfs on December 31, 1948. By way of contrast, the lowest recorded daily flow was 0 cfs on April 28-30, 1968. The high-flow events more likely to occur during the spring and fall result in less predictable flow conditions in these seasons than in winter and summer (Wells and Young 1992).

3. Tides

The lower Hudson River is a tidal estuary from New York Harbor to the Federal Dam at Troy. The tidal flow is significantly higher than the freshwater flow 300,000-500,000 cfs vs 3,000-30,000 cfs at Troy (Stedfast 1982). There are two floods and two ebbs in a 24-hr interval, which is referred to as a semidiurnal pattern. The moon's distance and phase are the principal factors influencing the tidal amplitude and current velocities within this semidurinal pattern.

The oscillating flow of water due to tidal action is ordinarily far greater than the freshwater flow. The tidal flow generally ranges from about 200,000 to 300,000 cfs, but may be as much as 494,000 cfs (Busby 1966). Consequently, currents generated by the freshwater flows can be masked by the much larger tidal oscillations.

Tidal behavior within any longitudinal segment of the estuary is the composite effect of ocean tidal amplitude (difference in height at high and low tide), channel configuration, and wave reflection. Ocean tides, which change from maximum amplitude (spring tides) to minimum amplitude (neap tides) and back in a 28-day cycle, are the primary variable.

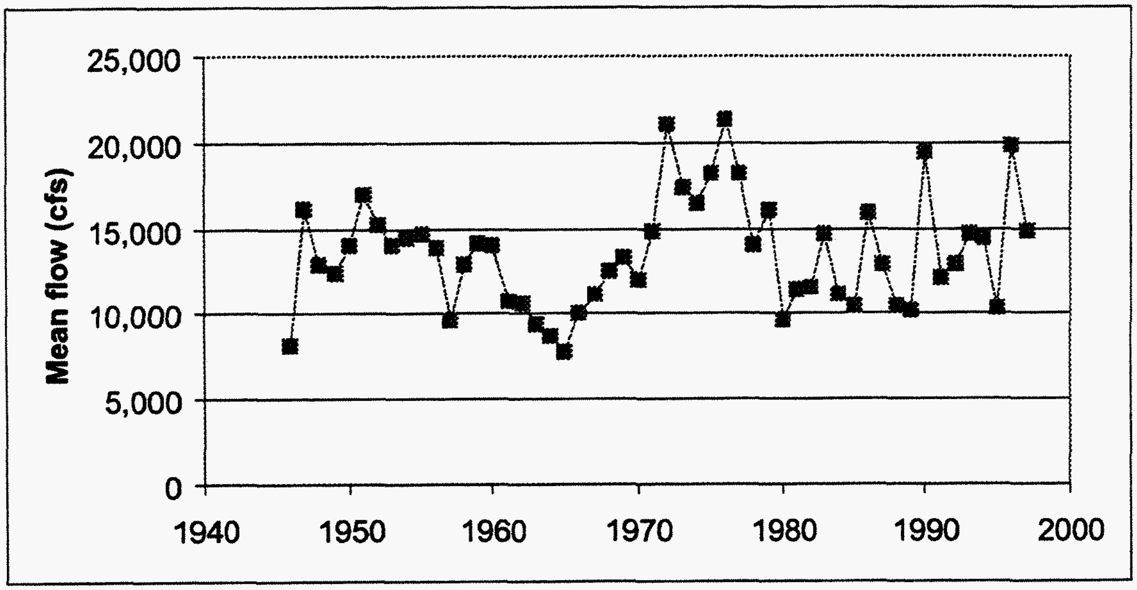


Figure V-7. Annual mean Hudson River flow at Green Island, 1945-1998.

TABLE V-7

MEAN AND RANGE OF MONTHLY AVERAGE FRESHWATER FLOWS (cfs) AT GREEN ISLAND, NEW YORK, FOR PERIOD 1947-1997

MONTH	MEAN	MINIMUM	MAXIMUM
January	13,438	4,187	33,968
February	13,978	4,527	31,255
March	21,481	9,123	38,058
April	30,729	9,073	61,817
May	18,801	5,503	40,522
June	9,749	3,573	29,630
July	6,552	3,082	18,379
August	5,673	1,692	14,631
September	6,313	2,066	17,027
October	8,852	2,525	30,142
November	12,917	3,270	26,152
December	14,866	6,096	34,939

Channel configuration, including width, cross-sectional area, slope, and obstructions, can modify tidal behavior. Significant changes in width can cause reflected secondary waves; complete reflection occurs at the Federal Dam. Variations in freshwater flow and barometric conditions also contribute to changes in amplitude. The interaction of these factors in the Hudson estuary produces a significant variation in the mean tidal amplitude. In fact, tidal amplitude is greater at Troy than it is at the Battery: Battery, 4.4 ft; Storm King, 2.6 ft; and Troy, 4.7 ft. During spring tides the range of high- and low-water elevations is greater, about 5.3 ft at the Battery, 3.1 ft at Storm King, and 5.1 ft at Troy.

Mean tidal flow decreases from a maximum of more than 400,000 cfs at the Battery to zero at Troy (Figure V-8). The tidal flow diminishes rapidly from the Battery to RM 40, remains relatively constant between RM 40 and RM 100, and then diminishes rapidly again from RM 100 to RM 140. Mean current velocity is variable, with peaks near 2 fps just above the Battery and at Hudson. Between RM 30 and RM 90 mean velocity is about 1 fps. The tidal flow and current velocity are influenced by the interaction of freshwater flow, tidal flow, channel morphometry, and wave reflection. Freshwater flow, for example, increases the surface ebb velocity and decreases the surface flood velocity. The influence of freshwater flow is greatest at high river discharge in the spring and at the upstream end of the estuary. Current velocities tend to peak where the channel is narrow and relatively shallow and tend to reach a minimum where the channel is wide (Figure V-8).

The time of a given tidal stage occurs progressively later in an upstream direction from the Battery and varies with the stage of the tidal cycle, resulting in variations in the duration of ebb, flood, and slack tides along the estuary. Typical values are shown in Table V-8. The lag time between locations is approximately linear with distance from the Battery.

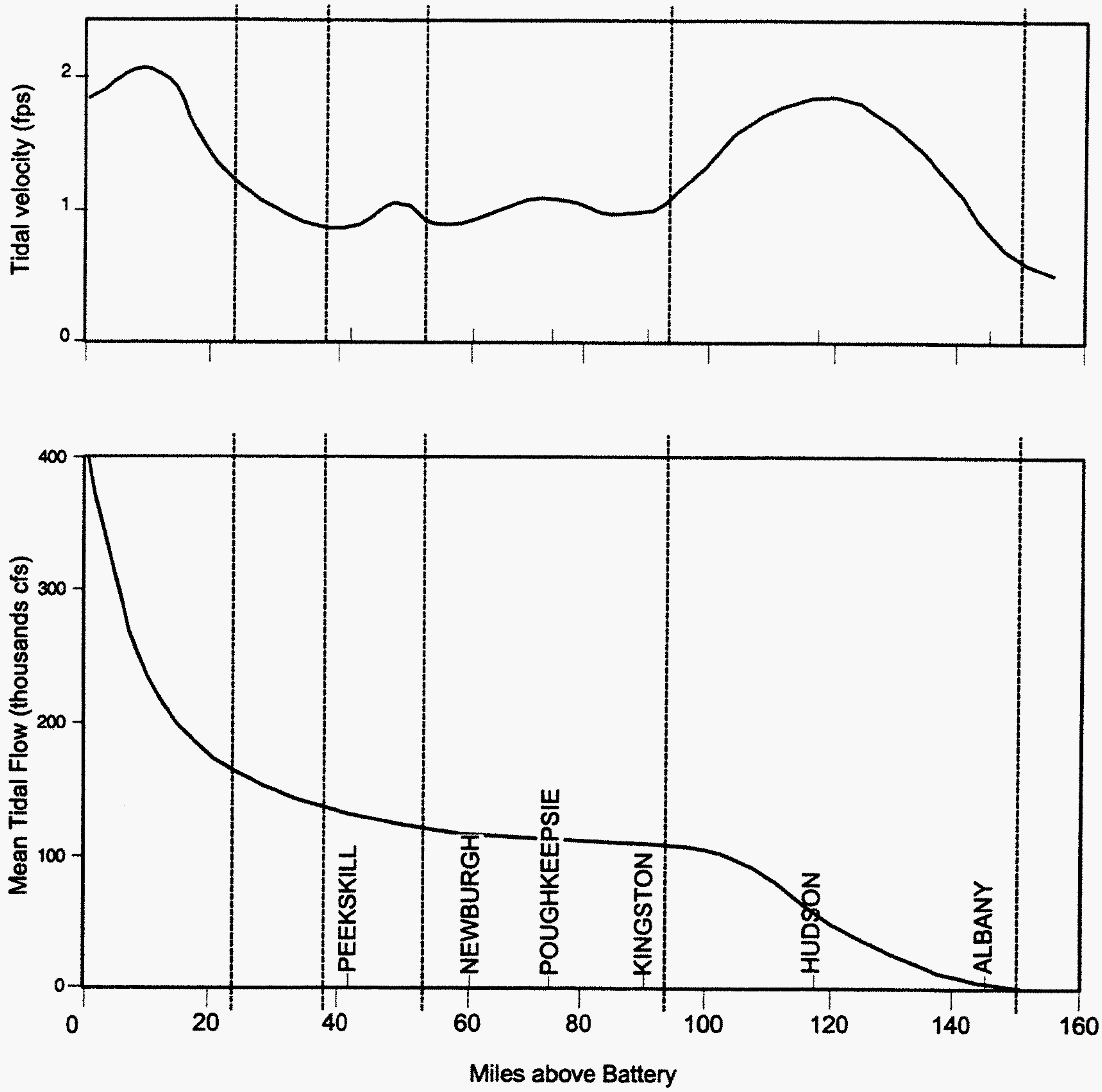
4. Water Temperature

Water temperature is an important environmental factor affecting aquatic biota. The temperature of the surrounding environment controls the physiological processes of aquatic organisms that are unable to regulate their own body temperatures. Each species has a preferred temperature range within which survival, growth, and reproduction occur most efficiently. Lethal temperatures are those warm or cool temperatures that can cause death. Ordinarily, fish and other organisms capable of directed movement are able to sense and avoid areas of lethal temperature as long as areas of non-lethal temperatures exist nearby. Other factors being equal (e.g., food, oxygen) within the preferred range, warmer temperatures increase metabolic functions, resulting in quicker growth and shorter times for

TABLE V-8

TIME LAG (hrs) BETWEEN BATTERY AND TROY

TIDE EVENT	TIME LAG (hrs)
Slack flood begins	7
Low water	10.5
Slack ebb begins	5.5
High water	9.5
Flood strength	5.5



Source: Modified, from Abood 1977.

Figure V-8. Hudson River tidal flow and current velocity.

development of eggs and larvae. Cooler temperatures slow metabolism, resulting in less demand for food and longer development periods. Temperature, often in combination with other factors such as the length of the day, may also trigger specific behavior such as spawning or emigration of anadromous fish.

Within any aquatic ecosystem, temperature varies both temporally (seasonally and daily) and spatially (over the length, width, and depth of the water body). The variations are natural phenomena caused by waterbody geometry, overland runoff, dispersion and exchange with fresh or ocean waters, and climatological conditions such as air temperature, wind, and solar radiation. Variations in the discharge of heat of artificial origin also contribute to temperature variations in the water body.

The predominant temperature pattern is the annual cycle of low winter and high summer temperatures. Hudson River temperature varies according to these natural seasonal cycles. Substantial variations in the pattern occur, particularly in the spring and fall. Daily water temperature, often collected by the Department of Public Works, City of Poughkeepsie, over a 47-year period (1951-1997) depicts the annual cycle (Figure V-9). Minimum water temperatures, occurring in January and February, average approximately 34°F; maximum temperature, in August, averages approximately 77°F. From April through June temperatures increase at an average rate of approximately 0.2°F per day; from mid-September through mid-December temperatures fall at the same rate.

Year-to-year variations in temperature can be evaluated by comparing the average annual temperatures. Although these comparisons obscure the seasonal variations that may be important to survival and reproductive success of biota, they allow identification of warming or cooling trends.

During the period from 1951 through 1997 the average annual temperature was 54.3°F (Figure V-10). For much of the 47-year period depicted in this figure, the average annual temperature for each year fell within one standard deviation of the average annual temperature for the period (+/- 1°F) and was random in distribution above and below the average for the multiyear period. The average temperature in 1991 was the highest average for the period, more than 2°F above the average for the period.

There is also considerable spatial variability in Hudson River temperatures today and in the historical data record. Water temperatures were recorded along the length of the Hudson River in 1929 as part of a current survey by the U.S. Department of Interior. The resulting composite temperature profile, which covered a period of two weeks between late August and mid-September, illustrates the longitudinal variation in ambient temperature of the

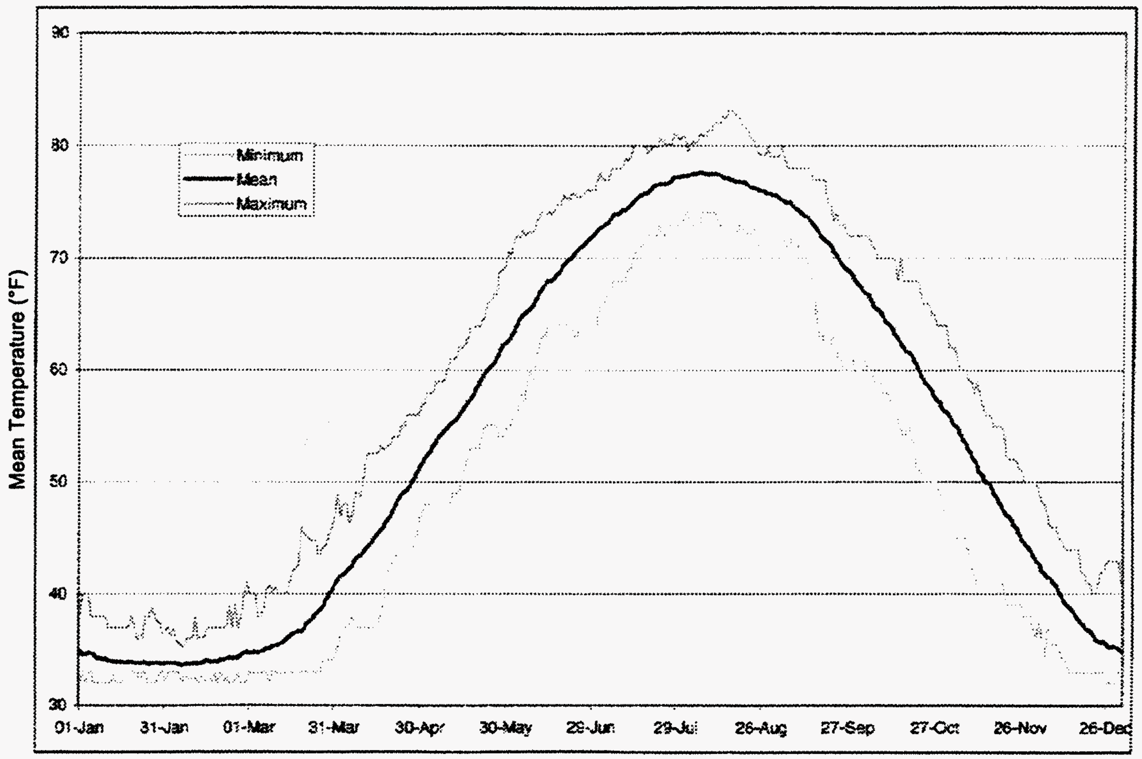


Figure V-9. Mean, minimum, and maximum daily Hudson River water temperature at Poughkeepsie Water Works, 1951-1992.

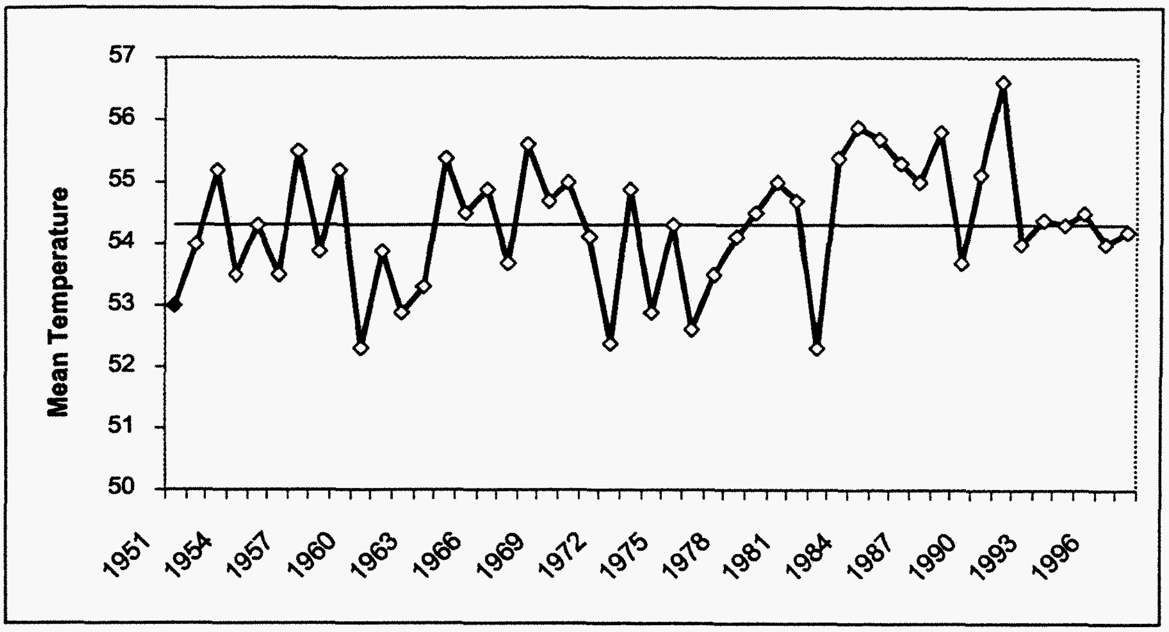


Figure V-10. Annual mean Hudson River water temperature measured at Poughkeepsie Water Works, 1951-1997.

Hudson River in 1929 (Figure V-11). Temperatures for the survey were about 64-65°F at RM 10 and about 10°F higher (74°F) in the Nyack area (approximately RM 30). Temperatures were about 2°F lower at Kingston than at Nyack, probably due to climatic patterns as well as to the hydrodynamic characteristics (lower velocities and the presence of shallows near Nyack). In the last segment, the area between Kingston and Albany, still lower temperatures were recorded (from about 72° to 68°F, a difference of about 4°F). This may be due to the hydrodynamic characteristics as well as climatic differences, i.e., a change in the atmospheric inputs to the river. Hydrodynamically, this river segment is deeper and has less shallow bay area than the lower river, resulting in higher river velocity and less heat exchange per volume of water. The climate of lower New York is warmer than the cooler, mountainous areas of the Catskill and Adirondack ranges of upper New York State and the upper Hudson River Valley. The air temperature in the Albany area during late summer is usually 8-10°F cooler than in the New York City area.

The present-day pattern of longitudinal variation in temperature during different seasons can be evaluated using the 1988 and 1991 data as examples (Figure V-12 andV-13). For much of each year the average difference over the length of 140 miles is only 6-8°F. Upstream, areas change quickly in response to freshwater flow and atmospheric conditions. Downstream, areas are less variable because their larger volumes dilute inflow and dampen fluctuations. Downstream regions warm more slowly in spring and summer than the upriver regions and cool more slowly in the fall. During spring and fall, longitudinal differences may be 10°F or more between fresh water coming into the estuary in the Albany region and the ocean waters intruding up the river.

Although the river is generally mixed, surface and bottom temperatures vary little for most regions (Figure V-12 and V-13). Distinct temperature differences occur in the lower estuary when cool, saline waters intrude along the bottom, and fresh water warmed in shallow areas tends to move downstream upon the surface. Thus spring temperature stratification is clearly shown in April and June 1988 (Figure V-12).

5. Sediment Relationships

The physical and biological processing of particulate material is a very important function of the estuary ecosystem. Sediment particle size, depth, and organic content are factors in the distribution and abundance of benthic invertebrates. Particulate organic material is a source of food, both directly and indirectly, for a variety of organisms, and the decomposition of organic material is a source of nutrients for organic production. Organic sedimentary

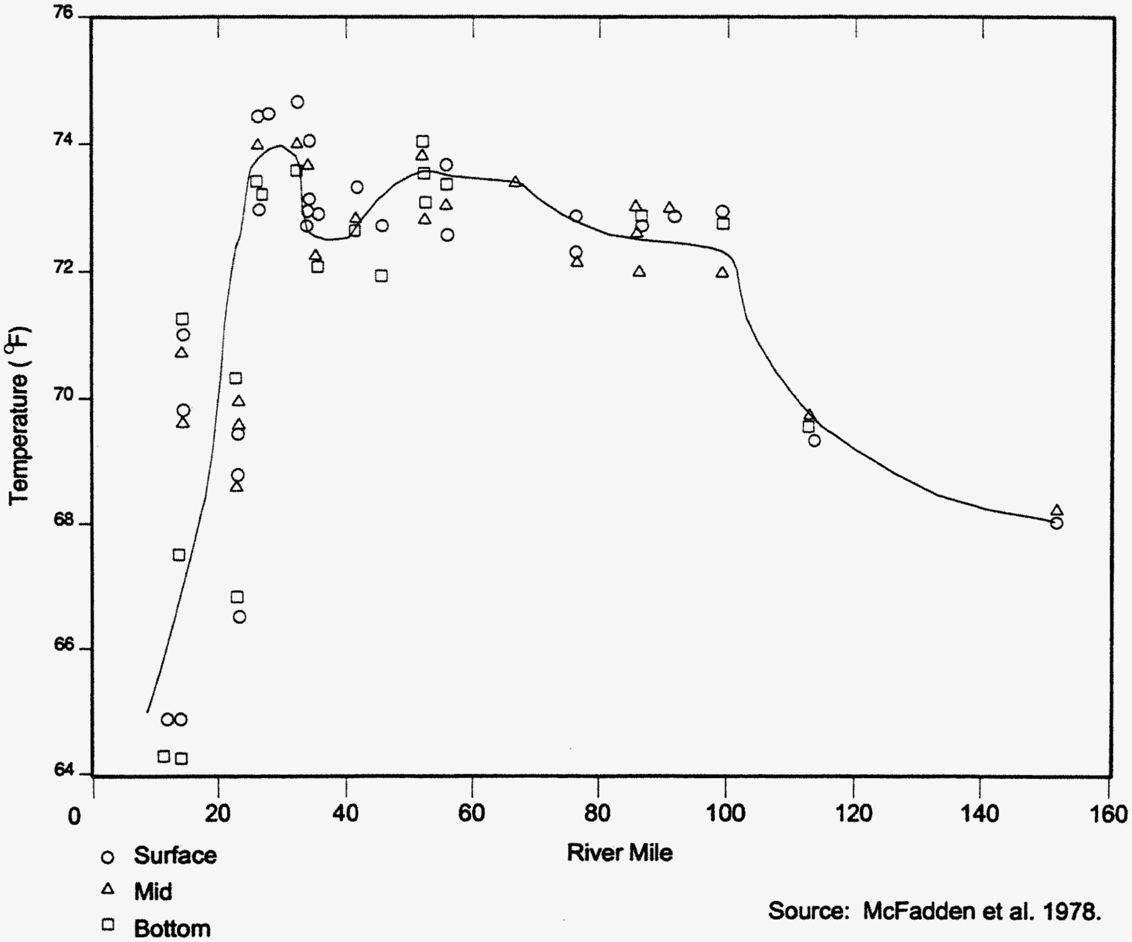


Figure V-11. Hudson River temperature readings in August and September 1929.

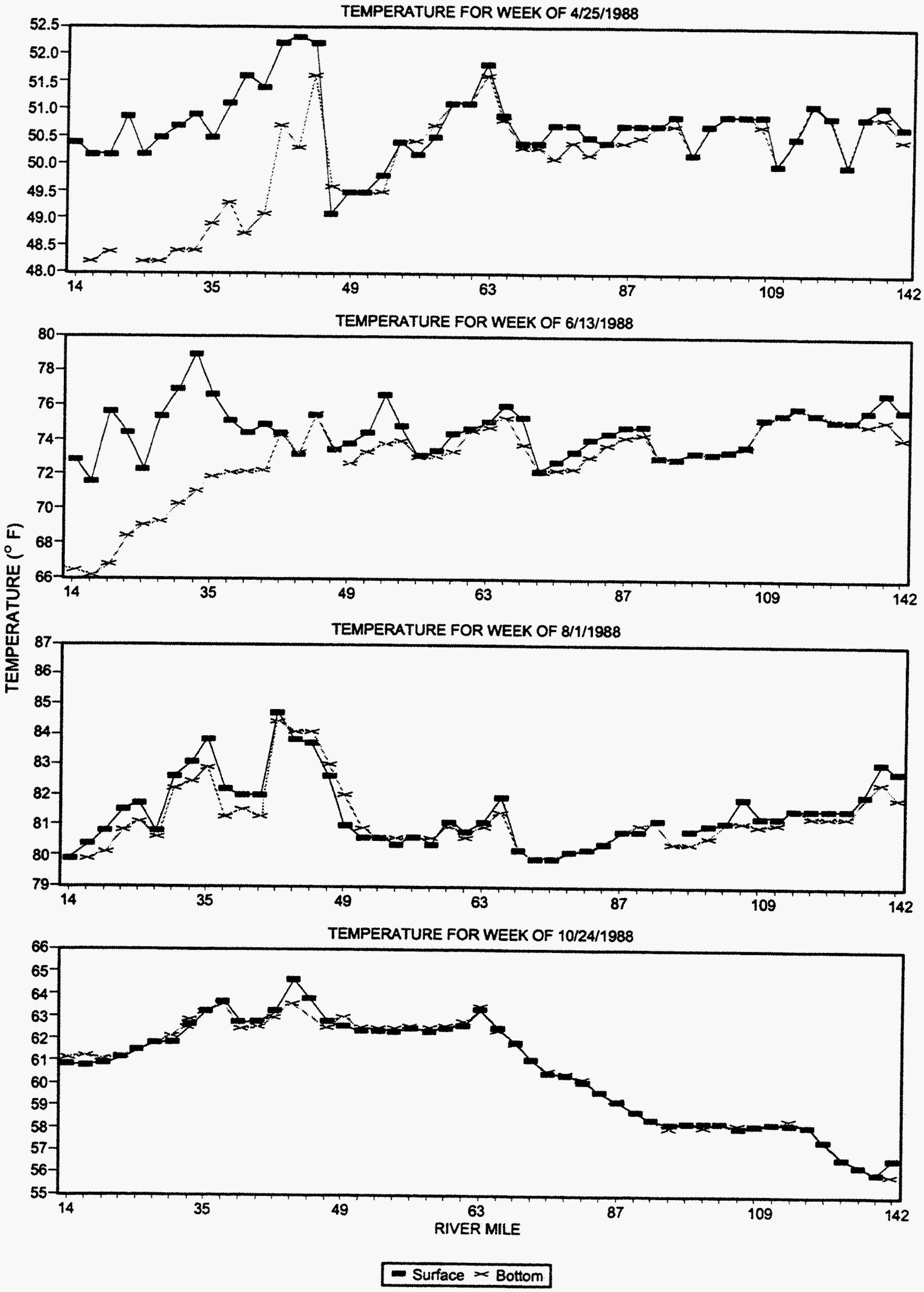


Figure V-12. 1988 longitudinal variation in temperature.

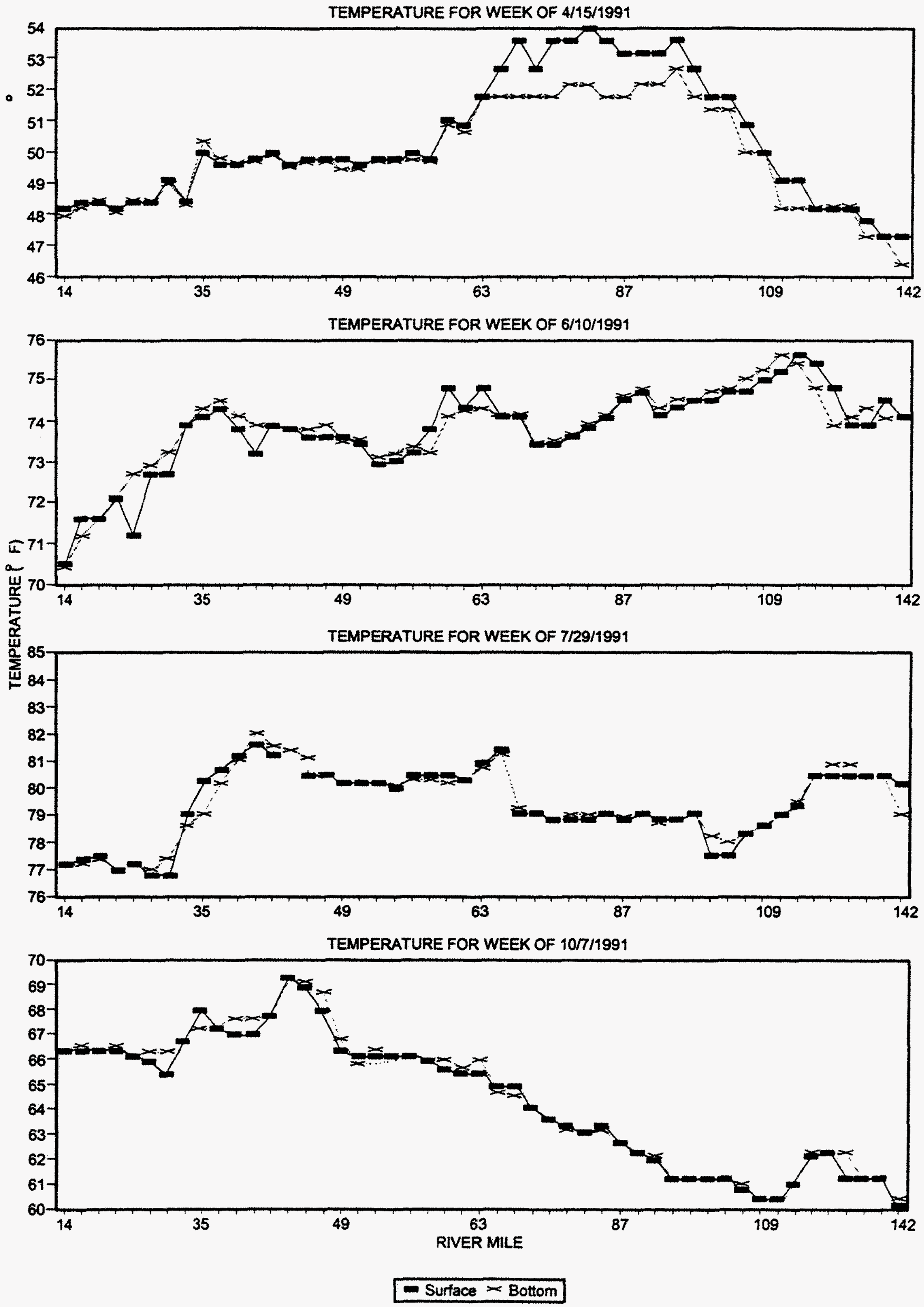


Figure V-13. 1991 longitudinal variation in temperature.

material is also important because toxic substances such as PCBs adhere to the organic particles and can form relatively high concentrations in localized areas. The subsequent movement and release of these substances play a role in their effect on the biota of the estuary and their use.

Organic and inorganic particulate matter enters the Hudson estuary from various sources and follows various pathways as it cycles through the estuary to its final fate. Particulate matter may be deposited as sediment on the estuary bottom; deposited and subsequently eroded and resuspended; carried through the estuary and discharged to the ocean; or, in the case of organic material, decomposed, assimilated, and transformed back to living organic material.

Inorganic sediment originates primarily as riverborne particles from erosional processes in the watershed, as littoral drift of sands along beaches, and from direct dumping of waste solids in the estuary. Organic particulates are derived from leaves and other terrestrial plant material carried in by tributaries or falling directly in the estuary, from the discharge of sewage treatment plants, from urban runoff, and from the upstream movement of marine organic material, primarily migratory fish. Organic particulates are also formed in the estuary through the excretion of animal wastes and the breakdown of dead plant and animal tissue.

The sedimentary processes in the Hudson River are very complex and not easily quantified. However, order of magnitude estimates for some major aspects of the sedimentary processes are available. With reference to inorganic sediment and estimates of suspended sediment concentrations, there are published sediment loading and sedimentation rates. Prior to 1980, the average concentration of suspended sediment particles (>0.45 μ) in the lower Hudson River below Troy Dam was shown to have been about 33 mg/l. These particles probably enter the river as individual silt-sized or clay-sized mineral grains. More recent studies (Bokuniewicz and Arnold 1984) found the average suspended solids concentration to be 35.3 mg/l. The average concentration near the riverbed was 45.6 mg/l; that in the surface water, 24.9 mg/l. The seasonal averages were 40.0 mg/l in April, 27.9 mg/l in August, and 38.0 mg/l in October (Bokuniewicz and Arnold 1984).

Olsen et al. (1984) estimated that 1.5 million metric tons of fine-grained particles accumulate annually in the Hudson estuary. Sediment input by shore erosion has been estimated to be negligible. About 1 million metric tons (dry weight) of fine-grained sediment particles is transported annually into New York Harbor from upstream sources (Olsen 1979). Most of the supply is introduced during the spring runoff.

Dredging data suggest that about half the sediment load transported by the Hudson River is deposited in the lower Hudson River between the George Washington Bridge and the Battery (Gross 1974). It appears that most of the fine-grained sediment transported in the lower Hudson River is deposited on the floor of the lower river. The most extensive fine-grained deposits are found there and these deposits are currently accumulating (Olsen 1979). Sedimentation rates of several centimeters per year are not unusual in dredged channels. Olsen (1979) measured sedimentation rates in the channels of New York Harbor in excess of 0.15 m/year using geochemical methods. Based on dredging records, the sedimentation rates in channels in the harbor have been calculated to be from 0.01 to 1.01 m/year, with an average value for 27 projects of 0.27 m/year (Bokuniewicz and Arnold 1984). Studies conducted by the U.S. Environmental Protection Agency (USEPA 1998) as part of the Phase 2 assessment of PCBs in the upper Hudson River suggest that upriver deposition rates are less than previously thought. Up to 30% of the coring sites in Thompson Island Pool indicated no gurial or even erosion.

Resuspension of fine-grained inorganic sediments occurs as a result of increased current velocity during high-flow events, through wind action in shoal reaches, and through wave action generated by boat wakes. The stability of bottom sediments is dependent upon local conditions such as water depth, tidal currents, the presence of rooted aquatic revegetation, and boat traffic. Harbor shoal sediments have been found to be very dynamic, with alternating episodes of deposition and erosion occurring during relatively short intervals of time (EEA 1988). Changes in the depth of bottom sediments of up to 1 ft within a month have been observed.

In the fall of 1998, Marine Sciences Research Center (Stony Brook) and Lamont-Doherty Earth Observatory began a detailed acoustic mapping of the surface sediments of the Hudson River from 41° 26'N to 41° 36'N (Ferrini et al. 1999). A multibeam echo sounder coupled with a Differential Global Positioning System (DGPS) is being used to classify seidments by analysis of the acoustic backscatter. Traditional sediment analysis is also being used to check the interpretation. The survey has identified areas of large rock outcrops, sediments ridges, sunken vessels and likely deposits of ship derived debris. Sediment analysis has revealed a complex distribution of sediments in this area consisting of primarily fine grained sediments and anthropogenic particles including coal and slag.