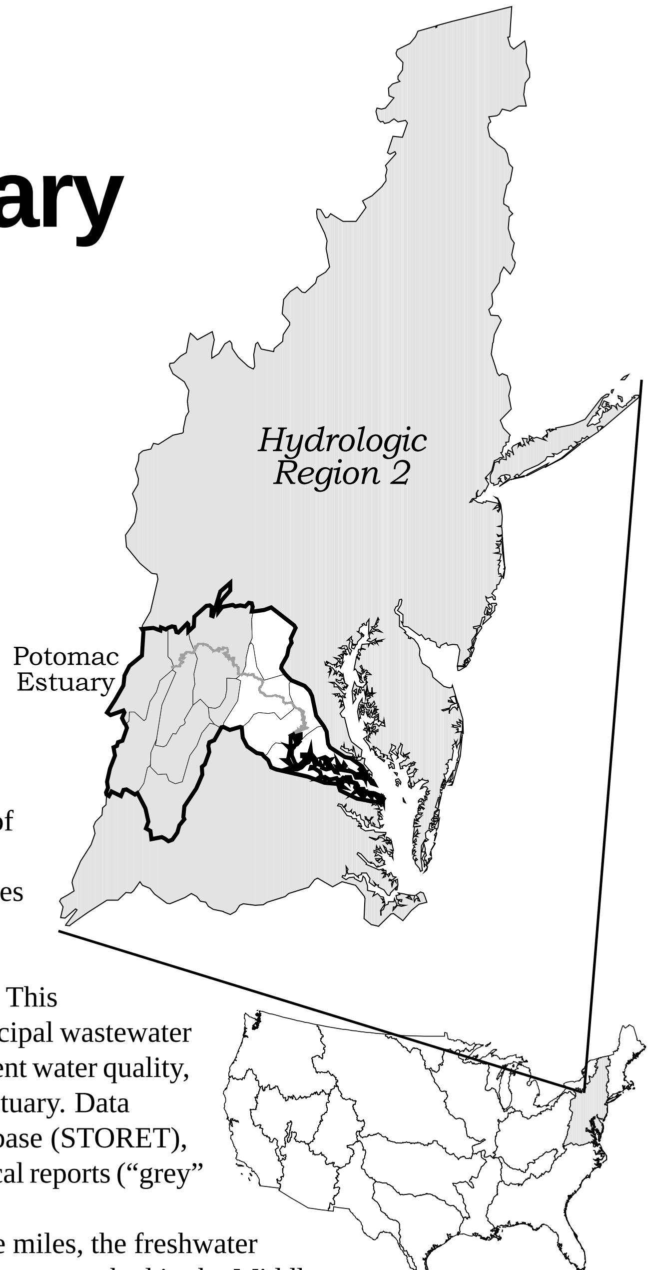
Chapter 8

Potomac Estuary Case Study



The Mid-Atlantic Basin (Hydrologic Region 2), covering a drainage area of 111,417 square miles, includes some of the major rivers in the continental United States. Figure 8-1 highlights the location of the basin and the Potomac estuary, the case study watershed profiled in this chapter.

With a length of 340 miles and a drainage area of 14,670 square miles, the Potomac River ranks 48th among the 135 U.S. rivers that are more than 100 miles in length (Iseri and Langbein, 1974). Urban-industrial areas in the watershed caused severe water pollution problems during the 1950s and 1960s (see Table 4-2). This chapter presents long-term trends in population, municipal wastewater infrastructure and effluent loading of pollutants, ambient water quality, environmental resources, and uses of the Potomac estuary. Data sources include USEPA's national water quality database (STORET), published technical literature, and unpublished technical reports ("grey" literature) obtained from local agency sources.

With a combined drainage area of 14,670 square miles, the freshwater and estuarine Potomac River basin is the second largest watershed in the Middle Atlantic region. The freshwater Upper Potomac River flows more than 220 miles from the headwaters of the North Branch in the eastern Appalachian Mountains to the fall line at Little Falls, Virginia, near Washington, DC. Tidal influences in the Potomac extend 117 miles from the fall line at Little Falls to the confluence with Chesapeake Bay at Point Lookout, Virginia (Figure 8-2).

Figure 8-1

Hydrologic Region 2 and the Potomac estuary watershed.

In this 117-mile reach, the Potomac River is classified into three distinct hydrographic regions—tidal river, transition zone, and estuary. The tidal river, extending 38 miles from the fall line to Quantico, Virginia, is characterized as freshwater (salinity < 0.5 ppt) with net seaward flow from surface to bottom. This section of the Potomac River receives the effluent discharge from the major municipal wastewater treatment facilities in the Washington, DC, metropolitan

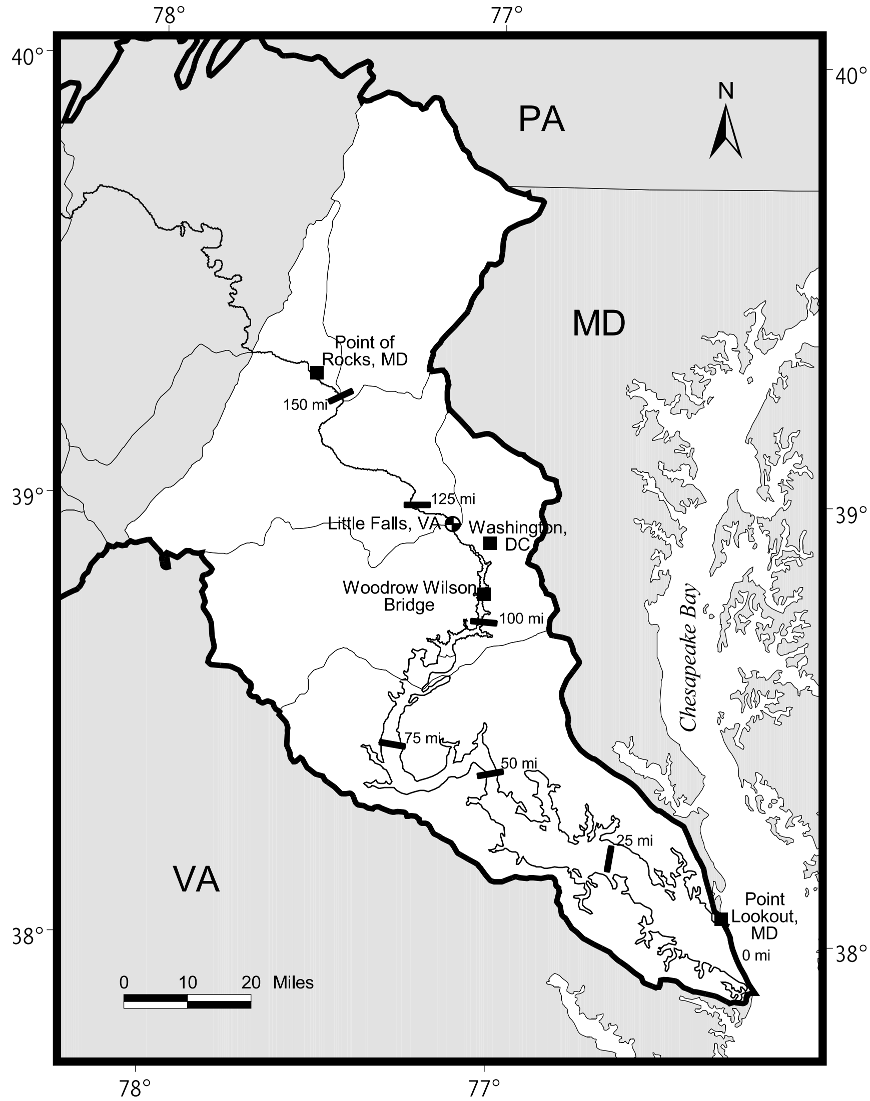


Figure 8-2

Location map of Middle and Lower Potomac River. (River miles shown are distances from the confluence of the Lower Potomac River with the Chesapeake Bay.)

area. The transition zone, extending 29 miles from Quantico, Virginia, to the Route 301 bridge in Maryland, is characterized by variable salinity (0.5-10 ppt) and significant mixing of freshwater and saltwater from Chesapeake Bay. In the mesohaline estuary region, extending 50 miles from the Route 301 bridge to Chesapeake Bay at Point Lookout, Virginia, salinity varies from 5 to 18 ppt, with estuarine circulation characterized as partially mixed (Haramis and Carter, 1983).

During much of the past century, the Potomac estuary has been characterized by severe water pollution problems—bacterial contamination, oxygen depletion, and nuisance algal blooms—resulting from population growth in the Washington, DC, area and inadequate levels of waste treatment. Historical DO data provide an excellent indicator to characterize long-term trends in the ecological status of the Potomac estuary. The water quality benefits attributed to implementation of secondary and advanced waste treatment by Washington, DC, area wastewater dischargers to the Potomac estuary represent a major national environmental success story.

Physical Setting and Hydrology

The Upper Potomac River, which has a drainage area of 11,560 square miles, is the major freshwater inflow to the estuary. Based on long-term (1931-1981) USGS data at Little Falls near the fall line, the mean annual daily flow is 11,406 cfs, with extreme discharge conditions of 374 cfs recorded during the drought of 1966 and 483,802 cfs recorded during the flood of 1936 (MWCOG, 1989). The long-term (1931-1988) mean 7-day, 10-year low flow (7Q10) at Little Falls is 628 cfs. Low-flow conditions typically occur from July through September, with the minimum monthly flow of 4,126 cfs recorded during September (Figure 8-3). The long-term (1951-1980) mean summer (July-September) flow for the Potomac River at Little Falls was 4,428 cfs (Figure 8-4).

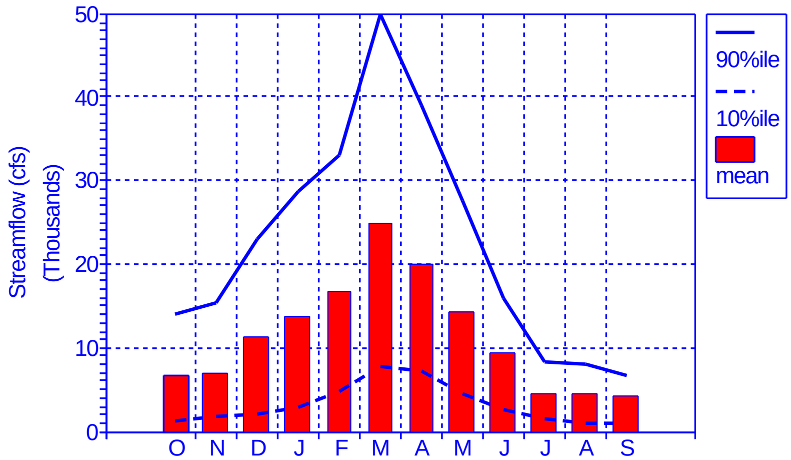


Figure 8-3

Monthly trends of mean, 10th, and 90th percentile streamflow for the Potomac River at Little Falls, VA (USGS Gage 01646500), 1951-1980.

Source: USGS, 1999.

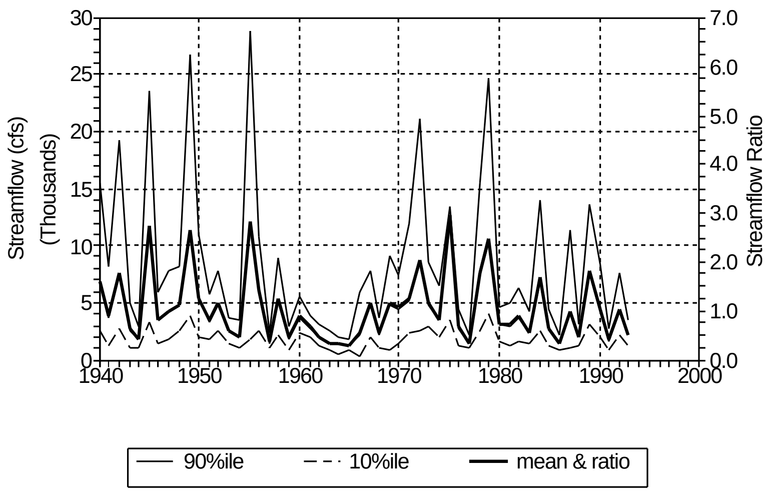


Figure 8-4

Long-term trends in mean, 10th, and 90th percentile streamflow in summer (July-September) for the Potomac River at Little Falls, VA (USGS Gage 01646500).

Source: USGS, 1999.

Table 8-1. Metropolitan Statistical Area (MSA) counties in the Potomac Estuary case study. *Source: OMB, 1999.*

Calvert County, MD	Prince William County, VA
Charles County, MD	Spotsylvania County, VA
Frederick County, MD	Stafford County, VA
Montgomery County, MD	Warren County, VA
Prince George's County, MD	Alexandria City, VA
Arlington County, VA	Fairfax City, VA
Clarke County, VA	Falls Church City, VA
Culpepper County, VA	Fredericksburg City, VA
Fairfax County, VA	Manassas City, VA
Fauquier County, VA	Manassas Park City, VA
King George County, VA	Berkeley County, WV
Loudoun County, VA	Jefferson County, WV

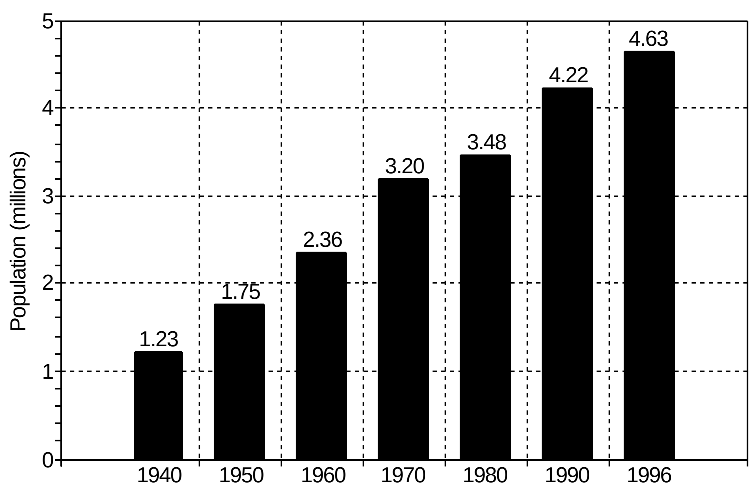
Population, Water, and Land Use Trends

In 1996 more than 4.5 million people lived in the Washington, DC, metropolitan area in the vicinity of the tidal river. The Potomac estuary case study area includes a number of counties identified by the Office of Management and Budget as Metropolitan Statistical Areas (MSAs) or Primary Metropolitan Statistical Areas (PMSAs). Table 8-1 lists the MSA and counties included in this case study. Figure 8-5 presents long-term population trends (1940-1996) for the counties listed in Table 8-1. From 1940 to 1996, the population in the Potomac Estuary study area nearly quadrupled (Forstall, 1995; USDOC, 1998).

Figure 8-5

Long-term trends in population of Washington, DC, metropolitan area.

Source: Forstall, 1995; USDOC, 1998.



Within the Potomac basin, land use is characterized as forested (55 percent), agricultural (40 percent), and urban (5 percent) (Jaworski, 1990). A rapid transition from agricultural land use to suburban land use has occurred since the 1960s in the Washington, DC, metropolitan area. In contrast to other major metropolitan areas, industrial activities are a negligible component of the regional economy (and wastewater loading). Upstream of the fall line, the free-flowing Potomac is used for five municipal water supply diversions with a total mean withdrawal (ca. 1986) of 386 mgd (MWCOG, 1989). As a result of major improvements in water quality over the past decade, boating and recreational and commercial fishing have become important resource uses of the Potomac estuary.

Historical Water Quality Issues

As in many other urban areas centered around rivers and harbors, water pollution problems have been documented in the tidal river since the turn of the century (e.g., Newell, 1897). In the late 1950s USPHS officials described the Potomac near Washington, DC, as "*malodorous . . . with gas bubbles from sewage sludge over wide expanses of the river . . . and coliform content estimated as equivalent to dilution of 1 part raw sewage to as little as 10 parts clean water.*" Dissolved oxygen levels near Washington, DC, were typically less than 1 mg/L during summer low-flow conditions, and nuisance algal blooms and fish kills were commonplace during the 1940s, 1950s, and 1960s. Between 1955 and 1960 the stock abundance of American shad in the Potomac River dropped precipitously despite favorable hydrographic conditions for spawning and development. American shad in northeastern estuaries such as the Potomac River, although influenced by spawning success, may be influenced to a larger extent by mortality suffered by young fish as they pass seaward through regions of poor water quality (Summers and Rose, 1987).

Legislative and Regulatory History

Following generally accepted engineering practices a century ago, a sewage collection system was constructed in Washington, DC, in 1870, with wastewater collected and discharged without treatment into the Potomac River. By 1913 USPHS surveys documented severely polluted conditions resulting from the discharge of raw sewage. Following the recommendations of city officials in 1920 and a study conducted in the early 1930s, the Blue Plains facility began operation in 1938 as a primary plant to serve 650,000 people. An unforeseen population influx related to World War II quickly exceeded the capacity of the new treatment plant.

In response to the continuing degradation of water quality in the Potomac, the 1956 Federal Water Pollution Control Act, and subsequent amendments, served as the mechanism for establishing cooperative federal, state, and local remedial action plans for wastewater treatment. For more than two decades, federal, state, and local officials have cooperated in developing regional water quality management plans and implementing recommended effluent limits.

Impact of Wastewater Treatment: Pollutant Loading and Water Quality Trends

In the Washington, DC, region, 13 wastewater treatment plants currently discharge effluent into the Potomac estuary. As of 1990 nine major plants (Table 8-2) served about 4 million people and discharged a total of about 615 mgd (ICPRB, 1990). The 370-mgd discharge of the Blue Plains plant, which serves the population of Washington, DC, accounts for about 75 percent of the total effluent discharge to the Potomac estuary during low-flow conditions (Figure 8-6).

Table 8-2. Effluent flow in 1990 from major tidal Potomac River municipal wastewater treatment plants (mgd). *Source: ICPRB, 1990.*

Alexandria	54
Arlington	40
Blue Plains	370
Dale City	4
Little Hunting Creek	6.6
Lower Potomac	72
Mattawoman	15
H.L. Mooney	24
Piscataway	30
Total	**616.6**

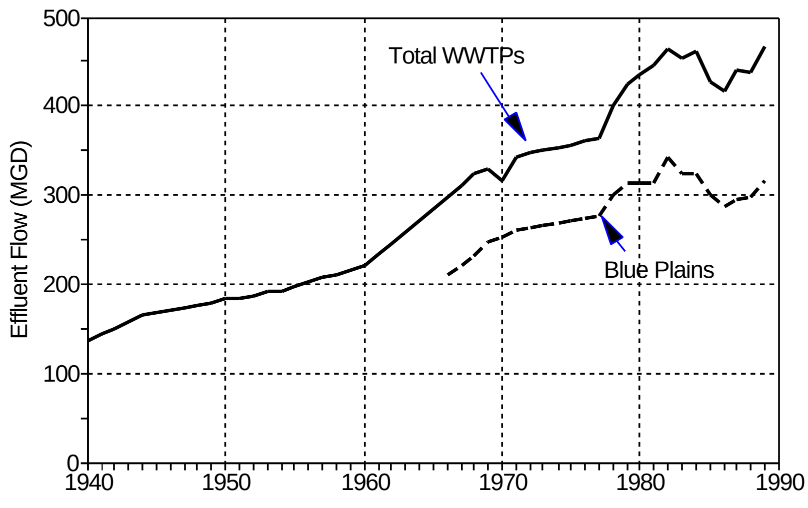


Figure 8-6

Long-term trends in effluent flow rate of municipal wastewater facilities.

Source: MWCOG, 1989.

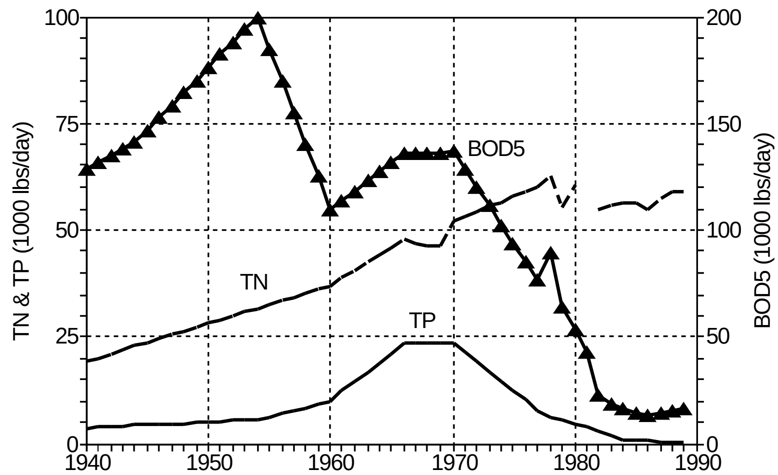


Figure 8-7

Long-term trends of BOD_5, total nitrogen, and total phosphorus effluent loads from municipal wastewater.

Source: Jaworski, 1990; Nemura, 1992.

Over the past 50 years, trends in BOD_5 and nutrient loading have reflected a growing population and increasing levels of wastewater treatment. The reduction in BOD_5 loading resulted from the implementation of secondary treatment at Blue Plains in 1959 and at the other facilities from 1960 to 1980. Beginning in the early 1970s, the dramatic drop in phosphorus loading by 1986 resulted from phosphorus controls implemented at all the major wastewater treatment facilities to minimize eutrophication in the Potomac estuary. Nitrogen loading, however, has increased with population in the absence of controls on effluent nitrogen levels (Figure 8-7).

DO, influenced by temperature, wastewater loading, and freshwater flow, is characterized by seasonal and spatial variations, with minimum levels observed during the high-temperature, low-flow conditions of summer. Historical DO data are available to characterize long-term changes in the spatial distribution of oxygen during the summer (July-September) over a distance of approximately 55 miles from Chain Bridge to Mathias Point. These historical data sets clearly show the significant problem with oxygen depletion during the 1960s (1960-1964, 1966) with recorded concentrations of less than 2 mg/L downstream of the Blue Plains wastewater treatment plant (located at about River Mile 106) (Figure 8-8).

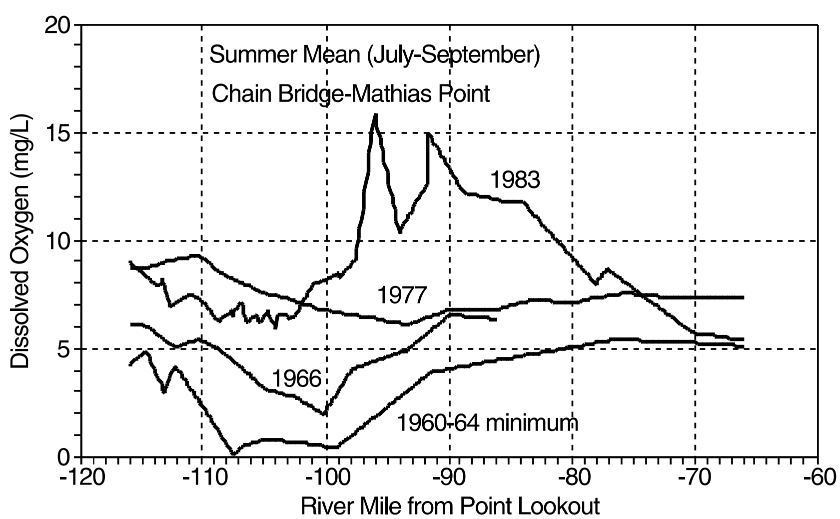


Figure 8-8

Long-term trends in summer DO levels at Chain Bridge-Mathias Point.

Sources: Davis, 1968; Thomann and Fitzpatrick, 1982; Fitzpatrick et al., 1991.

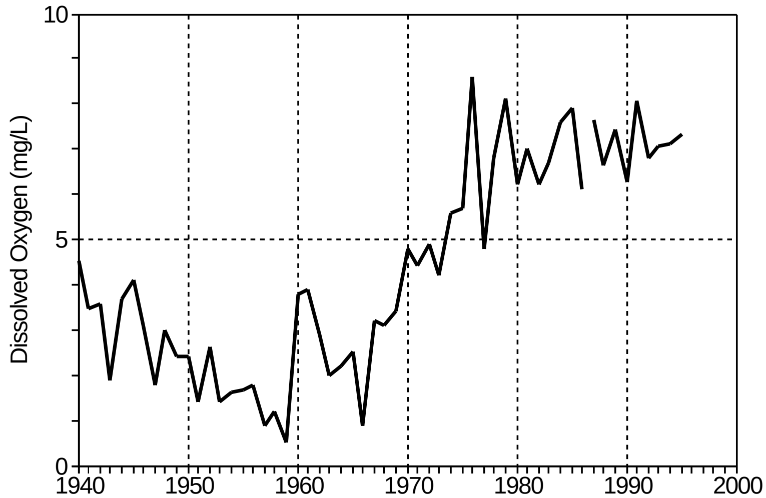


Figure 8-9

Long-term trends in summer DO levels on the Potomac River near the Wilson Bridge (mile 95). (Data for 1940-1986 from MWCOG averaged from June-September, data for 1987-1995 from STORET averaged from July-September.)

Source: MWCOG, 1989; USEPA (STORET).

Mean summer (June-September) oxygen records obtained from stations directly influenced by the wastewater discharge from Blue Plains near the Woodrow Wilson Bridge (RM 95) clearly show long-term trends in the ecological condition of the estuary from 1940 to 1990 (Figure 8-9). The decline from 1945 to 1960 reflects substantial increases in population and related raw and primary effluent loading from the Washington, DC, region. Low oxygen levels recorded in the mid-1960s (1 to 2 mg/L) reflect the reduction of freshwater available for dilution because of drought conditions (see Figure 8-4) rather than any increase of pollutant load. The water quality standard for DO of 5 mg/L was typically violated during the 1960s and 1970s. Compliance was attained for the summer average condition only after all the regional wastewater treatment plants achieved secondary treatment by 1980; minimum summer levels, however, continued to periodically be less than 5 mg/L (MWCOG, 1989).

Evaluation of Water Quality Benefits Following Treatment Plant Upgrades

From a policy and planning perspective, the central question related to the effectiveness of the secondary treatment requirement of the 1972 CWA is simply *Would water quality standards for dissolved oxygen be attained if primary treatment levels were considered acceptable?*

In addition to the qualitative assessment of historical data, water quality models can provide a quantitative approach to evaluate improvements in water quality achieved as a result of upgrades in wastewater treatment. The Potomac Eutrophication Model (PEM) (Thomann and Fitzpatrick, 1982; Fitzpatrick et al., 1991) has been used in this study to demonstrate the water quality benefits attained by the technology- and water-quality-based requirements of the 1972 CWA for municipal wastewater facilities.

The Potomac Estuary Model (PEM) was calibrated using observed data sets collected from 1983 through 1985. In the summer of 1983, an anomalous bloom of the blue-green alga *Microcystis aeruginosa* formed a dense, brilliant green scum-like mat on the surface that extended over a distance of about 20 miles in the central estuary and embayments. Peak chlorophyll levels in the main river were ~300 µg/L, and dense concentrations as high as ~800 µg/L were recorded in the embayments (Thomann and Mueller, 1987). During the peak of the bloom in September 1983, dissolved oxygen levels computed with PEM were in reasonable agreement with the observed monthly mean data (Figure 8-10); concentrations of ~6 mg/L were observed and simulated in the vicinity of the Blue Plains wastewater treatment plant (RM 105) (Fitzpatrick et al., 1991). The rapid increase from ~6 mg/L to observed (~10-16 mg/L) and computed (~12 mg/L) levels of dissolved oxygen ~5-10 miles downstream from Blue Plains is caused by high rates of phytoplankton primary productivity associated with peak algal biomass levels of ~150-250 µg/L (as chlorophyll *a*) in the vicinity of the Woodrow Wilson Bridge (RM 95). Further downstream in the transition zone of the Potomac estuary, observed and computed dissolved oxygen levels decline to ~5-7 mg/L in the vicinity of Indian Head (RM 85) to Maryland Point (RM 65) as a result of the attenuation of the *Microcystis* bloom by nitrogen limitation and the effects of salinity toxicity (Fitzpatrick et al., 1991). As documented by Fitzpatrick et al. (1991), dissolved oxygen, algal biomass, nutrients, BOD_5, inorganic carbon, pH, and salinity, the Potomac Estuary Model is considered well calibrated to the observed data for the period from 1983 through 1985.

Using data to describe effluent flow, pollutant loading, and hydrologic conditions during the lower-than-average flow conditions of September 1983, the calibrated model was used to evaluate the water quality impact of two regulatory control scenarios based on an assumption of (a) primary treatment and (b) secondary treatment compared to the existing (ca. 1983) effluent loading for all the municipal facilities in the Washington, DC, region (Fitzpatrick, 1991) (Figure 8-10). Water quality conditions for these scenarios were simulated using freshwater flow data for 1983, a year characterized by summer flow (2,333 cfs) that was about 53 percent of the long-term summer mean flow of the Potomac River (see

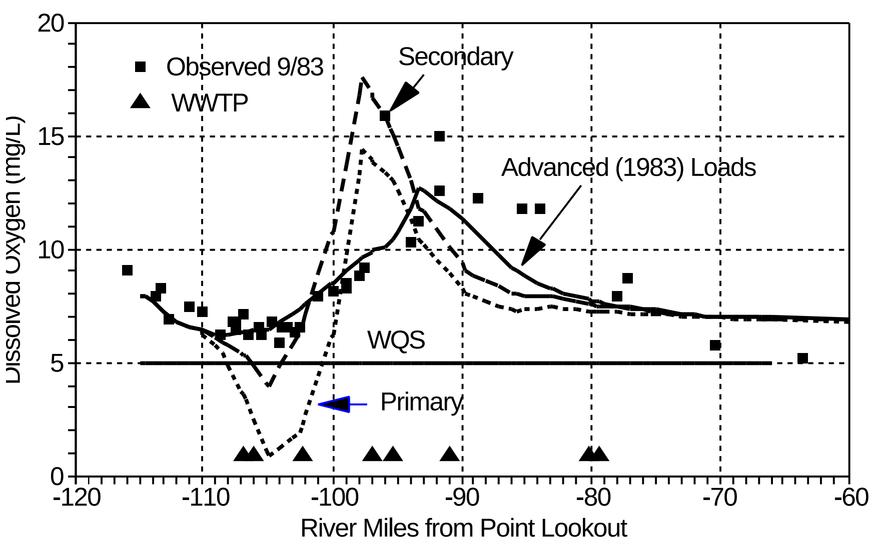


Figure 8-10

Potomac Estuary Model comparison of simulated DO for primary, secondary, and greater than secondary effluent loading scenarios (observed data is for September, 1983 calibration).

Source: Fitzpatrick, 1991; Fitzpatrick et al., 1991.

Figure 8-4). Other than the effluent characteristics, the ratio of ultimate-to-5-day BOD and the oxidation rate for CBOD (K_d) were the only parameters changed in the simulations to reflect differences in the proportion of refractory and labile organic carbon for the different levels of wastewater treatment (Fitzpatrick, 1991; Lung, 1996, 1998; Thomann and Mueller, 1987).

For the primary simulation, a value of $K_d = 0.21$ day^{-1}, obtained from the original PEM (Thomann and Fitzpatrick, 1982), is typical of wastewater effluent characterized by the high CBOD concentrations typical of primary treatment conditions observed during the 1960s. For the secondary simulation, a value of $K_d = 0.16$ day^{-1}, obtained from the original PEM (Thomann and Fitzpatrick, 1982), is typical of wastewater effluent characterized by the intermediate CBOD concentrations typical of secondary treatment conditions observed during the late 1970s. For the advanced (actual 1983) loading scenario, a value of $K_d = 0.10$ day^{-1}, obtained from calibration of the updated PEM (Fitzpatrick et al., 1991), is typical of wastewater effluent characterized by the low CBOD concentrations of advanced secondary and tertiary treatment conditions observed during the mid-1980s.

Under the primary effluent assumption, water quality is noticeably deteriorated in comparison to the 1983 calibration results. As a result of the effluent loading from the Blue Plains treatment plant, DO concentrations in the vicinity of Washington, DC (RM 10-15) are computed to be ~1 mg/L under the primary effluent scenario. With minimum levels less than 1 mg/L in the vicinity of the Blue Plains discharge (RM 106), the simulated results for the primary effluent scenario are remarkably similar to the historical data recorded for 1960-1964 and 1966 during the drought conditions of the 1960s (see Figure 8-8).

Under the secondary effluent assumption, the significant reduction in CBOD loading significantly improves dissolved oxygen near Washington, DC. In comparison to the primary scenario, minimum monthly-averaged oxygen levels increased to almost 3.5 mg/L from approximately 0.2 mg/L under the secondary effluent scenario. When compared to the model results for the existing 1983 conditions, the results of the secondary effluent simulation shows somewhat poorer water quality conditions for dissolved oxygen. The reason for the failure to achieve compliance with the 5 mg/L water quality standard for dissolved oxygen over only a few miles (RM 104-106) is that under the existing loading scenario for 1983, the 370-mgd Blue Plains facility (the largest wastewater discharger to the Potomac River) has instituted advanced secondary treatment with greater removal of BOD, ammonia, and phosphorus than is represented in the secondary effluent scenario (Fitzpatrick, 1991).

As shown with both observed data and state-of-the-art model simulations, the implementation of secondary and better treatment has resulted in significant improvements in the DO status of the estuary. As demonstrated with the model (and actually attained) better than secondary treatment is required to achieve compliance with the water quality standard of 5 mg/L for DO at the critical location downstream of Blue Plains (see Figure 8-10). In contrast to the 1950s and 1960s, the occurrence of low oxygen conditions has been virtually eliminated in the Upper Potomac estuary (see Figure 8-8). Additional improvements in Potomac water quality, in terms of reduced algal biomass and increased water clarity still greater improvements in dissolved oxygen levels, have been achieved as a result of advanced secondary and tertiary levels of wastewater treatment for the Upper Potomac estuary.

Impact of Wastewater Treatment: Recreational and Living Resources Trends

In addition to public water supply withdrawals (from the free-flowing river) and wastewater disposal from a number of municipalities, the uses of the Upper Potomac estuary include recreational and commercial fishing, boating and navigation, bird-watching, and secondary contact water-based recreation (e.g., windsurfing). Although recreational opportunities were severely limited during the 1940s, 1950s, and 1960s because of water pollution, the improvements in water quality during the 1980s have resulted in a significant increase in a variety of recreational uses of the river by the urban population of Washington, DC. Boating; windsurfing; walking, running, and bicycling on trails along the riverbanks; and recreational fishing are now extremely popular activities in the tidal river in the vicinity of Washington, DC.

Designated Uses and Bacterial Trends

Unlike the uses of many other major urban waterways, swimming, because of limited access from the shoreline and a lack of public bathing beaches, is not considered a major use of the Upper Potomac estuary. Most of the Potomac River from the upper freshwater reaches near Point of Rocks, Maryland, to the estuarine waters near Point Lookout, Maryland, is designated for primary contact recreational uses (swimming). In the vicinity of Washington, DC, however, the waters of the tidal Potomac are designated for secondary contact recreational uses such as boating or windsurfing. The estuarine portions of the Potomac downstream of Smith Point, Maryland, have been designated for shellfish harvest and must comply with more stringent bacteria level standards than those set for primary or secondary contact recreational uses. To protect public health from risks resulting from direct contact with the waters of the Potomac or ingestion of shellfish from the estuary, water quality standards have been established by the state of Maryland, the District of Columbia, and the state of Virginia for the maximum log mean fecal coliform bacteria levels (as most probable number (MPN) per 100mL) as follows:

- Primary contact < 200 MPN/100 mL
- Secondary contact < 1000 MPN/100 mL
- Shellfish harvest < 14 MPN/100 mL

Based on long-term historical water quality data from measurements taken downstream of the Blue Plains discharge, it is apparent that the introduction of effluent chlorination in 1968 resulted in dramatic improvements in bacterial contamination of the tidal Potomac (Figure 8-11). Prior to chlorination of wastewater effluent, summer coliform levels, typically on the order of 10^5 to 10^6 MPN/100 mL from 1940 to the mid-1960s, consistently were in violation of the secondary contact standard of 1,000 MPN/100 mL. Even with the dramatic reductions, summer bacteria levels still exceeded water quality standards during the 1970s. As bacteria loadings from the Washington area municipal wastewater plants continued to

Figure 8-11

Long-term trends in total coliform densities in the Potomac River downstream of the Blue Plains POTW near Gunston Cove, VA.

Source: USEPA (STORET).

decrease during the 1980s, summer bacteria densities began to be in compliance with the water quality standard for both primary and secondary contact. Since the 1980s periodic violations of bacteria level standards in the tidal Potomac have usually been related to storm event discharges from combined sewer overflows in the District of Columbia and Alexandria, Virginia (MWCOG, 1989).

Since the passage of the 1965 Water Quality Act, well-planned and coordinated water pollution control programs in the Washington metropolitan region have succeeded in achieving substantial reductions in pollutant discharges to the Potomac estuary. Despite the remarkable improvements in the bacteria levels of the tidal Potomac, it is unlikely that President Johnson's 1965 pledge to "*reopen the Potomac for swimming*" will be fulfilled because of the lack of beaches along the shoreline and access for swimming.

Submersed Aquatic Vegetation, Fishery, and Waterfowl Resources

In numerous accounts of the early colonists, the natural abundance of waterfowl and fishery resources of the Potomac basin was considered an important factor in attracting new colonists to the region. Like many freshwater and marine environments, the shallow littoral areas of the tidal Potomac River near Washington, DC, were characterized by extensive beds of a variety of species of aquatic macrophytes, or submersed aquatic vegetation (SAV), during the late 1800s and early 1900s (Carter et al., 1985). Detailed maps in 1904 and 1916, for example, showed extensive "grass" beds in Gunston Cove and shallow areas of the Maryland and Virginia sides of the river. In addition to the direct effect on the survival and condition of fish populations due to low DO concentrations caused by high organic loadings, fish populations are indirectly influenced by SAV abundance, necessary to provide nursery habitat for juvenile fish (Fewlass, 1991).

Increased municipal wastewater loading from the Washington area and the resulting poor water quality was most likely responsible for the disappearance of SAV from the tidal Potomac River (Carter et al., 1985; Carter and Paschal, 1981), first noticed in 1939. During the 1940s and 1950s, widespread losses of SAV were common, not only in the Potomac, but also throughout the Chesapeake Bay basin (Carter et al., 1985). Although the SAV beds were severely diminished by the late 1930s, periodic nuisance "invasions" of submersed aquatic vegetation were recorded in the tidal Potomac during the 1930s (water chestnut) and from 1958 through 1965 (Eurasian watermilfoil) (Jaworski, 1990).

Trends in Suspended Solids Load and Water Clarity

By the late 1970s, SAV in the Washington, DC, area had effectively disappeared from the tidal Potomac (Carter et al., 1985). The loss of SAV in the Potomac, and elsewhere in Chesapeake Bay region, has been attributed to the decreased availability of light in the littoral zone resulting from increased turbidity from the discharge of suspended solids and nutrients to the estuary (Carter et al., 1985). High levels of algae reduced light penetration and inhibited the growth of SAV. The natural abundance of fish and waterfowl of the Potomac, documented by the early colonists, was in fact directly related to the abundance and distribution of SAV in the shallow areas of the river. Redhead ducks, canvasbacks, and migrating widgeons and gadwalls feed on SAV, and other ducks such as mergansers feed on juvenile fish that depend on SAV for spawning and development (Forsell, 1992). The absence of SAV during the 1940s through 1970s resulted in a loss of habitat and food resources for fish and waterfowl dependent on the presence of the SAV beds.

The long-term ecological effects of the dramatic reductions of municipal wastewater loading of phosphorus (Figure 8-7) and suspended solids (Figure 8-12) to the estuary that began during the 1970s became apparent in the early

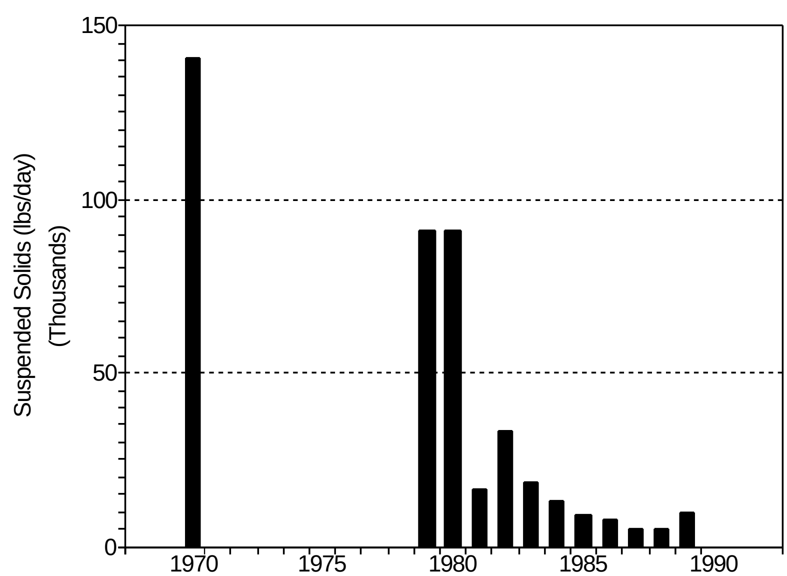


Figure 8-12

Long-term trends in municipal wastewater loading of suspended solids in the tidal Potomac River.

Source: Nemura, 1992.

1980s with the surprising reappearance of SAV beds in the tidal Potomac (Carter and Rybicki, 1990). The return of the SAV beds was directly related to improvements in the clarity of the water (Figure 8-13), resulting from reductions in suspended solids and phosphorus loading from municipal wastewater discharges to the estuary and subsequent reductions in ambient phosphorus and algal biomass (Figure 8-14) (Carter and Rybicki, 1990; Jaworski, 1990; Carter and Rybicki, 1994). The presence of the SAV beds, in turn, has further enhanced water quality by physical settling of particulate solids, filtering of nutrients by plant uptake, and reduction of algal production in the water column (Figure 8-15). The reemergence of SAV beds in the tidal Potomac has resulted in dramatic increases in the diversity, abundance, and distribution of waterfowl (Figures 8-16 and 8-17).

Figure 8-13

Long-term trends in SAV and water transparency in the tidal Potomac River.

Sources: Carter and Rybicki, 1990; Nemura, 1992; USEPA (STORET).

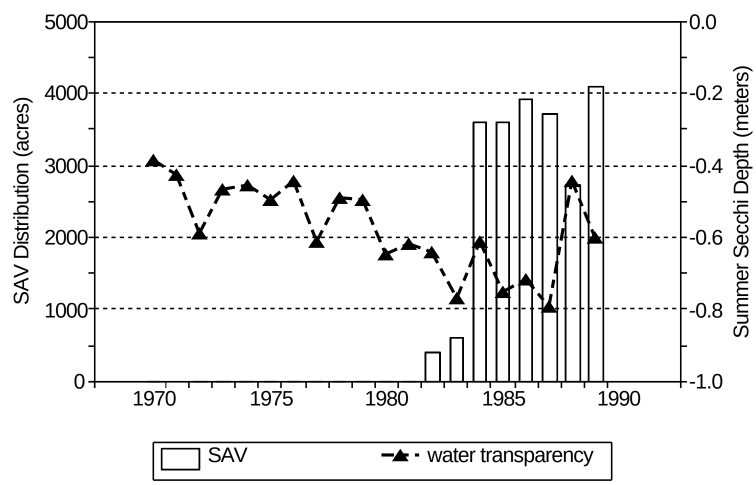
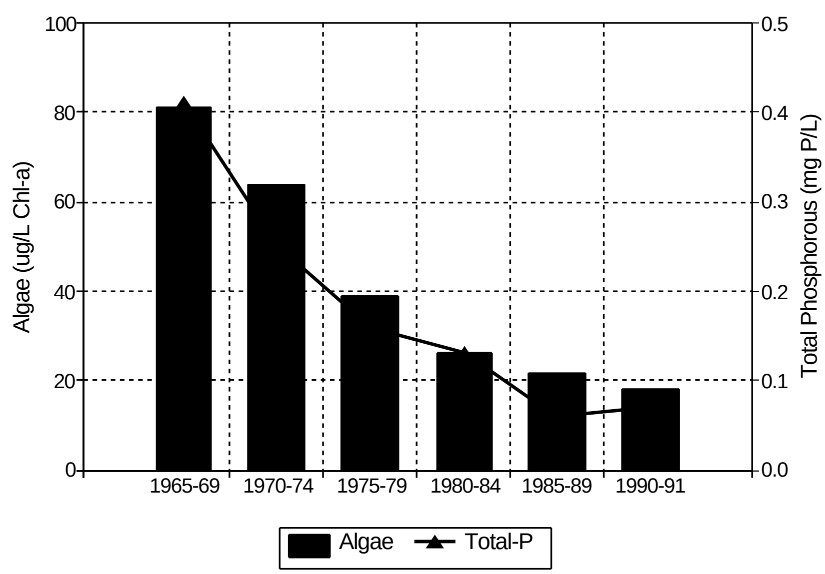


Figure 8-14

Long-term trends in algal biomass and total phosphorus in the tidal Potomac River.

Source: USEPA, 1992.



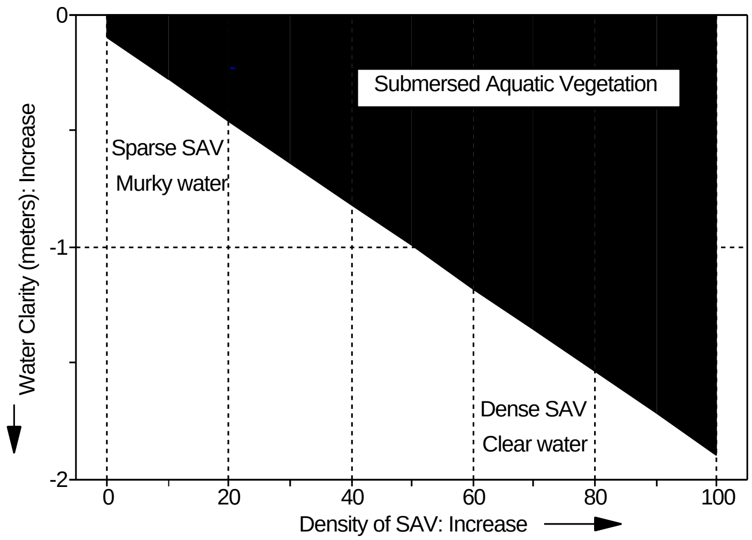


Figure 8-15

Conceptual relationship of SAV abundance and water clarity.

Source: Carter and Rybicki, 1990, 1994; Kemp et al., 1984.

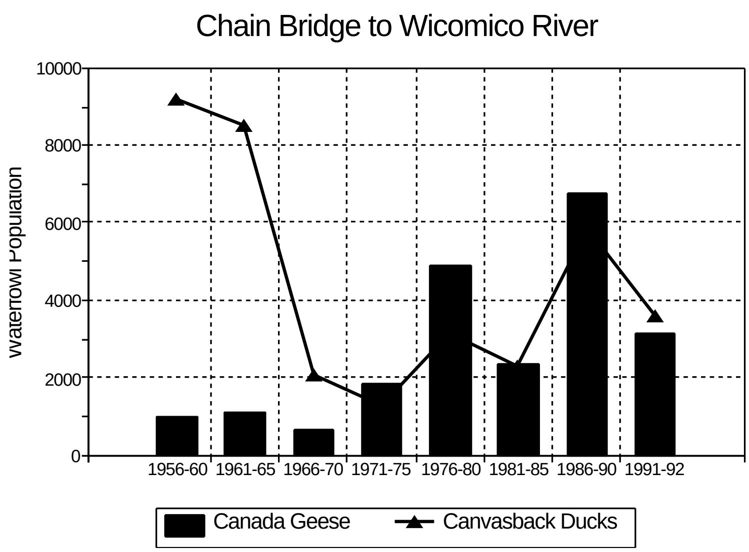


Figure 8-16

Long-term trends of waterfowl in the upper Potomac River. Observation from Washington, DC, to Route 301 bridge.

Source: Forsell, Unpublished data.

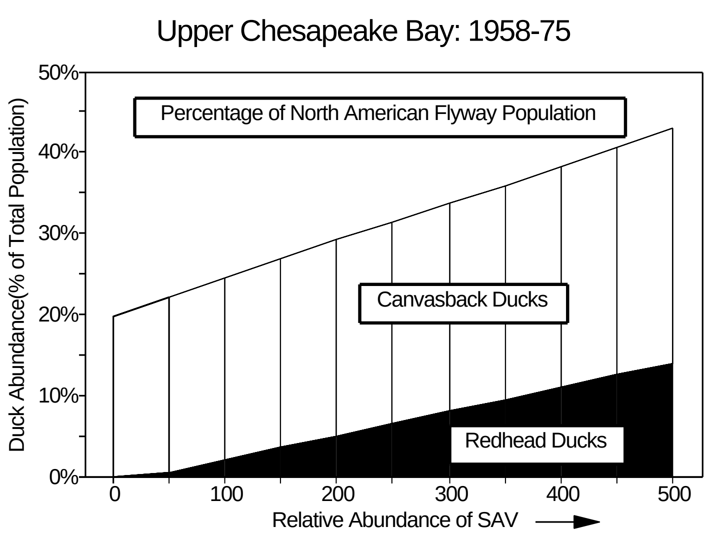


Figure 8-17

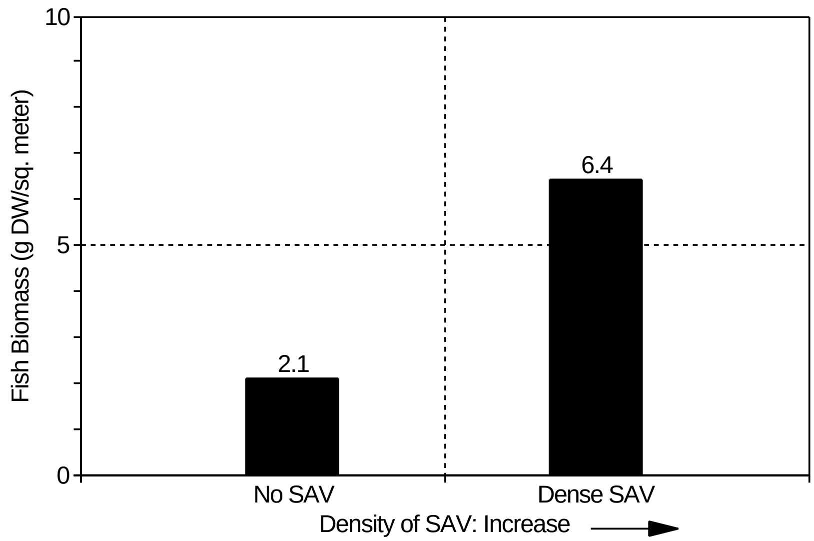
SAV and waterfowl abundance in Upper Chesapeake Bay (1958-1975).

Source: Kemp et al., 1984.

Figure 8-18

SAV abundance and fishery resources in the Choptank River.

Source: Kemp et al., 1984.



Fish surveys documented significant increases in species diversity and abundance from 1984 to 1986 (MWCOG, 1989) that are consistent with the SAV and fisheries abundance data reported for the Choptank River on the eastern shore of Maryland (Kemp et al., 1984) (Figure 8-18).

Before the disappearance of the SAV beds, waterfowl populations (ca. 1929-1930) were about an order of magnitude greater than after the disappearance of SAV during the 1950s, when the annual average waterfowl census was 6,547 birds. Historical data from the Upper Chesapeake Bay (1958-1975) are useful to illustrate the relationship between the availability of SAV, fisheries, and waterfowl populations (Figures 8-17 and 8-18). The importance of SAV in the overall biological health of the tidal Potomac is clearly demonstrated with recent observations of a doubling of waterfowl abundance and an increase in the diversity of species (MWCOG, 1989). In 1972 only 9 species of ducks wintered in the Potomac tidal river and transition zone (represented by more than one individual observed in winter transect counts); by 1992 the number of species had increased to 17 (Forsell, 1992). Fall-migrating, SAV-eating widgeons and gadwalls, absent from the estuary in winter for 15 years, have lengthened their stay in the Potomac, possibly encouraged by recent warmer winters and more plentiful food supplies. Populations of fish-eating mergansers, increasing since the 1970s, may be responding to increasing fish habitat available since the reemergence of SAV beds. Populations of Canada geese, tundra swans, and mallards, although not directly linked to SAV, are also increasing in the tidal Potomac, this trend has also been observed in other areas of the northeast.

Fishery surveys in the tidal Potomac, and elsewhere in the Chesapeake Bay, clearly document an increase in abundance and diversity of fish species. Juvenile fish survey data, collected between 1965 and 1987 at Indianhead and Fenwick in the tidal river, were analyzed using the Index of Biotic Integrity (IBI) (Figure 8-19). The IBI, developed by Karr (1981) for use in midwestern streams, has been adapted for use in other areas. This index is a composite of 12 ecological attributes of fish communities, including species richness, indicator taxa (both intolerant and tolerant), trophic guilds, fish abundance, and incidence of hybridiza-

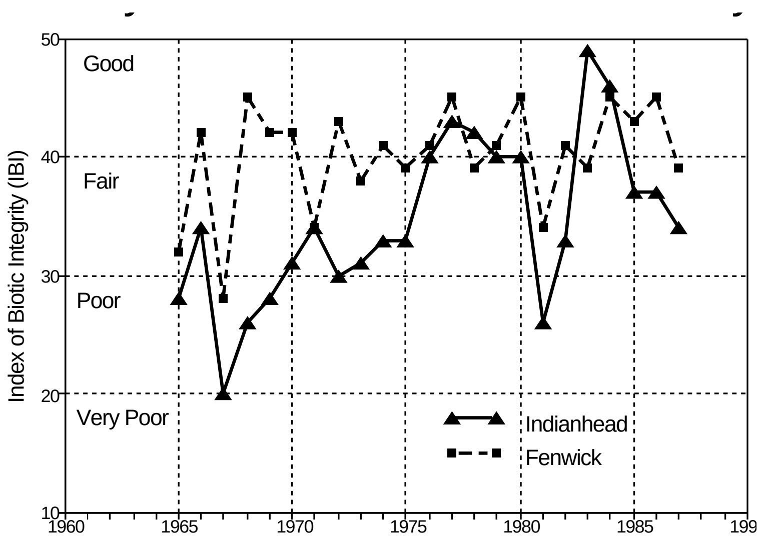


Figure 8-19

Long-term trends in fishery resources of the Potomac estuary based on Index of Biotic Integrity (IBI).

Source: Jordan, Unpublished data.

tion, disease, and abnormalities (Karr et al., 1986). IBI scores range from a low of 12 to a high of 60. A score of 12 is assigned to conditions where no fish are present even after repeated sampling; a score of 60 is assigned to conditions comparable to the best habitats without human disturbance (Karr et al., 1986). The trend in the IBI at Indianhead (Jordan, 1992, unpublished data) shows that the river quality for fish increased from poor, indicating an impaired or restricted habitat (IBI scores in the 20 to 30 range), to fair, indicating slightly impaired habitat (IBI scores in the 40 to 50 range). These data indicate that in the late 1960s and early 1970s the fish community at Indianhead was dominated by a few tolerant species, with few fish present at all in some years. In the last 20 years, a general upward trend in river quality for fish has been observed, evidenced by increasing numbers of pollution-intolerant species and a species mix suitable to provide for a reasonably balanced trophic structure. Indicator variables currently measured at Indianhead are at about two-thirds of their expected level in undisturbed habitats. The rise in the IBI at Indianhead, where a wastewater treatment plant discharge is located, is in contrast to stable or declining trends observed at other locations that lack wastewater treatment plant outfalls (Jordan, 1992, unpublished data).

In addition to the direct effect on the survival and condition of fish populations due to low DO concentrations due to high organic loadings (Tsai, 1991), fish populations are indirectly influenced by SAV abundance, necessary to provide nursery habitat for juvenile fish (Fewlass, 1991). The quality of river habitat for fish has increased with the resurgence of SAV habitat in comparison to areas characterized by the absence of SAV beds. During 1984-1986, years characterized by a rapid increase in the distribution of SAV beds (primarily *Hydrilla*) (see Figure 8-13), fishery surveys near Washington, DC, clearly showed an increase in species diversity; abundance increased from 79 to 196 fish per net haul over the same 2-year period (MWCOG, 1989). The relationship of SAV and fishery data from the tidal Potomac is consistent with data reported by Kemp et al. (1984) for the Choptank River on the eastern shore of Maryland (see Figure 8-18).

SAV and Ecological Resources

The evidence is clear from observations in Chesapeake Bay and the tidal Potomac River that the presence of SAV beds is critical for a healthy and diverse aquatic ecosystem. The presence of SAV beds has the following positive impacts:

- Increases habitat and food resource availability
- Increases species diversity and abundance
- Increases fishery resources
- Increases waterfowl populations
- Increases recreational opportunities (fishing, hunting, bird-watching)
- Enhances water quality
- Removes nutrients
- Allows particulate material to settle out
- Reoxygenates water column by photosynthesis

"...in the 1950s and 1960s the Potomac was a flowing cesspool...It was a disgrace, it was so polluted. If you fell in the river, it was recommended you go ti the hospital for examination. Now the river is much better. Pollution controls are higher and the fish population's are mostly solid. But the people still think of it as the old river. So people don't understand how good the fishing is here."

Travel Section, Washington Post, August 30, 1998 (Tidwell, 1998).

Summary and Conclusions

Water quality and biological resources data clearly illustrate the cause-effect relationship of reductions in wastewater loading of BOD_5, nutrients, and suspended solids and improvements in the ecological resources of the tidal Potomac. As a result of the significant improvements in water quality, the Potomac estuary emerged during the 1990s as one of the top-ranked largemouth bass sport fisheries supporting increasingly popular recreational fishing activities, including professional fishing guide services and several Bassmasters fishing tournaments. One of the earliest professional guides, Ken Penrod of Outdoor Life Unlimited in Beltsville, Maryland, now has one of the largest freshwater fishing guide services in the nation. Guides like Penrod have reported that since 1982 every year has been better than the previous year in terms of the quantity and quality of fish that have returned to the waters of the tidal Potomac (Soltis, 1992). The quality of river habitat for fish has increased with the resurgence of SAV habitat in comparison to areas characterized by the absence of SAV beds. The Potomac River was selected as an American Heritage River in 1998, acknowledging the substantial improvements in water quality and ecological conditions. In addition, some 300 people took part in the 1999 Bassmasters Fishing Tournament on the Potomac (Fishing Tournament Marks a River's Rebound, 1999).

References

Carter, V., and J.E. Paschal. 1981. Biological factors affecting the distribution and abundance of submerged aquatic vegetation in the tidal Potomac River, Maryland and Virginia. *Estuaries* 4(3): 300.

Carter, V., J.E. Paschal, and N. Bartow. 1985. *Distribution and abundance of submersed aquatic vegetation in the tidal Potomac River and estuary, Maryland and Virginia, May 1978 to November 1981.* Water-Supply Paper 2234-A. U.S. Geological Survey, Reston, VA.

Carter, V., and N.B. Rybicki. 1990. Light attenuation and submersed macrophyte distribution in the tidal Potomac River and estuary. *Estuaries* 13(4): 441-452.

Carter, V. and N.B. Rybicki. 1994. Role of weather and water quality in population dynamics of submersed macrophytes in the tidal Potomac River. *Estuaries* 17(2): 417-426.

Davis, R.K. 1968. *The range of choice in water management: A study of dissolved oxygen in the Potomac Estuary.* Published for Resources for the Future, Inc. by The Johns Hopkins Press, Baltimore, MD.

Fewlass, L. 1991. *Statewide fisheries survey and management study V: Investigations of largemouth bass populations inhabiting Maryland's tidal waters.* Maryland Department of Natural Resources, Tidewater Administration, Annapolis, MD.

Fitzpatrick, J.P. 1991. HydroQual, Inc., Mahwah, NJ. Personal communication, September 18, 1991.

Fitzpatrick, J.P., et al. 1991. *Calibration and verification of an updated mathematical model of the eutrophication of the Potomac estuary.* Prepared for Metropolitan Washington Council of Governments, Washington, DC, by HydroQual, Inc.

Forsell, D. Unpublished data. U.S. Fish and Wildlife Service.

Forsell, Doug. 1992. U.S. Fish and Wildlife Service. Personal communication, October 22, 1992.

Forstall, R.L. 1995. Population by counties by decennial census: 1900 to 1990. U.S. Bureau of the Census, Population Division, Washington, DC. <http://www.census.gov/population/www/censusdata/cencounts.html>.

Haramis, G.M., and V. Carter. 1983. Distribution of submersed aquatic macrophytes in the tidal Potomac River. *Aquatic Botany* 15(1983): 65-79.

ICPRB. 1990. *The healing of a river, The Potomac: 1940-1990.* Interstate Commission on the Potomac River Basin, Rockville, MD.

Iseri, K.T., and W.B.Langbein. 1974. *Large rivers of the United States.* Circular No. 686, U.S. Department of the Interior, U.S. Geological Survey.

Jaworski, N.A. 1990. Retrospective study of the water quality issues of the Upper Potomac estuary. *Reviews in Aquatic Science* 3(2): 11-40.

Jordan, S. Unpublished data. Potomac River Fisheries Commission.

Karr, J.R. 1981. Assessment of biotic integrity using fish communities. *Fisheries* 6(6): 21-27.

Karr, J.R., K.D. Fausch, P.L. Angermeier, P.R. Yant, and I.J. Schlosser. 1986. *Assessing biological integrity in running waters: A method and its rationale.* Special Publication 5. Illinois Natural History Survey, Champaign, IL.

Kemp, W.M, W.R. Boynton, R.R. Twilley, J.C. Stevenson, and L.G. Ward. 1984. Influences of submersed vascular plants on ecological processes in Upper Chesapeake Bay. In *The estuary as a filter,* ed. V.S. Kennedy, pp. 367-394. Academic Press, New York.

Lung, W. 1996. Postaudit of Upper Mississippi River BOD/DO Model. *Jour. Environmental Engineering*, 122(5):350-358.

Lung, W. 1998. Trends in BOD/DO Modeling for Waste Load Allocation. *Jour. Environmental Engineering*, 124(10):1004-1007.

MWCOG. 1989. *Potomac River water quality, 1982 to 1986: Trends and issues in the metropolitan Washington area.* Metropolitan Washington Council of Governments, Department of Environmental Programs, Washington, DC.

Nemura, A. 1992. Metropolitan Washington Council of Governments, Department of Environmental Programs, Washington, DC. Personal communication, March 3, 1992.

Newell, F.H. 1897. Pollution of the Potomac River. *National Geographic* (December 1997): 346-351.

OMB. 1995. OMB Bulletin No. 99-04. Revised statistical definitions of Metropolitan Areas (MAs) and Guidance on uses of MA definitions. U.S. Census Bureau, Office of Management and Budget, Washington, DC. <http://www.census.gov/population/www/estimates/metrodef.html>.

Soltis, S. 1992. Rebirth of an American river. *Washington Flyer Magazine* (March/April): 22-25.

Summers, K.J., and K.A. Rose. 1987. The role of interactions among environmental conditions in controlling historical fisheries variability. *Estuaries* 10(3): 255-266.

Thomann, R.V., and J.P. Fitzpatrick. 1982. *Calibration and verification of a mathematical model of the eutrophication of the Potomac estuary.* Prepared for Department of Environmental Services, Government of the District of Columbia, Washington, DC, by HydroQual, Inc.

Thomann, R.V., and J.A. Mueller. 1987. *Principles of surface water quality modeling and control*. Harper & Row, Inc., New York, NY.

Tidwell, M. 1998. *Where is this man fishing?* The Washington Post, Travel Section, Page E1, E8-E10, August 30.

Tsai, Chu-Fa. 1991. Rise and fall of the Potomac River striped bass stock: a hypotheiss of the role of sewage. *Trans. Amer. Fish. Soc*. 120(1):1-22.

USDOC. 1998. *Census of population and housing.* U.S. Department of Commerce, Economics and Statistics Administration, Bureau of the Census - Population Division, Washington, DC.

USEPA. 1992. *Water quality goals for living resources: Role in the Chesapeake Bay nutrient reevaluation, summary and preliminary results*. USEPA Chesapeake Bay Program, Annapolis, Maryland.

USEPA (STORET). STOrage and RETrieval Water Quality Information System. U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and watersheds, Washington, DC.

USGS. 1999. Streamflow data downloaded from the U.S. Geological Survey's National Water Information System (NWIS)-W. Data retrieval for historical streamflow daily values. <http://waterdata.usgs.gov/nwis-w>.