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The Historical Context of Water Quality Management for the Delaware Estuary

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ABSTRACT: The Delaware Estuary, bounded by the states of Delaware, New Jersey and Pennsylvania, is located in one of the most complex urban-industrial regions in the United States. Water pollution of the estuary was observable over two centuries ago and progressively worsened until after World War II. Four distinct governmental responses to the pollution have led to the vastly improved water quality of today. A fifth-generation response, now being initiated, is oriented toward remaining problems, including toxic contamination of the water column, bottom materials and aquatic life. Changes in water quality and the institutional responses to pollution are traced to demonstrate the evolutionary process of water pollution control.

Introduction

The cleanup of the Delaware Estuary represents one of the premier water pollution control success stories in the United States. Once largely a septic river virtually devoid of aerobic aquatic life, the Delaware Estuary now supports a variety of recreational uses, year-round fish populations and an expanding number of key migratory fish species. As a result, the river and its waterfront are becoming a regional focal point for water-dependent recreational uses.

Improving the water quality of the Delaware Estuary has been an evolutionary process spanning two hundred years. Five generations of responses are identifiable; the fifth generation is represented by ongoing programs and concerns (Table 1). The cleanup effort has been a complex endeavor involving four states, a major urban and industrial region, the federal government and two interstate agencies.

The purpose of this paper is to describe the evolution of pollution concerns in the Delaware, the subsequent responses to these concerns, and the results and benefits noted to date.

Description of Delaware Estuary

The Delaware Estuary (Fig. 1) is the 85 mile long reach of the Delaware River running from the head of tide at Trenton, New Jersey, past the Philadelphia, Pennsylvania; Camden, New Jersey and Wilmington, Delaware metropolitan areas to the legally-designated upstream boundary of Delaware Bay. The Delaware Estuary is a tidal freshwater river in its upper reaches and an estuary in its lowest reaches. Sea water annually intrudes into the Delaware Estuary from Delaware Bay, the extent of the intrusion being governed by rainfall and freshwater inflows. The latter are partially regulated by upstream reservoir releases particularly during drought.

The Delaware Estuary is the world's largest freshwater port (Philadelphia Planning Commission 1982) and the second busiest port in the United States in terms of tonnage (Sharp 1983). Along the Estuary is one of the world's greatest concentrations of heavy industry and the nation's second largest complex of oil-refining and petrochemical plants (Council on Environmental Quality 1975). A population greater than 5.7 million people (i.e., a population greater than 40 of the states) resides in the region (United States Dept. of Commerce 1985). Philadelphia, near the center of the estuary, is one of the nation's largest cities. Trenton and Camden, New Jersey, and Wilmington, Delaware are moderately sized urban areas contiguous to the Philadelphia metropolitan area.

The two largest tributaries to the Delaware Estuary are the Delaware River at Trenton and the Schuylkill River at Philadelphia. Together these freshwater rivers drain 65% of the 12,765 square mile Delaware River Basin (United States Geological Survey 1982). Along the Delaware Estuary are approximately 90 major municipal and industrial dischargers, major electric-generating plants (including two large nuclear power plants), over 300 combined sewer overflows, and a myriad of other pollution sources (Albert and Kausch, 1988). A 40 to 35-foot navigation channel is maintained in the estuary by dredging.

In spite of the intense development, the Delaware Estuary serves as a potable water supply for millions of people. The city of Philadelphia obtains

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TABLE 1. Description of the five generations of Delaware Estuary water pollution control efforts.

Generation	Approximate Time Span	Problem	Actions	Prime Participants*
First	1800–1860	Pollution of local water sources	Construction of municipal water systems with river intakes, some sewer line construction	Municipal government
Second	1880–1910	Water borne disease from consumption of river water	Construction of water filtration plants, development of alternative water supplies, sanitary sewer system construction	Municipal government
Third	1936–1960	Gross pollution	Construction of primary wastewater treatment plants after effluent standards adopted	INCODEL, States
Fourth	1960–1980	Substantial pollution	Construction of secondary or higher wastewater treatment plants after wasteloads allocated	DRBC, States and U.S. EPA
Fifth	1980–?	Public health and aquatic life concerns including toxics	Underway. Could include combined sewer correction, more stringent point source controls, non-point source controls, toxic materials controls and other	DRBC, States and U.S. EPA

* The efforts of the federal government prior to the creation of the United States Environmental Protection Agency and the efforts of most cities and industries to clean up their wastes in the third and fourth generation effort are recognized as well.

approximately 230 million gallons of water per day from the estuary via an intake in the northeast section of the city (Delaware River Basin Commission, unpublished data). This system, representing about 50% of the city's water supply, serves suburban service areas as well as the city. Under certain hydrologic conditions, the Delaware Estuary also recharges the Potomac-Raritan-Magothy aquifer along the reach of river running roughly from Wilmington, Delaware, to Camden, New Jersey (Barksdale et al. 1958). This aquifer is the primary source of potable water for the Camden (South Jersey) metropolitan area. Intakes on the estuary also provide water to Bucks County, Pennsylvania, and 38 industrial water users.

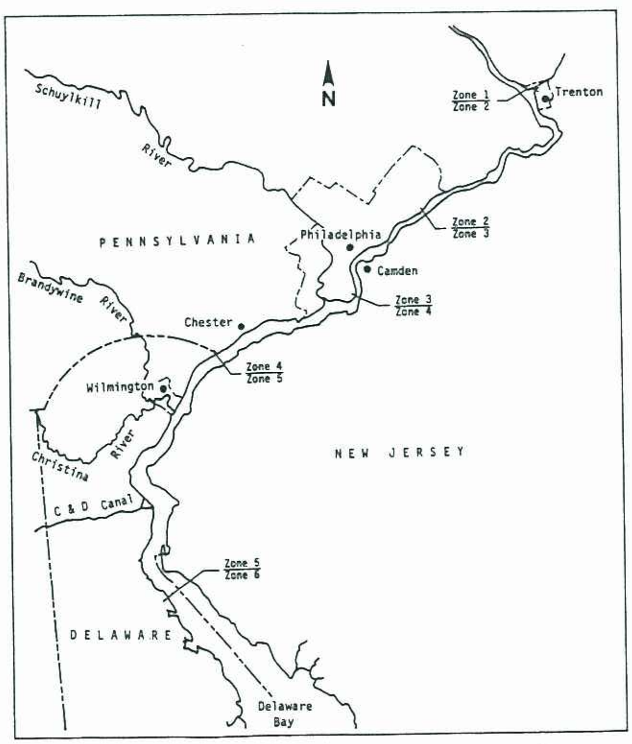

Fig. 1. The Delaware Estuary showing water quality zones adopted by the Delaware River Basin Commission. INCODEL's Zone 3 encompassed DRBC's Zone 3 and 4 and its Zone 4 encompassed DRBC's Zones 5 and 6.

The Delaware Estuary is the boundary between Pennsylvania and New Jersey in its upper reach, and Delaware and New Jersey in its lower reach. The same state boundaries are also the boundary between United States Environmental Protection Agency Regions II and III. Water pollution control entails multiple jurisdictions with various governmental entities sharing responsibilities. Not surprisingly, the Delaware River basin was the first river basin in the nation to have an interstate agency created in response to water pollution.

Early Pollution Concerns and the First Generation Response

When Henry Hudson discovered the Delaware River system in 1609, water quality was presumably pristine. By the early 18th century, however, water pollution was a recognized problem. The first identifiable pollution problem was the contamination of local sources of drinking water: springs, wells and small streams. In 1739, for example, Philadelphia made a concerted effort (which failed) to have slaughter house, tanning and similar wastes removed from Dock Creek which flowed through the city (Buckley 1948). By the latter half of the 18th century, pollution was so noticeable in the Philadelphia harbor area that a young Englishman named Isaac Weld, Jr. commented about the "mess" that had been created (Wolman 1941). The concern for water-borne diseases led one of the founding fathers, Benjamin Franklin, to leave money to Philadelphia in his will specifically for developing a municipal water system (Philadelphia Water Department 1987).

In 1799 the first pollution survey was conducted (Albert 1984). The survey noted a variety of pollution sources from the Philadelphia harbor area, including ships, wharves, polluted wetlands and various urban sources. Five years later, a Philadelphia inventor, Oliver Evans, invented what some consider the first automobile. His automobile was actually a dredge on a motorized wagon built specifically for removing the noxious sludge deposits that had formed along the Philadelphia waterfront (Tyler 1955).

The first generation response to the water pollution, addressing public health concerns, was the construction of municipal water supply systems that tapped the Delaware and Schuylkill rivers. Because of their size, these rivers were still much cleaner than the highly-contaminated local sources of water. Philadelphia built its first intake on the Schuylkill River in 1801 and, in 1850, Kensington, now part of Philadelphia, built the first Philadelphia intake on the Delaware Estuary (Blake 1956). By 1860 most citizens of Philadelphia, Trenton, Camden and nearby communities along the Delaware Estuary were drinking river water.

Although minor in comparison to the construction of municipal water supply systems, the first generation response also saw the first sewers built. Many, like Dock Creek cited above, were stream enclosures while others, built by private entities, were crude log pipes discharging to the nearest stream. In 1769, the Pennsylvania Assembly legalized the construction of common sewers discharging into the Delaware River (Neeson 1941), and by 1867, Philadelphia had 67 miles of sewers (Philadelphia Water Department circa 1970). Philadelphia's experience was repeated in other cities on the estuary. The purposes of the first sewer lines were to prevent groundwater contamination of public and private wells still in use while municipal water supply systems expanded and to remove nuisance conditions in local streams.

Second Generation Problems and the Response

Concurrent with the development of municipal water supply systems were tremendous industrial and population growth. Thus, while more people began using surface water, the Delaware Estuary became increasingly polluted. As a result, thousands of city dwellers died from water-borne diseases. For example, in 1864 the annual death rate from typhoid in Philadelphia was over 125 deaths per 100,000 population and rarely was the annual death rate from typhoid below 50 deaths per 100,000 in the 19th century (Webster et al. 1914).

The second-generation response to the pollution included a debate by the citizens of Philadelphia concerning water supply alternatives in the period from 1858 to 1890 before they began construction of the world's largest slow sand filtration plants in 1899 (Albert 1987). Camden used a different approach. That city abandoned the Delaware Estuary altogether and, in 1897 and 1898 the city drilled over 100 wells in the Potomac-Raritan-Magothy aquifer (Bascom 1904). Actions similar to Philadelphia's and Camden's were taken by other communities, and by 1915 most had a safe water supply. In Philadelphia, the death rate from typhoid fell nearly 90% as a result (Webster et al. 1914).

The Third Generation Response to Estuary Pollution

The provision of safe water supplies solved the public health concerns but did nothing about the pollution itself. Although pollution was evident in the 18th and 19th centuries and was considered a problem, it appears that the greatest degradation occurred sometime after 1900. At the turn of the century, for example, the Delaware River shad fishery was still one of the best of any river system along the Atlantic coast, but within two decades the shad populations had all but disappeared (Miller et al. 1982). The trend of declining populations in the 19th century with a collapse in the early part of the 20th century was experienced by other major fish species as well. Although other factors contributed to these declines (e.g., overfishing, loss of spawning grounds), water pollution was a major cause (Kiry 1974).

The rapid degradation of the Delaware Estuary (occurring over several decades) can be attributed to several related factors. The first was undoubtedly population and industrial growth. Through the second half of the 19th century, Philadelphia and the estuary region consistently maintained a population growth rate of 20% or greater per decade (Board of Consulting Engineers 1945). By 1900, Philadelphia itself reached 1.5 million and the region had a population greater than 2 million which was still growing rapidly. Related to this growth in population was a similar increase in industrial growth, particularly heavy industry, such as ship building, oil refining, metals, chemicals, paper and manufacturing. All of the industries discharged their wastes into the Delaware Estuary or its tributaries.

The expansion of the urban water and sewer systems was another major factor which resulted in the rapid degradation of the Estuary. In Philadelphia, for example, water demands in the 1885–1905 period increased on a per capita basis at a rate that greatly exceeded the city's growth in population (Board of Consulting Engineers 1945). In the same two decades, the length of sewer lines increased over 400 percent (Webster et al. 1914). By building sewers, Philadelphia hoped to reduce the pollution being discharged upstream of its intakes. The length of sewer lines would continue to grow tremendously in the ensuing decades, spreading out to serve suburban as well as urban areas.

The increasing water use resulted in increasing amounts of wastewater being discharged, via the newly constructed sewers, directly into the Delaware Estuary. The growth in population, industry, water usage and sewer line mileage resulted, by 1914, in a dissolved oxygen level as low as 1 mg l^{-1}, or less than 15% saturation, within the estuary (Webster et al. 1914). Surveys in 1929 and 1937 indicated that the entire estuary from Trenton to below Wilmington was "substantially" polluted, with a zone of "gross" pollution in the Philadelphia-Camden area (INCODEL 1940). By the outbreak of World War II dissolved oxygen levels near zero were being observed (Kiry 1974).

World War II put even greater stress on water quality because of the increased industrial activity along the estuary. Anecdotal accounts of wartime pollution episodes from the Delaware Estuary region are legendary. Widespread areas of anoxia existed. The anoxic conditions produced gases that discolored paint on buildings and ships, tarnished metal, corroded parts in manufacturing plants and ship engines, sickened dock workers and sailors and, allegedly, could be smelled by Navy airplane pilots in the air above Philadelphia (Selby and Selby 1946). Wastes from the river clogged ship engine cooling systems and fish kills were frequent and often massive. A typical story is that of the freshly-painted Red Cross ship that turned a rainbow of colors after several days on the Delaware. It was no longer identifiable as a hospital ship and required repainting before leaving for sea. In 1946, surveys by United States Fish and Wildlife Service personnel recorded the all-time worst condition—an area of anoxia running shore-to-shore and top to bottom for twenty miles (Ellis et al. 1947).

The third-generation response to the pollution began in 1936 with the decision to create the Interstate Commission on the Delaware River Basin (INCODEL), an advisory commission formed by Delaware, New Jersey, New York and Pennsylvania. The highest priority on INCODEL's agenda was the cleanup of stream pollution (INCODEL 1936). Through INCODEL, the states hoped to augment and coordinate the water pollution programs of the states which had been particularly ineffective in the region. Until the creation of INCODEL, all wastewater added to the estuary was discharged without treatment except for the city of Trenton and a small section of Philadelphia which had primary treatment plants.

INCODEL initiated a cleanup program as part of a basin-wide program. Through INCODEL, the first set of interstate water quality standards was adopted in the 1939–1945 period (INCODEL 1938). The standards divided the Delaware Estuary into three zones: Zone 2 from Trenton to the northeast section of Philadelphia; Zone 3 from Zone 2 to the junction of the Pennsylvania, New Jersey and Delaware state boundaries near Marcus Hook, Pennsylvania; and Zone 4 from Marcus Hook to the Atlantic Ocean (Fig. 1). Dischargers in Zone 2 were required to effect removal of 85% of the biochemical oxygen demand (BOD) (i.e., secondary treatment), in Zone 3 35% BOD removal (i.e., primary treatment), and in Zone 4 primary treatment was required although no BOD removal rate was stated. The intent of the INCODEL standards was to restore dissolved oxygen levels to at least 50% of saturation in the worst part of the estuary and to achieve at least some level of wastewater treatment at the 100 or so major discharges.

As a result of the INCODEL program, new sewage treatment plants were built throughout the Delaware River basin in the post-war period. By the end of the 1950s, the number of basin communities with "adequate" sewage treatment had risen from 20% to 75% (Albert 1984). These included the major cities (Table 2) which generated over 60% of the municipal sewage discharged into the basin (INCODEL 1940). Also notable was the cleanup of the coal siltation problem in the Schuylkill River. This program, one of the first nonagricultural, nonpoint source control programs in the nation, resulted in the dredging of 30 to 40 million tons of coal silt from the Schuylkill River and the Delaware Estuary, and the construction of desilting basins at coal mines in the upper Schuylkill River basin. INCODEL also promoted the studies which established, by the end of the 1950s, that the Delaware Estuary recharged the Potomac-Raritan-Magothy aquifer under certain hydraulic conditions (Barksdale et al. 1958). The fear of contaminating this aquifer by the pollutants in the estuary had stimulated these important studies. As the result of all these efforts, water quality in the Delaware Estuary improved. In the worst part of the grossly-polluted Delaware Estuary, dissolved oxygen levels rose at least 1 mg l^{-1} (Fig. 2). Pollution was still a problem but the river was no longer anoxic.

The Fourth Generation

The fourth generation effort was indirectly caused by a massive flood of the Delaware River in 1955. As a result of this flood, the United States Army Corps of Engineers initiated a comprehensive river basin planning effort in 1956—the first such study by the Corps of Engineers in the nation (Albert 1987). The United States Public Health Service was assigned the responsibility for the water quality portion of the study. As an outgrowth of this activity, the Delaware Estuary Comprehensive Study (DECS) was launched in the early 1960s. DECS was a pioneering study of water pollution control involving the development of one of the first water quality models for an estuary (Federal Water Pollution Control Administration 1966).

Another response to the planning effort of the Corps of Engineers was the creation of the Delaware River Basin Commission (DRBC) in 1962. DRBC is an interstate, federal water resources agency (the first of two nationwide) with five members: the four states of the Delaware River basin and the federal government. The Commission is distinctly different from the Title II river basin commissions that were created by the Federal Water Resources Planning Act of 1965 (P.L. 89-80) and abolished by Executive Order in 1981. DRBC was created by concurrent state and federal legislation (i.e., the Delaware River Basin Compact). Unlike INCODEL and the Title II river basin commissions, DRBC is not an advisory agency but one which is accorded broad responsibilities including regulatory authority in all facets of water resource management.

Using the DECS model, DRBC adopted new, higher water quality standards in 1967. INCODEL's Zone 2 was kept, but Zone 3 was split into two new zones: Zones 3 and 4. Likewise, INCODEL's Zone 4 became DRBC Zones 5 and 6, with the former comprising the lower reach of the Delaware Estuary and the latter Delaware Bay. Dissolved oxygen standards were adopted as follows:

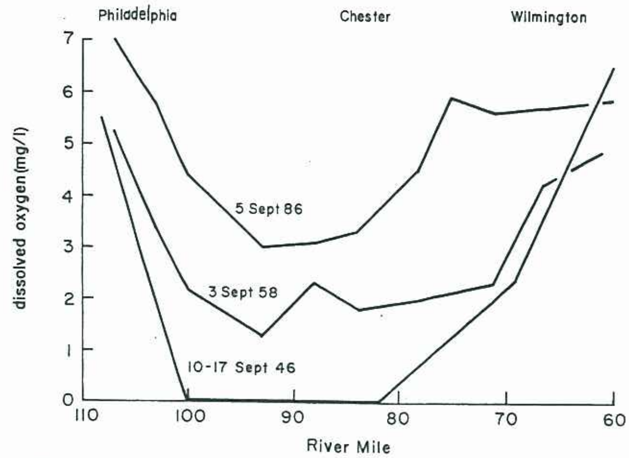

Fig. 2. Forty year change in dissolved oxygen concentration in the Delaware Estuary. 1946 data from Ellis et al. (1947). 1958 data from INCODEL (1962). 1986 data from the DRBC boat run monitoring program (unpublished). Measurements were made under similar conditions of tide, temperature and freshwater discharge.

a 24-hour average of 5.0 mg l^{-1} in Zone 2, 3.5 mg l^{-1} in Zones 3 and 4, and from 3.5 mg l^{-1} to 6.0 mg l^{-1} in Zone 5 with the former applying in the upper boundary of the zone and the latter 19.3 miles downstream (i.e., with a transition area in-between). Other standard changes included the adoption of bacterial standards for primary-contact recreation (bathing and similar activities) in the upper 16 miles of Zone 2 and the lower 11 miles of Zone 5. Secondary-contact recreation (boating and similar activities) and associated bacterial standards was adopted as a use in Zones 3 and 4 and the adjacent sections of Zones 2 and 5. Recreational uses had not been included in the INCODEL standards.

To meet these standards, DRBC issued wasteload allocations in 1968 to some 90 municipal and industrial dischargers (Delaware River Basin Commission 1987). The wasteload allocations were developed using the predictive capabilities of the DECS model. To meet the water-quality standards, modeling studies determined each zone's assimilative capacity for first-stage (or carbonaceous) oxygen demand as follows: Zone 2—18,600 lbs day^{-1};

TABLE 2. Treatment history of municipal discharges over 20 million gallons per day (MGD).

Plant	Design Size[a]	Primary Treatment	Upgraded Secondary	Notes
Trenton, NJ	20 MGD	1927	1983	Secondary—1962
Philadelphia, N.E.	210 MGD	1951	1985	60 MGD primary—1923
Philadelphia, S.E.	112 MGD	1955	1986	
Philadelphia, S.W.	200 MGD	1954	1980	
Camden-Main	75 MGD	1952	1987	
DELCORA (PA)	44 MGD	—	1980	County regionalization
Wilmington, DE	90 MGD	1951–1954	1974	Advanced primary—1960s

[a] Current design size.

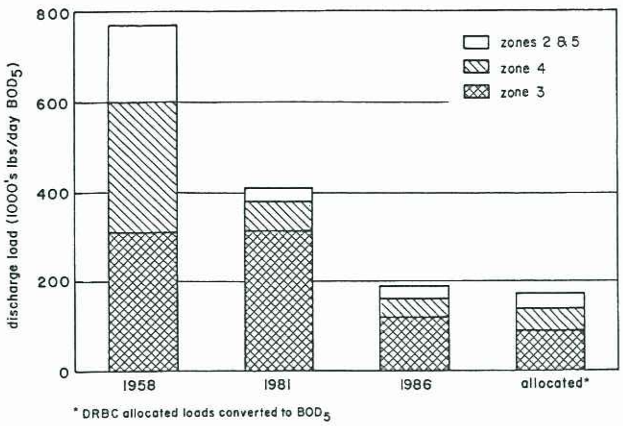

Fig. 3. Trend in oxygen-demanding wastes discharged to the Delaware Estuary. See Fig. 1 for location of zones.

Zone 3—144,800 lbs day^{-1}; Zone 4—91,000 lbs day^{-1}; and Zone 5—67,600 lbs day^{-1}. Zones assigned the highest assimilative capacities were those with the lowest dissolved oxygen standards.

After setting aside 10% of the assimilative capacity of each zone as a growth reserve, the assimilative capacity of each zone was allocated proportionately to each discharger based on waste flow. The individual allocations in lbs day^{-1} allowable discharge corresponded to a carbonaceous BOD removal rate of 88.5% in Zone 2, 86% in Zone 3, 89.25% in Zone 4, and 87.5% in Zone 5.

In addition to the initial allocations, an administrative program was established to handle new dischargers and other changes affecting allocations. Critics of the wasteload allocation system stated that it was too expensive and that nitrogenous oxygen-demanding wastes should have been addressed (Ackerman et al. 1974). The system nevertheless served as a prototype nationally for how complex water pollution control problems could be handled.

DRBC, as a multistate, federal agency, was not, of course, working unilaterally. Its program, like INCODEL's, was being conducted cooperatively with the four state water pollution control agencies and the Federal Water Pollution Control Administration (successor to, the United States Public Health Service, later the United States Environmental Protection Agency). Commission standards were subsequently adopted as state standards, and their allocation and other requirements became part of state and federal discharger permits.

Concurrent with DRBC's actions was increased public concern regarding water pollution. This concern culminated nationally in the passage of the 1972 Federal Water Pollution Control Act amendments which provided construction funds, added enforcement and other incentives which ensured the implementation of the DRBC, state and federal water pollution control efforts. Notable among the benefits derived from the 1972 legislation were the over one billion dollars in construction grants obtained by estuary communities, an action of the United States Environmental Protection Agency led enforcement that forced the city of Philadelphia to upgrade their treatment facilities in a timely fashion, and Section 208 funds which resulted in the development of a second-generation Delaware Estuary water quality model. This model, one of the few tangible benefits of over $10 million dollars of Section 208 funds spent in the estuary region, is a sophisticated, time-varying, two-dimensional model developed by the United States Environmental Protection Agency with assistance from DRBC and other agencies. The new model is currently being used by the DRBC to evaluate existing and future wasteload allocations (see discussion below).

As a result of the fourth-generation pollution control program, new municipal and industrial wastewater treatment facilities were built. Completion of the Camden plant in 1987 (Table 2) essentially marks the end of this response to pollution of the Delaware Estuary.

The Results of Delaware Estuary Water Pollution Control

The dissolved oxygen (DO) level has always been of particular concern in the Delaware Estuary. Improvements in oxygen levels have occurred in three ways: the minimum levels have risen, the areal extent of the dissolved oxygen sag curve has lessened, and the duration of the critical dissolved oxygen depression has decreased. The fourth-generation improvements in dissolved oxygen concentrations (Fig. 2) correlate with the decrease in the amount of oxygen-demanding wastes being discharged into the estuary (Fig. 3).

Based on automatic monitor data collected at Chester, Pennsylvania, a one to three month decrease has occurred since 1962 in the duration of the critical DO depression condition (Fig. 4). Although not as dramatic, upstream locations also indicate a decrease in the duration of the critical dissolved oxygen season. This improvement is probably even greater as the new Philadelphia Southeast and Camden County wastewater treatment plants were not fully operational until mid 1986 or 1987.

The improvements to dissolved oxygen levels have benefited fish populations. The first major evidence of this has been an increase in the population of Delaware River American shad and an expansion of their spawning areas. Prior to the recent improvements in dissolved oxygen, shad

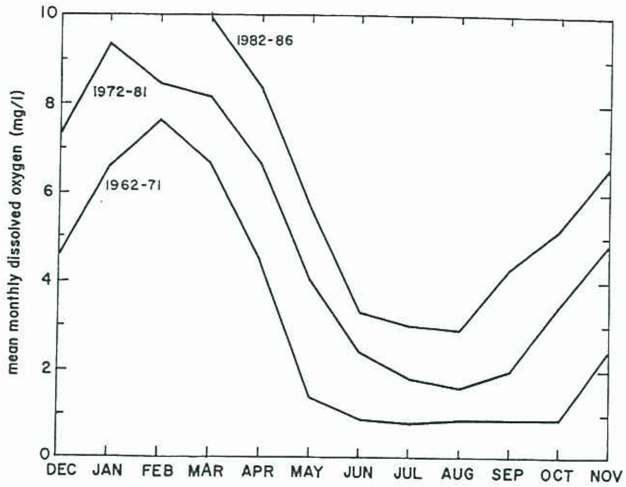

Fig. 4. Decreases in the duration of the critical dissolved oxygen period and changes in mean monthly concentrations at Chester, PA (from Vogel 1987).

spawned no lower in the Delaware River than the Delaware Water Gap, about 80 miles upstream of the head of tide at Trenton, New Jersey (Miller et al. 1982). Shad that might have spawned farther downstream in the river were kept from reaching these areas by the annual onset of low dissolved oxygen conditions in the late spring. The onset of these conditions stopped further migration through the estuary. With improved dissolved oxygen levels, shad spawning was observed 25 miles upstream of Trenton by 1982–84 (Maurice et al. 1987) and in the upper estuary below Trenton by 1987 (Versar Inc. 1987). A 1986 estimate of the recreational value of the spring shad sport fishery is $3.2 million annually (Miller and Lupine 1987).

The second major evidence of improved fisheries comes from fish population surveys conducted by the Pennsylvania Fish Commission in 1985 and 1986 (Summers 1987). In these two years, the Commission found 36 species of fish in Zone 3 during the August and September months. By comparison a summary of 1959 to 1982 fish studies identified only 16 species of fish residing in the zone (United States Environmental Protection Agency 1983). More surprising was the abundance of some fish species and the different life stages observed. During the critical warm months of the year, recreational fishing is now observed at locations where dock workers once experienced nausea from the septic river.

The improvement is reflected by other parameters as well. Based on fecal bacterial studies conducted by DRBC in 1986 and 1987, 34 miles of Zones 2, 4 and 5 have recently been recommended for upgrading from secondary-contact recreation to primary-contact recreation (Huff 1987a, 1987b).

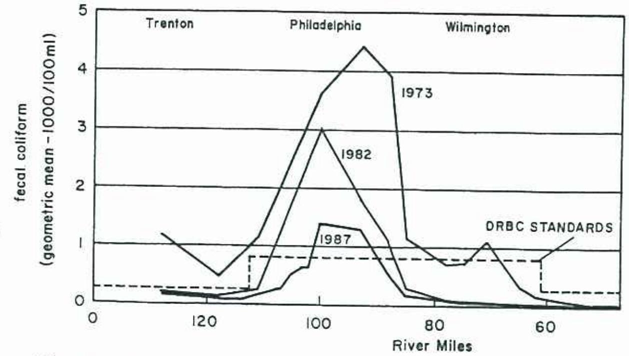

Fig. 5. Decrease in annual mean fecal coliform levels in the 1973–1987 period.

In the remaining 24 miles of secondary-contact recreational waters, the attainment of primary-contact recreation uses requires the correction of dry and wet weather combined sewer overflows (Kratzer and Albert 1988). In 1987, fecal coliform levels were the lowest ever observed in spite of troubles at one of the largest treatment plants (Fig. 5). Other improvements noted have been a decline in phosphorus concentrations, a shift in nitrogen species from unoxidized ammonia to nitrate (Sharp, personal communication) and changes in pH, alkalinity and acidity (Albert 1984).

Like many waterfront areas, the waterfront along the Delaware Estuary is currently in the midst of a renaissance. New public and private development, annual river-oriented festivals, and increasing water recreation are occurring. As a result of water quality improvement, the Delaware Estuary is becoming a focal point of the region. Over time the extensive investment in new wastewater treatment facilities will likely be returned by the economic implications of this renaissance.

The Fifth-Generation Response to Emerging Concerns

It would be an error to suggest the Delaware Estuary is problem-free. A fifth-generation effort is currently responding to the remaining problems and emerging concerns. For example, in early 1986, the Delaware River Basin Commission, with assistance from the basin states and the United States Environmental Protection Agency, initiated the two-year Delaware Estuary Use Attainability (or DEL USA) Project. The goal of the DEL USA Project is to determine what is needed to make the entire estuary "fishable and swimmable" as defined by the federal Clean Water Act. For swimmable water quality, answers to the combined sewer overflow problems need to be addressed in Zone 3 and the upstream section of Zone 4. Other reaches have attained swimmable water quality as discussed above and standards will likely be raised.

Dissolved oxygen is still a major concern in spite of the improvements to date. Approximately 40 miles of the estuary has designated uses and dissolved oxygen standards which are less than fishable. The DEL USA Project has demonstrated that portions of this 40-mile reach can be reclassified for fishable uses and standards, without further pollution controls (Albert and Davis 1987). In other reaches, particularly Zones 3 and 4, higher dissolved oxygen levels will require more stringent treatment requirements. That fishable water quality is attainable at all, however, is a major finding. Previous studies (United States Environmental Protection Agency 1973) suggested that fishable water quality standards were unattainable in the Delaware Estuary. If the decision is made to strive for higher dissolved oxygen levels, reductions in the nitrogenous component of the wastewater will be needed.

Toxic materials are a newer concern. Previous studies have shown the presence of toxics in the estuary system (sediments, water column, and biota) and studies done by the DEL USA Project have reaffirmed these findings (Henshaw 1987; Delaware River Basin Commission 1988). As a result of these concerns, control of toxic materials will be a major thrust of the fifth generation effort. At this time a multi-year study of the fate and effects of toxics is underway by the Academy of Natural Sciences of Philadelphia. This study, largely funded by major estuary industries, is nationally significant. Also being initiated is an interstate toxics assessment and control program. Toxics concerns will undoubtedly lead back to point source, nonpoint source, and combined sewer overflow issues, and public health concerns similar to those experienced in the latter part of the 19th century.

A highly visible manifestation of the fifth generation effort will likely be the conduct of a Delaware Estuary National Estuary Program (NEP) study (the NEP was established by the 1987 federal Clean Water Act). The Delaware Estuary was one of the eleven named estuaries that are to be given priority consideration by the U.S. EPA for the national program. The governors of Delaware, New Jersey, and Pennsylvania nominated the Delaware Estuary for the National Estuary Program at signing ceremonies held on the estuary at historic Newcastle, Delaware, on May 31, 1988. The program, approved in July 1988 by U.S. EPA, will be a five-year or more effort which will address many of the remaining water quality issues in the estuary and emerging issues as well.

Discussion

Pollution has been a recognized problem in the Delaware Estuary for over 200 years and the subject of pollution abatement programs for over 50 years. The Delaware Estuary, like many rivers and estuaries in the United States, has better water quality today than anytime in this century. The benefits of this cleanup are recognizable as waterfront redevelopment and the increased enjoyment of the water by the public at large. Dramatic improvements in aquatic life have also been observed.

The evolutionary process of water pollution control is not often recognized. An understanding of the historical context of water pollution is important for all persons involved in water quality management including the public at large. The cleanup of water pollution is a multi-step process involving years of effort. This is an important consideration when new efforts are planned and initiated.

Equally important is the knowledge that water quality degradation can be relatively rapid if the response to pollution concerns is piecemeal. The rapid degradation of the Delaware Estuary by building sewers without treatment at the end of the pipe, for example, was predictable at the time sewer construction programs were initiated. By 1914, the degradation had reached the point where Philadelphia's engineers developed the three treatment plant system used today. It took four decades to build them, however, and another three decades to upgrade them. That degradation can occur much quicker than the resulting pollution control response is still relevant. The maintenance of existing water quality levels and the improvement of these levels, if unsatisfactory, remain the primary goals of water quality managers.

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