AN INVESTIGATION OF POTENTIAL ENVIRONMENTAL HAZARDS AT TINICUM NATIONAL ENVIRONMENTAL CENTER

U.S. Environmental Protection Agency

U.S. Fish and Wildlife Service

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AT TINICUM NATIONAL ENVIRONMENTAL CENTER
PHILADELPHIA AND DELAWARE COUNTIES, PA

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EXECUTIVE SUMMARY

The Tinicum National Environmental Center (the Center) was added to the National Wildlife Refuge system by Act of Congress in 1972 to preserve and manage the largest remaining freshwater tidal marsh in Pennsylvainia. In 1980, Congress authorized the purchase of additional land containing the Folcroft Landfill. Because the landfill was alledged to have accepted hazardous wastes, Congress directed "... the Administrator of the Environmental Protection Agency, in consultation and cooperation with the Fish and Wildlife Service...to investigate potential environmental health hazards from the Folcroft Landfill . . . and to develop alternative recommendations as to how such hazards, if any, might best be addressed in order to protect the refuge and general public " (Public Law 96-315). A 1983 EPA study of Folcroft Landfill concluded that "no direct hazards to human health are apparent based on available data." The study was limited in scope and did not address hazards to fish and wildlife.

The purpose of this report is to identify whether Folcroft Landfill poses an environmental threat to the Tinicum National Environmental Center. This report also identifies sampling and analytical needs which would be required to develop alternative recommendations to address hazards from Folcroft Landfill.

Because Folcroft Landfill is not the only source of contamination to the Center, other sources in the watershed were also investigated. Contaminants in soil, water, sediments, and biota were identified based on existing data. The contaminants' potential to impact aquatic life and wildlife at Tinicum were then evaluated.

Available contaminant data at Tinicum is restricted in quantity and extent; the greatest data gap identified was a lack of information on organic contaminants. Even with limited data, however, a pattern of overall degradation of Tinicum's natural resources is clear. Water quality in Darby Creek in the Tinicum area is degraded, as evidenced by water column, sediment, and invertebrate data. Levels of copper, iron, ammonia, lead, and zinc in Darby Creek seriously exceed EPA water quality criteria. Creek sediments are contaminated by cyanide, chromium, chlordane, nickel, and PCBs. Benthic invertebrate populations in Darby Creek are limited to pollution-tolerant species. Chemical contamination discovered in fish and turtles collected from the Center has led to a fishing advisory and ban on commercial turtle harvesting.

Possible sources of the identified contamination at Tinicum were evaluated. Because of tidal influence, the Delaware River may be contributing to the high levels of chromium, lead, and zinc in Darby Creek. Data are generally inadequate to determine how much upstream sources contribute to contamination at the Center; however Clearview Landfill has been identified as a potential source of PCBs in Darby Creek and may also be contributing polynuclear aromatic hydrocarbons and heavy metals. The Folcroft Landfill may be a notable source of aluminum, cyanide, copper, lead, and zinc to the Center. Leachate from Folcroft Landfill, containing high levels of copper, iron, lead, manganese, nickel, and

zinc, was found to be toxic to laboratory organisims in bioassay tests conducted during the evaluation.

An evaluation of the contaminant data for possible toxicological impacts to fish and wildlife resources at Tinicum indicates that the identified heavy metal contamination of Darby Creek could pose acute and chronic threats to a variety of flora and fauna. Furthermore, chemical analyses of fish and turtles indicate that contaminants such as chlordane and PCBs are entering the food chain at levels that are expected to harm wildlife at higher trophic levels.

Based on the extensive evaluation conducted for this report, it seems likely that the goals and functions of the Tinicum National Environmental Center, in terms of preserving a quality fish and wildlife habitat with maximum educational and recreational opportunities, are being impaired by the contaminant burdens from upstream sources and the Folcroft Landfill.

As a result of the findings of this report, a full scale site assessment of Folcroft Landfill is recommended to determine the extent and degree of contamination at Tinicum. The data gathered during the site assessment should be used to develop and analyze a set of remedial alternatives to reduce contaminants migrating from Folcroft Landfill. The DOI, in conjunction with EPA, should investigate potential enforcement measures which could be taken against parties responsible for dumping hazardous wastes at Folcroft Landfill and pursue efforts to obtain funds necessary for investigation, remediation, and restoration. Federal and State Agencies should also increase their efforts to reduce other pollutant sources in the Darby Creek watershed.

ACKNOWLEDGEMENTS

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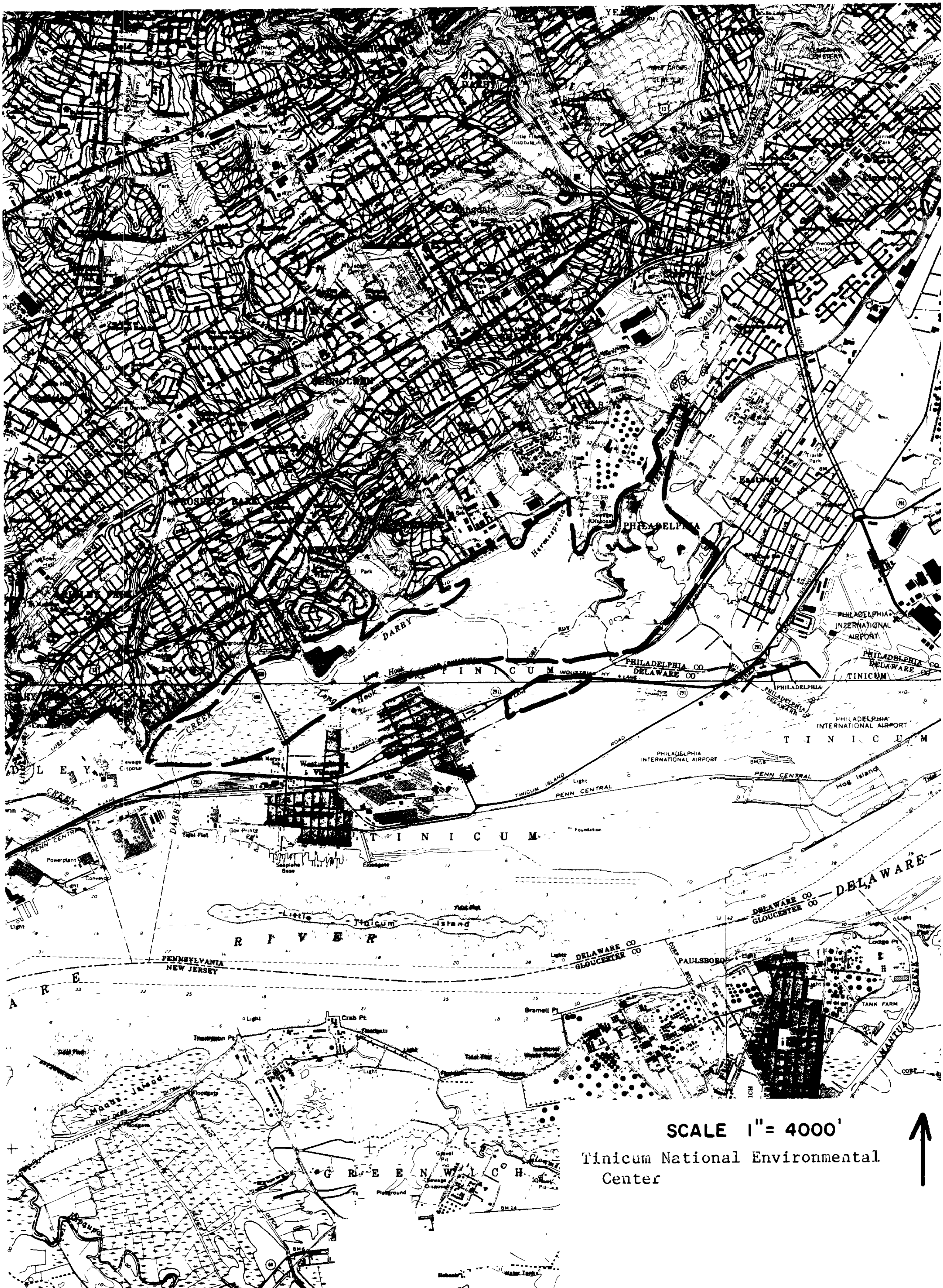

SCALE 1" = 4000'

Tinicum National Environmental Center

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AT TINICUM NATIONAL ENVIRONMENTAL CENTER

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I. INTRODUCTION

Tinicum Marsh is the largest freshwater tidal marsh remaining in Pennsylvania. The value of this ecosystem was recognized when the 1200 acre Tinicum National Environmental Center was established by Congress in 1972. The Center is a managed wildlife refuge and provides unique educational and recreational opportunities in the midst of the heavily urbanized Philadelphia area.

In 1980, Congress authorized the U.S. Department of Interior (DOI) to purchase additional land to increase the size of the refuge. Included in this land acquisition was the 62-acre Folcroft Landfill and Folcroft Landfill Annex. Because there were allegations that hazardous wastes were dumped at these landfills, Congress directed the U.S. Environmental Protection Agency (EPA), in coordination and consultation with the U. S. Fish and Wildlife Service (FWS) to "investigate potential environmental health hazards resulting from the Folcroft landfill... and to develop alternative recommendations as to how such hazards, if any, might best be addressed in order to protect the refuge and the general public" (Public Law 96-315).

An investigation of the Folcroft Landfill conducted in 1983 under the auspices of the Superfund program concluded that "no direct hazards to human health are apparent based on available data" (U.S. EPA, 1985). Concerns over the impacts of Folcroft Landfill to aquatic life and wildlife were not addressed in the 1983 effort.

The purpose of this report is to identify whether Folcroft Landfill poses an environmental threat to the Center. Because this investigation is based on existing data, this report also identifies sampling and analytical needs which would be required to develop alternative recommendations to address hazards from Folcroft Landfill. Because Folcroft Landfill is not the only contaminant source to the Center, other potential sources in the watershed were also determined. Contaminants in soil, water, sediment, and biota were identified based solely on existing data. Potential impacts to aquatic life and wildlife at the Center were then evaluated. These impacts to individual species were then discussed in terms of their potential to impair ecosystem processes and, in turn, the goals and functions of the Center.

Chapter 2 of the report describes the goals of the Tinicum National Environmental Center as established by Public Laws 92-326, 94-548, and 95-152. The natural functions and ecological values of the marsh are also described.

An overview of the physical and biological characteristics of the Center is presented in Chapter 3. Species of special importance are highlighted, and the final section of Chapter 3 summarizes the physical, chemical, and biological information in a brief discussion of ecological relationships.

Chapter 4 contains an enumeration and description of potential contaminant sources to the marsh. The level and extent of contamination in soil, water, sediment, and biota are presented based on a review of historical data.

The contaminants of concern identified in Chapter 4 are evaluated in Chapter 5 with respect to their ability to induce toxicological effects to the biota described in Chapter 3. The potential fate and transport of these contaminants in the ecosystem are evaluated based on surface water estimates of flushing rates, modeling of sediment desorption, and the contaminants' ability to bioaccumulate in the food chain.

Chapter 6 includes a summary of the major findings of this report. Conclusions regarding contaminant sources and impacts are presented. Based on these findings, recommendations for future action have been developed and are discussed in Chapter 7.

II. GOALS AND FUNCTIONS OF THE TINICUM NATIONAL ENVIRONMENTAL CENTER

II. A. Goals

The Tinicum National Environmental Center was established by Public Law 92-326, as amended by Public Laws 94-548, 95-152, and 96-315. These laws provide for the establishment of the Tinicum National Environmental Center to be administered as a unit of the National Wildlife Refuge System of the FWS. The Secretary of the Interior is authorized and directed to (a) acquire lands for the purpose of preserving, restoring and developing the natural area known as Tinicum Marsh, (b) construct, administer, and maintain a wildlife interpretive center for the purpose of promoting environmental education, and (c) afford visitors an opportunity for the study of wildlife in its natural habitat.

The FWS, to fulfill the intent of Congress and in keeping with its overall mission for the National Wildlife Refuge System, has recognized three major goals of the Tinicum National Environmental Center:

1) To preserve the natural resources of the Tinicum Marsh which represents the largest freshwater tidal marsh that remains in Pennsylvania.
2) To provide environmental education opportunities for the schools and residents of the surrounding region.
3) To provide quality wildlife-oriented recreation opportunities for the enjoyment of people in the surrounding region when it will not interfere with the primary purpose for which the area was established.

In 1983, the FWS completed a master planning document to outline the most efficient ways to meet the goals of the Center. Habitat management strategies were seen as an important step in meeting the Center's purposes.

Public Law 92-326, as amended, mandates the preservation of the existing wetlands and the restoration of former wetlands. Much of the land that is recommended for inclusion in Tinicum formerly was tidal wetland, but has been altered by diking, dredging, or filling. In total, the Center will contain approximately 1,200 acres of land that ranges from viable tidal wetland to nearly barren areas. The highly disturbed condition of much of these lands presents an unusual opportunity, as well as a challenge, to recreate the environments that formerly existed. To respond to the mandate of P.L. 92-326, the four following guidelines were formulated:

1. The existing tidal wetlands will be managed to maintain their integrity and to enhance productivity.

2. Areas that formerly were tidal wetlands, but which now are isolated from the tides by embankments, will be restored and managed as tidal wetlands wherever this restoration is considered to be the most environmentally suitable measure. Areas that were formerly tidal wetlands, but have since been excavated, forming tidal lagoons, will be filled and subsequently managed as tidal wetlands, unless they currently provide a valuable habitat

valuable habitat type for waterfowl that would otherwise not use the Center.

Figure 1 depicts the planned vegetation types which will form the core of the habitat management program. Approximately 221 acres of new tidal wetland are proposed, supplementing the existing 275 acres of tidal wetlands. These new wetlands are located primarily in the western portions of the center.

3. Areas of open non-tidal water will be retained or established at appropriate locations to provide habitats for migratory and resident waterfowl and for fish, and to provide areas for educational wildlife oriented recreation activities or scientific research.

4. At appropriate locations, areas will be developed and managed to facilitate scientific research on habitat restoration and/or wildlife management, and to provide educational demonstration of these techniques. The plan calls for construction of an "Environmental Education Building," to be the largest facility at the Center. The "EEB" will be located on the northeast side of the large existing impoundment. From this location, visitors will be able to follow a trail around the dike to an observation platform on top of the Folcroft Landfill that will overlook the tidal marsh area. The visitor can then continue south and west into the center of the site (where an observation tower provides views of the upland forest, ponds and tidal marsh), circle the impoundment and arrive back at the point of departure. Upland field and forest is proposed for the extreme eastern and central sections of the site and for the Folcroft Landfill area.

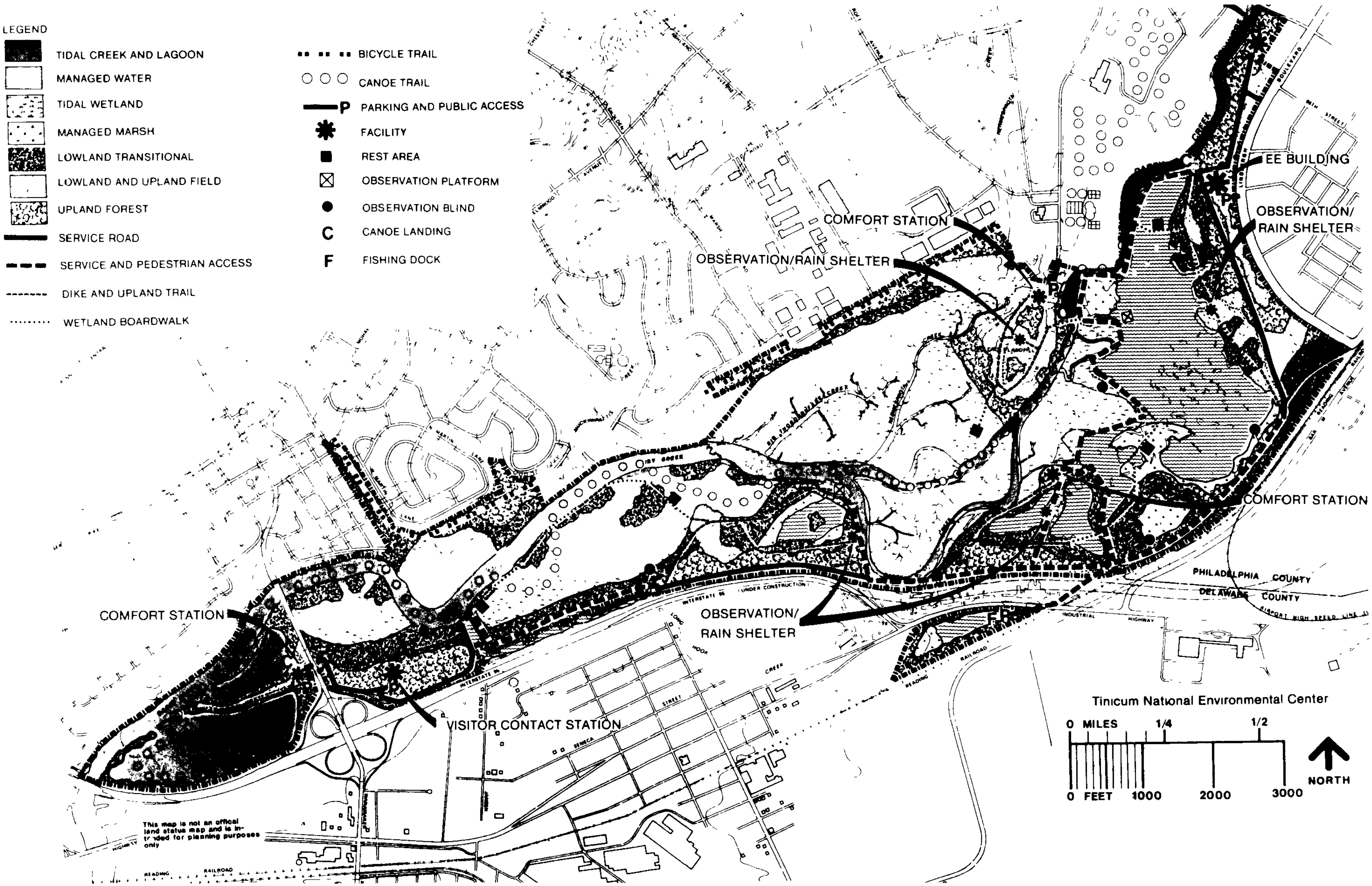
Various "contact stations" (an orientation center consisting of a small office, a small display area, and a lab to accommodate groups making studies) and parking areas are planned. In addition, a canoe launch will be provided. The trail system will provide rest areas, observation blinds, and interpretive materials.

II. B. Functions and Values

The habitat management strategies outlined above will increase the existing values of Tinicum Marsh as a functioning wetland ecosystem. Wetlands serve many functions important not only to fish and wildlife but also to man. For example, the tremendous amount of plant material present in the wetlands helps improve water quality by removing sediments and nutrients from the water column. The vegetative structure of wetlands also serves to retain and store flood waters, reducing the extent of downstream flooding. The unique habitat at Tinicum supports a diverse assemblage of plants and animals. The recreational, educational, economic, and aesthetic values of Tinicum are also enormous.

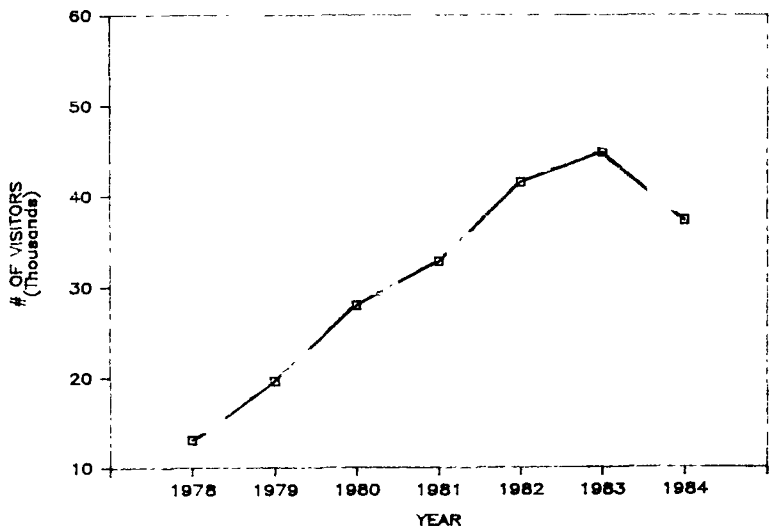
One of the major legislated purposes of the Center is to serve as a wildlife interpretive center to promote environmental education and to give visitors an opportunity to study wildlife in its natural habitat. As displayed in Figure 2, the number of visitors to Tinicum, as recorded by the Visitor Contact Station, has greatly increased since 1978. In 1984,

Figure 1. Land use goals of the Tinicum National Environmental Center.



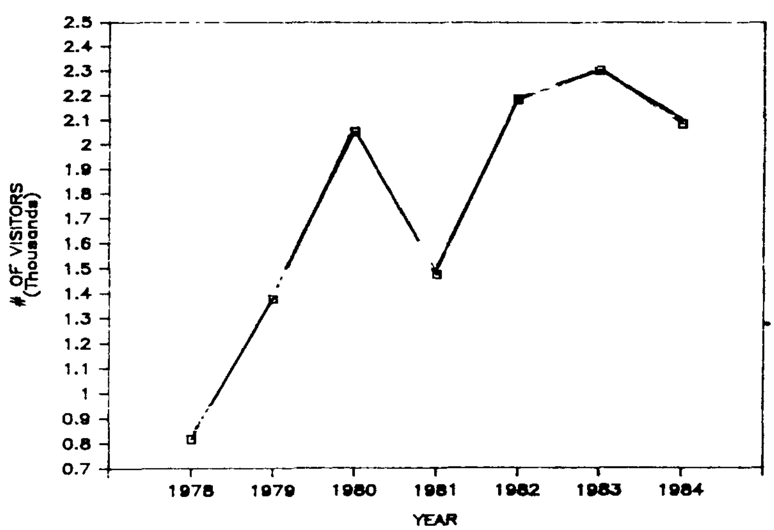
the Center experienced a 15% drop from the previous year in the number of visitors, but this was attributed in part to the many rainy weekends during the warmer months (Tinicum N.E.C., 1985). Over 37,000 people visited the Center in 1984.

Figure 2. Number of visitors to Tinicum.



Environmental education accounted for 5.6% of the visitors in 1984 as represented by the number of teachers and students coming to the Center. As shown on Figure 3, these visitors almost tripled in number from 1978 to 1983 with a slight decrease in 1984. Approximately 2,084 people used the Center in 1984 for educational purposes.

Figure 3. Environmental education at Tinicum.



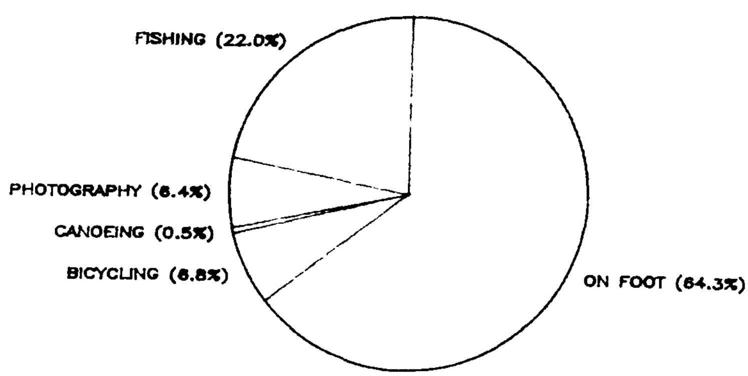
Visitors participate in many types of recreational activities ranging from bicycling to fishing to landscape painting. The activity hours vary widely, with the averages as follows on Table 1.

Table 1. Average Activity Hours per Visit to Tinicum.

Recreational Activity	Average No. of Hours
Wildlife Observation	
By Foot	1 1/2
By Bicycle	1
By Canoe	4
Fishing	3

Approximately 75% of the people engage in wildlife observation through walking, bicycling, canoeing, or photography. Fishing is also a popular activity. An estimated 20% of the 1984 visitors came to the Center to fish for carp, catfish, crappies, sunfish, and eels. Figure 4 displays the percentage of participants in each activity as estimated by the Visitor Contact Station.

Figure 4. Recreational activities at Tinicum.



Quantitative fishery catches for the marsh are not available, however the value of this resource is expected to be significant based on the amount of use. Additional economic values of the Center include the commercial harvesting of snapping turtles and the potential use of the marsh as a spawning area for anadromous fish.

III. SITE DESCRIPTION

III. A. Physical Characterization

Tinicum National Environmental Center is in Philadelphia and Delaware Counties in southeastern Pennsylvania. The Center is located near the confluence of Darby Creek and the Delaware River and will eventually comprise over 1,200 acres of tidal marsh and upland habitats. Areas surrounding the Center are highly urbanized and include an airport, and industrial, residential, and commercial areas. Darby Creek, Cobbs Creek, Muckinipattis Creek, and Hermesprota Creek are the major streams which form the Tinicum watershed.

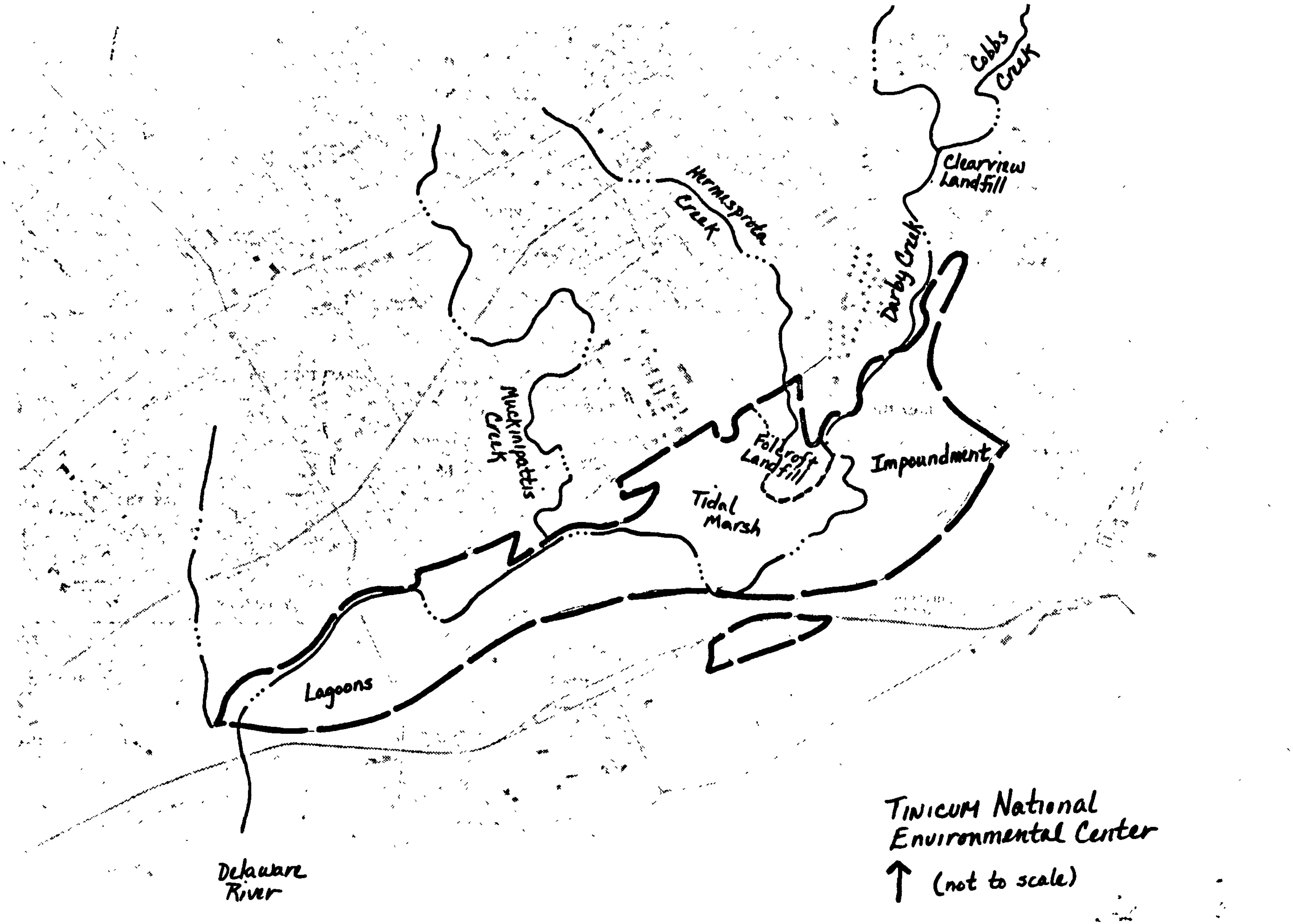
The climate in Delaware County is best described as a humid, temperate climate with mean yearly temperatures of 52°F. Precipitation is fairly evenly distributed throughout the year, and averages 44 inches per year. Annual mean evapotranspiration is 34 inches. Prevailing wind directions during the summer are from the southwest, while prevailing winds during the winter months are from the northwest. The annual prevailing wind direction is from the west-southwest. Flooding rarely occurs in the Delaware River (NOAA, 1979).

The Center has a very low elevation. Marsh areas vary from 2.0 feet below mean sea level to 7.0 feet above mean sea level. In dry areas located in the western portion of the Center, the elevation ranges from 7.0 feet below mean sea level to 11.0 feet above mean sea level. Dry areas in the eastern half rise from 7.0 to 46.8 feet above sea level (Soil Exploration, 1977).

Located directly on Thoroughfare Creek at approximately 50 feet above sea level, the Folcroft Landfill is the highest area in Tinicum. The landfill remains unaffected by tidal fluctuations except for the base of the landfill bordering the marsh and creeks. For the most part, Folcroft has moderate slopes of about 10% which form a rounded summit. However on the Darby Creek side, the highly erodible banks rise steeply to 20 feet.

Under the Clean Water Act, Pennsylvania DER designates water quality standards for State waters. DER bases its standards upon protected water uses. DER has not designated protected water uses specifically for Tinicum. Consequently, the protected uses which apply to Tinicum fall under several stream listings. Darby, Hermesprota, Cobbs, and Muckinipattis Creeks are protected for use as warm water fisheries, industrial water supply, livestock water supply, wildlife water supply, irrigation, boating, fishing, water contact sports, and aesthetics. The upper reaches of Darby Creek are stocked with trout by the Pennsylvania Fish Commission.

The hydrologic characteristics of most freshwater tidal systems are poorly studied. The wetlands within Tinicum further complicate the picture


Cobbs Creek
Clearview Landfill
Hermesprota Creek
Darby Creek
Muckinipattis Creek
Folcroft Landfill
Impoundment
Tidal Marsh
Lagoons
Delaware River
TINICUM National Environmental Center
(not to scale)

because of their ability to attenuate storm flows by storing surface water and releasing it during dry periods to maintain base flows (Wang, 1981). The hydrologic regime of freshwater wetlands strongly influences the chemical and physical properties of the marsh, including water exchange, nutrient exchange, toxicant transport, and oxygen availability. In turn, these chemical and physical properties play a major role in modifying ecosystem characteristics such as productivity, species heterogeneity, and nutrient cycling (Gosselink, 1978; Simpson, 1983).

Tinicum is located near the mouth of Darby Creek where it joins the Delaware River, and consequently may play a major role in attenuating storm flows for the entire Darby Creek basin. Average surface runoff in the Darby Creek watershed averages 15 to 28 inches per year. In the Tinicum area, runoff more closely ranges between 17 to 20 inches per year. The Darby Creek watershed drains 78.6 square miles of Philadelphia, Chester, Delaware and Montgomery Counties. Cobbs Creek, a major tributary to Darby Creek, originates in Delaware and Montgomery Counties. The confluence of Darby and Cobbs Creek is 0.75 miles north of Tinicum, and approximately coincides with the head of tide in Darby Creek. Within the Environmental Center, Darby Creek averages 220 to 250 feet wide with an average depth of 6 feet at mean low tide. Water levels remain within 2 feet of the maximum height for about 5 hours during each 12.4 hour tidal cycle (U.S. FWS, 1983a). Hermesprota Creek also flows into the marsh and drains approximately 1 square mile of industrial area in Delaware County. Muckinipattis Creek (drainage area 3.5 square miles) enters the marsh approximately 1/2 mile below Folcroft Landfill.

Gage data for these streams are listed in Table 2. Continuous flow data were collected at three USGS gaging stations on Cobbs Creek and one gaging station on Darby Creek between 1966 and 1972. Monthly discharge data are further detailed in Appendix Table A. The Cobbs Creek gaging station at Darby has a drainage area of 22 mi^2 which constitutes 29% of the total Darby Creek watershed. The Darby Creek gaging station at Darby represents 47% of the drainage basin.

Table 2. Hydrologic data for streams in the Tinicum watershed. Mean low flow, (7Q10), drainage area (DA), maximum discharge (Max), and date and mean discharge are listed for the most recent period of record.

Gage No.	Location	7Q10 (cfs)	DA (mi^2)	Max. (cfs)	Mean (cfs)
01475300	Darby Creek, Waterloo Mills, PA	1.4	5.15	1800(9/79)	10.9
01475510	Darby Creek, near Darby, PA	10	37.4	5920(8/74)	71
01475530	Cobbs Creek, U. S. Rte 1	0.95	4.8	3480(8/74)	7.4
01475550	Cobbs Creek at Darby, PA	-	22	4490(6/73)	31.1
01475550	Hermesprota Creek, Darby, PA	0.35	1.01	--	-
01475600	Muckinpattis Creek	0.92	3.5	1160(7/83)	-

Within the southwestern portion of the Center are three lagoons, approximately 0.7 miles above the confluence of Darby Creek and the Delaware River. The tidal amplitude at this point is approximately 4 1/2 ft (Ecological Studies, 1977). All lagoons have free interchange with water from Darby Creek, however, interchange between the lagoons is limited to high tides. Depths up to 40 feet are encountered in the lagoons. Sediment exchange between Darby Creek and the lagoons is expected to be minimal because dike remnants between the lagoons and Darby Creek inhibit exchange (Lloyd, 1986). A 145 acre impoundment is located in the eastern section of the Center; however exchange between Darby Creek and the impoundment is minimal because of the presence of dikes and flood gates.

Numerous dikes throughout the Center inhibit the exchange of water in several areas. In the Folcroft area, overland flow follows the topographic contours and runoff enters Darby Creek, Hermesprota Creek, and the adjacent tidal marsh.

A large area of the Center is covered by relatively sandy dredged materials. The materials in the Darby Creek disposal area north of I-95 originated from dredging during 1956 to 1958 when the U. S. Army Corps of Engineers excavated an anchorage and turning basin in the Delaware River. The thickness of the dredged material ranges from less than 1 inch to 9.9 feet. The exact composition of the material is unknown, but generally has a sandy silt texture. Dredged material placed in the cooperative management area during 1965 for the now defunct Cobbs Creek Expressway is similar, but ranges from 11 to 13 feet in thickness (U.S. FWS, 1981).

The most recent soil surveys which include Tinicum were conducted by the Soil Conservation Service in May 1963 for Delaware County and in July 1975 for Philadelphia County. Table 3 provides a summary of these soils' properties.

Table 3. Estimates of soil properties found in Tinicum and adjacent areas. Permeability is in inches per hour, depth to water table is in feet, and depth to bedrock is in feet. An asterisk indicates that the properties vary too much to estimate.

Soil Series	Depth (cm)	Permea-bility	Depth to water table	Depth to bedrock
BeA - Beltsville silt loam, 0 to 3 percent slopes	0-7	0.63-2.0	1-2	6+
	7-48	<0.2		
ByA - Butlertown silt loam, 0 to 3 percent slopes	0-8	0.2-6.3	2-2.5	6+
	8-48	<0.2		
ByB2- Butlertown silt loam, 0 to 3 percent slopes	48	0.63-2.0	2-2.5	6+
Ma - Made land, gravelly mat.	varies	varies	3+	4+
Ml - Made land, sanitary landfill	varies	varies	3+	4+
OtA - Othello silt loam	0-12	0.63-2.0	0-1	4+
We - Wehadkee silt loam	0-70	0.63-2.0	0-1	5-8
WnA - Woodstown loam	0-10	2.0-6.3	2-3	10+
Tm - Tidal marsh*			0	
Mh - Marsh*			0	
Ub - Urban land*				

Most of Tinicum is covered by Tidal Marsh or Marsh soils. Generally, the soil material consists of loamy to clayey marine and alluvial deposits and dark-gray, gray, or black smooth silty clay. Approximately 1 to 2 miles upstream from the mouth of Darby Creek, coarse-textured material washed from coastal plain sediments has capped the silty deposits of the tidal marsh. Folcroft Landfill is typed as made land, sanitary landfill comprised of alternate layers of soil and trash which have been compacted by heavy equipment.

Generally, the cover material used during the sealing of the landfill consists of well-drained sandy loam. More specifically, on the western half of Folcroft, the cover is approximately 2 feet thick. DER representatives have determined that a portion of this cover material was dredge spoils and the rest was brought in from the I-95 construction site and several other construction projects (Environmental Evaluation, 1979).

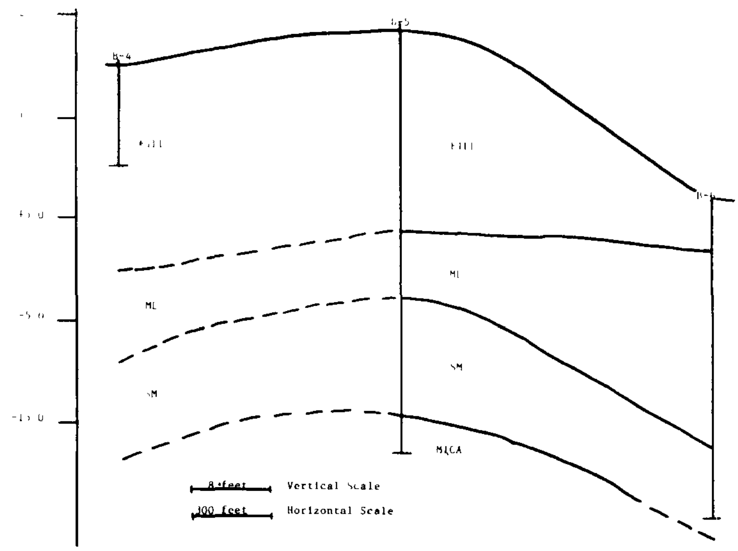
On the landfill's eastern half, material obtained from a construction site at the Sun Oil Refinery in Marcus Hook, PA, forms the main cover. Soil tests indicate a maximum of 7% oil within this cover material. The eastern half's cover ranges from an average of 4 feet thick to 10 feet thick (Environmental Evaluation, 1979). The permeability of the soil at the landfill varies from unknown to moderate (0.1 to 10 cm/sec) to high (10 to 1000 cm/sec) (U. S. EPA, 1980).

Other soils adjacent to the Center include Beltsville silt loam, Butlertown Series, Othello silt loam, Wehadkee silt loam, Woodstown loam, and Urban land. The properties of these soils are also listed in Table 3. Othello Silt Loam and Woodstown Loam are moderately permeable, and all soils exhibit high water tables.

The typical stratigraphy in mid-Atlantic coastal marshes is a hard bottom bedrock, varying layers of river, estuarine and marsh sediments, and a cap of recent freshwater tidal marsh sediments (Odum, 1981). Subsurface soils in the Center include silt, peat, sand, and gravel. Fill materials, described as wood, bricks, cinders, garbage, and paper range from the top surface to depths of 21 feet in the Folcroft Landfill.

Tinicum lies within two physiographic provinces, the Piedmont and Coastal Plain. The fall line between these two provinces lies along the northwestern side of the Center (Graham, 1970). In the Coastal Plain, deposits of recent alluvium are underlain by unconsolidated clay, sand, and gravel deposits of the Quarternary age. These deposits are in turn underlain by Cretaceous sediments which include beds of highly permeable sand and gravel separated by less permeable clay and silt. The Piedmont province in Darby and Ridley Townships is primarily composed of the Wissahickon Schist formation underlain by granite gneiss and covered with a layer of terrace gravel (Hall, 1973). North of the Center and along the fall line, the Wissahickon schist outcrops and is covered by a thin layer of the Cape May formation consisting of gravel, sand, and loam.

Figure 5. Test borings in the Folcroft Landfill. ML = gray silty sand, SM = fine to coarse brown sand and gravel.



Bedrock floors in both provinces are composed of pre-Cambrian crystalline rocks. In the area near the Center, these crystalline rocks are from the Wissahickon schist. The crystalline bedrock floor dips approximately 60 ft/mile in a southeasterly direction (Graham, 1970) and is a heterogeneous mix of medium to coarse grained rock composed of quartz, oligoclase, muscovite, and biotite (Lehigh, 1982). Along Darby Creek just south of Folcroft Borough, the bedrock floor is approximately 60 feet below the surface (U.S. FWS, 1983a). At the lower end of Darby Creek, the depth to bedrock is approximately 40 feet (Soil Exploration, 1977). Along the Delaware River most of the Cape May deposits have been removed by erosion and along Long Hook Creek, mica schist is encountered at depths of 10 feet.

Test borings in the Folcroft Landfill are illustrated in the cross-sectional diagram in Figure 5. Soils directly below the fill material are gray silty sand, underlain by fine and coarse brown sand and gravel. Mica schist under Folcroft Landfill is approximately 15 feet below sea level.

Wetlands play distinct roles in the hydrogeology of Tinicum because of the recharge/discharge relationship between the underlying aquifers and the overlying organic marsh sediments (Obrien, 1980). Ground water in Tinicum occurs both in the crystalline bedrock and in the unconsolidated coastal plain sediments. The recent deposits of organic mud, silt, and sand are not expected to be important sources of groundwater because they are generally much thinner and less permeable. However, these sediments would constitute a leaky, confining bed (Hall, 1973) and would be classified as low to moderate water yields for wetlands (Obrien, 1980). Water supplies in the Wissahickon schist are provided through faults and jointings and are only important sources along the fall line. However, water in bedrock may be a very significant source for the wetlands because these zones constitute a continuous water supply. The fall line joint planes are the primary source of ground water in the area, especially in the upper layer of bedrock where weathering has changed the bedrock to a micaceous clay (Hall, 1973). This residual clay also serves as a confining bed from the overlying consolidated Coastal Plain sediments (Greenman, 1961). Along the fall line, ground water generally occurs under water table conditions. The median yield in the Wissahickon formation is 10 gpm and ranges from 0 to 350 gpm. The median specific capacity is 0.4 gpm, and drawdown ranges from 0.06 to 8.4 gpm/foot.

Groundwater in the Coastal Plain area near Tinicum is found mostly in the Farrington Sand member of the Raritan formation and in the Cape May deposits. The Farrington Sand member, generally overlain by a confining bed of clays, is the primary artesian aquifer for the area. The average transmissibility for this aquifer is 50,000 gpd/ft, the average permeability is 1,000 gpd/ft^2, and the storage coefficient is 0.0002 (Greenman, 1961).

The Cape May deposits of sand, gravel, and clay comprise the most extensive water table aquifer in the lower Delaware River Valley in Pennsylvania. The yields of wells in the coastal plain sediments range widely from 8 to 7000 gpm. The field coefficients of transmissibility are generally lower than the Farrington aquifer and average 41000 gpd/ft. The average storage coefficient is 0.0006, indicating that in some areas deposits contain water under artesian conditions resulting from the deposition of recent, less permeable sediments (Hall, 1973).

Depths to groundwater during sampling at the Center ranged from 0 to 15 feet below the land surface. In the Folcroft Landfill, water tables were 0 to 15 feet below the surface. In the southeastern end of Tinicum, water table depths were 0 to 5 feet below the land surface. Both in the southwest and Folcroft Landfill, "fill" material lies within the water table.

The general pattern of groundwater movement in the water table system is from the high point along the fall line toward the Delaware and Schuylkill Rivers. Discharge points also occur in adjacent stream valleys and usually follow the local topography. Discharge from the water table is expected to be especially high through evapotranspiration in the marsh areas (Hall, 1973). In the Coastal Plain, the major source of recharge to groundwater is direct infiltration from precipitation (Lehigh, 1982).

Movement in the artesian system is more heterogeneous but again follows the fall line southeast to the Delaware River and its tributaries (Greenman, 1961, and Lehigh, 1982). Groundwater in the underlying crystalline rocks flows in interconnected paths following fractures, although the hydraulic gradient is in a southeasterly direction.

Discharge from the artesian systems is also primarily to streams. Near the Delaware River, seasonal fluctuations in the water table are not as pronounced because of tidal balancing. Fluctuations in the water table due to tides are not expected farther than several hundred feet from the river (Greenman, 1961) and thus would not influence Tinicum. However, tidal fluctuations within Darby Creek may influence water table levels. No monitoring data are available to verify local flow conditions.

III. B. Biological Characterization

The Center contains a variety of aquatic and terrestrial habitat types that include old field, forest, revegetated dredge spoil, open water, and marsh. The marsh habitat is perhaps the Center's most significant feature. Comprising about 350 acres (U.S. FWS, 1983a), Tinicum Marsh is the largest expanse of freshwater tidal marsh remaining in Pennsylvania. Historically, tidal marshes in the Philadelphia area covered over 5,700 acres, extending along the Delaware River from the Walt Whitman Bridge to a point beyond Eddystone, and more than 5 miles upstream from the mouth of the Schuylkill River (Tinicum N.E.C., 1985). Since World War I, more than 5,000 acres of tidal wetlands in the area have been filled to construct railroads, highways, boatyards, the Philadelphia International Airport, and residential and industrial developments (U.S. FWS, 1978).

Freshwater tidal wetlands are a relatively poorly studied ecosystem type found between the more well-known tidal "saltmarsh" ecosystems downstream, and freshwater non-tidal wetlands upstream (Odum et al., 1984). In general, freshwater tidal wetlands are characterized by an average annual salinity of 0.5 ppt or lower (except under certain drought conditions); freshwater plant and animal species; and a daily, lunar tidal fluctuation (Odum et al., 1984). Because few scientists distinguished between freshwater tidal wetlands and other estuarine ecosystems, the literature pertaining to biological and ecosystem processes of this specialized wetland type is sparse (Odum and Smith, 1981).

III.B.1. Flora

The distribution of plants in freshwater tidal wetlands is frequently described as occurring in "zones" of "reoccurring groups of species which form recognizable patterns" (Odum et al., 1984, p. 21). These zones are typically comprised of one or two dominant plant species and varying associated species. According to Odum et al. (1984), zonation is probably caused by variations in physical site characteristics (such as elevation and period of inundation) and ecological processes (such as interspecific competition). McCormick (1970) noted that the vegetation of Tinicum Marsh is "particularly well suited to mapping because . . .

> it is composed of numerous visually distinct subunits that differ in color, height and texture and that differ in position in relation to drainage channels and microtopography. Several of the types that were recognized were 'pure stands', that is, they were composed almost entirely of plants of a single species. This was true of the wild rice, common reed, spatterdock, creeping primrose willow and smartweed types. Over much of the area in which it occurred, the cattail type also was pure, but in part of the area it occurred in mixture with various other species of aquatic plants. The other vegetation types recognized in this survey were much more subjective categories. For example, a mixed-aquatics type was mapped in much of the tidal marsh. Generally, stands of mixed aquatics were composed of two or more species of smartweed growing with various mixtures of arrowheads, beggarticks, jewelweed, bur-reed, cattail, spatterdock, wild rice, iris, sedges and grasses. They were woven together in many places by masses of dodder--a parasitic, orange-colored vine. A shrub type, which actually was composed largely of shrublike herbs which die to the ground in winter, occurred primarily in diked sections of the marsh with impounded water. . . Purple loose-strife was the most common species, but marsh mallow was scattered throughout the stands. In some places, the shrub type was formed by dogwoods and willows and, in a few places, by alders and other woody shrubs. The tree type included several dozen species in the mapped area, but willows were the chief components in the marsh proper. The last type, characterized as oldfield herbaceous vegetation, included many kinds of grasses, goldenrods, asters, fleabanes and similar 'weeds'. This type occupied fields formerly cultivated on higher lands around the marsh and covered the dikes that anastamose through the wetlands (McCormick, 1970, pp. 34-35).

Other wetland plant species identified by McCormick include arrow-arum, pickerelweed, jewelweed, water plantain, buttonbush, sensitive fern, reed canary grass, water hemp, bulrush, bur marigold, sweetflag, golden club, pondweeds, rushes, blue vervain, marsh hoarhound, lizard's tail, water parsnip, mad-dog skullcap, and tall cone-flower.

McCormick's study included a rather detailed map of Tinicum's vegetation which clearly illustrates a high interspersion of vegetation types within the marsh. The wild rice type occupied the greatest acreage of the tidal wetlands (138 acres), but the spatterdock type (108 acres) and the mixed aquatic type (103 acres) were nearly as widespread. Cattail stands occupied 77 acres in the tidal marsh and 3 acres in the impoundment. The "mixed aquatic" type occurred on 100 acres of tidal marsh. The introduced primrose willow had taken over 20 acres of previously open water and cattail at the time of McCormick's study. The common reed type was really predominant throughout the region that was mapped, but the type occupied only 13 acres in the tidal wetlands. It was most characteristic of areas covered with dredged materials. At the time of McCormick's study, 295 acres of tidal marsh in the Long Hook Marsh section had recently been filled with dredged material, and common reed had already formed "vast colonies" on over 70% of the area (McCormick, 1970, p. 38).

McCormick also determined standing crop estimates for various vegetation types within Tinicum Marsh, and concluded that the data seemed to indicate "unusually great" productivity in Tinicum Marsh (Ibid, p.36).

Other interesting observations McCormick recorded in his study concern the area of the marsh adjacent to the Folcroft Landfill. In McCormick's opinion, the Folcroft Borough portion of Tinicum Marsh contained the "most pristine tidal marsh vegetation, which is . . . the most desirable for preservation" (p.14). McCormick evidently based this assessment on his observation that the Folcroft section was unmarked by mosquito ditches, retaining natural drainage patterns. Other areas of the marsh, ditched in the late 1930's for mosquito control, contained stands of giant ragweed that seemed to grow on the low, wide banks formed by sidecast materials from the ditch excavation. In contrast, giant ragweed was rare in the Folcroft section.

Other significant natural features of the Center include the 145 - acre impoundment in the northeast end of the refuge, separated from Darby Creek by dikes. The impoundment contains spatterdock, purple loosestrife, primrose willow, rose mallow, and cattails (Schwartz, 1976), and attracts large numbers of waterfowl. In addition, a 24-acre forested area consisting of oak, birch, black willow, white and red mulberry, and quaking and bigtooth aspen in the southeastern section of the center represents the only forested habitat remaining in south Philadelphia, and adds habitat diversity to the Center. Several other small stands are found throughout the Center, composed of such species as black gum, sweet gum, red maple oaks and willows.

A complete list of plant species found at Tinicum is in Appendix Table B.

Rare and Endangered Flora

No federally listed rare or endangered flora are known to occur at Tinicum. However, three plant species listed as "proposed rare" by the Commonwealth of Pennsylvania currently exist at Tinicum: river bulrush (Scirpus fluviatilis), Indian wild rice (Zizania aquatica), and waterhemp ragweed (Amaranthus cannabinus). Wright's spike-rush (Eleocharis obtusa var. peasei), a Pennsylvania "tentatively undetermined" species, has also been observed at Tinicum (Davison, 1986). Historical records exist for several other state-listed threatened or endangered species, but there have been no recorded observations of these plants since the early 1900's (Pennsylvania Natural Diversity Inventory, 1986).

III. B. Macroinvertebrates

Benthic macroinvertebrates seem to be the most poorly studied component of the Tinicum Marsh ecosystem. In 1968, the Delaware River Basin Commission (Craighead, 1971) investigated the chemical and biological condition of the Delaware River and its tributaries. The report concluded that 39 of the 46 tributaries studied were in a state of degraded water quality. Darby Creek was rated as a marginal quality stream based on an evaluation of phytoplankton, zooplankton, and macroinvertebrates.

Grant and Patrick (1970) determined the presence and relative abundance of plants and animals at 19 stations within the tidal marsh. Macroinvertebrates found along Darby Creek included large numbers of tubifex worms (a species that thrives in organically polluted waters) as well as leeches, mosquito larvae, midges, a few aquatic beetles, fingernail clams and small populations of isopods and snails.

In 1976, PA DER conducted an aquatic biological investigation of Darby Creek and its tributaries (Strekal, 1976). The objective of the study was to determine water quality of the headwaters of Darby Creek (the closest station to Tinicum was located near Route 3). The investigation concluded that benthic diversities were high in the headwaters and stream conditions were described as fair to good.

Stark (1978) conducted a study on the feeding habits of ruddy ducks at Tinicum, and included some limited benthic sampling to determine the availability of food material in ruddy duck feeding areas. Macroinvertebrate "food items" were broadly classified as one of three categories: tubificid worms, Tubificidae, fingernail clams, Sphaeriidae-Sphaerium spp., or midge larvae (Tendipedidae), and quantified as a percentage of the total volume of food items. Only three stations in Tinicum Marsh were sampled: Darby Creek near the confluence of Big Thoroughfare Creek, the wide lagoonlike area of Darby Creek just upstream of Wanamaker Avenue, and the large lagoon just upstream of the I-95 crossing.

Another study in the Tinicum area that included benthic macroinvertebrates was conducted by T. Lloyd Associates (1979) in an assessment of the two lagoons just upstream of the I-95 crossing (0.7 mile upstream of the Delaware River). The study documented the numbers of individuals within four Phyla in the lagoons:

1) Annelida, including tubificid worms and leeches. Limodilus spp. were

more common than Tubifex spp., but both were found in shallow water areas on submerged logs, trash and other debris. Placobdella were the most common type of leech found, while Glossiphonia and Hirudinea were also present.

2) Mollusca, represented by Sphaeriidae or freshwater clams. Both Sphaerium spp. and Musculium spp. were found, in sediments along the lagoons' shorelines. Musculium spp. were the more numerous of the two species.

3)Anthropods (uncommon) including amphipods (Gammarus sp.), isopods (Asellus sp.), midge larvae (Chironomidae) and dragonfly nymphs (Epicordullia sp.).

4) Bryozoans or "moss animals," occurring in small colonies on sunken logs.

Tom Lloyd (1986) cautions that macroinvertebrates in the lagoons are probably not at all characteristic of macroinvertebrates in Darby Creek, due to the extreme depth (35-40 ft.) and restricted tidal action in the lagoons. Furthermore, Lloyd's studies were limited to deepwater habitat only, ignoring the shallow habitats around the edges of the lagoons.

To our knowledge, no macroinvertebrate studies have been conducted recently at Tinicum Marsh.

III.B.3. Fish

According to the Tinicum National Environmental Center Master Plan (U.S. FWS, 1983a), forty species of fish occur or probably occur within the waters of the Tinicum area. Appendix Table C lists these species and provides a brief description of their food habits and life history. Carp, brown bullheads, white suckers, and a number of species of minnows are dominant. Two species of killifish, the mummichog and the topminnow, are relatively common. American eel, striped bass, and pumpkinseed sunfish are found occasionally, and the eastern mudminnow is found rarely. Goldfish, crappie, topminnow, and bluegill sunfish have been collected in the 145-acre impoundment. Mosquitofish (Gambusia spp.) were introduced in the early 1960's to control mosquito larvae. A large population of carp inhabits the Center's impoundment.

One of the more traditional roles of the FWS has been to lead efforts to restore nationally important fishery resources that have been damaged by overuse or habitat degradation. Restoration of anadromous fish (especially American shad) in the Delaware River has been the focus of a considerable amount of FWS's time and money. Many anadromous fish are known to use Delaware River estuary tributaries as spawning and/or nursery areas (Delaware River, 1979) and Darby Creek is probably no exception. American shad apparently do not currently use the Delaware's tidal tributaries, instead migrating through the estuary to reach spawning areas upstream of the Delaware Water Gap (Delaware River, 1979). This marks a change from historical records, which indicate that many of the Delaware's tidal tributaries supported large populations of spawning American shad (Delaware River, 1979). In fact, in 1904 the New Jersey Board of Fish and Game Commissioners reported that in 1820, a shad fishery existed at the mouth of every creek and river between Bayside and Trenton (Zich, 1977). It would seem likely that the same would be true for most streams on the Pennsylvania side of the Delaware, including Darby Creek. Unfortunately, pollution apparently eliminated the viability of these streams as spawning and nursery areas by the 1940's (Ellis et al., 1947).

During the 1970's, the Delaware River Basin Anadromous Fishery Project (1979) undertook a study of the use of selected major Delaware River tributaries as spawning and/or nursery habitat by anadromous fish. Darby Creek was sampled twice during the course of this study, once in 1973 and again in 1976. During the 1973 collection, blueback herring were the only anadromous species collected; during 1976, no blueback herring were found but a number of adult and juvenile white perch were present. Dissolved oxygen in Darby Creek on the day of the 1973 sampling was 5.0 ppm, the minimum level considered acceptable to support sensitive aquatic species. During the 1976 sampling, dissolved oxygen ranged from a low of 1.6 ppm on September 15 to a high of 6.0 ppm on April 8. In all 16 streams studied, the authors noted that American shad were never found where dissolved oxygen was below 5.0, and that shad presently made little or no use of Delaware River tributaries for spawning or nursery habitat. River herring (alewife or blueback) were abundant in all of the sampled streams except Darby Creek and two others. White perch were found to use the tributaries extensively for spawning, but only to a limited extent as nursery habitat. Few anadromous fish were collected below a dissolved oxygen concentration of 4.0 ppm (Delaware River, 1979).

October 1979 sampling by T. Lloyd Associates (1979) in the lagoons of Darby Creek yielded six white perch, one blueback herring, one alewife, one gizzard shad, and one American eel (in addition to a number of non-anadromous fish). In August 1984, the FWS State College Field Office collected brown bullheads and white suckers from Darby Creek for chemical analysis. During the field work, one white perch was caught in the tidal marsh area of Darby Creek, and a number of American eels were observed upstream of the marsh, adjacent to the Clearview Landfill. Tinicum staff report that white perch are commonly caught by anglers in the lagoons.

Unfortunately, no comprehensive studies of anadromous fish use of Darby Creek have been undertaken since the 1970's, when sewage treatment plants along Darby Creek caused severe organic pollution of the Tinicum area. With the elimination of these sources of biological oxygen demand, one would expect dissolved oxygen levels in Darby Creek to have improved to the point where anadromous fish may once again use the Tinicum area as spawning and nursery grounds.

Threatened and Endangered Fish

The only federally-listed threatened or endangered fish species in the Tinicum area is the shortnose sturgeon (Acipenser brevirostrum). This anadromous species is generally restricted to the east coast of North America. Although found most often in large tidal rivers, it has also been taken in brackish and salt waters. Shortnose sturgeon are bottom feeders, eating such benthic organisms as sludge-worms, chironomid larvae, small crustaceans and plants (Scott and Crossman, 1973). Historical and recent records for the Delaware River indicate that the species is confined to the main stem between river kilometer 0 and 238; the only known spawning ground is at Scudders Falls (Masnick and Wilson, 1980). Thus, the Tinicum Marsh/Darby Creek area would not be expected to constitute critical habitat for shortnose sturgeon. It is possible, however, that adult and sub-adults would make incidental use of the area (Goodger, 1986).

Other Aquatic Life

As with other aspects of the Tinicum Marsh biological community, non-fish aquatic life is also poorly studied and available information relies solely on anecdotal observations. Blue crabs and fiddler crabs are the only additional species known to use the Tinicum Marsh area.

III. B. 4. Amphibians and Reptiles

The amphibian and reptile species at Tinicum are cataloged in Appendix Table D. According to the Tinicum Master Plan (U.S. FWS, 1983a) eight species of amphibians and eighteen species of reptiles have been reported from the Tinicum area. Several specimens of the diamondback terrapin have been obtained from Darby Creek and from the 145-acre impoundment. These were considered to be released pets, or progeny of pets. However, this species is found regularly, although in small numbers, along the Delaware River at least as far upstream as Chester. Odum (1984) states that the diamondback terrapin is really a brackish and saltwater turtle, but often enters tidal freshwater areas. The specimens from Darby Creek, therefore, may be endemic.

The 145-acre impoundment supports a large population of snapping turtles. Because the omnivorous turtles pose a potential threat to successful waterfowl breeding in the impoundment, refuge officials have occasionally permitted commercial harvesting of snappers. In 1983, 1400 turtles totalling over 7 tons in weight were trapped. The false map turtle is described by Odum (1984) as being "very rare" and introduced in the Tinicum marshes. Turtle harvesting is now prohibited because of contaminants found in samples.

Life histories and habitat requirements of Pennsylvania-listed endangered amphibians and reptiles are provided in the following section on species of concern.

III. B. 5. Birds

Odum et al. (1984) have described the value of freshwater tidal marshes to birds:

> Tidal freshwater wetlands provide a varied habitat for birds. Of the different types of coastal wetlands, tidal freshwater wetlands are among the most structurally diverse. Structural diversity is provided by the broad-leaved plants characteristic of the low marsh, tall grasses of the high marsh, the intermediate canopy provided by the shrub zone, and the high canopy found in tidal freshwater swamps.
>
> Tidal freshwater wetlands harbor a higher diversity of birdlife than structurally simpler wetland types such as salt or brackish water marshes. Low marsh and adjacent exposed mudflats are used by shorebirds and rails. The grasses and sedges characteristic of higher elevations in the marsh are similar to grassland or savanna habitats and support an abundance of seedeating species. Tidal channels and pools provide habitat for wading birds. Waterfowl use the open water areas in addition to the marsh surface itself. Shrubs and trees found in the high marsh and along the upland-marsh ecotone provide habitat for a large number of arboreal birds. These arboreal birds can often be found feeding in or over the marsh proper.

The values of this wetland type to birds are magnified in the case of the Tinicum marshes because of their strategic location on the Atlantic Flyway. Delaware Bay represents a major interchange on the Atlantic Flyway. On their northward flight many migrating birds leave the coast and fly up the Delaware River valley. Similarly, many birds that have summered and nested in northern Canada fly down the Delaware River to the coast. Tinicum Marsh is a convenient stopover near this flyway junction and apparently is more heavily used than similar areas on other sections of the flyway. Because urbanization and agricultural diking along the lower Delaware River have eliminated thousands of acres of former tidelands, Tinicum Marsh and other wetland remnants in the lower Delaware Valley may be used more intensely now than in the past. Over 280 species of birds have been recorded in the Tinicum area (Tinicum N.E.C., 1985). Bird species known to nest at Tinicum are listed in Appendix Table D.

A brief discussion of specific types of birds and their use of tidal freshwater wetlands follows:

Waterfowl

> Few waterfowl breed in tidal freshwater wetlands of the mid- and south Atlantic coasts. Only wood ducks, and to a lesser extent American black ducks and mallards, commonly use these wetlands for breeding habitat. Stotts and Davis (1960) found that 65% of the nests of American black ducks were located in upland areas often hundreds of yards from the nearest water. Only 17% of the nests were in the marsh and these were located on elevated sites above the high-tide

> line. Once the eggs have hatched, the brood moves to the nearest wetland. Although brood rearing may occur in a number of habitats, it seems that sedge, cattail, and bulrush marshes are favored (Bellrose, 1976). Availability of cover is the most important criterion for brood-rearing areas since ducklings feed on aquatic insects, not vegetation. (Odum et al., 1984).

Nine species of waterfowl have been observed to nest in the Tinicum area. These include approximately 50 mallards, 20-30 black ducks, and 20 Canada geese. Several nests of pied-billed grebes, shovelers, green-winged and blue-winged teal and wood duck have been found. Only one pintail nest has been located (U.S. FWS, 1983a).

Schwartz (1976) documented a number of interesting observations about bird use of the Center's habitats in his study comparing waterfowl, waterbird and shorebird use of the large impoundment with that of the tidal marsh. Waterfowl (especially mallards, black ducks and Canada geese) appeared to use the tidal marsh and impoundment equally during the summer when vegetative diversity in the marsh is high, but they preferred the impoundment during the barren winter. Waterbirds (herons, egrets, gallinules and bitterns) spent more time in the impoundment than in the tidal marsh. Shorebirds (e.g., killdeer, sandpipers, etc.), however, used the tidal marsh more than the impoundment, feeding in the tidal mud flats.

Wading Birds, Rails and Shorebirds

Odum et al's (1984) description of the habitat and food of these birds is further testimony to the ecological value of wetlands such as Tinicum marsh.

> Fifteen species of herons, egrets, ibises, and bitterns [and 35 species of rails and shorebirds] make up this familiar group of marsh birds. These birds make heavy use of the tidal channels, creeks, and ponds found throughout the low and high marshes. They are also found commonly along the banks of watercourses in tidal swamps and salt marshes.
>
> Fish, from small minnows and silversides to catfish, are prefered prey. Other food items include: crayfish, snails, frogs, lizards, and snakes. Occasionally herons and bitterns consume some warm-blooded prey items such as mice and shrews or even young birds.
>
> Green herons and bitterns nest in tidal freshwater marshes. Green herons build nests of sticks in vegetation low to the ground. Bitterns use sedges and grasses to construct nests low over the water. Breeding colonies of herons use a wide variety of trees and shrubs to support

their nests, and sometimes nest on the ground in dense vegetation. The actual location of the nest site is not critical to these birds as they will fly long distances between heronry and feeding grounds (Kushlan 1977; Maxwell and Kale, 1977). During the summer when these waders are young, their fish prey is most abundant within the marsh. The food which the waders gather from tidal freshwater marshes is undoubtedly important to the maintenance of adults and to the growth and survival of their young.

At least 35 species of shorebirds and rails make extensive seasonal use of the high marsh, low marsh, and especially of the associated tidal flats. Hawkins and Leck (1977) observed killdeer, spotted sandpiper, sora rail, and American woodcock in tidal freshwater marshes in New Jersey during the summer. The woodcock was confirmed as nesting in the wildrice/arrow-arum zone of this wetland.

Primary food of these species include freshwater worms, crayfish, snails, and mollusks. In fact, they will eat almost any invertebrate organisms found in the upper few centimeters of the sediment surface (Baker and Baker, 1973; Schneider, 1978). During their fall migrations, surprising numbers of shorebirds make extensive use of the seeds of marsh plants such as wildrice, three-square, halberdleaf tearthumb, dotted smartweed, redroot sedge, rice cutgrass, and many other marsh plants. Many shorebirds are present only during the fall migration when the seed supply is maximum. An interesting note is the utilization of wildrice by rails. During autumn migration large numbers of soras (and possibly other rails) gather to feed on the seeds of this abundant marsh plant (Webster, 1964; Meanley, 1965). During the month-long period in the fall when wildrice seeds are ripening, they may comprise 90% of the sora's diet (Webster, 1964).

A number of the species discussed above nest in Tinicum. Interestingly, a stand of sweet gum and pin oak trees on the southern shore of the large impoundment supports a productive heron and egret rookery.

A number of birds known to nest at Tinicum are considered "Species of Special Emphasis" by the Northeast Region of the FWS. A more detailed discussion of these species is provided in a later chapter.

III.B.6. Mammals

There has never been an intensive survey of the mammals of Tinicum but Frederick A. Ulmer, Jr., Curator Emeritus of Mammals, Philadelphia Zoological Garden, has provided information based on occasional collections made in the marsh about 1940 (Appendix Table F). At that time, the meadow were common in the tidal wetlands and in upland old fields. White-footed mice were not found in the tidal wetlands, but they were frequent on the dikes, in old fields, and in other upland habitats. Short-tail shrews ranged as widely as meadow voles, from the tidal wetlands to various upland sites. Meadow jumping mice were listed as common in a checklist that formerly was maintained at the City Wildlife Preserve. The eastern mole also was listed as common, and a few tunnels made by moles were seen during 1968 at several places in the upland sections of the Tinicum area. Cottontails now are common on the dikes and in old fields around the marsh. They were present during the 1930's, but probably were not as abundant when Eastwick was densely populated and the farms in Folcroft and Essington were being cropped. The Pennsylvania Game Commission is reported to have released cottontails in the Tinicum area about 1960. Gray squirrels are also common (Tinicum N.E.C., 1985). River otters were sighted in the area of the marsh in 1969, and an unconfirmed otter sighting was reported in 1985 (Nugent, 1986). Norway rats also occur at Tinicum.

Rice rats were reported to nest in the marsh between Long Hook Creek and Darby Creek in 1916 (McCormick, 1970). In 1984, biologists with the Pennsylvania Natural Diversity Index visited the Center to determine whether the species still existed at Tinicum. Based on trapping and visual observations, the researchers concluded that rice rats are no longer present and that the habitat is poor for this particular species (the tidal fluctuations are too great and thick stands of grass are not found in the higher sections of the marsh) (Tinicum N.E.C., 1985).

The current white-tailed deer herd at the Center numbers 4-7 animals (Tinicum TNEC, 1985). Odum (1984) notes that this species uses freshwater tidal marshes to feed on the leaves and stems of wild rice, cattails and other wetland plants.

Muskrats have been known to inhabit the region since its earliest settlement. Muskrats still are common residents of the impounded and tidal wetlands; in 1983 they were estimated to number 250 animals (Tinicum N.E.C. 1983). McCormick and Somes (1982; cited in Odum 1984) indicate that muskrats along the Atlantic coast prefer freshwater tidal marshes dominated by sweetflag, arrow-arum, and wild rice. They are known to feed extensively on the "shoots, roots, and rhizomes of three-squares, cattail, sweetflag, arrow-arum, and other marsh plants," but the "leaves of marsh plants are seldom, if ever, consumed" (Odum et al. 1984, pp. 82-83). Lodge-building materials for Tinicum muskrats has been described as consisting of cattail, common reed, and purple loosestrife (Tinicum N.E.C., 1983).

III. C. Species of Concern

The FWS, through its seven Regional offices, is currently engaged in a planning effort called "Regional Resource Planning" (RRP). "Species of Special Emphasis" addressed in FWS's Region 5 (Northeast Region, which includes Pennsylvania) Regional Resource Plans are chosen according to criteria that narrow the list of species of highest interest based on biological, political, social and economic concerns. The selection criteria also take into account legal/administrative responsibilities, threatened and endangered status, population trends, habitat trends, ecological values, human/species conflicts, public demand/use, and data availability.

The following species, known to live and breed at the Tinicum National Environmental Center, are identified among Region 5's Species of Special Emphasis: wood duck, black duck, American woodcock, snowy egret, black-crowned night heron, and great egret. One of the primary reasons each of these birds has become a cause of concern is habitat loss. Each of these species requires wetland habitats for feeding, cover, breeding and nesting. Habitat alteration that has already occurred, and increasing development pressures on remaining wetland areas significantly increase the importance of protected wetland areas such as Tinicum Marsh, to the continued survival of these species.

A brief description of the pertinent aspects of these species' life histories is presented below:

Wood Duck (*Aix sponsa*)

Nesting Habitat: Wood ducks generally return to the same area to breed every year. They are cavity nesters, selecting a nesting site adjacent to water, or (rarely) more than a mile away from water.
Brood Habitat: Overhanging woody vegetation (e.g., willows, buttonbush) or emergent aquatic plants such as water lilies are important cover for ducklings .
Food: Ducklings feed on a variety of animal life, especially insects such as mayfly and dragonfly nymphs; even fish may be consumed. Their diet gradually changes to vegetative matter as they grow older, eventually including acorns, mulberries, wild grapes, and the seeds of buttonbush, arrow arum, and bur-reed.
(Bellrose, 1976).

Black Duck (*Anas rubripes*)

Nesting Habitat: Reaches highest breeding density in coastal marshes. nest sites are located in a variety of habitat types, from marshes to upland areas. Dikes and muskrat houses have been used by black ducks in Lake Erie marshes.
Brood Habitat: Varied: "sedge, cattail, and bulrush marshes; beaver ponds; alder-fringed streams; and swamp loosestrife bogs."
Food: Animal life (especially in winter) such as mussels and snails; seeds of wild rice, bur-reed, pickerel weed, smartweed, etc.
(Bellrose, 1976)

American woodcock (*Philohela minor*)

Nesting Habitat: Usually in wooded swamps, brushy corners of pastures, or in underbrush or tall weeds at the edge of a wooded area.

Food: Almost entirely animal life, most of which consists of earthworms, but many other insects are also consumed. Occasionally, salamanders, frogs, snails, and plant berries and seeds. Have been known to eat more than their own weight in earthworms in 24 hours.
(Terres, 1982)

Snowy Egret (*Egretta thula*)

Nesting Habitat: Nests singly or in colonies with other herons; can nest on the ground but usually 5 to 10 feet up in trees and shrubs, up to 30 feet high in trees.
Food: Small fish, frogs, snakes, fiddler crabs, crayfish, grasshoppers, aquatic insects. Uses one foot to stir the bottom substrate to bring prey into view.
(Terres, 1982)

Black-crowned Night Heron (*Nycticorax nycticorax*)

Nesting Habitat: Nests in colonies in many kinds of habitat ranging from stands of *Phragmites* to tall trees in urban parks.
Food: Mostly fish (gizzard shad, herring, suckers, pickerel, eels) as well as frogs, tadpoles, salamanders, crayfish, blue crabs, fiddler crabs, dragonflies and their nymphs. May even eat young of other birds.
(Terres, 1982)

Great Egret (*Casmerodius albus*)

Nesting Habitat: In colonies in wooded swamps, or trees such as willows near water, about 20-40 feet high. Sometimes in cattails only 1-4 feet above water.
Food: Fish, frogs, salamanders, snakes, crayfish, mice, aquatic insects, grasshoppers, moths, etc.
(Terres, 1982)

The Tinicum marshes are also home to several species of reptiles and amphibians designated as "Species of Special Concern" by the Pennsylvania Biological Survey.

Southern or Coastal Plain Leopard Frog (*Rana utricularia*)

Breeding: Begins in early March and lasts through April, but can begin in February depending upon temperature. Eggs are laid in shallow water, usually attached to aquatic vegetation at or near the water surface.
Food: Tadpoles - algae, decaying plant debris, some aquatic invertebrates. Adults - a wide variety of terrestrial and aquatic insects.
(McCoy, 1985)

Red-bellied Turtle (*Pseudemys rubriventris*)

Breeding: Nesting takes place in June; nest is dug in sandy clay or loam, usually in full sunlight.

Food: Mostly vegetarian, feeding on common aquatic plants such as *Sagittaria*. May also eat crayfish, snails and tadpoles.
(McCoy, 1985)

Bog Turtle (*Clemmys muhlenbergii*)

Breeding: Eggs are laid in June or July in sedge tussocks or under sphagnum moss.
Food: Omnivorous; plant foods include filamentous algae, berries, and plant seeds (*Potamogeton* spp. and *Carex* spp.), but insects represent the major portion of its diet. Also consumes snails, slugs, earthworms and carrion.
(McCoy, 1985)

Eastern Mud Turtle (*Kinosternon subrubrum subrubrum*)

Breeding: Nesting occurs from June through August in sandy, loamy soils near water, in open ground but often under piles of vegetation, logs or boards.
Food: Insects, aquatic invertebrates, amphibians, carrion and aquatic vegetation.
(McCoy, 1985)

III. D. ECOLOGICAL RELATIONSHIPS

From the preceding descriptions of Tinicum's flora and fauna, it is evident that a tidal freshwater marsh supports a unique, diverse assemblage of plants and animals. The geohydrology, soils, hydrology, and other physical components described in the previous sections provide the conditions necessary to support the marsh ecosystem. The various forms of life are interdependent on a complex series of ecological relationships commonly known as a food web. In turn, the delicate balance of the food web depends on the quality of the physical substrates of the system. The pollutants which exist in the Darby Creek watershed have the potential to upset the balance of the food web and thus impair the health and functions of the Tinicum Marsh ecosystem. Figure 6 illustrates some of the complex food pathways that would be expected to occur in the Tinicum Marsh ecosystem. Measurements of productivity and energy transfer through the food chain are not available.

The plant communities present at Tinicum Marsh can be broadly characterized into groups consisting of 1) broad-leaved emergent perrenial macrophytes, 2) herbaceous annuals, 3) annual and perenial sedges, rushes, and grasses, 4) grasslike plants or shrubform herbs, 5) hydrophytic shrubs, 6) deciduous forest, and 7) aquatic vascular plants and phytoplankton. Species density in the marsh is high, and primary productivity estimates are expected to be great. No recent data are available although historical studies have estimated peak standing crop in Tinicum to range from 523 g/m^2 for

Figure 6. Simplified diagram of possible food web at Tinicum Marsh. Not all possible food pathways are shown. Adapted from Odum et al. 1984 and Gosselink, 1980.

Notations:

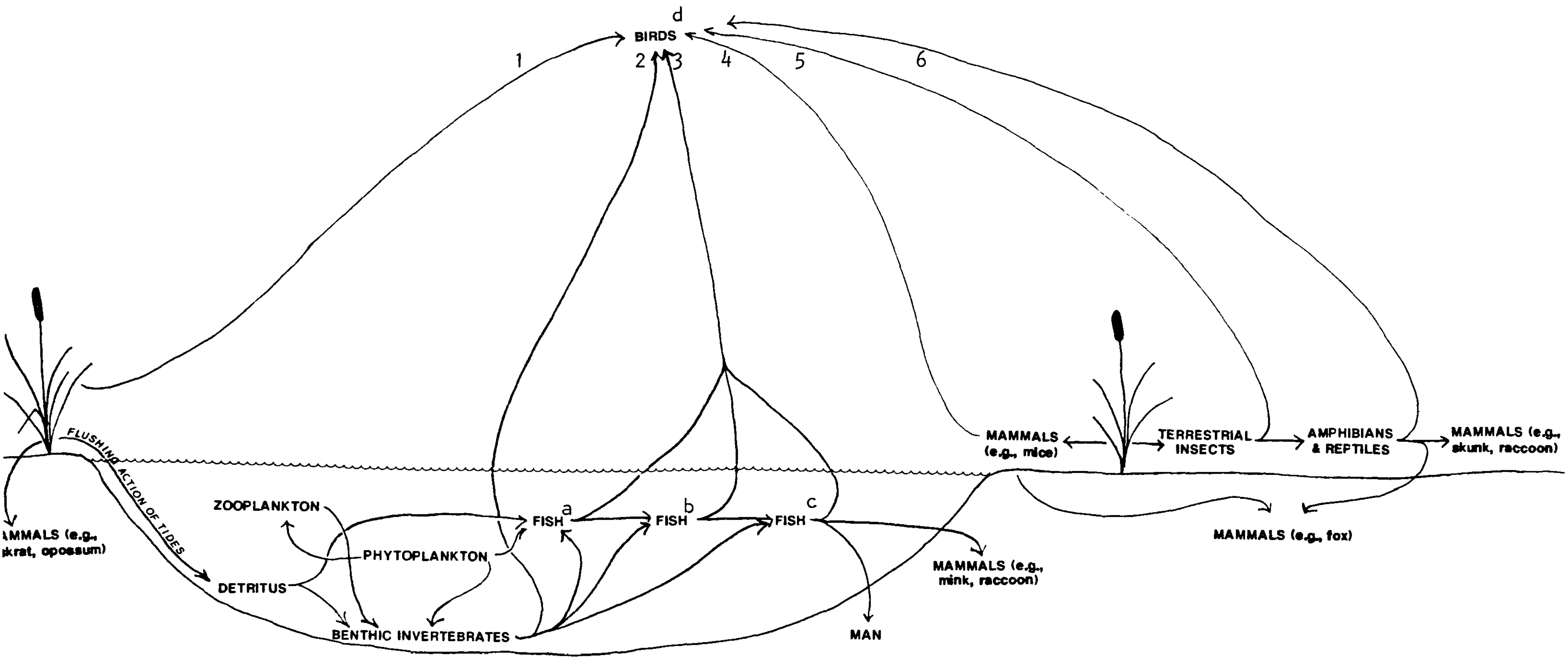
[a]Herbivorous and detritus-feeding fish include carp, minnows, shiners, mummichog, bluegill, black crappie, and adult gizzard shad.

[b]First-level carnivore fish include American eel, blueback herring, alewife, American shad, carp, white sucker, brown bullhead, white perch, striped bass, pumpkinseed, bluegill, largemouth bass, and yellow perch.

[c]Second-level carnivore fish include American eel, American shad, redfin pickerel, fallfish, white catfish, brown bullhead, white perch, striped bass, pumpkinseed, smallmouth bass, largemouth bass, white crappie, black crappie, yellow perch, and hogchoker.

[d]Many bird species would be found in each of the food pathways shown. For example, the following "species of concern" would use the food sources designated in the food web diagram:

1 Black duck, wood duck
2 Great egret, snowy egret, black-crowned night heron, black duck, wood duck
3 Snowy egret, great egret, black-crowned nigh heron
4 Great egret
5 Great egret, snowy egret, black-crowned night heron, woodcock
6 Great egret, snowy egret, black-crowned night heron



BIRDS
d
1
2
3
4
5
6
FLUSHING ACTION OF TIDES
ZOOPLANKTON
PHYTOPLANKTON
DETRITUS
BENTHIC INVERTEBRATES
FISH
a
FISH
b
FISH
c
MAN
MAMMALS (e.g., mink, raccoon)
MAMMALS (e.g., mice)
TERRESTRIAL INSECTS
AMPHIBIANS & REPTILES
MAMMALS (e.g., skunk, raccoon)
MAMMALS (e.g., fox)

smartweed to 1373 g/m^2 for purple loosestrife (McCormick, 1970). The structure of the aquatic and terrestrial vegetation also provides a physical habitat for aquatic life and wildlife. Tidal freshwater wetlands are believed to be primarily detritus-based ecosystems (Odum et al., 1984). A large fraction of the dead plant material may be decomposed by microbial populations while a significant portion of detritus is flushed into the water by tidal action becoming food for zooplankton, benthic invertebrates, insects, and fishes. Plants in the low marsh are expected to decompose more rapidly than those in the higher marsh (Odum, 1978).

The invertebrate community is poorly studied at Tinicum; however tubicifid worms, leeches, physa, mosquito larvae, midges, and freshwater clams have been documented in the Marsh. These species are primarily detritus feeders and are an important food source for fish. As illustrated in Figure 6, the benthic invertebrates are also consumed by birds. These invertebrates represent the primary consumers in the food chain.

The fish community at Tinicum can be broadly characterized as freshwater, oligohaline, and anadromous populations. The most common fish (carp, bullheads, white suckers, and minnows) are freshwater species and may consume vegetation, benthic invertebrates, and insects. Anadromous species in the marsh are rare and primarily consume vegetation and invertebrates although some consumption of smaller fish may occur. Game fish at Tinicum include white perch, carp, catfish, crappies, sunfish, and eels; these species represent both primary and secondary consumers in the food chain.

The diversity of the bird community at Tinicum is quite high and the marsh is used extensively for breeding and nesting. The majority of birds using freshwater wetlands are believed to be omnivores (Simpson et al., 1983). The avian species of concern are both omnivores (wood duck and black duck) and carnivores (American woodcock, snowy egret, blackcrowned night heron, and great egret).

The role of reptiles, amphibians, and mammals in the tidal marsh ecosystem is not well known. The amphibian and reptile species, including the species of concern at Tinicum, are primary or secondary carnivores. Mammals at Tinicum are primarily herbivores (cottontail, muskrats, deer, and mice) although omnivorous species are also common (Norway rats and shrews). Humans are included in the food chain as a consumer of fish, turtles, crabs, and ducks.

IV. ENVIRONMENTAL QUALITY

IV. A. Potential Contaminant Sources

Because the Center is located in a major urban area, potential pollutant sources are both diverse and numerous. Urban stormwater runoff to streams and vehicular emissions in the I-95 corridor represent potential nonpoint pollutant sources. Point sources such as wastewater treatment plants, industrial complexes, and power plants are found within a 3-mile radius of the Center. At one time, three sewage treatment plants discharged into the marsh. One Superfund site, Havertown PCP, is located in the Darby Creek watershed, and Clearview Landfill, located approximately one mile upstream of Tinicum, is suspected of leaching hazardous pollutants into the drainage basin. Contaminants may be transported to the Center through direct discharges to surface waters, stormwater runoff, or by discharge to storm sewers. Examples of potential sources in the Tinicum area are junkyards, electroplating operations, chemical processing industries, incinerators, and historical dumpsites. Sediments contaminated through historical spills or illegal discharges also represent a potential pollutant source. Since October 1984, ten spills to Darby Creek watershed have been reported to EPA's Regional Response Center. Three spills of oil, two spills of acids, one spill of raw sewage, and four spills of unknown substances were reported.

Within the Center itself, the Folcroft Landfill and Folcroft Landfill annex are suspected of being repositories for hazardous pollutants. Previous disposal practices from the closed Delaware County Incinerator, the Delaware County Joint Sewer Authority Waste Treatment Plant, and the Muckinipattis Wastewater Treatment Plant may have had a significant impact on environmental quality. Several wetlands in the Center have been filled with spoils from construction projects and dredging operations.

More detailed information on these potential pollutant sources is presented in the following sections. Because of the absence of information on loading rates, the relative contribution of non-point sources and point sources to ambient water quality levels could not be determined. Appendix Table G contains a listing of air toxicant point sources and potential point sources of water pollutants regulated under EPA's NPDES program.

Point source loadings of air toxicants are only available for sources within the city limits of Philadelphia. There are 26 air toxicant sources in Philadelphia which are within a 3 mile radius of Tinicum. Air toxicants emitted include: lead, chromium, benzene, chlorinated hydrocarbons, and aromatic hydrocarbons. Because of the lack of data on ambient air toxicant levels and the absence of information on air toxicants emissions in Delaware County, air toxicant levels could not be evaluated. Recent studies in Philadelphia (Haemisigger, 1986) also indicate that health risks from water sources are significantly greater than those from air sources.

Pollutant sources to the Darby Creek watershed include non-point source runoff and point source discharges. Approximately 21% of the Darby Creek watershed is located in Philadelphia County and has combined storm and sanitary sewers that discharge to Cobbs and Darby Creeks. The remaining

79% of the Darby Creek watershed has separate storm and sanitary sewers. No information on pollutant loads from storm sewers is available for the Darby Creek watershed. Annual loadings (Hagerman, 1978) from the combined sewers for Cobbs Creek in Philadelphia County have been estimated for BOD (684,000 lbs), NO_3 (122,000 lbs), org-N (47,800 lbs), NO_2 (26,700 lbs), and NH_3 (21,000 lbs). No data are available for other streams or other pollutants in the Darby Creek watershed.

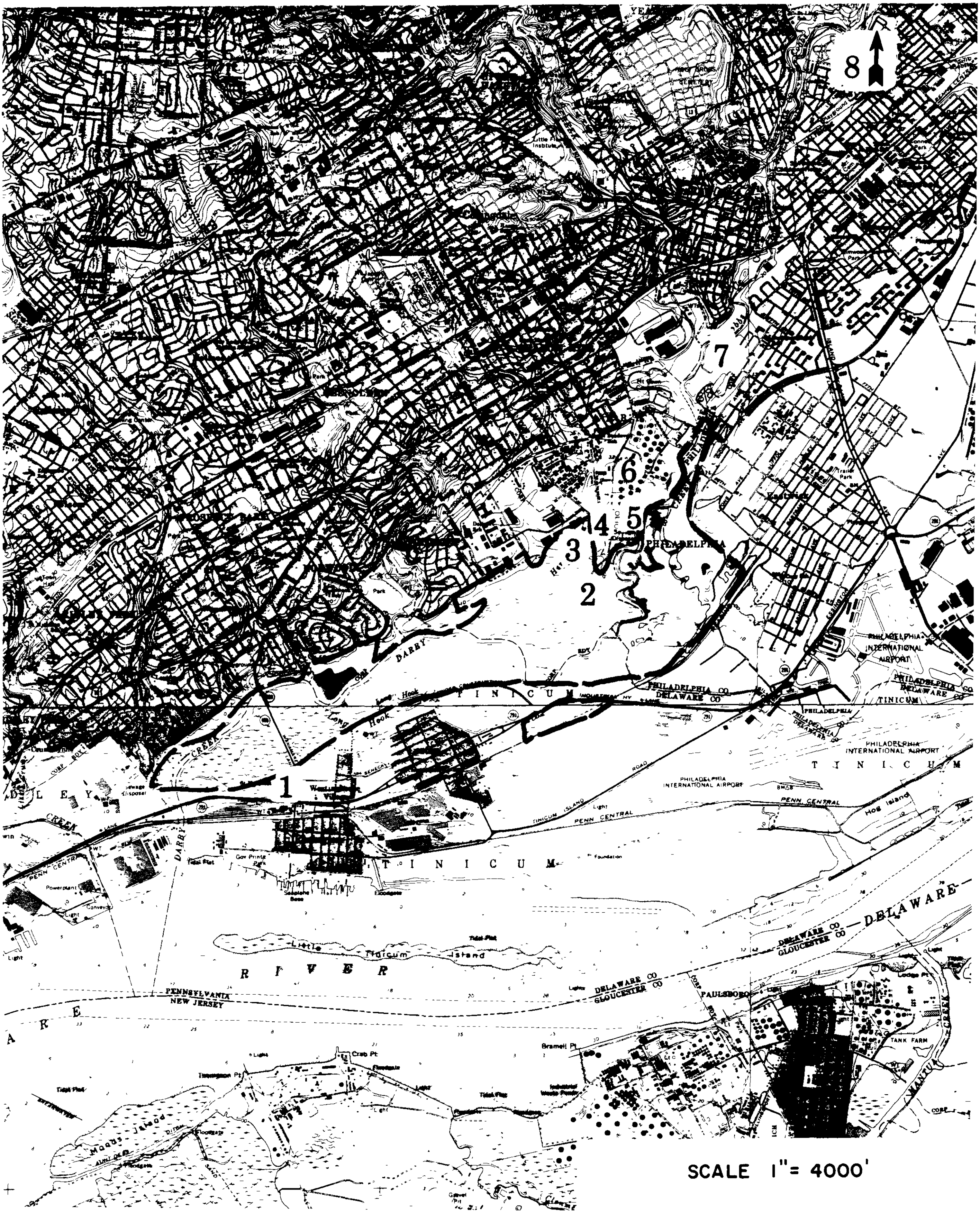
Urban non-point source loads of lead, cadmium, chromium, nickel, and copper have been investigated for other watersheds in the Philadelphia area with separate sewers. Annual metal loadings were calculated as lbs/acre for each urban land use category (Richards, 1977). By using these loadings and values of urban land use acreage in the Darby Creek basin (Chernik, 1979), the following estimates of metal loadings from urban sources to the Darby Creek watershed were derived: Lead - 1430 lbs/year, Cadmium - 329 lbs/year, Chromium - 356 lbs/year, Nickel - 539 lbs/year, and Copper - 56 lbs/year. These loads correspond to the following annual loading per acre of urban land: Lead - 0.051 lbs/acre, Cadmium - 0.012 lbs/acre, Chromium - 0.013 lbs/acre, Nickel - 0.019 lbs/acre, and Copper - 0.002 lbs/acre. It is stressed that these values are estimates and may differ from actual conditions because of differences in land use categories used in the two reports, site specific variation in industry, and the contribution of metal loads from combined sewers. However, these values indicate that nonpoint source metal contributions to the watershed may be important for the urban area in the Darby Creek watershed. Future studies should refine estimates of metal loadings from nonpoint sources and include water column sampling under various flow conditions to identify the importance of non-point source loads.

Major NPDES permits were evaluated for historical permit compliance. The following discussion identifies potential pollutant loadings from 1) the three sites within the watershed which have been investigated by EPA's Superfund program (Havertown PCP, Clearview Landfill, and Folcroft Landfill) 2) major NPDES dischargers which have been in noncompliance with their permit, and 3) two inoperating sites (Delaware County Incinerator and Delaware County Joint Sewer Authority) which were identified through site inspections and historical imagery analysis as potential pollutant sources. It was not possible to review PA DER's compliance records and site investigation reports for all other dischargers. A full evaluation of all sources should be included in future studies.

Tinicum Township Wastewater Treatment Plant, Essington (Figure 7, Site 1)

Tinicum WWTP is permitted under NPDES to discharge into Darby Creek at a rate of 1.4 MGD. A review of the monitoring records of the plant indicates that the plant has a history of noncompliance with BOD limits and high discharges of copper. The facility also has raw sewage overflow at Jensen Avenue and Front Street which discharges to the Delaware River. The bypass occurred 66 times during 1983 and each resulted in the discharge of 400,000 gallons of raw sewage into the river. A Municipal Compliance Plan has been required of the facility by DER to correct these violations and the copper discharges.

FIGURE 7. Potential contaminant sources to Tinicum NEC.



Sludge disposal also occurs on site. In 1980, EP toxicity tests on the sludge indicated that contaminants were below detection levels (Kagle, 1986).

Folcroft Landfill and Folcroft Landfill Annex, Tinicum (Figure 7, Sites 2 and 3)

Folcroft Landfill is located on the northeastern edge of the Center and is bordered by Darby Creek and Thoroughfare Creek on the east, Hermesprota Creek on the west, and the closed Delaware County Incinerator and Delaware County Sewage Treatment plant on the north. Although historical photographic analysis indicates dumping in the area as early as 1953, the site did not officially open until 1959. By 1958, the landfill covered about 2 acres of marsh area. The dump continued expanding until a total of 46 acres of wetland were filled, and directly abutted Darby Creek, Thoroughfare Creek, and Hermesprota Creek. Sixteen acres of wetland were also filled in an area directly west of Folcroft Landfill known as the Folcroft annex.

The Folcroft property was owned by Mr. Wilbur C. Henderson, Mr. Wilbur C. Henderson, Jr., and Folcroft Landfill Corporation and leased to Tri-County Hauling in 1961 (U.S. EPA, 1985). The annex was owned by Henderson-Columbia Corporation and was subsequently sold to the Department of Interior and the Philadelphia Electric Company. Disposal records for the landfill are not available; however, the site operated under DER Solid Waste Permit Number 10053 and was permitted to accept municipal, demolition, and hospital wastes.

PA DER inspection reports indicate that the landfill was not used solely for municipal dumping, nor was the landfill operating as required under the solid waste permit. A 1969 inspection report indicated that the landfill received wastes from the Philadelphia Navy Yard, Boeing Vertol, American Viscose, incinerator ash from the neighboring incinerators, sewage sludge, industrial waste drums, and oil soaked materials (Emerich, 1969). The Waste Site Disposal Directory indicates that the landfill may have been used by the E. I. Dupont Co. and the Rohm and Haas Co. between 1967 and 1973.

In 1970, the DER inspection reports chronicled that "a mix of soil and refuse is right up to the edge of Darby Creek." Noted on site were piles of oil-soaked industrial waste, pools of leachate flowing directly into Darby Creek, and six drums of industrial waste (Emerich, 1970). The waste overflowing into the marsh along the southeast corner of the landfill was described as oil-soaked earth-like material of various colors of green, lavender, white and red (Emerich, 1970). In 1972, 55-gallon leaking drums were found on the site labeled methyl ethyl ketone. Twenty other unlabeled drums of liquid waste were present on the site (Beitler, 1972). In 1973, drums were again found on the site and were labeled methyl salicylate, rholex, epoxy, and dulux skins (Beitler, 1973). Numerous leachate seeps were identified and the site was noted as having a "high" potential for contaminating groundwater and surface water.

In 1973 the landfill was closed for permit violations and improper management including direct dumping into Darby Creek. Closure operations began in 1974 with orders to regrade the landfill to eliminate the excessively steep slopes, eliminate fires, and cover refuse with fill. Fill was allegedly obtained from dredge spoils, I-95 construction sites, and a construction site at the SunOil Co. refinery in Marcus Hook (Environmental Evaluation, 1979). Cover material averaged 2 to 4 feet thick with depths in some locations ranging up to 10 feet. The area was reseeded with rye and fescue but good vegetative cover was not established on the eastern half of the site. Site inspection closure reports note the lack of vegetation and also the absence of leachate seeps. Cover material was described as well drained sandy loam. The landfill reached heights of about 50 feet above surrounding land and was sloped to encourage runoff.

On October 29, 1980, a site inspection was conducted for EPA by Ecology and Environment. Field observers noted smoke emanting from an underground fire and one major leachate flow with brown stain residue observed along Hermesprota Creek and Darby and Thoroughfare Creeks. A total of 12 environmental samples were collected (one leachate, four soil, and seven water) and analyzed for metals, organic compounds, and pesticides.

In July 1983, a fire occurred at the landfill annex and at that time several drums were uncovered. Soil, sediment, water, and air samples were taken to determine if hazardous materials were being released from the site. Eight samples were taken from the drums and classified in terms of pH, flammability, reactivity, corrosivity, and pesticide content. Two drum samples were also screened for metal content (As, Ba, Cd, Cr, Pb, Hg, Se, and Ag). The remaining samples were screened for 44 contaminants. Results of the ambient air samples taken during the fire are not considered representative of typical conditions and have not been included in this evaluation.

In September 1983, EPA conducted another sampling trip to the Folcroft Landfill. During the site visit four sediment samples and five surface water samples were collected and analyzed for priority pollutants.

In February 1986, EPA's Environmental Services Division collected and analyzed four samples from the Folcroft Landfill area to screen for aquatic toxicity. Samples were taken from leachate at the southeast corner of Folcroft landfill, in Darby Creek adjacent to the leachate, from leachate at the southern edge of the Folcroft annex, and in Hermesprota Creek between the landfill and the annex. Samples were analyzed for chronic toxicity to Ceriodaphnia dubia and Pimephales promelas. The samples were also screened for selected metal content. Numerous leachate seeps were observed flowing from the annex directly into the adjacent tidal flat. Seeps from the Folcroft Landfill were observed along the southeast and northwest edges of the landfill adjacent to Hermesprota Creek and Thoroughfare Creek.

Sampling results from the inspections in 1980, 1983, and 1986 are summarized in Tables 4 through 6. A quality assurance usability review of the 1980 data was conducted by EPA, Environmental Services Division, Annapolis CRL. The review indicates that a lack of supporting documentation and discrepancies in paperwork compromise the inorganic and pesticide data. Organics data are also compromised by blank contamination and exceedance of quality control criteria such as sample holding time and poor quality standards (Krantz, 1986). A usability review of the data collected in the September, 1983 investigation was performed by the NUS Corporation (Sloboda, 1986). As with the previous sampling, the 1983 analytical results are seriously compromised by poor quality data. Consequently, many data are not presented in the Tables and the results of a number of samples are qualified as to their interpretive value.

Table 4 lists the analytical results for the drum and soil samples taken from the annex area during the fire. All drum samples were non-halogenated and non-hazardous for reactivity. Two samples were ignitable. One drum contained polynuclear aromatic hydrocarbons (PAH's) at ppt levels. Barium, chromium, lead, mercury, and silver were detected in two drum samples ranging in levels from 1 ppb to 12.3 ppm. Metals were also detected in soil samples at similar levels, however PAH levels were all less than 10 ppm. Pesticide levels in all samples were less than detection limits (10 ppm).

Usable results from the onsite samples taken during the 1980 and 1983 inspections are summarized in Table 5. The only organic compounds which could not be attributed to blank contamination were found in the leachate sample. Methylene chloride, vinyl chloride, chloroethane, and chlorobenzene were tentatively identified in this sample. Runoff also contained unusually high levels of cyanide (4.5 ppm). Lead (54 ppb) and cadmium (0.26 ppb) were also present. Numerous metals were found in the ponded water and sediment including arsenic, cadmium, lead, aluminum, chromium, barium, cobalt, copper, iron, nickel, manganese, zinc, and vanadium. Aluminum and iron levels (144 ppm and 247 ppm) in the water and in the sediment (6.75 ppt and 11.2 ppt) are notably high. Vanadium, chromium, and lead also showed high sediment concentrations. As mentioned previously, results for all other compounds such as pesticides and chlorinated hydrocarbons were unacceptable for quality assurance reasons.

Table 4. Priority Pollutant Samples taken from Folcroft Landfill annex. July 16 and 18, 1983. Samples 2, 3, 7, 8 and 9 are taken from drums. Samples S1 and S2 are taken from soil. All compounds not listed were not detected; detection levels ranged from 10 ppm to 100 ppm. All data are in ppm. NA = not analyzed.

Compound	2	3	7&8	9	S1	S2
Arsenic	<.15	<.15	NA	NA	<.005	<.005
Barium	1.0	2.9	NA	NA	1.48	0.28
Cadium	<.1	0.1	NA	NA	0.02	0.01
Chromium	0.15	0.6	NA	NA	0.09	0.01
Lead	3.1	12.3	NA	NA	0.53	3.08
Mercury	0.005	0.008	NA	NA	0.001	0.0015
Selenium	<.15	<.15	NA	NA	<.005	<.005
Silver	0.70	12.0	NA	NA	0.02	<.01
Naphthalene	<10	<10	<10	8000	<10	<10
acenaphthene	<10	<10	<10	3870	<10	<10
fluorene	<10	<10	<10	7528	<10	<10
phenanthrene	<10	<10	<10	8000	<10	<10
fluoranthene	<10	<10	<10	8244	<10	<10
pyrene	<10	<10	<10	12713	<10	<10
chrysene	<10	<10	<10	25085	<10	<10
benzofluoranthene	<10	<10	<10	11794	<10	<10
benzo(a)pyrene	<10	<10	<10	11371	<10	<10
indenopyrene	<10	<10	<10	2512	<10	<10
benzopyrelene	<10	<10	<10	1636	<10	<10

Table 5. Priority pollutant samples taken from Folcroft Landfill and Folcroft Landfill annex. Locations: (1) ponded water, Folcroft Landfill, 1985, (2) ponded sediment, Folcroft Landfill, 1985 (3) runoff Landfill annex, 1980. NA = not analyzed, T = tentative identification, ND = not detected.

Compound	1(ppm)	2(ppm)	3(ppb)
methylene chloride	NA	NA	T
vinyl chloride	NA	NA	T
chloroethane	NA	NA	T
chlorobenzene	NA	NA	T
As	0.057	2.7	NA
Hg	ND	NA	NA
Cd	ND	13	0.26
Pb	0.085	1260	54
CN	ND	400	4560
Al	144	6750	NA
Cr	0.340	17.8	NA
Ba	1.57	66	NA
Co	0.088	4.7	NA
Cu	0.479	25.2	NA
Fe	247	11200	NA
Ni	0.214	0.5	NA
Mn	5.84	177	NA
Zn	2.60	125	NA
Va	0.359	17.2	NA
Ag	ND	ND	NA

Table 6a summarizes the chronic toxicity data collected in February, 1986. Undiluted leachate samples from both the Folcroft Landfill and the Landfill annex were acutely toxic to fathead minnows. The LC(50) to fathead minnows for the leachates ranged from 22.1% at the Folcroft Landfill to 86.4% at the Landfill annex. Ceriodaphnia tests indicate an EC(50) of 12.7% for the Folcroft Landfill leachate and 40.5% for the Landfill annex leachate. Microtox screening of both samples indicated no toxicity to bacteria. No effects were observed on Ceriodaphnia reproduction from the ambient samples. Only slight mortality to fathead minnows was observed from Darby Creek. Based on these results, the samples are characterized as follows: Folcroft Landfill leachate - moderate to high toxicity, Folcroft Landfill annex leachate - moderate toxicity, Darby Creek - no toxicity, and Hermesprota Creek - no toxicity.

Analytical results from the toxicity screen are summarized in Table 6b. Leachate from the Folcroft Landfill indicates that the landfill is a source of copper, iron, lead, manganese, nickel, and zinc to Darby Creek. Leachate from the Folcroft Landfill annex shows elevated levels of iron, lead, and zinc. The high toxicity observed for the annex leachate suggests that other toxicants besides those anlyzed are present in the leachate.

Table 6a. Chronic Toxicity Data Summary from Folcroft landfill and Folcroft landfill annex leachate samples. Samples were analyzed by EPA Environmental Services Division, Wheeling Field Office, February 1986. Data reported as the LC(50) +/- 1SD and the EC(50) +/- 1SD.

	Pimephales promelas	Ceriodaphnia dubia	Microtox
	LC(50)	EC(50)	EC(50)
Folcroft landfill leachate	22.1% (16.7-30.1%)	12.7%(4.8-25.7%)	none
Folcroft landfill annex leachate	86.4% (54.9-100%)	40.5%(31.3-55.8%)	none

Table 6b. Analytical results from February 1986 sampling for heavy metals at Folcroft landfill. Sampling was conducted at slack ebb tide. All results are in ppb except alkalinity (alk, mg/l), pH (standard units), and dissolved oxygen (DO, mg/l).

Location	pH	DO	Alk.	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn
Hermesprota Creek	-	-	224	<10	<40	<20	2800	8	550	<40	62
Folcroft Landfill annex leachate	7.2	5.2	1064	<10	<40	<20	4250	12	1000	<40	97
Darby Creek	-	-	124	<10	<40	<20	2200	22	710	<40	81
Folcroft Landfill leachate	7.4	7.0	1153	<10	<40	190	3030	200	1220	70	1090

In summary, the review of compliance inspection reports indicates that the Folcroft Landfill had poor operating practices and may have accepted hazardous wastes. Limited on-site samples indicate elevated levels of heavy metals and tentatively identified volatile organic compounds in waste streams. Leachate testing conducted in 1986 showed elevated heavy metals and toxicity to bioassay organisms. Because the landfill is located directly over tidal marsh substrate and because there is no liner or leachate collection system, any contaminants on site are likely to be transported into Tinicum Marsh. Data are inadequate to determine the full range of contaminants present in Folcroft Landfill, the extent of contamination in the landfill, the extent of contamination in all environmental media, and the degree of contaminant transport off-site. Future studies are needed to complete these data gaps. Samples should be taken to identify the extent and degree of contamination in the landfill, the rate of contaminant transport, and the likely transport mechanisms. All samples should be analyzed for a full range of priority pollutants and using detection levels which will allow adequate characterization of environmental risks.

Delaware County Incinerator #2 (Figure 7, Site 4)

The incinerator facility was closed in 1978. Incinerator residue and flyash were disposed on the southern end of the property adjacent to Hermesprota Creek and directly in marsh (now overlain by Folcroft Landfill). Two settling lagoons for quench water also discharged directly into Hermesprota Creek. A portion of Hermesprota Creek was rerouted to provide more area for disposal. The site may have been a significant source of pollutants to the marsh (U.S. EPA, 1984) during operation. The potential for continued contributions to heavy metal levels in Hermesprota Creek from this area should be investigated.

Delaware County Joint Sewer Authority (Figure 7, Site 5)

Primary treatment sludge was disposed in sludge beds up to 10 feet thick alongside Darby Creek. An Administrative Order was issued to the Authority in 1975 for illegal sludge disposal. Numerous seeps flowed directly into the Creek. The plant was closed between 1972-74, and until that time discharged directly into Darby Creek. Sludge deposits are still present at the site and there is a potential for continued seepage into the Creek. Future studies should identify whether this site is still a source of pollutants to Darby Creek.

Gulf Oil Darby Creek Tank Farm, Folcroft (Figure 7, Site 6)

The facility has an NPDES discharge to Darby Creek. Sludge is also disposed on site, and an EP-toxicity test of the sludge indicated non-hazardous conditions (Kagle, 1986). There were infrequent occurrences of phenol NPDES permit violations in 1983 and 1984; however, the site has been in compliance with the NPDES permit for the past year. No additional studies are recommended at this site.

Clearview Landfill (Figure 7, Site 7)

Clearview Landfill is located approximately 1 mile northeast of Tinicum adjacent to Cobbs and Darby Creeks. This 16.5 acre wetland site was filled in the late 1950's. The municipal waste landfill closed in 1973, and in 1984 and 1985 EPA performed site inspections to determine whether the site could qualify for remediation funded by the Superfund program. During the site visit numerous seeps were observed. Because there is no liner, no leachate collection system, and little cover over the landfill, it would be expected that seepage and contaminated on-site runoff would continue to flow into Darby Creek. Sampling of the leachate sediment indicated the presence of a number of polynuclear aromatic hydrocarbons, metals, and PCB's as listed in Table 7.

Iron levels in the sediment were the highest of all the metals at 119 ppm. Chromium (24 ppb), barium (132 ppb), and vanadium (17 ppb) levels are also noteworthy. PCB 1260 was detected on site at concentrations up to 143 ppb. Polynuclear aromatic hydrocarbons including fluoranthene, pyrene, and phenanthrene were detected both on-site and in the leachate sediment. Off-site sediment and water column data associated with Clearview Landfill are discussed in the water quality section.

Table 7. On-site samples taken from the Clearview Landfill area. Leachate sediment sample taken in July, 1983, soil samples taken on September 11, 1983. Sediment data are in ppb; soil data are presented as a range in ppb. Identification: P = positive, T = tenative. DL = detection limit.

	Soil		Sediment	
Compound	Range	DL	Ident.	Conc.
acenapthene	0.1-0.2	1	P	ND
anthracene	0.2-1.0	1	P	<.4
benzo(a)anthracene	0.4-2.0	1	P	1.4
benzo(b)fluoranthene	0.4-2.3	1	P	0.97
benzo(k)fluoranthene	0.4-1.9	1	P	<.80
benzo(a)pyrene	0.9-2.1	1	P	1.1
chrysene	0.4-2.1	1	P	1.3
fluoranthene	1.0-1.5	1	P	2.8
fluorene	0.10.3	1	P	ND
phenanthrene	0.63.7	1	P	1.7
pyrene	0.93.9	1	P	3.1
2,3,7-trimethyloctane	2.0	1	T	ND
2,6,11-dimethylundecane	2.1	1	T	ND
4,6-dimethylundecane	3.6	1	T	ND
2,5,9-trimethyldecane	1.6	1	T	ND
2,7,10-trinethyldodecane	2.8	1	T	ND
decanal	0.6	1	T	ND
PCB 1260	0.31-143	1	T	ND
napthalene	ND	-	T	<.4
chromium	ND	-	T	24.0
barium	ND	-	T	132
copper	ND	-	T	23.0
iron	ND	-	T	11900
manganese	ND	-	T	115
zinc	ND	-	T	140
vanadium	ND	-	T	17.0
arsenic	ND	-	T	8.5
lead	ND	-	T	85

PA DER collects water quality samples annualy to identify whether leachate from Clearview landfill presents an environmental health problem to Darby Creek. This monitoring should be continued. The potential for PCB's at the site to be transported to Tinicum through flushing and sediment transport should be investigated in future studies.

Havertown PCP Site (Figure 7, Site 8)

Havertown PCP site is listed on EPA's National Priority List and is currently under investigation by EPA and PA DER. Havertown PCP is located approximately 17 miles upstream of Tinicum. The site involves the release of pentachlorophenol (PCP) and oil into Naylor's Run, a tributary to Cobbs Creek. Approximately one million gallons of PCP sludge were alledgedly pumped into a shallow well. The subsurface sludge flow is intercepted by a concrete sewer line and is released into Naylor's Run (Massey, 1983). As part of EPA's emergency response actions, filter fences were installed in Naylor's Run to prohibit and reduce the release of the PCP/oil in downstream areas of Naylor's Run.

An assessment of water quality conditions in Naylor's Run by EPA's Emergency Response Team indicated that conditions in the stream were toxic to aquatic life. Approximately 1/2 mile downstream of the sewer line, the stream was devoid of aquatic life and instream concentrations of PCP were 780 ppb. Near the mouth of Naylor's Run, PCP concentrations ranged from 6 to 51 ppb and invertebrate surveys revealed a stressed invertebrate population. Tinicum was cited as an area of concern (Allen, 1981) since PCP is readily bioaccumulated, dilution ratios of Cobbs and Darby Creek with Naylor's Run are low, and sediment transport is high. Allen (1981) estimated that under worst case condition, PCP sediment concentrations in Tinicum could be as high as 39 ppb. Sampling conducted by EPA (U. S. EPA, 1985) identified pentachlorophenol, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, acenapthene, fluorene, dibenzofuran, benzo(b)fluoranthene, and indenopyrene in the water column and sediment near the discharge point at Naylor's Run. Chapter 5 of this report includes an evaluation of whether this site may be a contaminant source to the marsh through sediment transport.

IV. B. Air Quality

In general, air quality in the Tinicum area is typical of a major urban center. There are two air quality monitors near the Center, one in Folcroft and one in Chester. These monitors measure concentrations of criteria pollutants: total suspended particulates (TSP), sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), and lead.

In the Folcroft area, levels of TSP, SO_2, CO, and NO_2 are within EPA's standards set to protect human health and welfare. One exceedance of the secondary standard to protect welfare was observed for suspended particulates in Chester in 1985 and in Folcroft in 1983. All of Delaware and Philadelphia Counties are nonattainment areas for ozone. There are no lead monitors within the area, however the Philadelphia area has seen an increased trend in lead levels and violations were noted in 1982 and 1983 (Hankin, 1985).

Air quality modeling done by Scott Paper Co. in Eddystone in 1984 estimated that the Folcroft area would be in compliance with air quality standards for SO_2, TSP, NO_2, and CO (Air Quality, 1984). Except for the limited sampling done during the fire at Folcroft Landfill, there has been no toxicant air sampling in the area around Tinicum. The results of the sampling done during the fire are discussed in the previous section.

IV. C. Soil Quality

Limited soil data are available for the Tinicum area. All soils within the Center are classified as moderately to highly erodible. Soils in the tidal marsh are characterized as a silty clay while soil cover on the landfill consists primarily of sandy loam. The clay materials of the marsh would be expected to complex the heavy metals to a much greater extent than the soils in the landfill.

Erickson (1977) determined soil levels for lead, cadmium, zinc, and copper. The four study sites were the southwest area of the Center (1), the Landfill annex (2), the Folcroft Landfill (3), and the area east of the landfill (4). Soil samples were randomly selected from 5 meter interval grids at depths between 0 to 5 cm and 13-18 cm for a total of 20 samples from each site. Heavy metal concentrations were analyzed by site and sampling depth. Lead levels were significantly higher at the soil surface. Lead levels were also significantly higher in the landfill and the area east of the landfill.

Two soil samples were also taken in the annex area during the fire in 1983. Contaminant levels ranged from 0.53 to 3.08 ppm, and barium levels ranged from 0.28 to 1.48 ppm. Cadmium, chromium, silver, and mercury were detected at levels less than 0.1 ppm. A priority pollutant scan revealed that levels of all priority pollutants were less than 10 ppm (U.S. EPA, 1985). The lead levels are notably lower than the levels found in Erickson's 1977 study. This variability may be due to difference in soil type or to actual conditions.

The absence of on-site surface soil data for all priority pollutants is a serious shortcoming of the data base. Future studies should include soil sampling on Folcroft Landfill and in the adjacent tidal marsh.

IV. D. Sediment and Ambient Water Quality

Sediment and water column data in Cobbs, Darby and Hermesprota Creeks were reviewed to estimate possible impacts of toxic substances from Clear-view and Folcroft landfills on Tinicum.

Ambient data for the Tinicum area were obtained from four sources: (1) EPA's STORET national database, which contained 17 stations sampled since 1970, (2) the Pennsylvania Department of Environmental Resources (DER), which took water samples at 9 stations in 1984 and 1985, (3) a 1983, 14-station study by NUS Corporation on behalf of EPA, and (4) samples collected by EPA Annapolis CRL in 1984 as a follow-up to the NUS studies.

Water column data were combined into a single database using the

Table 8. Ambient Water and sediment station locations. RMI is the river mile, referenced from the conference of Darby Creek and the Delaware River.

Station	Location	RMI
C1	Cobbs Creek, Darby, PA	6.28
C2	Cobbs Creek, 500' upstream confluence of Darby Cr.	6.25
C3	Cobbs Creek, 350' upstream confluence of Darby Cr.	6.22
C4	Cobbs Creek, 200' upstream confluence of Darby Cr.	6.19
C5	Cobbs Creek, 50' upstream confluence of Darby Cr.	6.16
H1	Hermesprota Creek, Upstream Folcroft Landfill	5.00
H2	Hermesprota Creek, at Folcroft Landfill	4.50
D1	Darby Creek, Devon, PA	19
D2	Darby Creek, Upper Darby, PA	8.40
D3	Darby Creek, 1000' upstream confluence of Cobbs Cr.	6.34
D4	Darby Creek, 650' upstream confluence of Cobbs Cr.	6.28
D5	Darby Creek, 500' upstream confluence of Cobbs Cr.	6.25
D6	Darby Creek, 100' upstream confluence of Cobbs Cr.	6.17
D7	Darby Creek, 25' upstream confluence of Cobbs Cr.	6.16
D8	Darby Creek, at confluence of Cobbs Cr.	6.15
D9	Darby Creek, 75' downstream confluence of Cobbs Cr.	6.14
D10	Darby Creek, 150' downstream confluence of Cobbs Cr.	6.13
D11	Darby Creek, 300' downstream confluence of Cobbs Cr.	6.10
D12	Darby Creek, 1000' downstream confluence of Cobbs Cr.	5.97
D13	Darby Creek, 1800' downstream confluence of Cobbs Cr.	5.81
D14	Darby Creek, 2000' downstream confluence of Cobbs Cr.	5.76
D15	Darby Creek, Upstream Folcroft Landfill	4.73
D16	Darby Creek, at Folcroft Landfill	4.36
D17	Darby Creek, at Rte 291 Bridge	0.4

SAS statistical package (SAS Institute, Cary, NC) running on a 3270-series IBM mainframe computer. STORET data before 1980 were discarded because several sewage treatment plants in the basin were taken off line that year, and it was assumed that pre-1980 data were not representative. Data from the NUS and DER studies were combined where it appeared both had used the same locations. NUS sediment data were based on dry weight, but PA DER data were based on wet weight. PA DER data were normalized to dry weight equivalence by correcting for percent moisture in the sample.

The final data base contained 17 stations on Darby Creek (from Devon, PA to the confluence of Darby Creek and the Delaware River), five on Cobbs Creek (from Darby, PA to the confluence of Cobbs and Darby Creeks), and two on Hermesprota Creek (above and below Folcroft Landfill). The data base had the following potentially serious limitations, which made interpretation tentative at best:

1. Although many locations were monitored, most had only one observation. Internal variation could therefore not be compared statistically with variation due to location or time.

2. The DER study did not include adequate location data. Possible opportunities to gain statistical resolution by combining DER and NUS stations may have been lost.

3. The database included measurements of toxic metals, ammonia, and cyanide only; VOCs, PAHs, pesticides, and other classes of toxic organic

pollutants were not monitored. No estimate could be made of the potential presence or impact of these compounds.

Table 8 and Figure 8 identify the sampling locations which were evaluated. River miles (RM) were derived for each sampling location to allow easier graphic presentation and analysis. Samples taken at river miles 6.28 and 6.25 represent background levels on Cobbs Creek. Samples taken between river miles 19 and 6.16 represent background levels on Darby Creek. Locations between river miles 6.10 and 6.22 are adjacent to Clearview Landfill. Stations between river miles 4.73 and 6.1 are downstream of Clearview Landfill and upstream of Folcroft Landfill. Tidal influence on sampling stations is expected between river mile 5.97 and the mouth of Darby Creek.

Sediment Threshold Contamination Levels

Sediment concentrations of toxic pollutants were compared to threshold contamination levels currently under development by the EPA (U.S. EPA, 1985). In addition to evaluating threshold contamination levels, this document discusses possible methodologies for determining sediment criteria. There are currently no adopted EPA sediment criteria. In the absence of adopted criteria, the threshold contamination levels are the best available standards against which sediment data can be compared.

Threshold values were derived from sediment-water equilibrium partition coefficients and toxicological data available from established Water Quality Criteria. The approach is based on the assumption that the distribution of various chemicals is controlled by an equilibrium exchange among sediment, infauna, interstitial and overlying waters. The constants relating these concentrations at equilibrium are referred to as partition coefficients. Compound-specific partition coefficients are determined and used to predict the distribution of the compound between sediment and interstitial water. Because of the influence of organic carbon in the sediment on the distribution of many chemicals among phases, partition coefficients often are expressed in terms of organic carbon content of the sediment. It is assumed that the average sediment contains 4 percent total organic carbon.

Site-specific variations in physical and chemical factors (such as particle size or carbon content) complicate the quantification of the contaminant distribution among phases. For this reason, the actual biological effects of sediment concentrations observed in excess of the threshold values may vary by locations. Table 9 lists the toxicants found in Cobbs, Darby, and Hermesprota Creeks, and the corresponding threshold contamination concentration levels.

Sediment data were plotted using an IBM PC/AT desktop computer running Graphwriter. Locations are duplicated on some of the graphs because additional samples were taken at the same locations. Replicate samples were collected at RM 6.22 in 1983. One sample will be indicated as RM 6.22 and the other sample will be indicated by RM 6.22(a) in discussion. River mile

Figure 8. Locations of selected ambient water and sediment stations.

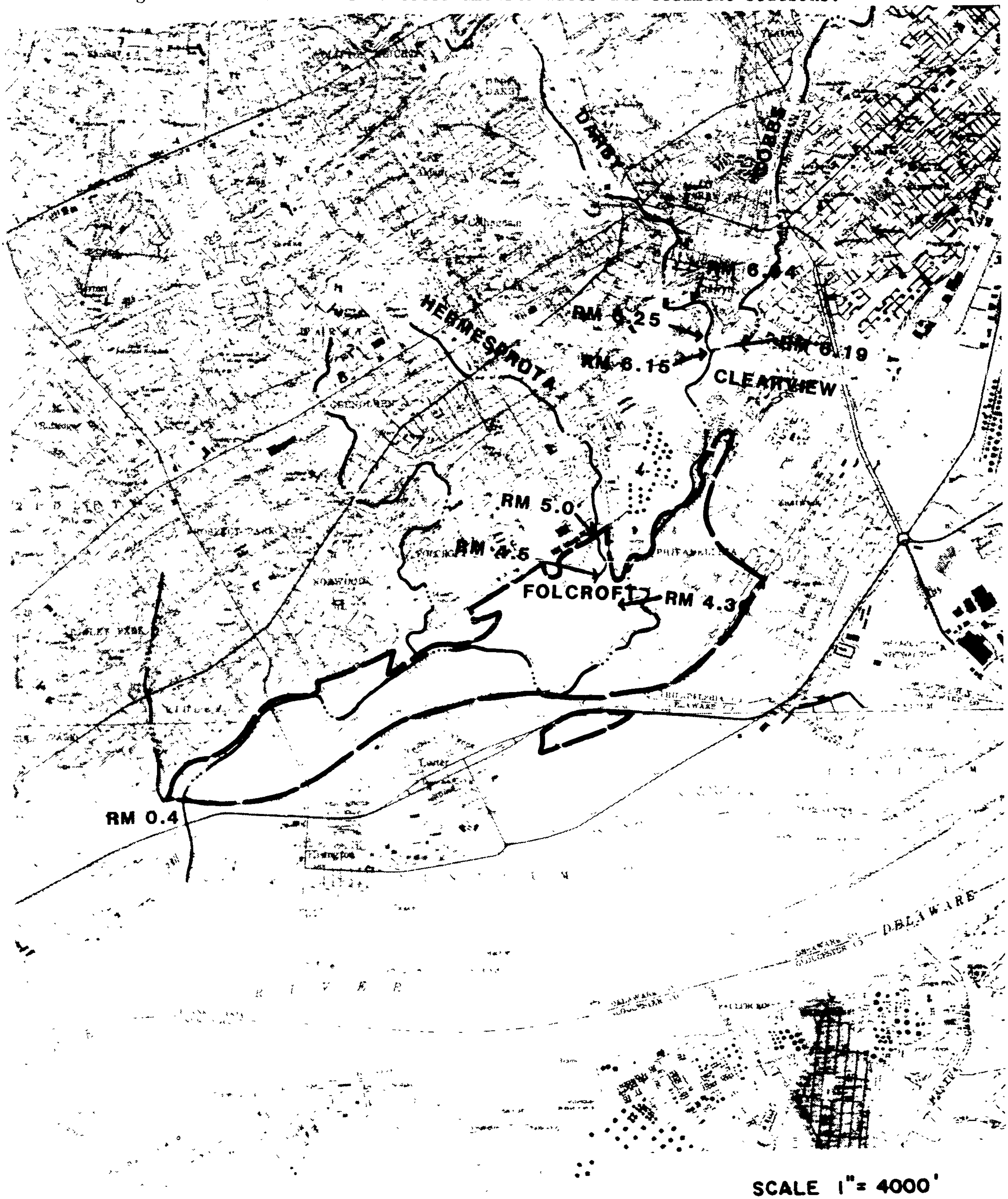


Table 9. Threshold contaminant concentrations for sediments. Values are based on dry weight (U.S. EPA, 1985) and reported in ppm.

Contaminant	Threshold	Contaminant	Threshold
Fluoranthene	28	Benzo(a)pyrene	1800
Chrysene	460	Arsenic	33
Pyrene	198	Mercury	0.8
Benzo(a)anthracene	220	Cadmium	31
Benzo(k)fluoranthene	5,000	Lead	132
Anthracene	66	Copper	136
Naphthalene	42	Nickel	20
PCB's	0.28	Zinc	760
Chlordane	0.02	Cyanide	0.1

6.16 was sampled in 1983 and 1984. River mile 5.97 was also sampled in 1983 and 1984. In discussion, these two locations will be identified by river mile and year.

Sediment Data Results

The sediment data obtained from the Tinicum area are listed in Appendix Table H. Generally, the sediments contained high concentrations of metals, cyanide, PCB's, and chlordane. The only parameters that exceeded the EPA threshold concentrations were cyanide, lead, chromium, PCB's, and chlordane. These parameters, as well as aluminum, copper, nickel, and iron (because of their high levels and known toxicity to aquatic life) were plotted for ease of comparison to location and criteria. It should be noted that there are no threshold contamination levels for aluminum and iron. The high concentrations of these metals in the sediments are a concern. PAH's were all below threshold contamination levels.

Figure 9 shows the level of PCB 1242 in Cobbs and Darby Creeks. There are no PCB data below river mile 5.97. River miles 6.28, 6.25, 6.19, 6.16(1984), 6.14, 6.1, and 5.97(1984) exceed the PCB threshold contamination level. The variation between 1983 and 1984 at river miles 6.16 and 5.97 suggests that temporal variance may have been as important as variance due to location. Background levels at river miles 6.25 and 6.28 are less than 0.4 ppm. River miles 6.19 and 6.16(1984) show the highest concentrations. The PCB concentration at river mile 5.97 was also considerably higher than background. These three locations are adjacent to Clearview Landfill. Soil samples at Clearview Landfill contain high concentrations of PCB 1260. These observations suggest that Clearview may be a source of PCB's in the sediment samples.

Figure 10 shows chlordane concentrations in the sediments of Cobbs and Darby Creeks. River miles 6.22, 6.22(a), 6.16(1983), 6.15, 5.97(1983), 5.0, 4.73, 4.5, and 4.36, exceeded the threshold level. The locations near Clearview (RM 6.22, RM 6.22(a), RM 6.16(1984), RM 6.16, RM 6.15) had lower concentrations than locations at river miles 5.97(1983), 5.0, 4.73, 4.5, and 4.36, which are under the influence of Folcoft Landfill. This suggests that Folcroft may be a possible source of chlordane contamination.

Figure 11 presents the sediment data for lead in Cobbs and Darby Creeks. All data except river mile 6.16 were below the threshold contamination level for lead of 132 ppm. Conversion of the Pa DER datum to dry weight using the percent moisture of the sample indicates that at river mile 6.16 the Pa DER value would exceed the threshold contaminant level with a concentration of 153 ppm. Background levels varied between 109.8 ppm on Cobbs Creek and 59.7 ppm on Darby Creek. The data in the vicinity of Folcroft (river miles 6.1 thru 4.7) were less variable with concentrations ranging from 54 to 122 ppm. There is no discernable trend or source of contamination for lead in the vicinity of Folcroft.

Figure 12 displays the cyanide concentrations in sediment for Cobbs and Darby Creeks. The threshold contamination concentration level is 0.1 ppm. All locations monitored for cyanide in the sediment were below the threshold contamination level except for the locations (RM 4.73, RM 4.36, RM 5.0, RM 4.5, RM 4.7) surrounding the Folcroft Landfill, and the values (820-5600 ppm) reported were far above background levels. The data suggest that Folcroft may be a source of cyanide contamination.

Figure 13 illustrates the aluminum concentrations in sediment samples in Cobbs and Darby Creeks. There is no threshold contamination value for aluminum. The data vary to extremes. River mile 6.22 had a concentration of 5070 ppm but the replicate sample (RM 6.22(a)) contained no detectable aluminum. Extremely high levels of aluminum were observed around the Folcroft Landfill. This suggests that the Folcroft landfill may be a source of aluminum contamination in Darby and Hermesprota Creeks.

Figure 14 illustrates the copper sediment data for the study area. The threshold contamination concentration for copper is 136 ppm. Data for all locations were below this threshold. Copper concentrations for river miles 6.25 thru 5.97 vary from 13 to 36.3 ppm. Copper values for the locations between RM 4.73 and RM 4.7 were higher (25 to 60 ppm). The metal concentrations tend to be higher in the Folcroft area.

Figure 15 presents the iron sediment data for the study area. There is no threshold contamination concentration level for iron. Background levels of iron on Cobbs Creek were 7584 ppm. The background station on Cobbs Creek (RM 6.25) had an iron concentration of 10389 ppm. The background station on Darby Creek (RM 6.28) had an iron concentration of 14709 ppm. The highest concentration of 20200 ppm was reported at location RM 6.16. River mile 6.16 was sampled one year later and a value of 10901 ppm was observed. The iron data are variable with no obvious trends.

Figure 16 displays the sediment data for nickel in the study area. The threshold contaminant level for nickel is 20 ppm, which was not exceeded at any location. However, river miles 4.73 and 4.5 had concentrations of 20 and 19.5 ppm, respectively. Both of these locations are adjacent to the Folcroft Landfill, suggesting a potential source.

Figure 17 shows chromium concentrations in sediment for the study area.

Figure 9. PCB concentration versus river mile.

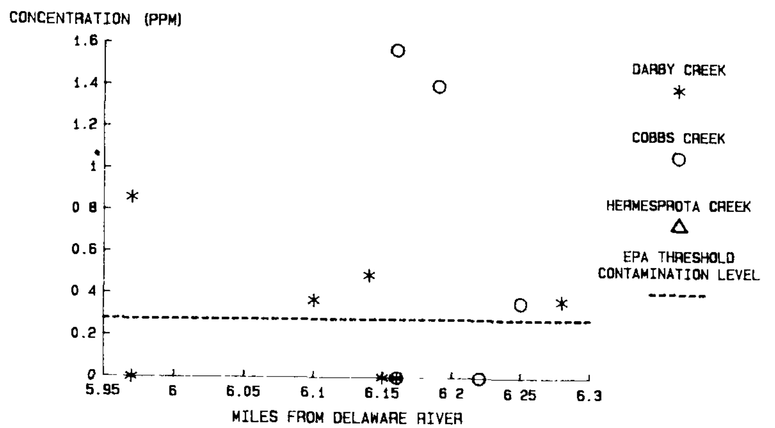


Figure 10. Chlordane concentration versus river mile.

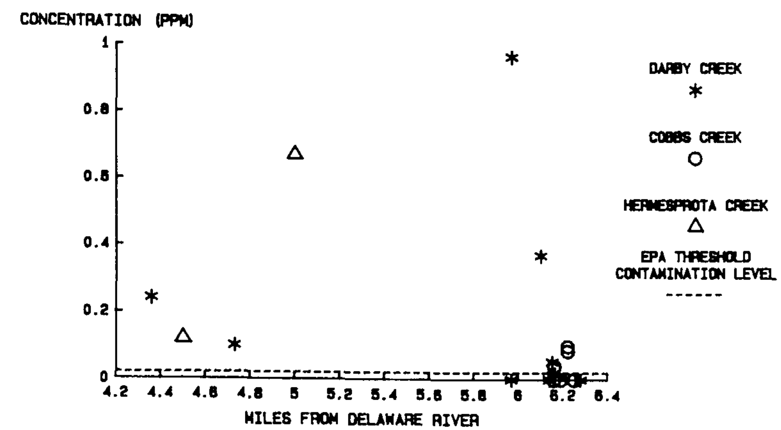


Figure 11. Lead concentration versus river mile.

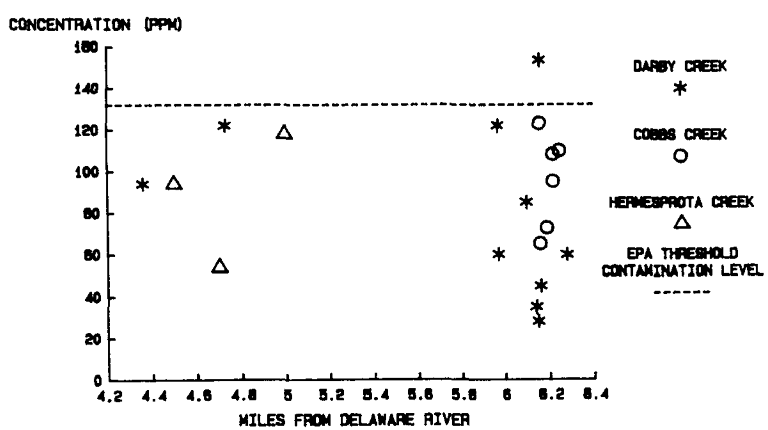


Figure 12. Log cyanide concentration versus river mile.

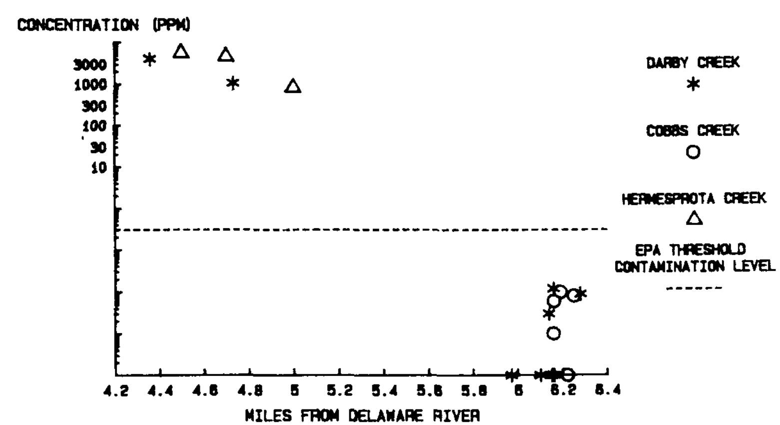


Figure 13. Aluminum concentration versus river mile.

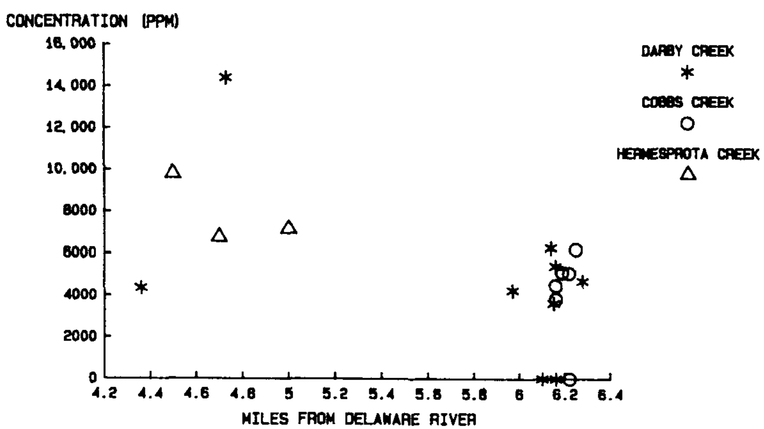


Figure 14. Copper concentration versus river mile.

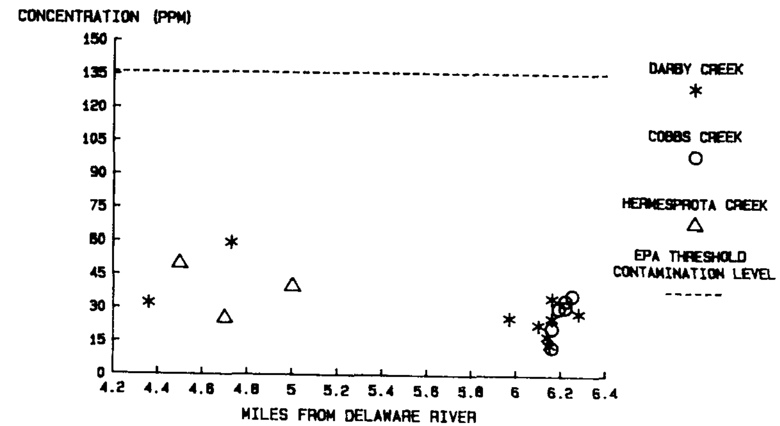


Figure 15. Iron concentration versus river mile.

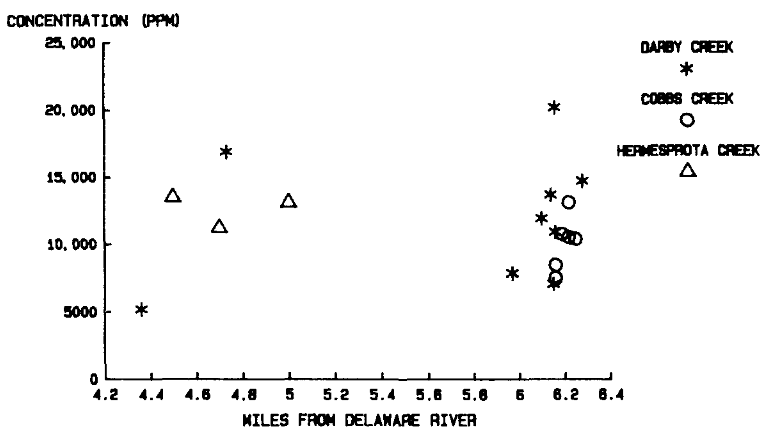


Figure 16. Nickel concentration versus river mile.

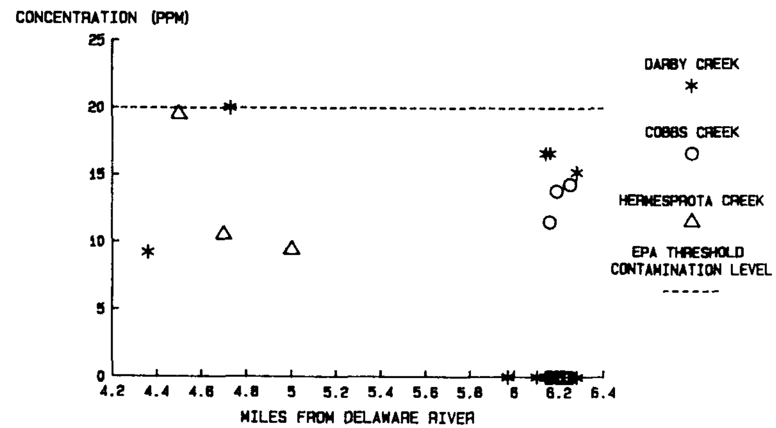
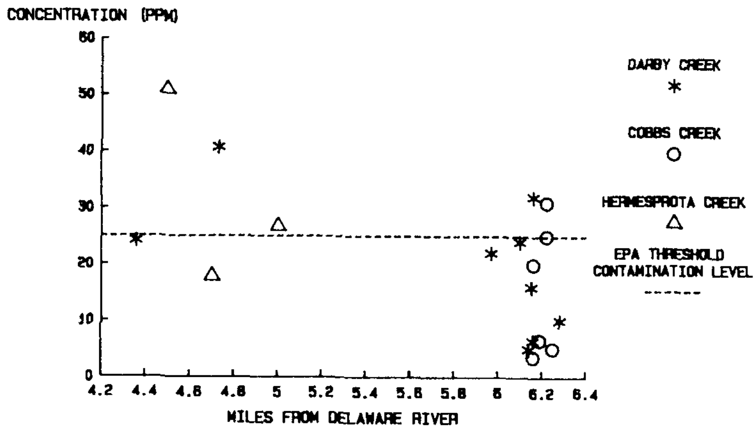


Figure 17. Chromium concentration versus river mile.



Data collected in 1983 are consistently high at all monitoring locations. Fifty percent of theses observations exceeded the EPA threshold toxicant contamination level of 25 ppm. The 1984 data did not approach the EPA threshold toxicant contamination level. Overall, six of eighteen observations exceeded this level. Other than the temporal differences in the data, no other trends were obvious.

Water Quality Evaluation Methods

Each observation of each toxic pollutant was individually compared with water quality criteria (US EPA, 1985, 1980, or 1973 as appropriate). For parameters having criteria related to hardness, observed hardness was used in the criteria calculation. If hardness data were not available, the observed mean total hardness of 97.7 mg/l as $CaCO_3$ was assumed. Possible stress on aquatic life by low dissolved oxygen, high temperature, or phosphate - related eutrophication were also considered by including "criteria" for these parameters (4 mg/l DO, 1.5 mg/l PO_4, and 30^oC). Comparison of observed ammonia concentrations (expressed as total ammonia) with EPA criteria (as unionized ammonia) presented a special problem because only the observations in STORET included the temperature and pH data needed to convert total to unionized ammonia. This comparison was done by hand using a separate STORET output.

After each observation was compared with its applicable water quality criterion, the proportion of measurements above the criterion was calculated for each parameter at each station. Correlation analysis was used to test for relations between both concentration and proportion of criterion exceedance and location, year, and temperature. Plots of mean concentration versus location were made using a desktop computer and Graphwriter.

Ambient Water Quality Results

Mean and maximum concentrations and number of observations of each parameter for Cobbs and Hermesprota Creeks are presented in Appendix Table I;

Table 10. Water quality criteria used for comparison to ambient observations. All values are ug/l except ammonia (mg/l), DO (mg/l), PO_4 (mg/l), and temperature (°C). Source: A = EPA, 1973; B = EPA, 1985; C = EPA, 1980.

Variable	Criterion (Mean)	Source	Variable	Criterion (Mean)	Source
Aluminum	200.0	A	Lead	2.98	B
Ammonia	0.012	B	Mercury	0.012	B
Arsenic	360.0	B	Manganese	20.0	A
Barium	500.0	A	Nickel	91.49	B
Cadmium	1.08	B	Phosphate	1.00	-
Cyanide	5.2	B	Selenium	35.0	C
Chromium	196.7	B	Silver	3.69	C
Copper	11.2	B	Temperature	30.0	-
DO	4.0	-	Zinc	47.0	C
Iron	1000	C			

similar data for Darby Creek are presented in Appendix Table J. Most toxic pollutants had very high concentrations at river mile 4.36 adjacent to the Folcroft landfill. In addition to the high concentrations measured at RM 4.36, the data show an apparent trend of increasing concentration with movement downstream.

Table 10 contains the means of water quality criteria to which the ambient observations were compared. Table 11 contains the mean proportion of criteria exceedances, number of observations, and standard error of the mean for Darby Creek stations. Exceedance data from Cobbs and Hermesprota Creeks were judged too sparse for tabulation. Concentrations of the following metals were judged to seriously exceed chronic water quality criteria at the mouth of Darby Creek: copper (52.8% of observations exceeded criteria), iron (22.6%), lead (67.9%), and zinc (19.2%). Cadmium and mercury had a notably lower 1.9% exceedance rate. Although upstream data were sparse, all metals except mercury exceeded criteria at least once. Aluminum, silver, and manganese were not monitored at the mouth of Darby Creek, but upstream data suggest these metals may also frequently exceed criteria.

Temperature did not exceed 30°C, unionized ammonia did not exceed 0.012 mg/l and phosphate did not exceed 1.5 mg/l in any sample. Dissolved oxygen exceeded 4 mg/l 85.7% of the time. The local biota may be stressed by low oxygen concentrations at high temperatures, especially during the 14.3% of the time when dissolved oxygen is below 4 mg/l.

Coefficients of correlation between observed concentrations and location, year, and temperature are presented in Table 12; similar correlation coefficients for mean proportion of criterion exceedance are presented in Table 13. Dissolved oxygen, ammonia, and nitrite concentrations were significantly correlated with temperature, as expected, suggesting the data may be of reasonable quality. Silver, aluminum, manganese, nickel, nitrite, and phosphate increased with movement downstream, and dissolved oxygen decreased downstream. Exceedances of criteria for silver, copper, manga-

Table 11. Proportion of measured ambient concentrations of toxic pollutants exceeding water quality criteria on Darby Creek. First line of each cell = mean proportion of exceedance (0 = no exceedancee, 1 = all exceedances), second line = number of observations, third line = standard error of the mean.

Parameter	Location/ Station Upper Darby PA D2	500 ft. upstream Cobbs Cr D5	100 ft. upstream Cobbs Cr D6	At Cobbs Creek D8	150 ft. dnstream Cobbs Cr D10	300 ft. dnstream Cobbs Cr D11	1000 ft. dnstream Cobbs Cr D12	1800 ft. dnstream Cobbs Cr D13	2000 ft. dnstream Cobbs Cr D14	At Route 291 D17
AG	. 0	. 0	0.000 1	0.000 1	. 0	. 0	. 0	. 0	1.000 1	. 0 .
AL	0.250 4 0.250	0.000 1	0.000 2	0.000 1	0.000 1	1.000 1	. 0	1.000 1	0.000 1	. 0 .
AS	0.000 4 0.000	. 0	0.000 1	0.000 1	. 0	. 0	. 0	. 0	0.000 1	0.000 53 0.000
BA	. 0	. 0	0.000 1	0.000 1	. 0	. 0	. 0	. 0	0.000 1	. 0 .
CD	0.000 4 0.000	0.000 1	0.000 2	0.000 1	0.000 1	1.000 1	. 0	0.000 1	0.000 1	0.019 53 0.018
CN	. 0	0.000 1	0.000 2	0.000 1	0.000 1	0.000 1	0.000 1	0.000 1	0.000 1	. 0 .
CR	0.000 4 0.000	0.000 1	0.000 2	0.000 1	0.000 1	0.000 1	. 0	0.000 1	0.000 1	0.000 53 0.000
CU	0.250 4 0.250	0.000 1	0.000 2	0.000 1	1.000 1	1.000 1	. 0	1.000 1	0.000 1	0.528 53 0.069
DO	1.000 11 0.000	. 0	. 0	. 0	. 0	. 0	. 0	. 1	. 0	0.857 21 0.078
FE	0.083 24 0.058	0.000 1	0.000 2	0.000 1	0.000 1	1.000 1	1.000 1	1.000 1	0.000 1	0.226 53 0.058
HG	0.000 4 0.000	. 0	. 0	. 0	. 0	. 0	. 0	. 1	. 0	0.019 53 0.018
MN	0.500 4 0.289	1.000 1	1.000 2	1.000 1	1.000 1	1.000 1	. 0	1.000 1	1.000 1	. 0 .
NH3	0.917 24 0.000	. 0	. 0	. 0	. 0	. 0	. 0	. 0	. 0	1.000 53 .

Table 11. Continued.

Parameter	Location/ Station Upper Darby PA D2	500 ft. upstream Cobbs Cr D5	100 ft. upstream Cobbs Cr D6	At Cobbs Creek D8	150 ft. dnstream Cobbs Cr D10	300 ft. dnstream Cobbs Cr D11	1000 ft. dnstream Cobbs Cr D12	1800 ft. dnstream Cobbs Cr D13	2000 ft. dnstream Cobbs Cr D14	At Route 291 D17
	0.058									0.000
NI	0.000	0.000	0.000	0.000	0.000	0.000	.	0.000	1.000	.
	4	1	2	1	1	1	0	1	1	0
PB	0.000	1.000	0.000	0.000	0.000	1.000	.	1.000	0.000	0.679
	4	1	2	1	1	1	0	1	1	53
	0.000									0.065
PHE	.	.	.	.	.	.	.	.	.	.
	0	0	0	0	0	0	0	0	0	0
										.
PO4	0.000	.	.	.	.	.	.	.	.	0.000
	24	0	0	0	0	0	0	0	0	51
	0.000									0.000
SE	.	.	0.000	0.000	.	.	.	0.000	0.000	0.000
	0	0	1	1	0	0	0	1	1	38
										0.000
TEMP	0.000	.	.	.	.	.	.	.	.	0.000
	13	0	0	0	0	0	0	0	0	25
	0.000									0.000
ZN	0.000	0.000	0.000	0.000	0.000	1.000	.	1.000	0.000	0.192
	4	1	2	1	1	1	0	1	1	52
	0.000									0.055

Table 12. Correlation analysis of mean concentrations of pollutants in ambient water with order (1 = upstream, 17 = downstream), year (1980 - 1985), and temperature. First line of cell = r, Pearson correlation coefficient; second line = p, probability of Type I error in accepting h_0: r=0; third line = number of observations.

	PHENOLS	PO4	SE	ZN
ORDER	0.46464	0.66998	0.06943	0.05365
	0.2076	0.0001***	0.6355	0.6408
	9	87	49	78
YEAR	-0.57266	0.43106	-0.28456	-0.03443
	0.1071	0.0001***	0.0475*	0.7648
	9	87	49	78
TEMP		0.00876	-0.26322	-0.44244
		0.9555	0.2140	0.0184*
	0	43	24	28

Table 12. Continued.

	AG	AL	AS	BA	BOD5	CD	CN_FREE
ORDER	0.90975	0.41009	0.02759	0.48042	0.19565	0.04812	0.28772
	0.0017**	0.0375*	0.8259	0.1599	0.0646	0.6717	0.1631
	8	26	66	10	90	80	25
YEAR	0.33333	-0.02218	-0.02973	-0.38682	-0.23498	-0.02926	-0.01358
	0.4198	0.9143	0.8127	0.2695	0.0258*	0.7967	0.9486
	8	26	66	10	90	80	25
TEMP		-0.50000	0.00000		-0.08843	-0.09843	
		0.6667	1.0000		0.6081	0.6183	
	0	3	28	0	36	28	0

	CR	CU	DO	FE	HG	KJEL_N	MG
ORDER	0.04200	0.06038	-0.60539	0.07201	0.04411	0.18596	0.00000
	0.7115	0.5947	0.0001***	0.4720	0.7401	0.1412	1.0000
	80	80	39	102	59	64	23
YEAR	-0.05246	-0.06630	-0.36859	-0.00988	0.18858	-0.18175	0.13853
	0.6440	0.5590	0.0209**	0.9215	0.1526	0.1506	0.5285
	80	80	39	102	59	64	23
TEMP	-0.07426	0.17665	-0.57415	-0.01012	0.34765	-0.40044	-0.19283
	0.7073	0.3685	0.0001***	0.9519	0.0699	0.0313*	0.5482
	28	28	39	38	28	29	12

	MN	NH3	NI	NO2	NO3	PB	PH
ORDER	0.42704	0.07627	0.44719	0.40069	-0.01324	0.04107	-0.10969
	0.0263*	0.4602	0.0193*	0.0001***	0.8992	0.7176	0.4210
	27	96	27	96	94	80	56
YEAR	-0.04436	-0.10825	0.01982	0.28895	-0.02072	-0.04238	-0.00429
	0.8261	0.2938	0.9218	0.0043**	0.8429	0.7090	0.9750
	27	96	27	96	94	80	56
TEMP	-0.75593	-0.37046	-0.50000	0.39331	-0.10115	-0.04125	-0.05439
	0.4544	0.0171*	0.6667	0.0110*	0.5401	0.8349	0.7457
	3	41	3	41	39	28	38

Table 13. Correlation analysis of mean proportion of observations in ambient water exceeding EPA water quality criteria. First line of each cell = r, Pearson correlation coefficient; second line = p, probability of Type I error in accepting H_0: r=0; third line = number of observations.

	AG	AL	AS	BA	CD	CN	CR
ORDER	0.97073 0.0013** 6	0.32982 0.1556 20	0.00000 1.0000 63	0.00000 1.0000 6	-0.06461 0.5871 73	0.00000 1.0000 18	0.00000 1.0000 73
YEAR	0.00000 1.0000 6	-0.40825 0.0739 20	0.00000 1.0000 63	0.00000 1.0000 6	-0.22904 0.0513 73	0.00000 1.0000 18	0.00000 1.0000 73
TEMP	0	-0.50000 0.6667 3	0.00000 1.0000 28	0	0.00000 1.0000 28	0	0.00000 1.0000 28

	CU	DO	FE	HG	MN	NI	PB
ORDER	0.23680 0.0437* 73	-0.26701 0.1003 39	0.17644 0.0872 95	0.03671 0.7863 57	0.47191 0.0357* 20	0.52159 0.0183* 20	0.37536 0.0011** 73
YEAR	-0.51666 0.0001*** 73	-0.16285 0.3219 39	-0.08419 0.4173 95	0.18814 0.1611 57	0.00000 1.0000 20	0.47140 0.0359* 20	-0.42001 0.0002*** 73
TEMP	-0.03782 0.8485 28	-0.20731 0.2054 39	-0.19944 0.2300 38	0.34765 0.0699 28	-0.50000 0.6667 3	0.00000 1.0000 3	-0.01151 0.9537 28

	PO4	SE	ZN
ORDER	0.00000 1.0000 81	0.00000 1.0000 46	0.12136 0.3099 72
YEAR	0.00000 1.0000 81	0.00000 1.0000 46	-0.38440 0.0009*** 72
TEMP	0.00000 1.0000 43	0.00000 1.0000 24	-0.13122 0.5057 28

nese, nickel, lead, and zinc increased significantly downstream. Exceedances of criteria for copper, lead, and zinc have decreased since 1980, but exceedances for nickel have increased. Five-day BOD and dissolved oxygen have decreased (paradoxically) since 1980, and nitrite and phosphate have increased.

Comparisons between Sediment and Water Quality Data

Tables 14 and 15 indicate where exceedances of EPA Water Quality Criteria and sediment threshold toxicant contamination levels occurred by stream and river mile. An exceedance signifies that one observation was above the criterion.

These tables illustrate some of the water quality problems in the Darby Creek basin. The tables were not developed to quantify the contamination, but rather to identify problem parameters by comparison to the best available criteria or guidelines. Parameter selection was limited by data availability. The contaminants with the most frequent exceedances of water quality criteria were aluminum, ammonia, copper, iron, lead, manganese, and zinc. The contaminants that exceeded the sediment threshold contaminants levels were PCB, chlordane, chromium, lead, and cyanide.

Concentrations of aluminum in the water column exeeded the water quality criterion (200 ppb) at river miles 8.4, 6.1, 5.81, 4.5, and 4.36. Sediment concentrations were above 3600 ppm at all locations except river miles 6.22a, 6.46, and 6.1 where aluminum was not detected. The highest concentrations of aluminum in the water column occurred at river mile 4.36 (398 ppm). The highest concentrations in the sediment occurred at river mile 4.73 (144,000 ppm). The highest values in both the water column and sediment occurred in the vicinity of Tinicum and the Folcroft Landfill.

There was one exceedance of the water quality criterion for cyanide (5.2 ppb) which occurred at river mile 4.36 with a concentration of 445 ppb. The threshold toxicant level of 0.1 ppm was exceeded at river miles 4.73 (1050 ppm), 4.36 (4040 ppm), 5.0 (820 ppm), and 4.5 (5600 ppm). All these exceedances occurred in the vicinity of the Folcroft Landfill and the Tinicum area.

The EPA water quality criterion for copper (11.2 ppb) was exceeded at river miles 8.4, 6.13, 6.1, 5.81, 4.36, and 0.4. The highest concentration of copper in the water column (2070 ppb) occurred at river mile 4.36. The water column copper concentrations were more variable than the sediment concentrations. The highest sediment concentration occurred in the Folcroft Landfill area. Copper levels were also elevated in Folcroft Landfill leachate.

The iron water qualtity criterion (1 ppm) was exceeded at river miles 7.19, 8.4, 6.34, 6.1, 5.97, 5.81, 4.73, 4.36, 5.0, 4.5, and 0.4. There is no threshold toxicant contaminant level for iron. Sediment concentrations ranged from 5200 to 20200 ppm. The highest sediment concentration was observed upstream of Clearview Landfill. The highest water column concentration was at Folcroft Landfill (505000 ppm). Both the sediment and water column data are highly variable with no apparent trend. High iron

Table 14. Summary of exceedances of EPA sediment threshold contaminant levels in samples taken in Darby Creek (D), Cobbs Creek (C), Hermesprota Creek (H), and on site at the Folcroft landfill (F). An x signifies an exceedance, a dash indicates that no data are available.

Contaminant	Threshold ppm	River Mile 6.28D	6.25C	6.22C	6.19C	6.16D	6.16C	6.15D	6.14D	6.10D	5.97D	5.0H	4.73D	4.7L	4.5H	4.36D
Anthracene	66		-		-				-			-	-	-	-	-
Benzo(a)anth-racene	220		-		-				-			-	-	-	-	-
Benzo(a)pyrene	1800	x	-		-	-		-	-		-	-	-	-	-	-
Benzo(k)fluo-anthene	5000		-		-				-			-		-	-	-
Chrysene	460	-	-		-				-					-		
Fluoranthene	28	-	-		-				-					-		
Napthalene	42	-	-		-				-			-	-	-	-	-
Pyrene	198		-		-				-					-		
PCB	0.28	x	x		x		x		x	x	x	-		-	-	
Chlordane	0.02			x			x	x		-	x	x	x	-	x	x
Arsenic	33															
Cadmium	31															
Chromium	25	x		x		x						x	x		x	
Copper	136															
Cyanide	20											x	x	x	x	x
Lead	132	x				x										
Mercury	0.8															
Nickel	20															
Zinc	760															

Table 15. Summary of exceedances of EPA water quality criteria in samples taken in Darby Creek (D), Cobbs Creek (C), and Hermesprota Creek (H). An x signifies an exceedance, a dash indicates that no data are available.

Contaminant	Criterion ppb	River Mile																	
		19.0	8.4	7.19	6.34	6.28	6.25	6.25	6.22	6.19	6.17	6.16	6.16	6.15	6.14	6.13	6.1	5.97	5.81
		D	D	C	D	D	D	C	C	C	D	D	C	D	D	D	D	D	D
Aluminum	200	–	x														x	–	x
Ammonia	12	x	x	–	–	–	x	–	–	–	x	–	x	x	x	–	x	–	x
Arsenic	360	–					–	–	–			–			–	–	–	–	–
Barium	500	–	–				–	–	–			–			–	–	–	–	–
Cadmium	1.08	–						x										–	
Cyanide	5.2	–	–																
Chromium	196.7	–																–	
Copper	11.2	–	x													x	x	–	x
Iron	1000.0	–	x	x	x										x		x	x	x
Lead	2.98	–	x	x	x		x	x	x						x		x	–	x
Mercury	0.012	–					–	–	–		–	–	–		–	–	–	–	–
Manganese	20.0	–	x	x	x		x	x	x		x		x	x	x	x	x	–	x
Nickel	91.5	–																–	
Selenium	35.0	–	–					–	–			–			–	–	–	–	
Silver	3.7	–	–					–	–			–			–	–	–	–	x
Zinc	47.0	–						x					x				x	–	x

Table 15 (continued). Summary of exceedances of EPA water quality criteria.

Contaminant	Criterion ppb	River Mile					
		5.76	5.0	4.73	4.5	4.36	0.4
		D	H	D	H	D	D
Aluminum	200		–	–	x	x	–
Ammonia	12	x	–	–	–	–	x
Arsenic	360	–	–	–		–	–
Barium	500					x	–
Cadmium	1.08				–	x	x
Cyanide	5.2					x	–
Chromium	196.7					x	
Copper	11.2					x	x
Iron	1000.0		x	x	x	x	x
Lead	2.98				–	x	x
Mercury	0.012	–	–	–	–	–	x
Manganese	20.0	x	x	x	x	x	–
Nickel	91.5	x				x	–
Selenium	35.0		–	–	–		
Silver	3.7	x		–	–	–	–
Zinc	47.0		x	–	x	x	x

iron levels were also measured in Folcroft Landfill leachate.

The EPA water quality criterion for lead (2.978 ppb) was exceeded at river miles 7.19, 6.34, 6.25, 6.22, 6.14, 6.1, 5.81, 4.36, and 0.4. The highest concentration was at river mile 4.36 (3450 ppb). The sediment threshold criteria was exceeded at river mile 6.16 (153 ppm). Sediment concentrations were variable upstream of the Tinicum area, and ranged from 94 to 122 ppm. Water column data indicate increased concentrations in the Tinicum - Folcroft area. High lead levels were measured in Folcroft leachate.

The water quality criterion for nickel (91.49 ppb) was exceeded at river miles 5.76 (116 ppm) and 4.36 (908 ppm). The sediment threshold toxicant contaminant level of 20 ppm was not exceeded. However, locations RM 4.73 (20 ppm) and RM 4.5 (19.5 ppm) were high enough to be of concern. Both sediment and water column concentrations were highest in the Tinicum - Folcroft area. Nickel concentrations were high in Folcroft leachate.

The USEPA water quality criterion for chromium (200 ppb) was exceeded only once at river mile 4.36 near Folcroft (1500 ppb). The sediment threshold toxicant contamination level was exceeded in 6 of 18 observations. Sediment data showed a wide variation, however no noticeable trend was observed for the data.

The water quality criterion for zinc of 47.0 ppb was exceeded at river miles 7.19, 6.22, 6.1, 5.81, 4.5, 4.36, and 0.4. The highest concentrations was reported at Folcroft Landfill (8460 ppb). The sediment threshold toxicant level for zinc is 760 ppm. The highest sediment value reported was 235 ppm at river mile 6.16 above Clearview Landfill. The overall trend in the water column shows an increase in concentration proceeding downstream to the Tinicum - Folcroft area. The sediment data are more variable with no obvious trends. High zinc concentrations were measured in Folcroft leachate.

Conclusions of Water Quality Evaluation

The data presented suggest that Clearview Landfill may be a source of PCB contamination in the area. The Folcroft Landfill appeared to be a source of chlordane, cyanide, chromium, copper, and nickel contamination in the study area. However, sediment transport effects and particle size were not studied. Therefore it will be necessary to confirm that the higher concentrations observed adjacent to these landfills reflected the location of the source and not a sediment transport phenomenon or particle size bias in the samples. Further investigation is needed to determine the effects upon aquatic life and to determine what remedial action is necessary.

The sediment data review found that PCB's, chlordane, cyanide, and lead (at one location) exceeded USEPA toxicant threshold contamination levels. Aluminum, iron, and nickel had concentrations in the sediments that were a concern. There are no threshold contaminant levels for iron and aluminum. The PCB's data were collected only in the area of Clearview landfill. High soil levels of PCB's at Clearview indicate that it may be source of PCB contamination. Cyanide, chlordane, lead, nickel, and aluminum were at their highest concentrations near the Folcroft landfill. Iron concentrations were high throughout the sampling area. If these observations were representative and accurate, they indicate that Folcroft may be a source of cyanide, chlordane, lead, and aluminum contamination. Elevated levels of copper, iron, lead, manganese, nickel, and zinc were also found in seeps at Folcroft Landfill, further supporting this theory that Folcroft Landfill is a likely source of heavy metals to Tinicum.

It is clear that at least four toxic metals (copper, iron, lead, and zinc) have routinely exceeded applicable EPA water quality criteria downstream of Tinicum and probably also at the Center. Measured concentrations of cadmium, mercury, aluminum, silver, and manganese also appeared excessive. Levels of contamination increased with travel downstream, and were very high in the Tinicum area. These observations support the theory that Folcroft Landfill is a continuing source of toxic metals. High metal concentrations measured in Hermesprota Creek on the other side of the landfill and in seeps from Folcroft Landfill annex lend further support to this theory.

This analysis concludes that, in general, data were too sparse to characterize trends and spatial distributions of pollutants in a statistically conclusive manner. However, the highest concentrations of several pollutants were observed around the Folcroft Landfill. These pollutants include metals, chlordane, and cyanide. High concentrations of PCB's and metals were also found in the area of the Clearview Landfill. Only qualitative statements linking sources to degraded water quality could be made because the results were highly variable, showed low reproducibility, and were not controlled for factors such as sediment particle size.

Additional sample collection will be necessary to identify sources in the areas where high concentrations were observed. Future monitoring should include multiple samples, background controls, and particle size analysis of sediment samples. Biological monitoring, such as artificial substrates, would also be useful as an indicator of water quality impacts. Studies should be done to identify the extent and degree of sediment and water contamination in Tinicum. Samples should be taken on Folcroft Landfill, in adjacent soils and sediments, and in water to identify the degree to which Folcroft contributes to degraded water quality in Tinicum. Samples should be taken under varying flow regimes to discern the relative pollutant contributions from upstream sources.

IV. E. Groundwater Quality

No groundwater samples have been taken during investigations of the Folcroft Landfill. Because of the local topography, hydrology, and water table depths in Tinicum, groundwater in the perched water table would be expected to discharge directly into the creeks and tidal flats.

General groundwater quality in the water table system is characterized as weakly acidic, slightly mineralized, and calcium bicarbonate or calcium sulfate water. The mean concentration of dissolved solids is

679 ppm, and iron ranges from 0.08 to 429 ppm with a median of 1 ppm. Contaminant levels vary highly in this system (Hall, 1972).

Water in the artesian system may also discharge to the streams and Delaware River; however, the flows should be verified through field sampling. General chemical conditions are similar to those in the water table. Groundwater in the artesian system also exhibits widespread degradation. Iron levels typically range from 0.09 to 25 ppm and hardness may exceed 150 ppm (Hall, 1973).

Various data sources (STORET, DER files, local well-drilling records, Township engineers) were searched to identify monitoring or supply wells in the Tinicum area. Thirteen monitoring wells were identified in the 3-mile radius around Tinicum. Unfortunately, sampling in these wells was inconsistent with respect to depth, well type, period of record, and sampling parameter and correlations could not be made with groundwater in Tinicum. Thirteen water supply wells were identified along Maple and Ashland Avenues in Folcroft. These wells are less than one mile from the landfill. It is not known whether these wells are currently being used because public water supplies are available in the area.

One water table well is located upgradient of Folcroft Landfill near Clearview Landfill at 8316 Buist Avenue (U.S. EPA, 1985). A sample taken from this well identified several organic compounds at ppb levels including 1,2 dichloroethylene, vinyl chloride, trichloroethylene, chlorobenzene, and tetrachlorobenzene.

One well used as a drinking water source is located approximately 1 mile south of Folcroft landfill. The well is approximately 20-30 feet deep and currently serves a family of 2. Samples taken by DER in May and August 1985 by DER indicated lead levels of 0.087 and 0.103 ppm (the drinking water standard for lead is 0.05 ppm). The continuity between the aquifer underneath Folcroft and this residence is unknown.

An industrial supply well is located at Atlas Environmental Company on Industrial Drive, approximately 1 mile north of the Folcroft Landfill. The well is currently used for fire protection.

Groundwater sampling conducted by Boeing Vertol in Eddystone (Fouler, 1985) indicates that shallow water table wells are contaminated with organic halogen compounds. Groundwater samples at the Westinghouse facility also indicate low levels of chloroform and tetrachloroethylene in the water table. Because of the discharge relationship between Darby Creek, the tidal marsh, and the water table, it is likely that these values reflect water quality conditions in the creek and marsh.

In summary, data are inadequate to determine whether contaminants at Folcroft Landfill have entered groundwater. Additional studies should be done to identify the extent of groundwater contamination in Tinicum and the local flow regimes of groundwater. Samples should be collected to identify local flow patterns, tidal fluctuations, and groundwater treatability. Local well use and the potential for contamination of these wells from Folcroft Landfill should be identified.

IV. E. Biota

No extensive studies have been undertaken to determine the extent to which environmental contaminants at Tinicum may be entering the food chain. However, several limited studies have been done.

Erickson (1977) determined lead, zinc, copper, and cadmium levels in soils, cattails (foliage, stem, and rootstock) and muskrats (livers and kidneys) form four locations within Tinicum in an effort to relate pollution levels to muskrat population characteristics. The results showed a strong correlation between lead levels in soils and cattails (where lead seemed to concentrate mostly in the rootstocks) and muskrat tissue levels. Soil and plant cadmium levels were positively correlated, but muskrat tissue levels were not related to cattail concentrations. Muskrat "vitality" (condition, reproduction, density, etc.) appeared unaffected by the levels of pollutants detected. Unfortunately, the author made no effort to collect animals from a control area or to seek out comparable studies in the literature that would help determine whether the metal levels in biota were higher than background levels.

In 1976, PA DER and the PA Fish Commission collected "catfish" and carp samples from Darby Creek about 0.4 miles downstream from the Darby Creek Joint Authority Plant. Cadmium, lead, mercury, nickel, and zinc were detected in the edible portion of the fish. Quality assurance information was not presented for these data and several values appear suspect based on the precision reported. Therefore, no quantitative data are presented. From these results, the PA DER concluded that the fish did not represent a hazard to human consumers (U. S. FWS, 1978).

In 1982, Tinicum staff collected carp and brown bullhead fillets from the large impoundment and "16 acre pond" and had them analyzed for organochlorine pesticides, PCB's and metals. The contaminant levels detected in the fish are shown in Table 16. Levels of organochlorine pesticides, PCB's, and DDE/DDD in the brown bullhead sample from the 16-acre pond exceeded criteria established by the National Academy of Sciences/National Academy of Engineers (U.S. EPA, 1973) for the protection of piscivorous fish and wildlife. It should be noted that both of these ponds are isolated from Darby Creek and do not receive regular inflows of water from the Creek; therfore, these fish should not be considered representative of fish exposed to Darby Creek water.

In 1984, the Service's State College Field Office collected whole fish from Darby Creek for chemical analysis. White suckers were collected from an area just upstream of 84th Street, adjacent to the Clearview Landfill, and brown bullheads were collected from Darby Creek in the Long Hook area. In addition, snapping turtles were collected from the large impoundment. Turtle fat and leg meat were submitted for organochlorine analysis; two leg meat samples were analyzed for polcyclic aromatic hydrocarbons and aliphatic hydrocarbons; and five turtle livers were analyzed for metals.

Table 16. Results of heavy metals/organochlorine analysis of fish fillets from two locations within Tinicum N.E.C. Collection conducted by U.S. Fish and Wildlife Service, Tinicum N.E.C. staff. Samples collected in 1982. Values reported in ppm wet weight.

	Impoundment		16-acre Pond	
	Carp	Bullhead	Carp	Bullhead
Cadmium	<0.01	0.06	<0.01	0.03
Chromium	0.06	0.07	0.03	0.07
Lead	0.18	<0.1	<0.1	<0.1
Selenium	0.45	0.11	0.31	0.13
Mercury	0.11	0.02	0.01	0.12
Zinc	14.9	7.6	13.8	6.6
DDE	0.08	0.19	0.33	0.52
DDD	0.12	0.26	0.48	0.59
PCB (1260)	0.18	0.33	0.27	0.86
Alpha-BHC	0.05	0.02	---	---
Gamma chlordane	---	---	0.03	0.03
Dieldrin	---	---	---	0.06
Cis-nonachlor	---	---	---	0.01

Table 17 lists the data from the organochlorine analysis of these fish and turtle samples. Both fish samples exceeded the NAS/NAE criteria for dieldrin, cis-chlordane, trans-nonachlor and PCBs. In addition, the brown bullhead sample taken near the Folcroft Landfill exceeded the NAS/NAE criterion for DDT and its metabolites. Both fish samples also contained higher levels of DDE, DDD, dieldrin, trans-nonachlor and PCBs than the average concentrations found in fish from over 100 sampling stations nationwide in the Service's National Pesticide Monitoring Program for 1980-1981. Turtle leg meat samples proved to be relatively uncontaminated; no organochlorines were found above detection limits. Turtle fat, however, contained a variety of organochlorine contaminants, and high levels (4.7 to 23 ppm) of PCBs.

Table 17. Organochlorines in whole fish samples collected by the U.S. Fish and Wildlife Service from Darby Creek near Clearview and Folcroft Landfills August 7-8, 1984, and in snapping turtle leg meat and fat. Results in ppm wet weight.

	Brown Bullheads (Folcroft)	White Suckers (Clearview)	Range in Snapping Turtle Fat
p,p'-DDE	0.70	0.38	0.49-3.4
p,p'-DDD	0.53	0.30	N.D.-0.70
p,p'-DDT	N.D.	N.D.	N.D.
Dieldrin	0.17	0.35	0.23-0.45
Heptachlor epoxide	N.D.	N.D.	N.D.-0.13
Oxychlordane	N.D.	N.D.	0.26-0.75
Cis-chlordane	0.43	0.48	0.22-0.80
Trans-nonachlor	0.17	0.28	0.42-1.2
Cis-nonachlor	N.D.	N.D.	N.D.-0.32
Endrin	N.D.	N.D.	N.D.
Toxaphene	N.D.	N.D.	N.D.
PCBs (1260)	1.8	2.0	4.7-23

N.D. = not detected. Lower limit of reportable residues = 0.1 ppm for pesticide and 0.5 ppm for PCBs.

The five turtle livers were analyzed for lead, copper, zinc, vanadium, cadmium, aluminum, thallium, mercury, arsenic and selenium. The ranges and means of the results are shown in Table 18. Two turtle leg meat samples were analyzed for polycyclic aromatic hydrocarbon (PAH) analysis. In its analytical procedure for testing for PAHs, the laboratory also tested for aliphatic hydrocarbons. The results showed an absence of PAHs, but a wide variety of aliphatics including tridecane, tetradecane, octylcyclohexane, pentadecane, nonylcyclohexane, hexadecane, heptadecane, pristane, octadecane, phytane, nonadecane, and eicosane. The levels of these compounds ranged up to 0.21 ppm.

Table 18. Residues of metals in five snapping turtle liver samples from the Tinicum N.E.C. Turtles collected by staff of the Pennsylvania State University. Results in ppm wet weight.

	Range	Mean
Lead	N.D. - 0.19	0.138
Copper	1.4-3.0	1.94
Zinc	30.-36	35
Vanadium	N.D.-0.20	0.04
Cadmium	N.D.	--
Aluminum	1.9-6.6	3.88
Thallium	N.D.	--
Mercury	0.04-0.10	0.072
Arsenic	N.D.-0.08	0.016
Selenium	0.27-0.78	0.526

N.D.= none detected. Lower limit of reportable residues = 0.10 ppm for lead, copper, zinc, vanadium, cadium, and thallium; 1.0 ppm for aluminum; 0.02 ppm for mercury; and 0.05 ppm for arsenic and selenium.

Two additional biological tissue sampling efforts were undertaken at Tinicum in 1985, but the results are not yet available. The Fish and Wildlife Service's Patuxent Wildlife Research Center collected slugs, voles, white-footed mice and short-tailed shrews from a Phragmites dominated former dredge spoil disposal area within the Center's boundaries to evaluate heavy metal uptake. Results are not anticipated for some time. Also in 1985, Center staff collected fish samples from Darby Creek for chemical analysis. These results are also unavailable.

In summary, limited sampling data indicate that PCB's and pesticides have been transported into the food chain. Studies should be done in Darby Creek to identify whether heavy metals are present in biota. Analyses should also be done for all bioaccumulative pollutants found at Folcroft Landfill. If on-site samples taken at Folcroft Landfill indicate elevated pollutant levels, tissue analyses of terrestrial organisms should also be considered.

V. ENVIRONMENTAL ASSESSMENT

V. A. Contaminants of Concern

The preceeding chapter identified numerous contaminants present in the Tinicum area. Heavy metals such as lead, zinc, cadmium, mercury, and copper are present in water, sediment, and biota. Aromatic hydrocarbons including benzene, phenanthrene, and chrysene were found in sediments and drum samples. Darby Creek sediments contained varying levels of all priority pollutant metals. PCBs detected in Darby Creek sediments were also present in biota. Chlordane was found in Darby Creek sediments and fish tissue. Table 19 summarizes the results of the contaminant sampling by environmental medium in the area around Folcroft Landfill.

A serious limitation of the historical data base is the general absence of analyses for organic compounds in environmental samples; the majority of analyses were conducted for heavy metals. Because of this sampling limitation, there are no data which would help define the source of organochlorine pesticide levels detected in biota or PAH's detected in Darby Creek sediments. Data are also lacking to define the extent of contamination in the watershed, in the soils on Folcroft Landfill, in the groundwater, and in the food chain. Because of these data limitations, the remainder of this report will focus on those contaminants which had a significant data base in all media. Further discussion is also limited to those contaminants present at levels which would be expected to adversely impact natural resources. These compounds are silver, cadmium, chromium, copper, mercury, lead, nickel, zinc, cyanide, PCBs, and chlordane.

V. B. Fate and Transport

V.B.1. General Processes

Metals in the aquatic environment exist as soluble ions, organic complexes, coprecipitates, or adsorbed to sediment hydroxide particulates. Metal equilibria among these phases are influenced by pH, DO, suspended solids, and concentration among other factors. Existing data are inadequate to predict predominant metal species in the water column or sediments. Future monitoring should focus on defining the equilibria of these metals in Tinicum Marsh.

Limited data are available on heavy metal fluxes in tidal freshwater marshes. Studies in Woodbury Creek Marsh (a Delaware River tidal freshwater wetland in New Jersey) indicate that cadmium is exported from the marsh through tidal fluxes, while nickel, copper, zinc, and lead are imported and retained in the marsh ecosystem. Metal uptake by vegetation was most notable during the growing season. Following dieback of macrophytic species, levels of heavy metals increase substantially in litter (Simpson et al., 1983) and may represent a short term sink for heavy metals following the growing season.

In soils, metals may be present bound to clays, as metal oxides

Table 19. Maximum concentration of contaminants detected in sampled media at Folcroft Landfill and in Darby Creek. An asterisk signifies that no data are available.

	Medium sampled											
Contaminant	Annex Soil ppm	Landfill Soil ppm	Landfill Runoff ppb	Landfill Sediment ppm	Annex Leachate ppb	Landfill Leachate ppb	Darby Cr Sed. ppm	Darby Cr Water ppb	Hermesprota Cr. ppb	Turtle Livers ppm	Turtle Fat ppm	Whole Fish ppm
Arsenic		*	*	2.7	*	*	26	92	12	0.08	*	*
Barium	1.4	*	*	*	*	*	132	3310	208	*	*	*
Cadmium	0.02	0.003	0.26	13			1.3	65			*	*
Chromium	0.09	*	*	17.8			40.7	1500	34	*	*	*
Copper	0.13	0.13	*	25.2		190	59	2070		3.0	*	*
Iron	*	*	*	11200	4250	3030	20200	50500	14000		*	*
Lead	3.1	0.34	54	1260	12	200	153	3450		0.19	*	*
Mercury	.0015	*	*	*	*	*	0.4	2.0		0.1	*	*
Nickel	*	*	*	0.5		70	19.5	908			*	*
Selenium		*	*	*	*	*	0.4	2.5		0.78	*	*
Silver	0.02	*	*		*	*	1.2				*	*
Zinc	0.57	0.54	*	125	97	1090	235	8460	206	36	*	*
Cyanide	*	*	4560	400	*	*	5600	445			*	*
PCB1242	*	*	*	*	*	*	1.57	*	*	*		
PCB1260	*	*	*	*	*	*	0.06	*	*	*	23	1.8
Chlordane	*	*	*	*	*	*	0.67	*	*	*		0.03
Cis-nonachlor	*	*	*	*	*	*	*	*	*	*	.32	0.01
Trans-nonachlor	*	*	*	*	*	*	*	*	*	*	1.2	0.17
Dieldrin	*	*	*	*	*	*	*	*	*	*	.45	0.17
Alpha-BHC	*	*	*	*	*	*	*	*	*	*		0.05
DDE	*	*	*	*	*	*	*	*	*	*	3.4	0.7
DDD	*	*	*	*	*	*	*	*	*	*	0.7	0.53
DDT	*	*	*	*	*	*	*	*	*	*		
toxaphene	*	*	*	*	*	*	*	*	*	*		
Heptachlor epoxide	*	*	*	*	*	*	*	*	*	*	0.13	
Fluoranthene	*	*	*	*	*	*	2.3	*	*	*	*	*
Chrysene	*	*	*	*	*	*	1.1	*	*	*	*	*
Phenanthrene	*	*	*	*	*	*	1.5	*	*	*	*	*
Pyrene	*	*	*	*	*	*	3.4	*	*	*	*	*
Benzo(a)anthracene	*	*	*	*	*	*	1.1	*	*	*	*	*
Anthracene	*	*	*	*	*	*	<.5	*	*	*	*	*
Naphthalene	*	*	*	*	*	*	<.5	*	*	*	*	*

or sulfates, or in a soluble form. In general, complexation with organic compounds increases the solubility of metals in soil as does reduced pH. Flooding and anaerobic decomposition in the tidal marsh would be expected to increase the complexation and leaching rate from marsh soils.

The distribution of PCBs in the environment is affected by adsorption, volatilization, and bioaccumulation. Sorption to suspended bed sediments is the dominant fate in natural waters because of PCBs low solubility. The degree of adsorption increases with increasing chlorination of the molecule, and with the organic content of the adsorbent (US EPA, 1979). PCBs in the heavier Aroclor series (such as PCB1260 detected in Tinicum) are essentially non-biodegradable.

Chlordane fate in the environment is affected by volatilization, sorption to sediments, and bioaccumulation. There is little known about biotransformation of chlordane (US EPA, 1979).

V. B. 2. Specific Transport Processes

Contaminant transport in the Tinicum Marsh was studied to determine whether substances are being transported from upstream sources to the Center, transported from Folcroft Landfill to adjacent tidal marshes and creeks, or transported out of the Center by tidal flushing.

V.B.2.a. Soil and Groundwater

Site specific data are not available to model groundwater transport and soil runoff. In addition, hydrologic and geologic data are unavailable to calibrate or verify models. Groundwater in the upper aquifer is expected to discharge directly into the tidal marsh, Darby/Thoroughfare Creeks, and Hermesprota Creek. In the absence of localized flow data, quantitative estimates of groundwater discharge could not be determined.

Site specific soil data are also lacking. Areas which have been poorly vegetated on Folcroft Landfill would be expected to be highly erodible. Portions of the landfill which directly abut the creeks and marsh are expected to be readily eroded by tidal action. Thus any contaminants sorbed onto the eroding soil will enter the aquatic system.

Future monitoring should identify whether soil runoff and groundwater transport to the marsh represent significant pathways for contaminant transport.

V.B.2.b. Water and Sediments

Although site specific data are generally not available for a number of hydrologic and water quality parameters, transport of surface water and sediments into and out of Tinicum Marsh was estimated using the best available information. Data were evaluated to determine the flow characteristics of Darby and Cobbs Creek, the flushing time of Darby Creek, the settling and resuspension rates of adsorbed materials and the desorption rate of organic contaminants.

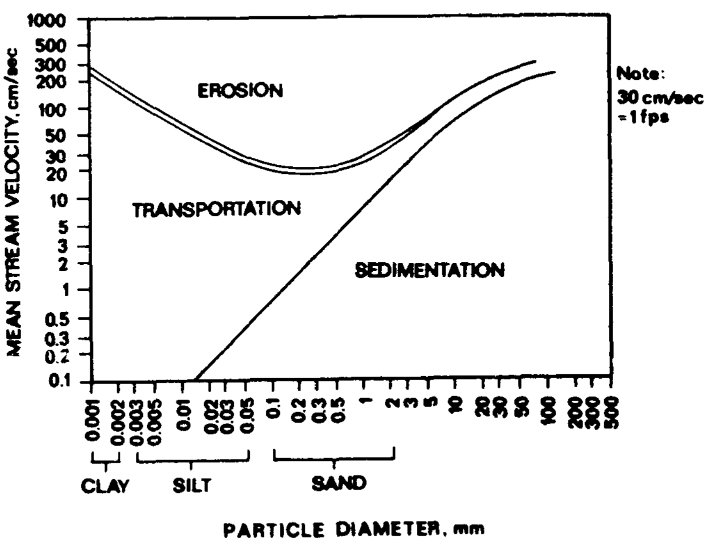
V.B.2.b.1. Flow characteristics of Darby and Cobbs Creeks

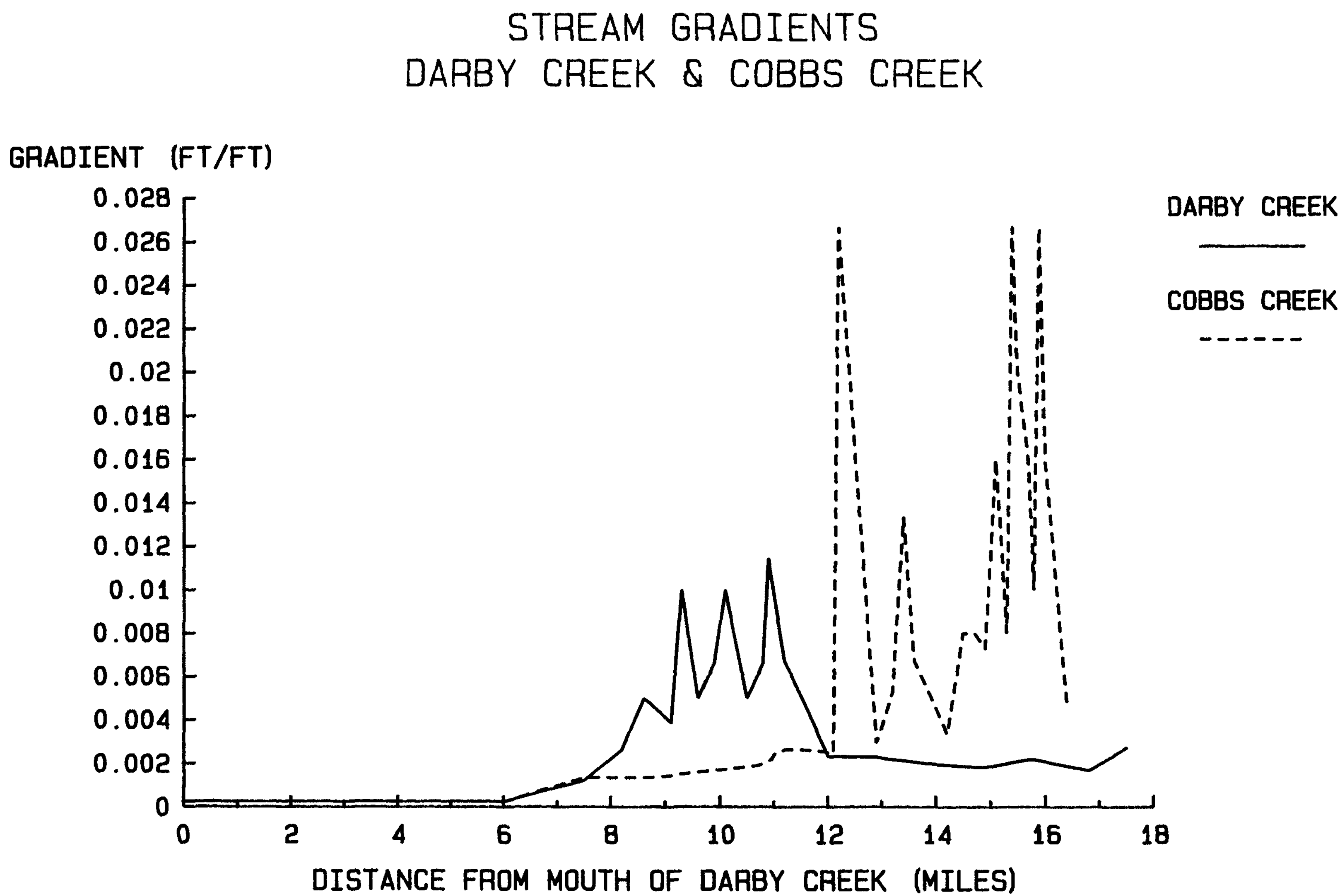
The stream gradients on Darby and Cobbs Creeks were examined to predict which stream segments are experiencing scour or settling of sediments. This determination depends primarily on stream velocity and particle size of sediments. Figure 18 illustrates this relationship. Stream velocity is a function of stream gradient, cross-sectional area and a coefficient representing the roughness of the stream channel. In general, increases in stream gradient results in increased velocities when other factors are constant. Because cross-sectional areas and roughness coefficients are not available for the various stream segments on Darby and Cobbs Creeks, predicting actual velocities is not possible. However, stream gradients have been analyzed to identify areas where increases or decreases in stream velocity might be expected.

The gradients for both streams are illustrated in Figure 19 as they relate to distance upstream from the mouth of Darby Creek. Darby Creek experiences its highest stream gradients through the 4 mile stream reach which begins approximately 8 miles from the mouth. The gradient exceeds 0.003 ft/ft throughout this reach and exceeds 0.01 ft/ft in three stream segments.

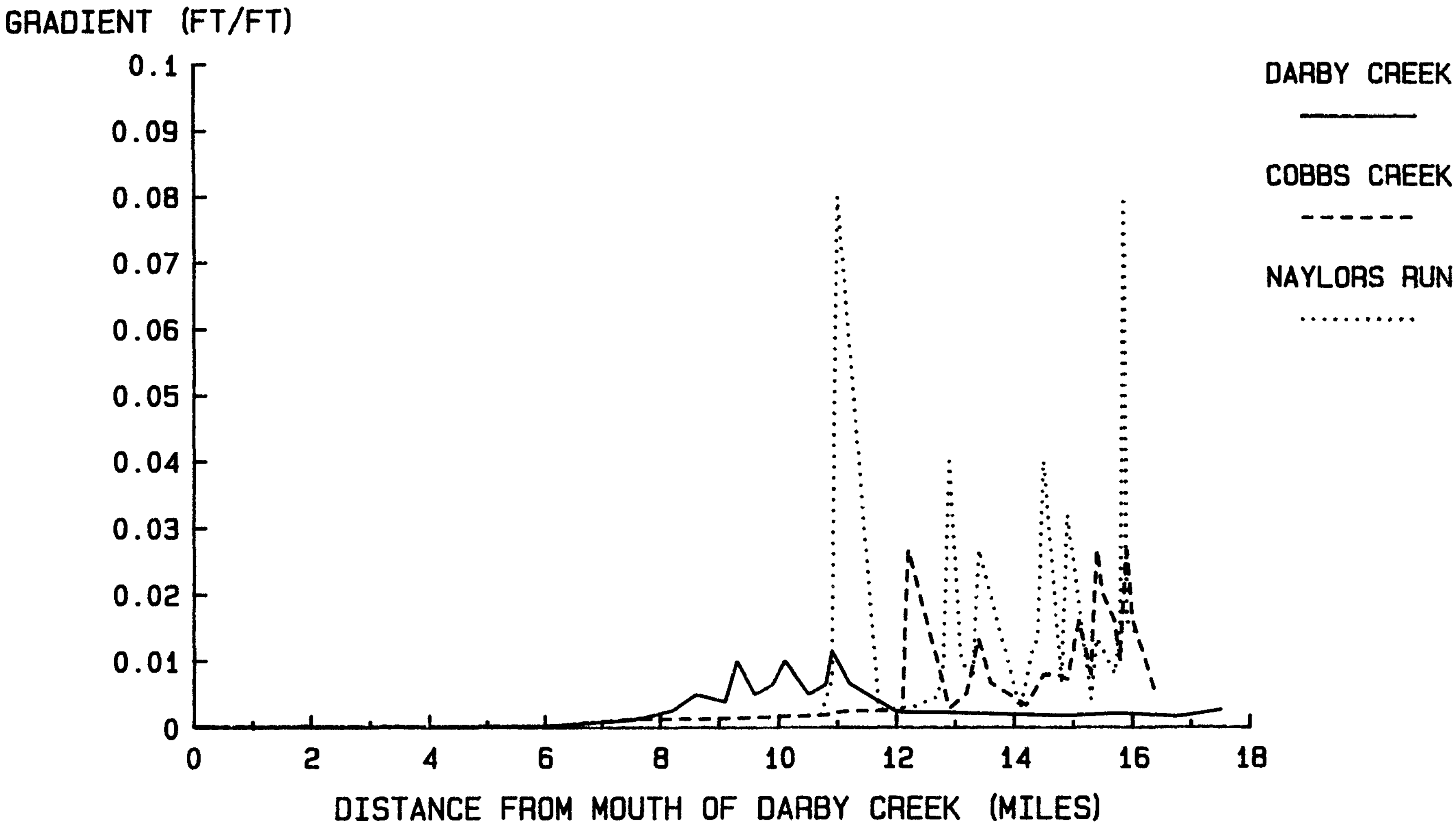
On Cobbs Creek, the stream gradient begins to fluctuate significantly beginning 12 miles from the mouth of Darby Creek. The gradient through the 4 mile reach upstream of this point exceeds 0.003 ft/ft throughout, exceeds 0.013 ft/ft in two segments, and exceeds 0.026 ft/ft in three segments.

Figure 18. Relationship between stream velocity, particle size, and the regimes of sediment erosion, transport, and deposition.




STREAM GRADIENTS
DARBY CREEK & COBBS CREEK
GRADIENT (FT/FT)
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0
2
4
6
8
10
12
14
16
18
DISTANCE FROM MOUTH OF DARBY CREEK (MILES)
DARBY CREEK
COBBS CREEK

STREAM GRADIENTS
DARBY CREEK, COBBS CREEK & NAYLORS RUN



The increased stream gradients through each of these reaches on Darby and Cobbs Creeks may result in velocities high enough to cause the scouring of stream sediments. Because stream gradients remain relatively low below each of these reaches, decreased velocities could be expected and sediment being carried by the stream would begin to settle.

The stream gradient was also examined on Naylors Run, a tributary to Cobbs Creek. The relationship between the gradient on this stream and Cobbs and Darby Creeks is illustrated in Figure 20. Stream gradients in Naylors Run range from a low of 0.00267 ft/ft to a high of 0.08 ft/ft. Scouring of sediments from this tributary could be expected in high gradient reaches.

Sediment scoured from the higher gradient reach on Darby Creek would have to be transported approximately 2 miles before reaching the section of stream influenced by tidal action. On Cobbs Creek, the higher gradient reach is approximately 6 miles above this point. Sediments scoured from Naylors Run would enter Cobbs Creek and have to travel approximately 3.7 miles before reaching tidal waters.

The section on Darby Creek influenced by tidal action begins at the mouth and extends upstream for approximately 6 miles. This tidal influence, along with the low stream gradient through this section (0.00027 ft/ft), results in low stream velocities. Sediment suspended in the water column would be expected to settle out or remain in suspension through this stream section depending on particle size. The stream velocity due solely to tidal action can be estimated as follows:

$$Q = \frac{V}{T} \qquad \text{and} \qquad U = \frac{Q}{A}$$

where

Q = discharge, m^3/s
V = intertidal volume, m^3
T = time of one-half of tidal cycle, s
U = stream velocity, m/s
A = cross-sectional area of channel, m^2

At the mouth of Darby Creek, the tidal velocity equals:

$$Q = \frac{452{,}854 \ m^3}{22{,}320 \ s} = 20 \ m^3/s$$

$$U = \frac{20 \ m^3/s}{90 \ m^2} = 0.22 \ m/s = 22 \ cm/s$$

According to Figure 18, sediment particles <0.05 mm in diameter would be transported at this velocity; particles between 0.05 and 1.0 mm would be eroded; particles between 1.0 and 3.0 mm would be transported; and particles >3.0 mm would be deposited.

If the cross-sectional area of Darby Creek remained the same, the tidal velocity approximately three miles from the mouth would be:

$$Q = \frac{68{,}179\ m^3}{22{,}320\ s} = 3\ m^3/s$$

$$U = \frac{3\ m^3/s}{90\ m^2} = 0.03\ m/s = 3\ cm/s$$

At this velocity, sediment particles <0.4 mm would be transported while those >0.4 mm would be deposited.

As mentioned earlier in this discussion, the stream gradient, the cross-sectional area and the roughness of the channel all are equally important in determining stream velocity. This analysis of potential scouring or settling of sediments in various stream reaches can only be used as a guide for future data collection. Cross-sectional areas and roughness coefficients must be determined for individual stream reaches to determine actual stream velocities. In addition, analysis of sediment particle size is necessary to predict if that particle will be subject to scouring or settling at a given stream velocity. Future studies should include an analysis of particle size, stream gradient, and stream cross-section so that these estimates can be refined.

V.B.2.b.2. Flushing Time on Darby Creek

Flushing time is a measure of the time required to transport a conservative pollutant from some specified location within the estuary (usually, but not always, the head) to the mouth of the estuary. The Modified Tidal Prism Method (US EPA, 1985) was used to describe the flushing time on Darby Creek. This method divides an estuary into segments whose lengths are defined by the maximum excursion path of a water particle during a tidal cycle. Within each segment, the tidal prism is compared to the total segment volume as a measure of the flushing potential of that segment per tidal cycle.

To calculate the tidal prism (or intertidal volume), a straight-line relationship was assumed between the cross-section of the stream at the mouth of Darby Creek and the cross-section at the upstream limit of the tidal influence. The intertidal width ranges from 40 feet (12m) at the upstream limit to 250 feet (75m) at the mouth of Darby Creek. The intertidal depth ranges from 0 at the upstream limit to 5.8 feet (1.74 m) at the mouth. The intertidal volume was calculated every 100 meters. These volumes along with the cumulative intertidal volume are presented in Appendix Table F.

The subtidal volume was also calculated on Darby Creek. A straight-line relationship was again used assuming a parabolic channel with a top width of 40 feet (12 m) and depth of 3 feet (0.9 m) at the upstream limit and a top width of 250 feet (75 m) and depth of 6 feet (1.8 m) at the mouth. The subtidal volumes were calculated every 100 meters. These volumes along with the cumulative subtidal volume are also presented in Appendix Table F.

To use the tidal prism method, the estuary must be segmented starting at the upstream limit so that each segment length reflects the excursion distance a particle can travel during one tidal cycle. The first segment must then have an intertidal volume completely supplied by stream flow. Since the average annual discharge of Darby Creek is 101 cfs (3 m^3/s), the discharge over one tidal cycle (R) equals the following:

$$R = 3\ m^3/s \times 12.4\ hrs/tidal\ cycle \times 3600\ s/hr$$

$$= 133{,}920\ m^3$$

The cumulative intertidal volume (I1) corresponding to this discharge volume occurs at a distance of 6169 meters from the upstream limit. The cumulative subtidal volume (S1) occurring at this same distance is 165,085 m^3. Hence, the total volume of this segment (V1) equals:

$$V1 = I1 + S1 = 133{,}920\ m^3 + 165{,}085\ m^3 = 299{,}005\ m^3$$

The downstream boundary of the next seaward segment is located at the distance where the subtidal volume of that segment equals the combined subtidal and intertidal volumes of the previous segment. Because the date is presented as cumulative volumes, the volume at any given distance represents the volume from the upstream limit to that distance. To find the volume for a particular stream segment, the volume at the upstream boundary of that segment must be subtracted from the downstream volume. Hence:

$$S2 = S2d - S2u$$

where

S2 = subtidal volume of segment 2
S2d = subtidal volume at downstream limit of segment
S2u = subtidal volume at upstream limit.

Since the subtidal volume of the upstream boundary of segment 2 (S2u) is the same as the subtidal volume of segment 1:

$$S2u = S1\ .$$

Therefore,

$$S2d - S2u = I1 + S1\quad S2d = I1 + S1 + S2u$$

$$= V1 + S1 = 299{,}005\ m^3 + 165{,}085\ m^3$$

$$= 453{,}090\ m^3$$

This volume exceeds the cumulative subtidal volume of Darby Creek at the mouth. Therefore, under normal flow conditions, the estuary has only one segment.

The flushing time (T) for that segment is calculated by:

$$T1 = \frac{S1 + I1}{I1} = \frac{V1}{I1}$$

$$= \frac{299{,}005\ m^3}{133{,}920\ m^3} = 2.2 \text{ tidal cycles .}$$

Flushing time for an estuary varies over the course of a year as the river discharge varies. Since low flushing rates correspond with low stream discharge, the flushing time was also calculated for low flow conditions on Darby Creek when stream discharge is 20 cfs (0.6 m3/s). Under these conditions, the estuary can be divided into three segments with boundaries approximately as shown in Figure 33. An estimated three tidal cycles or 1.5 days are required for stream flow entering the estuary to pass through the first segment. Flow through the second segment requires 1.79 tidal cycles or 22 hours and flow through the third segment requires 1.56 tidal cycles or 19 hours. The total flushing time for the Darby Creek estuary under low flow conditions is 6.29 tidal cycles or 3.25 days. Table 20 summarizes the segment information.

Table 20. Estimated flushing times on Darby Creek during low flow conditions.

Segment	Downstream Segment Boundary (m)	Intertidal Volume (m^3)	Subtidal Volume (m^3)	Segment Flushing Time (tidal cycles)
1	3363	55,288	26,784	2.94
2	5505	82,072	103,309	1.79
3	8505	185,381	333,926	1.56

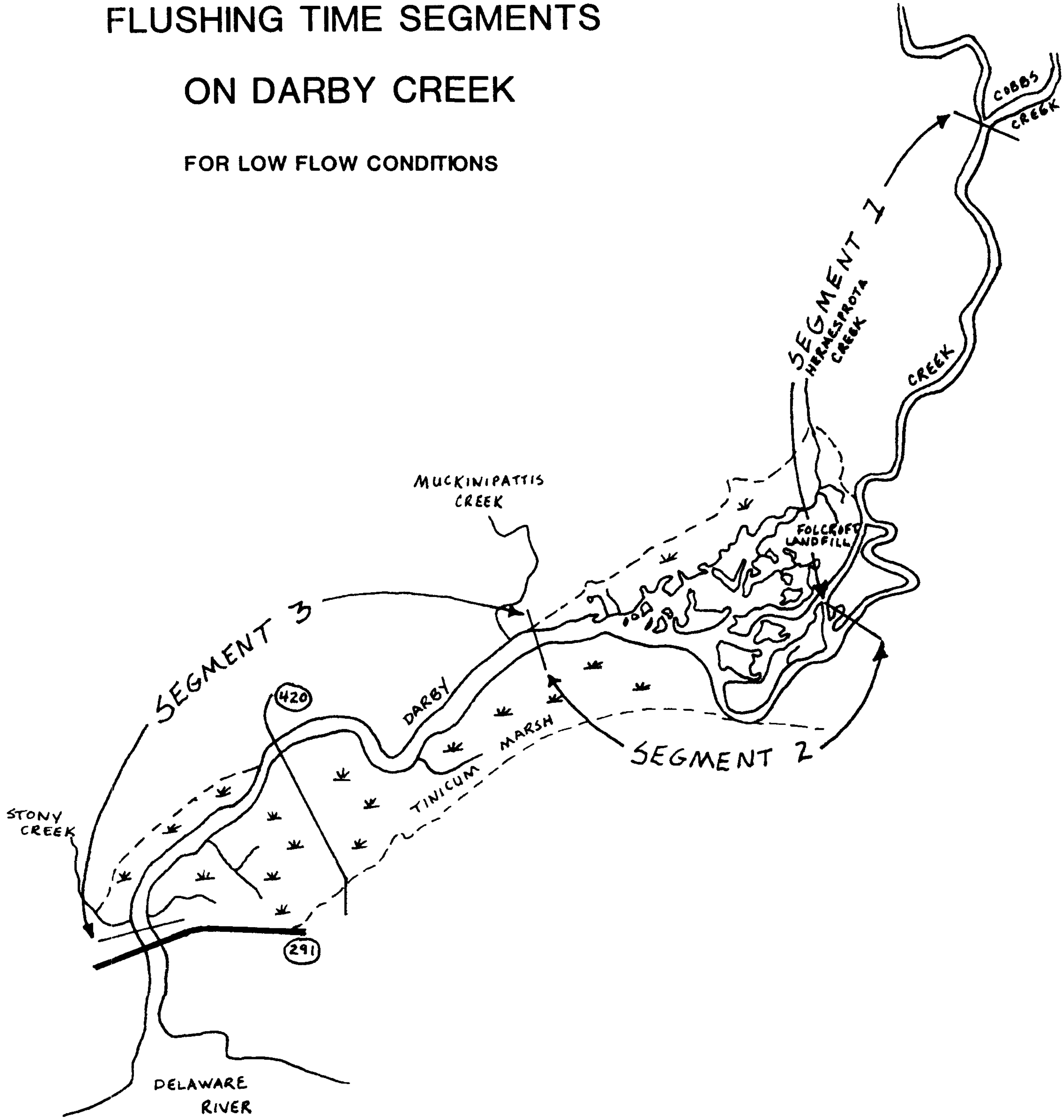
V.B.2.b.3. Settling and Resuspension of Adsorbed Metals

Resuspension and deposition of contaminated sediments redistributes adsorbed contaminants to and from the bed. According to EPA's Water Quality Assessment: A Screening Procedure for Toxic and Conventional

Figure 21

FLUSHING TIME SEGMENTS ON DARBY CREEK

FOR LOW FLOW CONDITIONS



Pollutants in Surface and Ground Water (Rev. 1985), the rate of resuspension and the rate of settling can be predicted as follows:

$$Wrs = \frac{uHl(SSd - SSu)}{mx(106)}$$

and

$$Ws = \frac{-Hlu}{x} \ln\left[\frac{SSu}{SSd} \right]$$

where

- Wrs = resuspension velocity, m/day
- Ws = settling velocity, m/day
- u = stream velocity, m/day
- Hl = water depth, m
- SSd = suspended solids concentration at downstream boundary, mg/l
- SSu = suspended solids concentration at upstream boundary, mg/l
- m = solids concentration in bed, kg/l
- x = distance downstream, m

While heavy metal concentrations have been measured in both the sediments and the water column on Darby and Cobbs Creeks, prediction of transport of contaminated sediments through resuspension and deposition has been impossible due primarily to lack of suspended solids data and cross-sectional areas of the stream channel. Future data collection efforts should first center on estimating stream velocities. This information can then be used to predict which stream segments may be experiencing resuspension and which are experiencing deposition. After this prediction is made, suspended solids concentrations need to be measured at the boundaries of each of these segments.

V.B.2.b.4. Desorption of Organic Toxicants from Darby Creek Bed

Sediment samples were collected from Darby and Cobbs Creeks and analyzed for organic toxicants. Ten samples were taken in the vicinity of the Clearview Landfill and four were taken at the Folcroft Landfill. Only the samples taken at Clearview Landfill yielded results adequate for further modeling. These samples were used to estimate the concentration of organic toxicants in the water column through the process of desorption. The following equation (US EPA, 1985) was used to calculate the average water column concentrations:

$$Cwc = \frac{Cs0}{KpD}$$

where

Cwc = average water column concentrations (ppm)

Cs = concentration of pollutant in bed (ppm)
O = equivalent depth of water in sediment (mm)
Kp = partition coefficient
D = depth of contaminated sediment (mm).

Because the depth of contaminated sediment (D) and the equivalent depth of water in the sediment (O) were unknown, these quantities were estimated using Table I which is provided in the screening procedure.

The percent solids by weight for the samples ranged from 59% to 100% with an average value of 84%. Using the value of 80% on Table 21, the ratio of the equivalent depth of water (O) in the sediment to the depth of contaminated sediments (D) is constant at 0.27. Therefore, the equation to calculate concentrations of the organic toxicants in the water column can be simplified to:

$$Cwc = \frac{Cs}{Kp} \times 0.27.$$

The partition coefficient (Kp) can be calculated using the following equation:

$$Kp = Koc[0.2(1-f)X^{s}oc + fX^{f}oc]$$

where

Koc = partition coefficient expressed on an organic carbon basis
f = mass fraction of fine sediments
$X^{s}oc$= organic carbon content of coarse sediment fraction
$X^{f}oc$= organic carbon content of fine sediment fraction

The value of Koc can be related to the octanol-water partition coefficient (Kow) by the following relationship:

$$Koc = 0.63Kow$$

In the absence of detailed information on sediment grain size and organic carbon content, the screening procedure provides the following equations for calculating typical and maximum values for the partition coefficient:

Typical value for Kp = 0.01Kow
Maximum value for Kp = 0.065Kow

The concentration of desorbed organic toxicants in the water was calculated using both the typical and maximum values for the partition coefficients. In addition, concentrations were calculated using both the mean and maximum concentration detected at the ten sample sites. Table 22 summarizes the results.

The effective removal velocity through desorption is estimated as follows:

Table 21. Mass of Contaminated Sediments and Equivalent Water Depth as a Function of Depth of Contamination.

Depth (mm)	Percent Solids by Weight	Ms (g/cm2)	O (mm)
1	20	0.02	0.9
	50	0.06	0.6
	80	0.11	0.3
5	20	0.11	4.5
	50	0.30	3.0
	80	0.55	1.4
10	20	0.23	9.1
	50	0.60	6.0
	80	1.10	2.7
20	20	0.45	18.0
	50	1.20	12.0
	80	2.20	5.5
50	20	1.10	45.0
	50	3.00	30.0
	80	5.50	14.0
100	20	2.30	91.0
	50	6.00	60.0
	80	11.00	27.0

$$Ue = \frac{UO}{Ms\,Kp}$$

where

Ue = effective removal velocity (cm/sec)
U = stream velocity (cm/sec)
O = equivalent depth of water in sediment (cm)
Ms = mass of contaminated sediment per unit of stream bed (g/cm2)
Kp = partition coefficient.

The stream velocity for the contaminated stream segment flowing by the Clearview Landfill was estimated assuming a parabolic channel with a top width of 40 feet and a depth of 3 feet. The stream gradient through this area is estimated to be 0.00027 ft/ft. Using Manning's equation with a roughness coefficient of 0.025, the stream velocity is calculated to be 1.5 ft/sec (45 cm/sec).

Using Table 21 for 80% solids by weight, the ratio of the equivalent depth of water in the sediment (O) to the mass of contaminated sediment per unit area of river bed (Ms) is a constant value of 0.25. This simplifies the effective removal velocity to:

$$Ue = \frac{U}{Kp} \times 0.25 .$$

The time required to desorb the toxicant is·

$$T = \frac{L}{Ue}$$

where

T = time required (sec)
L = length of contaminated stream segment (cm).

The length of the contaminated stream segment flowing by the Clearview Landfill is approximately 1400 feet (42000 cm). Table 22 presents the time required for desorption of the organic toxicants detected. These desorption times do not reflect the influence of other transformation processes such as microbial degredation on the contaminated sediments.

Table 22. Water column concentrations and required desorption times for organic toxicants in Naylors Run.

Parameter	Kp Typcial and Maximum	Cs 1 Mean Conc. (ppm)	Cs 2 Mean Conc. (ppm)	Cwc WC Conc Using Cs1 (ppm)	Cwc WC Conc Using Cs2 (ppm)	Desorption Time (days)
Fluoranthene	3400	1.36	2.80	1.08×10^{-4}	2.22×10^{-3}	147
	22100			1.66×10^{-5}	3.42×10^{-5}	955
Chrysene	4000	1.02	1.30	6.89×10^{-5}	1.89×10^{-4}	173
	26000			1.06×10^{-5}	2.91×10^{-5}	1123
Phenanthrene	290	1.29	1.70	1.20×10^{-3}	2.61×10^{-3}	13
	1885			1.85×10^{-4}	4.01×10^{-4}	81
Pyrene	2000	1.77	3.40	2.39×10^{-4}	3.78×10^{-4}	86
	13000			3.68×10^{-5}	5.82×10^{-5}	562
Benzo(a)anthracene	4000	1.03	1.40	6.95×10^{-5}	1.89×10^{-4}	173
	26000			1.07×10^{-5}	2.91×10^{-5}	1123
PCB1260	10000	0.14	0.23	3.78×10^{-6}	7.56×10^{-5}	432
	65000			5.82×10^{-7}	1.16×10^{-5}	2809
PCB1242	2000	0.77	1.57	1.04×10^{-4}	3.78×10^{-4}	86
	13000			1.60×10^{-5}	5.82×10^{-5}	562
Chlordane	6	0.21	0.96	9.45×10^{-3}	1.26×10^{-1}	0
	39			1.45×10^{-3}	1.94×10^{-2}	2
Benzo(a)pyrene	10000	1.10	1.10	2.97×10^{-5}	7.56×10^{-5}	432
	65000			4.57×10^{-6}	1.16×10^{-5}	2809

In addition to the sediment samples analyzed at the Clearview and Folcroft Landfills, the sediments in the headwaters of Naylors Run were analyzed for a number of organic toxicants. Several polynuclear aromatic hydrocarbons present in the samples taken near the Clearview Landfill were also present in the Naylors Run sediments. While the relative

Table 23. Relative proportion of organic toxicants in Darby Creek and Naylors Run sediments.

Compound	Darby Creek Average Conc. (ppm)	Darby Creek Relative Proportion (%)	Naylors Run Average Conc. (ppm)	Naylors Run Relative Proportion (%)
Fluoranthene	1.36	18	9.80	27
Chrysene	1.02	13	4.51	12
Phenanthrene	1.29	17	8.83	24
Pyrene	1.77	23	5.46	15
Benzo-a-anthracene	1.03	14	4.37	12
Benzo-a-pyrene	1.10	15	3.53	10
Totals	7.57	100	36.50	100

proportion of these compounds in the sediments does not remain constant (Table 23), the variation can be explained by differences in water solubility. The two compounds which decrease in relative proportion in Darby Creek are fluoranthene and phenanthrene. These are both three-ringed PAH's which are more water soluble than the other four- and five-ringed compounds. These data therefore support the hypothesis that contaminated sediments from Naylors Run are being transported in Darby Creek.

The water column concentration resulting from desorption of toxic organics in the sediments on Naylors Run can be calculated using the same procedure outlined for Darby Creek. These concentrations along with the time required to desorb these toxicants from the sediments are presented in Table 24.

Table 24. Water column concentrations and required desorption times for organic toxicants in Naylors Run.

Parameter	Kp Typcial and Maximum	Cs1 Mean Conc. (ppm)	Cs2 Mean Conc. (ppm)	Cwc WC Conc Using Cs1 (ppm)	Cwc WC Conc Using Cs2 (ppm)	Desorption Time (days)
Fluoranthene	3400	9.80	37.00	7.78×10^{-4}	2.94×10^{-3}	147
	22100			1.20×10^{-4}	4.52×10^{-4}	955
Chrysene	4000	4.51	15.00	6.62×10^{-4}	2.50×10^{-3}	173
	26000			1.02×10^{-4}	3.84×10^{-4}	1123
Phenanthrene	290	8.83	36.00	9.12×10^{-3}	3.44×10^{-2}	13
	1885			1.40×10^{-3}	5.30×10^{-3}	81
Pyrene	2000	5.46	16.00	1.32×10^{-3}	5.00×10^{-3}	86
	13000			2.04×10^{-4}	7.68×10^{-4}	562
Benzo(a)anthracene	4000	4.37	14.00	6.62×10^{-4}	2.50×10^{-3}	173
	26000			1.02×10^{-4}	3.84×10^{-4}	1123
Benzo(a)pyrene	10000	3.53	12.00	2.65×10^{-4}	9.99×10^{-4}	432
	65000			4.07×10^{-5}	1.54×10^{-4}	2809

V.B.2.b.5. Source Identification

The apparent increases in pollutant concentrations with distance downstream in Darby Creek and the observed elevated levels of metals in the Folcroft area can be explained by a number of hypotheses:

1. Important pollutant loads exist just above the downstream sampling location at the Route 291 Bridge on Darby Creek.
2. The samples reflect pollutant concentrations in the Delaware River waters which enter the Creek through tidal action.
3. Pollutants are resuspended or desorbed from contaminated downstream sediments.
4. Contaminated upstream sediments are scoured and transported downstream during ebb tide.
5. The effect is an artifact of sampling error.

The existence of high pollutant loads in the lower part of Darby Creek is suggested by the locations of the highest observed pollutant concentrations. Pollutant concentrations at the mouth of Darby Creek should reflect loadings from all sources upstream because samples were taken at low slack tide. Concentrations just downstream of Folcroft Landfill were greater than concentrations in the sample at the Route 291 bridge, suggesting that particulate settling or dilution is occurring between these stations. The high concentrations from Folcroft might have been diluted at the mouth of Darby Creek by tidal mixing from the Delaware River. Alternatively, high metal concentrations in the water column could be a result of metal-carbonate equilibrium resulting from the high alkalinity discharge from the landfill.

The observation that concentrations were greater just downstream of Folcroft Landfill than at the mouth of Darby Creek suggests that the Delaware was not the source of higher pollutant concentrations in the marsh. The proportion of Delaware River water at the Route 291 bridge is greater than that at Folcroft Landfill at the same tide stage. A positive correlation between contaminant levels and stream flow at low slack water flow also indicates that the Delaware was not the source of pollutants measured in Darby Creek near Folcroft Landfill.

To test the effect of tidal inflow from the Delaware, means of water quality constituents at the Route 291 bridge sampling station were compared with means measured in the Delaware River at Eddystone by the Student's t-test (Table 25). Of the 13 parameters compared, ammonia, nitrite, chromium, lead, and zinc were significantly more concentrated in the Delaware. Dissolved oxygen and nitrate concentrations were greater in Darby Creek. These results suggest that tidal inflow of Delaware River water may degrade the water quality of Darby Creek, but would also considerably dilute contaminants from upstream sources. The pollutant concentrations at Folcroft Landfill are probably not influenced by the Delaware.

The possibility that pollutants in Darby Creek just downstream of Folcroft Landfill were desorbed from sediments in this area is also unlikely because the system flushing times are short relative to diffusion times. Resuspension of sediments is also unlikely because ebb tide velocities are estimated to be too low to resuspend sands, silts, and clays.

Scouring of upstream sediments during ebb tide transport is a possibility that cannot be ruled out by the existing data. If scoured sediments were transported as far as the Tinicum area during each ebb tide, then high water column concentrations could occur even though upstream water column concentrations are low at slack tide. Upstream velocities are low and the resuspended material would be transported downstream during the ebb flow. If this scenario were occurring, the contaminated sediments would be located in the tidal portion of the creek which extends just above Route 84, downstream of Clearview Landfill.

None of these hypotheses can be accepted or rejected without additional monitoring designed to test each hypothesis. However, hypotheses 1 and 4 seem most probable. The elevated levels of heavy metals in leachate taken from Folcroft Landfill support the theory that the landfill is an important source above the most downstream station. Discrete samples collected throughout the ebb tide cycle under several flow conditions should provide data sufficient to determine what conditions are responsible for the observed increase in water column concentrations with distance downstream at low slack tide.

Table 25. Comparison of mean pollutant concentrations in Darby Creek and Delaware River. An asterisk indicates the difference between means is significant at the 95% confidence level based on the Student's t-test. Conductivity is in umohs; DO, BOD, ammonia, nitrate, and nitrite are in mg/l; pH is in standard units; and all other analytes are in ug/l.

	Darby Creek			Delaware River			Calc. T
	Mean	N	S. Dev.	Mean	N	S.Dev.	
Cond.	352.0	53	167.3	369.8	386	317.5	0.6342
DO	6.771	21	2.637	4.548	477	2.871	3.7656*
BOD	2.95	52	2.396	3.647	359	1.949	2.0054
pH	6.856	53	0.312	7.041	461	9.191	0.4291
Ammonia	0.742	53	0.571	1.017	445	0.678	3.2341*
Nitrite	0.979	53	0.104	0.155	469	0.156	3.5689*
Nitrate	1.819	53	0.665	1.378	456	0.665	4.5652*
As	107.8	53	282	<30			
Cd	0.375	16	0.377	<10			
Cr	15.22	23	8.979	34.45	27	34.68	2.7740*
Cu	27.75	35	17.92	27.05	23	38.83	0.0813
Fe	986.8	53	658	929.1	427	700.2	0.5972
Pb	17.45	36	37.0	62.38	26	59.02	3.4247*
Zn	39.59	43	19.36	81.80	134	45.28	8.6127*
Se	126.5	37	311.4	-----			
Hg	2.313	51	2.533	2.177	11	1.168	0.2728

V.B.2.c. Food Chain

Transfer of contaminants into the food chain at Tinicum represents another potential fate of the contaminants. The bioconcentration factor (BCF) is commonly used as an indicator of the degree to which a contaminant will mobilize into the food chain. BCF's are primarily available for fish, shellfish, and benthic invertebrates. BCF's for aquatic macrophytes and other organisms are seldom availble. The following section discusses the potential for the contaminants to mobilize in the food chain and the observed contaminant concentration in biota.

Aquatic organisms accumulate cadmium to a significant level above ambient conditions (Menzie, 1979). Reported BCF's range from 320 in cladocerans to 6100 in mosquitofish. Other reported BCF's include 603 l/kg in Lemna sp. and 960 l/kg in Salvinia natans (US EPA, 1980). Algae, mosses, lichens, and higher plants are also known to bioconcentrate cadmium (US FWS, 1986). Cadmium was not detected in snapping turtle liver samples.

The BCF for Chromium(VI) in rainbow trout is about 1 (US EPA, 1980). Some fish, however are able to bioconcentrate chromium up to 100 times ambient water concentrations. Upon entering uncontaminated water, fish rapidly eliminate chromium; therefore intermittent exposure would not be expected to result in significant chromium accumulation (Phillips, 1978).

BCF's for copper in algae range form 12-3240 l/kg. In fish BCF's range from 0 in bluegills to 290 for fathead minnows. Copper is also known to accumulate in aquatic insects (Phillips, 1978). Copper levels observed in Tinicum biota ranged from 1.4 to 3.0 ppm in snapping turtle liver.

Lead uptake from sediments by macrophytes and crayfish has been observed (Knowlton, 1983). Potamogeton foliosus and Nagas guadalopensis accumulate lead in root tissue and foliage; however senescent vegetation accumulates more lead than live plants. Crayfish exposed to contaminated sediments accumulate lead principally through adsorption to the exoskeleton. BCF's in other freshwater species include 45 for bluegills, 42 for brook trout, 1700 in snails (Lymnea palustris) and 1120 in stonefly (Pteronarcys dorsata) (US EPA, 1980). At Tinicum, lead levels in snapping turtle livers ranged up to 0.19 ppm.

BCF's for mercury have been reported at 12,000 in brook trout and 63,000 in fathead minnow. Tinicum snapping turtle livers showed mercury levels ranging from 0.04 - 0.1 ppm.

BCF's for silver range from <1 in bluegills to 240 in mayfly (US EPA, 1980). At least one algal species and freshwater mussel are known to bioconcentrate silver, but biomagnification is apparently not significant. There are no data to indicate whether silver is present in the Tinicum food chain.

Zinc BCF's range from 51 in Atlantic salmon to 1130 l/kg in mayfly. Food chain transfer appears to be a major source of zinc accumulation in higher trophic levels. Periphyton and benthic invertebrates appear to be the most active accumulators. Zinc levels in Tinicum snapping turtle livers ranged from 30-35 ppm.

Hydrogen cyanide is either rapidly metabolized or causes death and is therefore not likely to bioaccumulate. However, metal cyanides are known to accumulate in fish tissues (US EPA, 1979). There are no data to indicate whether metal cyanides are accumulating in Tinicum biota.

Chlordane BCF's have been reported as high as 8001/kg in fathead minnows. Total chlordane was found in whole fish collected in Darby Creek at levels up to 0.68 ppm.

Reported BCF's for PCB's in fish range from 3,000 to 274,000 (US EPA, 1980). PCB's also biomagnify in the food chain. PCB1260 has been detected in whole fish and turtle fat samples collected at Tinicum at levels of 1.8 and 23 ppm, respectively.

V.B.3. Summary of Fate and Transport Evaluation

Flow characteristics, flushing times, settling rates and desorption times in Darby Creek were evaluated to determine the potential transport of contaminants to Tinicum Marsh. Increased stream gradients on Darby Creek between river miles 4 - 8 and on Cobbs Creek between river miles 8 - 12 are great enough to cause sediment scouring. On Darby Creek between river miles 0 - 4, settling of sediments is expected based on stream gradient analysis. In this area, tidal velocities would be expected to transport sediment particles less than 0.4 mm in size. The flushing time from Darby Creek between the mouth of the Delwaware River and river mile 6.15 (just upstream of Clearview landfill) is estimated to be 2.2 tidal cycles under normal flow conditions or 6.5 tidal cycles under low flow conditions.

The settling and resuspension rate of metals sorbed to particulates could not be determined from exisiting information. Desorption times for organic contaminants in Darby Creek range from 2 days for chlordane to 7.7 years for PCB1260. Similar desorption times for organic contaminants from Naylors Run were predicted. A comparison of PAH levels in Darby Creek and Naylors Run suggests that contaminated sediments from Naylors Run may be reaching the marsh.

In general, data are inadequate to conclusively identify the relative pollutant source loads to the Tinicum Marsh. The data suggest, however, that important pollutant loads exist just above the Route 291 Bridge on Darby Creek. The most likely significant sources of contamination are Folcroft Landfill and Clearview Landfill. The Delaware River may be contributing to degraded water quality in Darby Creek, as evidenced by ammonia, nitrite, chromium, lead, and zinc levels. Future studies should focus on source identification through targeted sampling on-site, in surface water, and in sediments. These data should be evaluated and compared to non-point source estimates of pollutants to the Darby Creek watershed.

Bioconcentration rates for the contaminants vary widely. Contaminant transfer to fish is likely for cadmium, copper, mercury, chlordane, and PCB's. Bioconcentration rates for flora and other biota indicate that mobilization of cadmium, lead, and zinc into the food chain requires investigation.

V. C. Effects

The potential effects of Folcroft Landfill, Folcroft Landfill annex, and other pollutant sources on natural resources include physical perturbations, acute toxicity, and chronic toxicity. The following sections discuss the observed changes in the structure of the marsh habitat, and the predicted toxicological impacts to aquatic life and wildlife.

V.C.1. Observed Effects

No studies have been done to specifically identify effects of Folcroft Landfill on biota at Tinicum. The following discussion is based on studies undertaken for other purposes. Observed effects of Folcroft Landfill and non-source specific contaminants in the watershed include change in vegetative and habitat structure, decreased benthic populations, fish disease, and bioaccumulation of contaminants in the food chain.

The most visible and documentable impact of Folcroft landfill is the loss of 46 acres of valuable, productive tidal marsh. In 1968, the Folcroft Landfill occupied only 34 acres, but McCormick (1970) found that changes in the marsh adjacent to the landfill were already evident.

> In the tidal marsh, cattail stands were most extensive in areas that had once been fertilized. In the Borough of Folcroft extensive stands of cattail have existed at least since 1945. One large cattail area fringed the fallow, now built-up farmland along Maple Avenue. This land was formerly cultivated and must have received regular applications of fertilizer. A contiguous cattail stand, extending westward from the Folcroft landfill, had developed on most of its 1968 area during the preceeding years. That earlier stand was associated with drainage from agricultural lands along Hermesprota Creek. The cattail migrated westward as it was covered by the landfill, and apparently it now receives considerable organic enrichment (McCormick, 1970, p. 44).

The Delaware Valley Regional Planning Commission (1976) has noted that wild rice had diminished noticeabley in the 8 years since McCormick's field work. The Commission suggested that poor effluent quality from three local sewage treatment plants and leachate from the Folcroft Landfill had organically enriched the marsh, causing cattails to spread into former wild rice habitat. Siltation from dredging and filling associated with I-95 construction in the early 1970's was also believed to be a contributing factor in the loss of wild rice. Today, however, Tinicum officials believe that wild rice is expanding once again (Nugent, 1986).

Based on aquatic life surveys conducted in 1968, 1970, and 1976, Darby Creek was found to be of marginal water quality in the lower sections of Darby Creek basin from Route 13 through the tidal areas of Tinicum Marsh. There have been no recent studies to determine whether populations of biota have changed. The effects of Clearview Landfill, Folcroft Landfill, and the three sewage treatment plants which once discharged into the marsh were likely factors contributing to the decreased diversity. The DER investigation in 1976 showed fair to good water quality conditions in the headwaters of Darby Creek. This area is now a "put-and-take" trout fishery.

Incidental to the Fish and Wildlife Service's 1984 collection of the Clearview Landfill fish samples, a number of brown bullheads, largemouth bass, and American eels were taken from Darby Creek. These were submitted to Dr. Hans Rothenbacher, a Pennsylvania State University Veterinary Pathologist. Dr. Rothenbacher found a condition in the fish known as "hemorrhagic erosive dermatitis" a condition which could be caused by exposure to toxic chemicals. Brown bullheads, channel catfish, white suckers, and white bass caught near the Folcroft Landfill exhibited fatty livers, another condition which is associated with environmental stress and exposure to toxic chemicals.

Because of bioaccumulation effects, aquatic life tissue concentrations would be expected to be a least as high as sediment levels in Darby Creek. Therefore, tissue levels would be expected to approach the FDA action level of 2 ppm for PCBs and 0.3 ppm for chlordane. The direct measurement of fish and turtle flesh for PCB and chlordane concentrations confirmed that contaminants have bioconcentrated to levels of the same order of magnitude as sediment concentrations.

The results of the 1984 fish and turtle sampling effort were reviewed by an EPA toxicologist, who determined that the carcinogenic nature of some of the contaminants found warranted a public health advisory limiting consumption of these organisms (Brunker, 1985). The PA DER eventually issued such an advisory for the Tinicum area. Because of this health advisory, Refuge officials have also limited commercial harvesting of snapping turtles. Levels of organochlorine pesticides in whole fish exceed criteria established to protect wildlife and piscivorous fish. Contaminant levels in fish and snapping turtles represent a hazard to consumers. Additional studies should be done to establish baseline conditions of biota in the creeks and marsh. Histopathological studies shou also be conducted concurrent with tissue analyses to identify whether the health of resident biota is impaired.

V.C.2. Predicted effects

The data presented in the preceeding chapter are evaluated here to determine whether the contaminants found in Tinicum could toxicologically impact aquatic life and wildlife. Because of the absence of information regarding contaminants in soil and terrestrial vegetation, hazards to wildlife could not be estimated based on this exposure route. Therefore, only potential toxicological hazards to aquatic life and consumers of aquatic life could be evaluated.

Water quality data from the area near the Tinicum National Environmental Center were evaluated for the purpose of predicting toxic effects to aquatic flora and fauna. Table 26 summarizes water quality parameters which were observed to exceed applicable acute and chronic water quality criteria (US EPA, 1985, 1980, and 1972), including the ratio of the observed mean to the chronic criterion. The sum of the mean:criterion ratios for all pollutants was 10.6, suggesting that waters of Darby Creek were an order of magnitude more toxic than sensitive species can tolerate (assuming additive effects of these pollutants). Limited data are available for nickel and chromium; however because low levels of these elements may impact flora a limited discussion was included.

Available data on lethal and sublethal effects reported over acute and chronic time scales were considered in this analysis. EPA water quality criteria documents (US EPA, 1985 and 1980), which contain relatively complete literature surveys and summaries, were used as the principal sources of toxicological information. EPA has not proposed criteria for iron and manganese since 1972, and their toxicity has been inadequately studied. These metals were therefore not considered in this discussion. Toxicological data for freshwater plants, birds, and mammals are extremely limited. Unless otherwise noted, data for these species were taken from EPA water qualtiy criteria documents or US FWS publications on contaminant hazards to fish and wildlife (Eisler, 1985; Eisler, 1986a and b).

Table 26. Darby Creek, PA. Water quality parameters exceeding applicable criteria.

Param.	Chronic criterion	Observed mean	% exceed.	Mean: criterion	Acute criterion	Observed maximum
Ag	0.12	3.5	25	*	4.1	14
Cd	1.08	0.113	1.9	.105	3.9	65
Cu	11.2	18.3	52.8	1.64	18	2070
Fe	1000	987	22.6	.987	1000	505000
Hg	0.012	0.038	1.9	3.16	2.4	2
Mn	20	456	80.0	*	20	5760
Pb	2.98	11.9	67.9	3.99	82	3450
Zn	47	32.7	18.2	.696	320	8460

Total mean:criteria ratio: 10.6

* = sample size too small for meaningful ratio

Limitations of the Analysis

This toxicological evaluation is based on assumptions that: (1) observed water quality means were representative of ambient conditions, (2) the observed mean hardness of 100 mg/l (as $CaCO_3$) was typical, and (3) the observed maxima were not freak incidents, but may occur often enough to influence community structure. The water quality data did not unequivocally support these assumptions because (1) most locations were only monitored once, (2) some locations were inadequately identified, and (3) many pollutants likely to occur were not monitored. For more details about the ambient water quality database, see the water quality section of this report.

The aquatic toxicology database may have also limited the accuracy of conclusions. Most species found at Tinicum are not routinely used in toxicity testing, and closely related species were substituted, assuming toxicological similarity. There is, however, no way to prove such similarity. In fact, typical bioassay species have "non-average" sensitivity to toxicants, because they are not selected at random. Species tend to be used because they are easy to culture and maintain in a laboratory (and therefore unusually hardy), or because they are "indicator species" (and therefore unusually sensitive to toxicants). Species substitutions may therefore be a source of error.

The list of indigenous species at Tinicum is presented in Chapter 3 of this document. An attempt was made to confine the discussion to species actually found at Tinicum, in order to refine the conclusions of the criteria documents (which consider a broader range of species). However, toxicity data on Tinicum species were limited, and it was sometimes necessary to substitute data for similar animals. Data on fish species were substituted only within families. For example, the fathead minnow (Pimephales promelas), which was not on the Tinicum species list, was assumed toxicologically similar to the following listed cyprinids:

1. golden shiner (Notemigonus chrysoleucas)
2. satinfin shiner (Notropis analostanus)
3. bridle shiner (Notropis bifrenatus)
4. common shiner (Notropis cornutus)
5. spottail shiner (Notropis hudsonius)
6. blacknose dace (Rhinichthys atratulus)

The Atlantic silverside (Menidia menidia) was assumed similar to the tidewater silverside (M. beryllina), largemouth and smallmouth bass (Micropterus salmoides and M. dolomieui) were interchanged, and all sunfish (Lepomis spp.) data was considered for discussion. Data for invertebrates were usually substituted on the family level (eg., chironomid, tubificids), but were occasionally interchanged as high as the phylum level (e.g., bryozoans).

The list of aquatic macroinvertebrate species known to occur at Tinicum is short and certainly incomplete. It was therefore desirable in this analysis to include species not reported but likely to occur. For example, cladocerans and gastropods are widespread inhabitants of freshwater wetlands, and some species are certainly native to Tinicum. The common bioassay organism *Daphnia magna* was assumed representative of cladocerans; because of scarcity of gastropod data, all freshwater species were considered typical.

For euryhaline native species, results obtained in salt water were assumed equivalent to freshwater results (e.g., for the mummichog, *Fundulus heteroclitus*). Sublethal effects data from all species were included in the discussion, because such data are scarce.

It is difficult to predict toxic effects in nature on the basis of laboratory results. Laboratory tests are unable to take into account variations in nutritional status, reproductive condition, inter- and intraspecific competition, and other factors which exert stress on organisms. Laboratory tests also do not consider the ability of organisms to adapt to environmental insults lethal to laboratory stocks. This ability makes it possible for species to tolerate conditions believed impossible. Such adaptation is likely to exact a physiological cost, expressed as reduced growth or reproduction, however. Laboratory bioassays would also not reflect the actual temperature ranges, suspended solids levels, or temporal water quality variations which organisms would be exposed to in their natural environment. Because of interactions and effects not measured in the laboratory, toxicity tests are at best an over-simplified model of toxicants in nature.

A third source of uncertainty is that the list of species known to occur at Tinicum is probably limited to a small proportion of the actual fauna, so relevant toxicological data may have not been included in this analysis. Also, the Tinicum environment has probably been degraded for decades, and sensitive native species may have been lost. For this reason, the analysis may not consider all sensitive species.

A fourth possible source of error is that only the effects of single toxicants are considered. Interactions among toxicants (which may occur in the chemical soup to which the fauna of Tinicum are apparently exposed) are not discussed. Therefore, actual toxic effects may be worse than estimated.

Predicted Effects of Toxic Pollutants
Silver

The mean silver concentration was 3.5 ug/l, and the maximum was 14 ug/l, which exceeded the EPA chronic and acute criteria (at 100 mg/l hardness) of 0.12 and 3.5 ug/l. Only four observations exist, however, so it is unknown if these concentrations are typical. Biota were not analyzed for silver.

a. Acute effects. The most sensitive species were *Daphnia magna* (acute LC50 = 0.25-49 ug/l), the daces *Rhinichthys atratulus* and *R. osculus*

(4.9-14 ug/l), and the fathead minnow (*Pimephales promelas*, 3.9-270 ug/l). The least sensitive species tested were the chironomid *Tanytarsus* (3200 ug/l) and the amphipod *Gammarus* (4500 ug/l). Intermediate sensitivities were shown by juvenile Atlantic silverside (*Menidia menidia*, 400 ug/l) and bluegill (*Lepomis macrochirus*, 64 ug/ l). If the maximum observed silver concentration of 14 ug/l occurs frequently, it may periodically eliminate sensitive cladoceran and minnow species.

b. Chronic effects. *Daphnia magna* (chronic LC50 = 1.6-41.2 ug/l) was the most sensitive species for which chronic results were available. Largemouth bass (*Micropterus salmoides*, 93-105 ug/l) was the least sensitive species tested. In addition to lethality, silver exposure has been shown to depress oxygen consumption in fish and gastropods at concentrations as low as 120 ug/l, increase oxygen uptake in some marine molluscs at concentrations above 10 ug/l, and inhibit the activity of three liver enzymes in the mummichog (*Fundulus heteroclitus*) at 30 ug/l. The observed mean silver concentration of 3.5 ug/l, if typical, appears likely to exclude sensitive cladoceran species from Tinicum. Of 13 species for which EPA final chronic values were calculated (US EPA, 1980), four species had final chronic values lower than the mean silver concentration. If the test organisms were typical of natural communities, silver toxicity might eliminate significant numbers of species.

Cadmium

The mean cadmium concentration was 0.113 ug/l, and the maximum was 65 ug/l. The EPA chronic and acute criteria for cadmium (at 100 mg/l hardness) are 1.08 and 3.9 ug/l, respectively, and 1.9% of observations exceeded the chronic criterion.

a. Acute effects. The most sensitive species were *Daphnia magna* (acute LC50 = <1.6 - 166 ug/l), fathead minnow (*Pimephales promelas*; 11.7 - 72,600 ug/l), and the amphipod *Gammarus* (54.4 - 70 ug/l). Striped bass adults (*Morone saxatilis*) were relatively insensitive (1100 ug/l), but larvae and fingerlings had very low 96-h LC50s of 1 and 2 ug/l, respectively. The least sensitive species tested were the mummichog (*Fundulus heteroclitus*, 22,000-114,000 ug/l), goldfish (*Carassius auratus*, 2340 - 46,800 ug/l), and bluegill (*Lepomis macrochirus*, 1940-21,100 ug/l). Species showing intermediate sensitivity were the tubificid worms *Limnodrilus* (170 ug/l) and *Tubifex* (320 ug/l), American eel (*Anguilla rostrata*, 820 ug/l), and Atlantic silversides (*Menidia menidia*, 577 - 28,532 ug/l). If the maximum observed cadmium concentration of 65 ug/l occurs frequently, sensitive cladoceran, amphipod and minnow species might be eliminated. However, it is more likely that the mean hardness of 100 mg/l would be high enough to protect these species. The young of striped bass, and possibly other fish species, would be unlikely to survive these conditions, however.

b. Chronic effects. The species most sensitive to chronic effects were the cladocerans *D. magna* (chronic LC50 = 0.15-0.44 ug/l) and *Moina macrocopa* (chronic LC50 = 0.2 ug/l), the bivalve *Aplexa hypnorum* (3.4605.801 ug/l), the chironomid *Tanytarsus* (3.8 ug/l), and the white sucker (7.1 ug/l). The least sensitive species tested were the blue crab (*Callinectes sapidus*, 50-150 ug/l), fiddler crab (Uca pugnax, 2900 ug/l), and carp (Cyprinus carpio, hatch inhibited at 2094 ug/l). Sublethal effects included altered oxygen uptake in fiddler crabs (1 ug/l) and striped bass (0.5-5 ug/l), decreased activity of liver enzymes in striped bass (5 ug/l), avoidance by smallmouth bass (8.8 ug/l) and bluegill (41 ug/l), and reduced plasma sodium in goldfish (44.5 ug/l). With the exception of sensitive cladocerans, the tested species may be able to tolerate the observed mean cadmium concentration of 0.113 ug/l.

The primary toxicological impact to plants is growth reduction. Frond reduction has been observed in duckweed (Lemna minor) and the fern Salvina natans at cadmium levels as low as 10 ppb. Inhibition of leaf decomposition on mixed natural fungi and bacteria communities is reported at 5 ppb. Observed cadmium concentrations in Darby Creek would indicate that sublethal impacts to plants may occur.

Toxicological and dietary data for wildlife are sparse, however data indicate that birds and mammals are comparatively resistant to the biocidal properties of cadmium. Decreased metabolic rates and kidney lesions in mallards have been observed at dietary intakes of 450 ppm cadmium; however black ducks have exhibited behavorial effects from dietary intakes as low as 4 ppm. Generally, wildlife dietary levels greater than 100 ppb on a sustained basis are viewed cautionary.

3. Copper

The mean copper concentration was 18.3 ug/l, and the maximum was 2070 ug/l, which exceeded the EPA chronic and acute criteria (at 100 mg/l hardness) of 11.2 and 18 ug/l. 52.8% of observations exceeded the chronic criterion.

a. Acute effects. The most sensitive species tested were Physa (acute LC50 = 39-108 ug/l), Gammarus (20-910 ug/l), Chironomus (301690 ug/l), Daphnia (6.5-200 ug/l), goldfish (Carassius auratus, 36-300 ug/l), and fathead minnow (Pimephales promelas, 22-1760 ug/l). Among the least sensitive species were American eels (Anguilla rostrata, 2540-6400 ug/l), satinfin shiner (Notropis analostanus, 790-1900 ug/l), pumpkinseed (Lepomis gibbosus, 1740-2700 ug/l), and goldfish embryos (Carassius auratus, 5200 ug/l). Species of intermediate sensitivity included Tubifex (140 ug/l), several byrozoan species (140-510 ug/l), carp (Cyprinus carpio, 63-810 ug/l), blacknose dace (Rhinichthys atratulus, 320 ug/l), and brown bullhead (Ictalurus nebulosus, 170-540 ug/l). Although copper toxicity varies inversely with the log of hardness, the observed maximum copper concentration of 2070 ug/l is so high that 100 mg/l hardness would be insufficiently protective. If obtained frequently, a copper concentration of 2070 ug/l would probably eliminate all the above species except the American eel.

b. Chronic effects. The most sensitive species tested were the gastropod Physa (chronic LC50 = 8-14.8 ug/l), the amphipod Gammarus (4.6-8 ug/l), and Daphnia magna (1.4-43 ug/l). The most sensitive fish species were the fathead minnow (4.3-33 ug/l), white sucker (Catastomus commersoni, 12.9-33.8 ug/l), and bluegill (Lepomis macrochirus, 21-40 ug/l). The least sensitive species were the amphipod Ampelisca abdita (90 ug/l), Atlantic silverside (lesion formation at 500 ug/l), and mummichog (Fundulus heteroclitus, enzyme inhibition at 600 ug/l). Other sublethal effects included increased albinism in channel catfish at 0.5 ug/l. The mean copper concentration of 18.3 ug/l would probably result in the loss of sensitive gastropod, amphipod, cladoceran, and minnow species from the Tinicum community.

Tissue levels of 0.18 ppm in fish tissue are much less than dietary levels (550 ppm) which produce reduced growth and physiological effects to mallards. Copper inhibits plant growth and photosynthesis in freshwater plants at concentrations of 1 ppb to 8 ppm. Sublethal impacts to duckweed (Lemna minor) and watermilfoil (Myriophyllum spicatum) have been observed at 119 ppb and 250 ppb. Most studies on plants indicate that following copper exposure, freshwater algae and macrophyte populations shift to dominance by copper resistant species. Copper toxicity to plants decreases with increasing organic content in waters; however, because observed levels at Tinicum are up to one thousand times greater than observed effect levels, chronic impacts to freshwater plants are likely.

4. Mercury

The mean mercury concentration was 0.038 ug/l, which exceeded the EPA chronic criterion of 0.012 ug/l; the maximum concentration was 2 ug/l, slightly less than the EPA acute criterion of 2.4 ug/l. 1.9% of observations exceeded the chronic criterion.

a. Acute effects. The most sensitive tested species were the amphipod Gammarus (acute LC50 = 10 ug/l), Daphnia magna (1.47-5 ug/l) and Chironomus (20 ug/l). The least sensitive species were mummichog embryos (Fundulus heteroclitus, 67.4 ug/l), fathead minnow (150168 ug/l), and bluegill (160 ug/l). Species showing intermediate sensitivity were Atlantic silverside juveniles (Menidia menidia, 71-86 ug/l), mosquitofish (Gambusia, 37-44 ug/l), carp (Cyprinus carpio, 139 ug/l), and goldfish Carassius auratus, 82 ug/l). The observed maximum mercury concentration of 2 ug/l may result in the loss of Daphnia magna, but should be tolerated by the other tested Tinicum species.

Limited information is available for mercury effects to other wildlife. Lethal concentrations of elemental mercury to mosquitoes (Aedes aegypti; LC50=0.7-4.1 ppm), Rana pipiens (7 day LC50=7.3 ppb), and spring peeper (7d LC50 = 2.8 ppb) have been observed. The observed maximum concentration of 2 ppb may result in acute effects to these amphibians.

b. Chronic effects. Chronic toxicity data for mercury are limited. The most sensitive tested species were Daphnia magna (chronic LC50 = 0.96-1.287 ug/l) and fathead minnow (0.23-0.26 ug/l). These species should be able to tolerate the observed mean mercury concentration of 0.038 ug/l.

Freshwater plants are relatively insensitive to elemental mercury but are very sensitive to methylated mercury compounds. Decreased root weight in watermilfoil from Hg(II) is observed at 3.4 ppm (32-day EC50). Algae are more sensitive to methylmercury (15-day EC50= 0.8-4.0 ppb). Other chronic effects to wildlife include failure to metamorphose by Rana pipiens at 1 - 10 ppb.

In formulating the chronic freshwater criterion for mercury, EPA determined that bioaccumulation effects could occur at concentrations below those toxic to aquatic life. The chronic criterion (0.012 ug/l) is therefore based on the FDA action level of 1 mg/kg for methylmercury in fish tissue, and an observed BCF of 81700 for methylmercury in fathead minnows. It is not known whether the ambient mercury in Darby Creek was inorganic or methylated. However, if a high proportion of ambient mercury was methylated, or were to become methylated by the action of organisms in the sediment, bioaccumulated mercury could reach levels toxic to high-level predators, including humans. Observed mercury tissue concentrations in snapping turtle are below levels considered injurious by dietary intake to mink (1.1 ppm) and trout (5 - 7 ppm). Reduced hatching success and juvenile survival are observed in mallards and black duck diets containing 0.5 ppm and 0.1 ppm of mercury.

5. Lead

The mean and maximum lead concentrations were 11.9 ug/l and 3450 ug/l, respectively, which exceeded the EPA chronic and acute criteria of 2.98 and 82 ug/l. 67.9% of observations exceeded the chronic criterion.

a. Acute effects. The most sensitive organisms tested were an unidentified amphipod species (acute LC50 = 142 ug/l), mummichog (Fundulus heteroclitus, 315 ug/l), and largemouth bass larvae (Micropterus salmoides, 240 ug/l). The least sensitive species were the annelid worm Tubifex (27,500-450,000 ug/l), the chironomid Tanytarsus dissimilis (224,000 ug/l), mosquitofish (Gambusia sp., 240,000 ug/l), and bluegill (Lepomis macrochirus, 23,800-442,000 ug/l). Species of intermediate sensitivity were the bivalve Aplexa hypnorum (1340 ug/l), the gastropod Limnaea marginata (14,000 ug/l), tidewater silverside (Menidia beryllina, >3140 ug/l), and carp (hatch inhibition at 7293 ug/l). Taking into account to influence of hardness on toxicity, the highest observed ambient concentrations of lead might eliminate sensitive cladoceran and amphipod species from the Tinicum environment. Should high lead concentrations occur during spawning seasons for such sensitive fish species as the largemouth bass, reproductive success would probably be reduced.

b. Chronic effects. The most sensitive species tested were Daphnia magna (chronic LC50 = 9-193 ug/l), the gastropod Lymnaea palustris (12-54 ug/l), and the mysid Mysidopsis bahia (reduced spawning at 25 ug/l). The least sensitive species were the chironomid Tanytarsus dissimilis (chronic LC50 = 258 ug/l), mummichog (Fundulus heteroclitus, retarded hatch at 10,000 ug/l), and the bivalve Oronectes virilis (increased ventilation at 500 ug/l). Other sublethal effects observed included embryo deformation in the mummichog (100 ug/l), embryo deformities in goldfish (1660 ug/l), and inhibition of selected liver enzymes in goldfish (470 ug/l). The mean ambient lead concentration of 11.9 ug/l in Darby Creek is not predicted to eliminate any of the tested species.

Typical bioconcentration factors range from 42-45 for fish species to 500-1700 for invertebrates. Because fish, which are by far the most common high-level predators, apparently posess physiological mechanisms for elimination of tissue lead, toxic effects through food-chain biomagnification seem unlikely.

6. Zinc

The observed mean zinc concentration (32.7 ug/l) did not exceed the EPA chronic criterion (47 ug/l); the maximum concentration (8460 ug/l) did exceed the acute criterion (320 ug/l). 18.2% of observations exceeded the chronic criterion.

a. Acute effects. The most sensitive species were Daphnia magna (acute LC50 = 100-655 ug/l), striped bass (Morone saxatilis, 100-6800 ug/l), bluegill fry (Lepomis macrochirus, 235 ug/l), and the gastropod Physa heterostropha (600-4400 ug/l). The least sensitive species were the mummichog (Fundulus heteroclitus, 60,000-83,000 ug/l) pumpkinseed (Lepomis gibbosus, 20,000 ug/l) and white killifish (Fundulus diaphanus, 19,100 ug/l). Species of intermediate sensitivity were the amphipod Gammarus (8100 ug/l), carp (Cyprinus carpio, 7500 ug/l), goldfish (Carassius auratus, 6440-7500 ug/l), and golden shiner (Notemigonus chrysoleucas, 6000 ug/l). Assuming a hardness of 100 mg/l, it is estimated that 15 of the 29 tested species (including fathead minnows, striped bass, Physa, and Daphnia) would be unable to tolerate the maximum zinc concentration of 8460 ug/l.

b. Chronic effects. The most sensitive species were the chironomid Tanytarsus (chronic LC50 = 37 ug/l), Daphnia magna (42-190 ug/l), and fathead minnow (78-145 ug/l). The least sensitive species appeared to be the mummichog, which withstood 60,000 ug/l, although histological damage was sustained. Other reported sublethal effects were increased coughing in bluegill (3000 ug/l), decreased fecundity in the fathead minnow (180 ug/l), and reduced growth in mosquitofish (1150 ug/l). No species were predicted to be lost at the mean concentration of 32.7 ug/l.

Nickel

Only one nickel sample was taken in Darby Creek (908 ug/l), and effects to biota cannot be estimated. However because Folcroft Landfill appears to be a significant source of nickel, a brief discussion of nickel toxicity has been included. Acute effects to fish are not clear. Toad embryos (Gastrophyryne caroliensis) appear to be relatively sensitive to nickel (LC50=50ppb). Chronic impacts from nickel to biota appear to be more significant. Decreased growth of freshwater algae at 100 - 700 ppb and decreases in diatom diversity at 2 ppb are reported. Chronic impacts to fish are unlikely below levels of 10 ppb.

Chromium

Mean concentrations of total chromium in Hermesprota Creek were 34 ppb, 1.5 ppm in Darby Creek, and 0.07 ppm in whole fish. EPA water quality criterion for chromium (VI) is 11 ppb. Becuase data collected for chromium are for the total species, the water column levels cannot be estimated to impact aquatic life. However, aquatic plants are the most sensitive organisms tested. Therfore, a limited discussion of chromium hazards has been included. Chronic effects to algal species are reported at 62-9900 ug/l (growth reduction) and inhibition of photosynthesis in natural populations of river algae have been reported at 20 ppb of total chromium. Duckweed (Lemna minor) is among the most sensitive species tested (EC50= 10 ppb Cr(VI), decreased growth). Bioaccumulation of chromium by living and dead plant tissues is extensive although no adverse biological effects have been observed in native vegetation bearing high chromium residues. Bioaccumulation by aquatic fauna is expected to be low.

Summary

Predicted effects of each parameter found to exceed EPA water quality criteria in Darby Creek are summarized in Table 27. Copper, zinc, and silver present the most serious acute toxic threat to aquatic life, although the estimated effects of zinc are based largely on one very high observation. The pollutants which appear to pose the greatest chronic toxic threat to aquatic life are cadmium, copper, lead, and silver. Cadmium, copper, and zinc represent a chronic toxic threat to vegetation. Because of potential effects from chromium and nickel to aquatic vegetation, additional information is necessary on ambient levels in water. Because of their relatively high bioconcentration factors, mercury and cadmium may bioaccumulate to levels harmful to high-level predators and human consumers of fish. Fish tissue cadmium levels may pose a dietary threat to wildlife consumers. None of the six pollutants considered was estimated to be innocuous to fauna of Tinicum. Because of questions about the quality of the ambient water quality data (discussed in the introduction), it is not certain that all of these pollutants actually limit the quality of the biological community at Tinicum. Conversely, many pollutants which may be present at Tinicum have not been measured. Therefore, toxic pollutants which were not discussed here may exert an important influence on environmental quality. It is clear that no firm conclusions about toxic effects can be made without more complete water quality data.

Additional studies are needed to verify these toxicological impacts. Studies should include aquatic bioassays to assess the degree which habitat has been degraded. Phytotoxicity tests and earthworm bioassays at Folcroft Landfill are also warranted to identify whether hazards exist to these components of the Tinicum ecosystem.

Table 27. Predicted effects of contaminants on indicator species in Tinicum.

Toxicant	Time Scale	Bioassay Species eliminated	Other effects
Silver	acute	Daphnia magna, Rhinichthys atratulus, R. osculus, Pimephales promelas	
	chronic	Daphnia magna	
Cadmium	acute		Morone saxatilis - reduced reproductive success.
	chronic	Daphnia magna	possible bioaccumulation hazard, Lemna minor and Salvina natans - reduced growth.
Copper	acute	Physa, Gammarus, Chironomus, Daphnia, Carassius auratus, Pimephales promelas, Notropis analostanus, Lepomis gibbosus, Tubifex, Cyprinus carpio, Rhinichthys atratulus, Ictalurus nebulosus	Carassius auratus - reduced reproductive success
	chronic	Physa, Gammarus, Daphnia magna, Pimephales promelas	Algae, Lemna minor, Myriophyllum spicatum - reduced photosynthesis, population shifts.
Mercury	acute	Daphnia magna	Rana pipiens - metamorphic failure.
	chronic		bioaccumulation hazard- black duck, algae - reduced growth.
Lead	acute	unidentified amphipod, Daphnia magna	Micropterus salmoides - reduced reproductive success.
Zinc	acute	Daphnia magna, Morone saxatilis, Physa heterostropha, Pimephales promelas	Lepomis macrochirus - reduced reproductive success.
	chronic		Elodea canadensis, algae, Lemna minor - reduced growth and photosynthesis.

VI. SUMMARY AND CONCLUSIONS

Summary

The Tinicum National Environmental Center was established by Congress in 1972 to preserve 1200 acres of diverse fish and wildlife habitat for its natural and educational values. Contained within the Center is Tinicum Marsh, which at 350 acres is almost all that remains of approximately 5700 acres of tidal marsh that once existed in Pennsylvania's Delaware River floodplain. The presence of Tinicum Marsh within the highly urbanized Philadelphia area provides a unique educational model illustrating the values and functions of a freshwater tidal marsh; serving as fish and wildlife habitat, providing an area for stormwater detention, and improving water quality by removing nutrients from the water column. Over 37,000 people visited the Center in 1984, spending from 1 to 4 hours engaged in activities such as hiking, bicycling, canoeing, fishing, birdwatching, nature photography, and environmental education activities. Although its urban setting provides for maximum opportunities for human enjoyment of the Center, the location also means that urban influences, such as pollution, have the potential for harming the area's natural resources.

The Center's physical setting is along Darby Creek, just above the confluence of the Delaware River. The land features within the Center range from flat tidal marsh to grassy, forested uplands, to the steep-sided Folcroft Landfill rising 50 feet above the surrounding marsh. The Darby Creek watershed is predominantly urbanized. Limited public use of the creek for swimming, fishing, and boating occurs in many areas.

Overall, Tinicum represents a unique ecosystem surrounded by urban development. The Center contains a functioning tidal marsh with high primary productivity that forms the base of a complex detritus-based food web. However, identified water quality limitations, believed to be attributable to upstream sources, are probably impairing the health of this ecosystem.

Transport of contaminants into the Tinicum marsh ecosystem may be occurring by inputs from upstream sediments and water, tidal influx from the Delaware River, and migration of biota into the marsh.

The Tinicum watershed is approximately 70 square miles and receives drainage from Darby, Cobbs, Muckinipattis, and Hermesprota Creeks. Tidal inflows from the Delaware River extend approximately 3/4 of a mile upstream of the Center. Seven-day ten-year low flows in Darby Creek just north of the Center are 10 cfs.

Potential upstream sources of surface water and sediment contamination to the Tinicum Marsh are numerous. Based on historical records, runoff from sludge beds at the Delaware County STP and the Delaware County Incinerator may have been a significant source of contamination upstream of the Center. Data are inadequate to identify whether these sources, and other point and non-point sources, are significant contributors to degraded water quality in Tinicum. Havertown PCP is a potential contaminant sources to

Darby Creek located upstream of the Tinicum Center. This site is currently being investigated by EPA and DER.

Clearview Landfill is located approximately 1 mile north of Tinicum. Available samples on-site and in adjacent Darby Creek sediments support the theory that Clearview Landfill may be a source of PCBs to Darby Creek. Water quality data also suggest that Clearview Landfill contributes low levels of PAH's and metals to the creek.

Flow gradients in these upstream reaches of Darby Creek, Naylors Run, and Cobbs Creek are estimated to be high enough to cause scouring of contaminated sediments. The flushing time of Darby Creek in the upstream reach between Clearview Landfill and Folcroft Landfill indicates that this area is flushed through Tinicum approximately every three tidal cycles (1.5 days).

Ammonia, nitrite, chromium, lead, and zinc levels were significantly more concentrated in the Delaware River than in the mouth of Darby Creek. All other contaminant concentrations were statistically higher in Darby Creek, suggesting that tidal inflow to Tinicum is a source of these contaminants.

Folcroft Landfill is the only known pollutant source within Tinicum. Transport of contaminants from Folcroft to the marsh may be occurring by groundwater discharge to surface waters or soil runoff into surface waters. The limited data collected for Folcroft Landfill indicate that the site is a significant source of contaminants to Tinicum Marsh. Levels of aluminum, cyanide, copper, lead, and zinc in Darby Creek water and sediments are the highest in the Tinicum/Folcroft area. High metal levels are also found in the Hermesprota Creek water column adjacent to Folcroft Landfill. Leachate samples collected from the landfill annex show high levels of copper, iron, lead, manganese, nickel, and zinc. Historical samples taken on-site also contain elevated metal concentrations. Sediment chlordane levels are also highest in the Folcroft area. The lack of onsite data and the absence of information regarding sediment size make it impossible to determine whether sediment chlordane contamination is a result of Folcroft Landfill or from sediment transported from upstream.

Soils in the Center are primarily tidal marsh. These soils are generally anaerobic, highly organic, and primarily silty clay and silty loam. Soils in adjacent upland areas exhibit moderate to high permeabilities, high water tables, high erodibility, and low depth to bedrock. Average surface water runoff in the watershed is 17 to 20 inches per year. Limited contaminant data are available for soils within the Center. Lead, chromium, and cadmium were detected in soils on the Folcroft Landfill annex at low levels. Detection limits for other priority pollutants were 10 ppm and are too high to identify whether other problems exist.

Groundwater discharge from Folcroft Landfill represents a potential pathway for contaminants to be transferred into the marsh ecosystem.

Tinicum is located in the Coastal Plain province alongside the fall line of the Piedmont province. Coastal Plain deposits in the Center are primarily unconsolidated sediments underlain by a crystalline bedrock floor. Fill material in the Folcroft Landfill is deposited on the tidal marsh soils and underlain by gray, silty sand, fine sediments, and gravel. Groundwater occurs in the Center under water table conditions in the unconsolidated Coastal Plain sediments, under artesian conditions in the Farrington Sand member, and in the crystalline bedrock. Fill material within the Folcroft Landfill lies within the water table. Leachate samples from the landfill show elevated lead, nickel, copper, iron, and manganese levels. Industrial supply wells and monitoring wells in a 3-mile radius of Tinicum indicate non-source specific contamination of the water table with low levels of organohalogen compounds. Elevated lead levels have been observed in a private supply well approximately 1 mile south of the Center. No site specific groundwater data are available within Tinicum to document contamination or flow characteristics. Thirteen water supply wells were identified in the Folcroft Borough; however it is not known whether these wells are being used for drinking water. Data are inadequate to identify whether contaminants in Folcroft Landfill have entered the Farrington Sand aquifer and whether these contaminants have migrated to supply wells in the area. The topography, hydrology, and geology of the area indicate that groundwater discharge to the marsh is likely, and contaminant discharge from the water table to the marsh is documented from leachate testing.

Surface water and sediment quality in the lower reaches of Darby Creek are degraded, as evidenced by water column, sediment, and benthic biota sampling. Priority pollutant data collected during hazardous waste site investigations and as part of routine water quality monitoring are extremely limited. These data are inadequate to identify temporal trends or the extent of contamination in the Tinicum area. Levels of cyanide, chromium, nickel, and chlordane in Darby Creek sediments exceed sediment threshold contaminant levels downstream of Folcroft Landfill. PCB concentrations exceed threshold contaminant levels upstream of Folcroft, however no PCB sediment data are available in Tinicum. Concentrations of copper, iron, lead, and zinc seriously exceed EPA water quality criteria for the protection of aquatic life in Darby Creek. All metals except mercury exceeded criteria at least once in the Tinicum area. Levels of contamination decrease with travel downstream on Darby Creek and were higher in the Folcroft area. Copper, iron, and zinc levels have generally decreased since 1980 while slight increases in nickel levels have been observed. Dissolved oxygen levels decreased with travel downstream and approximately 14% of the measurements are below 4 mg/l. Data for ammonia, phosphate, and temperature are sparse but only ammonia levels exceed water quality criteria.

Air quality in the Folcroft area is typical of a major urban center. There are a great number of sources of conventional air pollutants and air toxicants within a 3-mile radius of the Center. Ambient monitoring and air quality problem indicate that, in general, no air quality problems from criteria air pollutants are present. Lead levels are elevated in the Philadelphia area. No data are available for monitoring or modeling air toxicant levels within the Center; however hazards to biota from air toxicants are expected to be less than those from water, soil, and sediments.

The biota within Tinicum represent the primary receptors for these contaminants in soil, water, groundwater, and sediments. Not only do the biota represent a contaminant sink within the marsh, these organisms may be directly or indirectly impacted by the contaminants either through food chain or toxicological effects. Water quality data and tissue data were evaluated to identify whether the contaminants in Tinicum represent a potential toxicological hazard to exposed biota.

The diversity of habitat at the Center provides the food, cover, and nesting requirements for a rich assemblage of wildlife.
The tidal marsh is characterized by zones of wetland plants such as wild rice, spatterdock, cattail, and countless combinations of associated plant species. A 145-acre impoundment attracts wintering waterfowl and is home to numerous other bird, reptile, amphibian, and fish species. Forested areas along dikes and other upland areas provide habitat for songbirds, and support a heron rookery. In addition, three plant species listed as "proposed rare" by the Commonwealth of Pensylvania also occur at the Center. There are no data on residue levels in vegetation within the marsh. A directly observed effect of Folcroft Landfill is the loss of 62 acres of valuable marsh habitat.

There are limited data on benthic invertebrate populations in Darby Creek, but the available information points to low-diversity benthic populations indicative of degraded water quality in the Tinicum area. Tubifex worms, leeches, beetles, some clams, a few midges, and mosquito larvae have been reported in Darby Creek. Several lagoons along Darby Creek contain tubicifid worms, leeches, molluscs, and a few arthropod species.

Over 40 species of fish have been documented at the Center. Use of Darby Creek by anadromous fish for spawning may have been historically significant, but degraded water quality eventually prevented this use. Today, American shad, white perch, blueback herring, alewife, gizzard shad, and American eel are known to use Darby Creek within the Center as feeding areas. The shortnose sturgeon, a Federally-listed endangered species, may occasionally use the area. Resident fish species in Darby Creek contain PCB's at levels up to 2.0 ppm, total chlordanes as high as 0.74 ppm, dieldrin at 0.35 ppm, DDD at 0.53 ppm, and DDE at 0.7 ppm. Overall, the levels of organochlorine contaminants in fish collected from Darby Creek were much higher than in those collected form the impoundment and 16-acre pond (neither of which receives Darby Creek water inflow).

Although there is limited information on the amphibian and reptile populations at Tinicum, almost 30 species have been reported, including several listed as rare or threatened by the Commonwealth of Pennsylvania. The large snapping turtles that inhabit the Center have been harvested commercially in the past. Recent analyses of snapping turtle leg meat, livers, and fat identified a number of aliphatic hydrocarbons (at low levels) but no organochlorine pesticides in the leg meat. The significance of the aliphatics is unknown. Turtle livers were analyzed for metals, revealing the presence of lead, copper, zinc, vanadium, aluminum, mercury, arsenic, and selenium. Turtle fat samples contained a variety of organochlorine pesticides, but most notably, PCBs at levels up to 23 ppm. Because of the variety and levels of organochlorine pesticides and PCBs present in the fish and turtle samples, in 1985 the PA DER issued a health advisory on consumption of fish and turltes from Tinicum.

Over 280 species of birds have been reported to use the varied habitats present at Tinicum. Nine species of waterfowl breed at the Center. In addition, seven bird species identified as "Species of Special Emphasis" by the FWS nest at Tinicum: wood duck, black duck, American woodcock, snowy egret, black-crowned night heron, and great egret. One of the primary reasons these species are of concern to the Service is habitat loss. Each of these species requires wetland habitat, such as Tinicum Marsh, for feeding, cover, breeding, and nesting. There are no data available on contaminant levels in birds residing at Tinicum. However, fish samples taken at Tinicum show levels of organochlorine pesticides and PCBs that would be anticipated to adversely affect fish-eating wildlife -- such as herons and egrets.

Available information on mammals present at Tinicum indicates a good variety of species ranging from mice, to fox and deer. There are no data on contaminant levels in mammals at Tinicum.

Limited data are available on the effects of contaminants in Tinicum on these natural resources. Contaminants within the watershed (which cannot be attributed solely to one source) have resulted in hemmorhagic erosive dermatitis and fatty livers in fish. Bioconcentration rates of cadmium, lead, zinc, chlordane, and PCBs indicate that mobilization of these contaminants into flora and fauna is likely. Elevated levels of heavy metals and organochlorine compounds in tissue is direct evidence that Tinicum biota represent a sink for these pollutants. These contaminant levels also represent a hazard to higher level consumers.

A review of the contaminant data by the FWS's Patuxent Wildlife Research Center (R. Eisler, letter dated August 23, 1986) notes that based on an evaluation of toxicity tests and contaminant loadings in sediment and biota that the Tinicum habitat "has been seriously degraded by anthropogenic contaminants to the extent that substantial endangerment exists to growth, survival, and reproduction of Service species of concern." In light of the important limitations of the water quality, toxicological, and tissue data, the toxicological review indicates that zinc, copper, and silver levels in the water column represent an acute toxicological threat to aquatic fauna. Levels of cadmium, copper, lead, silver, chromium, and zinc pose a potential chronic threat to aquatic flora and fauna. Levels of mercury and cadmium in the water column and biota are potentially harmful to higher level predators. Sensitive organisms which are predicted to be adversely impacted by the levels of these toxicants include primary producers, primary consumers, and secondary consumers.

Conclusions

There are a number of pollutant sources to the marsh and data are inadequate to define the relative pollutant loadings from each source. There are potentially significant upstream sources on Darby Creek to Tinicum Marsh. Estimates of non-point source loadings also indicate that these sources are significant.

Folcroft Landfill is located within the Center and is a significant heavy metal source to the marsh. It is likely that contaminated sediments from upstream sources are scoured and transported to the Center. Marsh sediments and biota represent a sink for these contaminants. Flushing from the Delaware River serves to dilute pollutant loadings and flush the marsh system of larger sized contaminated sediments. However, some pollutants are likely to be transported into the marsh by tidal inflow.

Environmental data show that the water quality and habitat value of the marsh are degraded; however these data are inadequate to define the extent and degree of degradation. Contaminants mobilized into the food chain have resulted in a fishing advisory and ban on commercial turtle harvesting. Toxicological estimates predict that water quality is limiting for the survival, growth, and reproduction of organisms within the Center. No data are available to document impacts to populations or communities within the marsh ecosystem.

In summary, the various pollutant sources in the Darby Creek watershed have an adverse environmental impact on the Tinicum marsh. Folcroft Landfill, located within the Center, is a source of contamination to the marsh. Data are currently inadequate to identify relative pollutant loadings from the various sources, the extent and degree of contamination, and the overall impact to the ecosystem. However, environmental data do indicate that the degraded water quality and habitat value of the marsh may result in decreased survival of sensitive species. Contaminant transfer to the food chain has resulted in reduced recreational fishing opportunities and loss of a commercial turtle harvest.

VII. RECOMMENDATIONS

Because of the outstanding natural and public values of the Tinicum National Environmental Center and as a result of the findings of this investigation regarding contaminants that are degrading the Tinicum Marsh ecosystem, the Tinicum Work Group recommends the following:

1. EPA and DOI should conduct a full scale site assessment to determine the extent and degree of contamination in Tinicum.

2. EPA and DER should increase their efforts to reduce upstream pollutant sources in Darby Creek, including Clearview Landfill.

3. DOI, with the assistance of EPA, should continue to investigate options to fund the recommended investigations and any subsequent remedial actions required.

A site assessment similar in scope to a Remedial Investigation conducted by the EPA Superfund program should be conducted in Tinicum. The results of the assessment should be used to develop a set of feasible remedial alternatives for the Folcroft Landfill. Because existing information is primarily limited to metals, future sampling and analysis should include all prioity pollutants. Initial efforts should concentrate on the Folcroft Landfill area including Darby Creek, Hermesprota Creek, and the tidal marsh. The investigation must be multi-media including soil, groundwater, surface water, sediment, and biota sampling. There has not been any air sampling at the Folcroft Landfill, and any potential for this exposure route should be determined. The site assessment should include the following investigations:

Source Identification - quantify point source loadings, non-point source contributions, and the relative contribution of pollutant loading from Folcroft Landfill.

Soils - determine the degree of contamination at surface and subsurface levels in Folcroft Landfill, determine the degree of contamination in tidal marsh soils, and identify the potential for toxicity to biota through earthworm toxicity and phytotoxicity tests.

Groundwater - identify local well use and the potential for contamination of these wells, and establish monitoring well clusters in and around Folcroft Landfill to identify local flow conditions in the three underlying aquifers and the extent of contamination.

Water - identify sources and extent of contamination through surface water and sediment sampling under several flow conditions, and determine the physical characteristics of the stream and its sediments to verify models of flushing, desorption, and transport.

Biota - determine priority pollutant levels in fish tissue, conduct benthic and fishery surveys to assess current populations, assess the health of aquatic populations using histopathology, and determine toxicological impacts using bioassays. These studies should be designed to identify existing impacts and to provide baseline conditions against which post-remediation conditions can be compared.

These data should be sufficient in scope to identify and evaluate possible remedial actions for the Folcroft Landfill. Of particular concern are the numerous leachates discharging to surface water and the banks of the landfill which are being eroded by tidal action. The alternatives analysis should be consistent with that required by the National Environmental Policy Act.

DER should continue its efforts to identify and investigate other contaminant sources in the Darby Creek watershed. EPA's and DER's work to remediate hazardous waste sites should, over time, improve water quality conditions in the Creek. However, increased monitoring and compliance are needed to reduce unauthorized discharges to storm sewers and creeks. In particular, work should focus on identifying enforcement and corrective strategies for other potential sources of pollution specified in this report. Efforts should be taken to improve NPDES discharges with a history of non-compliance which contribute to the degraded habitat in Darby Creek. Although actions taken at Folcroft Landfill will likely improve conditions in the marsh, good water quality cannot be expected when other sources, including Clearview Landfill, continue to discharge hazardous constituents into the watershed.

DOI should continue to pursue actions to obtain funds to investigate and reduce releases of hazardous pollutants from Folcroft Landfill. Federal and State agencies should also investigate potential enforcement actions against parties responsible for dumping hazardous wastes at Folcroft Landfill. These actions could be used to obtain compensation for restoration of natural resources injured by hazardous pollutants from Folcroft Landfill. EPA should assist DOI by examining all provisions of the Comprehensive Environmental Recovery, Compensation, and Liability Act (CERCLA) which may be used to investigate or remedy conditions at Folcroft Landfill.

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APPENDIX A - TABLES

Table A. Discharge data (cfs) for Cobbs and Darby Creeks.

	Cobbs Ck at U.S. 1	Cobbs Ck below Indian Ck	Cobbs Ck at Darby	Darby Ck at Darby
JANUARY				
1966	2.78	4.64	8.43	27.16
1967	6.61	12.66	17.4	84
1968	7.74	15.43	26.06	87.7
1969	3.49	8.98	6.96	33.51
1970	3.79	9.6	9.27	54.03
1971	6.16	14.3	24.9	68.29
1972	6.59	15.83	26.8	75.74
Average	5.31	11.63	17.12	61.49
FEBRUARY				
1966	10.24	18.83	32.43	95.92
1967	4.86	8.36	9.75	63.92
1968	4.28	8.06	12.36	56.65
1969	3.36	9.25	8.76	38.32
1970	6.58	12.88	22.94	93.46
1971	11.71	26.23	67.32	68.54
1972	10.44	21.34	44.27	98.44
Average	7.35	14.99	28.26	73.61
MARCH				
1966	4.36	7.18	8.1	63.51
1967	11.52	20.95	36.38	124.67
1968	12.05	20	39.89	108.87
1969	5.46	11.57	14.39	63.32
1970	6.12	12.3	23.1	73.41
1971	7.92	18.48	50.58	163.6
1972	9.24	20.19	40.7	113.96
Average	8.10	15.81	30.45	101.62
APRIL				
1966	5.12	8.05	17.49	49.69
1967	6.41	10.8	17.3	69.59
1968	6.69	13.92	24.14	66.46
1969	4.77	10.98	12.9	52.59
1970	10.93	28.86	53.74	143.69
1971	6.31	14.61	45.46	104.7
1972	10.15	19.13	37.43	99.76
Average	7.20	15.19	29.78	83.78

Table A. Continued.

	Cobbs Ck at U.S. 1	Cobbs Ck below Indian Ck	Cobbs Ck at Darby	Darby Ck at Darby
MAY				
1966	6.19	10.24	18.19	58.64
1967	7.72	14.25	22.39	78.61
1968	9.79	18.29	32.38	82.03
1969	4.87	10.94	23.03	49.12
1970	5.3	11.08	12.46	70.77
1971	7.17	18.26	32.74	80.22
1972	11.25	20.06	48.61	96.16
Average	7.47	14.73	27.11	73.65
JUNE				
1966	2.08	3.13	1.79	28.73
1967	3.89	8.51	13.28	50.19
1968	8.6	21.34	41.01	122.93
1969	5.31	13.52	55.15	59.66
1970	6.62	18.47	40.35	84.66
1971	3.61	11.02	19.36	44.93
1972	11.63	22.98	55.33	127.66
Average	5.96	14.14	32.32	74.11
JULY				
1966	3.29	9.22	24.58	34.16
1967	5.32	11.73	22.14	50.22
1968	3.93	12.09	21.29	56.54
1969	12.43	30.95	81.36	118.9
1970	4.65	16.06	22.08	54.96
1971	4.33	13.92	28.74	44
1972	5.55	14.62	29.61	68.93
Average	5.64	15.51	32.83	61.10
AUGUST				
1966	1.93	3.79	7.17	21.9
1967	8.76	18.44	43.28	89.32
1968	3.65	10.56	16.59	40.35
1969	8.95	17.08	24.54	77.22
1970	4.07	10.54	24.79	57.41
1971	10.71	27.01	60.86	97.61
1972	4.54	10.18	20.19	50.48
Average	6.09	13.94	28.20	62.04

Table A. Continued.

	Cobbs Ck at U.S. 1	Cobbs Ck below Indian Ck	Cobbs Ck at Darby	Darby Ck at Darby
SEPTEMBER				
1966	7.52	18.09	39.53	78.5
1967	4.27	8.42	15.25	47.33
1968	2.39	5.52	6.44	25.59
1969	4.78	10.77	18.23	53.83
1970	2.17	5.87	6.22	27.53
1971	20.21	48.34	96.76	189.96
1972	3.36	7.37	12.49	37.96
Average	6.39	14.91	27.85	65.81
OCTOBER				
1966	3.33	5.58	10.89	26.09
1967	7.17	13.37	29.5	74.35
1968	4.3	6.71	12.01	39.77
1969	3.6	9.03	11.78	33.9
1970	3.09	7.28	11.02	28.09
1971	7.72	13.69	25.62	60.33
1972	9.86	22.46	66.61	107.64
Average	5.58	11.16	23.92	52.88
NOVEMBER				
1966	2.12	3.39	4.41	22.03
1967	4.73	8.78	15.53	55.53
1968	4	6.68	9.08	41.46
1969	4.72	13.98	20.67	47.69
1970	3.73	9.01	39.41	37.96
1971	8.02	19.53	37.79	69.83
1972	10.74	17.45	68	99.09
Average	5.44	11.26	27.84	53.37
DECEMBER				
1966	2.49	4.85	8.18	25.64
1967	4.63	10.35	14.44	56.35
1968	9.77	20.8	43.31	100.16
1969	4.88	12.56	15.26	45.61
1970	7.69	16.89	9.27	75.74
1971	6.39	14.86	28.16	68.29
1972	6.31	15.83	27.48	79.38
Average	6.02	13.73	20.87	64.45

Table B. Common and scientific names of plant species mentioned in this report.

Narrow-leaved cattail	*Tpha angustifolia*
Broad-leaved cattail	*Typha latifolia*
Wild rice	*Zizania aquatica*
Common reed	*Phragmites communis*
Spatterdock	*Nuphas advena*
Primrose willow	*Jussinea repens*
Smartweed	*Polygonum* spp.
Arrowhead	*Sagittaria* spp.
Beggar-tick	*Bidens* spp.
Jewelweed	*Impatiens capensis*
Bur-reed	*Sparganium* spp.
Yellow iris	*Iris pseudacorus*
Sedge	*Carex* Spp.
Dodder	*Cuscuta* sp.
Purple loosestrife	*Lythrum salicaria*
Marsh mallow	*Hibiscus palustris*
Dogwood	*Cornus* spp.
Black willow	*Salix nigra*
Common alder	*Alnus serrulata*
Giant ragweed	*Ambrosia trifida*
Oak	*Quercus* spp.
Birch	*Betula* spp.
White mulberry	*Morus alba*
Red mulberry	*Morus rubra*
Quaking aspen	*Populus tremuloides*
Black gum	*Nyssa sylvatica*
Sweet gum	*Liquidambar styraci-flua*
Red maple	*Acer rubrum*
Arrow arum	*Peltandra virginica*
Pickerelweed	*Pontederia cordata*
Water plantain	*Alisma subcordatum*
Buttonbush	*Cephalanthus occidentalis*
Sensitive fern	*Onoclea sensibilis*
Reed canary grass	*Phalaris arundinacea*
Bulrush	*Scirpus* spp.
Bur marigold	*Bidens laevis*
Marsh hoarhound	*Lycopus europeaeus*
Sweetflag	*Acorus calamus*
Golden club	*Orontium aquaticum*
Pondweed	*Potamogeton* spp.
Rush	*Juncus* spp.
Blue vervain	*Verbene hastata*
Lizard's tail	*Saurus cernuus*
Water parsnip	*Sium suave*
Mad-dog skullcap	*Scutellaria laterifolia*
Tall cone-flower	*Rudbeckia laciniata*

*Listed as endangered species by the Commonwealth of Pennsylvania.

Table C. Species of fish known to occur in the Tinicum area, their general food habits, and brief life history description. (U. S. FWS, 1983a)

Name	Food Habits	Comments
Petromyzon marinus (Sea lamprey)	Young to 4 years nonparasitic, feeding on minute organisms. Adults parasitic, feeding on the blood of other fishes.	Anadromous; ascends freshwater streams in spring to spawn. Young stay 3-4 years in freshwaters.
Anguilla rostrata (American eel)	Young: benthic macroinvertebrates (insect nymphs & larvae, oligochaetes, cladocerans). Older eels: crayfish, tadpoles, fish, fewer invertebrates.	Catadromus; Largely nocturnal feeders and hig opportunistic. Burrow in mud in winter. Have been captured on freshwater tidal marsh surface.
Alosa aestivalis (Blueback herring)	Juveniles: feed at surface on cladocrans (primarily bosmids), copepods, crustacean eggs, chironomid larvae (as drift).	Anadromous; spawn in fast flowing water over hard substrate. Juveniles use tidal freshwater and low salinity nursery areas until autumn.
Alosa pseudoharengus (Alewife)	Juveniles: cladocerans, copepods, crustacean eggs, insects (various dipterans)	Anadromoous; spawn in slower moving water than blueback herring. Juveniles use freshwater tidal & low salinity nursery areas until autumn.
Alosa sapidissima (American shad)	Juveniles: feed somewhat opportunistically both at the surface & beneath the surface on cladocerans (primarily daphnids), chironomid larvae (as drift), water boatmen, terrestrial insects (flies, gnats, ants), fish larvae.	Anadromous; spawn primarily in main channels over sand shoals in areas of perceptible currents. Juveniles use freshwater tidal & low salinity nursery areas until mid to late autumn.
Dorosoma cepedianum (Gizzard shad)	Juveniles: protozoa, copepods, ostracods. Adults: microscopic plants, phytoplankton, algae, detritus.	Spawns in freshwater. Young inhabit freshwater & low brackish nursery areas. Prefers quiet waters of large rivers, estuaries. Young are important forage for several species of game fish.

Table C. Continued.

Umbra pygmaea (Eastern mudminnow)	In freshwater stream: copepods, caddisfly larvae	Inhabits small, sluggish muddy stream & weed beds. Burrows in soft, silty substrates.
Esox americanus (Redfin pickerel)	Fry: plankton. Juveniles: Cladocerans, amphipods, immature insects. Adults: fish, crayfish, dragonfly nymphs.	Inhabits sluggish streams, weed beds, swamps.
Carassius auratus (Goldfish)	Omnivorous with preference for phytoplankton. Young feed more on zooplankton and insect larvae.	Primarily inhabits still, often oxygen deficient waters with thick vegetation.
Cyprinus carpio (Common carp)	An omnivorous bottom-feeder taking vegetation, insects, worms.	Inhabits streams, rivers,, ponds, impoundments; both clear and turbid. Often considered a pest due to habit of stirring up bottom sediments during feeding.
Hybognathus nuchalis (Eastern slvery minnow)	Feeds in large schools near bottom on diatoms, desmids, filamentous algae.	More abundant in channel than in coves.
Notemigonus chrysoleucas (Golden shiner)	Omnivorous; algae, macrophytes, amphipods, molluscs, detritus, insects.	Prefers quiet vegetated water with access to extensive vegetated shallows.
Notropis analostanus (Satinfin shiner)	In freshwater stream, insect larvae (mayflies, caddisflies, stoneflies).	Preferentially inhabits weedless streams, straying into tidal freshwaters.
Notropis bifrenatus (Bridle shiner)	Small invertebrates, algae, macrophytes.	Inhabits sluggish streams over areas of mud, silt, detritus, in slack-water areas with moderate to abundant vegetation.
Notropis cornutus (Common shiner)	Omnivorous: algae, rotifers, small crustaceans, insects.	More common in moderate to swift weedless streams.

Table C. Continued.

Notropis hudsonius (Spottail shiner)	Small molluscs (*Corbicula manilensis*), crustacea (cladocerans, ostracods, copepods), plant seeds (*Sagittaria* sp., *Panicum* sp.), insects (chironomid larvae, ceratopognoid larvae), fish eggs.	Inhabits mainstream & sluggish weedy necks, creeks, swamps.
Rhinichthys atratulus (Blacknose dace)	In stream; 64% of diet microscopic plants & vegetative matter, remainder insects.	More likely to enter tidal freshwaters in in northern portion of its range.
Semotilus atromaculatus (Creek chub)	Omnivorous sight feeder; insects, cladocerans, algae, higher plant tissues.	
Semotilus corporalis (Fallfish)	Probably aquatic and terrestrial insects, crustaceans, fish.	More abundant in non-tidal freshwaters.
Catostomus commersoni (White sucker)	Insects, molluscs, worms, copepods, cladoceans, ostracods, microscopic plants.	Inhabits larger streams, ascends small creeks in spring to spawn.
Erimyzon sucetta (Lake chubsucker)	Young: copepods, cladocerans, chironomids.	Occupies ponds, oxbows, sloughs, impoundments. Prefers clear water & aquatic vegetation.
Ictalurus catus (White catfish)	An opportunistic feeder; amphipods, isopods, decapods, copepods, cladocerans, mysids, cumaceans, chironomid larvae, polychaete worms, small clams, larval & adult insects, fish.	Most tributaries, mainstream.
Ictalurus nebulosus (Brown bullhead)	Insect larvae (dipterans, mayflies, caddisflies, dragonflies), molluscs, algae, fish (spottail shiner, elvers), polychaete worms, zooplankton.	Inhabits sluggish oxbows, backwaters, impoundments.

Table C. Continued.

Fundulus diaphanus (Banded killifish)	Small crustaceans, insects, molluscs, annelid worms, detritus.	More likely to occur in freshwater than most others of genus. Common in bays, rivers, coves in low salinity areas, extending into freshwater.
Strongylura marina (Atlantic needlefish)	In low brackish estuary; small fishes, insects, shrimp, small amounts of vascular plant material and algae.	A marine form which readily enters fresh- Best considered a summer transient. May breed in tidal freshwaters in Potomac, VA.
Fundulus heteroclitus (Mummichog)	In tidal freshwater, crustaceans (ostracods, cyclopoid copepods), insects (dipterans, hemipterans), fish eggs, grass seeds (Panicum sp.), gastropods, spiders.	Inhabits muddy marshes, grassflats, channels, pools in marsh interior in summer. May burrow in silt in winter.
Fundulus luciae (Topminnow)		
Gambusia sp. (Mosquitofish)	(Gambusia affinis) Feeds primarily near surface; insects (hemipterans, dipterans).	(Gambusia affinis) Inhabits tidal pools, coves & backwaters. Readily follows flood tide onto marsh surface. May remain in marsh pools during low tide.
Menidia beryllina (Tidewater silverside)	Copepods, mysids, isopods, amphipods, insects.	Estuarine resident; readily enters freshwater. May spawn in tidal freshwater. Inhabits tidal creeks and grassflats in summer, channels in winter.
Apeltes quadracus (Fourspine stickleback)	Small crustaceans, mainly amphipods. In freshwater, chironomid & mayfly larvae, cladocerans.	Estuarine resident. Occupies shallows in summer, channel & channel edges in winter.

Table C. Continued.

Morone americana (White perch)	Juveniles: copepods, cladocerans, rotifers, amphipods, insect larvae (ceratopogonids & dipterans), small molluscs, mysids. Adults: Larger crustaceans (Crangon septemspinosa, Paleomonetes pugio, Rithropanopeus harrisii), small fish (eels, spottail shiners, Fundulus spp.).	Semianadromous; juveniles inhabit shallows, moving to deeper water in winter. Minor sport & commercial importance. Peak abundance Hudson River to Chesapeake Bay.
Morone saxatilis (Striped bass)	Postlarvae: Zooplankton. Juveniles 25 - 100 m: flexible nonselective feeders on insects (dipteran larvae & pupae, mayfly larvae), amphipods, Palaemonetes shrimp, other decapods, mysids, fish & fish larvae (Gobiosoma bosci, Lepomis gibbosus, Notropis hudsonius, Menidia spp.), polychaetes. Adults in tidal freshwater: 84% of diet clupied fish (Brevoortia tyrannus, Alosa aestivalis, A. pseudoharengus, Dorosoma cepedianum), 4% spiny-rayed fish, 3% invertebrates (amphipods, mayfly & dipteran larvae, blue crabs, palaemonid shrimp).	Anadromous; peak spawning in tidal freshwaters. Adults move downstream after spawning, juveniles move downstream as they grow. Inhabit deeper water by day, move into shallows at night to feed. Overwinter in deeper channels. Major sport & commercial importance.
Lepomis gibbosus (Pumpkinseed)	Primarily a benthic feeder. In freshwater stream, 63% diet dipteran larvae. Also other insects & insect larvae, crustaceans (copepods, ostracods,	Prefers quiet water with abundant vegetation. Spawns in tidal freshwater portion of the Potomac River, VA, & Hudson River, NY. Major sport importance.

Table D. Reptiles and amphibians known to occur in the Tinicum area. Compiled from McCormick, 1970; Jack McCormick and Associates, 1971; and Philadelphia 1976 Bicentennial Corporation, with taxonomic revisions according to Hall, 1981.

REPTILES

Snapping turtle	Chelydra serpentina
Stinkpot	Sternotherus odoratus
Eastern mud turtle*	Kinosteron subrubrum subrurum
Spotted turtle	Clemmys guttata
Bog turtle*	Clemmys muhlenbergii
Wood turtle	Clemmys insculpta
Eastern box turtle	Terrapene carolina
Northern diamondback terrap	Malaclemys terrapin
False map turtle	Graptemys pseudogeographica
Red-bellied turtle*	Chrysemys rubriventris
Red-eared turtle	Chrysemys scripta elegans
Eastern painted turtle	Chrysemys picta picta
Midland painted turtle	Chrysemys picta marginata
Smooth softshell	Trionyx muticus
Northern water snake	Nerodia sipedon sipedon
Northern brown snake	Storeria dekayi dekayi
Eastern garter snake	Thamnophis sirtalis sirtalis
Northern black racer	Coluber constrictor constrictor

AMPHIBIANS

Mudpuppy	Necturus maculosus
American toad	Bufo americanus
Spring peeper	Hyla crucifer
Bullfrog	Rana catesbeiana
Green frog	Rana clamitans melanota
Wood frog	Rana sylvatica
Northern leopard frog	Rana pipiens
Pickerel frog	Rana palustris
Southern leopard frog*	Rana utricularia

*Listed as endangered species by the Commonwealth of Pennsylvania.

Table E. Birds known to nest in Tinicum. (U. S. FWS, 1983b).

Common Name	Scientific Name
Pied-billed grebe	*Podilymbus podiceps*
American bittern	*Botaurus lentiginosus*
Least bittern	*Ixobrychus exilis*
Great egret	*Casmerodius albus*
Snowy egret	*Egretta thula*
Green-backed heron	*Butorides virescens*
Black-crowned night-	*Nycticorax nycticorx*
Canada goose	*Branta canadensis*
Wood duck	*Aix sponsa*
Green-winged teal	*Anas crecca*
American black duck	*Anas rubripes*
Mallard	*Anas platyrhynchos*
Northern pintail	*Anas acuta*
Blue-winged teal	*Anas discors*
Northern shoveler	*Anas clypeata*
Northern harrier	*Circus cyaneus*
American kestrel	*Falco sparverius*
Ring-necked pheasant	*Phasianus colchicus*
Northern bobwhite	*Colinus virgnianus*
King rail	*Rallus elegans*
Virginia rail	*Rallus limicola*
Sora	*Porzana carolina*
Common moorhen	*Gallinula chloropus*
American coot	*Fulica americana*
Killdeer	*Charadrius vociferus*
Spotted sandpiper	*Actitis macularia*
American woodcock	*Philohela minor*
Mourning dove	*Zenaida macroura*
Black-billed cuckoo	*Coccyzus erythropthalmus*
Yellow-billed cuckoo	*Coccyzus americanus*
Common barn-owl	*Tyto alba*
Eastern screech-owl	*Otus asio*
Great horned owl	*Bubo virginianus*
Ruby-throated hummin	*Archilochus colubris*
Downy woodpecker	*Dendrocopos pubescens*
Northern flicker	*Colaptes auratus*
Alder flycatcher	*Empidonax alnorum*
Willow flycatcher	*Empidonax traillii*
Least flycatcher	*Empidonax minimus*
Eastern phoebe	*Sayornis phoebe*
Great crested flycat	*Myiarchus crinitus*
Eastern kingbird	*Tyrannus tyrannus*
Purple martin	*Progne subis*
Tree swallow	*Iridoprocne bicolor*
Barn swallow	*Hirundo rustica*
Blue jay	*Cyanocitta cristata*
American crow	*Corvus brachyrhynchos*
Fish crow	*Corvus ossifragus*
Carolina chickadee	*Parus carolinensis*
Tufted titmouse	*Parus bicolor*
Carolina wren	*Thryothorus ludovicianus*

Table E. Continued.

House wren	_Troglodytes aedon_
Sedge wren	_Cistothorus platensis_
Marsh wren	_Telmatodytes palustris_
Wood thrush	_Hylocichla mustelina_
American robin	_Turdus migratorius_
Gray catbird	_Dumetella carolinensis_
Northern mockingbird	_Mimus polyglottos_
Brown thrasher	_Toxostoma rufum_
Cedar waxwing	_Bombycilla cedrorum_
European starling	_Sturnus vulgaris_
White-eyed vireo	_Vireo griseus_
Warbling vireo	_Vireo gilvus_
Red-eyed vireo	_Vireo olivaceus_
Yellow warbler	_Dendroica petechia_
American redstart	_Setophaga ruticilla_
Common yellowthroat	_Geothlypis trichas_

Table F. Mammals known to occur in the Tinicum area. (U. S. FWS, 1983a, and Tinicum NEC staff, personal communication).

Common Name	Scientific Name
Virginia opposum	*Didelphis virgniana*
Short-tailed shrew	*Blarina brevicauda*
Eastern mole	*Scalous aquaticus*
Big brown bat	*Eptesicus fuscus*
Raccoon	*Procyon lotor*
Long-tailed weasel	*Mustela frenata*
Gray fox	*Urocyon cinereoargenteus*
Red fox	*Vulpes vulpes*
Gray squirrel	*Sciurus carolinensis*
White-footed mouse	*Peromyscus leucopus*
Marsh rice rat	*Oryzomys palustris*
Meadow vole	*Microtus pennsylvanicus*
Muskrat	*Ondatra zibethicus*
Norway rat	*Rattus norvegicus*
House mouse	*Mus musculus*
Meadow jumping mouse	*Zapus hudsonius*
Eastern cottontail	*Sylvilagus floridanus*
White-tailed deer	*Odocoileus virginianus*
Mink	*Mustela vison*
River otter	*Lutra canadensis*
Striped skunk	*Mephitis mephitis*

Table G. Potential Point Sources in the Tinicum Area

Air Toxicant Sources within 10 km of Folcroft.

Name Address	Toxicant Emitted	Emission rate lb/yr
ARCO Petroleum, 2700 Passyunk	Benzene	511
ARCO Petroleum, 3144 Passyunk	Benzene	8202
	Chromium	523
Gulf Refining, 30th and Penrose	Benzene	31450
	Chromium	2150
	Nickel	1000
	Antimony	80
Inolex Chemical, Jackson and Swans	Manganese	87
Ashland Chemical, 2801 S. Delaware	Chromite	6.2
DAK International, 201 Pattison	Aldehydes	2962
E. I. DuPont, 3500 Grays Ferry	Acrylonitrile	.0319
	Formaldehyde	.0549
	Propylene Imine	.0215
Gulf Oil, Penrose Ave	Benzene	8
Naval Regional Med Ctr, Pattison and Broad	Ethylene Oxide	453
Saint Agnes, 1900 S. Broad	Ehtylene Oxide	4300
Sea Gull Lighting, 25th & Wharton	Trichloroethylene	2420
Southwark Cooperage, Meadow & Wolf	Lead Chromate	26
US Naval Base	Trichloroethylene	2420
	Perchloroethylene	4880
	Chromium	13.8
US Uniform, 1202 Reed St	Perchloroethylene	400
Amerada Hess, 1630 S 51st	Benzene	156
Amoco Oil, 63 &Passyunk	Benzene	3010
Chemical Compounds, 5525 Grays Ferry	Zinc Chromate	1
	Pentachloroethylene	.5
	Propylene Oxide	.3
	Mercury	.5
Chilton Printing, 5601 Chestnut	Formaldehyde	27
	Perchloroethylene	24
	Pentachlroethylene	123
Exxon Co, 6850 Essington	Benzene	900
General Electric, 6901 Elmwood	Zinc Chromate	7
	Chrome Plating	22.6
General Electric, 3198 Chestnut	Methlyene Chloride	100
Getty Refining, 49 & Grays Ferry	Benzene	2376
Hygrade Food, 8400 Executive Ave.	Formaldehyde	426
Industrial Lift, Isl. & Enterpr.	Lead Chromate	50.4
International Print, 711 S. 50th	Lead	90.5
	Antimony	3.3
	Trichloroethylene	144

Table G. Continued.

LEK Corp, 5420 Paschall	Zinc Chromate	7.5
MA Bruder, 5213 Grays Ave.	Lead	44.3
	Pentachloroethylene	.45
	Propylene Oxide	.37
Mckesson, 8335 Enterprise Ave.	Methylene Chloride	-
	Trichloroethylene	-
Paintarama, Island & Glenmore	Lead Chromate	5
Phila Intl Airport	Carbaryl	50
	Chlordane	-
Phillips & Jacobs, 8300 Escort	Methylene Chloride	222
	Perchloroethylene	13
	Trichloroethylene	65

NPDES Permitted Discharges in the Tinicum Area

Boeing Corporation, Permit # PA0013323, Darby Creek
Gulf Oil, Permit # PA0011550, Darby Creek
Jones Fuel & Heating, Permit # PA0040151, Darby Creek
National Wood Preservers, Naylors Run
Tinicum Township STP, Permit # PA0028380, Darby Creek
International Paper, Permit # PA0010952, Muckinipattis Creek
Lansdowne Steel and Iron, Muckinipattis Creek
Philadelphia Electric, Eddystone, Permit # PA0013714, Darby Creek
Earlton Treatment Co., Permit # PA0034037, Darby Creek (expired)
Muckinipattis STP, Permit # PA0027588 (expired)
National Paper, Permit # PA0010952, Muckinipattis Creek

Table H. Sediment data collected in the Tinicum area. Data are in ppm. Data qualifiers are as follows: ND = not detected, P = strong evidence compound is present, U = positive results which are clearly unreliablecompound should not be assumed present, T = tentatively present however absence of QA data prohibits confirmation or quantification.

MATRIX	RIVER MILE	DATE	FLOUR-ANTHENE	CHRYSENE	PHENAN-THRENE	PYRENE	BENZOA-ANTHRACEN	BENZOK-FLOURANT	ANTHRACEN	NAPTHALEN	PCB1260	PCB1242	CHLORDANE	BENZOA-PYRENE	BIS2ETHYL PTHALATE	DINBUTYL-PHTHALATE	4NITRO-PHENOL	PHENOL	METHYLENE CHLORIDE	VINYL CHLORIDE	CHLORO-ETHANE
SEDIMENTS (PPM)																					
CLEARVIEW COBBS CR. R.M.	6.25	1984									ND	0.36	ND								
	6.22	1983	2.3	1.1	1.5	1.9	1.1	<1.7	ND	ND	0.06	ND	0.1								
	6.22	1983	1.5	1.1	1.5	3.4	1	<1.0	<.5	<.5	ND	ND	0.086	ND							
	6.19	1984										1.4	ND								
	6.16	1983	0.62	<.4	<.4	0.62	ND	ND	ND	ND	ND	ND	0.041	ND							
	6.16	1984										1.57	ND								
DARBY CREEK	6.28	1984									ND	0.37	ND								
	6.16	1983	0.44	<.4	ND	ND	ND	ND	ND	ND	ND	ND	0.019								
	6.15	1983	0.92	0.56	<.4	0.87	0.61	<.8	ND	ND	ND	ND	0.054								
	6.14	1984									ND	0.49	ND								
CLAERVIEW LEACHATE SED.	6.10	1983	2.8	1.3	1.7	3.1	1.4	<.8	ND	<400	0.227	0.37		1.1							
	5.97	1983	0.92	<.4	0.44	0.72	ND	ND	ND	ND	ND	ND	0.963								
	5.97	1984									ND	0.86	ND								
FOLCROFT	4.73	1983	U	U	U	U		U					0.1						U		
	4.36	1983	<.2	<.4	<.2	<.2		<.4					0.24					U			
HERMSPROTA CREEK	5.00	1983	U	U	U	U							0.67								
	4.5	1983	U	U	U	U							0.12					U			
FOLCROFT PONDED SED.	4.70	1983				U											U	U			

MATRIX	RIVER MILE	DATE	AS	SB	SE	TL	HG	SN	CD	PB	CN	AL	CR	BA	CO	CU	FE	NI	MN	ZN	V	AG
SEDIMENTS (PPM)																						
CLEARVIEW COBBS CR. R.M.	6.25	1984																<140	70	30		
	6.22	1983	8.9	ND	ND	ND	0.4	ND	ND	108	ND	5070	31	103	ND	34	13100	ND	733	138	28	1
	6.22	1983	7.7	ND	ND	ND	0.3	ND	ND	95	ND	ND	25	81	ND	31	10500	ND	135	139	23	1
	6.19	1984																<140	130	30		
	6.16	1983	4.2	ND	ND		ND	ND	ND	65	ND	3830	20	37	ND	13	7480	ND	91	67	9.3	0.5
	6.16	1984																<140	250	100		
DARBY CREEK	6.28	1984																<140	<50	10		
	6.16	1983	26	ND	ND	ND	0.3	ND	ND	45	ND	ND	32	101	ND	26	20200	ND	204	235	40	0.4
	6.15	1983	4.7	ND	ND	ND	ND	ND	ND	28	ND	3630	16	33	ND	14	7060	ND	61	70	14	0.5
	6.14	1984																<140	120	30		
CLAERVIEW LEACHATE SED.	6.10	1983	8.5	ND	ND	ND	ND	ND	ND	85	ND	ND	24	132	ND	23	11900	ND	115	140	17	ND
	5.97	1983	5.1	ND	ND	ND	ND	ND	ND	60	ND	4250	22	32	ND	26	7850	ND	74	73	14	0.5
	5.97	1984																<140	70	<20		
FOLCROFT	4.73	1983	4.8		0.3				0.85	122	1050	14400	40.7	109	10.6	59.4	16900	20	322	200	33.6	U
	4.36	1983	1.7						0.61	94	4040	4350	24.1	35.4	3.5	32.1	5200	9.2	38.6	157	16	U
HERMSPROTA CREEK	5.00	1983	3.7				0.2		0.75	118	820	7150	26.7	124	6.9	39.7	13100	9.4	161	148	22.3	U
	4.5	1983	5.7		0.15		0.15		1.1	94	5600	9800	51	82	7.3	49.7	13500	19.5	200	191	25.2	U
FOLCROFT PONDED SED.	4.70	1983	2.7						0.26	54	4560	6750	17.8	66	4.7	25.2	11200	10.5	177	126	17.2	U

Table H. Continued.

RIVER MILE	PARAMETERS																						
	%MOISTURE	AL	CD	CR	CU	FE	MN	NI	PB	ZN	BA	BE	CO	B	V	AG	AS	SB	SE	TL	HG	SN	CN
6.25	27.22	6206.2	1.1	5.1	36.3	10389.8	123.4	14.3	109.8	141.7	45.9	<0.73	6.2	<624.3	<73.4	1.2	8.4	37.5	0.4	<8.8	0.1	<49.0	0.011
6.19	22.34	5106.5	0.9	6.6	30.5	10756.5	124.7	13.8	72.6	135.1	78.6	<0.63	5.0	<534.2	<62.5	0.3	8.8	30.5	<0.4	<7.5	0.1	<100.6	0.013
6.16	25.37	4473.6	0.9	3.6	21.5	8431.5	98.3	11.5	122.9	123.7	37.9	<0.60	4.2	<575.6	<60.7	0.3	4.9	28.2	<0.3	<7.3	<0.2	<97.1	0.008
6.28	26.53	4608.1	1.3	10.1	28.3	14709.7	160.0	15.2	59.7	147.8	95.1	<0.59	7.3	<503.0	<59.2	0.4	11.3	29.9	<0.3	<7.1	0.1	<94.7	0.012
6.16	28.42	5408.1	1.0	6.5	35.0	10901.3	172.7	16.6	153.2	166.9	90.1	<0.72	6.5	<612.9	<72.1	0.4	8.3	32.1	<0.4	<8.7	<0.1	<115.4	0.017
6.14	26.74	6272.5	1.2	5.0	17.8	13679.6	246.3	16.6	35.5	110.8	45.9	<0.77	6.5	<656.2	<77.2	0.4	8.6	32.0	<0.4	<9.3	<0.1	<123.5	0.004

Table I. Water quality data, Cobbs and Hermesprota Creeks, PA. Mean and maximum concentrations of pollutants in ambient water. First line of each cell = number of observations, second line = mean, third line = maximum. All concentrations of metals, cyanide, and ammonia are in ug/l; concentrations of BOD, dissolved oxygen, nitrogen, nitrates, and nitrites are in mg/l. pH is in standard units, turbidity in JTU, and temperature in °C.

	Cobbs Creek: Location/ Station					Hermesprota Creek: Location/ Station	
Parameter	Darby PA C1	500 ft upstream Darby Cr C2	350 ft. upstream Darby Cr C3	200 ft. upstream Darby Cr C4	50 ft. upstream Darby Cr C5	Upstream Folcroft Landfill H1	At Folcroft Landfill H2
AG	1 0.00 0.00	0 . .	0 . .	2 0.000 0.000	1 0.000 0.000	0 . .	1 0.000 0.000
AL	2 100.00 200.00	1 0.00 0.00	1 200.00 200.00	2 0.000 0.000	1 0.000 0.000	0 . .	1 11000.000 11000.000
AS	1 0.00 0.00	0 . .	0 . .	2 0.000 0.000	1 0.000 0.000	0 . .	1 12.000 12.000
BA	1 0.00 0.00	0 . .	0 . .	2 0.000 0.000	1 41.000 41.000	1 0.000 0.000	1 208.000 208.000
BOD5	0 . .	0 . .	0 . .	0 . .	1 6.500 6.500	0 . .	0 . .
CD	2 0.00 0.00	1 0.00 0.00	1 1.34 1.34	2 0.000 0.000	1 0.000 0.000	1 0.000 0.000	0 . .
CN_FREE	2 1.00 2.00	1 2.00 2.00	1 2.00 2.00	2 0.000 0.000	1 0.000 0.000	1 0.000 0.000	1 0.000 0.000
CR	2 0.00 0.00	1 0.00 0.00	1 0.00 0.00	2 0.000 0.000	1 0.000 0.000	1 0.000 0.000	1 34.000 34.000
CU	2 0.00 0.00	1 0.00 0.00	1 0.00 0.00	2 0.000 0.000	1 0.000 0.000	1 0.000 0.000	1 0.000 0.000
DO	2 8.00 9.50	0 . .	0 . .	0 . .	0 . .	0 . .	0 . .
FE	2 890.00 1780.00	1 490.00 490.00	1 940.00 940.00	2 0.000 0.000	1 439.000 439.000	1 1340.000 1340.000	1 14000.000 14000.000
HG	1 0.00 0.00	0 . .	0 . .	2 0.000 0.000	0 . .	0 . .	0 . .
KJEL_N	0 . .	0 . .	0 . .	0 . .	1 1.090 1.090	0 . .	0 . .
MG	0 . .	0 . .	0 . .	0 . .	0 . .	0 . .	0 . .

Table I. (Continued)

Parameter	Cobbs Creek: Location/ Station Darby PA C1	500 ft upstream Darby Cr C2	350 ft. upstream Darby Cr C3	200 ft. upstream Darby Cr C4	50 ft. upstream Darby Cr C5	Hermesprota Creek: Location/ Station Upstream Folcroft Landfill H1	At Folcroft Landfill H2
MN	2 125.00 250.00	1 70.00 70.00	1 130.00 130.00	2 0.000 0.000	1 81.000 81.000	1 107.000 107.000	1 796.000 796.000
NH3	0 . .	0 . .	0 . .	0 . .	1 0.270 0.270	0 . .	0 . .
NI	2 0.00 0.00	1 0.00 0.00	1 0.00 0.00	2 0.000 0.000	1 0.000 0.000	1 0.000 0.000	1 0.000 0.000
NO2	0 . .	0 . .	0 . .	0 . .	1 0.352 0.352	0 . .	0 . .
NO3	0 . .	0 . .	0 . .	0 . .	1 0.310 0.310	0 . .	0 . .
PB	2 5.10 10.20	1 5.90 5.90	1 8.60 8.60	2 0.000 0.000	1 0.000 0.000	1 0.000 0.000	0 . .
PH	2 7.45 7.50	0 . .	0 . .	0 . .	1 7.700 7.700	0 . .	0 . .
PHENOLS	0 . .	0 . .	0 . .	0 . .	1 0.000 0.000	0 . .	0 . .
PO4	1 0.03 0.00	0 . .	0 . .	0 . .	1 0.340 0.340	0 . .	0 . .
SE	1 0.00 0.00	0 . .	0 . .	2 0.000 0.000	1 0.000 0.000	0 . .	0 . .
TEMP	2 17.75 25.50	0 . .	0 . .	0 . .	0 . .	0 . .	0 . .
TURB	0 . .	0 . .	0 . .	0 . .	0 . .	0 . .	0 . .
ZN	2 50.00 100.00	1 30.00 30.00	1 30.00 30.00	2 70.000 140.000	1 0.000 0.000	0 . .	1 206.000 206.000

Table J. Water quality data, Darby Creek, PA. Mean and maximum concentrations of pollutants in ambient water. First line of each cell = number of observations, second line = mean, third line = maximum. All concentrations of metals, cyanide, and ammonia are in ug/l; BOD, dissolved oxygen, nitrogen, nitrates, and nitrites are in mg/l. pH is in standard units, turbidity in JTU, and temperature in °C.

	Location/ Station								
Parameter	Devon, PA D1	Upper Darby, PA D2	1000 ft. upstream Cobbs Cr D3	650 ft. upstream Cobbs Cr. D4	500 ft. upstream Cobbs Cr. D5	100 ft. upstream Cobbs Cr D6	25 ft. upstream Cobbs Cr D7	At Cobbs Cr D8	75 ft. dnstream Cobbs Cr D9
AG	0	0	1	1	0	1	0	1	0
	.	.	0.000	0	.	0.000	.	0.000	.
	.	.	0.000	0	.	0.000	.	0.000	.
AL	0	4	2	1	1	2	1	1	1
	.	180.000	0.000	0	80.000	55.000	0.000	0.000	200.000
	.	430.000	0.000	0	80.000	110.000	0.000	0.000	200.000
AS	0	4	1	1	0	1	0	1	0
	.	0.000	0.000	0	.	0.000	.	0.000	.
	.	0.000	0.000	0	.	0.000	.	0.000	.
BA	0	0	1	1	0	1	0	1	0
	.	.	0.000	0	.	52.000	.	47.000	.
	.	.	0.000	0	.	52.000	.	47.000	.
BOD5	1	0	0	0	1	2	0	1	0
	3.000	1.675	.	.	1.600	1.350	.	4.000	.
	3.000	9.900	.	.	1.600	1.500	.	4.000	.
CD	0	4	2	1	1	2	1	1	1
	.	0.000	0.110	0	0.000	0.000	0.000	0.000	0.200
	.	0.000	0.220	0	0.000	0.000	0.000	0.000	0.200
CN_FREE	0	0	2	1	1	2	1	1	1
	.	.	1.000	0	0.000	0.000	1.000	0.000	1.000
	.	.	2.000	0	0.000	0.000	1.000	0.000	1.000
CR	0	4	2	1	1	2	1	1	1
	.	7.500	0.000	0	0.000	20.000	0.000	0.000	0.000
	.	20.000	0.000	0	0.000	40.000	0.000	0.000	0.000
CU	0	4	2	1	1	2	1	1	1
	.	15.000	0.000	0	10.000	0.000	0.000	0.000	0.000
	.	50.000	0.000	0	10.000	0.000	0.000	0.000	0.000
DO	7	1	0	0	0	0	0	0	0
	9.957	10.436	.	.	.	.	.	.	.
	11.600	13.200	.	.	.	.	.	.	.
FE	0	4	2	1	1	2	1	1	1
	.	737.917	635.000	0	690.000	157.000	300.000	317.000	1380.000
	.	9360.000	1270.000	0	690.000	250.000	300.000	317.000	1380.000
HG	0	4	1	1	0	0	0	0	0
	.	0.000	0.000	0	.	.	.	.	.
	.	0.000	0.000	0	.	.	.	.	.
KJEL_N	5	1	0	0	0	1	0	1	0
	0.598	0.300	.	.	.	0.390	.	1.080	.
	1.000	0.300	.	.	.	0.390	.	1.080	.
MG	0	3	0	0	0	0	0	0	0
	.	9.720	.	.	.	.	.	.	.
	.	11.500	.	.	.	.	.	.	.

Table J. Water quality data, Darby Creek, PA. Mean and maximum concentrations of pollutants in ambient water. First line of each cell = number of observations, second line = mean, third line = maximum. All concentrations of metals, cyanide, and ammonia are in ug/l; BOD, dissolved oxygen, nitrogen, nitrates, and nitrites are in mg/l. pH is in standard units, turbidity in JTU, and temperature in °C.

	Location/ Station								
Parameter	Devon, PA D1	Upper Darby, PA D2	1000 ft. upstream Cobbs Cr D3	650 ft. upstream Cobbs Cr. D4	500 ft. upstream Cobbs Cr. D5	100 ft. upstream Cobbs Cr D6	25 ft. upstream Cobbs Cr D7	At Cobbs Cr D8	75 ft. dnstream Cobbs Cr D9
MN	0	4	2	1	1	2	1	1	1
	.	17.500	35.000	0	110.000	43.500	0.000	60.000	120.000
	.	30.000	70.000	0	110.000	50.000	0.000	60.000	120.000
NH3	3	4	0	0	1	2	0	1	0
	0.080	0.047	.	.	1.320	0.240	.	0.180	.
	0.180	0.270	.	.	1.320	0.380	.	0.180	.
NI	0	4	2	1	1	2	1	1	1
	.	5.000	0.000	0	0.000	20.000	0.000	0.000	0.000
	.	10.000	0.000	0	0.000	40.000	0.000	0.000	0.000
NO2	3	4	0	0	1	2	0	1	0
	0.007	0.014	.	.	0.036	0.044	.	0.220	.
	0.010	0.044	.	.	0.036	0.066	.	0.220	.
NO3	1	4	0	0	1	2	0	1	0
	1.500	1.877	.	.	2.480	1.265	.	1.580	.
	1.500	2.990	.	.	2.480	2.000	.	1.580	.
PB	0	4	2	1	1	2	1	1	1
	.	0.000	2.800	0	5.000	0.000	0.000	0.000	12.600
	.	0.000	5.600	0	5.000	0.000	0.000	0.000	12.600
PH	8	5	0	0	1	2	0	1	0
	7.122	7.910	.	.	7.200	7.600	.	7.700	.
	9.200	8.900	.	.	7.200	7.700	.	7.700	.
PHENOLS	0	0	0	0	1	1	0	1	0
	.	.	.	.	15.000	0.000	.	0.000	.
	.	.	.	.	15.000	0.000	.	0.000	.
PO4	6	4	0	0	0	1	0	1	0
	0.133	0.075	.	.	.	0.120	.	0.280	.
	0.310	0.270	.	.	.	0.120	.	0.280	.
SE	0	0	1	1	0	1	0	1	0
	.	.	0.000	0	.	0.000	.	0.000	.
	.	.	0.000	0	.	0.000	.	0.000	.
TEMP	8	3	0	0	0	0	0	0	0
	13.917	12.654	.	.	.	.	.	.	.
	33.000	24.000	.	.	.	.	.	.	.
TURB	0	0	0	0	1	1	0	0	0
	.	.	.	.	3.000	1.000	.	.	.
	.	.	.	.	3.000	1.000	.	.	.
ZN	0	4	2	1	1	2	1	1	1
	.	17.500	0.000	0	10.000	5.000	10.000	0.000	30.000
	.	30.000	0.000	0	10.000	10.000	10.000	0.000	30.000

Table J. Water quality data, Darby Creek, PA. Mean and maximum concentrations of pollutants in ambient water. First line of each cell = number of observations, second line = mean, third line = maximum. All concentrations of metals, cyanide, and ammonia are in ug/l; BOD, dissolved oxygen, nitrogen, nitrates, and nitrites are in mg/l. pH is in standard units, turbidity in JTU, and temperature in °C.

Parameter	Location/ Station 150 ft. dnstream Cobbs Cr D10	300 ft. dnstream Cobbs Cr D11	1000 ft. dnstream Cobbs Cr D12	1800 ft. dnstream Cobbs Cr D13	2000 ft. dnstream Cobbs Cr D14	Upstream Tinicum Center D15	At Tinicum Center D16	At Route 291 D17
AG	0	0	0	0	1	0	0	0
	.	.	.	.	14.000	.	.	.
	.	.	.	.	14.000	.	.	.
AL	1	1	0	1	1	0	1	0
	160.000	2210.00	.	1990.000	0.000	.	398000.00	.
	160.000	2210.00	.	1990.000	0.000	.	398000.00	.
AS	0	0	0	0	1	0	1	53
	.	.	.	.	0.000	.	92.00	0.000
	.	.	.	.	0.000	.	92.00	0.000
BA	0	0	0	0	1	1	1	0
	.	.	.	.	55.000	0.000	3310.00	.
	.	.	.	.	55.000	0.000	3310.00	.
BOD5	1	0	1	1	1	0	0	53
	1.600	.	10.00	1.000	1.100	.	.	2.894
	1.600	.	10.00	1.000	1.100	.	.	14.800
CD	1	1	0	1	1	1	1	53
	0.000	2.05	.	0.230	0.000	0.000	65.00	0.113
	0.000	2.05	.	0.230	0.000	0.000	65.00	1.660
CN_FREE	1	1	1	1	1	1	1	0
	0.000	0.00	0.00	0.007	0.000	0.000	445.00	.
	0.000	0.00	0.00	0.007	0.000	0.000	445.00	.
CR	1	1	0	1	1	1	1	53
	30.000	30.00	.	20.000	0.000	0.000	1500.00	6.604
	30.000	30.00	.	20.000	0.000	0.000	1500.00	40.000
CU	1	1	0	1	1	1	1	53
	20.000	120.00	.	30.000	0.000	0.000	2070.00	18.326
	20.000	120.00	.	30.000	0.000	0.000	2070.00	80.000
DO	0	0	0	0	0	0	0	21
	.	.	.	.	.	.	.	6.771
	.	.	.	.	.	.	.	12.100
FE	1	1	1	1	1	1	1	53
	320.000	12290.00	15056.00	3170.000	761.000	1990.000	505000.00	986.781
	320.000	12290.00	15056.00	3170.000	761.000	1990.000	505000.00	4360.000
HG	0	0	0	0	0	0	0	53
	.	.	.	.	.	.	.	0.038
	.	.	.	.	.	.	.	2.000
KJEL_N	0	0	1	0	1	0	0	50
	.	.	0.00	.	1.220	.	.	1.610
	.	.	0.00	.	1.220	.	.	16.000
MG	0	0	0	0	0	0	0	0
	.	.	.	.	.	.	.	.
	.	.	.	.	.	.	.	.

Table J. Water quality data, Darby Creek, PA. Mean and maximum concentrations of pollutants in ambient water. First line of each cell = number of observations, second line = mean, third line = maximum. All concentrations of metals, cyanide, and ammonia are in ug/l; BOD, dissolved oxygen, nitrogen, nitrates, and nitrites are in mg/l. pH is in standard units, turbidity in JTU, and temperature in °C.

	Location/ Station							
Parameter	150 ft. dnstream Cobbs Cr D10	300 ft. dnstream Cobbs Cr D11	1000 ft. dnstream Cobbs Cr D12	1800 ft. dnstream Cobbs Cr D13	2000 ft. dnstream Cobbs Cr D14	Upstream Tinicum Center D15	At Tinicum Center D16	At Route 291 D17
MN	1	1	0	1	1	1	1	0
	60.000	490.00	.	120.000	116.000	280.000	5760.00	.
	60.000	490.00	.	120.000	116.000	280.000	5760.00	.
NH3	1	0	1	1	1	0	0	53
	0.540	.	32.10	2.750	0.230	.	.	0.742
	0.540	.	32.10	2.750	0.230	.	.	2.730
NI	1	1	0	1	1	1	1	0
	10.000	30.00	.	10.000	116.000	0.000	908.00	.
	10.000	30.00	.	10.000	116.000	0.000	908.00	.
NO2	1	0	1	1	1	0	0	53
	0.026	.	0.08	0.038	0.220	.	.	0.098
	0.026	.	0.08	0.038	0.220	.	.	0.714
NO3	1	0	1	1	1	0	0	53
	1.990	.	1.84	1.980	1.680	.	.	1.819
	1.990	.	1.84	1.980	1.680	.	.	3.450
PB	1	1	0	1	1	1	1	53
	0.000	407.00	.	131.000	0.000	0.000	3450.00	11.851
	0.000	407.00	.	131.000	0.000	0.000	3450.00	224.500
PH	1	0	1	1	1	0	0	17
	7.500	.	7.90	7.500	7.700	.	.	6.893
	7.500	.	7.90	7.500	7.700	.	.	7.600
PHENOLS	1	1	1	1	1	0	0	0
	0.000	35.00	47.50	37.500	0.000	.	.	.
	0.000	35.00	47.50	37.500	0.000	.	.	.
PO4	0	0	0	0	1	0	0	51
	.	.	.	.	0.340	.	.	0.225
	.	.	.	.	0.340	.	.	0.420
SE	0	0	0	1	1	0	1	38
	.	.	.	0.000	0.000	.	2.50	0.263
	.	.	.	0.000	0.000	.	2.50	10.000
TEMP	0	0	0	0	0	0	0	25
	.	.	.	.	.	.	.	13.820
	.	.	.	.	.	.	.	27.000
TURB	1	0	1	1	0	0	0	0
	3.000	.	100.00	25.000	.	.	.	.
	3.000	.	100.00	25.000	.	.	.	.
ZN	1	1	0	1	1	0	1	52
	20.000	320.00	.	60.000	0.000	.	8460.00	32.738
	20.000	320.00	.	60.000	0.000	.	8460.00	110.000

Table K. Calculation of tidal prism on Darby Creek.

Distance From Upstream Limit (m)	Approx Intertidal Depth (m)	Approx Intertidal Width (m)	Intertidal Volume (cu m)	Cummulative Intertidal Volume (cu m)	Approx Subtidal Depth (m)	Approx Subtidal Width (m)	Subtidal Volume (cu m)	Cummulative Subtidal Volume (cu m)
0	0.00	12.00	0	0	0.90	12.00	720	720
100	0.02	12.66	23	23	0.91	12.66	768	1488
200	0.04	13.33	49	72	0.92	13.33	816	2304
300	0.05	13.99	77	149	0.93	13.99	866	3170
400	0.07	14.65	107	256	0.94	14.65	916	4086
500	0.09	15.32	140	396	0.95	15.32	967	5054
600	0.11	15.98	176	572	0.96	15.98	1019	6073
700	0.13	16.64	213	785	0.97	16.64	1072	7145
800	0.15	17.31	254	1039	0.98	17.31	1126	8271
900	0.16	17.97	296	1335	0.99	17.97	1180	9451
1000	0.18	18.63	341	1676	0.99	18.63	1236	10687
1100	0.20	19.29	389	2065	1.00	19.29	1292	11978
1200	0.22	19.96	439	2504	1.01	19.96	1349	13327
1300	0.24	20.62	491	2995	1.02	20.62	1407	14734
1400	0.26	21.28	546	3541	1.03	21.28	1465	16199
1500	0.27	21.95	603	4144	1.04	21.95	1525	17724
1600	0.29	22.61	663	4806	1.05	22.61	1585	19309
1700	0.31	23.27	725	5531	1.06	23.27	1646	20955
1800	0.33	23.94	789	6320	1.07	23.94	1708	22663
1900	0.35	24.60	856	7176	1.08	24.60	1771	24435
2000	0.37	25.26	925	8102	1.09	25.26	1835	26269
2100	0.38	25.93	997	9099	1.10	25.93	1899	28169
2200	0.40	26.59	1071	10170	1.11	26.59	1965	30134
2300	0.42	27.25	1148	11318	1.12	27.25	2031	32165
2400	0.44	27.92	1227	12545	1.13	27.92	2098	34263
2500	0.46	28.58	1309	13854	1.14	28.58	2166	36429
2600	0.48	29.24	1393	15247	1.15	29.24	2235	38664
2700	0.49	29.91	1479	16725	1.16	29.91	2304	40968
2800	0.51	30.57	1568	18293	1.17	30.57	2375	43342
2900	0.53	31.23	1659	19952	1.17	31.23	2446	45788
3000	0.55	31.89	1753	21704	1.18	31.89	2518	48306
3100	0.57	32.56	1849	23553	1.19	32.56	2591	50897
3200	0.59	33.22	1947	25500	1.20	33.22	2665	53562
3300	0.60	33.88	2048	27548	1.21	33.88	2739	56301
3400	0.62	34.55	2151	29700	1.22	34.55	2815	59116
3500	0.64	35.21	2257	31957	1.23	35.21	2891	62007
3600	0.66	35.87	2365	34322	1.24	35.87	2968	64975
3700	0.68	36.54	2476	36798	1.25	36.54	3046	68021
3800	0.70	37.20	2589	39387	1.26	37.20	3125	71146
3900	0.71	37.86	2705	42092	1.27	37.86	3204	74350
4000	0.73	38.53	2823	44915	1.28	38.53	3285	77635
4100	0.75	39.19	2943	47857	1.29	39.19	3366	81001
4200	0.77	39.85	3066	50923	1.30	39.85	3448	84450
4300	0.79	40.52	3191	54114	1.31	40.52	3531	87981
4400	0.81	41.18	3319	57433	1.32	41.18	3615	91596
4500	0.82	41.84	3449	60881	1.33	41.84	3700	95296
4600	0.84	42.51	3581	64463	1.34	42.51	3785	99081

Table K. Calculation of tidal prism on Darby Creek.

Distance From Upstream Limit (m)	Approx Intertidal Depth (m)	Approx Intertidal Width (m)	Intertidal Volume (cu m)	Cummulative Intertidal Volume (cu m)	Approx Subtidal Depth (m)	Approx Subtidal Width (m)	Subtidal Volume (cu m)	Cummulative Subtidal Volume (cu m)
4700	0.86	43.17	3716	68179	1.35	43.17	3872	102952
4800	0.88	43.83	3853	72032	1.35	43.83	3959	106911
4900	0.90	44.49	3993	76025	1.36	44.49	4047	110958
5000	0.92	45.16	4136	80161	1.37	45.16	4136	115093
5100	0.93	45.82	4280	84441	1.38	45.82	4225	119318
5200	0.95	46.48	4427	88868	1.39	46.48	4316	123634
5300	0.97	47.15	4577	93445	1.40	47.15	4407	128041
5400	0.99	47.81	4729	98174	1.41	47.81	4499	132540
5500	1.01	48.47	4883	103057	1.42	48.47	4592	137133
5600	1.03	49.14	5040	108097	1.43	49.14	4686	141819
5700	1.04	49.80	5199	113296	1.44	49.80	4781	146600
5800	1.06	50.46	5361	118657	1.45	50.46	4876	151476
5900	1.08	51.13	5525	124182	1.46	51.13	4973	156449
6000	1.10	51.79	5691	129873	1.47	51.79	5070	161519
6100	1.12	52.45	5860	135733	1.48	52.45	5168	166687
6200	1.14	53.12	6032	141765	1.49	53.12	5267	171953
6300	1.15	53.78	6206	147971	1.50	53.78	5367	177320
6400	1.17	54.44	6382	154352	1.51	54.44	5467	182787
6500	1.19	55.11	6560	160913	1.52	55.11	5569	188356
6600	1.21	55.77	6742	167654	1.53	55.77	5671	194026
6700	1.23	56.43	6925	174579	1.53	56.43	5774	199800
6800	1.25	57.09	7111	181690	1.54	57.09	5878	205678
6900	1.26	57.76	7299	188990	1.55	57.76	5983	211660
7000	1.28	58.42	7490	196480	1.56	58.42	6088	217749
7100	1.30	59.08	7683	204163	1.57	59.08	6195	223943
7200	1.32	59.75	7879	212042	1.58	59.75	6302	230245
7300	1.34	60.41	8077	220120	1.59	60.41	6410	236655
7400	1.36	61.07	8278	228397	1.60	61.07	6519	243174
7500	1.37	61.74	8481	236878	1.61	61.74	6629	249802
7600	1.39	62.40	8686	245564	1.62	62.40	6739	256541
7700	1.41	63.06	8894	254458	1.63	63.06	6851	263392
7800	1.43	63.73	9104	263562	1.64	63.73	6963	270355
7900	1.45	64.39	9317	272879	1.65	64.39	7076	277431
8000	1.47	65.05	9532	282411	1.66	65.05	7190	284621
8100	1.48	65.72	9749	292160	1.67	65.72	7305	291926
8200	1.50	66.38	9969	302130	1.68	66.38	7420	299346
8300	1.52	67.04	10192	312322	1.69	67.04	7537	306883
8400	1.54	67.71	10417	322738	1.70	67.71	7654	314537
8500	1.56	68.37	10644	333382	1.71	68.37	7772	322310
8600	1.58	69.03	10874	344256	1.71	69.03	7891	330201
8700	1.59	69.69	11106	355361	1.72	69.69	8011	338213
8800	1.61	70.36	11340	366702	1.73	70.36	8132	346344
8900	1.63	71.02	11577	378279	1.74	71.02	8253	354598
9000	1.65	71.68	11817	390095	1.75	71.68	8376	362974
9100	1.67	72.35	12058	402154	1.76	72.35	8499	371472
9200	1.69	73.01	12303	414456	1.77	73.01	8623	380095
9300	1.70	73.67	12549	427006	1.78	73.67	8748	388843
9400	1.72	74.34	12798	439804	1.79	74.34	8873	397717
9500	1.74	75.00	13050	452854	1.80	75.00	9000	406717