

**CONTAMINANTS IN FISH AND SEDIMENTS OF THE GREAT SWAMP
NATIONAL WILDLIFE REFUGE, MORRIS COUNTY, NEW JERSEY:
A 10-YEAR FOLLOW-UP INVESTIGATION**

DEC ID# 9950003.1



U.S. Fish & Wildlife Service
New Jersey Field Office

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EXECUTIVE SUMMARY

Located in Morris County, New Jersey about 25 miles west of New York City's Time Square, the U.S. Fish & Wildlife Service's (Service) Great Swamp National Wildlife Refuge (GSNWR) encompasses approximately 7,500 acres of which 3,660 acres are designated and managed as a National Wilderness Area. The GSNWR's wetlands provide important ecological functions, including floodwater attenuation, groundwater recharge, pollution abatement, wildlife habitat, as well as recreational benefits for the public. In many portions of the Great Swamp watershed, significant areas of native soils have been disturbed by development to the extent that the original soil profiles no longer exist. Development-related activities such as grading, infilling, and compaction have adversely altered the native soil's infiltration capacity and runoff potential and thereby have increased storm-water sediment loading into many of the watershed's streams.

The purpose of this investigation is to conduct a 10-year follow-up to a 1988 investigation (USFWS 1991) characterizing ambient concentrations of metals, organochlorines, and polycyclic aromatic hydrocarbons (PAHs) in GSNWR sediments, and metals and organochlorine in fish inhabiting the GSNWR. Moreover, data from the 1988 investigation were compared with 1999 data to determine whether ambient conditions have significantly changed.

By comparing the 1988 and 1999 sediment data to sediment quality screening criteria this investigation revealed several significant changes in sediment quality at discrete locations within the GSNWR. The use of sediment quality guideline criteria, particularly the Probable Effects Concentration (PEC) (MacDonald, *et al.*, 2000), revealed several current (*e.g.*, post 1999) areas of concern, namely:

- elevated mercury at station 16C;
- elevated lead at station 16;
- elevated PAHs and lead at station 16A;
- elevated zinc at station 27; and,
- elevated chlordane levels at stations 1 and 9.

Unfortunately, sediments from station 11, where the co-located fish sample had the highest chlordane, total PCBs, and DDE concentrations, did not get analyzed for organochlorines. It is recommended that stations **1, 9, 11, 16, 16A, 16C, 27** and the surrounding environs receive additional contaminant delineation.

With the exception of lead and zinc, whole-fish body burdens for aluminum, cadmium, chromium, copper, manganese, and nickel were comparable between the 1988 and 1999 sampling effort. The lead concentration geometric mean of whole-fish in the 1988 sampling effort was 0.18 mg/kg-ww. The lead concentration geometric mean had increased more than 2.5-fold to 0.5 mg/kg-ww in 1999. Interestingly, the range of lead concentrations in whole fish (0.4 to 0.53 mg/kg-ww) was fairly uniform across the 1999 sampling stations ($n=10$) with a coefficient of variation of 7.2 percent. This uniformity suggests that lead bioavailability to mud minnows is a GSNWR-wide phenomenon. Quantifiable levels of *p,p'*-DDE were detected in fish at all 10 sampling stations (geometric mean of 5.9 ug/kg-ww; range = 2.57 -15.3 ug/kg-ww).

Alpha chlordane was the second most prevalent organochlorine detected with quantifiable concentrations at 9 of the 10 sampling stations. Total PCBs, *p,p'*-DDD, heptachlor epoxide, *cis*-nonachlor, and *trans*-nonachlor were also detected at several stations demonstrating that GSNWR fish continue to be exposed to residual organochlorines. The PCB, DDE, DDD, and chlordane residue levels detected in fish analyzed during the 1999 effort are generally considered low from the perspective of acute or lethal toxicity.

The GSNWR includes part of the Rolling Knolls Landfill in Chatham Township. In 2003, the Rolling Knolls Landfill was designated a Superfund site, when it was placed on the final National Priorities List. The Service now has roles as both responsible party and trustee related to this Superfund site. Although the 1988 sampling stations associated with the Rolling Knolls Landfill were not included in this investigation, 1988 levels of total polychlorinated biphenyls (PCBs), mercury, and DDT were notably elevated and warranted further evaluation. It is recommended that future investigations related to the Rolling Knolls Landfill Superfund Site employ the proposed New Jersey-specific wildlife criterion for PCBs, mercury, and DDT (NJDEP *et al.*, 2001).

Additional recommendations made in this report include; 1) evaluate further the specific sampling stations where contaminant levels have increased since the 1988 sampling effort; 2) use of GPS/GIS technologies to monitor long-term trends in GSNWR contamination and storm-water runoff characteristics; 3) evaluate the source(s) of lead and zinc enrichment in GSNWR fish; 4) monitor GSNWR fish for mercury; 5) evaluate the causes prohibiting Loantaka, Great, and Black Brooks from attaining their designated uses; 6) work with the local 10 municipalities of the Great Swamp watershed to promote an ordinance to limit or ban the use of coal-tar-based sealants; 7) implement protocols for the collection and preservation of mink tissues and Ardeidae eggs; and, 8) implement an environmental quality-monitoring program that is robust, repetitive, and orchestrated with other federal, state and local monitoring programs. It is imperative that such a monitoring program be implemented as a standardized GSNWR function with a specific and guaranteed annual commitment for contaminant monitoring.

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INTRODUCTION

Located in Morris County, New Jersey, about 25 miles west of New York City's Time Square, the U.S. Fish & Wildlife Service's (Service) Great Swamp National Wildlife Refuge (GSNWR) encompasses approximately 7,500 acres of which 3,660 acres are designated and managed as a National Wilderness Area. The GSNWR lies in the western part of the former Lake Passaic - formed 12-15,000 years ago during the retreat of the Wisconsin Glacier. Currently, approximately 80 percent of the Great Swamp proper is protected in perpetuity and managed as the GSNWR. The GSNWR's wetlands provide important ecological functions, including floodwater attenuation, groundwater recharge, pollution abatement, wildlife habitat, as well as recreational benefits for the public.

Dominated by wooded upland and palustrine wetland areas, the GSNWR contains plant species of both northern and southern botanical zones. The GSNWR is inhabited by approximately 600 species of plants (including 215 wildflowers), 29 species of fish, 33 species of reptiles and amphibians, and more than 220 species of birds (of which almost half nest on the GSNWR). More than 25 species known to use the GSNWR are listed by the State of New Jersey as being threatened or endangered, including the wood turtle (*Clemmys insculpta*), the blue-spotted salamander (*Ambystoma laterale*), and the bog turtle (*Clemmys muhlenbergii*), which is also federally listed as threatened. Additionally, the Indiana bat (*Myotis sodalis*), a species federally listed as endangered, was documented as using the GSNWR as foraging habitat in the summer of 2005.

The Great Swamp watershed includes areas predominantly drained by Primrose, Loantaka, Great, and Black Brooks, and the upper Passaic River. These perennial waterways all converge within GSNWR and then drain through the Millington Gorge as the Passaic River. Primrose and Loantaka Brooks are tributaries to the Great Brook. The Great and Black Brooks are tributaries to the Passaic River; thus the overall drainage of the Passaic River within the Great Swamp watershed is approximately 55-square miles.

The GSNWR and surrounding Great Swamp watershed make up a diverse ecosystem integrated with 10 municipalities: Bernards Township; Bernardsville Borough; Chatham Township; Harding Township; Long Hill Township; Madison Borough; Mendham Borough; Mendham Township; Morristown; and, Morris Township. The Great Swamp watershed's topography is principally comprised of a Highlands physiographic province area, upland ridges, and a central basin, varying greatly across its aerial extent. Located in the watershed's northwest portion, the Highlands are characterized by a series of steep valleys separated by upland ridges with slopes often exceeding 10 percent. Elevations in the Highlands typically range from 300 to 700 feet. The balance of the watershed's boundary is formed by a relatively narrow ridgeline. This ridge varies from 0.25 to 1.0 miles wide, with elevations ranging from approximately 360 to 500 feet. An eight-mile portion of this ridgeline, Long Hill, forms the watershed's southern border. North of Long Hill, is the watershed's 20.4 square mile central basin, enclosed within a 260-foot elevation contour. Shallow north-to-south ridges and broad valleys characterize the basin's northern portion, primarily located in Morris and Harding Townships. The 14.6 square-mile Great Swamp, a broad, flat, low-lying area surrounded by a 240-foot elevation contour, occupies the central basin's southern portion. Ground slope within the Great Swamp is essentially

negligible. The Great Swamp's hydrology has been influenced by extensive drainage ditch construction that occurred between the early 1800's and early 1900's. The swamp is comprised largely of wetland areas and meandering streams with low hydraulic gradients. Thus, the swamp, including the GSNWR is inherently susceptible to flooding and pollutant loading from the surrounding watershed.

Several generalizations can be made describing soils in the Great Swamp watershed. Soils considered having high infiltration rates are essentially absent in the watershed. Soils considered to have moderate infiltration rates are generally limited to higher elevations, along ridges and the watershed's northwest quadrant. Soils considered to have low infiltration rates are located primarily within the Great Brook watershed.

Soils in the large contiguous area generally identified as the Great Swamp proper have a very favorable hydrologic regime for the minimization of contaminant transport. In this area, soils are considered hydric and have a low permeability with a highly impermeable clay/silt underlying. The swamp is underlain by large quantities of clay, silt, sand and gravel that were deposited by glacial ice. Peat continues to be deposited from the heavily vegetated swamp.

The relatively impermeable silt and clay beds confine the deep ground water of the Great Swamp watershed that exhibits artesian behavior leading to groundwater discharge in the swamp. Confined aquifer contamination is unlikely throughout most of the GSNWR due to the upwelling of ground water (*e.g.*, contaminants will not move against the artesian head) and the presence of clay confining beds, which are effectively impermeable barriers. The relatively flat hydraulic gradient and low permeability of surface materials impede contaminant migration via the aquifer and surface-water, which results in low groundwater velocity and surface-water pooling. When coupled with the pollutant retention capacity of highly organic soils, significant surface or shallow subsurface mobilization of contaminants is not expected. The exceptions to these generalizations occur where there are breaches in the subsurface clay layer.

In many portions of the watershed, significant areas of native soils have been disturbed by development to the extent that the original soil profiles no longer exist. Development-related activities such as grading, infilling, and compaction have occurred over time. These activities adversely alter the native soil's infiltration capacity and runoff potential and thereby have increased storm-water sediment loading into many of the watershed's streams.

There are many pollution point sources in the Great Swamp watershed, several of which are in close proximity to, or within the GSNWR that merit discussion. The Loantaka and Black Brooks are recipients of surface-water flow from 2 municipally-owned sewage treatment plants. The Woodland Avenue Plant, servicing the Morristown discharge area, flows to Loantaka Brook approximately 2 miles upstream of the GSNWR, while the Chatham Township plant discharges flow to the Black Brook approximately 1 mile upstream of the GSNWR. Between 1988 and 1999, both plants were upgraded for improved nutrients and solids removal, and replaced chlorine-based disinfection equipment with ultra-violet (UV) irradiation disinfection equipment.

Between 1988 and 1999, the remedial construction-phase at the Operable Units (OU) 2 and 3 of the Asbestos Dump Superfund Site, within the GSNWR, were completed and the OUs are now

functioning under their respective Operation and Maintenance Plans. Examination of topographic maps indicates that historic overland flow of storm-water at OU2 would have entered the wetlands north of the site. These wetlands drain through a ditch that terminates at Black Brook, north of the New Vernon Road bridge. Overland storm-water flow from OU3 would have discharged into the Great Brook east of Long Hill Road and upstream of the GSNWR Management Pool 1.

Although no cleanup activity occurred between 1988 and 1999, several preliminary remedial investigations were conducted at the Rolling Knolls Landfill (a/k/a Green Village Disposal, Miele Landfill, Rolling Knolls Farm, and the Great Swamp Refuse Dump). These investigations were conducted to determine the landfill's eligibility for inclusion on the National Priorities List (NPL). The approximately 200-acre unlined Rolling Knolls Landfill is a municipal solid waste facility situated at the southern end of Britten Road, in Chatham Township. Disposal operations at the landfill are believed to have commenced in the 1930's or 1940's. During the late 1950's there is evidence of at least one fire at the landfill, and another in 1974. In 1962, town ordinance requirements implemented at the landfill included the application of herbicides and rodenticides, dead animal disposal, and roadway oil application to control dust. In the 1960's mosquito control at the landfill and surrounding areas was implemented using DDT. Septic wastes were allowed to be pumped over the working surface and percolate into the landfilled material. The last load of non-hazardous municipal solid waste material accepted in December 31, 1968 (FWEC 2000). A waste-tracking manifest system was not used at the Rolling Knolls Landfill, consequently complete delineation of the landfill's contents are confounded. The landfill is not covered with an engineered cap, so many areas have exposed refuse while other parts are covered with scrub shrub or vegetation associated with highly disturbed soils. During the 1960's, approximately 30 acres of the landfill were transferred from the Miele Estate to the North American Wildlife Foundation and the New Jersey Conservation Foundation. Ownership of this acreage was subsequently transferred to the Service and incorporated into the GSNWR. Potential impacts of the landfill on surrounding biotic and abiotic resources are largely undocumented. The Black and Loantaka Brooks enter the landfill's vicinity by origins outside the GSNWR and upstream of the landfill. Great Brook enters the GSNWR west of the landfill, but receives the Loantaka Brook discharge downstream of the landfill. The landfill was placed on the Final NPL on September 29, 2003, and is now known as the Rolling Knolls Landfill Superfund Site (CERCLIS ID No.: NJD980505192).

The purpose of this investigation was to conduct a 10-year follow-up to a 1988 investigation (USFWS 1991) characterizing ambient concentrations of metals, organochlorines, and polycyclic aromatic hydrocarbons (PAHs) in GSNWR sediments, and metals and organochlorine in fish inhabiting the GSNWR. Moreover, data from the 1988 investigation are compared with 1999 data to determine whether ambient conditions have significantly changed.

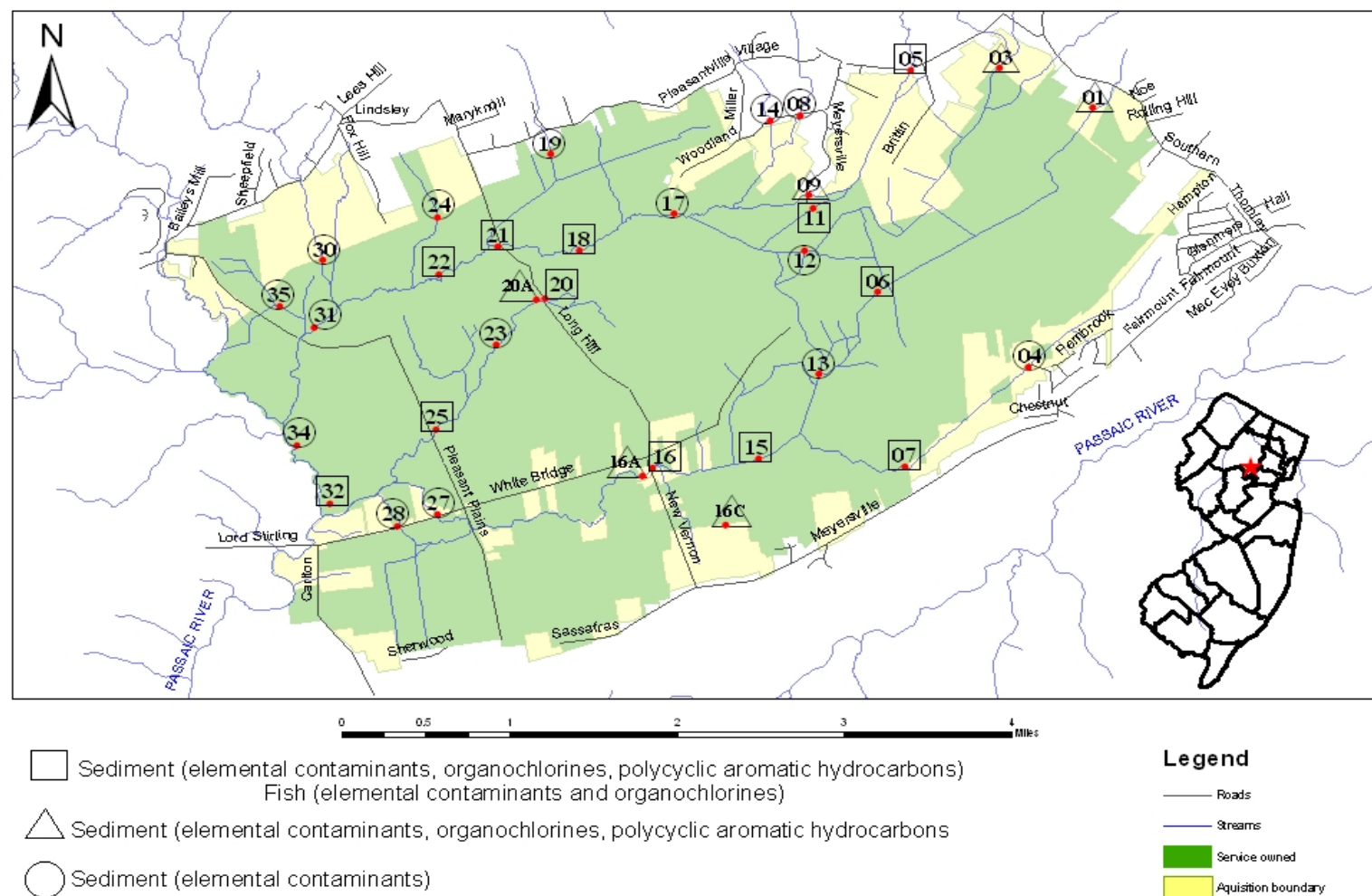
METHODS

Sampling Scheme

Sample stations (Figure 1, and Appendix A [narrative]) were chosen using an intentionally biased approach to concentrate sampling around known or potential sources of contamination and along most water courses entering the GSNWR near their point of entry (USFWS 1991). Samples were collected in June and July of 1999. Eastern mud minnow (*Umbra pygmaea*) was selected as the target fish species by virtue of its regional abundance and intimate association with area sediments (USFWS 1991). Every reasonable effort was made to locate (via a 1988 photographic log of sampling stations) and replicate sampling sites and contaminants analyzed in the 1988 sampling effort. The following variations in the 1999 sampling effort, relative to the 1988 sampling scheme, are noted below.

- Station 2 had silted in and was overgrown with cattails; no viable watercourse was found at this station, and it was therefore eliminated from the 1999 sampling effort.
- Repeated fish sampling at stations 5 and 7 did not yield any specimens.
- A processing error at the inorganic laboratory resulted in the loss of sediment samples 11b, 16C(b), 20b, and 20A(b) for organic analyses.
- A processing error at the inorganic laboratory resulted in no fish tissue arsenic, mercury, or selenium data being reported.
- The reagent blank and decontamination rinsewater blank were lost due to a laboratory accident (dropped while packing) at the New Jersey Field Office (NJFO). It should be noted that quality controls samples from other investigations are consistently acceptable (*e.g.*, no detections of any analyte); the NJFO uses commercially available certified pre-cleaned sample jars, employs a stringent equipment preparation and decontamination procedure, and produces its own on-demand Type I reagent grade water.
- A more stringent sample collection equipment preparation and decontamination procedure than used in the 1988 sampling effort was employed in the current investigation. The 1999 sampling effort decontamination procedure consisted of an ambient (or tap) water rinse, scrubbing with an 1 percent Liqui-Nox[®] solution, deionized water rinse, 1 molar nitric acid rinse, acetone rinse, methanol rinse, 3 deionized water rinses, air dry, and wrapping the sampling device in aluminum foil until ready for use.
- Stations associated with the Rolling Knolls Landfill (stations 37, 39, 39A, 40, and 41) were not sampled due to property access issues. These issues were not resolved by June 2000, and the sampling stations were eliminated from the 1999 effort.

**Figure 1. Location of Sampling Stations in the 1999
Great Swamp National Wildlife Refuge Contaminants Investigation**



Sampling Methods

Sediment samples were collected using stainless steel soil probes, hand trowels, or ponar grab (whichever was most appropriate for site-specific conditions). As in the 1998 effort, 5 approximately equal-sized sediment samples were collected from the 0-8 centimeter horizon working up-stream and then mixed as a composite. An aliquot of the composite was transferred to a 125 ml pre-cleaned I-Chem jars with teflon-lined lids for grain size and total organic carbon (TOC) analysis (these samples may be identified in the raw data by their station number followed by the letter "a"). A second aliquot was placed into 250 ml pre-cleaned I-Chem jars with Teflon-lined lids for all other analytical sediment testing (these samples may be identified in the raw data by their station number followed by the letter "b"). Samples were immediately placed in a cooler on blue ice. Upon return from the field, the grain size/TOC samples were stored at +4°C until shipment to the laboratory on wet ice. The other aliquots (250 ml jars) were stored at -20°C until shipment to the laboratory on dry ice.

Fish were collected using a battery-powered electroshocker. Whole fish composites were stored in pre-cleaned I-Chem jars with teflon-lined lids, immediately placed on wet ice for transport from the field, and then stored at -20°C until shipment to the laboratory on dry-ice (these samples may be identified in the raw data by their station number followed by the letter "c").

Analytical Methods

Inorganic analytes, grain size, and TOC analytes were performed at the Environmental Trace Substance Laboratory, University of Missouri-Rolla, Rolla, Missouri. Organic analytes were performed at the Mississippi State Chemical Laboratory, Mississippi State, Mississippi. Laboratory-specific analytical method descriptions, as required by the Service's Patuxent Analytical Control Facility (PACF), can be found in Appendix B.

Data Analysis

In addition to reporting analyte-specific minimum, maximum, and geometric mean concentrations, sediment analyte concentrations are compared to the New Jersey Department of Environmental Protection (NJDEP) criteria contained within the *Guidance for Sediment Quality Evaluations* (NJDEP 1998). For freshwater environs the NJDEP *Guidance for Sediment Quality Evaluations* are drawn from Persaud, *et al.*, (1993), utilizing the Lowest Effects Level (LEL) criteria which indicates concentrations at which adverse impacts to benthic organisms may begin to occur (a level tolerated by most benthic organisms). An exceedence of the LEL indicates a **potential** risk (adverse impact) to the benthic community and need for further investigations to reduce uncertainty and better characterize risk and natural resource injury. The NJDEP *Guidance for Sediment Quality Evaluations* also includes the Severe Effects Level (SEL) criterion. Analyte-specific SELs are based on the correlation of severe benthic impacts in 95 percent of the studies reviewed (Persaud, *et al.*, 1993). For non-polar organics, the SEL is calculated as a function of TOC content. Sediment analyte concentrations were also compared to consensus-based sediment quality guidelines (MacDonald, *et al.*, 2000). The consensus-based sediment quality guidelines use the Toxic Effect Concentration (TEC) defined as the concentration below which harmful effects to benthic organisms are unlikely to be observed, and

the Probable Effects Concentration (PEC) defined as the concentration above which harmful effects are likely to be observed. The LEL, SEL, TEC, and PEC are screening values, not enforceable cleanup standards.

Data Reporting

Reported values for sediment metal concentrations are in mg/kg-dry weight (dw); sediment polycyclic aromatic hydrocarbons (PAHs) and organochlorines are reported as ug/kg-dw. For ease of comparison to the 1988 data set and specific reference values, whole-fish metals are reported as mg/kg-wet weight (ww) as well as mg/kg-dw. Whole-fish metals data have been included herein with sample-specific moisture data. Whole-fish organochlorine concentrations are reported as ug/kg-ww.

Ten percent (10 percent) was the upper limit used for SEL and PEC calculations. One to 10 percent represents the average range over which the TOC normalization approach for generation of the SEL has been examined (EPA 1988). The PEC was derived from field-collected samples using the assumption of 1 percent TOC. The SELs were calculated assuming 1 percent TOC. Accordingly, for comparison to the PEC and SEL, reported dry weight contaminant concentrations were divided by the sample-specific percent-TOC. The dry weight-normalized values demonstrate good correlation with observed toxic effects when sample-specific TOCs exceed 1-2 percent, and predict sediment toxicity as well or better than organic carbon-normalized criterion in field-collected sediments (Ingersoll, personal communication, August 2005). Dry weight-normalized values are reported as ug/kg_{oc}. As with organic carbon-normalization, dry weight-normalization of planar halogenated and non-halogenated organics can be used as an indication of relative bioavailability.

In any table contained herein, when a reported value was less than the Method Detection Limit (MDL), the MDL was used and italicized.

Sediment contaminant concentrations are compared to sediment quality guidelines in Tables 3, 4, and 6. There are 2 sediment quality guideline criteria per column in each table (bottom 2 rows). When a reported value exceeds the top criterion, it is highlighted in bold font. When a reported value exceeds the bottom row criterion, it is highlighted by its cell being shaded.

Raw Data

Raw data in a customized format may be retrieved from the Environmental Conservation Online System (ECOS) web site through the Environmental Contaminants Data Monitoring System (ECDMS) – Catalog 5040048, and has not been included with this report. Spreadsheets used to interpret the raw data are electronically filed at the New Jersey Field Office and are available upon request.

RESULTS

Sediments

Geophysical Characteristics

As seen in Table 1, the high percentage of fine particulates (*e.g.*, ≥ 70 percent) in 29 of 33 samples indicates that sediment samples were collected in depositional areas and thereby provide a qualitative indication of bioavailability. Stations 23 and 31 demonstrated the lowest percentage of fine particulates at 65 percent and 45 percent respectively. Due to excessively high TOC content in samples 3 and 7 (56.3 percent and 51.5 percent respectively) grain size was not reported. The elevated TOC at stations 3 and 7 may be a function of high concentrations of cellulose (*i.e.*, decaying plant material) or the presence of a concentrated Carlisle muck substrate in the 0-8 cm horizon where the sediment sample were collected. Generally, surface-water pH at the sampling stations ranged from 6.5 to 7.1 (data not shown).

Metals

Dry weight sediment metal concentrations reported for the 1999 sampling effort are listed in Table 2. Dry weight sediment metals concentrations from the 1988 and 1999 sampling efforts were compared to the NJDEP *Guidance for Sediment Quality Evaluations* criteria (NJDEP1998) in Table 3 and a consensus-based sediment quality guideline (MacDonald, *et al.* 2000) in Table 4 where applicable criteria exist.

Several exceedances of the LEL were detected for arsenic, cadmium, chromium, copper, mercury, nickel, lead, and zinc in both the 1988 and 1999 samples. These exceedances suggest that further evaluation is warranted to reduce the uncertainty of the potential adverse risk posed by the exceedance. With a few exceptions, the 1988 and 1999 station-specific metals concentrations are not remarkably different (*e.g.*, an order of magnitude difference). Noteworthy in Tables 3 and 4 is the order of magnitude elevation of mercury at station 16C from the 1988 level of 0.3 mg/kg to the 1999 SEL and PEC exceedances of 2.16 mg/kg. The elevated mercury at station 16C is potentially related to the former Operable Unit 2 of the Asbestos Dump Superfund Site. Further evaluation of Station 16C is warranted. There are several other

Station	Moisture	Clay	Sand	Silt	TOC	Σ Sand & Silt
1	48.4	11	62	27	6.1	89
3	89.9				56.3	
4	54.1	5	73	22	7.3	95
5	22.4	5	75	20	1.4	95
6	61.8	5	78	17	8.6	95
7	85.3				51.5	
8	22	23	37	40	1.1	77
9	23.8	5	88	7	2.2	95
11	54.5	8	70	22	5.1	92
12	24.7	3	87	10	3.3	97
13	78.8	10	40	50	12.5	90
14	57.7	13	25	62	8.4	87
15	44.6	8	52	40	4.4	92
16	59.5	10	55	35	12.9	90
16A	16.4	3	95	2	1.3	97
16C	80.3	15	35	50	35.9	85
17	34.1	18	30	52	2.9	82
18	44.8	13	57	30	4.7	87
19	13.4	3	85	12	2.8	97
20	78.1	13	27	60	18	87
20A	69.2	18	27	55	15.8	82
21	67.4	13	22	65	10.9	87
22	38.1	18	17	65	7.5	82
23	56.5	35	15	50	5.9	65
24	24.9	13	57	30	1.8	87
25	66.3	23	22	55	12.2	77
27	43.8	8	57	35	5.7	92
28	44.5	13	40	47	4.5	87
30	24.5	15	47	38	2	85
31	23.2	55	12	33	1.5	45
32	65.6	23	25	52	11.7	77
34	44.2	30	20	50	6	70
35	57	18	32	50	10.3	82

Table 2. 1999 Sediment Metals Concentrations (mg/kg-dw)																			
Station	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg	Mg	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
1	13400	8.69	10.1	56.5	0.08	0.319	23.9	15.6	46800	0.185	1900	145	0.5	11.4	47.7	0.484	16.5	42.3	92.9
3	15400	8.79	9.76	122	0.66	1.06	18.6	39.1	31900	0.242	2360	216	1.07	17.1	89.4	2.3	37.4	31.1	160
4	7250	2.1	5.84	28.5	0.08	0.3	10.6	31.4	29500	0.0985	1550	82	0.5	7.73	24.4	0.37	9.91	16.6	84.6
5	6720	3.34	4.89	43.1	0.08	0.3	10.2	9.18	30600	0.05	1380	41.6	0.5	6.46	15.3	0.2	8.23	19.5	46.7
6	5440	2.63	4.26	54.4	0.08	0.3	7.86	13.4	25700	0.0753	813	31.3	0.5	5.44	22.8	0.577	15.3	10.1	37
7	6980	4.03	11.9	71.7	0.08	0.427	11.9	29.1	34500	0.119	2420	313	0.5	9.4	15.5	2.54	54.4	43.5	57.3
8	12900	2.77	4.4	87.2	0.889	0.3	19.9	14.7	44800	0.0328	3640	184	0.5	16.4	9.05	0.2	15	25.8	58.4
9	6690	2.92	8.96	31.3	0.08	0.3	10.4	14.8	35500	0.0392	1860	66.8	0.5	7.45	19.8	0.2	10.3	22.6	52.5
11	12500	5.02	25.7	78	0.08	0.3	15.4	40	16600	0.145	2280	326	1.85	11.5	34.6	0.664	19	36.2	104
12	6800	3.49	8.7	38.9	0.08	0.3	10.5	14.2	6090	0.0514	1510	84	0.5	7.93	24.7	0.35	13.7	28	59.9
13	15100	6.67	10.1	84.6	0.08	0.533	21.6	25.4	3770	0.136	1640	31.7	0.5	13	58.5	0.911	18.8	37.9	92.5
14	39000	4.45	8.41	141	1.28	0.426	25.9	27.2	105000	0.101	2400	134	0.5	16.4	42	0.964	23.4	53.2	92
15	15200	3.94	5.73	48.8	0.08	0.3	13	13.8	67700	0.0593	1400	53.7	0.5	9	23.2	0.312	9.54	22.1	40.6
16A	2240	4.01	15.3	22.4	0.08	0.3	6.59	49	8540	0.0325	750	16.7	0.5	5.19	145	0.2	5.89	9.05	208
16C	40200	8.24	15.8	154	1.11	1.16	27.9	42.8	66000	2.16	2550	49.1	0.5	20.5	108	2.28	119	51.4	130
16	21200	12.4	9.85	92.6	0.08	0.581	20.1	49.4	60000	0.257	2040	69.7	0.5	12.3	223	1.28	24.1	44.1	116
17	23700	3.41	7.28	128	1.39	0.3	27.2	11.3	60900	0.0575	2410	190	0.5	14	11.7	0.738	14.5	42.5	49.4
18	23100	5	11.6	138	1	0.415	24.7	19.5	97100	0.083	2660	335	0.5	14.2	28.2	0.844	19.9	36.7	91.4
19	15100	5.2	71.2	83.7	0.08	0.3	18.6	29.9	69900	0.0435	3480	521	0.5	17	24	0.266	18	85.9	92.9
20A	27900	7.96	17.9	184	2.51	0.832	34	31	54000	0.167	3280	332	0.5	19.6	42.6	1.62	26.1	51.5	115
20	29500	8.49	17.9	201	2.28	0.754	34.6	35.7	54500	0.167	3150	289	0.679	19.7	51.5	1.8	28.9	57.2	120
21	27300	8.94	14.8	183	2.18	1.83	32.2	33.7	51200	0.221	3380	406	0.5	21.4	74.3	1.37	22.9	53.9	216
22	21800	7.71	9.39	124	1.52	0.401	27.7	30.3	43700	0.0765	3910	375	0.5	20.2	14.5	0.804	18.5	40.5	70.2
23	21800	7.35	10.6	124	2.1	0.3	27.7	27.1	60800	0.0656	5180	276	0.5	24.9	18.3	0.228	18	39.6	85.2
24	17200	4.37	11.2	61.3	0.392	0.3	19.4	11	47000	0.0374	2080	156	0.5	9.95	10.4	0.303	8.63	44.6	43.4
25	35800	7.52	14.9	181	1.42	0.687	33.1	22.9	43700	0.157	3350	83.2	0.5	18.5	45.5	0.976	18.8	54.8	107
27	24000	8.56	27.1	232	2.5	0.506	63.2	43.5	58800	0.116	4050	214	1.69	24.1	119	0.508	91.7	46.8	1070
28	17600	4.88	17.7	88	0.509	0.3	18.1	17.7	46200	0.0743	3750	115	0.5	11.8	31.4	0.374	15.8	42.1	69.9
30	22700	3.87	6.78	100	1.18	0.3	29.2	19.3	44600	0.0428	2410	207	0.5	14.1	8.96	0.61	11.4	54.5	46.4
31	22800	8.96	9.99	120	2.49	0.3	30.8	30.2	63800	0.037	7290	686	0.5	29.9	13	0.2	22.6	40.2	71.4
32	24600	4.76	6.71	149	0.422	0.363	23.3	19.6	32200	0.144	2300	58.8	0.5	12.5	48.8	0.935	20.2	29.6	73.7
34	22800	5.88	8.38	170	1.34	0.3	26.5	20.8	49000	0.0961	3080	188	0.5	16.4	26.6	0.718	16.7	40.9	68.2
35	22400	5.03	7.73	157	1.59	1.05	26.7	23.9	41400	0.118	2800	254	0.5	17.7	27.6	0.848	13.8	35.9	116
Min	2240	2.1	4.26	22.4	0.08	0.3	6.59	9.18	3770	0.0325	750	16.7	0.5	5.19	8.96	0.2	5.89	9.05	37
Geo Mean	16132.3	5.3	10.7	92.8	0.4	0.4	20.4	23.5	38919.2	0.1	2432.6	140.7	0.6	13.4	31.9	0.6	18.7	35.6	87.7
Max	40200	12.4	71.2	232	2.51	1.83	63.2	49.4	105000	2.16	7290	686	1.85	29.9	223	2.54	119	85.9	1070

When an analyte concentration was less than the MDL, the MDL was reported as the italicized value

Table 3. Sediments Metals (mg/kg-dw*) versus NJDEP SQG (NJDEP 1998)																
	As		Cd		Cr		Cu		Hg		Ni		Pb		Zn	
Station	1988	1999	1988	1999	1988	1999	1988	1999	1988	1999	1988	1999	1988	1999	1988	1999
1	8	8.69	<i>0.3</i>	0.319	15	23.9	15	15.6	0.09	0.19	8	11.4	17	47.7	41.5	92.9
3	9	8.79	0.7	1.06	28	18.6	40.5	39.1	0.19	0.24	18	17.1	18	89.4	76.2	160
4	8	2.1	<i>0.3</i>	<i>0.3</i>	12	10.6	24.9	31.4	0.10	0.10	8	7.73	22	24.4	48.8	84.6
5	9	3.34	<i>0.3</i>	<i>0.3</i>	11	10.2	9.8	9.18	0.05	0.05	7	6.46	8	15.3	48.1	46.7
6	7	2.63	<i>0.3</i>	<i>0.3</i>	17	7.86	32	13.4	0.13	0.08	11	5.44	31	22.8	52	37
7	9	4.03	<i>0.3</i>	0.427	13	11.9	43.5	29.1	0.22	0.12	10	9.4	33	15.5	86.7	57.3
8	8	2.77	<i>0.3</i>	<i>0.3</i>	24	19.9	18	14.7	0.02	0.03	18	16.4	9	9.05	57	58.4
9	8	2.92	<i>0.3</i>	<i>0.3</i>	16	10.4	20.8	14.8	0.08	0.04	11	7.45	31	19.8	67.7	52.5
11	10	5.02	<i>0.3</i>	<i>0.3</i>	17	15.4	31.4	40	0.10	0.15	12	11.5	38	34.6	63.1	104
12	<i>10</i>	3.49	0.5	<i>0.3</i>	30	10.5	56	14.2	0.21	0.05	20	7.93	69	24.7	119	59.9
13	6	6.67	<i>0.3</i>	0.533	17	21.6	21	25.4	0.09	0.14	10	13	29	58.5	37	92.5
14	<i>10</i>	4.45	0.4	0.426	19	25.9	30.2	27.2	0.11	0.10	13	16.4	59	42	95.3	92
15	7	3.94	<i>0.3</i>	<i>0.3</i>	17	13	14	13.8	0.08	0.06	12	9	23	23.2	28	40.6
16	7	12.4	<i>0.3</i>	0.581	14	20.1	17	49.4	0.10	0.26	9	12.3	30	223	47.7	116
16A	7	4.01	<i>0.3</i>	<i>0.3</i>	9.1	6.59	12	49	0.06	0.03	7	5.19	44	145	35	208
16C	<i>10</i>	8.24	0.7	1.16	21	27.9	50.6	42.8	0.30	2.16	16	20.5	42	108	118	130
17	10	3.41	<i>0.3</i>	<i>0.3</i>	29	27.2	21	11.3	0.11	0.06	16	14	41	11.7	79	49.4
18	<i>10</i>	5	<i>0.3</i>	0.415	19	24.7	21	19.5	0.12	0.08	13	14.2	38	28.2	78.9	91.4
19	20	5.2	<i>0.3</i>	<i>0.3</i>	30	18.6	53.3	29.9	0.12	0.04	23	17	92	24	175	92.9
20	<i>10</i>	8.49	<i>0.3</i>	0.754	22	34.6	32.1	35.7	0.13	0.17	16	19.7	38	51.5	72.4	120
20A	9	7.96	<i>0.3</i>	0.832	19	34	18	31	0.10	0.17	13	19.6	25	42.6	49.7	115
21	<i>10</i>	8.94	0.7	1.83	25	32.2	44.2	33.7	0.17	0.22	17	21.4	59	74.3	142	216
22	<i>10</i>	7.71	0.8	0.401	35	27.7	53.6	30.3	0.13	0.08	21	20.2	23	14.5	66.9	70.2
23	7	7.35	<i>0.3</i>	<i>0.3</i>	18	27.7	10	27.1	0.04	0.07	8.8	24.9	10	18.3	31	85.2
24	<i>10</i>	4.37	0.9	<i>0.3</i>	22	19.4	28.9	11	0.14	0.04	12	9.95	46	10.4	79.2	43.4
25	<i>10</i>	7.52	<i>0.3</i>	0.687	22	33.1	18	22.9	0.07	0.16	15	18.5	23	45.5	56	107
27	8	8.56	<i>0.3</i>	0.506	15	63.2	14	43.5	0.09	0.12	10	24.1	51	119	62.1	1070
28	<i>10</i>	4.88	0.4	<i>0.3</i>	29	18.1	35.6	17.7	0.11	0.07	22	11.8	57	31.4	130	69.9
30	20	3.87	<i>0.3</i>	<i>0.3</i>	43	29.2	40	19.3	0.10	0.04	23	14.1	23	8.96	78.1	46.4
31	<i>10</i>	8.96	<i>0.3</i>	<i>0.3</i>	30	30.8	32	30.2	0.05	0.04	24	29.9	51	13	87	71.4
32	<i>10</i>	4.76	<i>0.3</i>	0.363	25	23.3	19	19.6	0.11	0.14	14	12.5	40	48.8	60.8	73.7
34	<i>10</i>	5.88	<i>0.3</i>	<i>0.3</i>	35	26.5	28.8	20.8	0.05	0.10	28	16.4	18	26.6	73	68.2
35	7	5.03	<i>0.3</i>	1.05	30	26.7	21	23.9	0.07	0.12	14	17.7	10	27.6	46	116
LEL	6		0.6		26		16		0.2		16		31		120	
SEL	33		10		110		110		2		75		250		820	

* Italicized values: the MDL was used when the reported value was less than the MDL

There are 2 sediment quality guideline criteria per column (bottom 2 rows). When a reported value exceeds the top criterion, it is highlighted in bold font. When a reported value exceeds the bottom row criterion, it is highlighted by its cell being shaded.

Table 4. Sediments Metals (mg/kg-dw*) versus Consensus SQG (MacDonald <i>et al.</i> 2000)																
	As		Cd		Cr		Cu		Hg		Ni		Pb		Zn	
Station	1988	1999	1988	1999	1988	1999	1988	1999	1988	1999	1988	1999	1988	1999	1988	1999
1	8	8.69	0.3	0.319	15	23.9	15	15.6	0.09	0.19	8	11.4	17	47.7	41.5	92.9
3	9	8.79	0.7	1.06	28	18.6	40.5	39.1	0.19	0.24	18	17.1	18	89.4	76.2	160
4	8	2.1	0.3	0.3	12	10.6	24.9	31.4	0.10	0.10	8	7.73	22	24.4	48.8	84.6
5	9	3.34	0.3	0.3	11	10.2	9.8	9.18	0.05	0.05	7	6.46	8	15.3	48.1	46.7
6	7	2.63	0.3	0.3	17	7.86	32	13.4	0.13	0.08	11	5.44	31	22.8	52	37
7	9	4.03	0.3	0.427	13	11.9	43.5	29.1	0.22	0.12	10	9.4	33	15.5	86.7	57.3
8	8	2.77	0.3	0.3	24	19.9	18	14.7	0.02	0.03	18	16.4	9	9.05	57	58.4
9	8	2.92	0.3	0.3	16	10.4	20.8	14.8	0.08	0.04	11	7.45	31	19.8	67.7	52.5
11	10	5.02	0.3	0.3	17	15.4	31.4	40	0.10	0.15	12	11.5	38	34.6	63.1	104
12	10	3.49	0.5	0.3	30	10.5	56	14.2	0.21	0.05	20	7.93	69	24.7	119	59.9
13	6	6.67	0.3	0.533	17	21.6	21	25.4	0.09	0.14	10	13	29	58.5	37	92.5
14	10	4.45	0.4	0.426	19	25.9	30.2	27.2	0.11	0.10	13	16.4	59	42	95.3	92
15	7	3.94	0.3	0.3	17	13	14	13.8	0.08	0.06	12	9	23	23.2	28	40.6
16	7	12.4	0.3	0.581	14	20.1	17	49.4	0.10	0.26	9	12.3	30	223	47.7	116
16A	7	4.01	0.3	0.3	9.1	6.59	12	49	0.06	0.03	7	5.19	44	145	35	208
16C	10	8.24	0.7	1.16	21	27.9	50.6	42.8	0.30	2.16	16	20.5	42	108	118	130
17	10	3.41	0.3	0.3	29	27.2	21	11.3	0.11	0.06	16	14	41	11.7	79	49.4
18	10	5	0.3	0.415	19	24.7	21	19.5	0.12	0.08	13	14.2	38	28.2	78.9	91.4
19	20	5.2	0.3	0.3	30	18.6	53.3	29.9	0.12	0.04	23	17	92	24	175	92.9
20	10	8.49	0.3	0.754	22	34.6	32.1	35.7	0.13	0.17	16	19.7	38	51.5	72.4	120
20A	9	7.96	0.3	0.832	19	34	18	31	0.10	0.17	13	19.6	25	42.6	49.7	115
21	10	8.94	0.7	1.83	25	32.2	44.2	33.7	0.17	0.22	17	21.4	59	74.3	142	216
22	10	7.71	0.8	0.401	35	27.7	53.6	30.3	0.13	0.08	21	20.2	23	14.5	66.9	70.2
23	7	7.35	0.3	0.3	18	27.7	10	27.1	0.04	0.07	8.8	24.9	10	18.3	31	85.2
24	10	4.37	0.9	0.3	22	19.4	28.9	11	0.14	0.04	12	9.95	46	10.4	79.2	43.4
25	10	7.52	0.3	0.687	22	33.1	18	22.9	0.07	0.16	15	18.5	23	45.5	56	107
27	8	8.56	0.3	0.506	15	63.2	14	43.5	0.09	0.12	10	24.1	51	119	62.1	1070
28	10	4.88	0.4	0.3	29	18.1	35.6	17.7	0.11	0.07	22	11.8	57	31.4	130	69.9
30	20	3.87	0.3	0.3	43	29.2	40	19.3	0.10	0.04	23	14.1	23	8.96	78.1	46.4
31	10	8.96	0.3	0.3	30	30.8	32	30.2	0.05	0.04	24	29.9	51	13	87	71.4
32	10	4.76	0.3	0.363	25	23.3	19	19.6	0.11	0.14	14	12.5	40	48.8	60.8	73.7
34	10	5.88	0.3	0.3	35	26.5	28.8	20.8	0.05	0.10	28	16.4	18	26.6	73	68.2
35	7	5.03	0.3	1.05	30	26.7	21	23.9	0.07	0.12	14	17.7	10	27.6	46	116
TEC	9.79		0.99		43.4		31.6		0.18		22.7		35.8		121	
PEC	33		4.98		111		149		1.06		48.6		128		459	

exceedances of the mercury LEL and / or TEC in both the 1988 and 1999 data sets that approximate the LEL and TEC. Considering the bioaccumulative nature of mercury, the exceedance of the LEL or TEC warrants further evaluation to reduce the uncertainty of potential risks to sensitive ecological receptors.

Also noteworthy in Tables 3 and 4 is the 2 orders of magnitude elevation of zinc at station 27 from the 1988 level of 62.1 mg/kg to the 1999 SEL and PEC exceedances of 1,070 mg/kg. The 1999 exceedance of the zinc PEC and SEL at station 27, likely related to roadway and suburban runoff, warrants further evaluation to reduce the uncertainty of the potential adverse risk posed by the exceedance.

Comparing detected exceedances of the NJDEP criteria (Table 3) and the consensus-based criteria (Table 4) yielded similar results, with the notable exception of lead. Lead exceeded the consensus-based PEC (128 mg/kg) in the 1999 sampling effort at stations 16 (223 mg/kg) and 16A (145 mg/kg) (a 7- and 3.3-fold increase respectively), and may be partially associated with road runoff. North of the White Bridge Road, the New Vernon Road changes to Long Hill Road. In 1999, lead sediment concentration at stations 20 (51.5 mg/kg) and 20A (42.6 mg/kg), up- and down-gradient of where Long Hill Road crosses Middle Brook, had enriched approximately 1.5-fold over the 1988 levels. This further suggests that the rate of lead enrichment at stations 16 and 16A may not be solely due to road runoff. Interestingly, lead levels at station 16C have more than doubled between 1988 (42 mg/kg) and 1999 (108 mg/kg). As with the aforementioned mercury enrichment at station 16C, the lead enrichment may be associated with the former OU2 of the Asbestos Dump Superfund Site. However, the source of the lead enrichment at stations 16, 16A, and 16C cannot be confirmed by the limited sampling herein. What the data do suggest is that at least one source of lead enrichment to the Black Brook exists between the Rubenstein dike (station 15) and the New Vernon Road bridge. Moreover, as the lead PEC was exceeded, and further sampling of Black Brook is clearly warranted.

Polycyclic Aromatic Hydrocarbons

Dry weight sediment polycyclic aromatic hydrocarbon (PAH) concentrations reported for the 1999 sampling effort are listed in Table 5. Dry weight sediment concentrations from the 1988 and 1999 sampling efforts were compared to the NJDEP the *Guidance for Sediment Quality Evaluations* criteria (NJDEP1998) and a consensus-based sediment quality guideline criteria (MacDonald, *et al.* 2000) in Table 6.

Numerous exceedances of the TEC and LEL are seen in Table 6 with the overall number of exceedance being greater in 1999 than 1988. However, only 2 stations had exceedances of the SEL and / or PEC. Station 16C's 1999 sample exceeded the PEC for chrysene, fluoranthene, phenanthrene, and the PEC and SEL for pyrene. Station 21's 1988 sample exceeded the PEC and SEL for phenanthrene and pyrene.

Based on the quantified PAHs at 14 stations in the 1988 and 1999 sampling efforts, 2 stations demonstrated a decrease in sediment PAH concentrations, 2 stations showed negligible change in sediment PAH concentrations, and the remaining stations all demonstrated increasing sediment PAH concentrations. The sediment PAH concentration at station 21 decreased one order of

magnitude from 8,100 ug/kg *oc* in 1988 to 342 ug/kg *oc* in 1999. The sediment PAH concentration at station 22 decreased 2 orders of magnitude from 5,500 ug/kg *oc* in 1988 to 37 ug/kg *oc* in 1999. Stations 21 and 22, are down-gradient of Operable Unit 3 (OU3) of the Asbestos Dump Superfund Site. Sampling station 18, up-gradient of OU3, showed much less pronounced change in the sediment PAH concentration from 517 ug/kg *oc* in 1988 to 169 ug/kg *oc* in 1999. Therefore, it is reasonable to conclude that the reduction in sediment PAH concentrations at stations 21 and 22 are likely linked to the remediation of OU3 during the 1990s. Station 7 also showed a negligible change in sediment PAH concentration from 262 ug/kg *oc* in 1988 to 221 ug/kg *oc* in 1999. Neither station 18, nor station 7 is directly influenced (*i.e.*, not at a bridge crossing or storm-water culvert) by roadway runoff, which may partially explain the negligible changes in sediment PAH concentrations at these stations. As seen in Table 6, in 1999, stations 6, 15, 25, and 32 had relatively low (≤ 102 ug/kg *oc*) summed PAH concentrations.

From 1988 to 1999, there was an one order of magnitude increase in sediment PAH concentrations at stations 1, 16, and 16A, all on the same branch of the Black Brook. The sediment PAH concentration at station 1 increased from 712 ug/kg *oc* in 1988 to 3,900 ug/kg *oc* in 1999, at station 16 the PAH concentration increased from 188 ug/kg *oc* in 1988 to 1,100 the PAH concentration and at station 16A the PAH concentration increased from 2,100 ug/kg *oc* in 1988 to 17,000 ug/kg *oc* in 1999. The increase of sediment PAH concentrations at station 1 may be due to its close proximity to the urbanized areas associated with the heavily traveled Southern Boulevard in Chatham Township. Roadway runoff likely accounts for most of the increase in sediment PAH concentration at station 16A (down-gradient of the New Vernon Road bridge and station 16). The New Vernon Road is a more rural, less-traveled road bordered by red maple swamp. Sediment PAH concentrations at stations 6 and 15, between stations 1 and 16 on the Black Brook, had relatively low sediment PAH concentrations (33 ug/kg *oc* and 102 ug/kg *oc*, respectively). Therefore, although it is plausible that another source(s) may be contributing to the PAH loading of Black Brook between station 15 and the New Vernon Road bridge, it appears that road runoff is the principal PAH contributor to sediments at stations 16 and 16A.

Organochlorine Pesticides and Polychlorinated Biphenyls

Of the stations sampled **in both** 1988 and 1999, the station 7 sediment sample was the only 1988 location with a quantifiable value for any organochlorine analyzed (Table 7). The detected organochlorine was *p,p'*-DDT at 523 ug/kg-dw (reported as 0.09 mg/kg-ww). Although the concentration of *p,p'*-DDT exceeded the LEL (7 ug/kg) and TEC (5.28 ug/kg), the TOC-normalized value of 52.3 ug/kg *oc* did not exceed the SEL (710 ug/kg *oc*) or PEC (62.9 ug/kg *oc*) (Table 7). No quantifiable level (MDL = 10) of *p,p'*-DDT was detected in the 1999 station 7 sample.

The 1999 sampling effort revealed total chlordane (sum of alpha and gamma chlordane, *cis*- and *trans*-chlordane, heptachlor-epoxide, and oxychlordane) sediment concentrations of 125 ug/kg at station 1, and 165 ug/kg at station 9. Both stations 1 and 9 exceeded the chlordane LEL (7 ug/kg) and TEC (3.24 ug/kg). When dry-weight normalized, station 1 (20.5 ug/kg *oc*) also exceeded the chlordane PEC (17.6 ug/kg *oc*), while station 9 (75 ug/kg *oc*) exceeded the

Table 5. 1999 Sediment Polycyclic Aromatic Hydrocarbon Concentrations

Station	1,6,7-Trimethyl-naphthalene	1-methylnaphthalene	1-methylphenanthrene	2,6-dimethylnaphthalene	2-methylnaphthalene	Benzo(a)anthracene	Cl-Fluoranthenes & Pyrenes	Cl-chrysenes	Cl-fluorenes	Cl-naphthalenes	Cl-phenanthrenes	C2-chrysenes	C2-fluorenes	C2-phenanthrenes	C3-naphthalenes	C3-phenanthrenes	C4-chrysenes	C4-naphthalenes	C4-phenanthrenes
1	60	77	460	42	55	1600	10	10	10	130	540	10	10	1900	310	10	10	180	10
3	35	21	110	44	34	320	10	10	85	55	140	10	10	600	200	10	10	74	10
5	20	10	280	12	10	580	10	10	24	10	350	10	10	1200	130	10	10	160	10
6	10	10	16	10	10	19	10	10	31	10	16	10	10	67	44	10	10	18	10
7	28	19	59	39	41	200	10	10	150	60	130	10	10	270	28	10	10	24	10
9	11	10	85	10	10	320	10	10	10	10	98	10	10	340	77	10	10	70	10
15	10	10	20	10	10	29	10	10	10	10	20	10	10	30	150	10	10	10	10
16A	63	50	710	57	31	2600	10	10	10	81	780	10	10	3100	410	72	10	410	10
16	46	82	380	86	57	1000	10	10	10	140	400	10	10	1700	340	10	10	270	10
18	15	10	27	20	11	57	10	10	42	11	27	10	10	97	96	10	10	28	10
21	25	13	88	28	19	260	10	10	100	32	94	10	10	420	25	10	10	88	10
22	13	10	22	15	10	10	10	10	76	10	83	10	10	10	90	10	10	10	10
25	17	10	27	21	11	100	10	10	84	11	31	10	10	140	99	10	10	44	10
32	20	10	22	22	13	10	10	10	42	13	30	10	10	110	150	10	10	72	10
Min	10	10	16	10	10	10	10	10	10	10	16	10	10	10	25	10	10	10	10
Geo Mean	22	17	75	24	18	154	10	10	32	24	97	10	10	265	112	12	10	59	10
Max	63	82	710	86	57	2600	10	10	150	140	780	10	10	3100	410	72	10	410	10

Station	Dibenz(a,h)anthracene	acenaphthalene	acenaphthene	anthracene	benzo(a)pyrene	benzo(b)fluoranthene	benzo(e)pyrene	benzo(g,h,i)perylene	benzo(k)fluoranthene	biphenyl	chrysene	fluoranthene	fluorene	indeno(1,2,3-cd)pyrene	naphthalene	perylene	phenanthrene	pyrene
1	410	96	240	280	1200	2200	1500	1300	1400	22	2600	5600	400	1600	51	260	4300	4700
3	96	53	17	52	430	440	340	350	270	16	370	540	53	480	25	440	450	550
5	38	35	18	76	540	480	380	280	410	10	760	980	40	440	11	140	600	1200
6	10	10	10	10	14	32	10	22	24	10	30	48	10	31	10	11	83	42
7	17	13	19	35	230	240	160	130	140	18	220	400	65	220	39	450	390	340
9	78	23	22	56	230	410	260	200	250	10	400	700	41	350	10	54	490	620
15	10	10	10	10	10	34	23	16	22	10	35	71	36	26	10	10	190	51
16A	550	300	110	380	1700	2400	1800	1600	1700	10	2400	4200	330	2000	35	370	2200	4600
16	140	140	77	230	1000	970	840	660	760	10	1300	1700	230	870	43	230	1700	2100
18	12	10	10	10	58	90	66	43	47	10	77	120	51	82	11	51	220	99
21	96	54	18	47	210	500	380	310	370	10	480	600	43	460	22	160	390	590
22	10	10	10	10	10	30	23	15	21	10	26	44	19	22	10	22	110	41
25	10	10	10	10	16	34	46	27	10	10	54	84	25	48	10	46	160	69
32	10	10	10	10	26	54	37	34	44	10	37	63	18	49	15	140	110	51
Min	10	10	10	10	10	30	10	15	10	10	26	44	10	22	10	10	83	41
Geo Mean	39	27	22	37	123	208	149	125	134	11	213	345	52	188	18	94	394	319
Max	550	300	240	380	1700	2400	1800	1600	1700	22	2600	5600	400	2000	51	450	4300	4700

* When the reported value was less than the MDL, the MDL was used and italicized

Table 6. Selected Sediment PAHs Compared to Sediment Quality Guidelines

			Acenaphthalene				Acenaphthene				Anthracene				Benzo(a)anthracene				Benzo(k)fluoranthene				Benzo(g,h,i)perylene			
			% TOC		ug/kg-dw		ug/kg-dw _{oc}		ug/kg-dw		ug/kg-dw _{oc}		ug/kg-dw		ug/kg-dw _{oc}		ug/kg-dw		ug/kg-dw _{oc}		ug/kg-dw		ug/kg-dw _{oc}		ug/kg-dw/x%TOC	
Station	1988*	1999*	1988	1999	1988	1999	1988	1999	1988	1999	1988	1999	1988	1999	1988	1999	1988	1999	1988	1999	1988	1999	1988	1999	1988	1999
1	1.6	6.1	NP	96	NP	16	NP	240	NP	39	ND	280		46	33	1600	21	262	ND	1400		230	132	1300	84	213
3	20.4	56.3	NP	53	NP	5	NP	17	NP	2	ND	52		5	63	320	6	32	ND	270		27	190	350	19	35
5	0.6	1.4	NP	35	NP	25	NP	18	NP	13	52	76	92	54	193	580	345	414	13	410	23	293	219	280	391	200
6	3.3	8.6	NP	<10	NP		NP	<10	NP		ND	<10			17	19	5	2	ND	24		3	ND	22		3
7	15.5	51.5	NP	13	NP	1	NP	19	NP	2	ND	35		4	116	200	12	20	58	140	6	14	58	130	6	13
9	1.4	2.2	NP	23	NP	10	NP	22	NP	10	15	56		25	15	320	11	145	ND	250		114	152	200	109	91
15	2.3	4.4	NP	<10	NP		NP	<10	NP		ND	<10			ND	29		7	ND	22		5	15	16	7	4
16	3.3	12.9	NP	140	NP	14	NP	77	NP	8	ND	380		38	ND	1000		100	ND	760		76	19	660	6	66
16A	2.4	1.3	NP	300	NP	231	NP	110	NP	85	128	230	54	177	201	2600	85	2000	36	1700	15	1308	693	1600	294	1231
18	1.5	4.7	NP	<10	NP		NP	<10	NP		ND	<10			79	57	53	12	16	47	11	10	94	43	63	9
21	2.1	10.9	NP	54	NP	5	NP	18	NP	2	482	47	186	5	1412	260	545	26	199	370	77	37	997	310	385	31
22	3.1	7.5	NP	<10	NP		NP	<10	NP		262	<10	124		377	<10	178		164	21	77	3	1066	15	503	2
25	1.6	12.2	NP	<10	NP		NP	<10	NP		ND	<10			ND	100		10	ND	<10			ND	27		3
32	2.7	11.7	NP	<10	NP		NP	<10	NP		ND	<10			14	<10	9		ND	44		4	14	34	9	3
MacDonald, <i>et al.</i> , 2000			TEC: NG		PEC: NG		TEC: NG		PEC: NG		TEC: 57.2		PEC: 845		TEC: 108		PEC: 1050		TEC: NG		PEC: NG		TEC: NG		PEC: NG	
NJDEP, 1998			LEL: 44		SEL: 640		LEL: 16		SEL: 500		LEL: 220		SEL: 3700		LEL: 320		SEL: 14800		LEL: 240		SEL: 13400		LEL: 170		SEL: 3200	

			Benzo(a)pyrene				Chrysene				Dibenz(a,h)anthracene				Fluoranthene				Fluorene				Indeno(1,2,3-cd)pyrene			
			% TOC		ug/kg-dw		ug/kg-dw _{oc}		ug/kg-dw		ug/kg-dw _{oc}		ug/kg-dw		ug/kg-dw _{oc}		ug/kg-dw		ug/kg-dw _{oc}		ug/kg-dw		ug/kg-dw _{oc}		ug/kg-dw	
Station	1988*	1999*	1988	1999	1988	1999	1988	1999	1988	1999	1988	1999	1988	1999	1988	1999	1988	1999	1988	1999	1988	1999	1988	1999	1988	1999
1	1.6	6.1	115	1200	73	197	247	2600	157	426	16	410	10	67	230	5600	147	918	16	400	10	66	NP	1600	NP	262
3	20.4	56.3	127	430	13	43	127	370	13	37	127	96	13	10	190	540	19	54	ND	53		5	NP	480	NP	48
5	0.6	1.4	309	540	552	386	180	760	322	543	52	38	92	27	387	980	690	700	52	40	92	29	NP	440	NP	314
6	3.3	8.6	ND	14		2	ND	30		3	ND	<10			33	48	10	6	ND	<10			NP	31	NP	4
7	15.5	51.5	174	230	17	23	174	220	17	22	ND	17		2	930	400	93	40	58	65	6	7	NP	220	NP	22
9	1.4	2.2	46	230	33	105	76	400	54	182	15	78	11	35	137	700	98	318	15	41	11	19	NP	350	NP	159
15	2.3	4.4	15	<10	7		ND	35		8	15	<10	7		31	71	13	16	0	36	0	8	NP	26	NP	6
16	3.3	12.9	37	1000	11	100	ND	1300	131	130	19	140	6	14	56	1700	17	170	ND	230		23	NP	870	NP	87
16A	2.4	1.3	529	1700	224	1308	310	2400	129	1846	310	550	131	423	620	4200	263	3231	146	330	62	254	NP	2000	NP	1538
18	1.5	4.7	63	58	42	12	142	77	95	16	16	12	11	3	63	120	42	26	ND	51		11	NP	82	NP	17
21	2.1	10.9	1362	210	526	21	2492	480	962	48	199	96	77	10	2326	600	898	60	864	43	334	4	NP	460	NP	46
22	3.1	7.5	967	<10	456		869	26	410	3	131	<10	62		2131	44	1005	6	311	19	147	3	NP	22	NP	3
25	1.6	12.2	18	16	6	2	ND	54		5	ND	<10			36	84	11	8	ND	25		3	NP	48	NP	5
32	2.7	11.7	14	26	9	3	29	37	18	4	ND	<10			14	63	9	6	ND	18		2	NP	49	NP	5
MacDonald, <i>et al.</i> , 2000			TEC: 150		PEC: 1450		TEC: 166		PEC: 1290		TEC: 33		PEC: NG		TEC: 423		PEC: 2230		TEC: 77.4		PEC: 536		TEC: NG		PEC: NG	
NJDEP, 1998			LEL: 370		SEL: 14400		LEL: 340		SEL: 4600		LEL: 60		SEL: 1300		LEL: 750		SEL: 10200		LEL: 190		SEL: 1600		LEL: 200		SEL: 3200	

			2-Methylnaphthalene				Naphthalene				Phenanthrene				Pyrene				Σ PAH		Σ PAH	
	% TOC		ug/kg-dw		ug/kg-dw _{oc}		ug/kg-dw		ug/kg-dw _{oc}		ug/kg-dw		ug/kg-dw _{oc}		ug/kg-dw		ug/kg-dw _{oc}		ug/kg-dw		ug/kg-dw _{oc}	
Station	1988*	1999*	1988	1999	1988	1999	1988	1999	1988	1999	1988	1999	1988	1999	1988	1999	1988	1999	1988	1999	1988	1999
1	1.6	6.1	NP	55	NP	9	ND	51		8	115	4300	73	705	214	4700	136	770	1118	23841	712	3908
3	20.4	56.3	NP	34	NP	3	ND	25		3	127	450	13	45	253	550	25	55	1203	3506	120	351
5	0.6	1.4	NP	<10	NP		ND	11		8	387	600	690	429	374	1200	667	857	2216	5515	3958	3939
6	3.3	8.6	NP	<10	NP		ND	<10			ND	83		10	ND	42		5	50	282	15	33
7	15.5	51.5	NP	41	NP	4	ND	39		4	407	390	41	39	640	340	64	34	2616	2206	262	221
9	1.4	2.2	NP	<10	NP		ND	<10			76	490	54	223	122	620	87	282	669	3385	467	1539
15	2.3	4.4	NP	<10	NP		ND	<10			ND	190		43	15	51	7	12	92	450	40	102
16	3.3	12.9	NP	57	NP	6	ND	43		4	ND	1700		170	56	2100	17	210	187	11013	188	1101
16A	2.4	1.3	NP	31	NP	24	33	35	14	27	1186	2200	503	1692	821	4600	348	3538	5015	22145	2122	17035
18	1.5	4.7	NP	11	NP	2	ND	11		2	79	220	53	47	220	99	148	21	770	795	517	169
21	2.1	10.9	NP	19	NP	2	150	22	58	2	5980	390	2309	39	4485	590	1732	59	20947	3418	8088	342
22	3.1	7.5	NP	<10	NP		ND	<10			2787	110	1315	15	2623	41	1237	5	11689	276	5513	37
25	1.6	12.2	NP	11	NP	1	ND	<10			ND	160		16	18	69	6	7	72	535	23	54
32	2.7	11.7	NP	13	NP	1	ND	15		2	14	110	9	11	14	51	9	5	116	398	73	40
MacDonald, <i>et al.</i> , 2000			TEC: NG		PEC: NG		TEC: 176		PEC: 561		TEC: 204		PEC: 1170		TEC: 195		PEC: 1520		* 10% TOC is the upper limit			
NJDEP, 1998			LEL: 70		SEL: 670		LEL: 160		SEL: 2100		LEL:560		SEL: 9500		LEL: 490		SEL: 1300					

chlordanes PEC and the SEL (60 ug/kg *oc*) (Table 7). Quantifiable chlordanes components (MDL = 10 ug/kg each) were not detected at any of the other 1999 sampling stations.

Total DDD was detected at 70 ug/kg at station 1 and 16 ug/kg at station 21, exceeding the total DDD LEL (8 ug/kg) and TEC (4.88). When dry-weight normalized, the total DDD concentration did not exceed the SEL (60 ug/kg *oc*) or PEC (28.0 ug/kg *oc*) (Table 7). Quantifiable *o,p'*-DDD and *p,p'*-DDD (MDL = 10 ug/kg each) were not detected at any of the other 1999 sampling stations.

Total DDE was detected at 12 ug/kg at station 3, exceeding the total DDE LEL (5 ug/kg) and TEC (3.16 ug/kg). When dry-weight normalized, the total DDE concentration did not exceed the SEL (190 ug/kg *oc*) or PEC (31.3 ug/kg *oc*) (Table 7). Quantifiable *o,p'*-DDE and *p,p'*-DDE (MDL = 10 ug/kg each) were not detected at any of the other 1999 sampling stations.

Table 7. Sediment Organochlorines Detected in 1988 and 1999								
Station (year)	7 (1988)	1 (1999)	3 (1999)	9 (1999)	21 (1999)	39A (1988)	PEC	SEL
	ug/kg-dw _{oc}	ug/kg-dw _{oc}	ug/kg-dw _{oc}	ug/kg-dw _{oc}	ug/kg-dw _{oc}	ug/kg-dw _{oc}	ug/kg-dw _{oc}	ug/kg-dw _{oc}
Σ Chlordane		20.5		75		50.5	17.6	60
Σ <i>o,p'</i> + <i>p,p'</i> DDD		11.5			1.6	33.7	28	60
Σ <i>o,p'</i> + <i>p,p'</i> DDE			1.2			16.8	31.3	190
Σ <i>o,p'</i> + <i>p,p'</i> DDT	52.3					55.3	62.9	710
Total PCBs						171	676	5,300

Reported values exceeding the PEC are noted as bold font.

Values exceeding the SEL have shaded cells.

The following compounds were not detected at quantifiable levels (MDL = 10 ug/kg) during the 1999 sampling effort:

- *o,p'*-DDT;
- *p,p'*-DDT;
- hexachlorobenzene (HBC);
- alpha benzene hexachloride (BHC);
- beta benzene hexachloride;
- delta benzene hexachloride;
- gamma benzene hexachloride;
- dieldrin;
- endrin; and,
- mirex.

The following compounds were not detected at quantifiable levels (MDL = 50 ug/kg) during the 1999 sampling effort:

- toxaphene; and
- total PCBs.

Fish

Gross external examination of mud minnows collected during the 1999 sampling effort did not reveal any lesions, tumors, or skeletal abnormalities. Despite repeated sampling efforts, mud minnows were not recovered at stations 5 and 7. The sediment contaminant levels were not significantly different between 1988 and 1999 data sets, and there is insufficient evidence to suggest that station-specific contamination played a role in the absence of mud minnows at stations 5 and 7. The absence of mud minnows at stations 5 and 7 is more likely a function of changes in shoreline vegetation (availability of cover), predation, or a combination of other ecological and life history factors.

Metals

Whole-fish metals concentrations detected during the 1999 sampling effort are seen in Table 8. As mentioned in the Methods section, metals are routinely reported as mg/kg-dw; however, for ease of comparison to the 1988 data set and other reference values, whole-fish metals are displayed as mg/kg-wet weight (ww). Whole-fish metals data (dry weight) have been included in Table 8a with sample-specific moisture data. Arsenic, mercury, and selenium were not reported due to a laboratory processing error. Broadly accepted fish screening benchmarks for whole-body metals concentrations are scarce. With the exception of lead and zinc, whole-fish body burdens for aluminum, cadmium, chromium, copper, manganese, and nickel were comparable between the 1988 and 1999 sampling effort. Moreover, the copper concentration geometric mean (0.66 mg/kg) approximates the 1984 National Contaminants Biomonitoring Program (NCBP) national geometric mean of 0.65 mg/kg (Schmitt and Brumbaugh 1990).

The lead concentration geometric mean for whole-fish in the 1988 sampling effort was 0.18 mg/kg-ww (converted a on sample by sample basis). The lead concentration geometric mean had increased more than 2.5-fold to 0.5 mg/kg-ww in 1999. Interestingly, the range of lead concentrations in whole fish (0.4 to 0.53 mg/kg-ww) was fairly uniform across the 1999 sampling stations ($n=10$) with a coefficient of variation of 7.2 percent. This uniformity suggests that lead bioavailability to mud minnows is a GSNWR-wide phenomenon. More critically, lead levels in GSNWR mud minnows now exceed the Lowest Observed Adverse Effects Level (LOAEL) of 0.4 mg/kg-ww as determined by Holcombe, *et al.*, (1976). Additionally, the 1999 lead concentration geometric mean (0.5mg/kg-ww) is approximately 5-times higher than the 1984 NCBP national geometric mean lead concentration of 0.11 mg/kg-ww (Schmitt and Brumbaugh 1990).

The geometric mean zinc concentration of whole-fish in the 1988 sampling effort was 72 mg/kg-ww, and has declined to a 1999 geometric mean of 47.2 mg/kg-ww. This concentration exceeds the zinc LOAEL of 44 mg/kg-ww as determined by Spehar (1976), and is twice the 1984 NCBP national geometric mean zinc concentration of 21.7 mg/kg-ww (Schmitt and Brumbaugh 1990).

Organochlorine Pesticides and Polychlorinated Biphenyls

Quantifiable levels of *p,p'*-DDE were detected in fish at all 10 sampling stations (geometric mean = 5.9 ug/kg-ww; range = 2.57 -15.3 ug/kg-ww). Alpha chlordane was the second most prevalent organochlorine detected with quantifiable concentrations at 9 of the 10 sampling stations. Total PCBs, *p,p'*-DDD, heptachlor epoxide, *cis*-nonachlor, and *trans*-nonachlor were also detected at several stations (Table 9) demonstrating that GSNWR fish continue to be exposed to residual organochlorines, although all quantifiable organochlorines are 1 or 2 order of magnitude below their respective 1984 NCBP national geometric mean concentrations (Schmitt *et al.*, 1990).

With exception of gamma chlordane at station 6, station 11 fish consistently had the highest body burden of each quantifiable organochlorine (Table 9). Overall, organochlorine levels were generally low or below detection limits. Consistent with the 1988 findings (USFWS 1991), plotting the 1999 organochlorine concentrations on a map of the GSNWR reveals an organochlorine concentration gradient that is highest in the northeastern part of the GSNWR which declines as it moves towards the southwest.

Table 8. Metal Concentrations in Whole Fish (mg/kg-ww)																				
Station	% Moisture	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg	Mg	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
6	79.2	6.76	NP	0.505	1.08	0.02	0.06	0.376	0.548	52	NP	268	3.58	0.1	0.157	0.4	NP	7.72	0.04	31.7
11	75.4	4.3	NP	0.82	0.672	0.02	0.07	0.2	0.942	62.5	NP	344	4.39	0.1	0.282	0.5	NP	8.7	0.05	55.3
15	75.3	10.2	NP	1.05	1	0.02	0.074	0.2	0.759	53.7	NP	332	2.61	0.124	0.271	0.5	NP	7.76	0.05	47.9
16	74.2	2	NP	0.397	1.46	0.021	0.08	0.206	0.826	64.8	NP	356	3.83	0.129	0.269	0.516	NP	8.44	0.052	54.8
18	75.5	37.4	NP	0.409	1.26	0.02	0.074	0.2	0.861	91.8	NP	326	8.01	0.123	0.23	0.5	NP	7.97	0.05	55.8
20	73.5	2	NP	0.331	1.22	0.021	0.08	0.212	0.606	55.5	NP	371	6.01	0.133	0.288	0.531	NP	10.3	0.053	45.5
21	74.2	2	NP	0.366	1.15	0.021	0.08	0.207	0.626	56.9	NP	346	8.58	0.129	0.225	0.517	NP	9.47	0.052	63.5
22	74.5	5.91	NP	0.286	1.33	0.02	0.08	0.204	0.7	55.7	NP	345	5.71	0.128	0.186	0.511	NP	8.93	0.051	46
25	76.6	11.5	NP	0.224	1.22	0.02	0.07	0.2	0.463	66.3	NP	309	3.75	0.117	0.162	0.5	NP	8.67	0.05	35.8
32	76.6	2.64	NP	0.314	0.932	0.02	0.07	0.2	0.459	61.6	NP	313	3.94	0.117	0.225	0.5	NP	8.87	0.05	44.8
Min	73.5	2		0.224	0.672	0.02	0.06	0.2	0.459	52		268	2.61	0.1	0.157	0.4		7.72	0.04	31.7
Geo Mean	75.5	5.25		0.42	1.11	0.02	0.07	0.22	0.66	61.27		329.78	4.72	0.12	0.22	0.50		8.65	0.05	47.19
Max	79.2	37.4		1.05	1.46	0.0212	0.08	0.376	0.942	91.8		371	8.58	0.133	0.288	0.531		10.3	0.0531	63.5

Table 8a. Metal Concentrations in Whole Fish (mg/kg-dw)																				
Station	% Moisture	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg	Mg	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
6	79.2	32.5	NP	2.43	5.18	0.08	0.3	1.81	2.63	250	NP	1290	17.2	0.5	0.755	2	NP	37.1	0.2	152
11	75.4	17.5	NP	3.33	2.73	0.08	0.3	0.8	3.83	254	NP	1400	17.8	0.5	1.15	2	NP	35.4	0.2	225
15	75.3	41.3	NP	4.23	4.04	0.08	0.3	0.8	3.07	217	NP	1340	10.5	0.5	1.09	2	NP	31.3	0.2	194
16	74.2	6	NP	1.54	5.67	0.08	0.3	0.8	3.2	251	NP	1380	14.8	0.5	1.04	2	NP	32.7	0.2	213
18	75.5	153	NP	1.67	5.16	0.08	0.3	0.8	3.51	375	NP	1330	32.7	0.5	0.938	2	NP	32.5	0.2	227
20	73.5	6.06	NP	1.25	4.59	0.08	0.3	0.8	2.29	209	NP	1400	22.6	0.5	1.09	2	NP	38.8	0.2	171
21	74.2	6.52	NP	1.42	4.45	0.08	0.3	0.8	2.42	220	NP	1340	33.2	0.5	0.869	2	NP	36.7	0.2	246
22	74.5	23.2	NP	1.12	5.22	0.08	0.3	0.8	2.74	218	NP	1350	22.4	0.5	0.73	2	NP	35	0.2	180
25	76.6	49.3	NP	0.956	5.24	0.08	0.3	0.8	1.98	284	NP	1320	16	0.5	0.692	2	NP	37.1	0.2	153
32	76.6	11.3	NP	1.34	3.99	0.08	0.3	0.8	1.96	264	NP	1340	16.9	0.5	0.961	2	NP	38	0.2	192
Min	73.5	6		0.956	2.73	0.08	0.3	0.8	1.96	209		1290	10.5	0.5	0.692	2		31.3	0.2	152
Geo Mean	75.5	20.1		1.7	4.5	0.08	0.3	0.9	2.7	250.5		1348.6	19.3	0.5	0.9	2.0		35.4	0.2	192.9
Max	79.2	153		4.23	5.67	0.08	0.3	1.81	3.83	375		1400	33.2	0.5	1.15	2		38.8	0.2	246

Table 9. Organochlorine Concentrations in Whole Fish (ug/kg-ww)											
Station	% Lipid	% Moisture	Total PCB	<i>p,p'</i> -DDD	<i>p,p'</i> -DDE	Chlordane metabolites					Total Chlordane
						alpha chlordane	<i>cis</i> -nonachlor	gamma chlordane	heptachlor epoxide	<i>trans</i> -nonachlor	
6	14.7	79.2	15.2		5.2	10.8		2.5		4.37	17.67
11	16.8	75.4	32	6.89	15.3	11.3	2.46		4.67	7.87	26.3
15	14.6	75.3	23	3.21	7.66	5.19				3.46	8.65
16	15.1	74.2	13.4		5.68	3.87					3.87
18	12.8	75.5	14.7	3.68	8.33	4.9				3.68	8.58
20	16.1	73.5			6.36	3.18				3.18	6.36
21	15.7	74.2			6.71	2.58					2.58
22	15.9	74.5			6.12	3.06					3.06
25	14.9	76.6			2.57						
32	14	76.6			2.81	2.81					2.81
Min	12.8	73.5	13.4	3.21	2.57	2.58	2.46	2.5	4.67	3.18	2.58
Geo Mean	15	75	18.6	4.3	5.9	4.6	2.5	2.5	4.7	4.3	6.4
Max	16.8	79.2	32	6.89	15.3	11.3	2.46	2.5	4.67	7.87	26.3

DISCUSSION and RECOMMENDATIONS

Essential to the understanding of contaminants issues at the GSNWR is the delineation of non-point sources and known or suspected point sources of pollution and the pathways by which these pollutants enter and impact the GSNWR's abiotic and biotic matrices. A comprehensive review of non-point and known or suspected point contaminant sources and their respective pathways was prepared as a Contaminant Assessment Process (CAP) in 2001 (USFWS 2001). Accordingly, the information contained therein will not be further addressed in this investigation. The GSNWR's CAP is scheduled to be updated in 2006.

Comparing the 1988 and 1999 sediment data to sediment quality screening criteria (*e.g.*, LEL, SEL, TEC, and PEC) this investigation revealed several changes in sediment quality at discrete locations within the GSNWR. The aforementioned criteria are often used to predict potential adverse impacts to benthic organisms. The consensus-based criteria (TEC and PEC), which with rare exception are more stringent than the LEL and SEL, reflect correlative effects and can be used to identify factors that are causing or substantially contributing to sediment toxicity. The utility of the TEC is that it can identify sediments which are probabilistically not toxic. In contrast, the PEC should be used to identify sediments that are likely toxic to sediment-dwelling organisms. As such, the TEC and PEC can be used to identify hot spots with respect to sediment contamination, determine the potential for and spatial extent of injury to benthic organisms, and evaluate the need for sediment remediation (MacDonald *et al.*, 2000). However, none of these criteria have demonstrable relevance for direct adverse effects of sediment toxicity to humans, higher trophic-level aquatic life, or aquatic-dependent wildlife such as mink (*Mustela vison*) or birds in the heron family. Therefore, if interpreted beyond their intended purpose, these criteria may underestimate the risks higher trophic organisms. Additionally, these criteria were not derived to account for bioaccumulative characteristics of substances such as PCBs and mercury. Nevertheless, when interpreted within their intended purposes, these criteria are useful indicators of potential adverse impacts to benthic organisms which are an important component of the aquatic food chain.

The use of sediment quality guideline criteria, particularly the PEC, revealed several current (*e.g.*, post 1999) areas of concern, namely:

- elevated mercury at station 16C;
- elevated lead at station 16;
- elevated PAHs and lead at station 16A;
- elevated zinc at station 27; and,
- elevated chlordane levels at stations 1 and 9.

Unfortunately, sediments from station 11, where the co-located fish sample had the highest chlordane, total PCBs, and DDE concentrations, did not get analyzed for organochlorines. It is recommended that stations **1, 9, 11, 16, 16A, 16C, 27** and the surrounding environs be considered for additional contaminant delineation. Additionally, stations 20A (Middle Brook/Long Hill Road crossing) and 21 (Great Brook/Long Hill Road) should be evaluated for sediment PAH loading as the road runoff potential at these stations is almost identical to station 16A which is less than 2 miles south on the same road.

Using the PEC, mean hazard quotients or mean PEC quotients, can be generated to reflect the toxicity of the mixture of contaminants. Using this approach, a mean PEC quotient of 0.5 represents a useful threshold that can be used to accurately classify sediments samples as toxic or non-toxic (MacDonald *et al.*, 2000). A mean PEC quotient was calculated for several selected sampling station (Tables 10 and 11). Stations 16C and 27 (Table 10), 16A and 21 (Table 11) have mean PEC quotients that exceeded 0.5, and therefore warrant further evaluation to assess sediment toxicity (*i.e.*, bioaccumulation studies, use of residual tissue contaminant guidelines). By assembling station-specific data as hazard quotients in a tabular form, as was done in Tables 10 and 11, normalized-relative toxicity of each analyte can be displayed and allows for a concise presentation for decision makers to evaluate which components, relative to one another, within the mixture are potentially driving the toxicity. When the metals and PAH PECs are additively combined at station 16A from Tables 10 and 11, the resultant mean PEC quotient is 0.925. Although station 16A's lead concentration has a hazard quotient of 1.13, lead appears to be less important than the PAHs, where 5 of 8 PAHs have a hazard quotient greater than 1. Moreover, when an individual PAH from Table 11 has a hazard quotient greater than 1, the predicted incidence of toxicity to benthic organisms is consistently above 92 percent (MacDonald, *et al.*, 2000). Clearly, station 16A is a candidate for management action to curtail further PAH enrichment.

Table 10. Metals PEC-Hazard Quotients for Selected Stations

Station (year)	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn	Mean PEC HQ
3 (1999)	0.27	0.21	0.17	0.26	0.23	0.35	0.70	0.35	0.32
16 (1999)	0.38	0.12	0.18	0.33	0.24	0.25	1.74	0.25	0.44
16A (1999)	0.12	0.06	0.06	0.33	0.03	0.11	1.13	0.45	0.29
16C (1999)	0.25	0.23	0.25	0.29	2.04	0.42	0.84	0.28	0.58
27 (1988)	0.26	0.10	0.57	0.29	0.11	0.50	0.93	2.33	0.64

Table 11. PAH PEC-Hazard Quotients for Selected Stations

Station (year)	Anthracene	Benzo (a) anthracene	Benzo (a) pyrene	Chrysene	Fluoranthene	Fluorene	Phenanthrene	Pyrene	Mean PEC HQ
1 (1999)	0.05	0.25	0.14	0.33	0.41	0.12	0.60	0.51	0.30
16 (1999)	0.05	0.10	0.07	0.10	0.08	0.04	0.15	0.14	0.09
16A (1999)	0.21	1.91	0.90	1.43	1.45	0.47	1.45	2.33	1.27
21 (1988)	0.22	0.52	0.36	0.75	0.40	0.62	1.97	1.14	0.75
22 (1988)	0.15	0.17	0.31	0.32	0.45	0.27	1.12	0.81	0.45

The fish collected at 10 sampling stations during the 1999 sampling effort indicate an enrichment of lead over their 1988 cohorts. There are several possible explanations for this enrichment including atmospheric deposition, urban runoff, as well as known and unknown point sources. Major sources of lead in Atlantic coast streams included wastes from metal finishing industries, brass manufacturing, lead alkyl production, primary and secondary lead smelting, coal combustion, and manufacture of lead oxide. The sources of the whole-fish lead enrichment should be further evaluated. Although lead does not biomagnify like mercury or selenium, all effects associated with lead are considered adverse. Perennial streams within the GSNWR support warm water fisheries, with chain pickerel (*Esox niger*) and largemouth bass (*Micropterus salmoides*) representing the top predatory guild. The State of New Jersey has issued and maintains a State-wide mercury consumption advisory on chain pickerel and largemouth bass.

For the general population the State advises not to eat these species more than once a week; for high risk individuals, do not eat more these specie more than once a month. High-risk individuals include infants, children under the age of 15, pregnant women, nursing mothers and women of childbearing age. Although whole-body mercury concentrations were not reported by the analytical laboratory, clearly mercury should be monitored in GSNWR fish.

The five principal perennial streams of the GSNWR are the Black Brook, Great Brook, Loantaka Brook, and the Passaic River. The State designated use of each waterbody is "Aquatic Life Use." The Black, Great, Loantaka, and Primrose Brooks are also designated as Freshwater 2-Non-Trout, Category 1 (FW2-NT (C1)), whereas the Passaic River is designated as FW2-Trout Production (C1) (FW2-TP (C1)). The FW2 designations means the general surface-water classification applied to those fresh waters that are not designated as FW1 or Pinelands Waters. Further, all FW2 waters have a designated use which provides for maintenance, migration and propagation of the natural and established biota (7:9B-1.12(c)1) which includes wildlife. The C1 designation refers to those waters listed in the tables in N.J.A.C. 7:9B- 1.15(c) through (h), for purposes of implementing the antidegradation policies set forth at N.J.A.C. 7:9B-1.5(d), for protection from **measurable changes** in water quality characteristics because of their clarity, color, scenic setting, other characteristics of aesthetic value, exceptional ecological significance, exceptional recreational significance, exceptional water supply significance, or exceptional fisheries resource(s). These waters may include, but are not limited to:..."*waters originating wholly within Federal, interstate, State, county, or municipal parks, forests, fish and wildlife lands, and other special holdings that have not been designated as FW1 at N.J.A.C. 7:9B-1.15(h) Table 6...[and]... other waters and their tributaries that flow through, or border, Federal, State, county, or municipal parks, forests, fish and wildlife lands, and other special holdings.*" Additionally, as defined in N.J.A.C. 7:9B, **measurable change** "*means changes measured or determined by a biological, chemical, physical, or analytical method, conducted in accordance with [U.S. Environmental Protection Agency (EPA)] approved methods as identified in 40 C.F.R. 136 or other analytical methods (for example, mathematical models, ecological indices) approved by the Department, that might adversely impact a water use (including, but not limited to, aesthetics).*"

Even though all five waterbodies are classified as C1, each was on the 1998 303(d) list as "Biology Moderately Impaired" (at the closest sampling point prior to entering the GSNWR). The State uses benthic macroinvertebrate monitoring based on Barbour, *et al.*, (1999) for water quality evaluations (*e.g.*, to determine the presence or absence of "impairment," but not the cause(s) of the impairment) pursuant to the 303(d) list for all GSNWR waterbodies. In addition, the Passaic River was also evaluated for phosphorus, temperature, pH, nitrates, total dissolved solids, and unionized ammonia. In 2004 the State prepared, under EPA guidance, a combined report which presents the extent to which waters of the State are attaining water quality standards (pursuant to section 305(b)) and identifies waters that are impaired and need a parameter-specific Total Maximum Daily Load (TMDL) established as required under section 303(d) of the Clean Water Act (CWA) of 1972, as amended (33 U.S.C. 1251 *et seq.*). The Integrated Report describes attainment of designated uses specified in New Jersey's Surface-water Quality Standards (SWQS) which includes: aquatic life, recreation, drinking water, fish and shellfish consumption, industrial and agricultural. In addition, ongoing and planned strategies to maintain and improve water quality statewide are described. The Integrated Report contains the

Integrated List that consists of five categories or lists (New Jersey terms them sublists). All assessed waterbodies are placed on a sublist based upon:

1. the degree of support of designated uses;
2. how much is known about the waterway's water quality status; and
3. the type of impairment preventing use support.

The GSNWR's five principal perennial streams are listed in the 2004 Integrated Report as follows along with the closest Service sampling station used in the 1988 and this investigation.

Passaic River: Tempewick Road, Mendham, New Jersey (no sampling station)

Primrose Brook: Lee's Mill Road, Harding, New Jersey (Station 30)

- *Sublist 1. Attaining the water quality standard and no use is threatened.* Threatened is defined as currently supporting uses but information suggests that such uses will not be met within the next two years. Waterways are listed in this sublist if there are data and information that meet the requirements of the State's assessment and listing methodology and support a determination that the water quality standard is attained and no use is threatened.

There were no sampling stations on the Passaic River during the 1988 or 1999 sampling efforts near Tempewick Road, in Mendham. Consequently, there are no data to further evaluate the State's inclusion of the Passaic River at Tempewick Road on *Sublist 1*. The limited sampling data from 1988 and 1999 did not reveal a significant sediment contamination at station 30. This is consistent with the State's inclusion of Primrose Brook on *Sublist 1*. Although Primrose Brook attained the water quality standard for support of Aquatic Life Use, increased urbanization around the GSNWR warrants continued long-term monitoring to establish defensible water quality trends and to insure the early detection and cessation of no measurable water quality degradation.

Loantaka Brook: Green Village Road, Chatham, New Jersey (Station 5)

- *Sublist 3. Insufficient or no data and information to determine if any designated use is attained.* Waterways are listed on this sublist where the data or information to support an attainment determination for any use are not available, consistent with the requirements of the state's assessment and listing methodology. To assess the attainment status of these waterways, the state should obtain supplementary data and information, or schedule monitoring as needed. Sublist 3 also includes locations where there are sufficient data to make assessments, however, criteria or guidelines for making a use attainment assessment are currently not available.

The limited sampling data from 1988 and 1999 did not reveal a significant sediment contamination at station 5. However, the designated use of Loantaka Brook upstream of station 5 is impacted by excessive nutrient loading (particularly phosphorus) from point and non-point pollution sources, and fecal coliform bacteria likely from the resident Canada goose (*Branta canadensis*) population at the Loantaka Preserve. Downstream of station 5, Loantaka Brook receives overland storm-water flow off the Rolling Knolls Landfill. Therefore, the inclusion of

Loantaka Brook on *Sublist 3* due to the need for the attainment of supplementary data and information, or monitoring appears to be prudent; however, inclusion on *Sublist 5* may be more appropriate. Regardless of which sublist, additional evaluation and long-term monitoring of Loantaka Brook is warranted if its existing and designated uses are to be attained.

Great Brook: Woodland Road, Harding, New Jersey (Station 8)

Black Brook: New Vernon Road, Long Hill, New Jersey (Stations 16/16A)

- *Sublist 5. The water quality standard is not attained. The waterway is impaired or threatened for one or more designated uses by a pollutant(s), and requires a TMDL.* This sublist constitutes the Section 303(d) list of waters impaired or threatened by a pollutant(s) for which one or more TMDL(s) are needed. A waterway should be listed on this sublist if it is determined, in accordance with the state's assessment and listing methodology that a pollutant has caused, is suspected of causing, or is projected to cause impairment. Where more than one pollutant is associated with the impairment of a single waterway, the waterway will remain on sublist 5 until TMDLs for all pollutants have been completed and approved by [EPA].

The limited sampling data from 1988 and 1999 did not reveal a significant sediment contamination at station 8 on the Great Brook, or provide insight as to why Great Brook's water quality standard was not attained. Accordingly, further evaluation is needed to determine the factors that are causing or significantly contributing to conditions not consistent with the attainment of the Great Brook's existing or designated uses.

The results of this investigation combined with 1988 investigation (USFWS 1991) suggest that a potential causal factor of benthic macroinvertebrate impairment at the New Vernon Road crossing of Black Brook is elevated PAHs and lead. These findings are consistent with the inclusion of Black Brook at New Vernon Road on *Sublist 5*. Further evaluation is needed to determine the factors that are causing or significantly contributing to conditions not consistent with the attainment of the Black Brook's existing or designated uses.

Land development towards increased suburbanization as seen around the GSNWR alters the hydrologic response of a watershed or drainage area to rainfall events. The degree of this impact depends on the level of land use changes, the physical features of the watershed including soil characteristics, and the intensity and duration of rainfall events. The results of the changes are as follows: the infiltration of rainfall is reduced, the rate of storm-water runoff is accelerated and the quality of storm-water runoff is degraded. In most cases, all three can be expected to occur, and storm-water management is necessary to mitigate the impacts. Accordingly, best management practices for storm-water management on and around the GSNWR will be necessary and should be implemented to mitigate these impacts. To assess the impacts of local land use changes the physical features of the Great Swamp watershed should include, but not be limited to, soil characterization (*i.e.*, type, grain size, and organic content), storm drain locations and outfalls, storm-water drainage and infiltration areas, storm-water sediment load, and percent impervious cover. These features should be thoroughly delineated, cataloged and periodically (*i.e.*, a 5-year cycle) updated using GPS-GIS techniques. Among the more toxic constituents of urban runoff are PAHs which can adversely affect mammals, birds, fish, amphibians, invertebrates, and plants associated with the aquatic environment. The effects of PAHs on

invertebrates include inhibited reproduction, delayed emergence, sediment avoidance, and mortality, and the effects on fish include fin erosion, liver abnormalities, cataracts, and immune system impairments (EPA 2003a).

A previously unidentified source of urban PAHs, parking lot sealcoat, may dominate loading of PAHs to urban water bodies in the United States. Particles in runoff from parking lots with coal-tar emulsion sealcoat had mean concentrations of PAHs of 3500 mg/kg, 65 times higher than the mean concentration from unsealed asphalt and cement surfaces (Mahler *et al.*, 2005). Coal-tar-based sealants are the most readily used sealant in the eastern United States. Moreover, through the combustion and distillation of petroleum in the production of coal-tar, toxic components are concentrated. This further underscores the need for periodic monitoring of stream sediments entering the GSNWR and sediments associated with road crossings within the GSNWR. Moreover, the promotion of an ordinance with the 10 municipalities of the Great Swamp watershed to limit or ban the use of coal-tar-based sealants would aid in the "no measurable change" intent of the C1 water designations and likely accelerate the improvement water quality where the biological impairment to benthic macroinvertebrates appears to be related to PAH sediment loading.

The 1988 sampling stations associated with the Rolling Knolls Landfill were not included in the 1999 sampling effort due to property access issues. Nonetheless, 1988 concentrations of total PCBs (1,700 ug/kg), mercury (8 mg/kg) and total DDT (1,070 ug/kg) at station 39A (sediment sampled at the ditch forming eastern toe of the Rolling Knolls Landfill along the GSNWR boundary) were notably elevated to levels which are of concern to wildlife health. Further, these compounds are bioaccumulative, environmentally persistent, and capable of eliciting adverse effects on multiple organ systems of higher-trophic aquatic-dependent mammalian and avian predators. During a 1999 Expanded Site Inspection of the Rolling Knolls Landfill (FWEC 2000), exploratory soil borings, some containing waste material (*e.g.*, glass and concrete), were advanced into the landfill; surface and subsurface soil samples were collected. Analytical results indicated the presence of metals, phthalates, and PCBs at levels significantly greater than levels detected in soil samples collected from areas of the facility that do not appear to have been impacted from landfill operations. Contaminants detected significantly above background concentrations included bis(2-ethylhexyl)phthalate, PCBs, barium, chromium, copper, lead, mercury, and zinc (FWEC 2000). Additionally, pesticides, volatile and semi-volatile organic compounds and possibly intermediate pharmaceutical wastes were also detected at elevated levels. A subsequent investigation in support of the Hazard Ranking System Documentation Package (Weston Solutions 2003) confirmed the presence of PCBs in the landfill. Use of EPA Method 4020: Screening for Polychlorinated Biphenyls by Immunoassay (EPA 1996a), indicated that PCBs are present at concentrations greater than 1,000 ug/kg surface soils and wetland sediments on both the privately- and GSNWR-owned portions of the landfill. Moreover, PCB concentrations greater than or equal to 50,000 ug/kg are indicated for two soil locations, and concentrations greater than or equal to 10,000 ug/kg are indicated for five other locations. One soil sample with a PCB concentration greater than 10,000 ug/kg was collected from the GSNWR-owned portion of the landfill (Weston Solutions 2003). The results of the immunoassay are consistent with the PCB levels reported at station 39A in 1998 (USFWS 1991).

As the Rolling Knolls Landfill is now a Superfund site and the Service has roles both as a responsible party and trustee for damage assessment liability, a discussion of the criteria and analytical methods for future sample analysis of PCBs, mercury and DDT is prudent. For ambient water, the proposed New Jersey-specific wildlife water quality criteria (NJDEP *et al.*, 2001) of 72 pg/l for total PCBs, 530 pg/l for mercury, and 4 pg/l for total DDT should be used as applicable and relevant criteria. These criteria have not been officially adopted by the State of New Jersey or promulgated by the EPA. Wildlife is a protected existing use under the existing New Jersey Water Quality Standards. These new wildlife criteria need to be adopted to meet the policy standard set in 7:9B-1.15(a)6, which states in part... "*where existing criteria are inadequate to support the existing or designated uses, the criteria shall be changed to support the existing uses.*" Further, these wildlife criteria are nondiscretionary terms and conditions from the Service's Section 7 consultation with the EPA on the 1994 New Jersey Water Quality Standards. Specifically, "*If NJDEP fails to adopt the resultant criteria, the EPA must take appropriate action to promulgate numeric wildlife criteria for the State of New Jersey*" (USFWS 1998).

In order to achieve the necessary analytical sensitivity, and for future risk characterizations; the EPA Method 1668A (EPA 1999) and a sample preparation method such as that described by Rushneck (2004) for tissue, water, sediment and soils must be employed. An excellent review of congener-specific analytical methods as applied to eggs, tissue and soil is Peterman, *et al.*, (1996). Congener-specific analysis of sufficient resolution is necessary to quantify total PCBs as well as the dioxin-like PCB congeners, which tend to be of greatest concern with respect to ecological and human health risks. As part of the Data Quality Objectives (DQO) established for future assessments, the contracted analytical laboratory should document its capability to detect and quantify all PCBs congeners, especially the coplanar non-ortho substituted PCBs.

Documented fires have occurred at the Rolling Knolls Landfill; therefore, it is plausible that dioxins may have been generated through pyrolytic transformation of PCBs or other dioxin precursors which may be present in the landfill. It is also possible, though no records are known to exist, that dioxin-containing waste was directly deposited into the landfill. Accordingly, future investigations of the landfill and its potential extent of off-site contamination should include a dioxin suite using EPA Method 1613 (EPA 1994). Combining the data from Method 1668A and Method 1613 allows for a comprehensive analysis of dioxin-like toxicity and the assessment of risk-based end points for piscivorous wildlife based on dietary contaminant concentrations from aquatic organisms (oral dose to receptor species) or a combination of diet and biomagnification to a target organ or tissue of the receptor species (*e.g.*, eggs of a fish or bird, livers of mammals) using the Toxicity Equivalence Factor (TEF) approach (Van den Berg, *et al.*, 1998). Useful guidance on the application of TEFs in ecological risk assessments includes the EPA's Workshop Report on the *Application of 2,3,7,8-TCDD Toxicity Equivalence Factors to Fish and Wildlife* (EPA 2001) and the draft *Framework for Application of the Toxicity Equivalence Methodology for Polychlorinated Dioxins, Furans and Biphenyls in Ecological Risk Assessment* (EPA 2003b).

The proposed New Jersey wildlife criteria also specify a mercury criterion of 530 pg/l. In order to quantify mercury in the range of the wildlife criterion, the use of EPA Method 1631, Revision E: Mercury in Water by Oxidation, Purge and Trap, and Cold Vapor Atomic Fluorescence

Spectrometry for Mercury (EPA 2002) should be employed. Moreover, one of the greatest difficulties in measuring metals at in the range of the wildlife mercury criteria is precluding sample contamination during collection, transport, and analysis. Therefore, EPA Method 1669: Sampling Ambient Water for Trace Metals at EPA Water Quality Criteria Levels (EPA 1996b) should be used as it was designed to provide the level of protection necessary to preclude contamination in nearly all situations. Method 1669 is also designed to provide the procedures necessary to produce reliable results at the lowest possible water quality criteria.

There currently is no EPA-approved methodology for the quantification of DDT in ambient waters with adequate resolution (sensitivity and specificity) in the range of the proposed wildlife DDT criterion. Nevertheless, this does not preclude the use of the most sensitive DDT detection techniques available for future delineations, until such time that a methodology is developed capable of quantifying DDT at the range of the criterion.

Both the 1988 and 1999 sampling efforts are of limited application to assessing adverse impacts of impaired sediment quality to aquatic-dependent wildlife such as mink or heron. These species are not fully protected from bioaccumulative contaminants such as mercury, organochlorines pesticides, and PCBs using existing sediment quality guidelines that focus on the correlative toxicity to benthic macroinvertebrates. In close coordination with the Service's NJFO, it is recommended that the GSNWR implement a protocol for the collection and preservation of mink carcasses (road kill and trapped) for subsequent contaminant analysis of select tissues (*i.e.*, liver, brain, products of conception). Additionally, a protocol for the archiving of Ardeidae (herons and bitterns) eggs for future investigations is strongly recommended. The analysis of the aforementioned tissues in concert with routine, periodic sediment, water and fish contaminant monitoring would form the basis of a minimal and scientifically-defensible contaminant monitoring program for the GSNWR, which could be replicated at other refuges throughout the State or country.

A goal of the CWA is to "restore and maintain the chemical, physical and biological integrity of the Nation's waters." Although the Service and other federal agencies work with the states and EPA to implement the applicable requirements of the CWA, further progress is needed both to prevent degradation of high quality waters and sensitive aquatic ecosystems and to accelerate the restoration of degraded water resources. The Unified Federal Policy for a Watershed Approach to Federal Land and Resource Management (Federal Register, Vol. 65, No.202 pp. 62566-62572) (UFP), to which the Department of the Interior is signatory, provides a foundation to help ensure that federal land and resource management activities meet the CWA's goals and that the federal government serves as a model for water quality stewardship. The completion of this investigation is consistent with that policy in that it implements a science-based approach to watershed assessment and uses information from the assessment to identify management opportunities and priorities and to develop alternatives to protect or restore watersheds. But because many factors (*e.g.*, stream flow, season, sampling frequency) can induce sample variation, several years of data are needed to determine a trend in analyte concentrations at a specific sampling station. Therefore, environmental quality trends can only be determined at sites where long-term records exist. The implementation of a GIS contaminants database that captures long-term GSNWR contaminants data and contaminants data from other sources (*i.e.*, U.S. Geologic Survey, NJDEP, Ten Towns Watershed Management Committee) should be a GSNRW and Service-wide priority. Accordingly, sufficient allocation of funds and manpower

are prerequisite for the implementation of any environmental monitoring program. Also to be consistent with the UFP, an environmental quality-monitoring program must be robust, repetitive, and orchestrated with other federal, state and local monitoring programs. It is imperative that such a monitoring program is implemented as a standardized GSNWR function with a specific and guaranteed annual commitment for contaminant monitoring.

SUMMARY of RECOMMEDATIONS

- It is recommended that stations **1, 9, 11, 16, 16A, 16C, 27** and the surrounding environs receive additional contaminant delineation. Additionally, stations 20A (Middle Brook/Long Hill Road crossing) and 21 (Great Brook/Long Hill Road) should be evaluated for sediment PAH loading as the road runoff potential at these stations is almost identical to station 16A, which is less than 2 miles south on the same road.
- Sediments in Black Brook from the Rubenstein dike to the New Vernon Road, and the ditch connecting the OU2 drainage area to Black Brook should be delineated for lead to determine the source(s) of lead enrichment in Black Brook sediments.
- The source(s) of lead and zinc enrichment in GSNWR fish should be investigated. Although whole-fish mercury concentrations were not reported herein, there is a State-wide consumption advisory for largemouth bass and chain pickerel. Accordingly, mercury should be monitored in GSNWR fish.
- Additional evaluation and long-term monitoring of Loantaka, Great, and Black Brooks is warranted to identify and address the cause(s) of impairment and to ensure that the existing and designated uses are attained.
- To assess the impacts of local urbanization and the resultant storm-water runoff to the GSNWR, the physical features of the Great Swamp watershed such as, soil characterization (*i.e.*, type, grain size, and organic content), storm drain locations and outfalls, storm-water drainage and infiltration areas, storm-water sediment load, and percent impervious cover should be thoroughly delineated, cataloged and periodically (*i.e.*, a 5-year cycle) updated using GPS-GIS techniques.
- Environmental quality trends can only be determined at sites where long-term records exist. Therefore, the implementation of a GIS contaminants database that captures long-term GSNWR contaminants data and contaminants data from other sources (*i.e.*, U.S. Geologic Survey, NJDEP, Ten Towns Watershed Management Committee) should be a GSNRW priority.
- Work with local the 10 municipalities of the Great Swamp watershed to promote an ordinance to limit or ban the use of coal-tar-based sealants. Such an ordinance would aid in the "no measurable change" intent of the C1 water designations and likely accelerate the improvement water quality where the biological impairment to benthic macroinvertebrates appears to be related to PAH sediment loading.
- For future evaluation related to the Rolling Knolls Landfill Superfund Site, use the proposed New Jersey-specific wildlife criteria for PCBs, mercury and DDT (NJDEP *et al.*, 2001), and employ the analytical techniques discussed herein to accurately quantify method-specific contaminants in the range of the wildlife criteria.

- Implement protocols for the collection and preservation of mink tissues and Ardeidae eggs.
- Implement an environmental quality-monitoring program that is robust, repetitive, and orchestrated with other federal, state and local monitoring programs. It is imperative that such a monitoring program be implemented as a standardized GSNWR function with a specific and guaranteed annual commitment for contaminant monitoring.

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Appendix A

Sample Station Narratives

Following is a narrative description of each sampling location for the 1988 investigation of contaminants in fish and sediments of Great Swamp National Wildlife Refuge, Morris County, New Jersey. Station numbers correspond to those in Figure 1 and in the main text.

<u>STATION</u>	<u>NARRATIVE</u>
01	Un-named brook entering mesic area between northeast refuge boundary and pond at Noe Pond Pool Club. Down-gradient of Southern Boulevard (Chatham Township) and the Fairmont Golf Course.
02	Headwaters of Black Brook inside northeast corner of refuge and opposite Green Village Post Office. Sample taken north of impoundment along power line easement.
03	Headwaters of Black Brook inside northeast corner of refuge and opposite Green Village Post Office. Sample taken in stream crossing under power line easement (northwest of station 02).
04	Chatham Township sewage treatment plant ditch (tributary of Black Brook) downstream of unpaved extension of Long Hill Avenue (off Fairmont Avenue).
05	Loantaka Brook at Green Village Road crossing. Sample taken south (down-stream) of road.
06	Black Brook within Wilderness Area of refuge near end of Yellow Trail.
07	Chatham Township sewage treatment plant ditch where it crosses power line right-of-way and enters refuge (up-stream of junction with Black Brook).
08	Easterly fork of un-named brook south of its crossing at Woodland Road (site of USEPA water quality sample).
09	Loantaka Brook at Meyersville Road crossing. Sample taken down-stream of bridge, entrance point to refuge Wilderness Area.
11	First stream crossing on trail from Meyersville Road parking lot to refuge Wilderness Area. Sample taken east (up-stream) of bridge.
12	Old Meyersville Road Trail at second stream crossing (south of Meyersville Road parking lot). Sample taken up-stream of bridge.
13	Black Brook east of the end of Blue Trail where brook pinches between two mesic headlands.
14	Un-named creek crossing at Woodland Road (less than 100 yards west of station 08). Sample taken south (down-stream) of road.
15	Black Brook above asbestos site off of White Bridge Road.
16	Black Brook at New Vernon Road bridge. Sample taken up-stream of bridge.
16A	Black Brook at New Vernon Road bridge. Sample taken down-stream of bridge.
16C	North (down gradient) of New Vernon Road Asbestos Site at a red maple swamp just inside refuge boundary.
17	Great Brook at Woodland Road Trail crossing. Sample taken on up-stream side of bridge.
18	Great Brook up-stream of Asbestos Mounds A and B (near first oxbow east of mounds).
19	Un-named brook below junction of Pleasantville Road and Millbrook Road. Sample taken about 20 to 30 yards downstream of house (Willeaen) in first pool past house.

- 20 Middle Brook at Long Hill Road bridge. Sample taken up-stream from bridge just down-stream of Asbestos Mound A.
 - 20A Middle Brook at Long Hill Road bridge. Sample taken down-stream from bridge (Pool 1).
 - 21 Un-named drainage at second bridge south of gas line easement on Long Hill Road. Sample taken down-stream of bridge and up-stream of Harding Dump. Fish for station 21 were collected in Great Brook (first bridge south of gas line easement) below Long Hill Road.
 - 22 Great Brook, up-stream of Pool 1 outlet.
 - 23 Middle Brook outlet from Pool 1 on north side of maintenance road.
 - 24 Un-named brook at intersection with gas line easement (near north refuge boundary, west of Long Hill Road). Sample taken up-stream of gas line.
 - 25 Middle Brook east of Pleasant Plains Road. Sample taken up-stream of water control structure.
 - 27 Black Brook at White Bridge Road crossing. Sample taken down-stream of bridge.
 - 28 Un-named tributary to Black Brook at Brown Farm House, north of White Bridge Road. Sample taken in pool area north of house and down-stream of pipe culvert.
 - 30 Primrose Brook at end of maintenance road for Pool 2 (down-stream of gas line easement).
 - 31 Down-gradient side of Pool 2. Sample taken north (up-stream) of water control structure at Great Brook.
 - 32 Pool 3B. Sample taken within 100 feet north (up-gradient) of water control structure for pool.
 - 34 Pool 3A. Sample taken north (up-stream) of water control structure.
 - 35 Un-named ditch draining to Great Brook behind refuge manager's former house. Sample taken down-stream of where a ditch from the north joins a ditch running west to east.
-

Sampling stations from the 1988 investigation not sampled in 1999 due to access issues

- 37 West side of Miele property. Sample taken in open water depression west of sandy borrow area and east of refuge border sign.
- 39 East side of Rolling Knoll Landfill on refuge property (east of 90 degree turn in boundary). Fish collected in flooded timber (off landfill) and sediment collected south of flooded timber on western side of pool vegetated by cattail (on landfill).
- 39A Ditch forming eastern toe of Rolling Knoll Landfill along refuge boundary.
- 40 Seep south of southeast toe of Rolling Knoll Landfill.
- 41 West of Rolling Knoll Landfill's southwest tip along refuge boundary.

Appendix B

Analytical Methods

INDUCTIVELY COUPLED PLASMA (ICP)

Environmental Trace Substance Laboratory

Method Code: 004

The instrument used for ICP analysis was a Jarrell-Ash Model 1100 Mark III with 40 analytical channels, controlled by a Digital Equipment Company (DEC) 11/23+ computer with two RLO2 disk drives, DEC VT100 terminal, and DEC LA120 Decwriter III. The instrument was standardized with a series of seven standards containing 36 elements. After the standardization, the detection limit was determined by taking ten integrations of the zero standard; three times the standard deviation of the mean was used as the detection limit. Instrumental quality control samples were then analyzed to check the ICP operation. If the values were acceptable, the samples were then analyzed. Standards were run every 10-15 samples to check for drift. If the drift was more than 5 percent, the instrument was restandardized. After the analysis was completed, the data was transferred to the Perkin-Elmer LIMS 2000 computer for calculation. The final detection limit for each element was further increased by 4 percent of the magnitude of the spectral interferences from the other elements. The data was checked before calculation to correct for possible errors in sample number, weight, volumes and dilution. The data was calculated using the ICP calculation program written by ETSRC computer staff, which corrected for blanks, standard drift, spectral interferences, sample weight, sample volume, and dilution. After quality control was reviewed, a final report was generated using a Hewlett Packard laser jet printer.

PERCENT MOISTURE

Environmental Trace Substance Laboratory

Method Code: 005

For animal tissue and sediments of sufficient size, moisture was determined by placing a weighed aliquot of the sample in a Fisher Isotemp oven and drying at 103 - 105 C. The dried sample was then weighed and the data entered into a computer program to generate the percent moisture and final report.

HOMOGENIZATION

Environmental Trace Substance Laboratory

Method Code: 006

Large tissue samples, such as whole fish, were first run through a meat grinder one or more times depending on the size of the sample. An aliquot of the ground sample was weighed and frozen. For smaller tissue samples and plant samples the entire sample was weighed and then frozen. For sediments, the sample was mixed and an aliquot weighed and frozen. The frozen samples were placed in a Labcono Freeze Dryer 8 until the moisture had been removed. The dry samples were then weighed and further homogenized using a blender, or Spex Industries, Inc. Model 8000 mixer/mill with tungsten-carbide vial and balls.

TOTAL ORGANIC CARBON ANALYSIS (SOIL AND SEDIMENT) DRY OXIDATION METHOD

Environmental Trace Substance Laboratory

Method Code: 018

The analyst will need to make three (3) replicates of each blank and each sample. Label all of the ampules with a high temperature grease pencil before weighing. Break all ampules open, trying to get as little glass inside the ampules as possible. When not using, cover the ampules with aluminum foil to keep additional contaminants out of the ampules.

Sample Preparation

Place ampule on pan of 5 place balance, tare to zero, add the desired mass of sample (usually 3-5mg), record the mass of the sample, put the ampule in the holding rack. Cover the ampule with aluminum foil. Start the same procedure with the next ampule. Add 100 ul of 10 percent HCl solution to all of the sample and blank ampules. The fizzing that may be observed is the reaction between the HCl and any inorganic carbon in the sample. Put the uncovered ampules into an oven and bake at 100 C for at least one (1) hour or however long it takes for sample to reach dryness.

Prepare a set of KHP stds. ranging from 25 ug to 250 ug C following the KHP std. prep method. These will be used to determine a std. curve for TOC values.

KHP Std. Prep.

2.126 grams of Potassium Hydrogen Phthalate is weighed then transferred to a 100 ml volumetric flask. The dilution to 100 mls is done with boiled D.I. H₂O. (The D.I. H₂O is boiled to drive off as much carbon as possible). This reagent (which equals 10,000 ug/ml C) is further diluted to 500, 400, 300, 250, 200, 100 and 50 ug/ml C levels. One half ml (500 ul) pipet is then used to make the 250 thru 25 ug C stds. Spikes are also made from the same reagent.

At least 4 ampules should be made of each std., and more depending on the total amount of analyses. The stds. are dried at 100 C but usually take as long as 4 hrs. to dry because of their 1/2 ml liquid volume. After all visible liquid has evaporated from samples and stds. remove the ampules from the drying oven and allow to cool. When the ampules are cool, add one (1) dipper (200 mg) of the combusted cupric oxide to each ampule. Purge each ampule with oxygen from the Purge & Seal Unit for 4 to 6 minutes and then seal. The ampules can then be carefully placed in the muffle furnace and baked at 550 C for 4-5 hours. Cool and then analyze using a non-dispersive infrared analyzer. (Oceanographic International Corp.)

Analysis

Set up standard curve using the KHP stds. Three or four ampules are broken of each std. to get a good representative curve. After the curve is established, begin analyzing the samples and determine their ugC according to this KHP curve. Detection limit for a 4 mg (0.004 gm) sample is 0.1 percent or 1000 mcg/g dw.

GRAIN SIZE DETERMINATION

Environmental Trace Substance Laboratory

Method Code: 019

Sieve an air dried, crushed sample. Place approximately 10 g of sample in a 500 ml Fleaker. Those samples with greater than 1.0 percent organic carbon (wet weight) need to be treated to remove organic matter. Add 10 mls deionized water, 10 mls 30 percent H₂O₂, and 1 drop acetic acid. Stir, cover and heat to approximately 60 C. Then add additional H₂O₂ in 5 ml increments at 15 minute intervals until organic matter is oxidized (no bubbling). If the reaction is too vigorous, slow with the addition of DI water. After organic matter is removed, oven dry the samples (still in Fleakers) at 105 C. Weigh samples. Add 10 mls sodium hexametaphosphate to each sample, and bring volume to approximately 150 mls with DI water. A blank consisting of 10 mls sodium hexametaphosphate and 150 mls DI water should also be made at this time. Put stoppers in the Fleakers and shake either for 4 hours or overnight (minimum 12 hours) on a horizontal reciprocating shaker (120 oscillations/minute). Sieve samples through a 50 um sieve to remove sand fraction. Transfer the sand fraction that remains in the sieve to a weighing pan, oven-dry, cool in a desiccator and weigh. Arrange the fleakers for pipetting and bring volume to 400 mls with DI water. Determine average temperature of the suspensions, and cover each Fleaker with a watch glass. Remove watch glass from the first Fleaker, cap with a rubber stopper, and shake vigorously for approximately 10 seconds. Then shake end-over-end for 15 seconds. Remove rubber stopper and replace watch glass. Shake samples at approximately 2 minute intervals.

Pipet an aliquot at 5.0 cm below the surface within a 15- to 20-second interval, discharge into a weighing pan, rinse the pipet and add the rinse to the pan. Oven dry the aliquots, cool in a desiccator, then weigh. The correction factor for the weight of the sodium hexametaphosphate must be subtracted to obtain the weight of the clay.

Percentages of sand, silt and clay are then determined according to the following equations:

percent sand = $100 \times (\text{total sand weight} / \text{total soil weight})$

percent clay = $(\text{clay weight} / (400 / \text{pipette volume})) \times (100 / \text{total soil weight})$

percent silt = $100 \times (\text{percent sand} + \text{percent clay})$

Table 1. Setting times at corresponding temperature for pipetting <2-um fraction at a 5-cm depth.
Temperature Setting Times

C	h: mm
17	4:22
18	4:15
19	4:09
20	4:03
21	3:57
22	3:51
23	3:46

24	3:41
25	3:36
26	3:31
27	3:26
28	3:22
29	3:17
30	3:13

ANALYSIS FOR ORGANOCHLORINE PESTICIDES AND PCBS IN ANIMAL AND PLANT TISSUE

Mississippi State Chemical Laboratory
Method Code 001

Ten gram tissue samples are thoroughly mixed with anhydrous sodium sulfate and soxhlet extracted with hexane for seven hours. The extract is concentrated by rotary evaporation; transferred to a tared test tube, and further concentrated to dryness for lipid determination. The weighed lipid sample is dissolved in petroleum ether and extracted four times with acetonitrile saturated with petroleum ether. Residues are partitioned into petroleum ether which is washed, concentrated, and transferred to a glass chromatographic column containing 20 grams of Florisil. The column is eluted with 200 ml 6 percent diethyl ether/94 percent petroleum ether (Fraction I) followed by 200 ml 15 percent diethyl ether/85 percent petroleum ether (Fraction II). Fraction II is concentrated to appropriate volume for quantification of residues by packed or capillary column electron capture gas chromatography. Fraction I is concentrated and transferred to a Silicic acid chromatographic column for additional cleanup required for separation of PCBs from other organochlorines. Three fractions are eluted from the silicic acid column. Each is concentrated to appropriate volume for quantification of residues by packed or megabore column, electron capture gas chromatography. PCBs are found in Fraction II.

ANALYSIS FOR ORGANOCHLORINE PESTICIDES AND PCBS, ALIPHATIC AND POLYNUCLEAR AROMATIC HYDROCARBONS IN SOIL AND SEDIMENT

Mississippi State Chemical Laboratory
Method Code 004

Twenty gram soil or sediment samples are extracted with acetone, followed by petroleum ether, by allowing to soak one hour in each with intermittent shaking. A final acetone/petroleum ether extraction is done, and the extracts are combined, centrifuged, and transferred to a separatory funnel containing sufficient water to facilitate partitioning of residues into petroleum ether portion. The petroleum ether is washed twice with water and concentrated by Kuderna-Danish to appropriate volume. An aliquot of the concentrated extract for pesticide determination is transferred to a 1.6 gram Florisil mini-column topped with 1.6 grams sodium sulfate. Residues are eluted from the column in two elution fractions. Fraction I consists of 12 milliliters hexane

followed by 12 milliliters of 1 percent methanol in hexane, and Fraction II consists of an additional 24 milliliters of 1 percent methanol in hexane. If additional cleanup is required to separate PCBs from other organochlorines in Fraction I, further chromatography on a Silicic acid column is performed. Quantification of residues in the two Florisil fractions and three Silicic acid fractions is by packed or megabore column, electron capture gas chromatography. A second aliquot of the concentrated extract for hydrocarbon determination is transferred to a 20 gram 1 percent deactivated silica gel column, topped with five grams neutral alumina. Aliphatic and polynuclear aromatic hydrocarbon residues are fractionated by eluting aliphatics from the column with 100 ml petroleum ether (Fraction I) followed by elution of aromatics using first, 100 ml 40 percent methylene chloride/60 percent petroleum ether, then 50 ml methylene chloride (Combined eluates, Fraction II). If needed, Fraction I containing aliphatics is subjected to additional cleanup by concentration and transfer to a deactivated (2 percent water) Florisil column. Aliphatic residues are eluted from the Florisil column using 200 ml 6 percent diethyl ether/94 percent petroleum ether. The eluate is concentrated to appropriate volume for quantification by capillary column, flame ionization gas chromatography. The silica gel Fraction II containing aromatic hydrocarbons is concentrated, reconstituted in methylene chloride, and subjected to gel permeation chromatographic (GPC) cleanup prior to quantification by capillary, flame ionization gas chromatography and fluorescence HPLC.