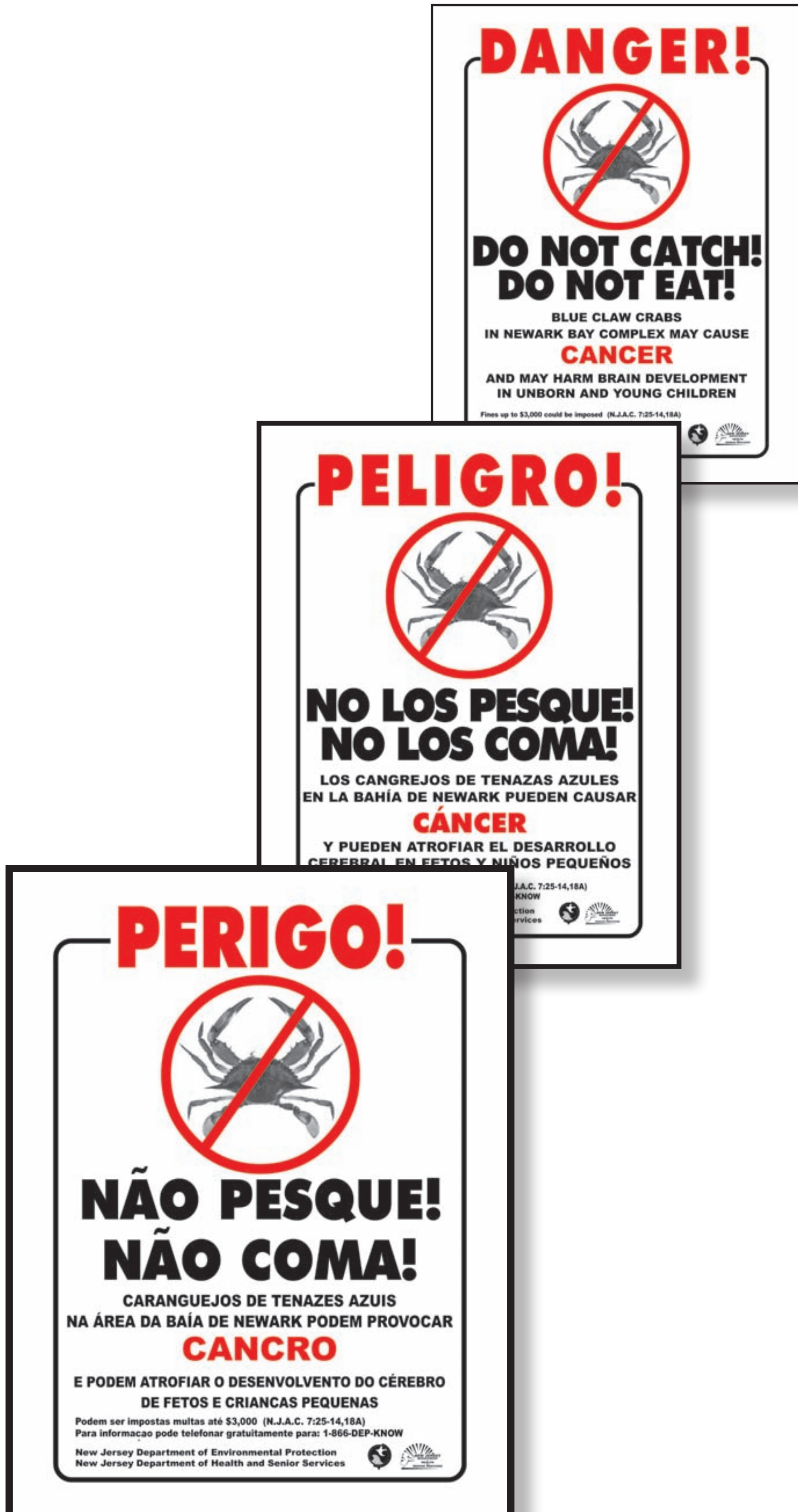
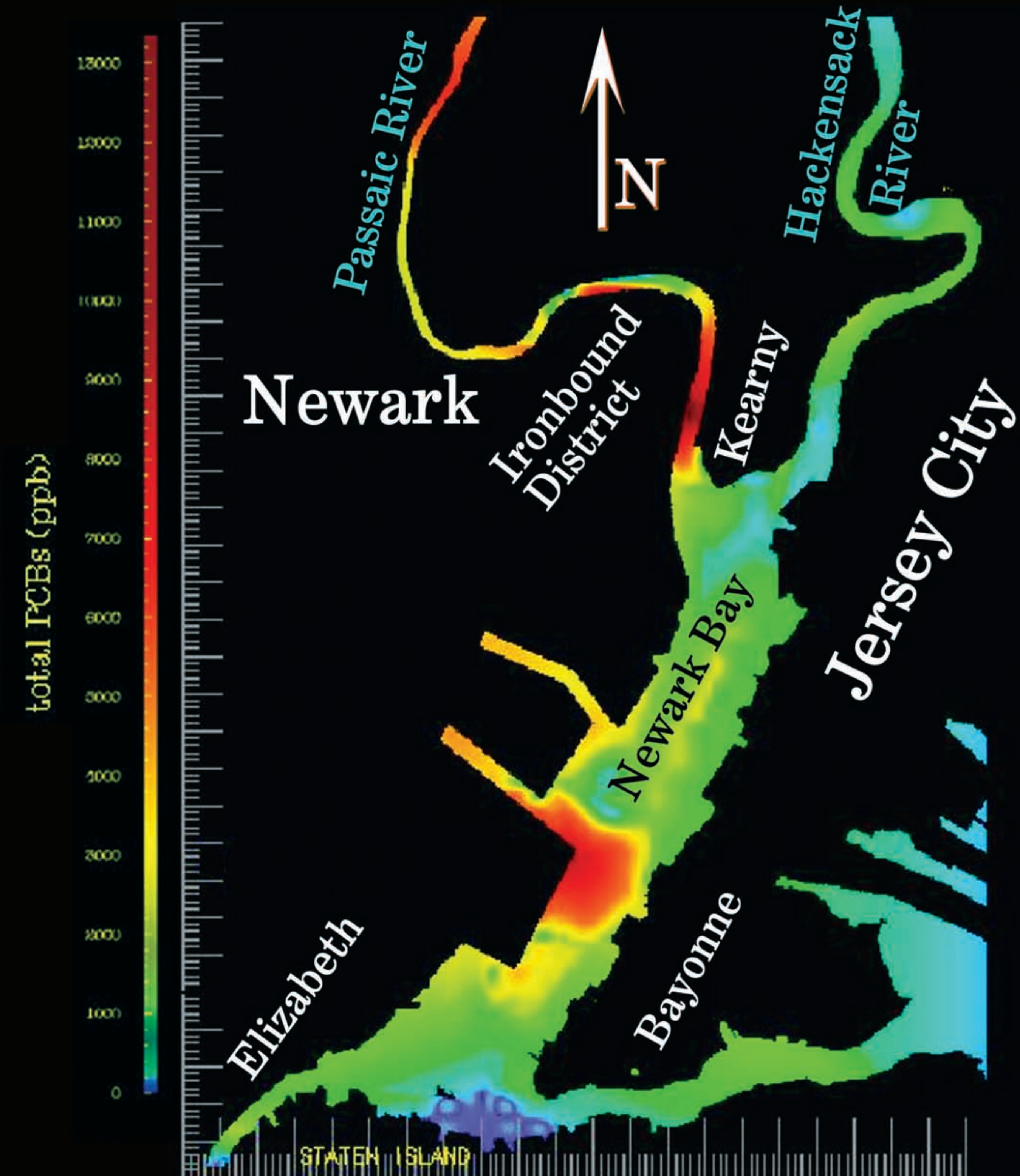
IV. Hydrology and Contaminants



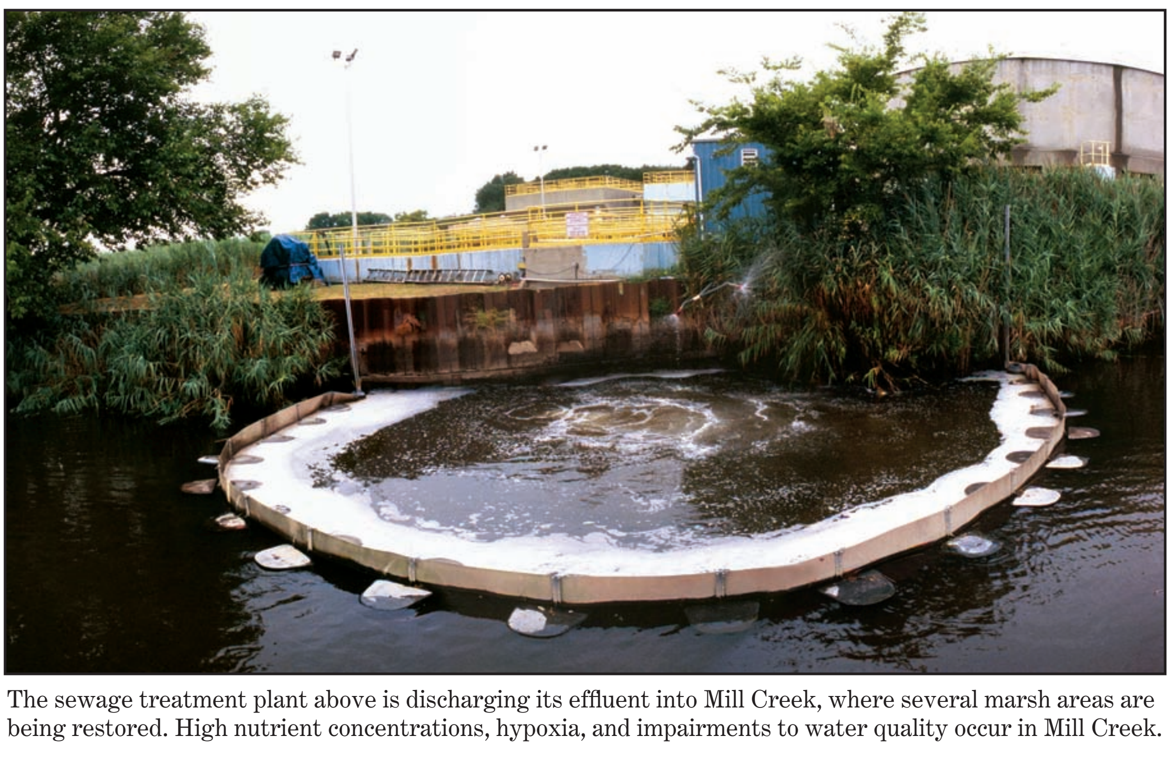

total PCBs (ppb)
N
Passaic River
Hackensack River
Newark
Ironbound District
Kearny
Jersey City
Newark Bay
Elizabeth
Bayonne
STATEN ISLAND

IV. Hydrology and Contaminants

The Hackensack and Passaic Rivers and Newark Bay have much in common; they share contaminants carried in diverted river flows and by tidal currents. More than 50 million gallons of water are diverted daily from the Passaic River through Pascack Brook into the upper Hackensack River; even larger diversions are being considered to meet public needs. A change in the hydrology of these waterbodies and land-use activities in upper portions of their watersheds can change the distribution and availability of contaminants.

Hot spots of contaminants in the Passaic River and Newark Bay (see the map on the left) are potential sources of contaminants in the Meadowlands because of tidal currents. Contaminants from the Passaic River and even the Hudson River have been found in sediments in the Hackensack River as far upstream as the Oradell Dam. Certain fishes in the Hackensack River are contaminated with PCBs and dioxins from the Hudson and Passaic Rivers. Contamination may be exacerbated by endocrine disruptors and nutrients discharged in sewage effluent, which now comprises roughly 80 percent of the Hackensack's "freshwater" flow.

Storm surge, flooding, and even modest sea level rise also have the potential to increase scouring of contaminated sediments in any of these water bodies and redistribute contamination. Thus, remediation and restoration must address water quality and supply issues and must be coordinated throughout the region. Otherwise, restoration may contribute to "attractive nuisances," which further imperil fish and wildlife resources.



The sewage treatment plant above is discharging its effluent into Mill Creek, where several marsh areas are being restored. High nutrient concentrations, hypoxia, and impairments to water quality occur in Mill Creek.

The map on the left indicates the concentration of PCBs in the sediments of the Newark Bay and adjacent rivers. A red color indicates extremely high levels of PCBs; blue indicates a zero level (map modified from U.S. Enviromental Protection Agency *et al.*, 1999). Recent studies suggest PCBs from several sources have contaminated the Hackensack River up to Oradell Dam.

IV. HYDROLOGY AND CONTAMINANTS

IV. HYDROLOGY AND CONTAMINANTS

A. INTRODUCTION

The long history of land and water use by the large human population in the HRW, often without regard to the biological values of the area, has resulted in extensive, cumulative, adverse impacts to the Meadowlands, including reductions and losses of fish and wildlife populations. Dams, diverted and regulated river flows, groundwater extraction, sewage effluents, industrial contamination, non-point source run-off, and urban/suburban land and water use in the surrounding watersheds have contaminated and disturbed the Meadowlands ecosystem and more severely impaired its functioning. The Hudson Raritan Estuary (HRE), including the Hackensack Meadowlands, was recognized for many years as one of the three most polluted estuaries in the United States (*e.g.*, U.S. Department of the Interior, 1994). In recent years, considerable improvements have been made in water quality throughout most of the HRE and have been attributed in part to improved sewage treatment (*e.g.*, Brosnan and O'Shea, 1996; Steinberg *et al.*, 2004). However, in comparison with the HRE, water quality in the Meadowlands ecosystem remains impaired for many criteria (*e.g.*, mercury, fecal coliform) and has not shown similar improvements (Keller *et al.*, 1990; DiLorenzo *et al.*, 2004). In 2001, American Rivers listed the Hackensack River as one of the most "endangered" rivers in the United States.

Despite increased government and public concern about hydrologic, contaminant, and related issues (*e.g.*, sea level rise as discussed below), adverse effects will likely worsen as the region's human population increases and urbanization of the landscape continues. Much of the information needed to guide the remediation and restoration of the Meadowlands is not currently available on a site-specific or species-specific basis. Improved coordination is needed among federal and State agencies to identify information gaps, design suitable monitoring and assessment programs, and develop comprehensive solutions. Long-term protection of the public's natural resources in the Meadowlands requires strengthened institutional, scientific, and legal tools to monitor, assess, and manage the hydrology and remediate contamination of the Hackensack and surrounding rivers of the NY-NJ Harbor estuary (*e.g.*, Pringle, 2000).

Habitat restoration planning and projects are occurring in the Meadowlands to counter decades of abuse. Habitat restoration is increasingly recognized and supported by the general public. The challenge to achieve successful protection and restoration of the Meadowlands is formidable and requires a deliberative and iterative approach that can define restoration success. There must be collaboratively defined success metrics or performance measures for all activities, including: restoring physical habitat and vegetative cover, managing hydrology and water supply, improving water quality, remediating contaminated sites and sediments, improving contaminant-related species health, and controlling invasive species. How all stakeholders embrace these challenges and work cooperatively to define successful restoration and management will be critical. For instance, the degree of successful wildlife restoration will be directly proportional in many cases to remediation of contaminated sites and sediments. Also, restoration success must be clearly defined. To ensure successful restoration and healthy fish and wildlife, performance metrics currently being developed collaboratively for the HMER must be comprehensive (*i.e.*, they must include reproduction of key species, appropriate tissue criteria, and other measures).

B. HYDROLOGIC CHANGES

1. Dams, Reservoirs, and Flow Diversions

Beginning in 1922 with the construction of the Oradell Dam, several large reservoirs were created along the Hackensack River to provide a regional water supply for the growing suburban/urban population. Dams have caused profound changes to the Meadowlands and the entire HRW: they eliminated extensive areas of riverine habitats, altered and fragmented the remaining riverine habitats, and created several large reservoirs. The dams also changed the river's hydrology (*e.g.*, flow volume, seasonality, and pulsing), geomorphology (*e.g.*, channel location, depth, and width), temperature (*e.g.*, greater seasonal and daily ranges), and chemistry (*e.g.*, salinity and nutrient ions). Moreover, the dams and changes to the landscape undoubtedly altered ecosystem functions (Table 13; *e.g.*, eutrophication[1] from nutrient loading, sediment trapping) and especially disrupted ecosystem processes that occur as water and materials flow down the river (*e.g.*, Vannote *et al.*, 1980; Ward and Stanford, 1983; Junk *et al.*, 1989). Studies in other systems indicate that dams and consequent landscape changes probably resulted in decreased or changed diversity (*e.g.*, local extirpation of species or shifting of guilds[2] — warm water fish in reservoirs, cold water fish in streams below the dam) of nearly all major taxa, including algae, plants, invertebrates, and fishes (*e.g.*, Paul and Meyer, 2001).

The effects of dams and reservoirs (descriptions of individual reservoirs are included in Section III) on the Hackensack Meadowlands and its estuarine biota have not been well studied. Construction of the Oradell Dam caused a drop in the local water table and oxygenation of deeper soils, which resulted in subsequent peat decomposition, ground subsidence, and saltwater penetration into the Hackensack Meadowlands (Sipple, 1972). Water regime is critical to the survival and growth of Atlantic white-cedar (Golet and Lowry, 1987); therefore, construction of the dam and subsequent flow reduction hastened the demise of remaining stands of Atlantic white-cedar (and has made it impractical, if not impossible, to return the Hackensack Meadowlands to its previous condition, as an ecosystem forested extensively by Atlantic white-cedar). Populations of freshwater fishes and invertebrates were further fragmented by construction of additional dams on the upper Hackensack to create water-storage reservoirs and by diversions of Passaic and Hudson River flows into storage reservoirs within the HRW (see Section III). These hydrologic alterations likely contributed to losses of certain fauna from the watershed (*e.g.*, freshwater mollusks). The diversion of flows from the Passaic and the Hudson Rivers into the HRW also has increased certain risks to fishes and wildlife. For example, the diversion of flows may disperse invasive species (*e.g.*, zebra mussel), contaminants, and pathogens.

The flow of the Hackensack River has been increasingly altered and managed to meet public demand for drinking water; however, ecosystem maintenance and the needs of fish and wildlife are not included in present-day water management within the watershed. The base flow of the

[1] Eutrophication- the process whereby water bodies receive excess nutrients that stimulate excessive plant growth leading to low oxygen concentrations, which cause mortality of other aquatic organisms.

[2] Guild- a group of species that exploit an environmental resource similarly.

Table 13. Ecosystem functions and services provided by wetlands (from Daily *et al.*, 1997).

Modify/regulate the hydrologic cycle and local climate

Transfer water from ground into the atmosphere, and thus affect local precipitation and temperature

Modify/regulate surface and groundwater water quantity

Reduce peak flood flows and volumes through surface and groundwater storage
Increase drought flows through surface and groundwater storage
Recharge groundwater aquifers

Modify/improve water quality

Assimilate biodegradable waste products and nutrients
Trap and detoxify contaminants
Trap nutrients and sediments

Modify/improve air quality

Modify global carbon cycle (usually carbon dioxide sinks)
Modify global nitrogen cycle (transform various forms of nitrogen)
Modify global phosphorus, sulfur, and other biogeochemical cycles (modifies forms of nutrients and other materials)

Transport/secure materials

Transport nutrients and sediments
Trap nutrients and sediments
Protect shorelines

Support primary and secondary production

Support growth of plants, including food plants and timber
Support growth of animals, including invertebrates, fishes, and birds

Maintain biodiversity

Provide critical/essential habitat for bacteria, fungi, plants and animals

Hackensack River at the Oradell Dam from 1922-2002 averaged 58.4 mgd (U.S. Geological Survey, 2003). Recent flows have been much lower than the average due to below-average precipitation (New Jersey State Climatologist, 2005); for example, the daily flow just below Oradell Dam from July 2000 to July 2003 was only 26.7 mgd (T. Wilson, pers. comm. 2004). Only 8.3 mgd is required currently by the NJDEP Bureau of Water Allocation's Water Diversion Permit (No. 5111); however, minimum flows to comply with that permit condition have not always been met during dry periods. Thus, flows from the Passaic and Hudson Rivers have been diverted into reservoirs on the Hackensack River to address acute and long-term water supply needs in the region (New Jersey Department of Environmental Protection, 1996; U.S. Geological Survey, 2003). Improved conservation and water-reuse programs are needed to meet long-term water supply needs (New Jersey Department of Environmental Protection, 1996).

In addition, in-stream flow maintenance goals for ecosystem protection (*i.e.*, fish and wildlife) must also be developed (New Jersey Department of Environmental Protection, 1996; U.S. Geological Survey, 2005a). The long-term protection of the Hackensack Meadowlands and its biotic resources must be considered in planning future water projects.

Increasing water withdrawal from reservoirs to support the region's human population has steadily reduced the daily flow of the Hackensack River, and increased the volume of "water" being returned to the river in the form of sewage effluent. Unlike most of the NY-NJ Harbor estuary, where sewage effluent comprises approximately 15 percent of the freshwater input (Tetra Tech, Inc. and Andrew Stoddard and Associates, 2000), sewage effluent from STPs comprises more than 75 percent of the "freshwater" input into the HRW under normal (*i.e.*, non-storm) conditions. Under normal conditions, the largest freshwater input to the Meadowlands is the sewage effluent discharged by the Bergen County Utilities Authority sewage treatment plant (BCUA STP), which averaged approximately 75 mgd from July 2000 to July 2003 (Wilson, pers. comm., 2004). The permitted treatment capacity of the BCUA STP is 109 mgd (New Jersey Meadowlands Commission, 2004d). Thus, pollutants, nutrients, and other materials are concentrated within the Meadowlands as a whole and even more so within certain portions of the Meadowlands (*e.g.*, Mill Creek). High nutrient inputs lead to excessive algal and bacterial growth, which may cause hypoxic (low-oxygen) and anoxic (no oxygen) conditions and initiate a "cascade" of complex changes (*e.g.*, altered biogeochemical cycling) that adversely affect biological communities (*e.g.*, nuisance algal blooms, impaired benthic communities, loss of shellfish resources, fish kills; Cowardin *et al.*, 1979; Adam, 1990; Mitsch and Gosselink, 1993; Kemp *et al.*, 1997). Contaminant and nutrient problems may also be exacerbated by other users of Hackensack water that discharge directly into the river. For example, PSEG's Hudson Generating Station in Jersey City continues to use Hackensack River water (as much 913.8 mgd but an average of only 474 mgd; Versar, Inc., 1989; Furnari, pers. comm., 2005) for cooling. In contrast, the PSEG Bergen Generating Station in Ridgefield now recycles waste water for cooling. Previously, the daily intake of river water by the Bergen facility exceeded 650 million gallons (Versar, Inc., 1989). These thermal (and other industrial) dischargers represent an additional stressor to aquatic fish and wildlife resources in the Hackensack River, especially in summer when oxygen concentrations are already low.

Dams on the Hackensack River have long impeded the migration of anadromous fishes throughout the watershed and fragmented populations of freshwater fishes and invertebrates. The Oradell Dam, located roughly mid-way on the Hackensack River mainstem, blocks upstream passage of American shad, alewife (*Alosa pseudoharengus*), and blueback herring (*Alosa aestivalis*), and possibly other species (Zich, 1977; New Jersey Department of Environmental Protection, 2000). Installation of a fishway at the Oradell Dam is being considered by certain stakeholders. Installing a fishway may help restore spawning runs of native fishes, provided that suitable habitat for spawning and the support of early life history stages (eggs, larvae, and juveniles) is present above the dam. However, installation of a fishway may also introduce contaminants in migrating fishes into those upstream habitats and affect other species, such as piscivorous[3] birds (*e.g.*, ospreys, bald eagles) that are sensitive to bioaccumulation of certain contaminants (*e.g.*, endocrine disruptors; see Section C.6. below).

[3] Piscivorous- fish eating.

The status of federal authorizations for dams on the Hackensack River is presently unknown. The Rivers and Harbors Appropriations Act of 1899, which requires a federal permit from the Corps for any structure placed in navigable waters, predates the construction of the dams that created the water storage reservoirs in the HRW. Planning that provides consideration for anadromous fish spawning would be apparent in the design of the dam. Prior to passage of the Federal Power Act (16 U.S.C. 791-828c, as amended) in 1920, the Secretary of Commerce had primary responsibility for fish passage facilities at federally licensed projects pursuant to the Dam Act of 1906 (P.L. No. 262, 34 Stat. 386, Sec. 3). The Act states: "The persons owning or operating any such dams shall maintain, at their expense . . . such fishways as the Secretary of Commerce and Labor shall prescribe." The status of the authorization of all dams in the HRW needs to be verified in order to determine the legal requirements for providing fish passage at these structures.

2. Flooding, Stormwater, and Tidegates

The frequency of and extent to which wetlands are flooded (inundated) are two of the most important factors determining the physical environment and the biological communities living in wetlands (Cowardin *et al.*, 1979; Middleton, 2002). Wetlands modify the quality and quantity of flood and storm waters moving through them. Flood events can structure fish and other aquatic communities (*e.g.*, Grossman *et al.*, 1982) and eliminate exotic species from aquatic ecosystems (*e.g.*, Minckley and Meffe, 1987).

In addition to storm events, the frequency and extent of flooding in urban watersheds may increase due to certain land uses and other human activities that modify how precipitation is stored and runs off the land. For example, buildings, parking lots, roads, and other transportation infrastructure create a network of impervious surfaces that do not absorb or process precipitation; thus, in urban areas, less water is stored on and in vegetation, surface depressions, and in soils. A 1-acre parking lot releases 16 times more stormwater runoff than a 1-acre meadow (Schueler, 1994). Landscape alterations that are implemented to protect human life and property from flooding (*e.g.*, filling, bulkheads, tidegates) also change the natural movement and processing of precipitation. Removing vegetation, grading and hardening land surfaces and riverbanks, and constructing drainage networks increase flooding frequency, velocity, total volume, and peak discharge (Butler and Davies, 2000). Urban landscapes also introduce pollutants and exacerbate wastewater treatment (Butler and Davies, 2000; Center for Watershed Protection, 2003).

The effects of land use changes noted above are more severe in the Meadowlands due to its physiography. Nearly all of the acreage within the HMD now classified or used as uplands was formerly wetlands (Tiner *et al.*, 2002), and filling has reduced the flood-storage detention and retention capacity of remaining wetlands. Flooding during severe weather is a common occurrence in the HMD and other portions of the watershed (Table 14). Though flooding in the HRW historically has been neither as frequent nor as severe as in the nearby Passaic River watershed (*e.g.*, U.S. Army Corps of Engineers, 2002a; 2005a), flooding of these former wetlands has occurred repeatedly within every municipality in the HMD and is viewed by residents and local governments as a significant problem (*e.g.*, New Jersey Meadowlands Commission, 2004f; 2004g). For example, Little Ferry, Teterboro, and Rutherford were damaged substantially by flooding from Tropical Storm Floyd in 1999 with damage and cleanup costs estimated in the multimillions of dollars (Carola, 1999). Most of these flood-prone areas lie within the 100-year flood zone (Federal Emergency Management Agency, 1995). Several municipalities in the HMD (*e.g.*, Kearny, Jersey City) have been among the national leaders in properties for which the National Flood Insurance Program (NFIP) has repeatedly paid claims (Conrad *et al.*, 1998). For example, in Kearny, one building flooded 34 times in 12 years for which the building's owners have received nearly $4 million from the NFIP (Johnson, 1998). Thus, it is clear that greater consideration and development of programs employing non-structural means of flood control are needed. Moreover, those upland areas for which repeated flood-damage claims have been made should be reclaimed as floodplain and wetlands.

Table 14. Flood-prone areas in various municipalities of the Hackensack Meadowlands District. Sources of information for these flood-prone areas are also provided.

Municipality	Flood-prone Areas	Information Source(s)
Carlstadt	Berry's Creek/ Patterson Plank Road area	New Jersey Meadowlands Commission, 2004d
East Rutherford	Berry's Creek/ Patterson Plank Road area	New Jersey Meadowlands Commission, 2004d
Hackensack	Green Street, Newman Avenue	Rethage, 2004
Jersey City	Downtown area	U.S. Department of Housing and Urban Development, 2005
Kearny	Various	Johnson, 1998; Skelly, 2002; New Jersey Meadowlands Commission, 2005b
Little Ferry	along Losen Slote	Federal Emergency Management Agency, 1999
Moonachie	Moonachie Avenue, Grand Street	New Jersey Meadowlands Commission, 2004f; 2005b
North Bergen	along Bellman's Creek (*e.g.*, 91^{st} Street, West Side Avenue)	New Jersey Meadowlands Commission, 2005b
Rutherford	Rt. 17	Borough of Rutherford, 2004; New Jersey Meadowlands Commission, 2005b
Secaucus	Mill Ridge Road, Penhorn Road	New Jersey Meadowlands Commission, 2004f; 2005b

Nearly all modifications that have been made historically (*e.g.*, drainage pipes, ditches, retention basins) to address specific flooding problems have some adverse impacts on fish and wildlife. Until recently, the urban problems of storm runoff, drainage, and flooding were addressed by transferring large quantities of water downstream as quickly as possible. This approach required putting large volumes of stormwater into the sewage treatment system (*i.e.*, a combined sewerage system) or building a separate system of storm drains. While these approaches provide a solution at the source, each system creates problems downstream due to increases in volume, flow, erosion, and pollution. In the Meadowlands, the former approach is still used in numerous locations, resulting in the need for 32 combined sewer overflows (CSOs) to discharge the excess volume of runoff generated by large storms (New Jersey Meadowlands Commission, 2004d). In CSOs, this excess volume of stormwater is mixed with wastewater. As a result, excessive volumes of water are delivered rapidly to the wetlands, causing even greater contamination of wetlands and waterways during storm events. While separate stormwater systems do not discharge sewerage waste, they do contribute contaminated runoff to waterways and aquatic systems. Stormwater runoff has been identified as a major source of certain contaminants and materials (*e.g.*, coliform bacteria, oil, and grease) into the NY-NJ Harbor estuary (Harbor Estuary Program, 1996).

The State of New Jersey has begun implementing new regulations (Stormwater Regulations; N.J.A.C. 7:8) designed to address the shortcomings of traditional stormwater approaches. The new regulations require an integrated approach that includes local disposal of stormwaters (*e.g.*, infiltration devices, vegetated surfaces), inlet and pollution controls on runoff (*e.g.*, temporary storage to delay runoff, screening to reduce floatable debris), and other measures (*e.g.*, larger wetland buffers). The NJMC is in the process of developing its own rules within the HMD for consistency with the State regulations. The Service recommends that the NJMC work with federal and other State agencies to develop and implement rules that not only provide protection for human life and property but also reduce adverse impacts to fish and wildlife resources, especially through practices that will reduce physical and chemical impacts on waters and wetlands from storm runoff.

In 2006, several large development projects in the Meadowlands are ongoing, just beginning, or in planning stages (*e.g.*, EnCap, Xanadu, new sports stadium). Based upon the total acreage and extent of impervious surfaces potentially included in these projects, comprehensive storm-water control programs should be developed that employ best management practices, including use of low-impact solutions, sufficient water storage capacity, and water treatment designed to address contaminants on-site. In addition, planning of all large projects should include acquisition of open-space, floodplain reclamation, and wetlands creation elsewhere in the watershed to augment existing flood storage.

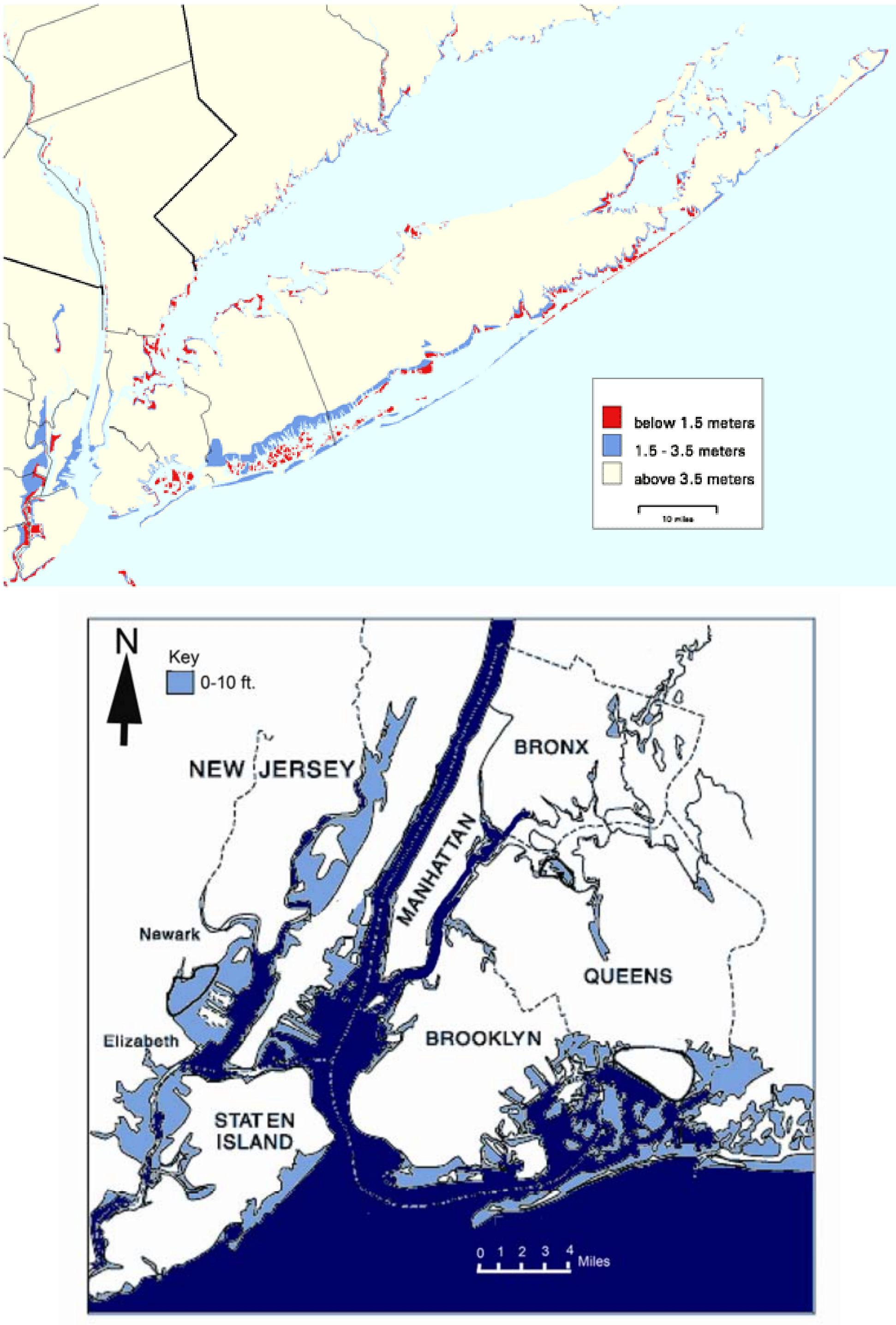
Finally, to reduce flooding throughout the HMD, 30 flood control structures such as tidegates and culverts are located along the Hackensack River and its tributaries (U.S. Army Engineer Research and Development Center *et al.*, 2000). One or more tidegates are located in at least eight tributaries of the Hackensack River (New Jersey Meadowlands Commission, 2004d) and are planned for additional tributaries (*e.g.*, Sack Creek, which, though confined to culverts for much of its length, drains wetland areas in Secaucus). Remnants of former or non-functioning tidegates are visible in several other tributaries (*e.g.*, Mill Creek, Penhorn Creek). Used in concert with other coastal modifications (*e.g.*, levees, pump stations), tidegates can be effective in reducing and preventing flooding if properly designed, located, and maintained. Nevertheless, poorly designed or maintained tidegates have diverse impacts on wildlife (Giannico and Souder, 2004) and have facilitated the spread of invasive species in coastal wetlands of the northeastern United States (Roman *et al.*, 1984). Thus, evaluation of all flood control structures should be undertaken and former and non-functioning tidegates removed to improve tidal flow. Careful consideration should also be given to the need, design, maintenance, and potential adverse impacts of tidegates on fish and wildlife, especially on nearby restoration efforts.

3. Sea Level Rise

Recent natural tragedies around the globe have heightened public concern about the vulnerability of coastal communities and renewed interest in understanding sea level rise (SLR) and its modifiers. Global sea level change is, in part, an indicator and integrator of global climate change; however, the complex linkages between global climate change and SLR are just beginning to be recognized and remain poorly understood (Douglas *et al.*, 2001; Church *et al.*, 2001). Two processes directly increase *global* SLR: (1) an increase in the mass of the oceans due to the addition of waters from land sources (the eustatic, or true, water-rise component of SLR) and (2) an increase in the volume of the water as the oceans warm (the steric component of SLR). Measuring these SLR components individually and collectively has been plagued with difficulties (Cabanes *et al.*, 2001; Meier and Wahr, 2002; Munk, 2002). Nonetheless, there is general agreement that global sea level has risen 10 to 20 cm throughout much of the past century and that global SLR will continue at similar or higher rates as global warming progresses (Intergovernmental Panel on Climate Change, 2001; Meier and Wahr, 2002) and lowland subsidence increases.

Though the predicted 10 to 20 cm (approximately 1 to 1½ feet) of global SLR seems small, certain low-lying coastal areas will experience additional relative SLR (SLR that incorporates eustatic, steric, and other regional/local factors) due to movements of tectonic plates. Some areas are also more vulnerable to adverse effects from SLR due to other local factors such as subsidence (Titus and Narayanan, 1995; Intergovernmental Panel on Climate Change, 2001; Munk, 2002). During the past century, the mid-Atlantic coast of the U.S. (New Jersey to Virginia), including the New York Harbor area, is among those areas that has experienced the greatest relative SLR (Figure 39; National Ocean Service, 2002), a trend that is expected to continue. The vulnerability of coastal environments also is affected by coastal geomorphology and other risk factors (Table 15; Thieler and Hammar-Klose, 1999). For example, sandy barrier islands and salt marshes are more vulnerable to SLR and "drowning" than coasts comprised of rocky cliffs; and areas with low tidal amplitudes are at greater risk than areas with large tidal amplitudes. Except for its comparatively sheltered, upstream location within the New York Harbor estuary, the Meadowlands fits into several high-risk categories due to its low elevation, flat topography, and other factors (see Table 15; Thieler and Hammar-Klose, 1999).

Figure 39. Areas at risk from sea level rise in the New York-New Jersey metropolitan region. The upper figure (from Titus and Richman, 2001) shows relative risk of sea level rise in the metropolitan region. The lower figure (from Gornitz, 2000) shows the risk of flooding of low-lying areas in the New York City area, including the Hackensack Meadowlands, from increased storm surge.



Wetlands are among the coastal areas most vulnerable to SLR (Table 15). Sea level rise is predicted to: (1) increase tidal flooding and coastal erosion of low-lying areas, and (2) contribute to a higher frequency and greater magnitude of storm surges throughout much of the NY- NJ Harbor and coastal New Jersey (Sorensen *et al.*, 1984; Zhang *et al.*, 1997; Gornitz *et al.*, 2001). Sea level rise during the past century may already be affecting some NY-NJ Harbor wetlands, such as Jamaica Bay, which is already experiencing considerable loss of low marsh wetlands (more than 38 percent of area lost since 1974; Hartig *et al.*, 2002). Considerable losses of the exterior and interior portions of marshes have also occurred at sites in mid-Atlantic and southern New England States (Erwin *et al.*, 2004). In nearly every case, formerly vegetated wetlands are being converted to open water as they are inundated by rising ocean water. In southern New England, increasingly flooded and stressed high marsh areas also are being overgrown by "landward-migrating" low-marsh vegetation, primarily smooth cordgrass (Donnelly and Bertness, 2001). Monitoring of the Coastal Virginia Long-Term Ecological site indicates that most high-marsh vegetation is not accumulating inorganic and organic materials at rates sufficient to keep pace with SLR, whereas low marsh vegetation is keeping pace with SLR (Hayden *et al.*, 2003). A considerable portion of marshes in the Meadowlands (*i.e.*, the Sawmill Creek Wildlife Management Area) was converted to open water in 1950 as a result of a single storm event; this suggests that wetlands in the Meadowlands are at risk to storm events with continued SLR.

Losses of, and changes in, marsh landscapes have considerable implications for ecosystem functions and for fish and wildlife resources in the Meadowlands. First, many bird species breeding in the Meadowlands' wetlands (*e.g.*, common moorhen, least bittern) would suffer loss of breeding habitat. Erwin *et al*. (2004) has raised additional concerns about potential marsh losses on waterfowl and other bird species that forage in marshes. Marsh losses also will likely result in increases in contaminants, decreases in sediment accretion and water quality, and changes in community composition (Poff and Hart, 2002).

The above observations have several implications for restoration activities planned or underway on several sites; SLR will clearly affect the type(s) of natural communities we can expect to become established in the Meadowlands. First, additional tidal flow resulting from modest SLR may have both beneficial and adverse impacts on restoration that are difficult to predict without additional information (*e.g.*, more precise elevation information through LIDAR [light detection and ranging], site-specific sedimentation/erosion rates, predicted future current velocities). For example, additional salt-water intrusion into the Meadowlands may facilitate establishment of smooth cordgrass in certain areas (*e.g.*, mesohaline [5 ppt < salinity < 18 ppt] areas where salinities favor growth of common reed) of the HMD. Second, high marsh comprised primarily of salt marsh hay, a rare vegetation throughout the Meadowlands that is valued at several current restoration sites (*e.g.*, Marsh Resources Inc., Mitigation Bank), appears vulnerable to even modest SLR. Third, the vegetative responses to dynamic conditions related to SLR are likely to be "constrained" by the hardened condition of banks throughout the HMD and the HRW. Urban areas and upland areas along the edge of the wetlands, where most shorelines are hardened, are likely to experience greater marsh losses than undeveloped areas, where shoreline movement is less constrained (Galbraith *et al.*, 2002). With increasing SLR, the "drowning" of wetlands may have some beneficial short-term effects (*e.g.*, increased production with conversion of high marsh to low marsh; Kana *et al.*, 1988), but will ultimately result in net losses of vegetated wetlands and increases of permanently flooded, shallow-water areas. Finally, by increasing the tidal prism (the volume of water that moves in and out of an estuary with each tide), SLR increases tidal currents and scour of sediments in certain areas within the Meadowlands and thereby increases the resuspension and availability of contaminants throughout the Meadowlands and adjoining water bodies.

Table 15. Geomorphic and other risk categories (Thieler and Hammar-Klose, 1999) affecting coastal vulnerability to sea level rise. The risk level(s) of wetlands and adjoining properties in the Meadowlands for each risk variable is denoted by shading. (> = more than; < = less than)

			RISK LEVEL		
VARIABLE	Very low	Low	Moderate	High	Very high
Geomorphology	Rocky cliffs and fiords	Indented coasts and moderate cliffs			
Shoreline change (± meters per year)	Rapid accretion (> +2.0)				Rapid erosion (< - 2.0)
Coastal slope (percent)					
Sea level rise (millimeters per year)	Low, < 1.8	1.8 - 2.5	Moderate, 2.5 - 2.9		
Mean tidal range (meters)	> 6.0	4.1 - 6.0	2.0 - 4.0		< 1.0
Mean wave height (meters)		0.55 - 0.85	0.85 - 1.05	1.05 - 1.25	> 1.25

C. CONTAMINANTS AND WATER QUALITY

1. Introduction

The Meadowlands and surrounding area have been a center of industrial activity for more than 200 years. For decades, manufacturing plants, refineries, energy facilities, and landfills discharged or otherwise disposed of their waste and hazardous materials directly into the river or adjacent wetlands. Many sites became contaminated with numerous pollutants, many of them quite toxic, including mercury, other heavy metals, dioxins, polychlorinated biphenyls (PCBs), pesticides, and other hydrocarbons. Containing most of the historic Hackensack Meadowlands, the HMD includes seven Superfund sites[4] in or within 2 miles of its borders, two power plants, three public STPs, and roughly 2,500 acres of landfills (Table 16, Figure 40). Each of these components of the Meadowlands' landscape has resulted in substantial impacts upon the environment. Two of the Superfund sites (*e.g.*, Ventron-Velsicol NPL site on Berry's Creek, U.S. Environmental Protection Agency, 2004a; Diamond Alkali, U.S. Environmental Protection Agency, 2004e) have been identified as among the worst contaminated sites in the United States, and have extensively degraded nearby wetlands and subtidal regions of the Hackensack River.

Table 16. Survey of Superfund National Priority List sites in the Hackensack Meadowlands District and in adjoining waterbodies. These and other industrial sites have contributed to contamination of wetlands and waterbodies in the HMD.

Site Name/Location	Site Status	Major contaminants
Hackensack Meadowlands District		
Ventron-Velsicol/ Woodridge, Bergen County	Superfund NPL	mercury
Universal Oil Products/ East Rutherford, Bergen County	Superfund NPL	VOCs[5], PCBs[6], PAHs[7], lead
Scientific Chemical Processing/ Carlstadt, Bergen County	Superfund NPL	VOCs, phenol, PAHs, heavy metals
PJP Landfill/ Jersey City, Hudson	Superfund NPL	chromium, lead, VOCs, pesticides, phenols
Syncon Resins/ Kearny, Hudson County	Superfund NPL	DDT[8], aldrin, PCBs, VOCs, heavy metals
Standard Chlorine Chemical Co., Inc. Kearny, Hudson County	Proposed for Superfund NPL	naphthalene, dioxin, PCBs, VOCs, chromium
Passaic River/Newark Bay		
Diamond Alkali Co. Newark, Essex County	Superfund NPL	Dioxin, PCBs, VOCs, DDT, PAHs

[4] Superfund site- any federal priority listed site in the United States that has been contaminated by hazardous waste and identified by the EPA as a candidate for cleanup because it poses a risk to human health and the environment
[5] VOC = Volatile organic compound
[6] PCB = Polychlorinated biphenyl
[7] PAH = Polycyclic aromatic hydrocarbon
[8] DDT = Dichloro-diphenyl-trichloroethane

Figure 40. Map of the Hackensack Meadowlands District (HMD) modified from the U.S. Army Corps of Engineers (2004). The location of major landfills (green outline) and Superfund sites (yellow star) is shown. Some landfills are being remediated and redeveloped, whereas others are to be remediated and capped and used to provide open space. The future use of most Superfund sites is currently undecided.

In addition, the HMD is subject to more than 50 active industrial discharges, combined sewer overflow (CSO) discharges, and tidally transported contamination from Newark Bay and the lower Passaic River. Tidal and riverine currents introduce additional contaminants from sources outside the Meadowlands (*e.g.*, PCBs from the NY-NJ Harbor estuary, pesticides and dioxin from the Passaic River, and leachates from landfills along Overpeck Creek). Certain contaminants (*e.g.*, PCBs) are dispersed broadly throughout the HMD; however, heavy metals and other contaminants may accumulate in subbasins and certain areas such as turbidity maximum zones (areas of intense settlement of suspended particulate matter; Williams *et al.*, 1994; Nedwell *et al.*, 1999; Feng *et al.*, 2002).

Historical and current uses of the Hackensack Meadowlands and its watershed have created a spatial mosaic of environmental contaminants throughout tidal waters and wetlands characterized by excessive nutrient concentrations, dissolved and suspended contaminants, abundant microbes, and summer hypoxia. The interactive effects of these chronic and acute stressors on fish and wildlife are largely unknown, but have contributed to historical declines of fish and wildlife diversity in the Meadowlands and its watershed. Identifying and describing all contaminants of potential concern, all contaminated sites within the HMD, or all of the associated adverse impacts on fish and wildlife resources are beyond the scope of this document. Rather, this section of the Plan identifies two basic concerns: the Meadowlands' potential to function as a wildlife "population sink," and the potential for contaminants to broadly compromise the restoration. This section also identifies and describes four specific categories of pollutants and related concerns: (1) mercury and other heavy metals, (2) hydrocarbon contaminants, (3) novel contaminants, and (4) eutrophication and hypoxia.

2. Population Sinks

Historical declines in fish and wildlife populations may be difficult to recognize because of complex movement patterns of animals (Holt, 1985; Pulliam, 1988). For example, individuals may regularly occur and breed in "sink" habitats, where (within-habitat) reproduction is insufficient to balance local mortality. Nevertheless, populations may persist in such sink habitats, maintained by immigration of individuals from nearby higher-quality "source" habitats, where reproduction exceeds local mortality. Sink habitats increasingly are being attributed to anthropogenic causes, including habitat fragmentation, invasive species, and contaminants for diverse taxa (*e.g.*, insects, fishes, amphibians, reptiles, birds, and mammals; Dias, 1996; Pulliam, 1996). Recent laboratory and field studies indicate that certain contaminants, invasive species, and other anthropogenic factors contribute to establishment of sink habitats (*e.g.*, Rowe *et al.*, 2001; Borgman and Rodewald, 2004). Localized and regional movements of individuals among different sites (habitats or areas) within the region have not been characterized for most species in the Meadowlands. For instance, animals that feed in the Meadowlands may accumulate contaminants, then migrate and reproduce outside of the Meadowlands (or the region) in productive source habitats. Movements of contaminated animals to source habitats have the potential for long-term adverse impacts to the entire population.

Conservation and management based on species abundance in sink habitats may lead to tragic results, including local extirpation of a species (Pulliam, 1988). Recognizing source and sink populations requires habitat-specific information on birth, death, and movement rates (*e.g.*, Pulliam and Danielson, 1991; Howe *et al.*, 1991). With the possible exception of certain species that are closely monitored throughout the region (*e.g.*, peregrine falcon), such information is not known and has not been reported for any population in the Meadowlands. Most of the biological information being collected in the Meadowlands (*e.g.*, abundance data, species presence-absence) is inadequate to distinguish between sink and source habitats. Furthermore, abundance or density measures may actually provide misleading information about habitat quality or value (*e.g.*, Van Horne, 1983; Vickery *et al.*, 1992); large numbers or high densities may reflect production in and emigration from other habitats. Thus, reproductive success of species must be compared among habitats, regions, and years to understand local population trends (*e.g.*, Murphy, 2001). Without habitat-specific information on reproductive success, restoration and management may place uncommon and rare species at increased risk of extirpation locally or regionally, especially in fragmented landscapes (Collier and Powell, 1998; Cornutt *et al.*, 2000; Donovan and Lamberson, 2001), and/or may result in failure of efforts to re-introduce populations of locally extirpated species (*i.e.*, species that occurred formerly in the Meadowlands).

Available information raises serious concerns that contaminants may have “created” sink habitats for certain invertebrates and fishes in the Meadowlands. For example, dioxins, furans, and PCBs accumulate in, alter gonadal and embryonic development of, and reduce larval survival of certain bivalve mollusks (*e.g.*, softshell clam [*Mya arenaria*] and American oyster [*Crassostrea virginica*]; Gardinelli *et al.*, 2004; Wintermyer and Cooper, 2003; Butler *et al.*, 2004). Mummichogs in marshes contaminated by heavy metals have significantly lower prey capture rates than mummichogs inhabiting clean reference sites (Smith and Weis, 1997). Moreover, fish from clean sites housed in tanks with contaminated sediments showed significant declines in prey capture rates and significant increases in vulnerability to predation by blue crabs (Smith and Weis, 1997; Weis *et al.*, 1999a). In addition, mummichogs from contaminated marshes have exhibited: (1) decreases in reproductive success when exposed to additional pesticides (Weis *et al.*, 1999b); (2) development of resistance to toxicity of chlorinated aromatic hydrocarbons (Prince and Cooper, 1995a; 1995b) and methyl mercury (Weis and Weis, 1989); and (3) physiological (*e.g.*, poor fin regeneration) and reproductive (*e.g.*, a reduced salinity range for fertilization) impairments associated with resistance to toxicity (Bush and Weis, 1983; Weis and Weis, 1987). Such findings raise additional questions about assessing contaminant risks and the potential impacts of contaminants to higher trophic levels by toxicity-resistant species, which have implications for restoration planning in the Meadowlands (Clotfelter *et al.*, 2004; Wirgin and Waldman, 2004). For example, evolution of pollution-tolerant mummichog has raised concerns regarding the potential for increased bioaccumulation of certain contaminants (*e.g.*, mercury, PCBs) in higher predators such as piscivorous fishes and birds (Wirgin and Waldman, 2004).

The pervasiveness of contaminants in the Meadowlands may contribute to “sink habitats” for species that use terrestrial habitats for most of their lives or that use the Meadowlands solely as foraging habitat. For example, trace-metal contaminants known to impair development, growth, reproduction, and survival of amphibians (*e.g.*, Rowe *et al.*, 1996; Raimondo *et al.*, 1998; Hopkins *et al.*, 2000; Baud and Beck, 2005) have been shown to create sink habitats for certain amphibian species in other regions (Rowe *et al.*, 2001). For example, in sites contaminated with metal-laden coal ash, tadpoles of southern toad (*Bufo terrestris*) usually died prior to their metamorphosis; as a result, the adult population contained few recent metamorphs and was reliant on adult recruits from other sites (Rowe *et al.*, 2001). Bioaccumulation of contaminants in certain birds (*e.g.*, American kestrel, *Falco sparverius*) may result in smaller eggs, smaller clutches, delayed clutches, and other adverse effects on reproduction and survival; moreover, some adverse effects may extend for several generations beyond the exposed generation (*e.g.*, Fernie *et al.*, 2000a; 2000b; 2001a; 2001b). Those same contaminants also impair the immune systems and potentially increase the susceptibility of kestrels to environmental stressors (*e.g.*, Smits *et al.*, 2002; Love *et al.*, 2003). These findings further emphasize the need for detailed studies on behavior (especially movements) and reproduction of select species within different vertebrate groups (*e.g.*, fishes, birds) to determine to what extent the Meadowlands may function as sink habitat and to guide and ensure the success of subsequent restoration decisions.

3. Contaminant Effects on Restoration

Sampling of wetland sites throughout the Meadowlands, including potential restoration sites, has identified several contaminants at levels associated with substantial adverse effects on fish and wildlife. Most recently, a Screening-Level Ecological Risk Assessment (SLERA) conducted for the NJMC (ENSR, International, 2004) identified seven heavy metals, two pesticides, and two other hydrocarbon compounds (Table 17) as Contaminants of Potential Concern (COPCs) at potential restoration sites. In a review of wetland contamination from one or more Superfund sites located in the Berry's Creek Study Area, (U.S. Army Corps of Engineers and U.S. Environmental Protection Agency, 2004), eight heavy metals, PCBs, dioxins, furans, and other hydrocarbons were identified as COPCs (Table 17). The Berry's Creek Study Area is among the worst mercury contaminated sites in North America (U.S. Environmental Protection Agency, 2004a). The NJDEP (2002a) previously identified the Hackensack River and several of its tributaries as impaired for a number of persistent toxic contaminants (Table 17) and other water quality parameters (*e.g.*, dissolved oxygen, total phosphorus, fecal coliform bacteria).

Comprehensive assessments of contaminant distribution, bioavailability, and effects (including bioaccumulation) on fish and wildlife have not been determined before, during, and after restoration. To date, only limited contaminant information has been collected from sites recently restored in the Meadowlands (*e.g.*, Louis Berger Group, Inc., 2000). As a result, the effects of restoration activities (*e.g.*, sediment removal, marsh contouring, ditching) on contaminant availability and accumulation are largely unknown; thus, adverse effects of any contamination on subsequent restoration success remain unknown. For example, the MRI Mitigation Bank site experienced low planting success and has been colonized extensively by volunteer species (Louis Berger Group, Inc., 2000; 2004b). Potential causes of the poor survival of plantings and of atypical plant communities on restoration sites, such as increased contaminant availability, should be evaluated to guide restoration of other sites. Therefore, restoration projects must include comprehensive assessments of contaminant availability and effects to prevent adverse impacts on fish and wildlife (and human) health. Failure to address contaminants in Meadowlands restoration efforts has the potential to: (1) adversely affect results (*e.g.*, inhibit re-vegetation by target species); (2) negatively affect the health of fish and wildlife in the Meadowlands and the region, possibly contributing to a species' local extirpation; (3) contribute to continued advisories on consuming fish and shellfish (New Jersey Department of Health and

Senior Services, 1998) or establish new advisories on other wildlife, such as waterfowl; and (4) adversely affect future human use of the Meadowlands.

Table 17. Contaminants of Potential Concern (COPCs) identified by three different Screening Level Ecological Risk Assessments conducted in the Hackensack Meadowlands.

	Screening Level Ecological Risk Assessments (Year)		
COPC by category	ENSR, Intl. (2004)	Corps/EPA (2004)	NJDEP (2002)
Heavy Metals			
Arsenic	X	X	X
Cadmium[9]			
Chromium	X	X	X
Copper	X	X	X
Lead	X	X	X
Mercury	X	X	X
Selenium		X	
Zinc	X	X	
Pesticides			
Chlordane	X		
DDT/DDE[10]	X		
Other Hydrocarbons			
PCBs[11]	X	X	
X			
PCDDs[12]		X	X
PCDFs[13]	X	X	X
PAHs[14]	X	X	

Stakeholders continue to learn about the distribution of contaminants in the Meadowlands; however, site- and species-specific information sufficient for a comprehensive risk assessment to guide restoration plans is not yet available. Screening level assessments (*i.e.*, SLERAs, see above) have identified contaminants of concern on some but not all potential restoration sites in the HMD. The Service (2005b) has ranked potential restoration sites into three general

[9] Although toxic and present throughout NY-NJ Harbor, cadmium is slowly "washing out" of the harbor in the dissolved phase, which is less available to fish and wildlife, and is generally decreasing in sediments harbor-wide (Boehme and Panero, 2003; Steinberg *et al.*, 2004).
[10] DDT/DDE = Dichloro-diphenyl-trichloroethane and its breakdown product
[11] PCB = Polychlorinated biphenyl
[12] PCDD = Polychlorinated dibenzodioxin (dioxin)
[13] PCDF = Polychlorinated dibenzofuran (furan)
[14] PAH = Polycyclic aromatic hydrocarbon

categories (Minimal, Moderate, and Substantial Concerns) based on available contaminant information. Contaminant data are generally lacking or do not provide sufficient depth of sediment profiles to identify potential contaminant "hotspots" at some of the potential restoration sites (U.S. Fish and Wildlife Service, 2005b). Because restoration activities on one site have the potential to increase contaminant exposure and availability on another site, an overall picture of the suitability of different sites for restoration is needed. A SLERA should be conducted for all potential restoration sites to evaluate their suitability for restoration, potential risks, and courses of action. Priority target groups (*e.g.*, species), stressor responses, exposure estimates, and contaminant effects (U.S. Environmental Protection Agency, 2005a) have not been identified or determined to characterize the overall risk of activities on any potential restoration site. Contaminant issues must be addressed consistently for all restoration projects. Equally important, contaminant guidelines protective of fish and wildlife (*e.g.*, Buchanan *et al.*, 2001) must become standards to guide restoration activities in the Meadowlands.

Contaminant problems in the Meadowlands are pervasive, technically complex, and potentially costly to address. Presently, unremediated contamination of several priority restoration sites and adjoining areas in the Hackensack Meadowlands (*e.g.*, Oritani Marsh and other sites near Berry's Creek; U.S. Army Corps of Engineers, 2003a) creates the potential for restoration activities to increase exposure of fish and wildlife (and people) to additional contaminants. In addition, STPs, CSOs, and stormwater have been identified as substantial contributors of certain contaminants (*e.g.*, mercury [de Cerreño *et al.*, 2002], PCBs [Panero *et al.*, 2005]). Such observations suggest that improved sewage treatment and stormwater management are as important to restoration as on-site remediation. Finally, future land-use planning (*e.g.*, drinking water supply, sewage treatment, flood control, transportation) must recognize and accommodate ecosystem functions, native species, and increasing human use of the Meadowlands if it is to protect the Meadowlands ecosystem and sustain its fish and wildlife resources.

4. Mercury and Other Heavy Metals

a. <u>Introduction to Heavy Metal Contamination</u>

As a group, heavy metals (*e.g.*, arsenic, chromium, lead, mercury, zinc; Table 18) potentially represent the most significant challenges to achieving successful restoration of the Meadowlands: such metals are difficult to assess, and restoration activities can increase their availability and adverse effects on fish and wildlife. Heavy metals originate from transportation, energy, waste disposal, and industrial sources and may be highly localized or widespread in their distribution. For example, surface sediments in many marshes contain concentrations of mercury and zinc sufficiently high to cause adverse impacts to wetland communities in the Meadowlands; however, deeper sediments generally contain those and additional metals (chromium and cadmium) at toxic concentrations (ENSR International, 2004). Due to their high concentration in deep sediments, heavy metals potentially complicate restoration at several sites, such as the Kearny Freshwater Marsh (Langan Engineering and Environmental Services, Inc., 1999) and especially the marshes along Berry's Creek and Canal (*e.g.*, Oritani Marsh; Barrett and McBrien, 2004), where construction and earth-moving activities may bring up and expose buried sediments and exacerbate air, water, and soil contamination. For example, portions of the Secaucus High School Mitigation Marsh are heavily contaminated (TAMS Consultants, Inc., 2001); appropriate monitoring of contaminant accumulation and effects needs to be conducted during and after the site's restoration.

Table 18. Summary of effects of heavy metals (other than mercury) on fish and wildlife.

Metal	Effects and Affected Taxa	References
Arsenic	Toxic to plants; highly toxic to fish Mutagen and teratogen Interactive with other metals, bioaccumulative	National Research Council, 1997 Hamilton and Hoffman, 2003
Cadmium	Altered behavior and physiology; reduced growth and reproduction in fish and wildlife Highly toxic to fish and wildlife Teratogen and carcinogen; probable mutagen	Eisler, 1987
Chromium	Reduced growth and chlorosis in plants at high concentrations Sublethal and lethal effects vary widely in fish and wildlife Mutagen, teratogen, and carcinogen Interactive with other metals	Eisler, 1987 Chandra and Kulshreshtha, 2004
Copper	Toxic to algae and plants; highly toxic to invertebrates, fishes, and amphibians Reduced growth and fecundity in birds Developmental and other effects in birds and mammals	U.S. Environmental Protection Agency (EPA), 2005b
Lead	Low toxicity to plants Reduced growth and impaired flight in birds Reduced growth, altered behavior and reproductive failure in mammals Toxic to fish, birds, and mammals Interactive with other metals, bioaccumulative	Pattee and Pain, 2003
Selenium	Reduced growth of algae Reduced growth and reproduction in aquatic animals; possible mutagen Interactive with other metals Bioaccumulative	Ohlendorf, 2003 EPA, 2005b
Zinc	Toxic to plants Reduced growth, reproduction, and survival in aquatic animals Carcinogenic, teratogenic, and mutagenic Diverse effects on reproduction and physiology in birds and mammals	Eisler, 1987 EPA, 2005b

Heavy metals cause both acute and chronic toxicity, and some bioaccumulate and biomagnify in upper trophic level species, such as predatory fishes and fish-eating birds and mammals (Table 18; Eisler, 1987). Metal contamination in the Meadowlands (and other wetlands) is difficult to assess because complex, interacting processes affect metal forms, properties, toxicity, and bioavailability. Such processes include microbial transformation (in biogeochemical cycles), sediment-water interactions, plant uptake, and subsequent animal bioaccumulation (Gambrell, 1994). Minor changes in the chemical environment (*e.g.*, pH, salinity, sulfide and oxygen concentrations) during restoration can alter a metal's form, distribution, toxicity, and bioavailability; thus, restoration may increase the adverse effects of contaminants on fish and wildlife resources (Gambrell, 1994). For example, copper, nickel, and zinc bind to small particles (*e.g.*, silts and clays) and are less available under anaerobic conditions (Lau and Chu, 1999). Metals bound to particulates may be available to deposit feeders and filter feeders, some of which may be affected by relatively low metal concentrations (Millward *et al.*, 2001). Because physicochemical and other conditions in estuaries are dynamic, accurate prediction of the behavior and toxicity of metals may not be a function of their total abundance.

b. <u>Effects of Mercury</u>

Mercury is the contaminant that presents the most problems for the restoration of the Hackensack Meadowlands. No known form or compound of mercury has any documented beneficial function in living organisms; thus, any substantial sink of mercury in the environment is potentially a source of contamination to fish and wildlife (Eisler, 1987). Organic mercury is a potent neurotoxin. In living organisms, organic mercury can pass through the blood-brain and placental barriers, be transferred to eggs and developing embryos, pass through individual cell membranes, and cause disruptions at the cellular and nuclear level (Eisler, 1987; Heinz, 1996; Wolfe *et al.*, 1998; Wiener *et al.*, 2003). Organic mercury causes diverse, subtle, sublethal effects (*e.g.*, altered activity patterns and behaviors, poor condition, neural lesions) that broadly impair survival and reproductive success in fishes, birds, and mammals (Eisler, 1987; Heinz, 1996; Wolfe *et al.*, 1998; Wiener *et al.*, 2003). Studies establishing definitive causal carcinogenic, mutagenic (causing a mutation, a change in the base sequence of a cell's DNA), and teratogenic (causing a non-heritable mutation or malformation in the developing embryo or fetus when a pregnant female is exposed to that substance) relationships for all forms of mercury have not been conducted (Agency for Toxic Substances and Disease Registry, 2005a). However, mercuric chloride and methylmercury are considered possible carcinogens in humans (U.S. Environmental Protection Agency, 2005b), and methylmercury has been reported to be a mutagen and teratogen in studies of animals (Costa *et al.*, 1991; Agency for Toxic Substances and Disease Registry, 2005a). Though not well studied, mercury's adverse effects may also be synergistic with other contaminants (Beckvar *et al.*, 1996). Mercury bioaccumulation has been associated with the decline of federally listed species, including a subspecies of clapper rail (*Rallus longirostris obsoletus*; Schwarzbach *et al.*, 1996). Eggshells of an eastern U.S. population of clapper rail with high mercury concentrations have exhibited egg-shell thinning and anomalous eggshell microstructure (Rodriguez-Navarro *et al.*, 2002).

Mercury contamination of aquatic environments became widely recognized as a serious human-health problem in the late 1950s, when 1,800 people near Minimata, Japan died, or suffered congenital birth defects, cerebral palsy, or other serious neurological impairments from eating seafood contaminated with mercury (Eisler, 1987). This incident was one of several tragedies that focused attention on understanding the mercury cycle and sources of mercury pollution, and prompted government efforts in the early 1970s to identify and reduce mercury contamination of aquatic environments in the United States. Mercury was the first contaminant chosen for study in the NY-NJ Harbor estuary by the Harbor Consortium of the New York Academy of Sciences (de Cerreño *et al.*, 2002).

c. Distribution of Mercury in the Meadowlands

Much of the concern about mercury contamination in the U.S. and especially in New Jersey and other northeastern states results from mercury in: (1) emissions from power plants and waste incinerators, and (2) waste generated by health-care facilities, including hospitals (New Jersey Department of Environmental Protection, 2000). Localized mercury contamination also results from the use of many products containing mercury that are discarded in household garbage (*e.g.*, disinfectants, paints, detonators, barometers, thermometers, batteries, switches, and lamps). While mercury emissions from power plants and incinerators have contaminated most aquatic sites from atmospheric deposition throughout New Jersey, local industrial activities have resulted in unparalleled levels of mercury contamination within the Hackensack Meadowlands (de Cerreño *et al.*, 2002; New Jersey Department of Environmental Protection, 2002b).

The Meadowlands is heavily contaminated by mercury from the Ventron-Velsicol site (New Jersey Department of Environmental Protection, 2002b; U.S. Environmental Protection Agency, 2004a). The 38-acre Ventron-Velsicol site on Berry's Creek (Figure 40) was occupied from 1929 until 1974 by the largest producer of intermediate inorganic mercury compounds and processor of contaminated mercury materials in the U.S., and is recognized as among the world's most severely mercury-contaminated aquatic sites (New Jersey Department of Environmental Protection, 2002b; U.S. Environmental Protection Agency, 2004a). Most contamination at the production site (estimates range from 30 to 289 tons) was composed of the liquid, elemental (inorganic) form; nonetheless, recent mercury concentrations in surface (13,800 µg/g) and subsurface (123,000 µg/g) soils remain acutely toxic (New Jersey Department of Environmental Protection, 2002b). In addition to contaminating the production site, the Ventron-Velsicol plant discharged 0.9 to 1.8 kg of mercury per day into Berry's Creek (Lipsky *et al.*, 1980). Mercury concentrations in surface (0 to 2 cm) sediments have been reported as high as 11,100 µg/g in Berry's Creek (New Jersey Department of Environmental Protection, 2002b); moreover, mercury concentrations in subsurface sediments to at least 6 feet in depth exceed sediment guidelines (U.S. Army Corps of Engineers and U.S. Environmental Protection Agency, 2004).

Mercury continues to disperse from the Ventron-Velsicol site to nearby waters and wetlands through erosion, ground-water transport, volatilization, and biological transformation and uptake (New Jersey Department of Environmental Protection, 2002b; U.S. Army Corps of Engineers and U.S. Environmental Protection Agency, 2004). Mercury concentrations in ground (8.2 µg/L) and surface (15.6-17.6 µg/L) waters adjacent to the site, including Berry's Creek, exceed the acute and chronic water quality criteria for mercury (Exponent Environmental Group, 1998; New Jersey Department of Environmental Protection, 2002b) and far exceed (more than 30,000 times) the State's draft water quality criterion (530 pg/L) to protect fish and wildlife (Buchanan *et al.*, 2001). Mercury concentrations in Hackensack River sediments (average = 99.9 ng/L ± 94.4 ng/l) are the highest in the entire HRE. The highest mercury concentrations (190.8 ng/L ± 130.8 ng/L) were measured in river sediments between Routes 46 and 80, well upstream of the confluence of the river and Berry's Creek. Pecchioli *et al.* (2003) hypothesized that the mercury concentrations in upper tidal areas of the Hackensack River are higher than areas near the mouth of the river because mercury-contaminated sediments are being resuspended, distributed with flood tidal currents, and redeposited in mid-river areas without being flushed from the river.

d. Forms and Availability of Mercury

While most mercury released at the Ventron-Velsicol site was in elemental or inorganic forms with relatively low toxicity, mercury is readily transformed in aquatic ecosystems into the organic form methylmercury, which is highly toxic to plants, fish, wildlife, and humans (Watras and Huckabee, 1994). The majority of mercury found in living organisms is methylmercury (Wolfe *et al.*, 1998). Methylmercury production is especially high in productive wetland ecosystems, both freshwater (Zillioux *et al.*, 1993) and estuarine (Compeau and Bartha, 1985; Davis *et al.*, 2003); therefore, understanding methylmercury production in the Meadowlands is necessary for evaluating appropriate remediation and restoration activities of mercury-contaminated sites.

Sulfate-reducing bacteria are the most important producers of methylmercury in freshwater and saltwater ecosystems (King *et al.*, 2000). Mercury methylation is highest at the interface of the aerobic and anaerobic layers of sediment, where sulfate-reducing bacteria are most abundant (Bloom and Lasorsa, 1999; Langer *et al.*, 2001). Methylmercury diffuses into the water and is distributed by currents; thus, high methylmercury production in any wetland, such as Berry's Creek, acts as a source for other wetlands (Langer *et al.*, 2001). Methylation of mercury in aquatic systems varies with environmental features (Table 19, from Davis *et al.*, 2003) and also depends on mercury loadings, microbial activity and species, nutrient content, redox condition, suspended sediment load, and sedimentation rates (Compeau and Bartha, 1985; Berman and Bartha, 1986; Jackson, 1986; King *et al.*, 2000). Modifiers of methylation are potentially affected by restoration activities; therefore, restoration of sites with high mercury concentrations has the potential to increase mercury methylation and bioavailability.

A major concern regarding any increase in the availability of methymercury is its subsequent accumulation and biomagnification. Methylmercury is moderately lipophilic (soluble in fats) and hydrophilic (soluble in water), properties that facilitate its availability to organisms, especially animals. These properties also ensure the increasing accumulation, or biomagnification, of mercury from one trophic level to the next. Eventually, biomagnification results in higher, more toxic doses of mercury in higher trophic level animals, such as piscivorous birds (*e.g.*, herons, raptors) and humans. For example, total mercury concentrations in water of less than 1 part per trillion may result in mercury concentrations in fish in excess of 1 ppm (Zillioux *et al.*, 1993). Mercury also can bioaccumulate from the environment into plants, especially aquatic species (Zillioux *et al.*, 1993; Heller and Weber, 1998). Mercury concentrations as high as 13 ppm (dry weight) have been found in the wetland vegetation near Berry's Creek (Ludwig, 1988).

Table 19. Factors identified by Davis *et al.* (2003) that influence mercury methylation and affect the spatial availability of mercury in wetlands.

Variable	Relationship
Oxygen	Creates aerobic conditions that decreases methylation of mercury by sulfate-reducing bacteria (which require anaerobic conditions).
pH	Low pH increases methylation; more likely in wetlands with high organic content
Sulfate	In low sulfate waters, increased sulfate increases methylation. In high sulfate waters (*e.g.*, estuaries), increased sulfate increases demethylation. Increased sulfide decreases methylation.
Dissolved organic carbon (DOC)	High DOC in the water column may indicate high organic loading leading to high bacterial activity and anoxic sediments. Complexation of Hg forms by DOC may increase dissolved concentrations without appreciably increasing biological uptake.
Temperature	Up to 35-40ºC, increasing temperatures increases bacterial activity (*e.g.*, methylation).
Salinity	Bacterial and algal mercury uptake reduced by complexation with chloride (*i.e.*, formation of $HgCl_2$, MeHgCl); chloride is the major component of salinity.

e. Criteria for Mercury

Mercury concentrations in water, sediment, and the biota that have been examined in the Meadowlands far exceed most environmental guidelines. Mercury concentrations in tissues of certain common marsh invertebrates (*e.g.*, grass shrimp, mud snails) inhabiting Berry's Creek often exceed 1 µg/g (Lipsky *et al.*, 1980; ERM-Southeast Inc., 1985), which is high for low trophic level species. In its review of published and unpublished data from Berry's Creek sites, NJDEP (2002) reported mercury concentrations of 0.01 to 0.79 µg/g in mummichog, which feed predominantly on invertebrates, and 0.30 to 1.90 µg/g in white perch (*Morone americana*), which feed more extensively on fishes. These tissue concentrations are sufficiently high to be lethal to sensitive fishes (Eisler, 1987). ENSR, International (2004), in a screening-level environmental risk assessment, reported a mercury hazard quotient of 1,190 for great blue heron in the Meadowlands (*i.e.*, the levels are 1,190 times too high to be protective for this species). Finally, mercury guidelines protective of fish and wildlife developed by the State, EPA, and the Service (Buchanan *et al.*, 2001) have not been adopted as binding regulatory standards in accordance with the Service's (1996b, 1998) Biological Opinion. Such criteria would help guide restoration activities in the Meadowlands as well as support efforts to clean up the other waters and wetlands in New Jersey.

In summary, mercury is the contaminant of greatest potential concern to fish and wildlife and to the restoration of the Hackensack Meadowlands. Considerable effort is needed to assess mercury's distribution, dispersal, availability, and effects on fish and wildlife in the Meadowlands. Assessing bioavailability of mercury deserves a high priority when considering restoration of any site in the Meadowlands. In addition, water and sediment criteria protective of wildlife should be established and considered in planning restoration sites to prevent creation of attractive nuisances (*i.e.*, sink habitats or sites with preferred vegetative communities but high mercury availability). Lastly, sites that are most heavily contaminated by mercury should be restored only when its site-specific availability and effects on fish and wildlife are known.

5. Hydrocarbon Contaminants

a. Introduction

Hydrocarbon contaminants (*e.g.*, various crude and refined petroleum products, pesticides, PCBs, dioxins, furans, and polycyclic aromatic hydrocarbons [PAHs]) became a worldwide problem in the early 20th Century when ocean transport of crude oil began and developments in chemical engineering led to increased production of synthetic hydrocarbon compounds. Although some hydrocarbons enter the environment through natural processes, certain hydrocarbons (*e.g.*, PAHs) enter the environment from human activities such as petroleum spills, CSOs, landfills, and disposal. Other hydrocarbons, such as pesticides, were dispersed intentionally or discarded accidentally during manufacturing and use. Hydrocarbon pollutants differ in their general properties, bioavailability, and toxicity (Table 20; Albers, 2003; Rice *et al.*, 2003). Because most hydrocarbon contaminants are hydrophobic and have low solubility in water, they bind to particles in water and subsequently accumulate in sediments. Certain hydrocarbon contaminants may be absorbed from the environment but ingestion is the most common route of exposure for animals (Meador *et al.*, 1995). Certain hydrocarbons are metabolized and excreted, whereas others are stored in lipid-rich tissues (Albers, 2003; Rice *et al.*, 2003). Nearly all hydrocarbon contaminants have adverse effects on fish and wildlife and human health. For example, PAHs may cause tumors (Chang *et al.*, 1998), decreased egg viability (Hose *et al.*, 1981), and suppressed immunity (Arkoosh *et al.*, 1994) in fishes. Young-of-the-year bluefish in the Hackensack River show a five-fold increase in DNA adduct formation (*i.e.*, a chemically induced gene mutation, often a precursor to a cancerous tumor) compared to the same fish from a cleaner estuary in southern New Jersey (Samson and Deshpande, 2003).

Hydrocarbon contaminants are widespread in sediments of the Meadowlands and elsewhere in the NY-NJ Harbor estuary (Gunster *et al.*, 1993a; 1993b; Crawford *et al.*, 1995; Dimou *et al.*, 2003; Steinberg *et al.*, 2004). Inputs of certain hydrocarbon contaminants have decreased throughout the NY-NJ Harbor estuary as a result of bans on their production and use; however, concentrations of most of the above-identified hydrocarbon contaminant groups remain sufficiently high to cause adverse effects to fish and wildlife resources (Huntley *et al.*, 1995; Steinberg *et al.*, 2004). For example, hydrocarbons such as PAHs are nearly ubiquitous in urban areas as a result of the extensive area of asphalt surfaces (Mahler *et al.*, 2005).

Bioaccumulation of certain hydrocarbon contaminants (*e.g.*, pesticides) is generally high in ecosystems such as the Meadowlands, where exposures can occur frequently (Meador *et al.*, 1995). Hydrocarbon contaminants differ in their potential to bioaccumulate within each trophic level (Corner *et al.*, 1976; Whittle *et al.*, 1977; Clements *et al.*, 1994). The forms and toxicities of hydrocarbon contaminants, unlike those of metals, generally will not change during restoration. Additionally, the concentrations of certain hydrocarbons (*e.g.*, PAHs) may decrease with restoration activities due to biodegradation (Eijsackers *et al.*, 2001). Concentrations of all hydrocarbon contaminants and changes in their bioavailability should be addressed in restoration planning.

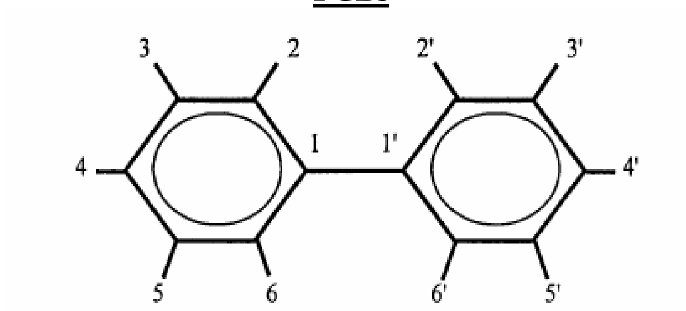
Table 20. Survey of effects of selected hydrocarbon contaminants on fish and wildlife. Selected contaminants are those reported frequently at Superfund and other contaminated sites in the Meadowlands. Information on PCBs, dioxins, and furans is presented in the text.

Hydrocarbon	Effects and Affected Taxa	References
Organochlorine pesticides		
Aldrin/dieldrin	Toxic to aquatic plants Highly toxic to invertebrates, fishes, birds, and mammals Carcinogenic; endocrine disrupting Bioaccumulative	Briggs *et al.*, 1992 Agency for Toxic Substances and Disease Registry (ATSDR), 2006a
Chlordane	Highly toxic to invertebrates and fishes Toxic to birds and mammals Carcinogenic; Endocrine disrupting Bioaccumulative	Eisler, 1987 Briggs *et al.*, 1992 ATSDR, 2006b
DDT/DDE	Decreased growth of algae Highly toxic to invertebrates and fishes Toxic to amphibians, reptiles, birds, and mammals; diverse non-lethal effects Carcinogenic and mutagenic Endocrine disrupting Bioaccumulative	Briggs *et al.*, 1992 ATSDR, 2006c
PAHs	Diverse, poorly known non-lethal effects Altered metamorphosis and reduced reproduction in invertebrates Toxic to aquatic invertebrates and fishes Adverse effects on reproduction, immunity, and development in mammals Highly carcinogenic to all animals	Eisler, 1987 EPA, 2005b ATSDR, 2006d

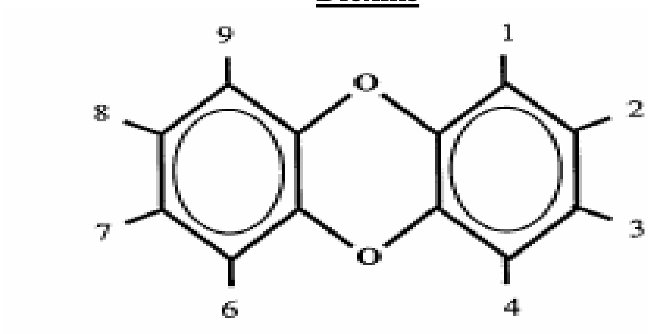
The hydrocarbons of greatest potential concern for fish and wildlife and for restoration of the Meadowlands are the polyhalogenated organic contaminants, which include three major groups: (1) PCBs, (2) dioxins (polychlorinated dibenzodioxins or PCDDs), and (3) dibenzofurans (polychlorinated dibenzofurans, furans, or PCDFs). All three groups share a common chemical "backbone" of two benzene rings, but differ in the connection between the benzene rings (Figure 41). Changing the number and location of the chlorine atoms that are substituted along the backbone (Figure 41) potentially results in a maximum of 209 PCB compounds, 75 dioxin compounds, and 135 furan compounds. In general, each compound (or congener) has distinct properties; however, congeners of PCBs, dioxins, and furans that have the same number and location of chlorine atoms may share pathways, modes of action, and effects (Rice *et al.*, 2003).

Figure 41. Chemical structure of three classes of polyhalogenated organic contaminants: PCBs, dioxins, and furans. PCBs may be halogenated at any carbon numbered 2 to 6 or 2′ to 6′, whereas dioxins and furans can be halogenated at carbons 1 to 4 and 6 to 9.

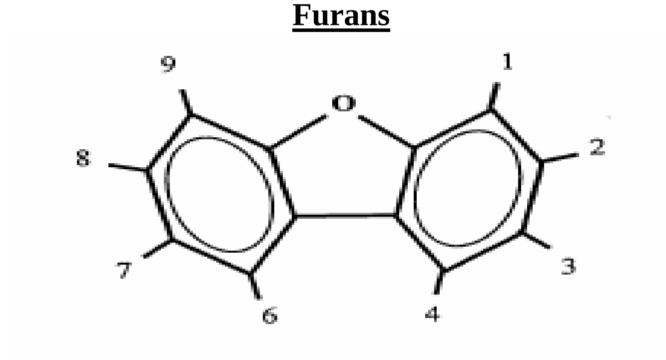
PCBs



Dioxins



Furans



b. Polychlorinated Biphenyls

Depending on their degree of chlorination, PCBs range in consistency from heavy oils to sticky resins to waxy crystals. All PCB congeners are inert, hydrophobic, and stable across a wide range of temperatures. They resist oxidation and other chemical aging processes, and do not conduct electricity. First produced commercially in 1927 in Alabama, PCBs became widely used in electrical equipment (*e.g.*, transformers, insulators, capacitors, circuit breakers), hydraulic systems (*e.g.*, compressors, vacuum pumps), coating materials (*e.g.*, paints, plastics, adhesives, wood preservatives), pesticides, and pressure-sensitive copying paper. Commercial PCB formulations, sold under the trade-name Aroclor in the U.S. by Monsanto, were produced as mixtures of different PCB compounds.

Jensen (1966) first reported PCBs in fishes and birds in Sweden, and expressed concern about bioaccumulation. Two years later, more than 1,600 people in Yusho, Japan became ill after eating PCB-contaminated rice oil. Many people exhibited acute or chronic effects, including liver cancer, and other skin, immune, reproductive, nervous, and gastrointestinal disorders (Masuda, 1994; Panero *et al.*, 2005). Shortly after a similar incident occurred in Taiwan, other countries began to prohibit manufacturing, sale, and use of PCBs. In the U.S., PCB production voluntarily ceased in the mid-1970s and was subsequently prohibited in 1977 with passage of the Toxic Substances Control Act of 1976 (P.L. 94-469; 90 Stat. 1686; 15 U.S.C. 2601-2671). Continuing concern about the effects, persistence, and mobilization of PCBs led to their inclusion as one of 12 Persistent Organic Pollutants that were banned in 2001 by international treaty (Stockholm Convention on Persistent Organic Pollutants).

Exposure to PCBs has resulted in acute toxicity and death of fish and wildlife; however, chronic exposures and effects are more commonly reported (Hoffman *et al.*, 1996). Fishes with chronic exposure to PCBs exhibit immune system suppression (Zelikoff, 1994), enzyme modulation (Otto *et al.*, 1997), histopathological lesions (Teh *et al.*, 1997), liver tumors (Barron *et al.*, 1999), and reproductive and developmental impairments (Niimi, 1996). PCBs in Great Lakes fish are believed to adversely affect reproduction of bald eagle, other fish-eating birds, mink (*Mustela vison*), and river otter (*Lutra canadensis*; Wren, 1991; Giesy *et al.*, 1994). Also, reproductive failure, liver damage, immunosuppression, and wasting syndrome in wildlife have been attributed to chronic exposure to PCBs (Hoffman *et al.*, 1996). Improved recognition of the modes of action of specific congeners has resulted in identification of twelve PCBs as dioxin-like (Van den Berg *et al.,* 1998). Thus, toxicities of these congeners, such as PCB 77 and 126, is expressed in a widely accepted (but not regulatory) protocol as Toxic Equivalency (TEQ), in which the toxicity of these compounds is determined relative to 2,3,7,8-tetrachlorodibenzo-*p*-dioxin, the most potent and prototypical dioxin congener (Rice *et al.*, 2003).

PCBs are common in the water, sediment, and biota of the NY-NJ Harbor estuary, including Newark Bay and the Hackensack River (Achman *et al*., 1996; Skinner *et al*., 1997; Adams *et al*., 1998; Durell and Lizotte, 1998; Feng *et al*., 1998; Litten, 2003; Monosson *et al*., 2003; Fernandez *et al*., 2004). Nearly 30 years after the ban on their production, PCBs continue to enter the NY-NJ Harbor estuary (including the Hackensack River) through riverine and other inputs (Totten, 2004). For many years, General Electric's Fort Edward and Hudson Falls facilities discharged 500,000 to 1.1 million pounds into the Hudson River (U.S. Environmental Protection Agency, 2004g). These two facilities were considered the primary sources of PCBs to the estuary. Atmospheric input, CSOs, and stormwater runoff collectively are now thought to contribute nearly as much total PCB-contamination as the Hudson River inputs; landfills may also contribute substantial quantities of PCBs (Totten, 2004). Based on the information currently available, Newark Bay and portions of the Hackensack River (upriver potentially as far as Snake Hill) appear to have among the highest sediment burdens of total PCBs in the entire NY-NJ Harbor estuary. Of greater concern, PCBs in certain fishes collected in the Hackensack River near Snake Hill have PCB concentrations as high as in the same species collected in the Hudson River (Fernandez *et al.*, 2004).

Low molecular-weight PCB congeners (*e.g.*, PCB 11) have not been considered in contaminant assessments for the NY-NJ Harbor estuary, in part due to the lack of congener-specific data and other information on their toxicity (Totten, 2004). New methods providing congener-specific information, such as EPA (1999) Draft Method 1668A, have stimulated interest in all congeners that are present in the environment and their effects on fish and wildlife. For example, a hydroxylated form of PCB 35 is known to disrupt the actions of certain thyroid and sex hormones (Lans *et al.*, 1993; Kester *et al.*, 2000). Available information regarding PCB 11 also raises concern. Preliminary surveys found PCB 11 constituted greater than 90 percent of the total PCBs in the treated-sewage discharge of the Passaic Valley Sewerage Commissioners' treatment facilities. Though comprising only hundredths of a percent of commercial PCB formulations (*i.e.*, Rushneck, 2004), PCB 11 may be the most abundant congener in the NY-NJ Harbor estuary (*e.g.*, Litten *et al.*, 2002). This congener's relatively high solubility in comparison to other PCB congeners may increase its dispersion and availability in the water column. This congener may be neuroactive *in vitro* (Kodavanti and Tilson, 1997), and, like other light-weight congeners, may be associated with DNA-adduct formation (McLean *et al.*, 1992; Oakley *et al.*, 1996; Schilderman *et al.*, 1999; Pereg *et al.*, 2002). Finally, available information on hydroxylation of PCBs raises concerns about the potential endocrine-disrupting effects of PCB 11 (Lans *et al.*, 1993; Darnerud *et al.*, 1996; Andersson *et al.*, 1999; Kester *et al.*, 2000).

Many aromatic compounds, including PCBs, are hydroxylated (the addition of a hydroxyl group [-OH] to a molecule) in all vertebrate species to increase their polarity and thus facilitate their excretion. However, hydroxylated PCBs often remain in tissues at concentrations similar to heavy, persistent PCBs (Klasson-Wehler *et al.*, 1998; Sinjari *et al.*, 1998; Hovander *et al.*, 2002). Hydroxylated PCBs resemble hormones (chemical messengers produced by different organs such as the ovary and thyroid) that have diverse roles in metabolism, development, and reproduction. For example, hydroxylated PCBs have an affinity for (*i.e.*, may bind with) certain female-hormone receptors (*e.g.*, estrogen receptors; Korach *et al.*, 1988; Andersson *et al.*, 1999) and certain enzymes that deactivate female hormones (*e.g.*, sulfotransferase; Kester *et al.*, 2000). Thus, these hydroxylated PCBs have considerable potential to interfere with sexual differentiation and cause abnormal growth and development of reproductive structures and products (Bergeron *et al.*, 1994; Kester *et al.*, 2000).

In addition, hydroxylated PCBs resemble thyroid hormones (*e.g.*, thyroxin and triiodothyronine) and have an affinity for several molecules affecting thyroid metabolism such as transthyretin, a transport protein (Lans *et al.*, 1993). Perhaps not coincidentally, mummichogs in the NY-NJ Harbor estuary show evidence of adverse effects on thyroid tissue and thyroid hormone levels (Zhou *et al.*, 1999), which may be due to high concentrations of PCBs. The State of New York is reported to have taken steps to identify sources and reduce manufacturing and discharge of PCB 11 into the NY-NJ Harbor; the Passaic Valley Sewerage Commissioners are also reported to be taking steps to identify sources of PCB 11 to its STP (Panero *et al.*, 2005). While definitive evidence does not exist that hydroxylated PCB 11 is adversely affecting fish and wildlife health, PCBs should be monitored in a manner that can identify and detect all PCB congeners and their metabolites to assess their potential adverse effects on fish and wildlife resources.

c. Dioxins and Furans

Polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzofurans are two related classes of aromatic compounds that share certain structural similarities to PCBs (Figure 41) and are persistent in the environment. As with PCBs, congeners of dioxins and furans are hydrophobic and lipophilic, giving them low solubility in water and high affinity for organic particles. In contrast to PCBs, these two classes of compounds have no commercial uses but are formed and are released into the environment as by-products of: (1) chlorine bleaching of pulp and paper, (2) chemical manufacturing of chlorophenols (*e.g.*, pesticides) and other chemicals (*e.g.*, PCBs, polyvinyl chloride [PVC] plastics), and (3) combustion from municipal waste incinerators (Rice *et al.*, 2003).

Seventeen dioxins and furans are considered highly toxic to vertebrate wildlife and pose a significant risk to human health (Grassman *et al.*, 1998; GPA Clearinghouse, 2001). There is no clear consensus on the toxicity of other congeners (Rice *et al.*, 2003). Because congeners differ in their toxicity, their potency is expressed in Toxic Equivalents to 2,3,7,8-tetrachloro-dibenzo-*p*-dioxin (TCDD), the most potent, hazardous and well-studied dioxin (Rice *et al.*, 2003). Specific effects of dioxins documented in laboratory mammals and humans include wasting, immunotoxicity, endocrine disruption, reproductive and developmental abnormalities, cancer, and death (*e.g.*, Peterson *et al.*, 1993; Pohjanvirula and Tumost, 1994). Similar adverse effects have been reported for fishes and birds (*e.g.*, Spitsbergen *et al.*, 1991; Walker *et al.*, 1991; Heid *et al.*, 2001). A recent National Institute of Health study also indicates that dioxin-like congeners are additive in their ability to induce cancerous and precancerous conditions in controlled experiments (Walker *et al.*, 2005).

Invertebrate animals lack an aryl hydrocarbon receptor that binds to coplanar dioxins, furans, and PCBs, and are generally less sensitive than vertebrate animals to dioxin and dioxin-like compounds (Powell-Coffman *et al.*, 1998; Butler *et al.*, 2001). However, recent work indicates that certain invertebrates are adversely affected by low concentrations of dioxin. Butler *et al.* (2004) reported that a mechanism independent of the aryl-hydrocarbon receptor was responsible for alteration of gametogenesis (*i.e.*, gamete formation) in softshell clam (*Mya arenaria*). Wintermyer and Cooper (2003) also found eastern oyster (*Crassostrea virginica*) reproduction may be impaired at dioxin tissue concentrations as low as 2 pg/g, well below concentrations known to occur in bivalves in Newark Bay (Brown *et al.*, 1994). If dioxins and related compounds adversely affect invertebrates, timely remediation is needed of sites heavily contaminated by dioxin. Additional research investigating the effects and exposures of dioxins, dioxin-like compounds, and related hybrid compounds (*e.g.*, polybrominated/chlorinated diphenyl ethers, dioxins, and furans) on invertebrates, fishes, and wildlife is necessary to guide remediation and restoration of the Meadowlands (Litten *et al.*, 2003).

Dioxins and furans are common throughout the HRE due to their inadvertent production during industrial processes. In particular, the manufacture of chlorophenols has resulted in considerable contamination of Newark Bay and the Meadowlands with both dioxins and furans. The Kolker Chemical Works' Diamond Alkali plant (ID No. NJD980528996; U.S. Environmental Protection Agency, 2004f) on the Passaic River produced 15 million tons of 2,4,5-trichlorophenoxyacetic acid (2,4,5-T; a chlorophenol herbicide) and 50,000 tons of dichloro-diphenyl-trichloroethane (DDT, a widely used organochlorine pesticide). Some of these products, including impurities in their manufacture (*e.g.*, the most potent and hazardous dioxin congener [2,3,7,8-tetrachloro-dibenzo-*p*-dioxin]), were discarded into the lower Passaic River (Wahrman, 2000). The Diamond Alkali plant is recognized as the single largest contributor of dioxin to Newark Bay and its tributaries, including the Hackensack River. In addition to the Diamond Alkali site, the Standard Chlorine State Remediation Site (NJDEP Bureau of Case Management No. NJD002175057, proposed EPA Superfund Site ID No. NJD002175057) is a potential source of substantial dioxin and certain other contaminants (*e.g.*, benzene, chlorobenzene, di- and tri-chlorobenzenes, naphthalene, PCBs) to the Hackensack River and nearby wetlands (U.S. Environmental Protection Agency, 2004g). Dioxin (2,3,7,8-TCDD) has been found on-site and in nearby river sediments (96.1 ng/kg; U.S. Environmental Protection Agency, 2004f).

Recent sampling has revealed that dioxin congener profiles in the Hackensack River upriver to the Oradell Dam are identical to those in the Passaic River and are attributed to the Diamond Alkali Superfund Site (Wilson, pers. comm., 2004). Transport of Passaic River dioxins upstream in the Hackensack River is likely due to transport of sediment-associated contaminants in (tidal) flood currents along the bottom. Such transport of dioxin would suggest that other contaminants in the Passaic and in lower portions of the Hackensack have also been distributed throughout the tidal regions of the HRW. Because concentrations of PCBs, dioxins, and furans may vary in their depth distribution within sediments (Wilson, pers. comm., 2004), typical restoration activities (*e.g.*, excavation of fill materials to increase tidal flow) may increase the exposure of fish and wildlife to these compounds. Thus, the Service recommends assessment of the specific depths of different contaminants to guide restoration and to prevent exposure of buried contaminants to fish and wildlife. Where heavy contamination is present, remediation of buried, contaminated sediments must precede restoration. Finally, PCB and DDT guidelines protective of fish and wildlife developed by the State, EPA, and the Service (Buchanan *et al.*, 2001) were not adopted as binding regulatory standards: adoption of such criteria would help guide restoration activities in the Meadowlands as well as support efforts to clean up other waters and wetlands in New Jersey.

6. Novel Contaminants

Over 40 years ago, Rachel Carson's (1962) *Silent Spring* warned about the dangerous consequences to fish and wildlife resulting from pesticide use. Later examples of such consequences included eggshell thinning in peregrine falcon from bioaccumulation of DDT (Hickey and Anderson, 1968). More recently, the production, use, and disposal of a broad variety of synthetic chemicals used in industry, agriculture, medicine, and everyday life are creating concern regarding adverse ecological and human health effects (U.S. Geological Survey, 2005b). Many of these products, including over-the-counter medications, have been widely used and generally considered safe for many years. However, recent studies have revealed that many such chemicals, including detergent metabolites, steroid hormones, caffeine, antimicrobial disinfectants, antibiotics, fire retardants, and plastic by-products (Table 21), have increasingly entered, and in some cases, accumulated, and become widespread in aquatic systems (Kolpin *et al.*, 2002). Collectively referred to as "novel" or "emerging contaminants," most of these chemicals are not monitored routinely. Although their effects on fish, wildlife, and human health are largely unknown, their potential effects, properties, and exposure raise concerns for the health of fish and wildlife.

Much of the concern regarding novel contaminants arises from their potential actions as endocrine disruptors. Endocrine disruptors are exogenous (produced outside the body) chemical substances or mixtures that alter the structure or function of the endocrine system; they cause adverse effects at the level of the organism, its progeny, populations, or subpopulations (U.S. Environmental Protection Agency, 1998). Known endocrine disruptors include many chemical groups with diverse uses in agriculture, industry, medicine, and the home, including various pesticides (*e.g.*, DDT, kepone, lindane, methoxyclor); certain PCB-, dioxin-, and furan-congeners; various cadmium, mercury, lead, and organo-tin compounds; alkylphenols, other non-biodegradable detergents, and anti-oxidants; certain styrene dimers and trimers and other plastics; laboratory animal, pet-food, and soy products (Colburn and Clement, 1992; Colburn *et al.*, 1996). Recognized endocrine disruptors are structurally diverse and have different mechanisms of action that may depend on the "timing" of exposure (*e.g.*, life history stage, degree of reproductive maturity, season) and may not be detected for many years (Gillesby and Zacharewski, 1998). For example, alkyl phenol detergents and their degradation products are toxic to algae and invertebrates, may cause development of an ovotestis instead of a typical ovary or testis in fishes (*e.g.*, Gray and Metcalf, 1997), disrupt metamorphosis in aquatic invertebrates and fishes (Servos, 1999), and may be persistent in the environment (McGuire, 1999). Tributyltin, widely used in marine anti-fouling paints, persists in estuarine sediments, bioaccumulates in estuarine invertebrate taxa that are forage for other wildlife (Pereira *et al.*, 1999), and causes malformation of reproductive organs in mollusks (Schulte-Oehlmann *et al.*, 2000). Other novel endocrine disruptors may include new pesticides, fungicides, flame retardants, polyhalogenated surfactants and paraffins, and certain pharmaceuticals (*e.g.*, Brown *et al.*, 2004). The diverse effects of novel contaminants on growth, development, and reproduction may result in extirpation of local populations (Colburn *et al.*, 1996).

Several studies have identified a number of adverse contaminant effects that are not attributable to any specific compound. For example, effluent from STPs in urbanized estuaries causes slower growth, increased mortality, abnormal gonad development and secondary sexual characteristics, and lower reproductive success of fishes (Kime, 1998; Matthiessen, 2003). Antibiotic resistance has been shown to increase in bacteria exposed to pharmaceuticals and other contaminants in waste streams in industrialized areas (Roane and Kellogg, 1996; Gońi-Urizza *et al.*, 2000). Genes that code for antibiotic resistance are carried on the same genetic components (*i.e.*, plastids) that confer metal resistance (Wireman *et al.*, 1997). Thus, elevated exposures to metals

Table 21. Novel and organic wastewater contaminants (by chemical use) and their effects.

Antibiotics	Known/probable effects
Erythromycin	Antibiotic resistance
Lincomycin	Antibiotic resistance
Sulfamethoxazole	Antibiotic resistance
Trimethoprim	Antibiotic resistance
Disinfectants/detergents and metabolites	
Triclosan	Antibiotic resistance
Methyl phenol (cresol)	Endocrine disruption
Alkyl-, methyl-, nonyl- and octyl-phenols and ethoxylates	Endocrine disruption
Flame retardants	
Polybrominated diphenyl ethers (PBDEs)/metabolites	Endocrine disruption
Tris (2-chloroethyl) phosphate	Endocrine disruption
Fungicides/herbicides//pesticides/repellants	
Carbaryl	Toxic
N,N-diethyl-meta-toluamide (DEET)	Toxic
Diazinon	Toxic
Dichlorobenzene	Toxic
Phamaceuticals/byproducts	
Acetaminophen	Toxic
Caffeine	Toxic/stimulant
Cotinine (nicotine metabolite)	Toxic/stimulant
Dimethylxanthine	Stimulant
Methyl benzotriazole	Toxic
Solvents/resins/plasticizers	
Bis phenol A	Endocrine disruption
Dichlorobenzene	Toxic
Ethanol butoxy-phosphate	Toxic
Phthalic anhydride	Toxic
Tetrachloroethylene	Toxic
Steroids	
Cholesterol	
Coprostanol	
Estrogens (estriol, estradiol)	Endocrine disruption
Progesterones	Endocrine disruption
Androgens (testosterone)	Endocrine disruption
Other	
Fluoranthene	Toxic
Pyrene	Toxic

is somehow contributing to development of antibiotic resistance in those bacteria. Brominated flame retardants such as polybrominated diphenyl ethers are also a concern (Birnbaum and Staskal, 2004). These flame retardants and related contaminants such as polybrominated dioxins, polybrominated furans, and their chlorinated and brominated hybrids are common in the NY-NJ Harbor (Litten *et al.*, 2003), persistent in the environment, and appear to bioaccumulate and biomagnify in fish and other wildlife (Eljarrat *et al.*, 2004; Morris *et al.*, 2004). These flame retardants also appear to impair neurodevelopment and actions of thyroid hormones (U.S. Geological Survey, 2004). Finally, certain antidepressants (*e.g.*, fluoxetine, sertraline) have been detected in all tested tissues (including muscle) of several fishes inhabiting river systems receiving considerable discharges of effluent from STPs (Brooks *et al.*, 2005). Though the concentrations in muscle were too low to have therapeutic effects if consumed by humans, fishes exposed to such chemicals exhibit altered reproductive and other behaviors (*e.g.*, Perreault *et al.*, 2003).

Given the large human population of this urban region, fish and wildlife (and humans) will likely be exposed to endocrine disruptors and other “novel” contaminants from human waste streams and other sources. Failing to account for the amounts, fates, or adverse effects of synthetic materials will likely perpetuate the *status quo* of the Meadowlands as an extensively degraded environment or, under worse circumstances, exacerbate its current contaminant problems. The above-referenced and other studies have established the need to: (1) identify compounds in waste streams, (2) determine the distribution, transport, and availability of such compounds in the environment, (3) assess ecological effects and impacts on fish and wildlife (and human) health, and (4) if necessary, develop corrective measures that are protective of fish and wildlife (and human) health (Kolpin *et al.*, 2002; U.S. Geological Survey, 2005b). Designing sewage-treatment systems to eliminate or reduce all of these materials in human waste-streams may not be feasible or cost-effective at this time; however, these and other compounds should be monitored to determine the extent of contaminant problems. New compounds are being produced every year; therefore, the Service recommends periodically revising the list of synthetic materials being monitored and updating sampling protocols to improve detection of existing and novel contaminants.

7. Eutrophication, Nutrients, and Hypoxia

Tidal marsh ecosystems are widely considered among the most productive ecosystems in the world (Mitsch and Gosselink, 1993). For example, marshes in the northeastern U.S. may produce annually as much as 4,500 metric tons of plant material per hectare (4,500 g m^{-2} yr^{-1}; Valiela *et al.*, 1976). Nitrogen, phosphorus, and other nutrients are essential for growth and reproduction of producers (*e.g.*, marsh grasses, phytoplankton, and benthic algae) in tidal marsh ecosystems. Nitrogen has long been thought to be the primary limiting nutrient of production in coastal ecosystems, including tidal marshes (*e.g.*, Ryther and Dunstan, 1971; Valiela and Teal, 1974; Smart and Barko, 1980). However, prolonged periods of excess nutrients may lead to unsustainable primary production and eutrophication (a highly increased rate of supply of organic matter, which leads to rapid “aging” and impaired functioning of an ecosystem; Nixon, 1995). Although eutrophication may result from natural causes, the major factor along the industrialized east coast of the U.S. has been an intensified supply of nutrients to estuaries as a consequence of the accelerated development of cities, farms, and industries in the watersheds (Bricker *et al.*, 1999; National Research Council, 2000).

Effects of nutrient over-enrichment are diverse and largely detrimental (U.S. Environmental Protection Agency, 2003b). During eutrophication in estuaries, primary producers respond to excessive nutrients by increasing their growth and production. Consumers and decomposers also increase production, but may be unable to keep pace with the increased primary production. Biological needs for dissolved oxygen eventually exceed the available oxygen supply (especially in summer when water temperatures are high), and result in hypoxia[15], which has numerous adverse effects on aquatic wildlife (as discussed below). Eutrophication frequently results in impoverished biological communities dominated by nuisance (food-web disrupting) or toxic species (Burkholder *et al.*, 1995; Paerl *et al.*, 2003). Eutrophication also alters certain ecosystem functions (*e.g.*, decreased nitrogen fixation, Valiela and Teal, 1974; microbial sulfate reduction, Hargrave, 2003). Hypoxia and certain associated conditions (*e.g.*, altered hydrogen sulfide concentrations and oxidation-reduction potentials) associated with eutrophication may also exacerbate other environmental stressors by changing form and availability of contaminants (National Oceanic and Atmospheric Administration, 2005a). In addition, toxic trace elements such as arsenic, copper, and cadmium may have complex effects on primary and secondary production in eutrophic systems (Wiegner *et al.*, 2003). Such effects have included a reduction in primary production in experimental studies (Wiegner *et al.*, 2003). Effects of trace elements in the Meadowlands, with its diverse sources of contamination, remain unknown.

Water quality in the Hackensack River estuary, Newark Bay, and the adjoining Passaic River estuary (the Passaic River watershed is 11 times larger than that of the Hackensack) has been highly degraded for many years (Squibb *et al.*, 1991) by excessive contamination and eutrophication (Crawford *et al.*, 1995; Steinberg *et al.*, 2004). Because contaminants and hypoxia cause adverse impacts on fish and wildlife (see below), poor water quality in the Hackensack River estuary and the adjoining waterways represents a considerable challenge to the restoration of the Meadowlands and its aquatic resources. Despite substantial improvements in sewage treatment throughout the Meadowlands and the rest of the NY-NJ Harbor estuary in the 1970s and 1980s, no significant overall improvements in water quality in the Meadowlands were reported for the period 1971-1988 (Keller *et al.*, 1990). This lack of improvement may have resulted from the comparatively poor flushing of the Meadowlands in comparison to other portions of the HRE, which appear better flushed by freshwater flows (Steinberg *et al.*, 2004).

Although reported to be somewhat improved from the 1970s and 1980s, water quality within the HMD continues to show evidence of eutrophication. For example, average ammonium concentrations from 1993 to 2004 have remained high (*e.g.*, > 12 mg/L) in some portions of the HMD (*e.g.*, Cromakill Creek, where secondary sewage effluent is discharged from a STP; New Jersey Meadowlands Commission, 2005c). The continuous discharge of high concentrations of ammonium in the sewage effluent of the Bergen County Utility Authority's STP (the single largest source of freshwater into the Hackensack River estuary) results in consistently high ammonium concentrations in the vicinity of the discharges and tidal transport of ammonium to upriver and downriver portions of the estuary (DiLorenzo *et al.*, 2004). Though ammonium is subsequently dispersed and converted to less toxic forms of nitrogen (nitrites and nitrates) by

[15] Hypoxia- low oxygen concentration; in water, usually defined to indicate oxygen concentrations less than 2 ppm.

nitrification (DiLorenzo *et al.*, 2004), studies (*e.g.*, Valiela and Teal, 1979; Valiela, 1991) suggest that considerable quantities of nitrogen are likely accumulating in the sediment in portions of the HMD. Some forms of nitrogen may be present periodically in concentrations known to be toxic to some species of plants (*e.g.*, Van Katwijk *et al.*, 1997); also, high concentrations of different forms of nitrogen may affect plant community composition by facilitating the spread of invasive plant species (*e.g.*, Trémolières, 2004). The accumulating reservoirs of various forms of nitrogen may be contributing to the trapping of contaminants in the Meadowlands. Finally, DiLorenzo *et al*. (2004) noted that seasonal water sampling activities in the HMD, such as those performed by the NJMC for the past 10 years, are inadequate to detect weak trends (*e.g.*, improvements) in water quality. Thus, comparison of numerous water quality criteria in the Meadowlands for symptoms of eutrophication (*e.g.*, fecal coliform, other nutrients) may be of limited utility, except when improvements or deteriorations are exceptionally pronounced (DiLorenzo *et al.*, 2004).

Comparison of dissolved oxygen concentrations from 1971-1988 with seasonal water quality data provided by the NJMC (2005b) does suggest some improvements in water quality, yet indicates that hypoxia continues to occur in the Meadowlands during the summer growing season when water temperatures are warm. Oxygen concentrations in the Hackensack River and its tributaries regularly fall below the NJDEP's water quality criterion (4.0 mg/L; N.J.A.C. 7:9B) and EPA's (2003c) protective minimum oxygen concentration (2.3 mg/L) for adult fishes. Even periodic hypoxia may affect the normal behavior, growth, and reproduction of many estuarine organisms (Diaz and Rosenberg, 1995; Diaz, 2001). For example, juveniles of several common estuarine fishes that are commercially important (*e.g.*, winter flounder, black sea bass) experience reduced growth rates and may die even when exposed to hypoxia for a few days (Bejda *et al.,* 1992; Hales and Able, 1995). Aquatic invertebrates such as polychaetes and other benthic infaunal taxa are generally more sensitive to oxygen concentrations than fishes (Diaz and Rosenberg, 1995).

D. SUMMARY

Land and water use by the large human population has resulted in extensive cumulative impacts to the Meadowlands over time, including losses of fish and wildlife populations. Hydrologic alterations to the HRW to satisfy the public need for potable water include construction of several dams and water storage reservoirs, diversions of water from other watersheds, controlled river flows, and groundwater extraction. These alterations have resulted in a substantial reduction in the freshwater flow throughout the HRW. Consequently, secondary treated sewage effluent is now the largest source of "freshwater" in the Hackensack River. Sewage effluents, together with CSOs, non-point source run-off, landfill leachates, pollutants from industrial sites, and contaminants transported by tides have created a mosaic of heavily contaminated sediments washed by waters with excessive nutrient concentrations, abundant microbes, and hypoxic water. As a result, water quality in the Hackensack River remains broadly impaired for many criteria (*e.g.*, mercury, fecal coliform bacteria) in comparison with water quality throughout the rest of the HRE.

Historic declines in fish and wildlife populations are difficult to recognize because of largely unknown, yet potentially complex movement patterns in animals. Because of these movement patterns, populations may persist in contaminated and other "sink" habitats, in which local reproduction is insufficient to balance local mortality. Historic losses of certain taxa from the Meadowlands (*e.g.*, aquatic invertebrates, amphibians, fishes) raise serious concerns about the potential functioning of wetlands in the Meadowlands as sink habitats. Several contaminants that originated from multiple sources or dispersed from localized "hotspots" have become widely distributed in the Meadowlands, and have considerable potential to adversely affect fish and wildlife. For example, Berry's Creek, which adjoins three of the seven Superfund sites in the Meadowlands, may be the most heavily contaminated mercury site in the nation. Mercury and the other contaminants of greatest concern in the Meadowlands (*i.e.*, PCBs, dioxins, certain hydrocarbons) are not only toxic to many species, but bioaccumulate and are endocrine disruptors that have adverse effects on growth, survival, and reproduction of animals. Restoration activities (*i.e.*, regrading marsh elevation and planting native vegetation) may create "attractive nuisances" by increasing the availability of those contaminants and their subsequent bioaccumulation in fish and wildlife populations that use restored wetlands. Finally, the legacy of contamination in the Meadowlands will continue and may likely worsen with increasing demand and reuse of the region's water resources, unless a program to monitor and address novel contamination is developed and implemented.

Poor water quality and environmental contaminants potentially limit the recovery of the aquatic fauna and dependent species in the Meadowlands. The reduced flow of the Hackensack River combined with the high nutrient concentrations in sewage effluents that dominate the freshwater inputs have created a system that is stressed, as evidenced by the hypoxia that occurs during the summer growing season, for most fishes and invertebrates. Heavily contaminated wetlands along Berry's Creek and possibly other contaminant hotspots also represent a considerable challenge to restoration. Burgeoning human population and industry will continue to increase water consumption; thus, water quality degradation will continue and may worsen with increasing demand and reuse of the region's water resources. The Service recommends improvements to sewage treatment and the flows of the Hackensack and Passaic Rivers to improve the health of fish and wildlife throughout the region. Development of a comprehensive program to monitor and assess contaminants is essential to guide remediation and restoration of the Meadowlands. In addition, the Service recommends that a priority task of government agencies and stakeholders be development of a plan to remediate and restore wetlands along Berry's Creek and beyond without creating an attractive nuisance to fish and wildlife populations. Remediation and restoration activities, combined with comprehensive improvements in water quality, will eventually increase opportunities for appropriate recreational and other uses (see Sections VIII and IX) of the Meadowlands and improve the quality of life for area residents. A strategy for water conservation, including the monitoring, management, and restoration of water resources, is necessary to ensure that future water quality and quantity needs will be met for fish, wildlife, and people.