CLH 581
(19936)

CLH 561

CLH Sponsored Publication Information

ECOTOXICOLOGY AND ENVIRONMENTAL SAFETY 25, 202–213 (1993)

Assessment of Chemical Loadings to Newark Bay, New Jersey from Petroleum and Hazardous Chemical Accidents Occurring from 1986 to 1991

DONALD G. GUNSTER, NANCY L. BONNEVIE, CAROL A. GILLIS, AND RICHARD J. WENNING

ChemRisk—A Division of McLaren/Hart Environmental Engineering, Stroudwater Crossing, 1685 Congress Street, Portland, Maine 04102

Received January 30, 1992

Newark Bay, New Jersey, is particularly vulnerable to ecological damage from accidental petroleum and chemical spills due to the enclosed nature of the bay and the large volume of chemical and petroleum commerce within the region. A review of the New Jersey Department of Environmental Protection and Energy's database of hazardous chemical spills in New Jersey waterways was conducted to determine the frequency and volume of chemical and petroleum spills in Newark Bay and its major tributaries. Accidents reported from 1986 to 1991 were extracted from the database and summarized. The compilation of records indicated that 1400 incidents, resulting in the release of more than 18 million gallons of hazardous materials to the estuary had been reported to state officials. The bulk of the chemicals released to the aquatic environment were petroleum products, specifically No. 2 Fuel Oil (4,636,512 gallons) and No. 6 Fuel Oil (12,600,683 gallons). The majority of the reported incidents occurred in the Arthur Kill and its tributaries. The results indicate that accidental discharge of petroleum and other hazardous chemicals to Newark Bay represents a significant ongoing source of chemical pollution. © 1993 Academic Press, Inc

INTRODUCTION

Since the March, 1989 grounding of the tanker *Exxon Valdez* in Prince William Sound, Alaska, there has been an increasing public awareness of the complex problems associated with the transportation and accidental release of petroleum products and hazardous chemicals into aquatic environments (Westermeyer, 1991; Kelso and Kendziorek, 1991). Normal shipping operations, accident-related oil spills, and discharges incurred during routine terminal operations make marine transportation of chemical and petroleum products an important source of chemical pollution in the environment (NOAA, 1984). From an ecological standpoint, such releases are significant due to their instantaneous nature; when a spill occurs, there is little time for dilution before initial acute affects are manifested (Robilliard, 1991). In addition, many of the chemicals and petroleum products commonly involved in accidental spills are persistent in the aquatic environment and may accumulate in the sediments or be transported to adjacent areas (RPI, 1989).

Newark Bay, New Jersey, along with its tributaries and associated wetlands, is one of the world's largest urbanized and industrialized estuarine systems. The natural harbor of Newark Bay serves as a major center for commerce and industry, including the refining of crude oil, chemical manufacturing, and the transport of refined petroleum and chemical products (Tavolaro and Freeman, 1990). The Port of New York/New Jersey (Fig. 1) is responsible for handling more general and containerized cargo

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Newark Bay Study Area
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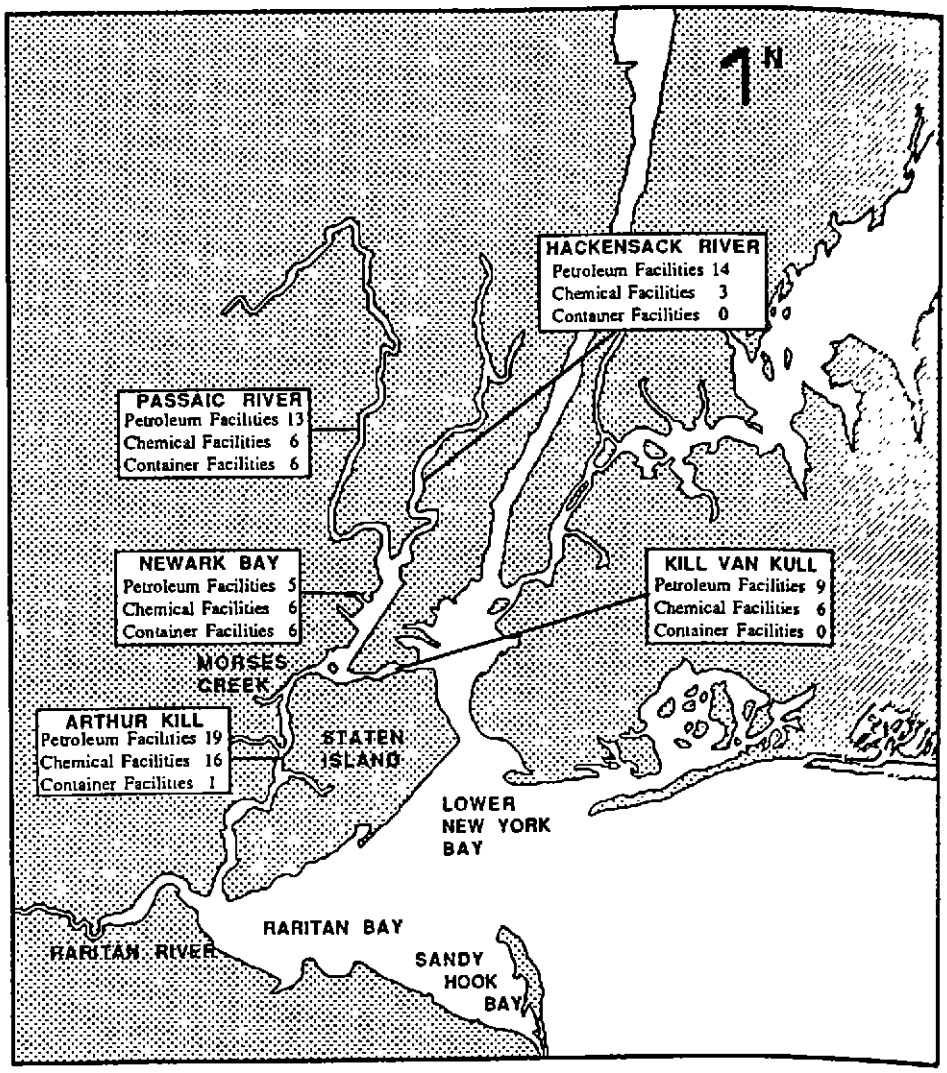


FIG. 1. Locations of major petroleum, chemical, and container storage terminal facilities in Newark Bay and its tributaries. Information was obtained from data reported in RPI (1989).

than any other port in the United States (Tavolaro and Freeman, 1990). Commerce data for 1984 indicated that the Port handled 161 million tons of containerized and bulk cargo (RPI, 1989); 76% of these materials were petroleum products (123 million tons) and 2% were other hazardous chemicals (3.35 million tons) (RPI, 1989). Due to the large volume of chemical and petroleum commerce within Newark Bay, environmental degradation from petroleum and hazardous chemical spills has been significant (Grassle, 1990; Mueller, 1990; Suszkowski *et al.*, 1990; NOAA, 1982).

Ecological degradation from chemical contamination of Newark Bay has been recognized for more than a century. The first substantial period of environmental degradation is reported to have occurred between 1890 and 1920 (Franz, 1982). By 1951, the Arthur Kill and Kill van Kull were found to receive the highest pollutant loadings

of any area monitored by the Interstate Sanitation Commission, which includes Connecticut, New York, and New Jersey (ISC, 1951).

The objective of this study was to assess the impact of recurrent petroleum and chemical releases on the overall environmental quality of the estuary. As part of an ongoing environmental assessment of Newark Bay, the frequency and volume of accidental chemical spills reported between 1986 and 1991 were summarized from database records maintained by the New Jersey Department of Environmental Protection and Energy (NJDEPE). The NJDEPE Bureau of Communication and Support has maintained a computerized database of petroleum products, hazardous materials releases, and permit violations for New Jersey waterways since 1986. The potential short- and long-term ecological impacts of petroleum and chemical spills in Newark Bay are also discussed.

METHODS

Records of all incidents reported between 1986 and 1991 within the navigable channels, shipping terminals, anchorages, and tributaries of Newark Bay were extracted from the NJDEPE database. The study area extended from approximately 40°44′ longitude and 74°10′ latitude southward to approximately 40°30′ longitude and 74°05′ latitude. Each incident was categorized by chemical, quantity released, type of incident (fire, spill, illegal dumping, etc.), receiving water body, date of release, and the suspected source. Data were summarized for the entire study area and for each waterway within the estuary, including the Passaic River, Newark Bay, Arthur Kill, Elizabeth River, Morses Creek, Hackensack River, Rahway River, Raritan Bay, Raritan River, and Woodbridge Creek.

Prior to data analysis, the NJDEPE records were standardized with respect to descriptive terminology. To quantify the volume of materials released, the records were grouped according to three general categories: petroleum products, hazardous chemicals, and "other". The "other" category refers to unidentified or infrequently spilled materials, such as waste water, paint, ink, and products that could not be classified as either petroleum products or hazardous chemicals. Within the petroleum products category, the frequency and volume of spills for specific petroleum products were quantified. A subcategory, "other oil" was utilized to classify releases of nonspecific petroleum products that were identified in the NJDEPE database as "fuel oil," "oil sheen," or "oil product." Relative to accidents involving petroleum products, releases of organic chemicals and solvents were relatively infrequent and usually involved small quantities. Nonpetroleum compounds were therefore grouped together and were quantified only as hazardous chemicals.

Database records were also standardized with respect to the quantity of material released to Newark Bay. Since the volumes of discharged material identified in the NJDEPE database were typically reported in U.S. gallons, those reported as drums, barrels, and quarts were converted to gallons. When a range was reported, such as "10 to 20 gallons," the quantity released was assumed to be equivalent to the larger value. Where the volume of an accidental spill was unknown, the volume was designated as "not quantified." For the small number of incidents that reported spill volume amounts in pounds, the volume was converted to gallons based on the specific density of the released material. For all petroleum products, the specific density was assumed to be 0.90 g/cm^3.

Four main categories, fire, illegal dumping, spill, and other releases, were used to describe the type of incident involved in the release of petroleum or hazardous materials to the environment. The other releases category consisted of incidents that were attributed to infrequent or unusual events.

RESULTS

Records indicate that 1393 accidental releases, resulting in more than 18,276,051 gallons of hazardous materials and petroleum products, entered Newark Bay between October 1986 and August 1991. On average, 3,545,141 gallons of petroleum products were released into waterbodies in this region annually, or approximately 10,000 gallons per day. The majority of the spills into the Arthur Kill, its tributaries, and municipal sewer facility were comprised of petroleum products (17,657,579 gallons). A significant amount of petroleum products reportedly entered municipal sewer systems. From 1986 to 1991 over 219,545 gallons of diesel fuel and 200,821 gallons of oils classified as "other" were introduced to sewer treatment facilities. In the first 8 months of 1991, 329 releases consisting of 30,750 gallons were reported in Newark Bay. The largest number of incidents occurred in 1990, during which 495 accidents resulted in the release of 4,902,814 gallons of hazardous materials into the estuary.

The number of spills was not a good indicator of the volume of chemicals introduced to the environment. For example, the number of incidents reported in 1989 (318 releases) was similar to the number of incidents reported in 1988 (356 releases); however, a substantially larger total volume of material was released in 1989 than in 1988 (Fig. 2). The volume of hazardous materials released during 1990 was largely due to a single release of 4,620,300 gallons of No. 2 Fuel Oil that occurred as a result of a fire at the Citgo Petroleum Corporation terminal located on the Arthur Kill. A summary of accidental spills equal to or greater than 1000 gallons is presented in Table 1.

Nearly 50% of the incidents contained in the NJDEPE database did not identify the volume of material released to the environment; therefore, the actual volumes of

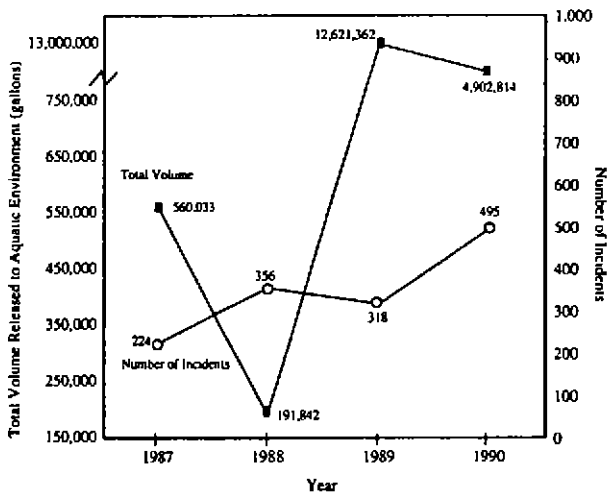


FIG. 2. Annual volume and frequency of petroleum and hazardous chemical spills in Newark Bay between 1987 and 1990 are indicated.

chemicals released is likely substantially larger than what was reported to the NJDEPE. Furthermore, chemical releases that are suspected to occur in the region as a result of illegal dumping and permit discharge violations were not reported.

Petroleum products constituted the majority of materials released into Newark Bay, comprising 96.8% (17,725,706 gallons) of the total volume of spilled material (Table 2). Among the petroleum products, No. 6 Fuel Oil represented 71% of the total volume discharged to the estuary over the 5-year period. In contrast, data for 1991 indicated that gasoline and diesel fuel represented 84% of the total volume of petroleum products released to Newark Bay. Hazardous chemicals comprised less than 1% (81,347 gallons) of the total volume released between 1986 and 1991. Aldehydes, antifreeze, chromic acid, and other solvents represented the majority of the hazardous chemicals identified

TABLE 1

MAJOR INCIDENTS IN NEWARK BAY INVOLVING THE DISCHARGE OF 1000 GALLONS OR MORE OF PETROLEUM OR HAZARDOUS CHEMICALS BETWEEN 1986 AND 1991

Total estimated volume of spill (gallons)	Material	Site or facility	Waterway	Date of incident
4,620,000	No. 2 Fuel Oil	Citgo Petroleum Corp	Arthur Kill	3/90
4,000,000	Other	Shell Oil Refinery	Woodbridge Creek	1/87
200,000	Oil other	Hyatt Clark Ind.	Sewer	2/90
53,000	Liquid asphalt	Outer Bridge	Arthur Kill	8/87
42,000	Other	Tank Barge Pioneer	Arthur Kill	1/90
30,000	Chemicals	FMC Corp.	Arthur Kill	8/87
23,000	Chemicals	FMC Corp.	Sewer	6/87
21,000	Oil other	GATX Terminal	Arthur Kill	4/90
20,000	Oil other	FPN Enterprises	Unknown	4/87
12,600	Gasoline	Citgo Petroleum Corp.	Arthur Kill	7/87
9,000	Gasoline	Sun Oil Truck	Unknown	10/87
6,000	Gasoline	NJ Turnpike Exit 12	Unknown	6/91
5,500	Oil other	NJ Turnpike Exit 13	Sewer	3/90
3,500	Sodium hydroxide	Gist Brocades	Unknown	10/91
3,000	No. 1 Fuel Oil	Conrail	Sewer	10/87
3,000	Benzene	Merck & Co.	Unknown	1/91
3,000	Diesel fuel	Naval Weapons Station	Sandy Hook Bay	2/91
2,000	Oil diesel	Waterfront Naval Weapons Pier	Raritan Bay	2/91
2,000	Aldehyde	Area of River Rd. & Factory Lane	Raritan River	2/91
2,000	Aldehyde	Intersection of Factory Lane & River Rd.	Unknown	2/91
2,000	No. 2 Fuel Oil	Shopping Center	Unknown	8/91
1,680	Chemicals	Hatco Corp.	Unknown	2/90
1,000	Oil other	Academy Dye Casting	Unknown	2/87
1,000	HCL	CP Chemical Co.	Unknown	10/87
1,000	Ink	Unidentified Facility	Unknown	2/90
1,000	Gasoline	Citgo Petroleum Corp.	Arthur Kill	3/90
1,000	Oil other	Larry Moll Town Auto Shop	Unknown	11/90
1,000	Potassium permanganate	Woodbridge TWP/ Keasby Complex	Raritan River	3/91

TABLE 2

VOLUME OF PETROLEUM AND HAZARDOUS CHEMICALS RELEASED INTO NEWARK BAY AND ITS MAJOR TRIBUTARIES FROM OCTOBER 1986 TO AUGUST 1991[a]

Material	Total volume released (gallons) 1986–1991	1991
Petroleum products		
No. 1 Fuel Oil	3,125	NR[b]
No. 2 Fuel Oil	4,636,512	597
No. 4 Fuel Oil	201	NQ[c]
No. 6 Fuel Oil	12,600,683	266
Creosote	75	75
Crude oil	1	NQ
Diesel fuel	50,278	6,380
Gasoline	42,659	7,672
Hydraulic oil	70	NQ
Kerosene	306	NQ
Liquid asphalt	53,000	NR
Motor oil	931	NR
Transmission fluid	30	NR
Waste oil	80,374	NR
Other oil products[d]	257,461	1,760
Total	17,725,706	16,750
Hazardous chemicals		
Alcohol	150	50
Aldehyde	4,000	4,000
Ammonia	100	NR
Antifreeze	5.5	5.5
Benzene	3,000	3,000
Chlorine	1,500	NQ
HCL	1,080	NR
Hexane	150	150
Hydrocarbons	10	NR
Isobropenyl	50	50
D-Liminone	10	10
Milk	75	75
Naptha	210	210
PCBs	130	30
Pesticides	NQ	NQ
Phenol	NQ	NQ
Solvents	1,261	NQ
Unidentified chemicals[e]	69,615	2,790
Total	81,346.5	10,307.5
Other materials		
Ink	NQ	NR
Paint	513.5	24
Waste water	16,075	16,075
Unidentified materials[f]	494,562	685
Total	511,150.5	16,784

[a] Data were compiled from a computer database maintained by the NJDEPE Bureau of Communication and Support.

[b] An accidental spill incident involving this material was not recorded (NR) on the database.

[c] One or more spill incidents was reported to NJDEPE but the volume of the spill was not quantified (NQ) in the data base.

[d] Oil products in this category included infrequently released or unidentified petroleum products.

[e] Hazardous chemicals in this category included chemical compounds not specifically identified.

[f] Other material in this category included materials which were reported as unknown in the database.

in this category. Ink, paint products, and wastewater, classified within the "other" category, comprised less than 1%, or 517,219 gallons, of all materials released to the environment.

A summary of the types of incidents that have been reported to the NJDEPE in Newark Bay between 1986 and 1991 is presented in Table 3. Spills were responsible for 74% of the volume of material released. During the first 8 months of 1991, spills constituted 85% of the total volume of material released to Newark Bay; illegal dumping contributed an additional 7.5%. During this 8-month period, illegal dumping of hazardous materials was reported only in Raritan Bay and represented 41% of the total volume of hazardous material and petroleum products entering Raritan Bay. Fires were responsible for 26% of the volume of material released; however, a single fire at the Citgo Petroleum refinery near the Arthur Kill was responsible for nearly all of the materials released in this category. If the volume of petroleum released as a result of this fire (4,620,300 gallons) is excluded, fires would account for 0.38% of the material released into Newark Bay.

DISCUSSION

The ecological degradation of Newark Bay appears to be ongoing and is attributable to a variety of anthropogenic inputs, including the cumulative impact of historical industrial activity and marine transportation of chemical products (NOAA, 1988). Marine transportation, in particular, is considered the most important source of petroleum compounds to the estuarine environment (NOAA, 1984). Within the U.S. Coast Guard district responsible for the Port of NY/NJ, 152 marine facilities are involved in the transfer, storage, or processing of petroleum products or chemicals

TABLE 3

TOTAL VOLUME OF PETROLEUM AND HAZARDOUS CHEMICALS RELEASED TO NEWARK BAY AND ITS MAJOR TRIBUTARIES FROM 1986 TO 1991 ACCORDING TO THE TYPE OF INCIDENT RESPONSIBLE FOR THE ACCIDENT

	1986–1991 (gallons)				1991 (gallons)			
Waterbody	Fire	Illegal dumping	Spill	Other	Fire	Illegal dumping	Spill	Other
Arthur Kill	4,620,300	—	12,769,972	—	—	—	6,000	—
Bound Creek	—	—	20	—	—	—	—	—
Elizabeth River	—	—	320	1	—	—	110	1
Kill Van Kull	—	—	275	—	—	—	205	—
Lower Bay	—	—	601	—	—	—	1	—
Morses Creek	—	50	182	—	—	—	50	50
Newark Bay	—	—	210	—	—	—	—	—
Passaic River	—	—	105	—	—	—	4	—
Rahway River	—	150	659.8	—	—	—	—	—
Raritan Bay	—	22	3,484	1,000	—	—	—	—
Raritan River	—	1,200	12,790	—	—	1,000	2,100	1,000
Sandy Hook	—	1,000	36,736	—	—	—	3,235	—
Woodbridge Creek	—	0.5	80,228	30	—	—	—	—
Sewer	3,605	276	219,412	—	—	—	12.5	—

(RPI, 1989). Among the 110 terminal facilities (60 petroleum facilities, 37 chemical facilities, and 13 container facilities) located in Newark Bay, including the Arthur Kill, Kill van Kull, Passaic River, and Hackensack River, 19 petroleum facilities are located on the Arthur Kill (RPI, 1989). A majority of these facilities have storage capacities greater than one million barrels (RPI, 1989). Among the 33 facilities located along the Passaic and Hackensack Rivers, 27 facilities are petroleum terminals (RPI, 1989). Not surprisingly, the terminal facilities and chemical plants located on the shores of these waterways correspond with the incidents reported to the USCG National Response Center. The predominance of petroleum products as the major category of substances released to Newark Bay is consistent with other industrial and commercial ports. In San Francisco Bay, 99% of the spilled material reported to the USCG between 1978 and 1980 was comprised of petroleum compounds (Ritschard *et al.*, 1981).

Normal shipping operations, ship accidents, and bilge discharges during routine terminal operations make marine transport of chemical and petroleum products an important source of chemical pollution in the marine environment (NOAA, 1984). Accidental chemical spills have been demonstrated to result in a range of adverse impacts to aquatic marine organisms including mortality, reproductive impairment, depressed growth rates, and increased susceptibility to infectious and noninfectious diseases (Guzman *et al.*, 1991; Harding *et al.*, 1991; Bourodimos and Carvounis, 1990; Pople *et al.*, 1990; U.S. EPA, 1986). Bottom fish and shellfish from several heavily industrialized coastal harbors have been reported to exhibit gross pathological abnormalities, including liver lesions, fin erosion, and shell disfigurements (McCain *et al.*, 1992; O'Connor and Huggett, 1988; Mix, 1986; Carpenter, 1981). Marine larvae appear to be especially sensitive to chemical pollution: petroleum concentrations as low as 0.1 ppm have been shown to be acutely toxic (U.S. EPA, 1986). Small quantities of crude oil mixed with seawater have been shown to effect the feeding behavior of fish and shellfish (Connell and Miller, 1980; Atema and Stein, 1974). The aliphatic and polycyclic aromatic hydrocarbon fractions of dissolved petroleum products are readily absorbed by most aquatic organisms due to their high lipid solubility (Vandermeulen *et al.*, 1985; Varanasi and Malins, 1977). These and other toxic effects are dependent on many factors, including the chemical composition, partitioning properties, bioavailability, bioaccumulation, and toxicity of the chemical mixture and its constituents (Connell and Miller, 1980, 1981).

Although extensive research has not been conducted to correlate contaminant inputs with observed biota effects in the NY/NJ Harbor Estuary, several recent studies have investigated the potential petroleum-related impacts (Arnold *et al.*, 1991; Khan *et al.*, 1991; O'Connor *et al.*, 1991; NOAA 1991a,b). A study of birds collected from the Arthur Kill following the January 1990 spill of 567,000 gallons of fuel oil concluded that half of the observed mortalities were spill related (O'Connor *et al.*, 1991). A decrease in growth at one of three test sites and impaired sexual maturity at two of three test sites was observed in mysid shrimp (*Mysidopsis bahia*) collected from the Arthur Kill as part of an evaluation of the chronic effects from a spill (Khan *et al.*, 1991). Several researchers have noted declines in fish populations, lower species diversity, and a prevalence of infectious and noninfectious diseases that may be associated with anthropogenic contamination (NJMSC, 1987; Pearce, 1987; Moser, 1990). Extensive fin erosion in bottom-feeding fish has been observed throughout the estuary and is suspected to be related to petroleum contaminated sediments (Cali, 1988). Several diseases associated with environmental degradation, including lymphocystis,

ulcers, and microsporidiosis in finfish, and shell disease among anthropods have been reported in fish and shellfish collected from the estuary (Cali, 1988).

The significance of petroleum and hazardous chemical spills on the integrity of the Newark Bay ecosystem can be difficult to discern, particularly the long-term impacts from chronic, low-level releases (Arnold *et al.*, 1991; Khan *et al.*, 1991; Nakatani and Nevissi, 1991; Pelletier *et al.*, 1991; Feder *et al.*, 1990; Peckol *et al.*, 1990; Dauvin, 1989; Williams *et al.*, 1988; Bunch, 1987; Snowden and Ekweozor, 1987; Carpenter, 1981; Ritschard *et al.*, 1981; Webb *et al.*, 1981). The impacts of a No. 6 Fuel Oil spill (875,000 gallons) near Grays Harbor, Washington, and a No. 2 Fuel Oil spill (4 million gallons) near Bourne, Massachusetts, to intertidal biota were still measurable 3 years later (Hampson and Moul, 1978; Harding *et al.*, 1991). Recent studies of freshwater ecosystems indicate that petroleum spills stimulate benthic microorganisms, which increases oxygen consumption and nutrient utilization, and thereby impose additional stresses on fish and shellfish (Werner *et al.*, 1985). Responses of benthic macroinvertebrate communities to petroleum spills typically include elimination of entire species and reduced community diversity (Hampson and Moul, 1978; Connell and Miller, 1980, 1981; Harrel, 1985; Snowden and Ekweozor, 1987).

Attempts to discern biological effects from oil spills are confounded by the fact that many coastal estuaries are already highly contaminated (McCain *et al.*, 1992; O'Connor and Huggett, 1988; Mix, 1986; Carpenter, 1981). For example, geochemical fingerprint analyses conducted on sediments collected from the Mersey Estuary, United Kingdom, and in San Francisco Bay, California, following oil spills were complicated by the degraded nature of the oil and the similarities of the remaining constituents to those already present in the sediments from anthropogenic petroleum contamination, pyrogenic sources, and urban drainage (Hostettler *et al.*, 1992; Davies and Wolff, 1990). In the Mersey Estuary, United Kingdom, evidence of minimal impact to benthic organisms was noted due to the presence of exceptionally high background levels of residual petroleum hydrocarbons in sediments (Davies and Wolff, 1990). A recent study of sediment toxicity and benthic populations following a No. 2 Fuel Oil spill in the Arthur Kill concluded that historical contamination of these sediments had severely impacted the benthic community structure prior to the oil spill (Arnold *et al.*, 1991).

CONCLUSION

A review of records from the NJDEPE Bureau of Communication and Support database indicates that the petroleum products spilled into Newark Bay and its tributaries between 1986 and 1991 represent a significant recurring source of chemical contamination. More than 18,362,046 gallons of hazardous materials were released in the 5-year period. The majority of the spilled material was comprised of two types of fuel oil, No. 2 Fuel Oil and No. 6 Fuel Oil, which have been shown to be toxic to marine life. Petroleum hydrocarbons represent one of the greatest threats to estuarine systems due to their tendency to bioconcentrate in fish and shellfish and chronic toxicity to marine biota. The water bodies most often impacted included the Arthur Kill, Woodbridge Creek, and Sandy Hook Bay. A significant amount of petroleum has also been introduced to Newark Bay through municipal wasterwater treatment facilities; nearly 220,000 gallons of diesel fuel and 201,000 gallons of various petroleum products have been discharged into sewers since 1986. The toxicity of these compounds to microorganisms can effect the efficiency and capacity of biologically based treatment

facilities to handle other chemical inputs. The available evidence on the impact of petroleum and hazardous chemical spills in Newark Bay suggests that the average annual release of approximately 3.5 million gallons of petroleum products is having a significant adverse impact on this aquatic ecosystem. Although few reliable records of chemical accidents are available prior to the last few decades, past observations of contaminated fish (Talbot, 1954) suggest that releases of these materials were likely greater during the time period preceding this analysis.

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