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PETROLEUM AND HAZARDOUS CHEMICAL SPILLS IN NEWARK BAY, NEW JERSEY, USA FROM 1982 TO 1991

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Abstract

Newark Bay, New Jersey, is particularly vulnerable to ecological damage from petroleum and chemical spills, as a result of the enclosed nature and shallow depth of the bay, the high frequency of shipping traffic, and the numerous chemical and petroleum transfer terminals located along its shores. To evaluate the potential impacts to the natural resources of this coastal estuarine ecosystem, chemical and petroleum accidents reported to the US Coast Guard (USCG) between 1982 and 1991 were compiled to determine the frequency and volume of these incidents in Newark Bay and in each of its major tributaries. Records obtained from the USCG National Response Center's computerized database indicated that more than 1453 accidental incidents, resulting in the release of more than 18 million US gallons of hazardous materials and petroleum products, occurred throughout Newark Bay during this period of time. The bulk of the materials released to the aquatic environment consisted of petroleum products, specifically No. 6 Fuel Oil (103 spills, 12 829 272 US gal) and gasoline (207 spills, 48 816 US gal). The majority of the reported incidents occurred in the Arthur Kill and its tributaries, as well as in the Kill Van Kull and the Passaic River. The results of this study indicated that the accidental discharge of petroleum and hazardous chemicals represents a significant source of chemical pollution in Newark Bay. Based on the frequency of spills and the volume of materials released to the aquatic environment, it is likely that these events are having a deleterious effect on the Newark Bay ecosystem.

Keywords: petroleum accidents, chemical spills, fuel oil, marine pollution, Newark Bay.

INTRODUCTION

The accidental discharge of hazardous materials such as petroleum and chemical solvents to the aquatic environment has become the focus of increasing regulatory and public concern because of the adverse impacts of such materials on human health and the environment (Ritschard *et al.*, 1981; National Oceanic and Atmospheric Administration (NOAA), 1982; PTI Environmental Associates, 1989; Bourodimos & Carvounis, 1990). From an ecological perspective, such releases are significant because of their instantaneous nature; when a chemical spill occurs, there is little time for dilution before initial acute affects are manifested in sedimentary biota, fish, and waterbirds.

Studies conducted in the past decade have shown that accidental chemical and petroleum spills can impose a wide range of adverse impacts on aquatic marine organisms, including mortality, reproductive impairment, depressed growth rates, and increased susceptibility to infectious and non-infectious diseases (US Environmental Protection Agency (USEPA), 1986; Bourodimos & Carvounis, 1990; Pople *et al.*, 1990; Guzman *et al.*, 1991; Harding *et al.*, 1991). Bottom fish and shellfish collected from several industrialized coastal waterways have been reported to exhibit gross pathological abnormalities, including liver lesions, fin erosion, and shell disfigurements (Carpenter, 1981; Mix, 1986; O'Connor & Huggett, 1988; McCain *et al.*, 1992). Petroleum concentrations as low as 0·1 ppm have been shown to be acutely toxic to marine larvae (USEPA, 1986), and small quantities of crude oil mixed with seawater have been shown to affect the feeding behavior of fish and shellfish (Atema & Stein, 1974; Connell & Miller, 1980). The elimination of entire species and reductions in biotic diversity have typically been observed among benthic macroinvertebrate communities subjected to petroleum spills (Hampson & Moul, 1978; Connell & Miller, 1980, 1981; Harrel, 1985; Snowden & Ekweozor, 1987). These and other toxic effects are dependent on many factors, including the chemical composition, partitioning properties, bioavailability, bioaccumulation and the toxicity of the chemical mixture and its constituents (Connell & Miller, 1980, 1981).

In addition, many of the chemicals and petroleum products typically involved in accidental spills are long-lived in the environment. The aliphatic and polycyclic aromatic hydrocarbon fractions of dissolved petroleum are readily absorbed by most aquatic organisms because of their high lipid solubility and are bioconcentrated in fish and shellfish (Varanasi & Malins, 1977; Vandermeulen

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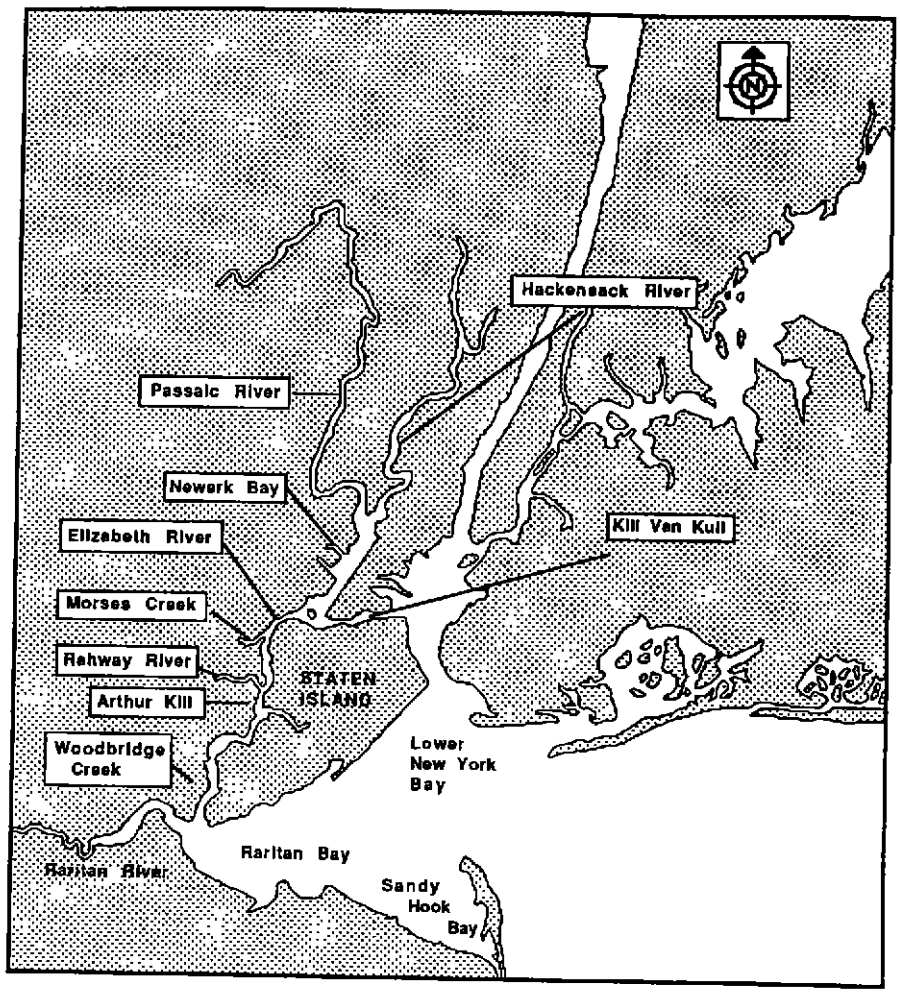


Fig. 1. Study area.

et al., 1985). These compounds tend to accumulate in sediments, thereby posing a chronic threat to aquatic organisms long after the acute initial effects of the spill have abated (O'Connor & Huggett, 1988).

Newark Bay, New Jersey, along with its tributaries and associated wetlands, is one of the world's largest urbanized and industrialized estuarine systems. Newark Bay is a small and enclosed coastal port, with a natural water depth of approximately 19 feet. As a result of considerable dredging during the past 75 years to maintain a shipping channel of 35-foot depth, Newark Bay now functions as a major commercial port supporting numerous industries, including crude oil refineries, chemical manufacturing, and the transport of refined petroleum and chemical products (Tavolaro & Freeman, 1990). The Port of New York/New Jersey (Fig. 1) is responsible for handling more general and containerized cargo than any other port in the USA (Tavolaro & Freeman, 1990). Commerce data for 1984 indicated that the Port handled 161 million US tons of containerized and bulk cargo (RPI, 1989); 76% of these materials were petroleum products (123 million US tons) and 2% were other hazardous chemicals (3·35 million US tons) (RPI, 1989).

Because of the large volume of chemical and petroleum commerce, normal shipping operations and bilge discharges during routine terminal operations suggest that marine transport of chemical and petroleum products is an important source of chemical pollution in the marine environment (NOAA, 1984). Several studies have suggested that the environmental degradation of Newark Bay attributable to petroleum and hazardous chemical spills has been significant (NOAA, 1982; Grassle, 1990; Mueller, 1990; Suszkowski *et al.*, 1990). As part of a continuing investigation of the sources of chemical pollution in Newark Bay, the frequency and volume of petroleum and hazardous spills reported between 1982 and 1991 were summarized from computerized database records maintained by the US Coast Guard (USCG) National Response Center. The potential short-term and long-term ecological impacts of chemical spills in Newark Bay are also discussed.

METHODS

Records of all incidents reported between 1982 and 1991 which involved the discharge of hazardous materials within the navigable channels, shipping terminals, anchorages, and tributaries of Newark Bay were queried from the USCG National Response Center database. The area of interest extended from approximately 40°30' to 40°44' N and from 74°05' to 74°10' W.

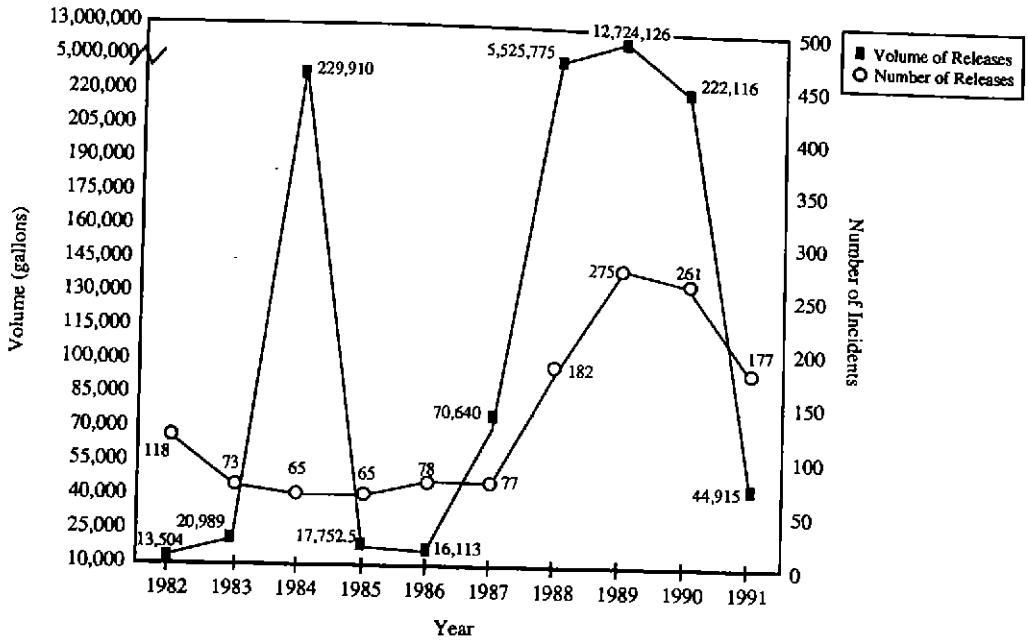


Fig. 2. Total volume and frequency of petroleum products and hazardous chemicals annually released into the Newark Bay Estuary between 1982 and 1991.

Each reported incident was categorized according to the chemical involved and quantity released, the receiving water body, the date of release, and the suspected source. Data were summarized for the entire study area, as well as for specific waterways within Newark Bay, including the Passaic River, Arthur Kill, Elizabeth River, Morses Creek, Hackensack River, Kill Van Kull, and Rahway River. Incidents reported for minor tributaries were included within the larger receiving waterways.

The USCG records were standardized with respect to the descriptive terminology before data analysis. To quantify the volume of materials released, records were grouped according to three general categories: 'petroleum products', 'hazardous chemicals', and 'other'. The 'other' category referred to unidentified, or infrequently spilled materials such as industrial wastewater, ink, and paint 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 was quantified. A subcategory designated 'oil other' was used to classify discharges of petroleum products that were identified in the USCG database as fuel oil, miscellaneous oil, or oil unknown, as well as infrequently released petroleum products such as crude oil and lubricating oil.

The database records also were standardized (in US gallons) with respect to the quantity of material released to Newark Bay. For cases in which spill volumes were reported in units of mass (e.g. pounds or kilograms), the quantity was converted to gallons based on the assumption that the average specific density of all petroleum products was 0·90 g/cm^3. In cases where spill volumes were reported as a range, the quantity released was assumed to be equivalent to the larger value. In several of the database records, the volume of an accidental spill was identified as unknown or estimated as 'several drums' or a 'sheen'. In the absence of an estimate of the total volume of hazardous chemical or petroleum involved in the incident, the spill volume was designated as not quantifiable.

RESULTS

National Response Center records indicated that at least 1453 accidental incidents, resulting in the release of 18 885 790 US gallons of hazardous materials and petroleum products, were reported throughout Newark Bay from 1982 to November 1991 (Fig. 2). This was equivalent to an average daily discharge into Newark Bay of approximately 3600 US gal during that 10 year span. This figure was based on those incidents where the volume of the chemical spill was known. Nearly 50% of the incidents reported to the USCG did not identify the volume of material released to the environment. Furthermore, chemical releases suspected to have occurred in the region as a result of illegal dumping and permit discharge violations were not included in the database. Therefore, the number of spill events and the actual volume of chemicals released during this time period is likely to have been substantially larger than reported to the USCG.

The annual number of incidents and the total volume of spilled materials for each waterbody are summarized in Table 1. In 1991, 177 accidental releases, involving approximately 45 000 US gal of hazardous chemicals and petroleum, were reported in Newark Bay. The largest number of incidents occurred in 1989, during which 275 accidents resulted in the release of more than 12 million US gal of potentially hazardous chemicals. It is apparent that the number of accidental

Table 1. Number of petroleum and chemical spills in the Newark Bay Estuary reported to the US Coast Guard National Response Center between 1982 and 1991[a]

Receiving water	1982		1983		1984		1985		1986	
	No. of incidents	Total volume (US gal)	No. of incidents	Total volume (US gal)	No. of incidents	Total volume (US gal)	No. of incidents	Total volume (US gal)	No. of incidents	Total volume (US gal)
Arthur Kill	61	2 782	41	8 324	26	217 306	27	2 845 5	20	1 178
Elizabeth River	1	95	3	1 000	0	—	1	—	0	—
Hackensack River	2	63	3	5 300	4	801	2	20	3	1 500
Kill Van Kull	7	375	2	15	5	2 186	5	243	4	—
Morses Creek	0	—	0	—	0	—	0	—	0	—
Newark Bay	3	90	6	348	4	5 044	2	284	1	10
Passaic River	4	345	4	40	7	1 020	7	473	13	8 160
Rahway River	0	—	0	—	1	10	1	—	3	110
Woodbridge Creek	10	83	0	—	0	—	1	100	0	—
Unknown location[b]	22	2 525	4	480	10	375	11	138	20	3 600
Sewer[c]	8	7 146	10	5 482	9	3 168	8	13 649	14	1 555

Receiving water	1987		1988		1989		1990		1991[d]	
	No. of incidents	Total volume (US gal)	No. of incidents	Total volume (US gal)	No. of incidents	Total volume (US gal)	No. of incidents	Total volume (US gal)	No. of incidents	Total volume (US gal)
Arthur Kill	29	51 456	87	13 698	118	12 612 596	124	15 349	69	16 600
Elizabeth River	0	—	3	200	1	84	0	—	3	20
Hackensack River	3	100	9	5 504 500	16	59 450	13	660	4	1 500
Kill Van Kull	10	168	18	1 177	50	37 427	52	1 982	37	3 339
Morses Creek	0	—	2	3 101	4	42	1	1	0	—
Newark Bay	4	NQ[e]	10	1 097	18	1 025	14	23	16	3 506
Passaic River	10	15 210	20	357	11	NQ	8	10	11	310
Rahway River	1	50	5	NQ	2	NQ	3	50	0	—
Woodbridge Creek	2	30	2	12	2	NQ	2	126	1	NQ
Unknown location[b]	5	140	9	110	22	1 912	7	22	11	392
Sewer[c]	13	3 486	17	1 523	31	11 590	37	203 893	25	19 248

[a] Total volumes reflect only those spills that were reported. Actual volumes are likely to be higher.
[b] The location of the spill incident was not reported in the USCG database.
[c] The USCG database identified municipal and industrial rivers as the ultimate receiving waterways for these spill incidents.
[d] Data for 1991 include all spills occurring on or before 24 November 1991.
[e] NQ indicates that the volume of the reported spills was not quantified.

releases is not a good indicator of the volume of material introduced to the environment. For example, the number of incidents reported in 1989 (275 releases) was similar to that reported in 1990 (261 releases), yet the volume of material released in 1989 exceeded the amount released in 1990 by more than 12 million US gal (Fig. 2).

Petroleum products constituted the majority of materials released to Newark Bay, comprising approximately 70% (13 185 743 US gal) of the total volume of spilled materials (Table 2). On average 1·3 million US gal of petroleum products were released throughout Newark Bay annually between 1982 and 1991. Of the petroleum products released, 97% of the total volume discharged to the estuary over the 10-year period was No. 6 Fuel Oil. For example, records for 1991 indicated that the majority of petroleum products released into the estuary consisted of No. 6 Fuel Oil (approximately 17%) and gasoline and diesel fuel (67%). Chemical spills constituted only 7% of all spill accidents and less than 1% (84 414 US gal) of the total volume of materials reported to the USCG between 1982 and 1991. Among the hazardous chemicals identified in this category, solvents represented 4·4%, acids represented 41%, and various chemical products represented 55% of the total volume of spilled material.

Although the majority of spills reported were relatively small in size, more than 50 incidents involved spill volumes exceeding 1000 US gal (Table 3). The majority of petroleum and chemical spills (13 212 875 US gal) occurred in marine ship traffic lanes located on the Arthur Kill and the Kill Van Kull (Fig. 3). A significant volume of petroleum products reportedly entered municipal sewer systems (Fig. 3). From 1986 to 1991, over 219 545 US gal of diesel fuel and 200 821 US gal of oils (classified in this analysis as 'other') were released to Newark Bay from municipal and industrial wastewater treatment facilities.

DISCUSSION

The ecological degradation of Newark Bay as a result of chemical contamination has been recognized by researchers for more than a century (Meyerson *et al.*,

Table 2. Summary of petroleum and chemical spills in Newark Bay exceeding 1000 US gallons[a]

Quantity (US gal)	Material	Site or facility	Waterway	Date
12 600 000	No. 6 Fuel Oil	Northville Linden	Arthur Kill	7/89
5 000 000	Other	Rockland County Sewer District	Hackensack River	5/88
500 000	Cooling water	Henkel	Unknown[b]	2/88
210 000	No. 6 Fuel Oil	Mobile	Arthur Kill	9/84
200 000	Oil other	General Motors	Sewer	2/90
30 000	Sodium phosphate	FMC Corp.	Arthur Kill	8/87
30 000	No. 2 Fuel Oil	NR[c]	Kill Van Kull	5/89
25 000	Other	Merck and Co.	Hackensack River	3/89
20 000	Acid	FMC Corp.	Arthur Kill	6/87
15 000	Other	NR[c]	Hackensack River	10/89
15 000	Transformer oil	Public Service Electric and Gas	Passaic River	6/87
13 000	Monosodium phosphate	FMC Corp.	Sewer	6/85
8 000	Gasoline	USEPA Region II	Passaic River	12/86
7 800	Diesel fuel	NR[c]	Hackensack River	2/89
7 500	Diesel fuel	NR[c]	Hackensack River	2/89
5 300	Gasoline	Exxon Corporation	Hackensack River	3/83
5 190	Other	Anheuser–Busch	Sewer	9/89
5 000	Methyl ethyl ketone	Exxon Chemical	Arthur Kill	6/83
5 000	Gasoline	NR[c]	Arthur Kill	5/90
5 000	Other	Badische Corp.	Sewer	10/82
4 500	Acid	American Cyanamid	Arthur Kill	11/88
4 480	Other	Archer Daniel Midland	Unknown	10/83
4 200	Jet fuel	NR[c]	Arthur Kill	9/90
4 200	No. 2 Fuel Oil	NR[c]	Kill Van Kill	5/89
4 000	Other	Matheson Gas and Electric	Hackensack River	8/89
3 500	Other	Public Service Electric and Gas	Hackensack River	3/88
3 150	No. 6 Fuel Oil	Amarada Hess	Arthur Kill	3/89
3 100	Other	General Motors	Morses Creek	12/88
3 000	Sodium hydroxide	Dana Transport, Inc.	Unknown	4/86
2 627	Toluene	American Cyanamid	Arthur Kill	7/84
2 600	Oil unknown	NR[c]	Arthur Kill	5/88
2 600	Acid	Matheson Gas Products, Inc.	Sewer	7/87
2 520	No. 6 Fuel Oil	Northville Industries	Arthur Kill	4/84
2 100	Gasoline	IMTT	Kill Van Kill	4/91
2 100	No. 2 Fuel Oil	Edgerley and Gison, Inc.	Sewer	2/82
2 000	No. 2 Fuel Oil	NR[c]	Arthur Kill	6/88
2 000	Other	Bayonne Terminal	Kill Van Kull	11/89
2 000	No. 6 Fuel Oil	NR[c]	Newark Bay	4/91
2 000	Oil other	General Foods USA	Sewer	6/90
1 680	No. 2 Fuel Oil	Eklof	Unknown	10/89
1 500	Solvent	NJDEP	Arthur Kill	2/83
1 500	No. 2 Fuel Oil	Wolf Realty	Hackensack River	11/86
1 500	No. 6 Fuel Oil	NR[c]	Sewer	5/91
1 500	Diesel Fuel	Kelly Hart and Hallman	Unknown	1/91
1 470	Fuel Oil	NR[c]	Newark Bay	10/91
1 450	No. 6 Fuel Oil	Koppers Industries	Sewer	7/89
1 400	Diesel fuel	NR[c]	Kill Van Kull	7/90
1 400	No. 4 Fuel Oil	Vista Management, Inc.	Sewer	5/91
1 190	Acid	American Cyanamid	Arthur Kill	1/84
1 081	Acid	American Cyanamid	Unknown	7/82
1 050	No. 2 Fuel Oil	Texaco, Inc.	Arthur Kill	10/82
1 000	Acid	Exxon Chemical	Arthur Kill	7/83
1 000	Acid	Merck and Co.	Arthur Kill	8/85
1 000	Gasoline	Crown Central Petroleum	Arthur Kill	11/85
1 000	Oil other	NR[c]	Arthur Kill	12/89
1 000	Gasoline	NR[c]	Arthur Kill	3/90
1 000	Other	Bristol Myers	Elizabeth River	6/83
1 000	Other	NR[c]	Newark Bay	3/88
1 000	Other	Marcal Paper Mills	Passaic River	11/84
1 000	No. 6 Fuel Oil	Hoffman la Roche, Inc.	Sewer	12/89

[a] Data recorded in the USCG database between 1982 and 1991.
[b] The specific waterway was not identified in the USCG database.
[c] Responsible party was not reported in the database.

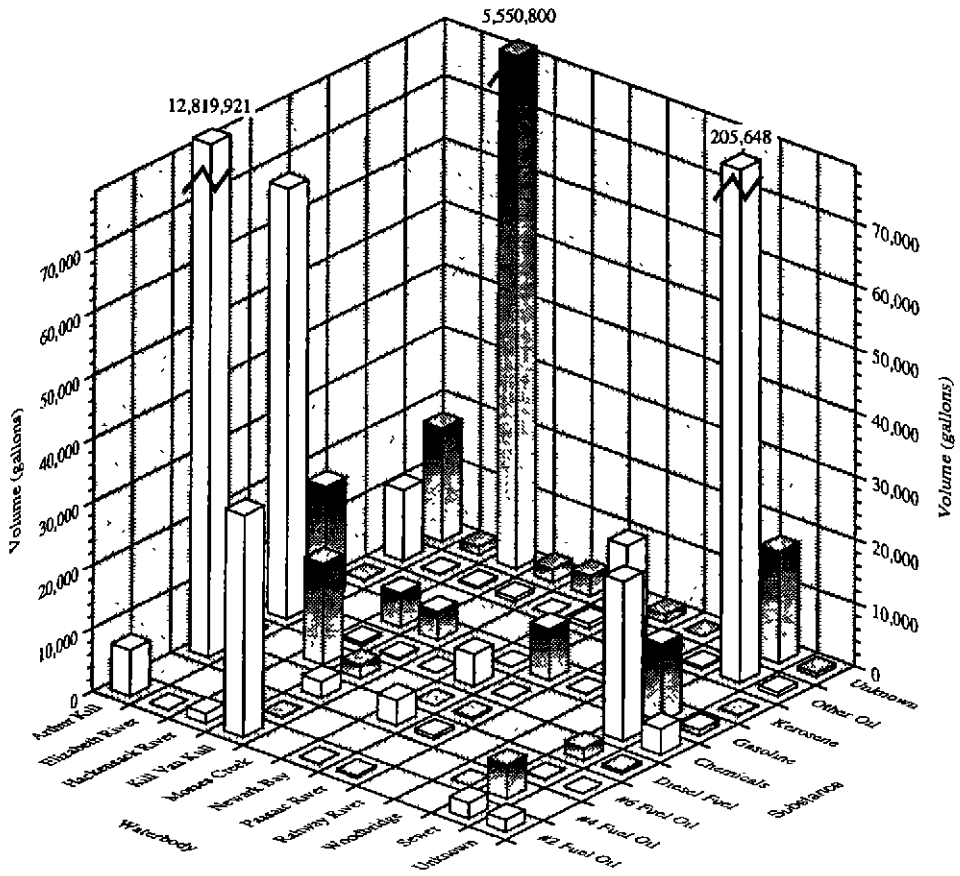


Fig. 3. Total volume of petroleum products and hazardous chemicals released to selected waterways within the Newark Bay Estuary between 1982 and 1991.

1981; Franz, 1982; NOAA, 1984). A decline in shad fish catches in the Passaic River was attributed to chemical pollution as early as 1885 (Esser, 1988). Industrial wastes discharged into Raritan Bay more than fifty years ago resulted in declines in shellfish populations (NOAA, 1988). The Interstate Sanitation Commission (ISC), representing the states of New York, New Jersey, and Connecticut, reported in 1949 that pollution from oceangoing ships and small pleasure boats was a significant environmental concern (ISC, 1949). In 1954, Talbot (1954) reported that shad collected from the lower Hudson River tasted like gasoline and kerosene.

The degradation of Newark Bay is attributable to a variety of anthropogenic sources, as well as the cumulative impacts of historical industrial and shipping activities (NOAA, 1984). Marine transportation, in particular, is considered an important source of petroleum to the estuary (NOAA, 1984). Within the USCG district responsible for the Port of New York/New Jersey, 152 marine facilities are involved in the transfer, storage, or processing of petroleum products and chemicals (RPI, 1989). Among the 110 shipping terminal facilities (60 petroleum facilities, 37 chemical facilities, and 13 container facilities) located in the Newark Bay estuary, 19 petroleum facilities are located on the Arthur Kill and a majority have storage capacities greater than 1 million barrels (RPI, 1989). Among the 33 shipping terminals located along the Passaic River and Hackensack River, 27 facilities are petroleum terminals (RPI, 1989). Not surprisingly, the locations of terminal facilities and chemical plants on the shores of these waterways correspond to several accidental chemical and petroleum spills 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. For example in San Francisco Bay, nearly all of the spilled material reported to the USCG between 1978 and 1980 consisted of petroleum compounds (Ritschard *et al.*, 1981).

Newark Bay is particularly vulnerable to the effects of a large petroleum or chemical spill due to its small size and enclosed nature. Considering the predominantly north–south tidal circulation patterns, it has been claimed that the chemical constituents from a large spill could be easily confined to the estuary and distributed throughout Newark Bay during one complete tidal cycle (RPI, 1989). A single predominant wind pattern does not appear to exist in Newark Bay; wind patterns are strongly influenced by season and maximum wind velocities are usually less than 34 mph (Suszkowski, 1978; RPI, 1989). Consequently, tidal flushing and wind-generated currents are the principal mechanisms for dilution of the chemical concentrations of a large petroleum or chemical spill.

Table 3. Total volumes of petroleum products and hazardous chemicals (US gal) accidentally discharged to Newark Bay and its major tributaries from 1982 to 1991 as reported by the US Coast Guard National Response Center[a]

Material	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991[b]	Total volume
Petroleum products											
No. 1 Fuel Oil		15	100								115
No. 2 Fuel Oil	3 939	122	76	792	2645	156	2 940	36 726	573	520	48 489
No. 4 Fuel Oil	5							40		2 900	2945
No. 6 Fuel Oil	445	215	214 788	8	10	23	912	12 607 910	1 083	3 878	12 829 272
Asphalt	42			210			42				294
Crude oil						30					30
Diesel fuel	450	195	20	103	105	155	440	15 919	2 673	1 180	21 240
Gasoline	555	6 052	97	1 181	8 235	1 320	4 128	5 325	7 554	14 369	48 816
Hydraulic oil							6	125	23		154
Jet fuel							66	40	4 300	30	4436
Kerosene	22						10	41			73
Motor oil	0·1					3	6				9
Oil other	637	568	5	150	112	76	397	1 463	203 059	366	206 833
Oil unknown	1 230		3 292	353	165	21	2 850	463	544	70	7888
Transformer oil						15 000	109	40			15 149
Subtotal	6 225	7 167	218 378	2 797	11 272	16 784	11 906	12 668 092	219 809	23 313	13 185 743
Hazardous chemicals											
Acids	1 381	1 000	1 290	1 150	20	22 700	5 158		1 310	375	35 384
Chemicals	201	5 000	2 627	50	3 000	30 150	570	1 417	210	3 080	46 305
Polychlorinated biphenyls		40		10							50
Solvents	500	1 500			1 400				125	150	3675
Subtotal	2 082	7 540	3 917	1 210	4 420	52 850	5 728	1 417	1 636	3 605	84 414
Other											
Other	5 205	5 776	7 605	13 305	415	905	5 507 856	54 615	657	17 796	5 614 135
Unknown		500	10	442	5	100	240			201	1498
Subtotal	5205	6 276	7 615	13 747	420	1 005	5 508 096	54 615	657	17 997	5 615 633
Total	13 512	20 983	229 910	17 754	16 112	70 639	5 525 730	12 724 124	222 111	44 915	18 885 790·1

[a] Total volumes reflect only those spills that were reported. Actual volumes are likely to be higher.
[b] Data for 1991 include all spills occurring on or before 24 November 1991.
[c] The composition of the material spilled was not reported in the USCG database.

Although extensive research has not been conducted to correlate chemical inputs with observed effects on biota in the New York/New Jersey 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). A study of birds collected from the Arthur Kill after the January 1990 spill of 567 000 US gal of fuel oil concluded that half of the observed mortalities were spill related (O'Connor *et al.*, 1991). A decrease in the growth potential at one of three test sites and impaired sexual maturity at two of three test sites were 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 non-infectious diseases that may be associated with anthropogenic contamination (New Jersey Marine Sciences Consortium (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; Esser, 1988). Several diseases associated with environmental degradation have been reported in fish and shellfish collected from the estuary, including lymphocytosis, ulcers, and microsporidiosis in finfish, and shell disease among arthropods (Cali, 1988).

The significance of petroleum and hazardous chemical spills on the integrity of estuarine ecosystems is difficult to ascertain, particularly the long-term impacts from chronic, low-level chemical discharges (Carpenter, 1981; Ritschard *et al.*, 1981; Webb *et al.*, 1981; Snowden & Ekweozor, 1987; Williams *et al.*, 1988; Dauvin, 1989; Peckol *et al.*, 1990; Arnold *et al.*, 1991; Khan *et al.*, 1991; Pelletier *et al.*, 1991). For example, the impacts of a No. 6 Fuel Oil spill (875 000 US gal) near Grays Harbor, Washington, and a No. 2 Fuel Oil spill (4 million US gal) near Bourne, Massachusetts, on intertidal biota were still measurable 3 years after the accidents occurred (Hampson & Moul, 1978; Harding *et al.*, 1991). In contrast, there were few adverse effects on lobster populations after a spill of 27 500 US gal of light crude oil in Placentia Bay, Newfoundland (Williams *et al.*, 1988). Recent studies in freshwater ecosystems suggest that petroleum spills stimulate oxygen consumption and nutrient utilization by benthic microorganisms, thereby placing additional stresses on fish and shellfish higher in the food chain (Werner *et al.*, 1985). In more severe cases, petroleum spills typically result in the elimination of entire species of benthic macroinvertebrates and reduce community diversity (Hampson & Moul, 1978; Connell &

Miller, 1980, 1981; Harrel, 1985; Snowden & Ekweozor, 1987).

Attempts to discern biological effects from oil spills are confounded by the fact that sediments in many coastal estuaries are already contaminated (Carpenter, 1981; Mix, 1986; O'Connor & Huggett, 1988; McCain *et al.*, 1992). For example, geochemical fingerprint analyses conducted on sediments collected from the Mersey Estuary, UK, and in San Francisco Bay, California, after 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 (Davies & Wolff, 1990; Hostettler *et al.*, 1992). In the Mersey estuary, some effects on benthic organisms were attributable to the presence of exceptionally high background levels of petroleum hydrocarbons in sediments (Davies & Wolf, 1990). Also, in a recent study of sediment toxicity and benthic populations after a No. 2 Fuel Oil spill in the Arthur Kill, Arnold *et al.* (1991) concluded that historical contamination of the sediments had severely affected the benthic community structure before the incident.

CONCLUSION

A review of records from the USCG National Response Center database indicates that petroleum releases to the Newark Bay estuary between 1982 and 1991 represent a significant recurring source of chemical contamination. More than 18 million US gal of hazardous chemicals have been released in the past decade. The majority of the spilled materials consisted of No. 6 Fuel Oil, No. 2 Fuel Oil, and gasoline, all of which have been shown to be toxic to aquatic organisms. Petroleum hydrocarbons represent a significant threat to biota because of their chronic toxicity and potential for bioconcentration in fish and shellfish. The Arthur Kill, Passaic River, and Hackensack River have been the areas most affected by the discharge of hazardous chemicals and petroleum products during the past 10 years. A significant source of petroleum to Newark Bay appears to be municipal and industrial wastewater treatment facilities; more than 600 000 US gal of petroleum products have been discharged since 1982. The available evidence on the effect of petroleum and hazardous chemical spills in Newark Bay suggests that the average annual release of approximately 1·3 million US gal combined with high background levels resulting from historical and current industrial and municipal activities, is having a significant adverse impact on the aquatic ecosystem.

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