PETROLEUM HYDROCARBONS IN THE
HUDSON-RARITAN ESTUARY
A REVIEW

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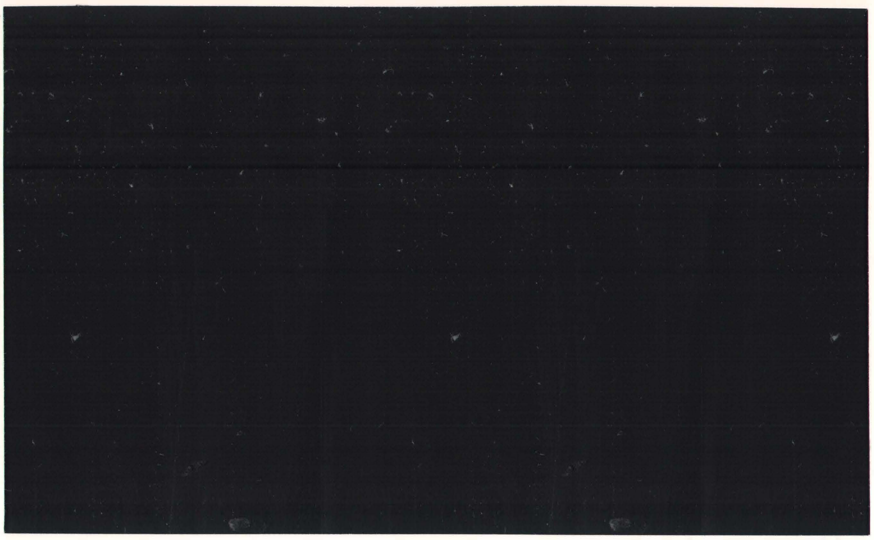

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Summary

The sources for petroleum hydrocarbon discharges to the Hudson Raritan estuary were identified and quantified according to the available information. Similarly losses to the system were quantified allowing an overall budget to be developed. The possible effects of existing concentrations of petroleum hydrocarbons in water and sediments on plankton, benthic invertebrates, fish and birds were evaluated. The importance of petroleum hydrocarbons in seafood to public health was assessed.

INTRODUCTION

Pollution of the sea due to petroleum can arise from a wide variety of sources (see Table 1). These can be divided into three broad categories:

1. Extraction and transport of petroleum products in marine areas
2. Atmospheric deposition
3. Land--based discharges and dumping
4. Natural seeps.

Table 1 lists the attempts to quantify petroleum inputs into the oceans and the estimate of 6.11 x 10^6 tonnes/year by NAS (1975) is generally considered the most accurate. Although tanker accidents and spills arising from other sources are important, many other less obvious sources of petroleum are quantitatively equally important. Urban run-off, municipal wastes and atmospheric deposition have been identified as significant in this group. In addition, it is noteworthy that pollution from the sources identified is not uniformly distributed throughout the oceans but tends to be concentrated in oil ports, harbors, shipping lanes and urban areas. Petroleum products are chemically and physically diverse and the fate and effects can be correspondingly different but the data indicates that quantitatively petroleum hydrocarbons are probably the major toxic organic pollutant discharged to the oceans.

The general effects of oil pollution on marine life have been summarized by GESAMP (1977) as follows:

1. Lethal toxic effects, where the components of the oil interfere with cellular and subcellular processes in the organism to such an extent that death follows directly.

2. Sublethal effects that disrupt physiological or behavioral activities but do not cause immediate death, although this may follow because of interference with feeding and reproductive activities or other abnormal behavior, greater risks of predation or other indirect causes.

3. Direct uptake of the oil, or certain fractions of it, by the organism causing tainting or, in some cases, cancers.

4. Possibly the initiation of a sequence whereby the pollutant is transferred to other members of the food web causing them to be unfit for consumption by other animals including man.

5. Direct smothering and suffocation or interference with movements to obtain food or escape predators as a result of being coated by oil.

6. Alterations to the chemical and physical habitat which result in changes in the populations of individual species as well as shifts in species composition and diversity.

In addition, oil pollution can directly affect man in a number of ways. The health hazards associated with contaminated food organisms and domestic water are yet to be fully evaluated (Connell and Miller, 1981). Recreation areas can be severely damaged through contamination of beaches, boats and so on.

Commercial fishing in some areas has been damaged due to tainting of fish stocks (Connell and Miller, 1981) and the inability of fishermen to operate gear in oil slick affected areas.

The MESA New York Bight Project (NOAA, 1978, O'Connor and Stanford, 1979) has identified contaminants of major significance in the Bight. This resulted in the designation of polynuclear aromatic hydrocarbons (PAHs) as major threats which require continued study. This suggests that petroleum hydrocarbons (PHCs) and in particular, PAHs, are of considerable importance in the adjacent Hudson-Raritan estuary.

Significant oil pollution dates from the 1920's when comparatively large numbers of oil burning ships began plying the world's sealanes. In 1922 Britain passed an act to control water pollution by oil and two years later the United States passed a similar act. Since that time numerous local, state, national and international laws and conventions have been formulated.

ENVIRONMENTAL CHEMISTRY OF PETROLEUM HYDROCARBONS

Crude petroleum is an extremely complex mixture consisting of hydrocarbons together with low concentrations of related substances containing sulphur, nitrogen, oxygen and other elements. In investigations of environmental behavior it is convenient to divide the hydrocarbons into the following groups (see Fig. 1):

1. Normal alkanes
2. Iso and cyclo alkanes
3. Low molecules weight aromatic hydrocarbons
4. Polynuclear aromatic hydrocarbons (PAHs)

The n-alkanes have limited toxicity and physiological effects and are degraded comparatively readily. The iso and cyclo alkanes are similar but are more resistant to environmental degradation. In contrast, the aromatic hydrocarbons are toxic and the PAH compounds contain many potent carcinogens. In some refineries the "cracking" process is used which may lead to the formation of another group, the "alkenes," which have properties somewhat similar to the normal alkanes (Connell and Miller, 1981).

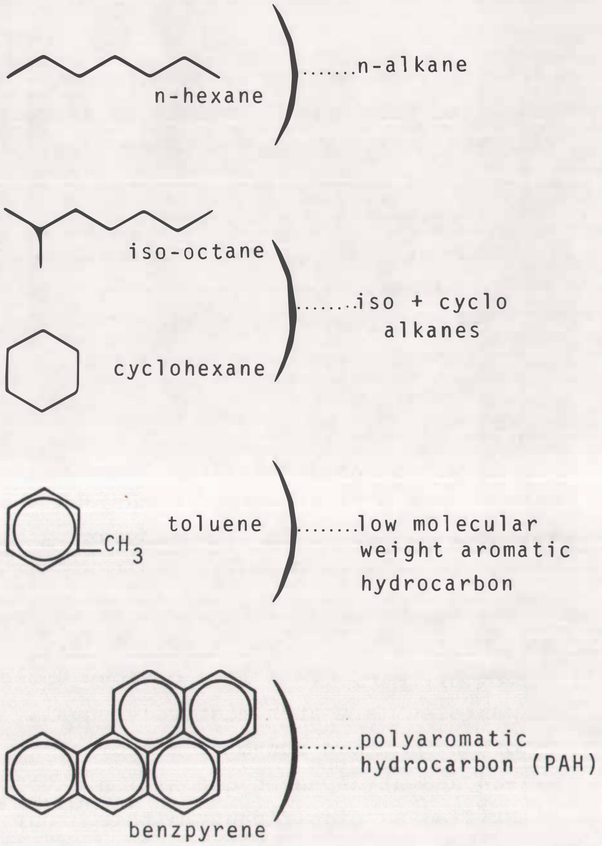


Fig. 1 - Examples of some Petroleum Hydrocarbons

THE HUDSON-RARITAN ESTUARY

The Hudson-Raritan estuary, for the purposes of this study, covers the shaded area (about 290 km^2) in Fig. 2 in which water depths usually range from 5 - 20 m. The estuary receives water from the Hudson-Mohawk River system draining over 34,000 km^2 mainly in upper New York state and smaller

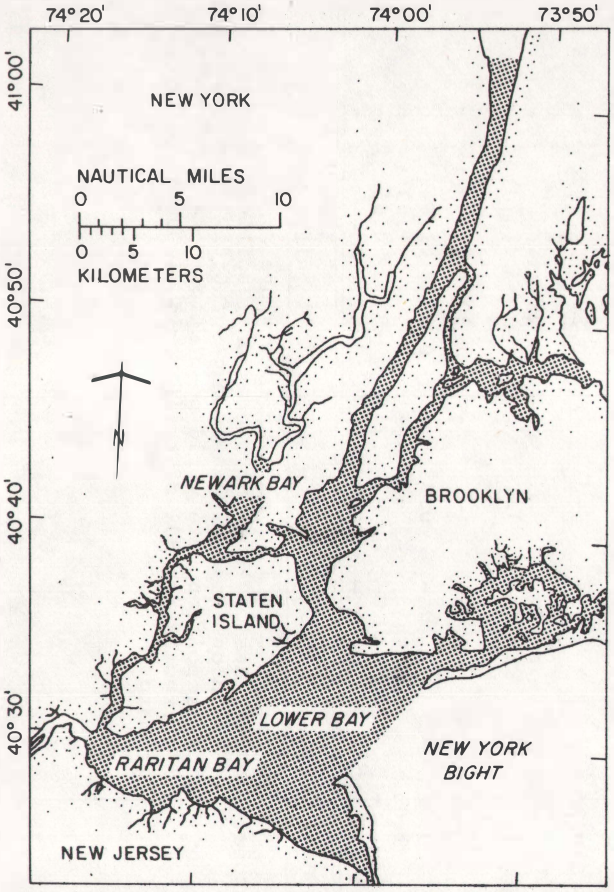


Fig. 2 - Primary HRE Study Area

streams (Hackensack, Passaic, Raritan) in central and northern New Jersey with a catchment of 6,700 km^2 (Mueller and Anderson, 1978). The estuary is tidal with saltwater intrusion profiles being measured at an upstream limit of Hyde Park (130 km upstream). At the Battery, mean tidal flows are 12.0 x 10^3 m^3/sec, while fresh water reaches a maximum mean flow of 1.1 x 10^3 m^3/sec in spring and a minimum of 0.4 x 10^3 m^3/sec in summer (Abood, 1974). The estuary is partially stratified with maximum stratification in spring and a minimum in winter.

The catchment contains the largest manufacturing and population centre in the U.S., with a population estimated at 15.5 million in 1970. Most of this is concentrated along the shores of the estuary; the wastewaters are generated from domestic waste and industries producing such products as chemicals, petroleum, fabricated metals and electrical equipment (Mueller and Anderson, 1978).

A substantial proportion of the shoreline is occupied with port and shipping activities which require dredging of Upper and Lower New York Bay, Newark Bay, East and Harlem Rivers, Kill van Kull, Arthur Kill, parts of Jamaica Bay and the Hudson River. The zone is also used for sand and gravel mining. Sport and commercial fishing, swimming and recreational boating are popular activities in the Lower New York Harbor and Raritan Bay (Duedall et al., 1979).

There are relatively high concentrations of nutrients in the estuary which originate from sewage effluents and are used substantially in biological processes then transported seaward to New York Bight (Duedall et al, 1979). Swartz and Brinkhuis (1978) have reported that the bottom waters of the lower Bay can be depleted during the summer months when microbiological activity is increased and the water column is poorly mixed. Hardy and Weyl (1971) found that in August 1970, the entire water column in the East River was less than 25% saturated. This was attributed to the effects of sewage effluents and industrial wastes.

SOURCES OF PETROLEUM HYDROCARBONS

In previous investigations, global estimates for inputs of petroleum substances to the oceans were made (see Table 1). Consideration of these studies has allowed the identification of the factors in Table 2 as relevant inputs to the Hudson-Raritan estuary.

There are considerable difficulties in quantifying the mass loads of PHCs being discharged to the HRE due to the lack of data. However, data on somewhat similar situations is often available and can be applied. The relevance of this

Table 1. Listing of Estimated Petroleum Inputs to the Marine Environment (in million metric tons per annum)*

SOURCE	SCEP	Jeffrey	Porricelli et al.	USCG	Brummage	Charter et al.	Duce and Quinn	Feuerstein	Storrs	Wilson	NAS	Grossling	Koons & Monaghan	Smith
Marine Operation Losses														
LOT tankers	0.03	0.10	-		0.25	0.26	-	-	-	-	0.31		-	1.00
Non-LOT tankers	0.50	0.60	-		0.75	0.46	-	-	-	-	0.77	0.41	-	
Bilges, Bunkering, and other normal ship operations (all ships)	0.50	0.05	-	1.72	0.50	0.61[a]	-	-	-	-	0.50		-	0.30
Offshore accidental discharges														
Tanker accidents	0.10		-		0.12	0.21	-	-	-	-	0.20	0.22	-	
Accidents, other ships		0.20	-		0.02	0.14	-	-	-	-	0.10	-	-	0.35
Pipeline accidents	-		-	-	-	-	-	-	-	-	-	<0.01	-	
Offshore oil production	0.10	0.15	-	0.12	0.10	0.12	-	-	-	0.08	0.08	<0.38	-	0.15
Natural marine oil seeps	-		-	-	-	-	-	-	-	0.2-6.0	0.60	0.24-7.00	0.60	0.60
Atmospheric deposition	(9.0)[b]	-	-	-	-	-	1.5	0.4-0.8						
Land based discharges														
Refineries	0.30	0.30	-	-	0.30	0.20	-	-	-	-	0.20	<0.62[c]	-	
Terminal transfer operations	0.10[d]	-	-	e	0.01	0.03	-	-	-	-	0.25[f]		-	
Pipeline accidents	-	-	-	-		0.03	-	-	-	-	-	<0.01	-	
Runoff (urban and river		-		-		-	-	-	-	-	1.90	-	-	1.30
Industrial wastes	0.45			1.98	0.50	0.72	-	-	0.08	-	0.30	1.64		
Automotive wastes		0.50	4.4	-		1.03	-	-	-	-	-	1.03	-	
Aviation wastes	-			-		-	-	-	-	-	-	0.05	-	
Municipal wastes	-			-		(11.8)[b,g]	-	-	0.20	-	0.30	-	-	
TOTAL	2.08	1.90	9.50	-	2.55	3.81	-	2.4-3.8	-	-	6.11	3.6-11.4	-	3.70

*Data from Goldberg (1979)

[a] Includes product tankers, ore and bulk-oil carriers, disposal prior to dry-docking, and tanker barges and bilges.

[b] Not included in total.

[c] Includes onshore oil production accidents

[d] Includes all nonship accidental spills.

[e] Included in 1.72 million tons above.

[f] Includes dry-docking operational spills.

[g] Based on Philadelphia average of 0.0177 tons/(person*yr) extrapolated to a world population of 4×10^9 and corrected for 30% of total world oil usage by United States.

TABLE 2

SOURCES OF PHC RELEVANT TO THE HUDSON-RARITAN ESTUARY

Sewage discharges
Refinery discharges
Non-refinery industrial discharges
Urban and rural run-off from the catchment
Accidental spills
Atmospheric deposition

transposed data to the HRE cannot be determined but should provide a "first approximation." Thus it should be recognized that the estimates made are approximations only. Nevertheless, some idea of relative importance can be obtained and is useful in delineating areas for future research or consideration of management options.

Sewage Discharge

Mueller and Anderson (1978) and Mueller et al. (1976) have published data indicating locations, quantities and loads of various substances in municipal wastewater discharged to the estuary. The total volume for the HRE for sewage discharges is shown in Table 3. It should be noted here that a substantial proportion of the industrial discharges in the area are made to the municipal wastewater system and municipal wastewater can be discharged raw or treated to primary or secondary standard.

There is data available on the oil and grease content of municipal wastewater discharging to the HRE (Mueller et al., 1976). However, PHC constitute only a proportion of the oil and grease content of municipal wastewater (Farrington and Quinn, 1973; Anon, 1975). Therefore, average date on the PHC content of municipal wastewater from Rhode Island and Trenton, N.J. (Van Fleet and Quinn, 1977; Whipple et al., 1976; Farrington and Quinn, 1973) was used (see Table 3). This allowed an estimate of total quantity of PHC discharge to be made. Tanacredi (1977) has produced data indicating that PHCs are present in biota, water and sediments in Jamaica Bay. The type of PHC was identified as crankcase oil originating from municipal wastewater discharges.

It is difficult to evaluate the accuracy of this estimation but the prime source of error is in the figure used for PHC content. This will vary according to treatment procedures and the nature of industries discharging to the wastewater system. The only method to obtain a more accurate figure is by direct analysis of the various municipal wastewater discharges to the HRE.

Oil Refinery Discharges

From the data produced by Mueller and Anderson (1978) the volume of direct discharges to the HRE by oil refineries was calculated (see Table 3). Bond and Straub (1974) have estimated the average concentration from data obtained from twelve refineries (see Table 3). In earlier work a concentration of 20 mg/ℓ was used (NAS, 1975) which would give a total quantity discharged at approximately half that in Table 3. Thus the quantity in Table 3 could be an overestimate.

TABLE 3

ESTIMATES OF THE PHC DISCHARGES TO HRE

Factor	Total Volume ($x\ 10^6$ ℓ/day)	Concentration (mg/ℓ)	PHC Quantity (kg/day)	Reliability
sewage discharges	9,230	3.8	35,000	moderate
oil refinery discharges	23	57	1,300	moderate
non-oil refinery industrial discharges	1,134	15	17,000	low
oil spills	Coast Guard figures		1,500	moderate
atmospheric deposition	NAS (1975) figures for deposition rates		2	low
urban and rural run-off	from Eganhouse et al. (1980)		37,000	moderate

Total ca. 92,000 kg/day

Non-oil Refinery INdustrial Discharges

The total volume of direct non-oil refinery industrial discharges to the HRE was obtained from Mueller and Anderson (1978). Data on average PHC content of discharges from the wide variety of industries in the HRE catchment is not available is not available. Thus a figure of 15 mg/ℓ, typical of metal industries, was used (Bond and Straub, 1974). In view of the large range of industries present, many of which have low PHC content in their effluents, this could be an overestimate. The total quantity discharged is shown in Table 3.

Oil Spills

Direct observations on the quantity of petroleum spilled in HRE are made by the United States Coast Guard (1980). The average rate of spills in the system was calculated from the data gathered between 1974 to 1979 (see Table 3).

Atmospheric Deposition

The rate of deposition of hydrocarbons from the atmosphere into the oceans was calculated by NAS (1975). Using this, the quantity deposited in HRE was estimated (see Table 3). There are many sources of hydrocarbons in the atmosphere other than fossil fuels and Goldberg (1979) has drawn attention to the low reliability of estimates of quantities of PHC deposited in this way. In addition, most PHC deposited in the region will be in terrestrial areas and some of these substances could be present in urban run-off. In view of the heavy concentration of motor vehicles in the region, it is likely that atmospheric deposition is higher than the figure shown in Table 3. Nevertheless, the estimate suggests that atmospheric deposition is insignificant as PHC source.

Urban and Rural Run-Off

No data is available on the concentrations of PHC in urban and rural run-off water. In many respects estimates of quantities of substances in run-off presents some particular difficulties. The principal problem is concerned with variation of concentrations of substances in relationship to rainfall events. Usually highest concentrations are observed in initial run-off but these decrease with increasing quantity of run-off water. Taking these factors into account Eganhouse and Kaplan (1981) and Eganhouse et al. (1981), in studies of the Los Angeles area, estimated that run-off water contained PHCs in relation to population at the rate of 875 g/person/year. Applying this to the HRE catchment, an input of PHC in run-off can be made (see Table 3).

DISTRIBUTION AND TRANSPORT PROCESSES AFFECTING PHCs IN THE HRE

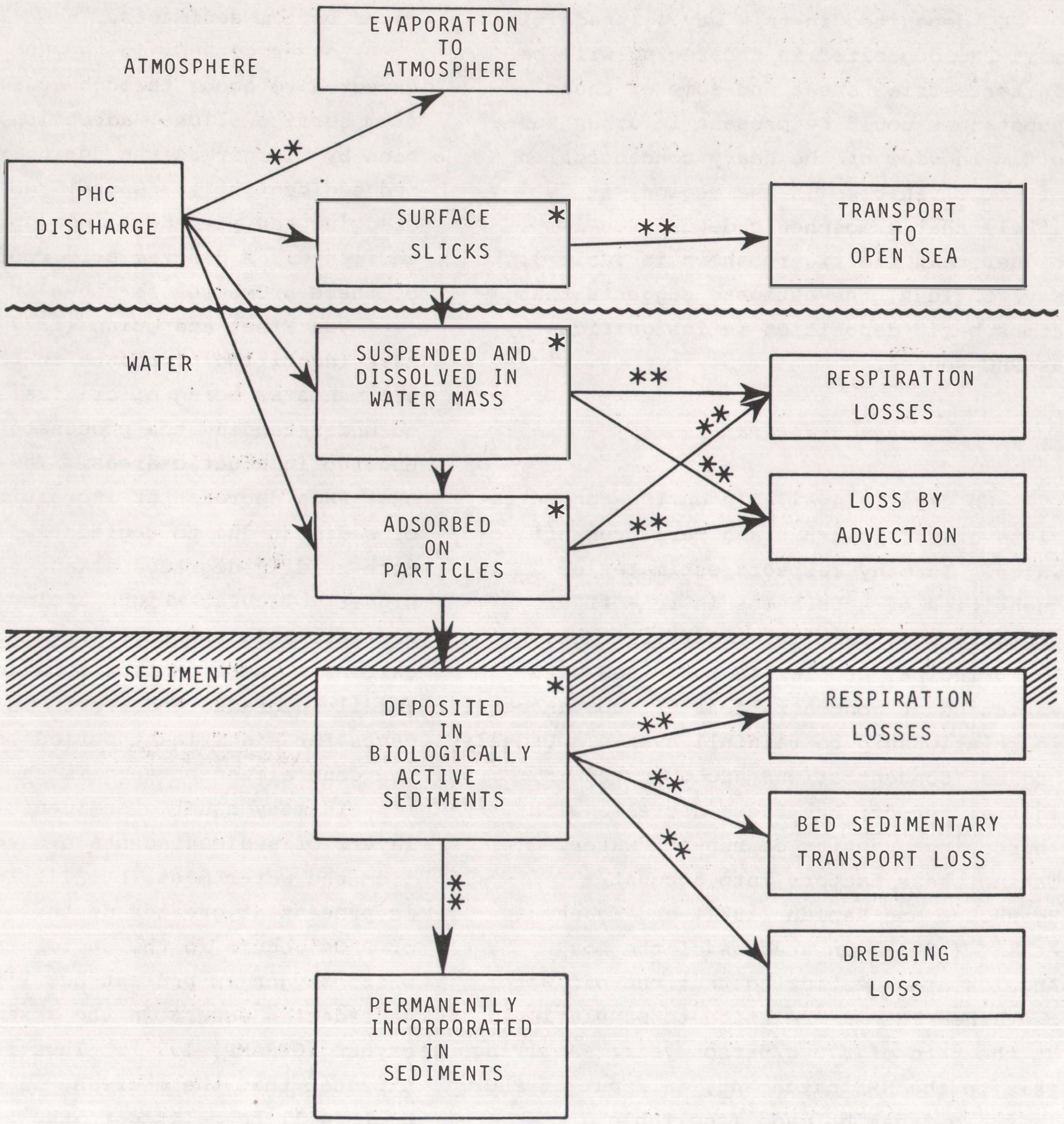
GESAMP (1977) have reviewed the fate of petroleum in the aquatic environment principally in the form of surface slicks. In addition Van Fleet and Quinn (1977) and Van Fleet and Quinn (1978) have investigated the fate of low concentrations of PHC in sewage discharges. In general, these investigations have indicated that PHCs in sewage are bound to suspended matter and are comparatively rapidly sedimented out of the water mass to enter bottom sediments.

Losses of PHCs in the HRC can be expected to occur through evaporation from surface slicks, advection, degradation by microorganisms during respiration, bed sedimentary transport, removal by dredging and permanent incorporation in sediments. A diagrammatic representation of these processes is shown in Fig. 3.

Van Fleet and Quinn (1977 and 1978) have identified processes in the bottom sediments as being of critical importance to understanding the processes PHCs undergo in aquatic areas. They found that PHCs decrease at increasing depths of sediment due to degradation of the more readily degraded alkanes leaving higher molecular weight cycloparaffins plus aromatic and nаpthеno-aromatic hydrocarbons. These complex substances are not readily degraded and remain in the sediments for significant periods of time. The generalized pattern is shown in Fig. 4.

In many aquatic sediments, the upper layers of sediment contain oxygen, derived from the water mass, but little oxygen is present at greater depths. Degradation of PHCs occurs in the sedimentary zone where oxygen is present but little degradation occurs in the absence of oxygen (GESAMP, 1977). Thus it could be expected that the decrease in PHCs with depth will be related to the sediment zone where oxygen is present (see Fig. 4).

Olsen et al (1978) have conducted a geochemical analysis of sediments and sedimentation in the HRE. By examination of the coloration of the sediment, they estimated that oxygen was present in the 0.1 - 3 cm upper layer. Normally when oxygen is present iron occurs as brown iron oxides but when absent, is converted to black iron sulphides. Thus PHCs in



* active standing quantities

** losses to the system

Fig. 3 - Fate of PHCs Discharged in HRE

the HRE would be expected to follow the pattern shown in Fig. 4 with maximum concentrations at the sediment surface and minimum concentrations at 0.1 - 3 cm depth. Thus in taking samples of bottom sediment the removal of samples in excess of 3 cm of the upper layer will contain concentrations more closely approximating the minimum concentration at depth than the maximum at the surface.

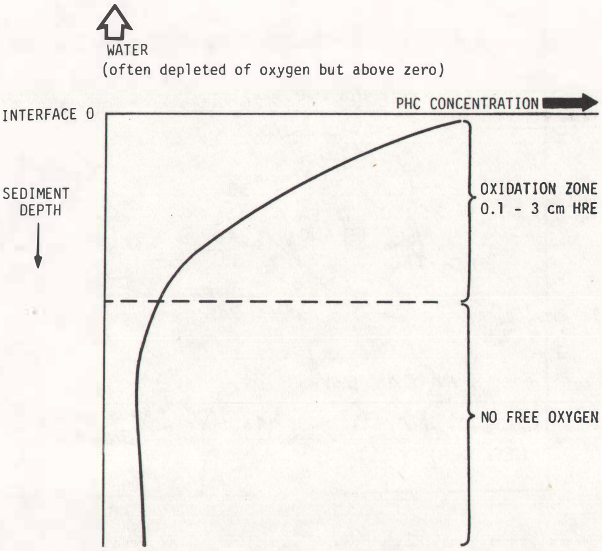


Fig. 4 - Diagrammatic representation of processes at the water sediment interface.

Analyses of the total hydrocarbons greater than C15 in HRE sediments have been made by Koons and Thomas (1979). These analyses should account for most of the PHCs since only small proportions should be less than G15 (see Fig. 5). In addition, McLeod et al (1981) have determined the PAH, and in particular, the benzo(a)pyrene content. An investigation by O'Connor et al (in press) concluded that the PAHs in sewage sludge derives from "waste crankcase oil," i.e., from automotive engine lubricants. The data of Connell and Miller (1981) on the benzo(a)pyrene content of a wide variety of petroleum products indicated an average content of 137 mg/ℓ. Using this, the figures of McLeod et al (1981) were converted into total PHC and are indicated in Fig. 6.

By assuming an active upper sediment layer of 1.5 cm and calculating an average concentration of 1940 mg/kg (see Figs. 5 and 6), this indicated an active PHC reservoir in the sediments of approximately 8.4 x 10^6 kg (see Table 4). In a somewhat similar manner the PHC reservoir in the water mass was calculated as 0.091 x 10^6 kg from the data of Searl and Thomas (1977) as shown in Fig. 7. Stainken and Frank (1979) have conducted an investigation of PAH in bottom waters of Raritan Bay (see Table 4). This indicates the quantitative importance of the sediments in understanding PHC dynamics in the HRE. No data was available to allow an estimation of the standing mass of surface slicks in the HRE.

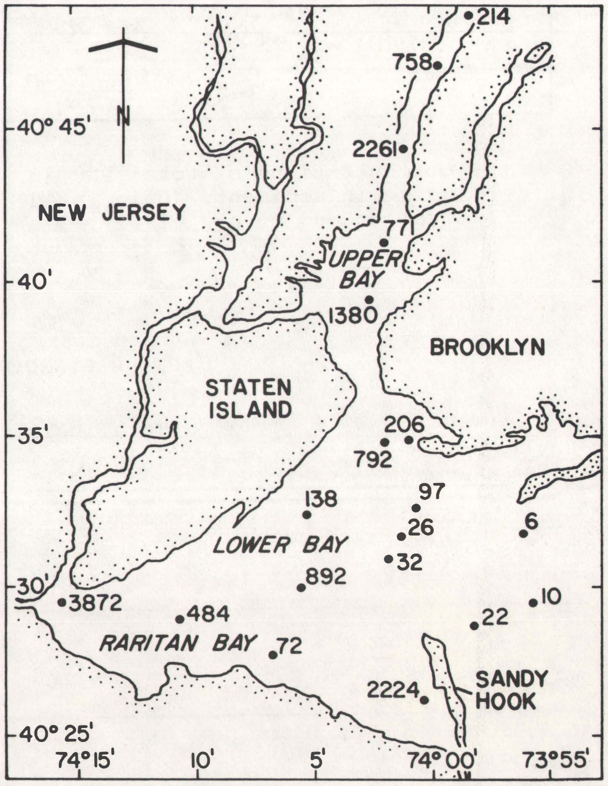


Fig. 5 - Distribution of hydrocarbons greater than C15 in sediments in the HRE (from Koons and Thomas, 1979) (in mg/kg).

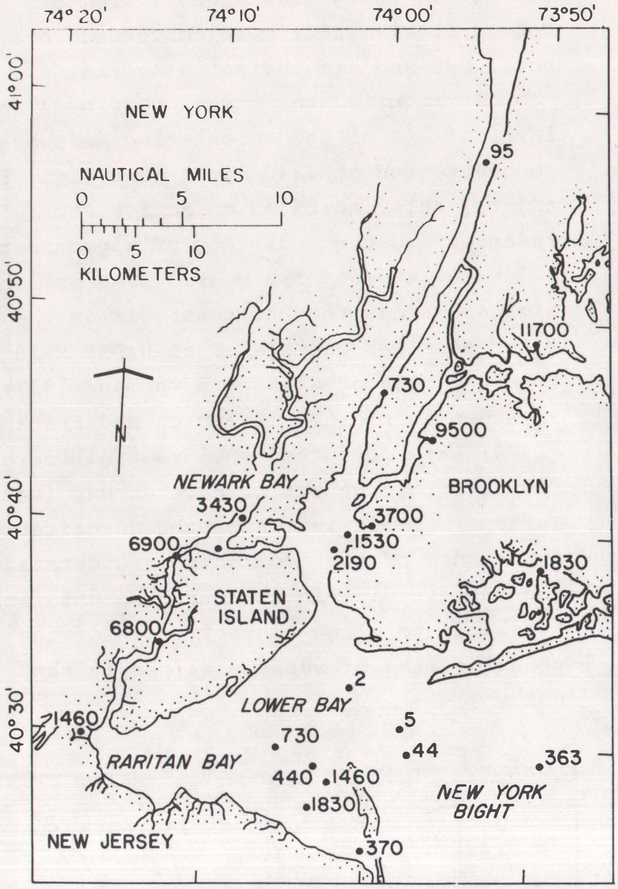


Fig. 6 - Concentrations of total PHC in mg/kg in sediments (calculated from McLeod et al., 1981).

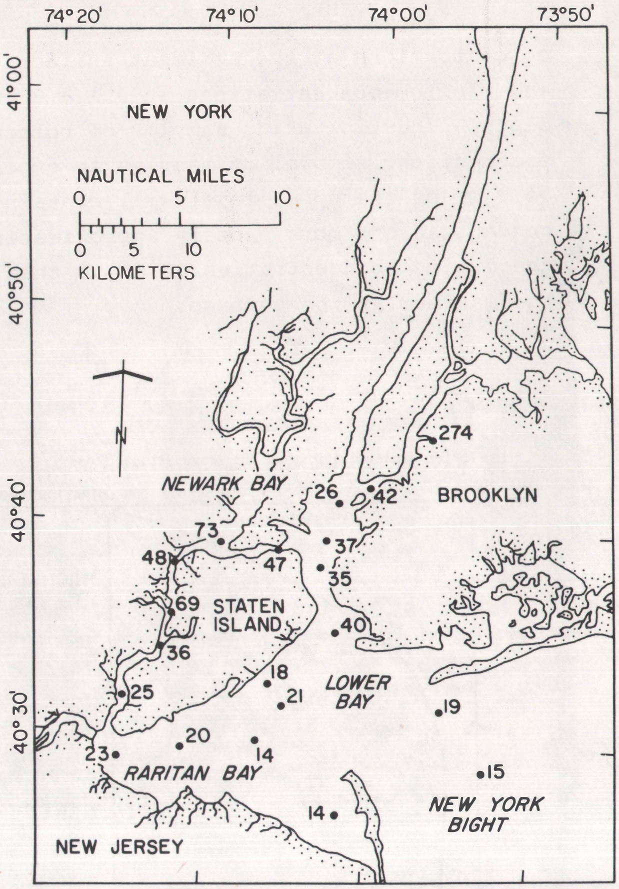


Fig. 7 - Total PHC in water (μg/ℓ) (from Searl and Thomas, 1977).

TABLE 4

ACTIVE STANDING MASSES OF PHC IN HRE

Environmental Component	Total Volume (m^3)	Average Concentration	PHC Quantity (kg)
surface slicks	?	?	?
water mass	232×10^7	39*μg/ℓ	91,000
biologically active sediments	43.5×10^5	1940**mg/kg	8.4×10^6

*Searl and Thomas (1977).

**Calculated from Fig. 5 and 6.

LOSSES OF PETROLEUM HYDROCARBONS

In the previous section, losses of PHC from the HRE were characterized as:

permanent deposition in sediments
dredging
advection of dissolved and suspended matter
bed sedimentary transport
decomposition in water and sediments
evaporation
movement of surface slicks to the sea

The estimation of total quantities for all of these processes presents a number of difficulties. Limited data is available on the HRE but this in conjunction with data obtained from other areas allows estimations to be made. As with the input calculations the transposition of data from other areas to the HRE raises questions as to the accuracy of the determinations. Thus it should be kept in mind that these calculations can only represent "first approximations."

Permanent Deposition in Sediments

The concentrations shown in Fig. 5 and some appropriate values from Fig. 6 were taken to represent the concentrations of PHC in sediments which were passing into permanent deposition situations. The rate of accumulation of sediments has been determined by Bopp et al. (1978) for various sections of the HRE. From this data, the rate of loss of PHCs from the estuary was calculated (see Table 5). This estimate would be improved by an investigation of PHC sedimentary profiles.

Dredging

The quantities of dredged sediments taken from the HRE have been estimated by Bopp et al. (1978) and average concentrations of total PHC estimated from the data of McLeod et al. (1981) allowing the total quantity to be calculated (see Table 5). Direct determination of total PHC in dredged sediment would allow a more accurate determination of this figure.

Losses by Advection of Dissolved and Suspended Matter

Busby and Darmer (1970) have estimated the volume transported during the ebb or flood tide in the Hudson River at the Battery as shown in Table 5. A greater flow would be expected at the Sandy Hook-Rockaway Point transect so the use of this figure will result in an underestimate of total PHE transported from this factor. Jay (1974) has collated data available on the East River and daily ebb flow is shown in Table 5. Using the average PHC content in water obtained from Searl and Thomas (1977) for the vicinity of the transect, the total PHC loss was calculated. Overall, these figures are likely to be overestimates since no account is taken of re-entry of estuarine water on the flood tide.

Bed Sedimentary Transport

The large reservoir of PHC in the sediments indicates that sediment movement may be an important factor in redistribution of the PHC load in the HRE. Sediment movement through the Sandy Hook-Rockaway Point transect will result in losses of PHC from the HRE. Gadd et al. (1978) have reported that there is the most intense sedimentary transport at the transect and bottom currents in the vicinity of 80 cm/sec are common. The rate of net movement of bed sediments were reported and averaged at 0.365 g/cm/sec. From the distance across the transect a total rate of movement was calculated. The total PHC loss was estimated (see Table 5) using the figure obtained as above together with an average sediment

TABLE 5

ESTIMATION OF PHC LOSSES FROM HRE

Factor	Total Volume or Mass (per day)	Concentration (mg/kg)	PHC Quantity (kg/day)	Reliabiltiy
permanent deposition in sediments	5.5×10^3 tonnes	1800	10,000	moderate
dredging	0.62 tonnes	3430	5,800	moderate
dissolved and suspended matter advection	Sandy Hook-Rockaway Pt. Transect: 4.1×10^8 m^3	0.017	7,000	moderate
	East River: 2.5×10^8 m^3	0.017	4,300	low
bed sedimentary transport	3.15×10^5 kg	224	70	moderate
decomposition in water and sediments	average rate of decomposition from lit, 0.14 $g/m^2/day$	area $290 \times 10^6 m^2$	42,000	low
evaporation	average literature from surface slicks 25%		400	low
movement of surface slicks to sea	c.f. evaporation		400	very low

Total ca. 70,000 kg/day

concentration in the vicinity obtained from the data of Koons and Thomas (1979) (see Fig. 5).

Degradation in Water and Sediments

From investigations reviewed by GESAMP (1977), the half life of petroleum hydrocarbons in the water mass is commonly approximately 30 days. From the total standing mass of PHC in the water (see Table 4) a daily rate of degradation can be calculated at 1500 kg/day.

GESAMP (1977) have also reviewed data on the rate of degradation of PHC in sediments. This is often limited by the availability of nutrients and oxygen. Nutrients are in comparatively plentiful supply from discharges of both treated and untreated sewage. Although the bottom layers of water in large areas of the HRE are often deficient in oxygen, the observations by Olsen et al. (1978) indicate that some oxygen is available in the upper layers of sediment.

This is in accord with the investigations of Atlas and Bartha (1973) who have shown that the microorganisms present in Raritan Bay were able to support extensive degradation of crude oil when nitrogen and phosphorus were supplied. It was calculated that approximately 70% of a crude oil would be degraded in 18 days.

Since light will be very limited on the bottom, it would be expected that microbiological processes will constitute the major degradation processes. Rates of degradation (GESAMP, 1977) for crude oil, lubricating oil and cutting oil range from 0.02 - 0.40 $g/m^2/day$ and average 0.14 $g/m^2/day$. This data was obtained from laboratory experiments since no appropriate data on decomposition rates in estuaries comparable to HRE are available. This coupled with the area of sediments in HRE indicated an estimate of degradation that would be approximately 40,000 kg/day. Thus the total amount degraded each day in water and sediments would be 42,000 kg/day.

The reliability of this estimate will be affected by the comparability of the laboratory experiments to the conditions in the HRE. In addition, the seasonal variations in sediment temperature will affect decomposition rates.

Evaporation

It is expected that evaporation will principally occur with accidental spills giving rise to surface slicks. The other sources of PHCs in the system are likely to yield PHCs depleted in volatile fractions. Butler et al. (1976) estimated that, as a general rule, approximately 25% of spilled petroleum oils evaporate into the atmosphere. Thus an estimate of evaporation losses from accidental spills can be made (see Table 5).

Movement of Surface Slicks to the Sea

There is no data available to enable an estimate of this loss from the system to be made. It was therefore assumed it would be similar to evaporation (see Table 5).

A BUDGET FOR PHCs IN THE HRE

In the previous sections, the quantities of the various sources and losses of PHCs in the HRE were estimated and can be summarized as in Fig. 8. Overall PHC figures were arrived at as follows:

Total sources - approximately 92,000 kg/day
Total losses - approximately 70,000 kg/day

Considering the difficulty in obtaining accurate data and the transposition of data from other areas to the HRE, these figures are in reasonable agreement. The following areas are those where accurate data would provide more reliable estimates:

1. The PHC content of inputs such as municipal wastes, industrial wastes and run-off water

2. The PHC content of sediments and water

3. Dynamics of PHC in sediments.

There are clearly many other areas where information is needed but those indicated above can be identified as of prime importance.

Overall the results suggest that most PHC originates from sewage and industrial discharges and run-off water and that direct refinery discharges, atmospheric deposition and accidental spills are quantitatively less important. However, it is significant that refinery discharges and accidental spills are discharged in a concentrated form and are probably less susceptible to breakdown since nutrient concentrations are comparatively lower. In addition, surface slicks create a number of special problems related to bathing, fishing, aesthetics and so on.

The results suggest that processes in the sediment are highly significant in the removal of PHCs from the system and a comparatively low proportion of PHCs discharged to the HRE are eventually discharged to New York Bight through the Transect. However, the combined total discharged into the Bight by dredging and advection is significant.

EFFECTS OF PHCs ON PHYSICAL AND CHEMICAL PROCESSES

In some cases, high concentrations of petroleum oil in sediments have altered the physical characteristics of the intertidal zone. This has led to erosion in some situations but there is no evidence to suggest that these processes are of any significance in the HRE.

In the previous sections degradation of the PHC by microorganisms was estimated at 0.14 $g/m^2/day$. The oxygen demand for this to occur would be about 0.6 $g/m^2/day$ for a long chain alkane. This would create an oxygen demand of about 30 ppm over 5 days in the 10 cm of water above the sediment surface. This could have a significant impact on dissolved oxygen in the interstitial water in the sediments and the overlying water depending on water movement and other factors.

EFFECTS OF PHCs ON PLANKTON

The effects of PHCs on phytoplankton have been summarized by GESAMP (1977) and are shown in Table 6. Of the species listed, three exhibit absence or retarded cell division at concentrations of 0.1 - 0.01 mg/ℓ. Concentrations reported by Searl and Thomas (1977) range from 0.014 - 0.274 mg/ℓ. Thus it is possible that the concentrations of PHC present may be having an effect on the phytoplankton population.

The effect outlined above could alter the species composition of the population of phytoplankton or may cause a reduction in biomass. Such effects could be difficult to distinguish from the effects of nutrients and other toxicants. Changes may lead to changes in the zooplankton population.

There is limited information available on the direct effects of PHCs on zooplankton. Some of this information is summarized in Table 7. Extended exposure periods could be expected to lead to lower lethal concentrations.

Lee and Takahashi (1979) noted that copepods appear to exhibit lethal effects at comparatively high concentrations of hydrocarbons. However, they had indications of slower growth rates for one copepod species during exposure to 0.04 mg/ℓ of fuel oil. Thus effects on the zooplankton population at concentrations observed are possible.

TABLE 6

REACTION OF ALGAE TO VARIOUS OIL CONCENTRATIONS (mg/ℓ)

Type	Death of Cells	The Absence Or Retarded Cell Division	Do Not Differ From Control
Glenodinium foliaceum	1,000 - 100	100 - 10	1 - 0.1
Chaetoceros curvisetus	10,000 - 10	10	1 - 0.1
Gymnodinium wulffii	1,000 - 100	10 - 0.01	--
Ditylum brightwellii	1,000 - 0.1	--	--
G. kowolovskii	1,000 - 0.1	1 - 0.1	0.01
Prorocentrum micans	1,000	100 - 0.01	--
Peridinium trochoideum	1,000	1,000	100 - 0.01
Licmophora chrenborgii	1,000	100 - 1	01 - 0.01
Platymonas viridia	1,000	10 - 1	0.1
Coscinodiscus granii	1,000	1,000 - 100	100 - 0.1
Molosira moniliformis	10,000 - 1,000	10,000 - 100	100 - 10

From GESAMP (1977)

TABLE 7

LETHALITY OF OIL TO MIXED SPECIES OF COPEPOD

(*Acartia clausii and Oithona nana*)

Time	Concentration (mg/ℓ)
3 - 4 days	ca. 10
24 hours	ca. 100
5 - 60 minutes	ca. 1000

(From GESAMP, 1977)

EFFECTS OF PHCs ON BENTHIC INVERTEBRATES

PHCs in high concentrations resulting from oil spills are known to cause heavy mortalities to benthic communities (GESAMP, 1977). Some data on the lethal concentrations for a variety of invertebrate fauna are shown in Table 8. The concentrations of PHCs in the HRE generally are lower than these concentrations although limited exposure times have been used to obtain this data.

In the comparatively low concentrations found in the HRE, effects can be expected to be principally of a sublethal nature. For example, populations of the clam, *Mercenaria mercenaria*, in Narragansett Bay, Rhode Island, were found to be patchy and the clam was found to have a comparatively short life span. This was attributed to a stress syndrome induced by sublethal concentrations of petroleum hydrocarbons (Jeffries, 1972). It is also relevant that Grassle et al. (1981) found that low concentrations of No. 2 fuel oil caused a reduction in total macrofaunal numbers after five months particularly suspension feeders. Michael et al. (1975) and Michael (1977) and other workers have found a variety of effects including reduction in number of species, higher proportion of opportunistic species than control areas and reduction in the numbers of individuals.

The situations investigated in the studies described above contained PHCs derived directly from petroleum spills. In the HRE only a comparatively small proportion is derived from oil spills, most PHCs originate from municipal wastewater, urban run-off and industrial discharges. As a result the PHCs in the HRE co-occur with a variety of other substances which exert ecological effects.

The PHCs are principally deposited in the sediments (see Fig. 8). Here they can be expected to have two principal effects of importance to benthic biota:

1. cause enrichment of the sediments with organic matter and energy giving rise to a reduction in the dissolved oxygen content of interstitial water and the overlying water mass,
2. have toxic effects on biota due to the presence of toxic substances in PHCs.

The effects on composition of the benthic community will be different in each case. With effect 1, it would be expected that there would be a reduction in number of species but an increase in number of individuals present. With effect 2, there would be a reduction in the number of species and also a reduction in the number of individuals.

Ristich et al. (1977) have investigated the composition of the benthic invertebrate community in the area shown in Fig. 9. Their results together with relevant data on PHC content of sediments and water are shown in Table 9.

The number of individuals tends to decrease with decreasing PHC content whereas limited variation can be seen with species numbers. This suggests that enrichment of the sediments with organic matter is having the major impact on the benthic biota. The apparent relationship of PHCs with number of individuals possibly results from the co-deposition of PHCs and organic matter in sediments. These results (see Table 9) do not indicate that the PHCs are having a toxic effect on the benthic biota in this region. An analysis of the change in species composition over this section of the river may provide a more detailed insight into any relationships.

McGrath (1974) conducted an investigation of the benthic fauna in Raritan Bay. He reported depressed communities (see Table 10) and the lack of amphipods in the genus *Ampelisca* which were dominant 10 years earlier (Dean and Haskin, 1964). These effects were attributed to PHCs although no data on PHC concentrations were available. Genus *Ampelisca* has been

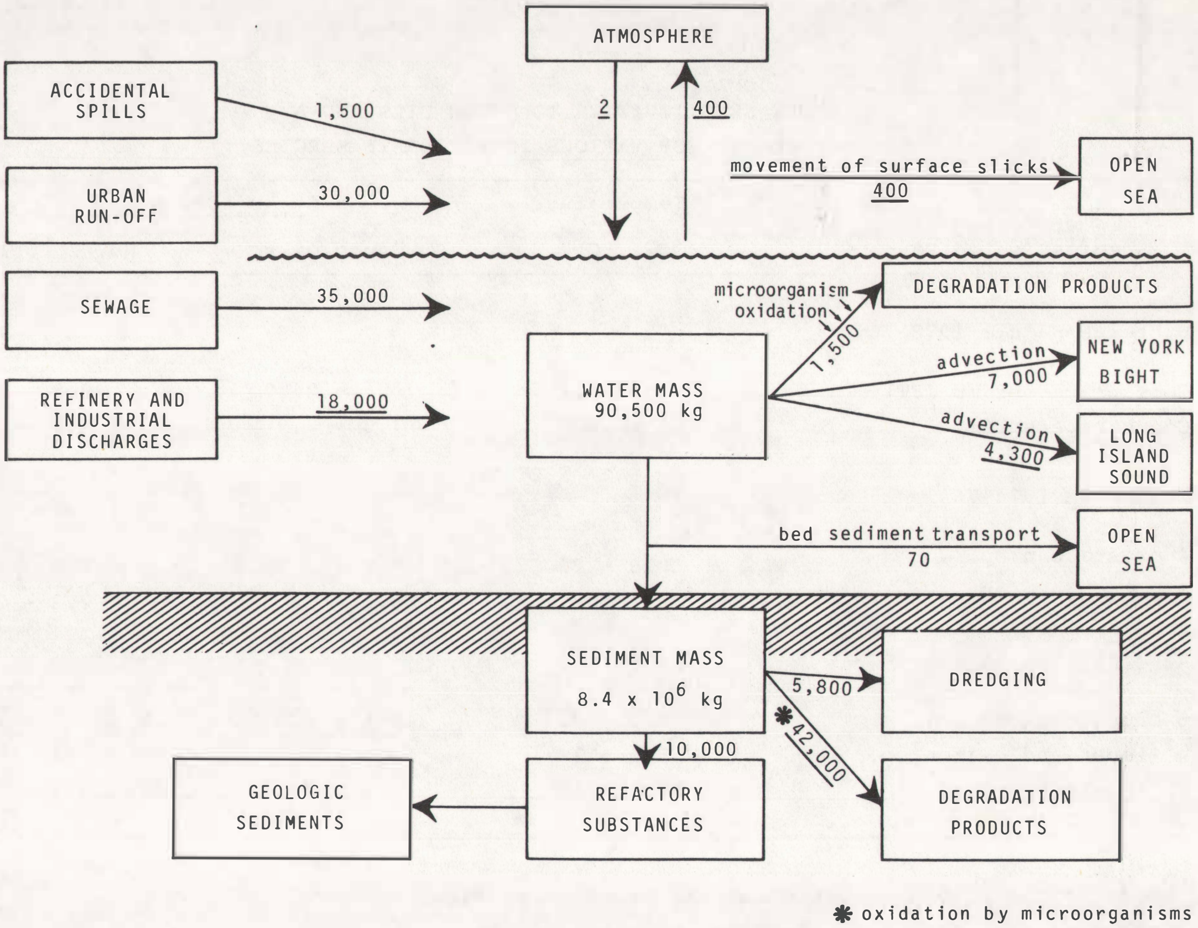


Fig. 8 - Diagrammatic representation of the transfers of PHCs in the HRE (kg/day). (Those estimates made with low to very low reliability are underlined.)

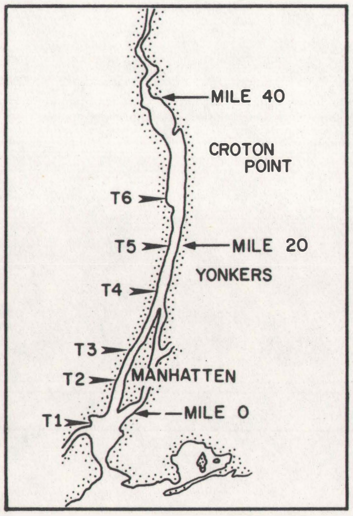


Fig. 9 - Sampling stations in the Hudson River used by Ristich et al. (1977).

TABLE 8

ADULT SENSITIVITIES TO CRUDE OILS AND A NO. 2 FUEL OIL FOR VARIOUS INVERTIBRATE SPECIES††

Study and	Temperature	96 hr LC50's (ppm)	
Species Tested Range	(°C)	Crude Oils	No. 2 Fuel Oil
Battelle/Sequim 1973-76†			
Coonstripe shrimp (FT)	10 - 11	6.6 - 24.9	0.8
Coonstripe shrimp	8	1.3 - 4.9	-
Texas A&M 1974-76			
4 crustacean sp.	18 - 22	6 - > 19.8	1.3 - 4.9
3 polychaete sp.	20	9.5 - 12.5	2.3 - 2.7
Auke Bay Lab 1976			
6 crustacean sp.	3.5 - 5.4	0.6 - 4.2	0.5 - 1.7
4 limpet and chiton sp.	3.9 - 7	3.6 - 9.6	0.4 - 5.0
12 invertebrate sp.	3.6 - 10	> 3.1 - 14.7	> 0.9 - 5.6

†Most of the LC50's reported for the Battelle studies are estimates calculated from Battelle's raw data.

††From Rice et al. (1977)

FT denotes flowthrough rates

TABLE 9

DISTRIBUTION OF INVERTEBRATES AND PHC IN HUDSON RIVER

Station	*Sediment Concentration of PHC (mg/ℓ)	**Sediment Concentration of PHC (mg/ℓ)	***Water Concentration of PHC (mg/ℓ)	****Species Numbers	****Numbers of Individuals
T_1	1360	ca. 2190 - 1530	0.047 0.037	5 - 21	7800 - 41,250
T_2	2261	ca. 730	NA	6 - 19	2576 - 20,196
T_3	758	ca. 730	NA	4 - 20	8944 - 18,494
T_4	ca.214	ca. 95	NA	8 - 16	8879 - 9026
T_5	NA	NA	NA	4 - 13	2114 - 3274
T_6	NA	NA	NA	3 - 12	1604 - 5867

*From Koons and Thomas (1979).

**Calculated from McLeod et al. (1981).

***From Searl and Thomas (1977).

****From Ristich et al (1977).

TABLE 10

DATA ON RARITAN BAY AND OTHER AREAS

Area	Number of Species	Number of Individuals $(1m^2)$
Upper New York Bay	5 - 21/m^2	2,576 - 41,250
Raritan Bay	4 /0.1 m^2	109
Moriches Bay	---	2,420
Barnegat Bay	---	500 - 600

Ristich et al. (1977)
McGrath (1974)

shown to be a sensitive indicator of petroleum pollution (Blumer et al., 1970). In addition, amphipods were entirely absent from samples closer to the Arthur Kill where PHC concentrations are higher, lending some support to a possible association between PHCs and depressed benthic communities.

A somewhat similar situation exists in the New York Bight where sediments originating from HRE have been deposited. Michael (in press) has concluded that contaminants in the New York Bight and lower Hudson River estuary have affected the distribution and abundance of benthic invertebrates and PHCs play a major role in this.

EFFECTS OF PHCs ON FISH

The variety of effects which PHCs have on fish are considered below. Generally lethal concentrations only occur in the vicinity of oil spills and then usually occur with spills of lighter petroleum products such as gasoline, jet fuel, kerosene, etc., (GESAMP, 1977).

However a number of deleterious effects have been reported at sublethal concentrations by Connell and Miller (1981). These include:

depression of metabolic rate
damage to gill tissue
fatty infiltration of the liver
narcotic effects
decline in lipogenesis in some organs.

Anderson (1979) in an analysis of the effects of PHCs concluded that the lethal toxicity range is approximately 1 - 20 ppm and the lowest concentration which would be expected to adversely affect organisms in the New York Bight would be about 100 ppb. In addition, the combination of low dissolved oxygen concentrations with PHCs leads to higher apparent toxicity of the PHCs. Many of the effects reported above have been noted at the concentrations of PHC which occur in HRE, i.e., 0.014 - 0.274 mg/ℓ.

The larval stages and eggs of fish are well known as being more sensitive than adults to toxicants (GESAMP, 1977). Also these organisms do not have the mobility to avoid contaminated areas. Black Sea Flounder larval stages have been shown to have a decreased survival rate at concentrations of 0.25 - 2.5 mg/ℓ.

This data suggests that it is possible for existing concentrations of PHCs in the HRE to have had an impact on the health of fish in the estuary and the survival of larvae and eggs. Direct investigation of fish, larvae and eggs from HRE would clarify this situation. Sindermann (1976) has concluded that petroleum hydrocarbons and other contaminants pose a significant threat to fisheries in the Middle Atlantic Bight.

Another important aspect of PHC in industrial waterways is the contamination of food organisms with PHCs leading to tainting and unsaleability of the product (e.g., Connell and Miller, 1981). Francis and Busch (1973) have partially attributed the decline in the shad (*Alosa sapidissima*) fishery to tainting by petroleum products. In fact, this problem was reported about 100 years earlier by Goode (1887) who indicated that shad from Newark Bay had a "coal oil" taint. It is also significant that McHugh and Ginter (1978) assess the shad fishery as underutilized.

EFFECTS OF PHCs ON BIRDS

Bird mortalities can be very high when oil slicks occur and feathers become severely contaminated by oil. Death usually results from exposure or starvation (GESAMP, 1977). Available information does not indicate that this is a significant problem in HRE.

However, recent work (Miller and Connell, 1980) indicates that seabirds may accumulate petroleum hydrocarbons from contaminated seafoods in an estuary suffering from chronic oil pollution. Such processes would be expected to occur in the HRE. The significance of petroleum hydrocarbons in the muscle tissue of seabirds, in terms of physiological disorders and related aspects, is not known.

PUBLIC HEALTH ASPECTS

The polycyclic aromatic hydrocarbons (PAH) include a number of substances which have been identified as potent carcinogens (Anon., 1973). Many of these substances occur in petroleum products and as a result, it has been suggested that the discharge of PHCs into the aquatic environment constitutes a potential carcinogenic hazard to man and aquatic organisms (Connell and Miller, 1981).

McLeod et al. (1981) have identified a number of PAHs in sediments and biota in HRE which are well known carcinogens, e.g., benzo(a)pyrene and benzo(a)anthracene. However, an analysis of health risk in man requires a quantitative evaluation of exposure to PAHs and a knowledge of exposure and cancer induction relationships. Such information is not available but it is possible to make an approximate evaluation of exposure from the available information.

The role of PHCs in assessing exposure to PAHs is complicated by the fact that there are quite a number of other possible sources of PAH apart from PHC. These include:

combustion products of fuels
cooked and smoked foods
cigarette smoke
seafoods
drinking water.

In the HRE area McLeod et al. (1981) have obtained data on the concentrations of a variety of PAHs in seafoods. Since most information is available on benzo(a)pyrene this substance was selected for further investigation. Table 11 contains a summary of some of their data. Most of this data consists of figures obtained at the lower limits of detection thus there is considerable uncertainty concerning the actual amount. It indicates that no particular organism stands out as being heavily contaminated with benzo(a)pyrene. The Striped Bass data suggests that there is no variation in benzo(a)pyrene concentration from the west of Montauk Point to the Hudson River. This could be due to the mobility of the fish or the fish acquiring the PAH from sources other than water and sediments, etc., in the HRE vicinity.

It is important to note that PAHs other than benzo(a)pyrene occur in comparatively high concentrations in some organisms (see Table 11).

The most reliable data in Table 11 is on the Striped Bass. This indicates concentrations of between 4 - 6 ng/g with an average of 5 ng/g. Using this figure and data from Connell and Miller (1981), the human exposure to benzo(a)pyrene can be calculated as in Table 12. The average U.S. consumption of seafood is 16.5 g/day (U.S. Dept. of Commerce, 1980) which yields an annual intake from seafood of 30 μg. Thus for a nonsmoking and non-smoked food consumer, the intake due to seafood is small compared with the intake from food in general (275 - 550 μg/year). An above average seafood consumer (i.e., 200 g/day) could be exposed to 365 μg/year from seafood and in this case, this would be a comparatively significant source of benzo(a)pyrene. If the other PAHs are taken into account, the exposure would be much higher.

It is difficult to assess the health risk from this data but it could be important in the case of above average seafood consumers and when all PAHs are considered.

TABLE 11

CONCENTRATIONS OF BENZO-A-PYRENE IN BIOTA
(From McLeod et al., 1981)

Sample	Number of Specimens	Area	Concentration (ng/g)	Comments
Winter flounder flesh	5 - 6	Raritan Bay	<6-<20	
	6 - 9	Raritan Bay	<8-<10	
Striped bass	5	West of Montauk Pt.	<8-<9	
	5	Montauk Pt.	5-6	
	5	Hudson River	4-6	
Lobster flesh	5	Raritan Bay	<6-<7	
digestive glands	5	Raritan Bay	aver 300	
Blue mussel	63	Sandy Hook	<5-<9	Other PAHs are present in high concentration, e.g., benz-a-anthracene 700 ng/g
	324	Staten Is., Coney Is., Rockaway Beach	<10	As above, pyrene 1100 ng/g
Surf clam	---	Rockaway Beach	<4-<20	
Shrimp	---	Raritan Bay	<23-<30	Other PAHs with concentrations, e.g., pyrene 280 ng/g

TABLE 12

ESTIMATED HUMAN EXPOSURE TO BENZO-a-PYRENE VIA RESPIRATORY AND GASTRO-INTESTINAL INTAKES IN THE NEW YORK AREA*

Source	Daily Consumption	Estimated Annual Intakes (micrograms) B(a)P
Respiratory Intake		
Air		0.05-500
Cigarette Smoking		
	20 cigarettes	15-900
	40 cigarettes	30-1800
	60 cigarettes	42-2700
Gastro-Intestinal Intake		
Water	2.5 litres	6-70
Food		
Normal Diets	1.5 kg	250
	1.5 kg	275 -550
Smoked Food Diet	1.5 kg	500-3000
Potential Seafood Contribution	10 g	18
	25 g	46
	50 g	91
	100 g	183
	200 g	365
	500 g	913
Contaminated Seafood Loadings Estimated by GESAMP	24-84 g	293-920

*Adapted from Connell and Miller, 1981.

CONCLUSIONS

The main conclusions which can be drawn from currently available information are set out below:

1. The major discharges of PHCs into the HRE probably arise from sewage, industrial wastes and urban run-off.

2. Benthic respiration is likely to be an important mechanism for the removal of PHC from the estuary.

3. A comparatively low proportion of the PHCs discharged to the HRE pass through the Sandy Hook-Rockaway Point Transect to the New York Bight. But this combined with discharges due to dredging activities is significant.

4. Toxic components of PHC seem to have had a deleterious effect on benthic populations in Raritan Bay.

5. The sublethal toxic effects of PHCs could have a deleterious effect on populations of fish and phytoplankton.

6. Seafood could contribute a significant proportion of benzo(a)pyrene to the total intake of this substance in some members of the population.

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