

ALASKA LEGISLATURE SPECIAL COMMITTEE/SUBJECT FILE 8672

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(The half-life of benzene in water is about 37 minutes: Fishbein, 1984.)

When detected at all in the water column, VOAs are present nearly always at very low concentrations. The detection limit for the VOA analytical method is about 1 ppb. Many of the results obtained in this study were below this method detection limit. Thus, average concentrations for groups of samples from a field survey often were below 1 ppb because the averages included zero values. (For completeness, additional detail concerning sample data and numerical treatment of concentrations below the detection limits are provided in the Appendix.)

The highest measured concentrations of volatile aromatic hydrocarbons in the water column occurred in the days immediately after the spill (Figure 3). The curve in Figure 3 was constructed from the average concentrations of VOAs from all depths at all primary stations for each field survey. VOAs were not measured in the February-March, 1990 survey. The average measured concentration of VOAs peaked at slightly less than 2 ppb at the time of the second field survey in early April (April

4 to 10). The lower average VOA concentration at the time of the first water quality field survey may be because the spilled oil had not yet reached all the primary stations at the time of that field survey. In addition, because of contamination problems with one of the sampling devices (discussed above), results of analysis of many subsurface water samples from the first field survey were rejected.

At the time of the first and second field surveys in late March and early April, the average concentration of VOAs in the water column at background sites was about 1 ppb, comparable to average concentrations in field blank samples collected at the same times. By late April, the average concentrations of VOAs at background (0.18 ppb) and primary (0.20 ppb) sites were indistinguishable, and comparable to concentrations in blank samples, and they have not varied significantly since then. The decrease in VOA levels in background and blank samples from 1 ppb to about 0.18 ppb was due primarily to improvements in the sampling and analytical methods that resulted in lowering in the limits of detection for the analytical technique.

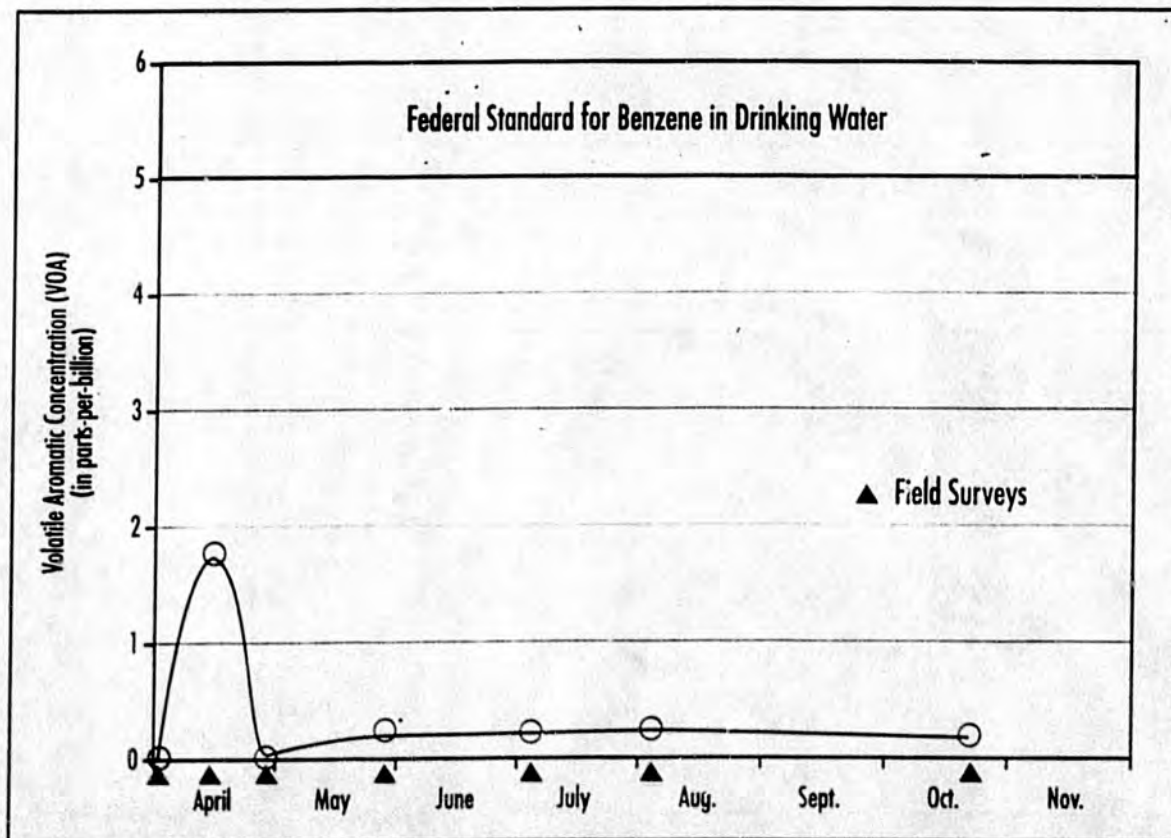


Figure 3. Average Volatile Aromatic (VOA) Concentrations at Primary Offshore Sites in Prince William Sound

When quality control samples (blanks) yield concentrations similar to those in seawater samples, it is an indication that the analysis method is being pushed to its limit of applicability. In such cases, actual concentrations in the water column probably are lower than the values reported.

To put these extremely low concentrations in perspective, the federal standard for the concentration of benzene (one of the components of VOA) in drinking water is 5 ppb, a benzene concentration never exceeded in any seawater sample collected with noncontaminating water sampling devices during the offshore water quality program in Prince William Sound.

A total of 755 water samples (including 302 quality control samples) were collected for VOA analysis. Of the 453 samples of seawater from Prince William Sound, more than 91 percent (413 samples) contained less than 1 ppb total VOAs (Figure 4). Only 1.5 percent of samples (seven samples collected from primary stations in April) contained more than 5 ppb total VOAs. The highest concentration measured was 25 ppb.

As described above and in the Appendix, one water sampling device was difficult to clean to the required standards and VOA data from samples collected with that device were not used. Another sampling device used also had contamination problems, but not severe enough to warrant

rejection of the data produced for samples collected with it. This sampler was used almost exclusively to collect water samples from 3 and 9 meters below the water surface. All 7 of the water samples containing more than 5 ppb VOA were collected with this sampler during the second water quality survey (early April) from 3 or 9 meters below the water surface, and probably were contaminated by the sampling device.

Given the generally very low concentrations of VOAs at all stations and the short duration of slightly elevated concentrations of VOAs in the water column at a few primary stations in April, it is extremely unlikely that any adverse effects to water column organisms in Prince William Sound occurred as a result of exposure to these volatile aromatic hydrocarbons.

• Polycyclic Aromatic Hydrocarbons (PAH)

Polycyclic aromatic hydrocarbons are composed of two or more fused (sharing two carbon atoms) benzene rings. Most PAH in the marine environment come from two sources, petroleum products and soot produced by the burning of organic materials, including fuels (Neff, 1979). More than 90 percent of the PAH in crude oil contain two or three rings. These compounds are slightly soluble in seawater (solubility of naphthalene is about 22 ppm and that of phenanthrene is about 1 ppm) and they are moderately toxic to marine organisms (Neff and Anderson, 1981). Because they evaporate from seawater more slowly than the VOAs, they are thought to be the most important contributors to the toxicity of spilled oil to organisms living in the water column (Neff, 1990b).

PAHs do not persist long in solution in the ocean. They adsorb rapidly to solid surfaces, such as particles suspended in the water, or collect at the water surface to form a surface sheen. Because the concentrations of these compounds in the water column are so low, the detection capabilities of an existing EPA-approved analytical method were improved by a factor of about 100 to allow better tracking of the distribution and fate of these components of oil in the water column over time. The method developed has a nominal detection limit of about 10 parts per trillion (0.01 ppb) per component (e.g., naphthalene) of the PAH mixture. However, during the course of the Prince William Sound and Gulf of Alaska water quality programs, the method was modified to lower the

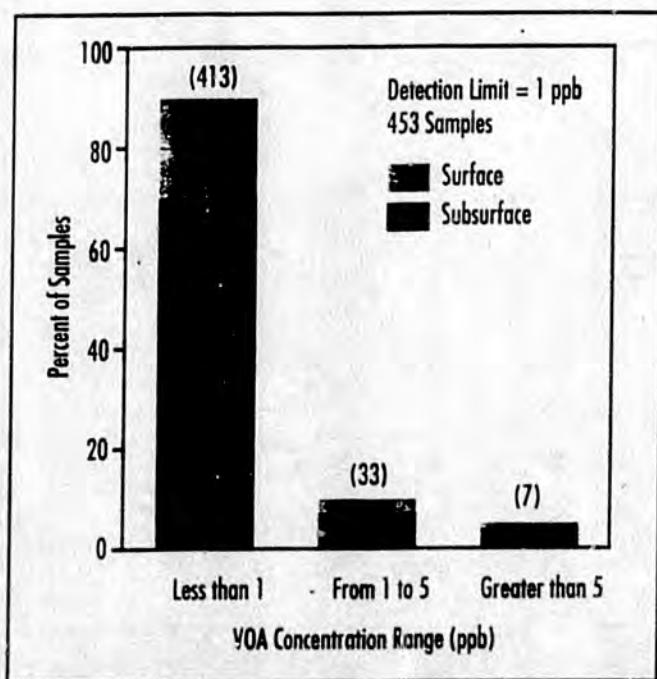


Figure 4. Distribution of Volatile Organic Analyses (VOA) (Offshore Prince William Sound)

detection limits even further. The method was also modified to improve its specificity for PAHs characteristic of crude oil. Total PAH, as discussed in this report, is the sum of the concentrations of a total of 37 individual PAHs ranging from naphthalene to benzo[*g*, *h*, *i*]perylene.

A total of 1,003 water samples for PAH analysis were collected between the end of March, 1989 and March, 1990 as part of the offshore water quality program. This total includes 203 samples collected for quality control. As with the VOA concentrations, average concentrations of PAHs in the water column of Prince William Sound reached a peak in April (*Figures 5a and 5b*). As expected, the highest concentrations were in bays and offshore waters near islands in the western Sound where large amounts of oil drifted in the first few weeks after the spill. The highest average concentration of total PAH in the water column of the three most heavily contaminated sites in the period shortly after the spill (Bay of Isles, Smith Island, and Herring Bay) was only 0.7 ppb (7 percent of the State of Alaska marine water quality standard of 10 ppb aromatic hydrocarbons: *Figure 5b*). The slightly elevated average value (0.32 ppb) indicated on the July survey results almost entirely from a single surface sample with a 3.2 ppb PAH concentration from Smith Island. The inclusion of this sample analysis increased the average value from 0.041 ppb to the 0.32 ppb indicated in *Figure 5a*. The highest average concentration of total PAH at all primary sites was about 0.2 ppb, only 1/50th of the State standard. This average value was recorded for samples collected during the third field survey about 1 month after the spill.

As expected, the average concentrations of total PAH in seawater from background sites were very low (the highest mean value was 0.08 ppb) and did not vary significantly with time during the spring and summer of 1989. The apparent very slight elevation in the average concentration of total PAH in seawater from background sites at the time of the second and third field surveys in April was due to four samples (two from each survey) containing much higher concentrations of total PAH than other samples from all background sites.

The two anomalous samples from the second field survey were collected from 1 and 9 meters at an open-water site about halfway between Port Fidalgo and the north shore of Hinchinbrook Island just east of the tanker lanes. The anomalous

samples from the third field survey were collected from 3 meters at Unakwik Inlet and from the surface in upper College Fjord. The College Fjord sample had the highest concentration of total PAH (0.99 ppb: one-tenth of the Alaska standard) of all water samples from background sites and may have been contaminated by a micro-tarball or bilge washings from the survey vessel. The PAH assemblage had characteristics of both a diesel fuel and a pyrogenic (engine exhaust) source.

The average concentrations of total PAH in water samples from the fourth through eighth field survey ranged from 0.02 to 0.06 ppb. Thus, the results of the analysis of water samples from background sites both north and east of where the spilled oil drifted provide strong evidence that there was not widespread contamination of the water column throughout Prince William Sound, even for a short period after the spill.

However, elevated concentrations of PAH were observed at some primary sites, particularly during April. Between March and June, 1989, the highest average concentrations of total PAH at primary sites occurred in samples from the water surface (*Figure 6a*). PAH concentrations tended to decrease with depth in the water column. Samples collected from the water surface following an oil spill often contain sheen, mousse, or tar balls that were floating on the water surface and so were not actually present in the water column. The average concentration of total PAH in water samples from the surface reached a peak of nearly 0.9 ppb in late April. The highest average concentration of total PAH in deeper waters (1, 3, 9, and 30 meters) was just over 0.1 ppb and was reached in mid-April. After the fifth field survey (early July), average PAH concentrations were uniformly low (mean concentrations ranging from 0.03 to 0.06 ppb) at all water depths. These concentrations were similar to those in water samples from background stations and in blanks collected at the same time as the water samples. Therefore, they reflect a return to background conditions in the offshore water column of Prince William Sound. All average concentrations are well below the Alaska standard (*Figure 6b*).

As shown in *Figure 7*, 6.5 percent of all water column samples (52 of 798 samples) from the offshore water quality program contained total PAH concentrations below the approximate method detection limit of 0.01 ppb (10 parts per trillion). More than 78 percent of the samples

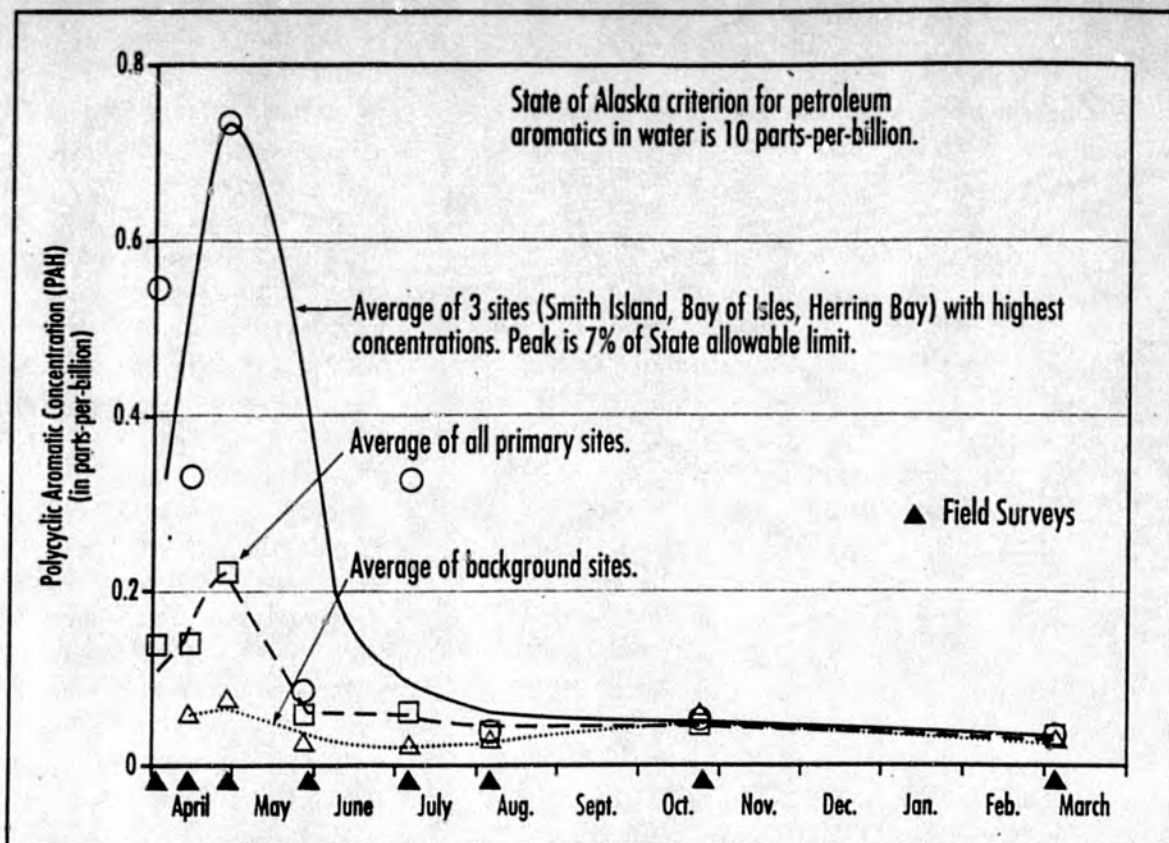


Figure 5a. Average Polycyclic Aromatic Hydrocarbon (PAH) Concentrations at Primary Offshore Sites in Prince William Sound

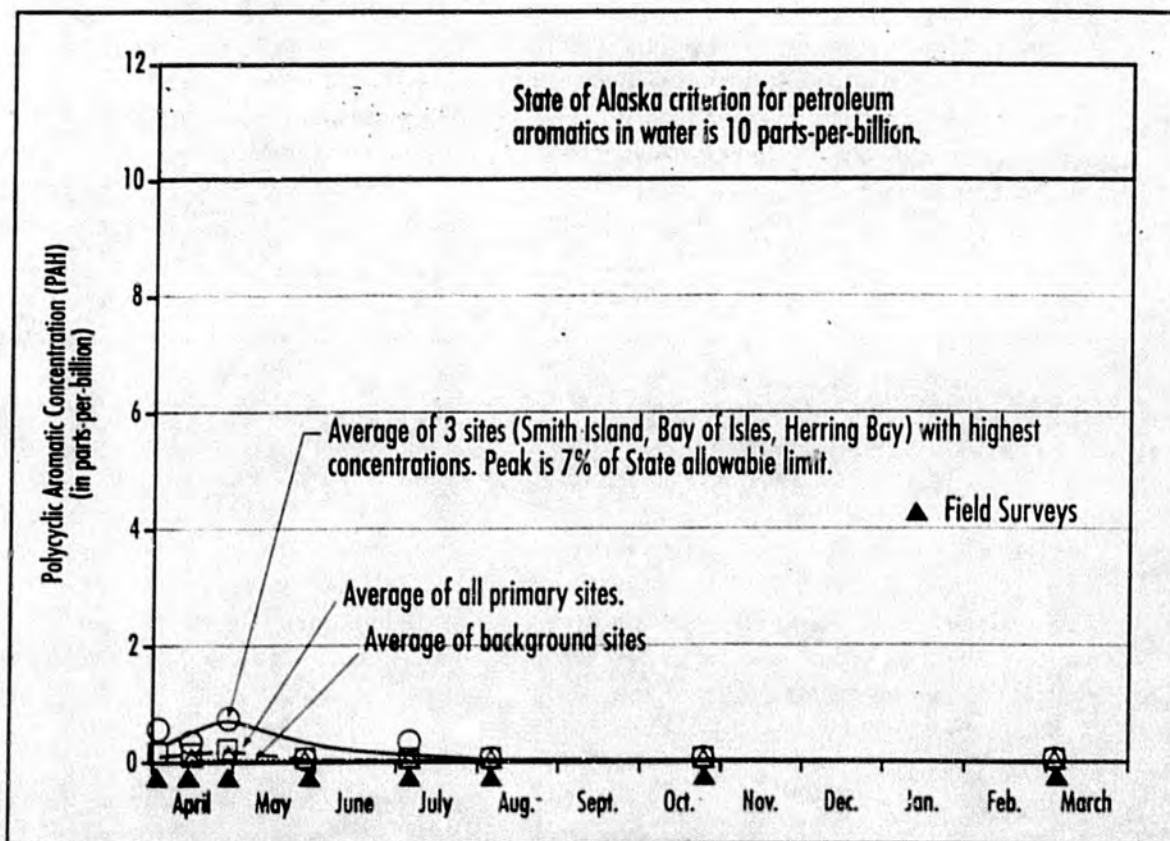


Figure 5b. Average Polycyclic Aromatic Hydrocarbon (PAH) Concentrations at Primary Offshore Sites in Prince William Sound (expanded scale)

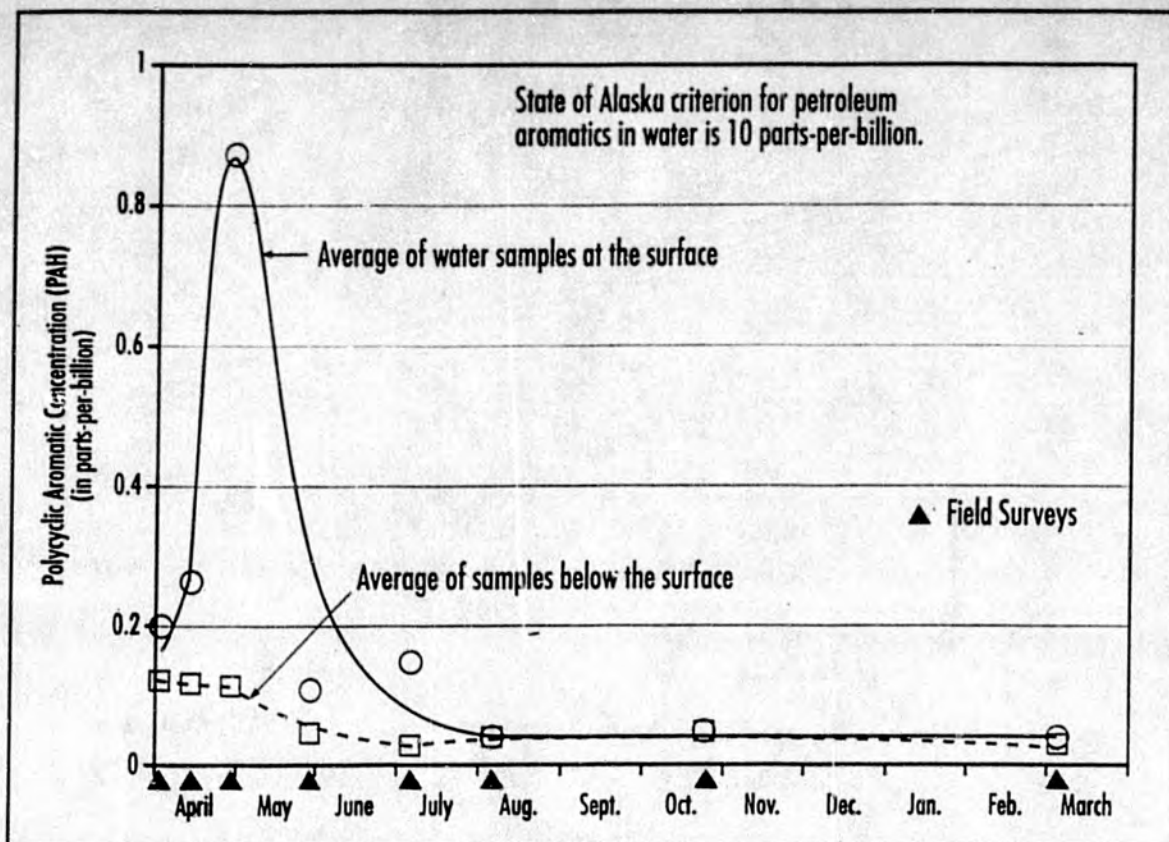


Figure 6a. Average Polycyclic Aromatic Hydrocarbon (PAH) Concentrations for Surface and Deeper Water at Primary Offshore Sites in Prince William Sound

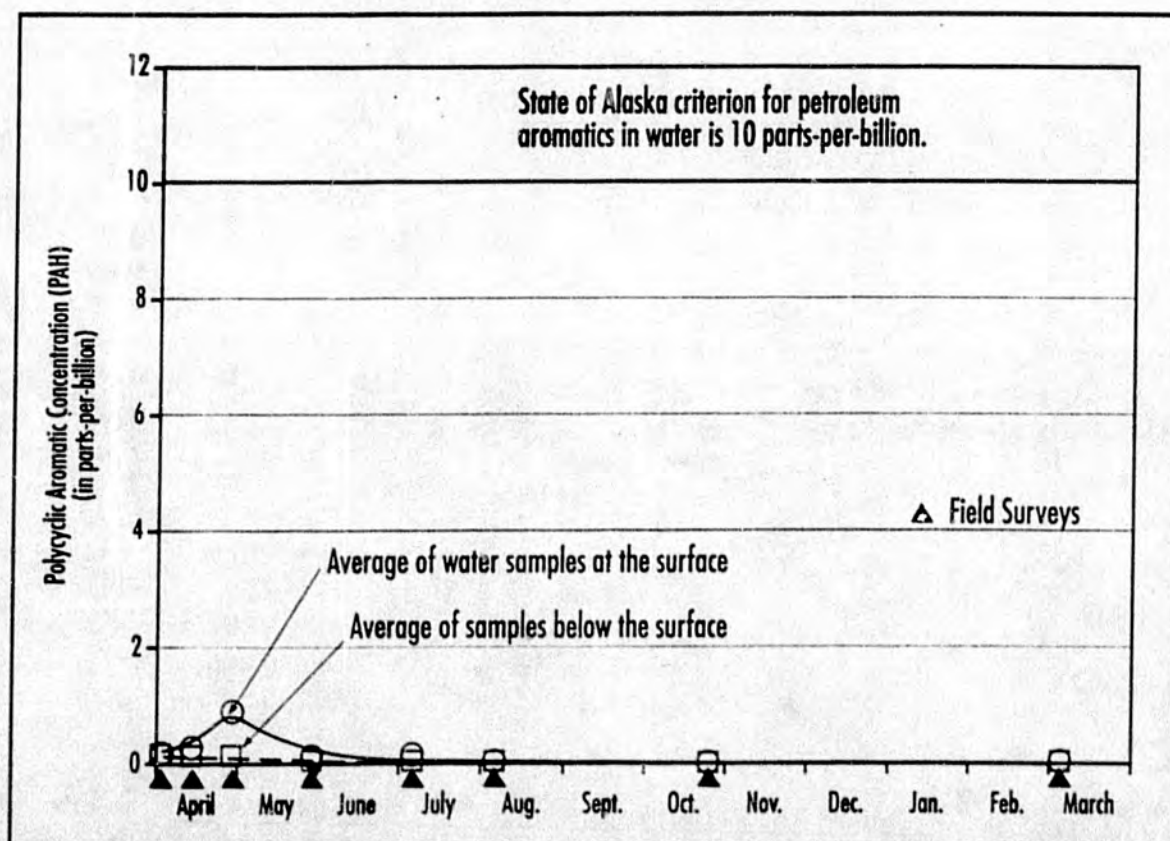


Figure 6b. Average Polycyclic Aromatic Hydrocarbon (PAH) Concentrations for Surface and Deeper Water at Primary Offshore Sites in Prince William Sound (expanded scale)

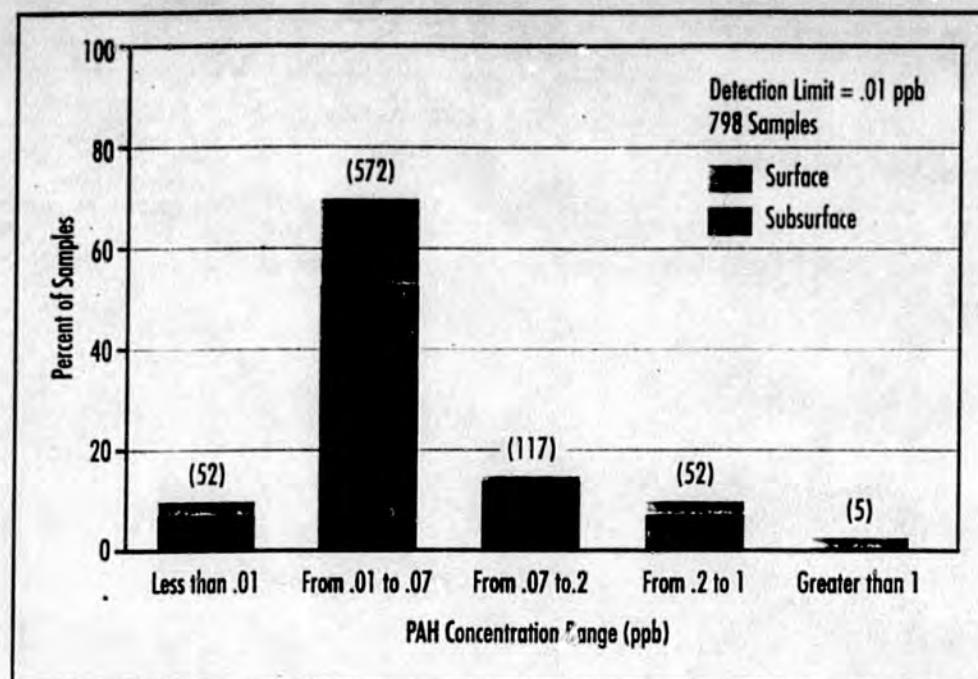


Figure 7. Distribution of Polycyclic Aromatic Hydrocarbon (PAH) Analyses (Offshore Prince William Sound)

contained 0.07 ppb or less of total PAH. One surface water sample each from Snug Harbor and Northwest Bay, collected in late April, contained 12.5 and 41.7 ppb PAH, respectively. These samples contained mousse material [see the discussion of total petroleum hydrocarbon (TPH) concentrations below] and so were not included among the samples used to calculate means. The next highest PAH concentration measured in a sample collected in this program was 7 ppb. This sample was from the surface and was collected in late April from the Bay of Isles, a heavily oiled area. Only 5 water samples (0.6 percent) contained more than 1 ppb PAH. All these samples were surface water samples.

The highest average concentrations of total PAH shown in Figures 5, 6, and 7 are at least 10 to 1,000 times lower than concentrations that are lethal or cause harmful sublethal effects in even the most sensitive species and life stages of marine organisms. In addition, the distribution of PAH in the water column has been extremely uneven over both wide temporal and spatial scales so that organisms occupying different positions in the water column probably would not be exposed for long to any PAH concentrations higher than background levels.

• **Petroleum Hydrocarbons (PHC) and Total Petroleum Hydrocarbons (TPH)**

Two additional methods were used to characterize the distributions and concentrations of petroleum hydrocarbons in the water column. The first of these methods is a gas chromatographic analysis of total recoverable petroleum hydrocarbons (PHC). It has a detection limit of about 50 ppb and measures all the petroleum hydrocarbons (both saturated and aromatic) in the sample. It is subject to interference by saturated hydrocarbons produced naturally by terrestrial plants and marine plants and animals.

The second method is an infrared analysis for total hydrocarbons (TPH). It is not very sensitive (detection limit of about 1 ppm), is very subject to interference from nonpetroleum organic matter, and is useful only for rapid screening at heavily contaminated sites. These two methods are used primarily to provide estimates of the concentration of total petroleum hydrocarbons in samples. In addition, gas chromatographic analysis provides information on the composition and relative concentrations of saturated hydrocarbons in the sample. This information may be used with the PAH compositional information to identify the source of the hydrocarbons present in a sample.

More than 89 percent of the water samples analyzed for PHC contained nondetectable concentrations (less than 50 ppb); slightly less than 3 percent (23 of 778 water samples) contained more than 100 ppb, and the remainder contained from 50 to 100 ppb. The highest values obtained corresponded to the highest values for PAH, mentioned above. All of these were surface samples from Snug Harbor (459 ppm PHC), Northwest Bay (1,700 ppm PHC), and the Bay of Isles (1 ppm PHC). The first two concentrations are much larger than the solubility of hydrocarbons in sea water and contained mousse material, as confirmed by the contractor involved. The Bay of Isles sample may have contained some sheen oil, as the PAH profile in the sample resembled that of weathered North Slope crude oil.

Concentrations of TPH in more than 96 percent of all seawater samples (276 of 286 samples) were below the method detection limit. Additional information about the results of PHC and TPH analyses, including figures, is provided in the Appendix.

OFFSHORE RESULTS SUMMARY

More than 3,160 samples of water (including 845 quality control samples) collected at offshore locations throughout Prince William Sound and at several water depths between the end of March, 1989 (6 days after the spill) and March, 1990 have revealed that the concentrations of total petroleum hydrocarbons as well as the toxicologically more important volatile aromatics (VOAs) and polycyclic aromatic hydrocarbons (PAH) have been consistently very low. Highest concentrations occurred in April, within one month of the spill, and then quickly returned to near background levels where they have remained ever since. The highest concentrations of PAH that were observed always occurred in samples from the water surface and probably contained sheen, mousse, or tar ball material.

NEARSHORE WATER QUALITY

A total of 1,342 water samples (plus 690 quality control samples) were collected for analysis of petroleum hydrocarbons in shallow waters adjacent to oil-contaminated shores in Prince William Sound. Study sites were selected to encompass a wide variety of shoreline types, extent of exposure to the energy of storm waves, and

degrees of oil cover. Two types of study sites were included in the nearshore water quality program:

- **Shoreline Monitoring Sites**

At these 51 oiled sites, nearshore water quality was monitored five times between March and October, 1989, independent of the time the sites were treated. These sites are identified by circles in Figure 8.

- **Shoreline Treatment Monitoring Sites**

At 14 sites, water quality samples were collected outside boomed areas before and at intervals between 1 and 30 days after treatment of the adjacent shoreline by different methods to remove oil. These sites are identified by triangles in Figure 8.

FIELD PROGRAM

Water samples were collected at shoreline monitoring sites during five field surveys from March through October, 1989. Water samples were collected below the low tide line at or near the water surface and at depths below the surface ranging from 1 to 42 meters (3 to 138 feet).

Water samples were collected between mid-July and mid-September, 1989 at shoreline treatment monitoring sites in western Prince William Sound shortly before (usually one day) and at intervals between 1 and 30 days after the adjacent shoreline was treated with cold water, high-pressure hot water, beach cleaning agents, or a combination of methods to remove oil. During treatment, oil from the shore was washed onto the nearshore water surface in an area enclosed by booms. The oil on the water surface was recovered with skimming equipment. Water samples were collected outside boomed areas 0.5 to 1 meter (1.5 to 3 feet) below the surface and 0.5 meter (1.5 feet) above the bottom at locations offshore near where the booms were deployed.

Sampling methods, sample-handling procedures, quality assurance/quality control, and analytical methods were the same as used for the offshore water quality program.

ANALYTICAL RESULTS

The focus of the discussion here is on the potentially toxic VOAs and PAHs in the water column adjacent to oiled shores. As with the water samples from the offshore water quality program, most measurements of PHC (82 percent) and TPH

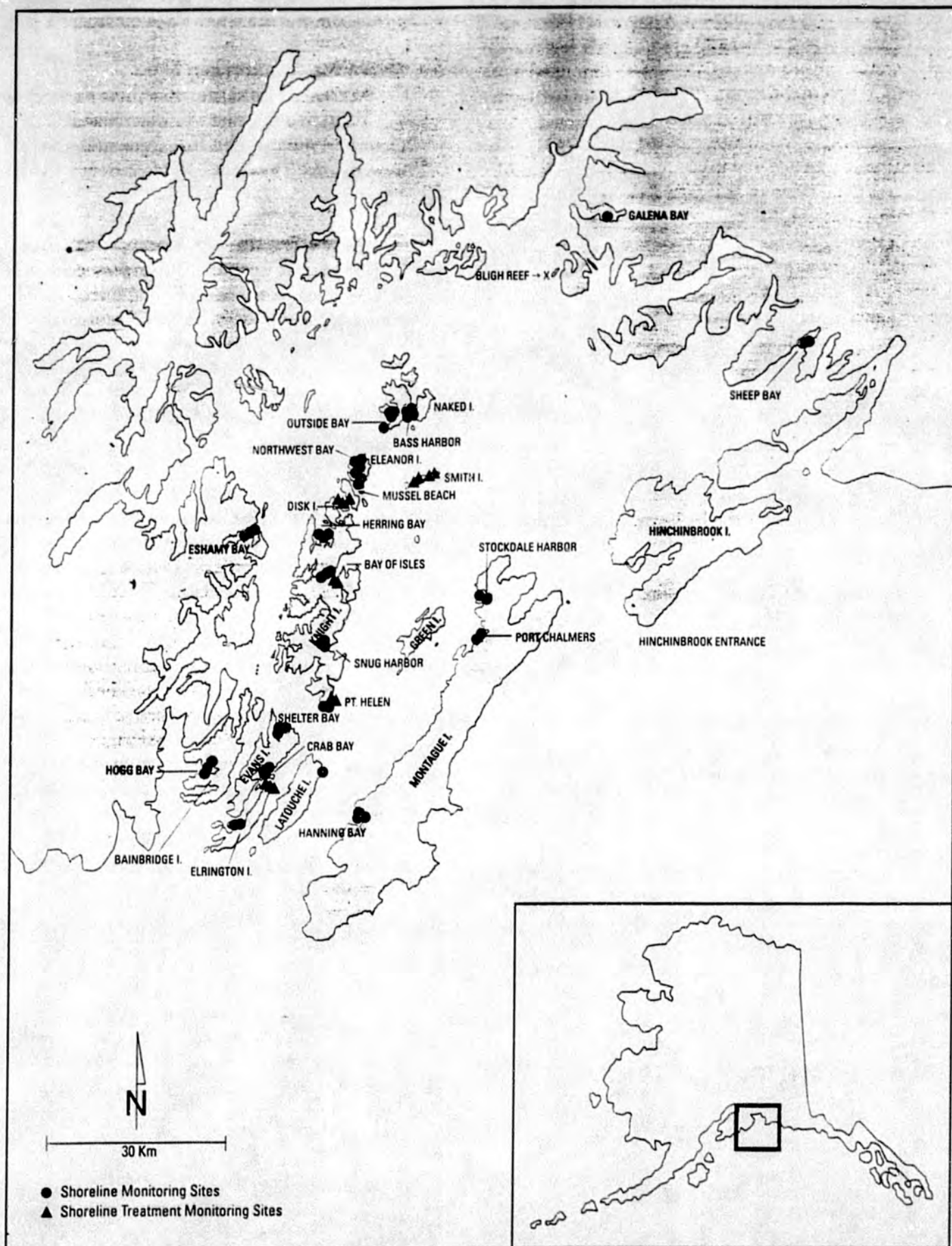


Figure 8. Station Locations in Prince William Sound Where Nearshore Hydrocarbon Concentrations Were Measured.

(96 percent) were below the method detection limits, indicating that concentrations of total petroleum hydrocarbons were generally very low in the water column adjacent to oiled shores. The results of these analyses are discussed further in the Appendix.

• **Volatile Organic Analytes (VOA)**

The results of the analysis of 349 water samples from shoreline monitoring sites for VOAs (plus 194 quality control samples) are shown in Figure 9. No samples for VOA analysis were collected during the shoreline treatment monitoring study. Concentrations of VOAs in 82 percent of the water samples (286 samples) were below the method detection limit of about 1 ppb; 16 percent contained between 1 and 5 ppb, and 1.7 percent (6 samples) contained more than 5 ppb.

The highest VOA concentration measured was 16 ppb in a surface water sample collected in Northwest Bay on Eleanor Island on June 24. The water sample from the 1-meter depth at the same sampling station and date contained 12.7 ppb total VOAs. Other water samples from several depths and locations in Northwest Bay sampled on the same date contained from 1.7 to 6.3 ppb total VOAs, indicating that the distribution of VOAs in the water column of the bay was very uneven. Most of the volatile aromatics in these samples were toluene and xylenes. Concentrations of benzene were below the federal standard for drinking water. It is highly probable that the concentrations of VOAs in even the most heavily contaminated samples were many times lower than concentrations that might cause adverse effects in sensitive marine organisms.

• **Polycyclic Aromatic Hydrocarbons (PAH)**

Results of the analysis for PAH of 310 water samples (plus 158 quality control samples) collected during the shoreline monitoring program are summarized in Figure 9. As described below, one sample, that apparently included a tar ball, was excluded from Figure 9. Results are also included from the analysis of an additional 82 water samples (plus 55 quality control samples) collected during the shoreline treatment monitoring program.

Most of the shoreline monitoring samples for PAH analysis were collected during the June-July and September-October field surveys. The shoreline treatment monitoring study samples were collected between mid-July and mid-September.

Concentrations of total PAH in about 11 percent (42 samples) of the water samples from both studies combined were below the method detection limit of about 0.01 ppb. Over 73 percent of the water samples contained from 0.01 to 0.2 ppb total PAH, and 12 percent (47 samples) contained between 0.2 and 1 ppb total PAH. A total of 16 samples (4 percent) from both studies contained more than 1 ppb total PAH.

Eight of the 16 samples that contained more than 1 ppb total PAH were obtained in the shoreline monitoring study on June 24 from Northwest Bay, the site and time of the collection of the water samples containing high VOA concentrations.

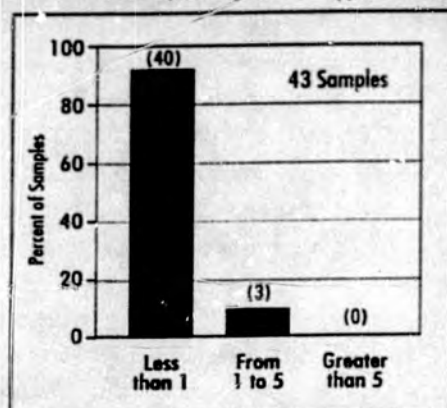
The sample with the highest concentration (30 ppb total PAH) was a surface water sample from the same location in Northwest Bay as the surface sample containing the highest concentration of VOAs. Water samples from other locations and water depths in Northwest Bay sampled in June contained between 0.39 and 14 ppb total PAH, indicating, as did the VOAs, a very uneven distribution of hydrocarbons in the water column of the bay. Water samples collected from Northwest Bay during the next field survey in September contained between 0.005 and 0.014 ppb total PAH, suggesting that the presence of elevated concentrations of PAH in the water column of this bay was a short-lived event. One water sample from 1 meter below the water surface, collected off a heavily oiled beach at the entrance to Shelter Bay in mid-September as part of the shoreline monitoring study, contained 710 ppb total PAH and apparently contained a tar ball. This sample was excluded from consideration. Eight other samples collected at the same time and location from several water depths contained between 0.01 and 0.04 ppb PAH.

Five water samples from the shoreline treatment monitoring study contained more than 1 ppb total PAH. Three of the samples were from the water surface and two were from one meter below the surface; the samples contained 1.0 to 2.4 ppb PAH and were collected after treatment of heavily oiled beaches on Disk and Knight Islands.

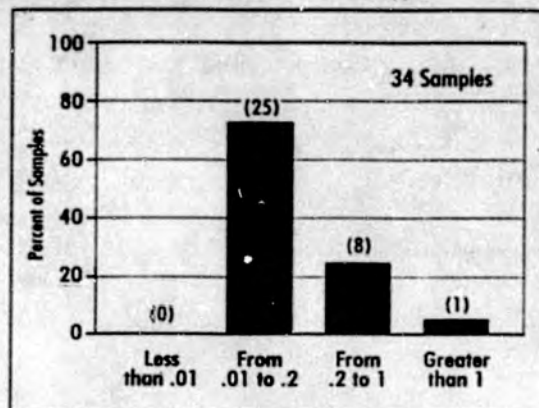
Shoreline Monitoring Sites

March - May
Surveys

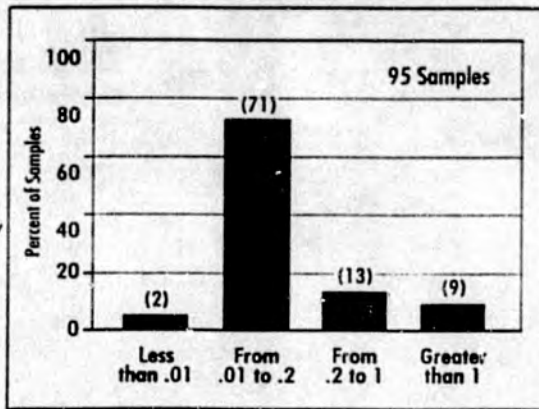
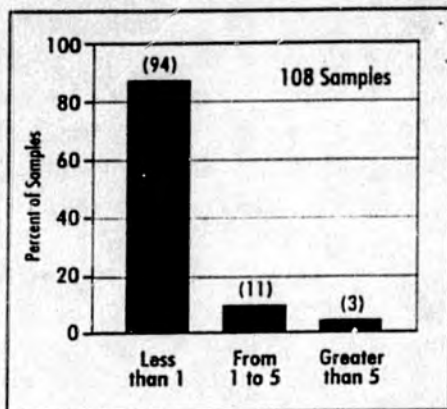
VOA (Detection Limit = 1 ppb)



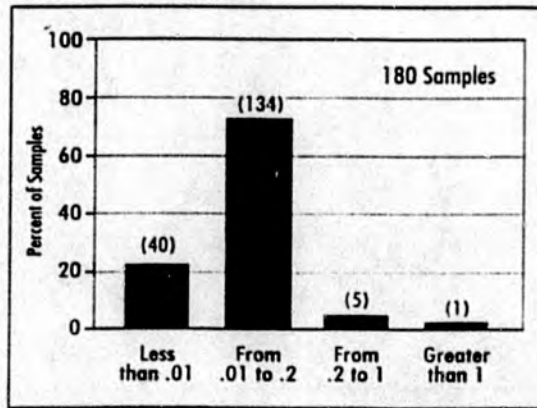
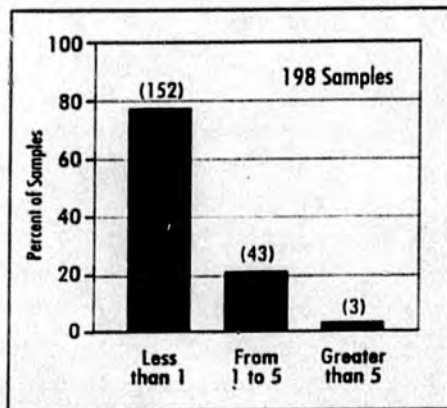
PAH (Detection Limit = .01 ppb)



June - July
Surveys



September -
October
Survey

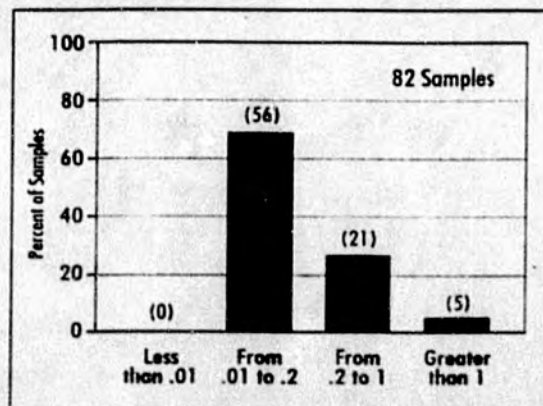


VOA Concentration Range (ppb)

Shoreline Treatment Monitoring Sites

July -
September
Surveys

No VOA Measurements
Made at Shoreline Treatment Sites



PAH Concentration Range (ppb)

Figure 9. Distributions of Volatile Aromatic (VOA) and Polycyclic Aromatic Hydrocarbon (PAH) Analyses (Nearshore Prince William Sound)

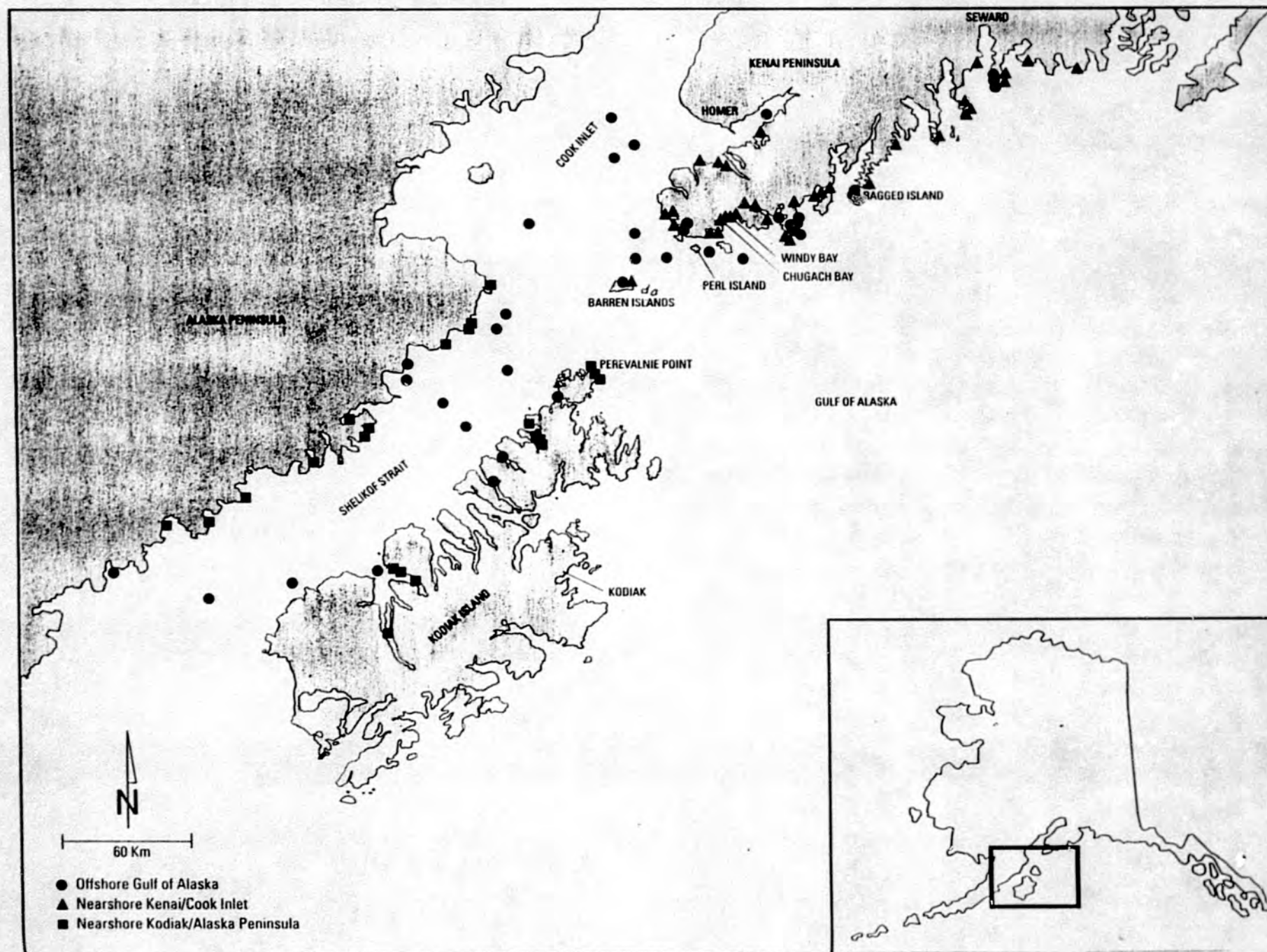
NEARSHORE RESULTS SUMMARY

Water samples collected near several oiled shorelines in Prince William Sound contained very low concentrations of VOAs and PAHs, comparable to those measured in water samples collected during the offshore water quality program.

Therefore, it is highly unlikely that petroleum hydrocarbons present at trace concentrations in the water column adjacent to oiled shores produced any adverse effects on marine plants and animals living in the water column.

The highest concentrations were localized in sheltered bays (particularly Northwest Bay, a heavily oiled site). Even in these sheltered bays, concentrations of petroleum hydrocarbons in the water column were quite variable in both space and time, strongly suggesting that these elevated concentrations were short-lived.

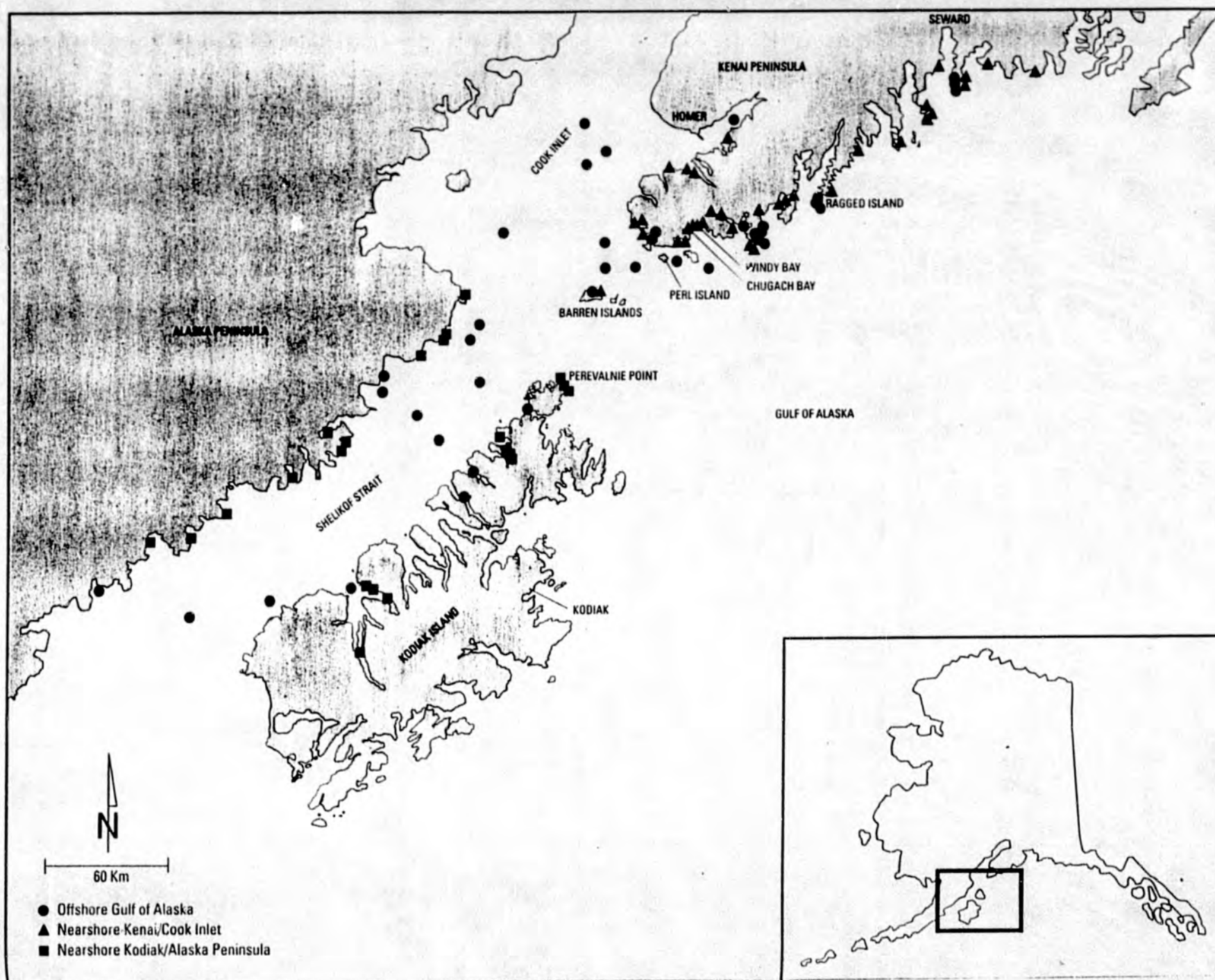
Figure 10. Station Locations in Western Gulf of Alaska Where Hydrocarbon Concentrations Were Measured.



CORRECTION

**THIS DOCUMENT
HAS BEEN REPHOTOGRAPHED
TO ASSURE LEGIBILITY**

Figure 10. Station Locations in Western Gulf of Alaska Where Hydrocarbon Concentrations Were Measured.



WATER QUALITY IN THE GULF OF ALASKA

A total of 1,356 water samples (plus 870 quality control samples) were collected for analysis of petroleum hydrocarbons from coastal and offshore areas of the western Gulf of Alaska (Figure 10) where some of the spilled oil moved. Three water quality studies were performed in the Gulf of Alaska:

- **Gulf of Alaska Offshore Water Quality Study**

Water samples were collected at 39 locations in offshore waters of the western Gulf of Alaska and lower Cook Inlet in April and May, 1989. Samples were collected in areas through which oil slicks and mousse were moving.

- **Kenai/Cook Inlet Nearshore Water Quality Study**

Water samples were collected in nearshore waters adjacent to 34 oiled shorelines during April and August of 1989.

- **Kodiak/Alaskan Peninsula Nearshore Water Quality Study**

Water samples were collected in nearshore waters adjacent to 22 oiled shorelines during July and August of 1989.

FIELD PROGRAM

Samples were collected during four field surveys during April and May, 1989 as part of the Gulf of Alaska Offshore Water Quality Study. Each field survey was to a different area of the Gulf of Alaska or lower Cook Inlet. Most samples were collected under or adjacent to visible oil slicks or patches of mousse on the sea surface. Sampling depths were 1, 3, 10, and occasionally 2 and 5 meters below the water surface. In the nearshore water quality studies, water samples were collected at or near the water surface and at 1 and 9 meters below the water surface in shallow water near oiled shorelines (within 100 meters).

Sampling methods, sample-handling procedures, quality assurance/quality control, and analytical methods were similar to those described above for the Prince William Sound studies.

ANALYTICAL RESULTS

The focus of the discussion here is on the potentially toxic VOAs and PAHs in the water column of the Gulf of Alaska. As in the water quality studies in Prince William Sound, nearly all the water samples analyzed for PHC (92 percent) contained concentrations below the method detection limit of 50 ppb. The results of these analyses are discussed further in the Appendix. Only six TPH analyses were performed on water samples from these studies, all resulting in nondetectable values.

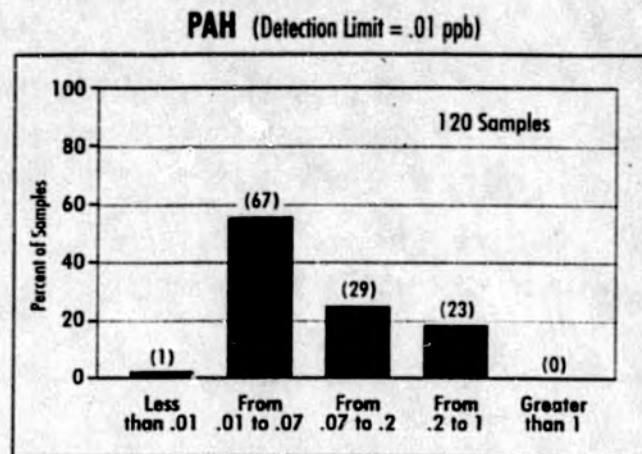
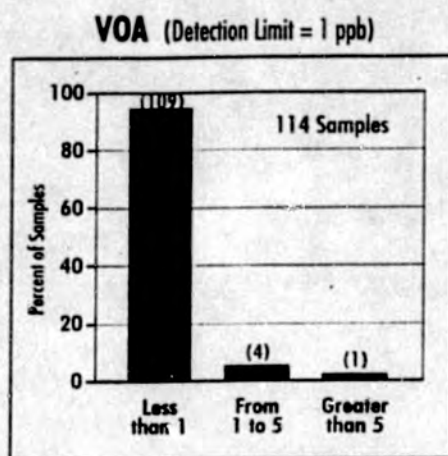
- **Volatile Organic Analytes (VOA)**

A total of 457 water samples (plus 271 quality control samples) were analyzed for VOA as part of the three Gulf of Alaska water quality studies. About 96 percent (109 samples) of the water samples for VOA analysis from the Gulf of Alaska Offshore Water Quality Study contained less than 1.0 ppb (Figure 11). Only one sample contained more than 5 ppb VOA. This sample contained 6.1 ppb VOA and was collected midway between the western tip of the Kenai Peninsula and the Barren Islands. The average concentration of VOA in all offshore water samples combined was 0.15 ppb.

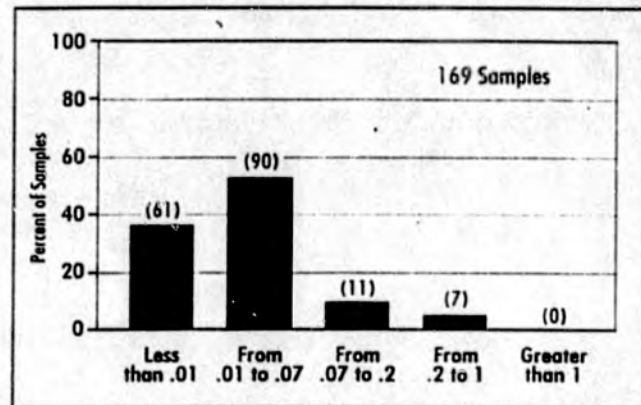
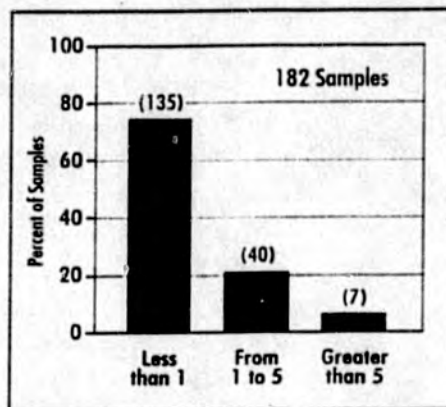
Concentrations of VOA were below the method detection limit of 1 ppb in more than 74 percent (135 samples) of the water samples collected for VOA analysis as part of the Kenai/Cook Inlet Nearshore Water Quality Study (Figure 11). Just under 4 percent of the samples (7 samples) contained more than 5 ppb VOA. The highest VOA concentration measured was 25 ppb in a water sample collected at the water surface in Chugach Bay in mid-August. A replicate sample contained 8.6 ppb VOA. The VOAs in these samples probably were derived from a source other than the spilled crude oil, since these volatile components do not remain long after a spill.

More than 81 percent (131 samples) of the 161 water samples collected as part of the Kodiak/Alaska Peninsula Nearshore Water Quality Study for analysis of VOA contained less than 1.0 ppb (Figure 11). Only two samples contained more than 5 ppb VOA. One of these, a surface water sample from Perevalnie Passage, contained 9.2 ppb

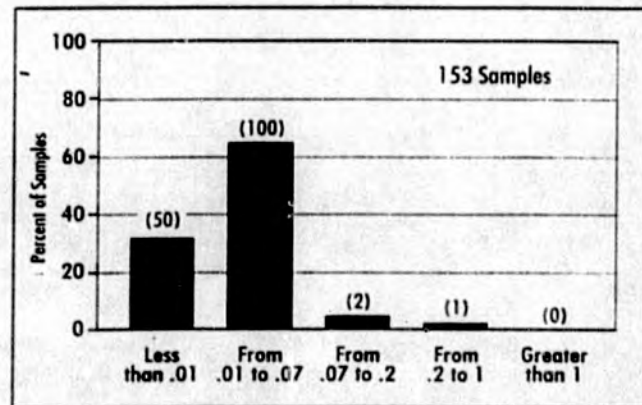
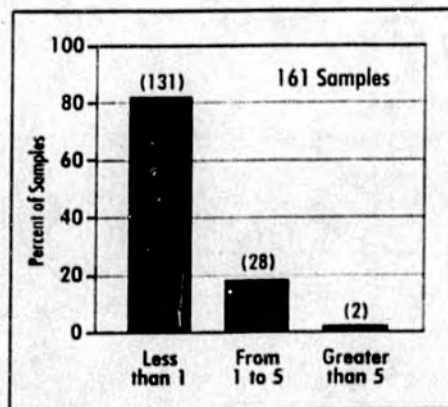
**Offshore
Gulf of Alaska**



**Nearshore
Kenai/Cook**



**Nearshore
Kodiak/Alaska
Peninsula**



VOA Concentration Range (ppb)

PAH Concentration Range (ppb)

Figure 11. Distributions of Volatile Aromatic (VOA) and Polycyclic Aromatic Hydrocarbon (PAH) Analyses (Western Gulf of Alaska)

VOA. The average VOA in all water samples combined from the Kodiak/ Alaska Peninsula Nearshore Water Quality Study was 0.7 ppb.

• **Polycyclic Aromatic Hydrocarbons (PAH)**

A total of 452 water samples (plus 307 quality control samples) were analyzed for PAH as part of the three Gulf of Alaska water quality studies. Results of analysis of water samples for PAH from these studies are summarized in *Figure 11*. Concentrations of total PAH in the offshore water column of the western Gulf of Alaska were quite low in April and May of 1989 at the time when surface oil slicks and mousse were moving through the area. The average for all 120 water samples collected during the Gulf of Alaska offshore water quality study for PAH analysis was 0.12 ppb. No water samples contained more than 1.0 ppb PAH. The highest concentration measured was 0.99 ppb in a sample collected east of Perl Island in early April from 9 meters below the water surface. Over eighty percent (97 of 120 samples) of the water samples contained less than 0.20 ppb PAH.

Approximately 34 percent of the water samples (111 of 322 samples) collected for PAH analysis during the nearshore water quality studies in the Gulf of Alaska contained less than 0.01 ppb PAH (*Figure 11*). Ten surface water samples collected adjacent to a heavily oiled site in Morning Cove on Ragged Island near the Kenai Peninsula during a storm in August contained 2.0 to 4,320 ppb total PAH. These samples also contained 2.2 to 2,800 ppm PHC and were reported by the field team to contain mousse material washing off the shore; they are not included in *Figure 11*. No other water samples from these two studies contained more than 1.0 ppb PAH. The average PAH concentration in water samples from the Kenai/Cook Inlet Nearshore Water Quality Study was 0.034 ppb; the average PAH concentration in water samples from the Kodiak/Alaska Peninsula Nearshore Water Quality Study was 0.019 ppb.

GULF OF ALASKA RESULTS SUMMARY

Concentrations of VOA and PAH in offshore and nearshore waters of the western Gulf of Alaska in areas affected by the spilled oil were uniformly very low during the spring and summer of 1989. Average concentrations of both VOA and PAH in water samples from the Gulf of Alaska were comparable to concentrations in water samples from Prince William Sound. A small number of surface water samples collected off a heavily oiled shore on the Kenai Peninsula during a storm contained very high concentrations of both PAH and PHC in the form of mousse and were not included in concentration averages because they contained free (undissolved) oil.

OIL SHEENS ON THE WATER SURFACE

INTRODUCTION

The results of the extensive water quality monitoring efforts discussed in the previous sections of this report indicate that concentrations of petroleum hydrocarbons in the water column throughout Prince William Sound, particularly since late April of 1989, have been sufficiently low that it is unlikely that there have been any adverse biological effects in marine plants and animals living in the water column. Oil washing off oiled shorelines during tidal flushing or storms may form a thin film (sheen) of oil on the water surface. Most of the highest petroleum hydrocarbon concentrations measured in the water quality studies were in samples collected at the water surface and probably contained material from surface sheens. Therefore, studies were initiated in October, 1989 to sample and analyze petroleum hydrocarbons in sheens observed in some heavily oiled bays in western Prince William Sound.

BACKGROUND

Poorly soluble organic materials, including petroleum, when added to water, tend to form a film on the water surface. A very thin film is colored and, therefore, is called a sheen. The color of a sheen changes with its thickness. A rainbow-colored sheen of petroleum is about three ten-thousandths of a millimeter thick (0.3 micrometers). By comparison, a typical sheet of paper is more than 450 times thicker than a rainbow sheen. Thinner sheens are silvery or blue; thicker sheens tend to have dull colors. Sheens thicker than a few thousandths of a millimeter (greater than about 2 micrometers) take on the color of the material forming the sheen and usually are called slicks. Table 1 illustrates the relationship between the color and thickness of a sheen or slick. Because rainbow sheens are so thin, they contain very little petroleum per unit area of water surface. A tablespoon of oil would form a rainbow sheen of about 625 square feet (a square 25 feet on a side).

Crude oil is not the only source of sheens in Prince William Sound. Natural organic material from decaying vegetation or from heavy schooling

of some fish, such as herring, can cause sheens that are difficult to distinguish from sheens caused by oil. Refined petroleum products such as gasoline, diesel fuel and lubricating oil readily cause sheens. Normal boat operations, particularly pumping of bilges, frequently produce oil sheens. In fact, Hodgson (1990) reported that tests performed by the National Oceanic and Atmospheric Administration, National Marine Fisheries Service in 1989 revealed that some fisheries in Prince William Sound were closed not only because of oil sheens from the crude oil spilled in the accident, but also because of sheens that were later shown to be bilge oil, diesel oil, and hydraulic fluid, and not related to the spill. That sheens in Prince William Sound result from various sources was also demonstrated by the Exxon sheen surveillance overnight program during 1990. As reported during weekly Exxon/agency (Alaska Department of Environmental Conservation and Coast Guard) meetings, by late summer only a small percentage of sheens observed were identified to be oil from the spill.

Table 1. Approximate Thickness of Crude Oil on the Sea Surface Based on Appearance (Color). (National Research Council, 1985)

Appearance	Approximate Oil Thickness (Micrometers)*
Barely visible	0.05
First trace of color (blue/silver)	0.15
Bright rainbow colors	0.30
Dull colors	1.0
Yellowish brown	10.0
Light brown or black, easily visible from aircraft	100.0
Thick dark brown, black, or orange emulsion (mousse)	1,000.0

*A typical page is about 140 micrometers (millionth of a meter) thick.

Regardless of the source, sheens typically are small, often containing no more than a few ounces to a few gallons of oil, and patchy in distribution. They usually are short-lived. Oil sheens dissipate rapidly due to natural weathering processes, including physical dispersion by breaking waves, evapora-

tion, degradation by the abundant bacteria living at the sea surface, photo-oxidation by sunlight, and dissolution into the water beneath the sheen.

COMPOSITION AND ENVIRONMENTAL SIGNIFICANCE OF CRUDE OIL SHEENS

In the sheen study, water samples were collected in one-liter bottles from 10 heavily oiled bays in western Prince William Sound in October, 1989. Surface water samples were collected in sheens whenever they were observed. The sampling method collected water from approximately the upper centimeter (0.4 inches) of the water column, including an area of the water surface of about 1,000 square centimeters (155 square inches). The sampling method produced samples that allowed the composition of the sheen to be determined and provided a semiquantitative estimate of the amount of hydrocarbons present per unit area of water surface. Fifty-three samples (including 14 quality control samples) were submitted for PAH analysis and 57 samples (including 15 quality control samples) were submitted for PHC analysis.

The concentrations of total PAH in 39 sheen samples ranged from below the detection limit (about 0.01 ppb) to 18.4 ppb (Figure 12). The sample containing 18.4 ppb was obtained from Northwest Bay, a site identified in the shoreline monitoring study, discussed earlier, as having high concentrations of PAH and VOAs in surface water samples. Fifteen percent (6 samples) of the samples contained more than 1.0 ppb PAH. Over 69 percent (27 samples) of the samples, however, contained less than 0.2 ppb total PAH.

Seventeen percent (7 samples) of 42 sheen samples analyzed for PHC contained more than 100 ppb PHC (Figure 12). Seventy-nine percent (33 samples) contained less than 50 ppb PHC. The highest concentration of PHC measured was 2,470 ppb in the same sample that contained 18.4 ppb PAH. Generally, there was a good correlation between the concentrations of PAH and PHC in the sheen samples.

By comparison, the concentrations of PAHs, measured as chrysene (a PAH) equivalents, in sheens collected from the open Atlantic Ocean near Bermuda were in the range of 0.4 to 3.04 ppb (Knap et al., 1986). These concentrations can be considered open ocean background values.

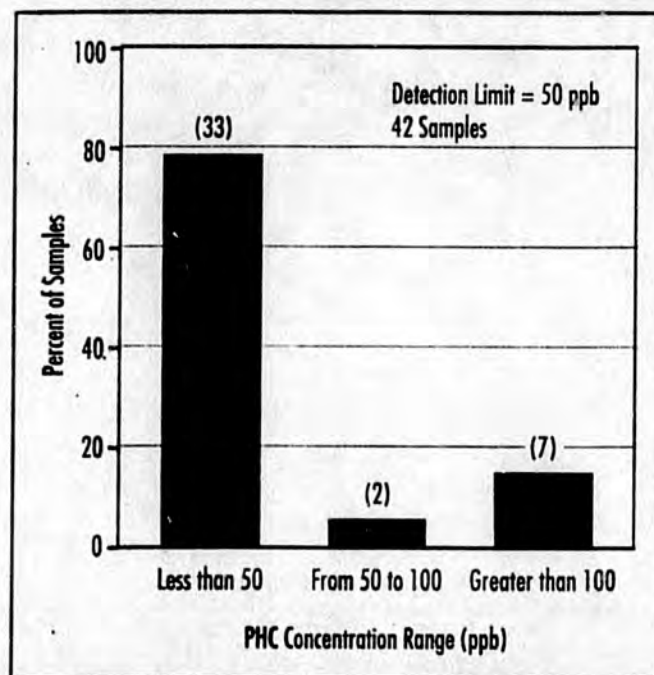
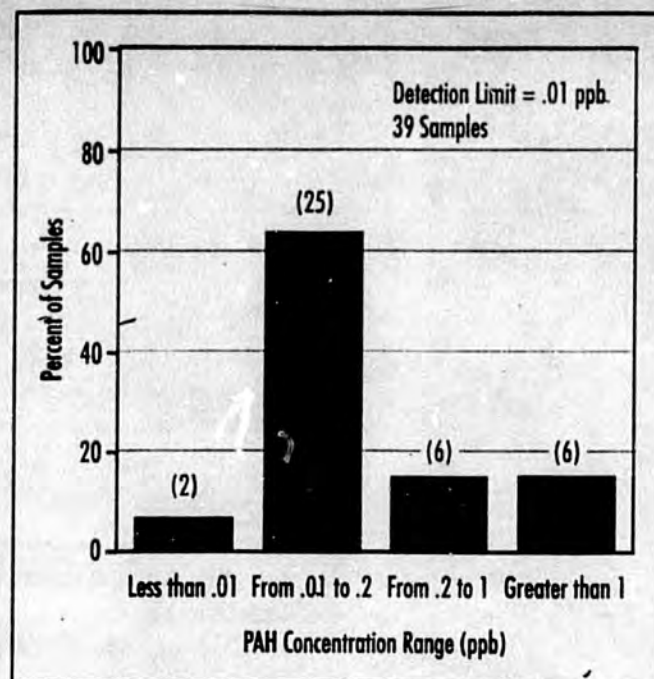


Figure 12. Distributions of Polycyclic Aromatic Hydrocarbon (PAH) and Petroleum Hydrocarbon (PHC) Analyses in Sheens from Bays in October, 1989 (Western Prince William Sound)

Careful evaluation of the PAH composition of the most concentrated sheens revealed that they contained PAHs from two different sources. Most of the PAHs were from highly weathered North Slope crude oil (the spilled oil). However, there were also relatively high concentrations of several PAHs that are found almost exclusively in PAH

assemblages produced during combustion of fossil fuels. These PAHs probably were derived from engine exhaust soot.

Due to the sampling method, it is uncertain exactly where the PAHs were distributed in the upper one centimeter of the water column. One hypothesis is that they were distributed throughout the upper one centimeter. A more likely hypothesis is that the bulk of the PAHs are concentrated in the sheen itself. This latter hypothesis is supported by the current understanding of how poorly soluble organic chemicals like PAHs become distributed between the water column and the air/water interface (Valsaraj, 1988).

A great many species of organisms live on or just below the surface of the ocean. Neuston are bacteria, plants, and animals that spend all or part of their life cycles associated with the water surface (Hardy, 1990). Included among the neuston are the eggs and larvae of several species of fish and invertebrates that spend the remainder of their lives deep in the water column or on the bottom of the sea. Walleye pollock and several species of soles are examples of commercially important Alaskan species of fish whose eggs and early larvae are neustonic.

A wide variety of potentially toxic organic chemicals and metals of natural and man-made origin tend to collect and accumulate at the air/sea interface. Although these accumulations of materials have been shown in laboratory tests to be toxic to neustonic organisms, the organisms apparently are able to adapt rapidly to chemicals in the microlayer (Hardy et al., 1987 a,b; Riznyk et al., 1987). Rich and diverse neuston communities can be found even in industrial ports where sheens contain high concentrations of toxic chemicals, including PAH.

In Puget Sound, Washington, there was a poor correlation between the high concentration of aromatic hydrocarbons in surface sheens and survival of the neustonic eggs of sand sole (Hardy et al., 1987 a,b). The mean concentration of total aromatic hydrocarbons in Puget Sound sheens was 132 ppb, and the maximum concentration was 8,030 ppb. In spite of this very high concentration, thirty-six percent of the fish eggs exposed to the sheen containing 8,030 ppb total aromatics (as well as high concentrations of PCBs, pesticides, and metals) produced normal larvae. Phytoneuston (microscopic plants living at the sea surface) were able to adapt within two days to artificial sheens

containing 1,000 ppb fluoranthene, another PAH (Riznyk et al., 1987). Thus, neustonic organisms do not appear to be particularly sensitive to PAH in surface sheens.

The concentrations of PAH measured in sheens from oil-contaminated bays in western Prince William Sound are all well below concentrations of aromatic hydrocarbons measured in sheens from Puget Sound. Because the sampling methods used in this study are only semiquantitative, actual PAH concentrations in some sheens could be higher than estimated here. However, the concentrations estimated in this study for sheen-covered waters are orders of magnitude below those found in the field or laboratory to cause harmful effects in the sensitive early life stages of marine organisms.

It is extremely unlikely that the permanent neuston (the organisms whose entire life cycle is spent at the water surface), upon which some commercially important species feed, or the temporary neuston (including the eggs and larvae of some commercially important fish and shellfish) of Prince William Sound are being adversely affected by the patchy, short-lived sheens of weathered crude oil occasionally being observed in parts of western Prince William Sound. If some of the neuston directly under a sheen were killed through direct contact and coating with sheen hydrocarbons, they would be replaced rapidly by influx of neuston from areas adjacent to the sheen and by the rapid reproduction of a majority of the permanent neuston organisms.

SHEEN SAMPLING AND ANALYSIS SUMMARY

Oil sheens are patchy, short-lived phenomena in parts of western Prince William Sound. Surface waters covered with oil sheens derived from spilled oil washing off oiled shores contain low concentrations of highly weathered crude oil. Measured concentrations of the PAH and PHC fractions of weathered crude oil in sheen-covered surface waters are very low, usually less than a few parts per billion, and rarely to 18 ppb and 2,000 ppb, respectively. These concentrations are well below concentrations found in laboratory and field studies to cause deleterious effects in organisms (neuston) occupying the sea surface. Therefore, it is unlikely that marine organisms in Prince William Sound are being adversely affected by sheens of spilled crude oil.

SUMMARY OF WATER QUALITY IN PRINCE WILLIAM SOUND AND THE GULF OF ALASKA

Concentrations of PAH were the best indicators of the degree of contamination of the spilled crude oil in the water column of Prince William Sound and the Gulf of Alaska. A total of 1,683 water samples were analyzed for PAH as part of the seven water quality studies discussed in this report. Thirteen of these samples contained large amounts of mousse, tar balls, or sheen material. The PAH concentrations in them were not representative of PAH concentrations in the water column, and so they are not included in this summary. These samples were described and discussed in earlier sections of this report. More than 12 percent (208 samples) of the remaining 1,670 water samples from all water quality sampling stations in Prince William Sound and the Gulf of Alaska contained less than 0.01 ppb PAH (Figure 13). Sixty-three percent of the samples (1,050 samples) contained between 0.01 and 0.07 ppb PAH. Only

27 water samples (1.6 percent) contained more than 1 ppb PAH. Most of the water samples (16 samples) containing more than 1 ppb PAH were collected at nearshore water quality sites in Prince William Sound. With the exception of a small number of surface water samples probably containing sheen material, mousse, or tar balls, the nearly 1,700 water samples collected from Prince William Sound and the western Gulf of Alaska during the year after the spill contained concentrations of PAH well below concentrations known to be toxic or cause adverse sublethal effects in marine organisms.

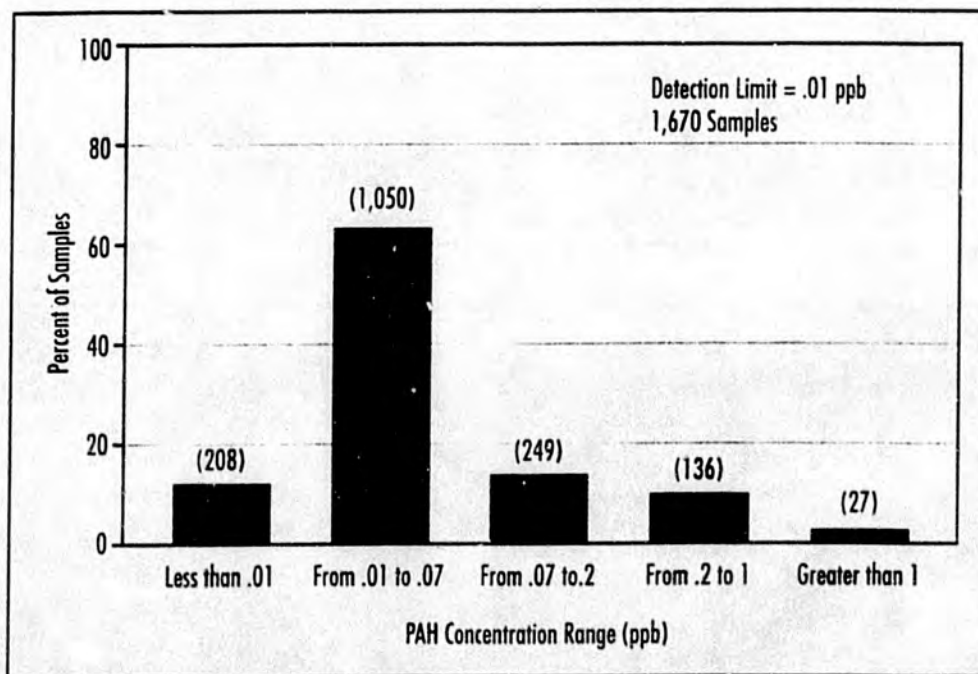


Figure 13. Distribution of Polycyclic Aromatic Hydrocarbon (PAH) Analyses (Prince William Sound and Western Gulf of Alaska)

BIOLOGICAL EFFECTS OF CRUDE OIL ON MARINE ORGANISMS IN PRINCE WILLIAM SOUND AND THE GULF OF ALASKA

INTRODUCTION

As discussed in earlier sections of this report, the concentrations of petroleum hydrocarbons measured in more than 5,000 samples of seawater from nearshore and offshore waters of Prince William Sound and the western Gulf of Alaska in 1989 and early 1990 are well below concentrations that have been shown in laboratory and field studies to be lethal to marine organisms, including commercially important species. This conclusion is based on a review of the vast amount of information published in the last two decades on the acute, chronic, and sublethal effects of crude and refined oils and their constituent chemicals in marine plants and animals. This section of the report provides background information on the toxicity of crude oil and relates the published information to the concentrations of petroleum hydrocarbons actually measured in the water column of Prince William Sound and the western Gulf of Alaska.

DEFINITIONS

Crude oil is defined as imparting a deleterious effect, lethal or sublethal, to an organism, population, or community (National Research Council, 1985). The toxicities of different crude oils vary widely, primarily for three reasons:

- Crude oils vary widely in chemical composition and physical properties. Light and medium weight (low viscosity) crudes containing abundant PAHs (e.g., naphthalene and phenanthrene) are more toxic than heavy crudes that are deficient in PAHs.
- After a spill, most crude oils weather quite rapidly. During weathering, the most toxic fractions of the oil are lost through evaporation to the atmosphere or dissolution in the water column. Other components of the oil are broken down by the action of marine bacteria and sunlight. Through weathering, the chemical composition, viscosity, and toxicity of a spilled crude oil change continuously.

- Marine plants and animals differ widely in sensitivity to crude oil and the different components of crude oil. In most but not all cases, the early life stages of marine animals are more sensitive to crude oil than are juvenile and adult life stages (National Research Council, 1985).

Care must be taken in comparing the results of oil toxicity tests (Neff and Anderson, 1981). Many studies use refined petroleum products, such as diesel fuel, which usually are substantially more toxic than crude oils (Anderson et al., 1974; Rice et al., 1985). Results of studies with refined oils cannot be extrapolated to predict effects of a crude oil spill. In many earlier studies, hydrocarbon concentrations were reported as the total volume of oil added to a unit volume of water. However, only a small fraction of the oil added to water actually goes into solution. It is widely accepted that the fraction of the oil contributing the most to its toxicity to water column organisms is the fraction that is actually in solution in the water (the so-called water-soluble or water-associated fraction, usually abbreviated as the *WSF*). To obtain meaningful results for laboratory toxicity effects tests, the actual exposure concentration must be measured by quantitative analytical methods.

Fortunately, most of the recent biological effects studies have been performed with the *WSF* and actual exposure concentrations have been measured. A majority of the petroleum hydrocarbons in the *WSF* are the same as those measured by the *VOA* and *PAH* methods discussed above. Thus, tests in which effects are reported in relation to measured concentrations of the *WSF* can reasonably be compared to concentrations of *VOAs* and *PAHs* measured in the water column of Prince William Sound.

The results of laboratory toxicity tests usually are reported as the *LC50* or *EC50* value after a given exposure period to the crude oil (Neff, 1987). The *LC50* is the median lethal concentration (the concentration estimated to cause 50 percent mortality among test organisms); the *EC50* is the median effective dose (the concentration

causing a particular non-lethal response in 50 percent of test organisms). For example, a 96-hour LC50 of 10 ppm total PAH means that exposure of a group of test organisms for 96 hours to 10 ppm total PAH resulted in 50 percent mortality.

Both static and flow-through tests have been performed in the laboratory with crude oils. Static tests are performed in closed systems (e.g., an aquarium) containing a WSF of the test oil. Most of the hydrocarbons are lost rapidly from the water in static systems, leading some investigators to replace the WSF with freshly prepared WSF periodically during the test. In the flow-through system, the WSF is prepared continuously and dosed into the exposure tanks containing the test organisms. These systems are able to maintain constant exposure concentrations for long periods of time, and the results of such tests are easier to interpret.

Near an oil spill or under a surface oil sheen, organisms in the water column are exposed to continuously changing concentrations of petroleum hydrocarbons, an exposure regime that cannot be simulated easily in the laboratory. The dose of a chemical to a marine organism has two components, the concentration of the chemical, and the duration of exposure to that concentration. In recognition of this and to make comparisons between doses administered in the laboratory and field more realistic, Anderson et al. (1984) and McAuliffe (1987) have recommended that dose be expressed as the product of exposure concentration and hours of exposure to that concentration (e.g., exposure to a petroleum concentration of 2 ppm for 24 hours would be expressed as a dose of 48 ppm-hrs or 2 ppm-days).

BIOLOGICAL EFFECTS

Three classes of pelagic (living in the water column) organisms are of particular concern with respect to effects of the spilled oil on the Prince William Sound/Gulf of Alaska ecosystem. These are the phytoplankton, the zooplankton, and the pelagic fish. All are concentrated primarily in the upper 20 to 30 meters (65 to 98 feet) in the zone of maximum penetration of sunlight. The phytoplankton and zooplankton are important direct or indirect sources of food for pelagic fish of commercial importance such as herring and salmon.

PHYTOPLANKTON

Phytoplankton are small, usually microscopic plants (usually algae) that are the primary producers at the base of most marine food webs. The toxicity of petroleum to phytoplankton usually is measured as a change in growth rate (rate of cell division) and photosynthetic activity (expressed as an EC50) of a single species or a natural assemblage, compared to controls (National Research Council, 1985; Capuzzo, 1987). Toxicity of a particular oil seems to be related to the concentration in the oil of low molecular weight aromatic hydrocarbons (VOAs and PAHs) (Vandermeulen and Ahearn, 1976). Decreases in growth rate or inhibition of photosynthesis have been reported at concentrations of the WSF of crude oil in the range of 1,000 to 10,000 ppb. However, exposure to lower concentrations of crude oil in the range of 5 to 100 ppb in the laboratory and field (particularly after weathering has removed the most volatile components) often results in stimulation of growth and respiration (Prouse et al., 1976).

Several attempts to document decreases in the abundance of phytoplankton or changes in the species composition of natural phytoplankton communities following major crude oil spills have failed (National Research Council, 1985). However, there were decreases in phytoplankton abundance in nearshore and estuarine waters near the wreck of the *Amoco Cadiz* for a few weeks immediately after the spill. The observations of either no effects or just temporary effects of spilled oil on phytoplankton are primarily a result of two factors. First, the doubling time of the algae (time for a single cell to divide into two new cells) is very rapid (9 to 12 hours), and second, replacement from adjacent, unaffected populations is efficient due to the normal mixing of water masses. Because of these factors, even if a large number of phytoplankton cells is adversely affected, their abundance in the affected area returns to normal almost immediately (National Research Council, 1985).

The concentrations of water-soluble aromatic hydrocarbons (VOAs and PAHs) measured in the water column of Prince William Sound and the Gulf of Alaska during 11 months after the spill were always much lower than the concentrations that have been shown to cause adverse effects in phytoplankton and usually lower than even the concentrations (5 to 100 ppb) shown to stimulate phytoplankton growth. Therefore, it is highly

likely that the very rich phytoplankton communities of Prince William Sound were largely unaffected by the spilled oil.

ZOOPLANKTON

Zooplankton are animals (usually very small) that drift with the prevailing water currents. Included among the zooplankton are a wide variety of different species, representing a diversity of feeding types and life histories. There are permanent members of the zooplankton community that spend their entire life cycles as plankton. The dominant permanent zooplankton animals, such as copepods (small crustaceans sometimes called the insects of the sea because of their vast numbers) feed primarily on the phytoplankton and, like the phytoplankton, have short life cycles and rapid reproduction rates.

Also included among the zooplankton are temporary zooplankton that spend only a part of their life cycles in the zooplankton community. These include the eggs and larvae of many pelagic and bottom-living fish and invertebrates, including all the commercially-important fish and shellfish species of Prince William Sound except the salmon. Thus, the zooplankton are important both as links in the food web to commercially important fishery species and as the young life stages of many of these important species.

In most, but not all cases, the early embryo/larval life stages of marine animals are more sensitive than later life stages to chemical contaminants, including spilled oil (Rosenthal and Alderdice, 1976). Acutely lethal concentrations (measured as the 24-, 48-, or 96-hour LC50) of crude oils to both permanent and temporary zooplankton, as summarized by Capuzzo (1987), fall in the range of 200 to greater than 43,000 ppb total petroleum hydrocarbons. Corner (1978) and Johnston (1984) reported acutely lethal concentrations of the WSF of crude oil in the range of 100 to 10,000 ppb for copepods and several other permanent members of the zooplankton community.

Sublethal responses, such as decreases in growth rate, usually were observed at exposure concentrations only slightly lower than to about one-tenth the concentrations that were lethal (Anderson et al., 1987a; Neff, 1987). When returned to oil-free water, fish and invertebrates nearly always recover quickly and completely from most sublethal effects. Survival of mussel larvae following exposure for 24 hours to 10 ppb

naphthalene (a major component of the PAH fraction of oil) was about half that of unexposed control larvae (Malins et al., 1982). This concentration is more than a factor of ten higher than any naphthalene concentration measured in the water column of Prince William Sound or the Gulf of Alaska.

Excluding samples that obviously contained mousse or tar balls, as discussed in earlier sections of this report, concentrations of total PAH in the water column of Prince William Sound and the Gulf of Alaska have remained below 1 ppb, with few exceptions. Concentrations up to about 30 ppb were observed in surface samples (probably containing sheen material) in just a few cases and these higher concentrations appeared to be very short-lived. Therefore, it is highly likely that adverse impacts of the spilled oil on zooplankton, including early life stages of fishery species, have been minimal. Any losses of permanent zooplankton organisms would have been made up rapidly by reproduction or influx of animals from unaffected areas (National Research Council, 1985). Any losses of eggs and larvae of important food web or fishery species would have been very localized, affecting only a very small fraction of the individuals available for recruitment to the adult stocks.

FISH

Adult fish are not particularly sensitive to oil. Effects on adult fish usually are reported at oil (WSF) concentrations of 1,000 to 50,000 ppb, whereas growth of the young fry of some species of salmon was affected by oil concentrations in the range of 700 to 5,000 ppb (Vandermeulen and Capuzzo, 1983; Rice et al., 1985). The acutely lethal concentration of the WSF of Cook Inlet crude oil for pink salmon fry was about 1,700 ppb (Rice et al., 1979). There have been some reports of sublethal effects on eggs and larvae of a few species of fish during chronic exposures lasting several days to aromatic hydrocarbon concentrations of about 10 ppb (Capuzzo, 1987). Coho salmon and starry flounder (both Alaskan species) exposed for five days to 100 ppb of the WSF of Prudhoe Bay crude oil developed gill lesions resulting from loss of surface cells (Roubal et al., 1977). Growth rate of Pacific herring larvae was depressed during exposure for 14 days to 300 ppb of the WSF of Cook Inlet crude oil (Carls, 1987). Homing migrations of several species of Pacific salmon do not appear to be very sensitive to effects

of crude oil (Nevissi and Nakatani, 1990). Different species of salmon avoided water containing 1,600 to 4,600 ppb of the WSF of crude oil during their upstream migration. Homing of coho salmon in seawater was not affected by preexposure of the salmon to 1,600 ppb of the WSF of crude oil.

Because of concerns about the potential effects of major oil spills on commercial fisheries, many attempts have been made after other spills to document adverse effects on commercially important fish and fisheries. Fish kills have been reported after some oil spills, though it is important to note that there have been no verified reports of fish kills in Prince William Sound, Alaska attributable to the oil spill. Fish kills were reported following other spills, and the most affected were shallow-water and bottom-living species (Teal and Howarth, 1984). Large kills of offshore pelagic fish species have not been reported. Thus, direct effects of oil on adult fish populations probably are small and have little or no effect on the fishery as a whole.

Although the commercial fishery catch along the Brittany coast of France declined for a few months after the *Amoco Cadiz* oil spill, it appears that the decline was due primarily to a lack of fishing effort while the fishermen were harbor-bound to avoid oiling their boats and fishing gear (Anderson et al., 1983). However, there was a decline lasting for one year in the reproduction rate of a species of commercially important flatfish (a bottom-dwelling species) inhabiting some heavily oiled estuaries near the spill site (Conan, 1982).

The two most important commercial fisheries species in Prince William Sound are Pacific herring and pink salmon and these fish were not significantly affected by oil spilled in the Sound as evidenced by spawning activity and fishing results. Results of aerial surveys flown by field biologists from the Alaska Department of Fish and Game confirm that spawning activity of herring in shallow intertidal and subtidal waters of the Sound in 1989 and 1990 was comparable to historical averages for the year immediately preceding the spill (Maki, 1991). There was an all-time record catch rate of herring in Prince William Sound in 1990. The pink salmon which emerged from the intertidal sediments and hatcheries of the Sound as fry into the spill covered waters of Spring, 1989 returned to the Sound and were caught in record numbers in 1990. The commercial harvest exceeded 44 million pink salmon, about 14 million fish

more than the previous record Prince William Sound harvest in 1987.

Death of fish eggs and larvae was reported after two spills (the *Argo Merchant* and the *Tsesis* spills; both spills involved refined oil products) (Teal and Howarth, 1984). These mortalities were associated with sheens and slicks of fresh, unweathered oil immediately after the spills. They affected the floating eggs and larvae of a few species over small areas but had no measurable effect on recruitment to the adult stocks. There have been no reports of death of fish eggs and larvae in the field following exposure to weathered crude oil, like that present in sheens washing off shores in Prince William Sound. These weathered crude oil sheens are likely to be much less toxic than sheens of fresh crude oil or refined oil products because the weathered oil contains much lower concentrations of volatile, toxic aromatic hydrocarbons than unweathered oil.

Tainting of fish by oil was reported following a few large spills (*Amoco Cadiz*, *Argo Merchant*, and *Ekofisk Bravo*), but only in small numbers and a small percentage of the fish analyzed (Teal and Howarth, 1984). Except for very slightly elevated hydrocarbon levels in shellfish (Maki, 1991), no such tainting of the edible tissues of fish has been reported in Prince William Sound. In those cases where it was reported after other spills, this tainting of fish occurred for only a short time immediately after the spill. Detectable concentrations of potentially toxic PAH persisted in the edible tissues of commercial fish and shrimp species for no more than a few months after even massive spills, such as the *Amoco Cadiz* spill (six times larger than the *Exxon Valdez* spill). This is due to the fact that fish and shrimp have the ability to very rapidly break down (detoxify) aromatic hydrocarbons and excrete them in the urine or feces (Neff, 1979).

Based on these observations from Prince William Sound and other spills, it is unlikely that the oil spill affected fishery populations in Prince William Sound or the Gulf of Alaska. Any effects would have occurred in the few weeks immediately after the spill and would have been very localized and minor relative to fishery stock sizes and future catches. As discussed above, no such effects on commercial fishery catches were observed in 1989 and 1990. It is extremely unlikely that any long-term effects directly attributable to the spill will be observed in terms of reduction in reproduction and early survival of fisheries species or in decreased

fishery catch of any commercial species.

This conclusion is supported by the large difference in the concentrations of petroleum hydrocarbons required to cause mortalities or deleterious sublethal effects in juvenile and adult fish and the concentrations of petroleum hydrocarbons measured in the water column of Prince William Sound and the Gulf of Alaska. In most cases the concentrations measured were at least one-thousand-fold lower than concentrations that are known to be harmful to fish. Thus, the margin of safety for fish in Prince William Sound and the Gulf of Alaska was very large and grew larger as the concentrations of petroleum hydrocarbons in the water column decreased over the summer and fall of 1989.

As discussed above, another way to extrapolate from results of laboratory biological effects studies to predictions of possible effects at the concentrations of petroleum hydrocarbons observed in the water column is to express the effects in terms of both exposure concentration and exposure duration. McAuliffe (1987) summarized data from Anderson et al. (1987b) for Prudhoe Bay crude oil and from Rice et al. (1979) for Cook Inlet crude oil in this way (Table 2). The median lethal doses of Alaskan crude oil reported in these papers are many-fold higher than the estimated doses of aromatic hydrocarbons (expressed as concentrations of VOAs or PAHs) present in the water column of Prince William Sound (Table 3). An estimated safety factor can be calculated by dividing the median lethal doses (Table 2) by the estimated actual doses in the water column (Table 3). Depending on species and estimated dose in the water column, safety factors measured in this way range from 79 (or 15/0.19) to 21,400 (or 62/0.0029).

These comparisons between harmful concentrations of petroleum hydrocarbons and concentrations actually measured in the water column of Prince William Sound and the Gulf of Alaska provide convincing evidence that the amounts of oil that were in the water column, even in the first few weeks after the spill, were much lower than concentrations known to be harmful to commercial fisheries species. Concentrations of petroleum hydrocarbons dropped to near background levels offshore by the end of May, 1989. In protected bays, particularly those whose shores were heavily oiled, slightly elevated, though still nontoxic, concentrations of petroleum hydrocarbons persist-

Table 2. Doses (Concentration Times Duration-of-Exposure) of Prudhoe Bay Crude Oil and Cook Inlet Crude Oil Causing 50 Percent Mortality in Several Species of Alaskan Marine Animals. (Adapted from McAuliffe, 1987)

Species	Median Lethal Dose (ppm-hr)
Coonstripe shrimp	15
Kelp shrimp	62
Grass shrimp	29
Pacific herring	41
Dolly varden	52
Pink salmon	57
Chum salmon fry	19

Table 3. Doses Based on a 96-hour Exposure to Petroleum Hydrocarbons at Average Concentrations Measured in Prince William Sound.

Measurement	Estimated Dose (ppm-hr)
Peak average offshore VOA (2 ppb)	0.19
Peak average offshore PAH, worst case (0.7 ppb)	0.068
Peak average offshore PAH (0.2 ppb)	0.019
Average VOA, October (0.2 ppb)	0.019
Average PAH, October (0.03 ppb)	0.0029

ed in small areas of the water column (e.g., under slicks) into June, 1989. It is unlikely that these small regions containing slightly elevated concentrations of petroleum hydrocarbons will have any measurable effect on the populations of marine animals living there.

Chronic exposure to petroleum hydrocarbons may produce a wide variety of sublethal biological effects in marine fish and invertebrates. Many of these responses are general responses to an environmental disturbance and may cause no lasting harm unless the disturbance is persistent (National Research Council, 1985). Rice et al. (1985) have studied the sublethal effects of Alaskan crude oils to several species of Alaskan fish and crustaceans. Sublethal responses were elicited by exposure to oil concentrations from about 10 to 50 percent of the acutely lethal concentrations. In most cases, the sublethal responses returned to normal (the animals recovered) very rapidly after the animals were returned to oil-free seawater. The safety factors

discussed above are large enough that it is unlikely that pelagic fish and invertebrate populations in Prince William Sound or the Gulf of Alaska have or will experience any deleterious sublethal responses to the spilled oil.

When fish are exposed to petroleum dissolved or dispersed in the water or bound to sediments, an enzyme system, known as the cytochrome P450 mixed function oxygenase (MFO) system, is induced in the liver and some other tissues (Neff, 1979; Stegeman, 1981). The result is that the amount of the enzymes and their activity increases. Biochemical methods have been developed to determine when MFO activity is induced in fish and this approach has been recommended as a sensitive method for determining exposure of fish populations to oil (Payne, 1984). MFO activity is induced at low concentrations of petroleum PAH, as well as several other chemicals such as polychlorinated biphenyls and PAH derived from combustion sources (Kleinow et al., 1987). However, because of the sensitivity of the MFO system, many natural populations, particularly of bottom living fish, from presumably clean environments show evidence of MFO induction (Stegeman et al., 1987). In addition, MFO activity is affected by many natural variables, such as season, temperature, sex, and stage in reproductive cycle (Kleinow et al., 1987; Edwards et al., 1988). Therefore, induction of MFO activity must be used with caution as a tool for monitoring exposure of fish populations to oil. Induction of MFO is an adaptive response in animals, designed to aid the animal to excrete potentially toxic compounds (Neff, 1985). It is not by itself an indication of existing or pending pathology in the affected animal.

Levels of MFO induction reported in Prince William Sound fish after the spill (Bayliss, 1990) are quite low compared to induced levels found elsewhere (Stegeman et al., 1987). The Coast Guard has indicated that the measurement of enzyme induction, particularly at the low levels reported by Bayliss, is an unproven technique for demonstrating injury to marine species resulting from exposure to hydrocarbons (Ciancaglini, 1990). Payne et al. (1987) have shown that pathological effects possibly associated with MFO induction only occur in heavily contaminated environments in fish that are maximally induced. This was not the case in Prince William Sound or the Gulf of Alaska.

CONCLUSIONS OF BIOLOGICAL EFFECTS STUDIES

Concentrations of petroleum hydrocarbons in the water column of Prince William Sound and the Gulf of Alaska, even in the month immediately after the spill, have consistently remained below concentrations of crude oil hydrocarbons that have been demonstrated in laboratory and field studies to be toxic to or produce sublethal effects in organisms living in the water column. Therefore, harmful effects, if any, of the spill on water column organisms in 1989 and 1990 are expected to be quite isolated, and result in little or no damage at the population or community levels. There is no reason to expect that there will be any harmful long-term effects of the remaining oil in 1991 or beyond on water column organisms, including commercially important herring and salmon populations.

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APPENDIX

UPDATES TO THE APRIL, 1990 WATER QUALITY REPORT

This March, 1991 update to the April, 1990 report expands both the geographic and temporal coverage of available data. Approximately twice as much data as was available in April, 1990 is included. In addition, it was determined that reprocessing a portion of the data was desirable to ensure the methods were comparable among laboratories. Finally, since April, 1990 the cause of a sampling problem identified in that report was clarified.

As indicated in Table A-1, data from three additional sources became available since publication of the April, 1990 report. These include (1) data from offshore studies in Prince William Sound, primarily from the February-March, 1990 offshore water quality survey, (2) additional sample analyses from the two Prince William Sound near-shore water quality studies, and (3) data from the three water quality studies performed in the western Gulf of Alaska. The total number of analytical results more than doubled from 3,053 (including 706 quality control samples) in April, 1990 to 7,532 (including 2,434 quality control samples) in March, 1991. It was felt that a combination of these newly available data, with the data available in April, provide a more comprehensive picture of the status of water quality during the first year after the spill in areas where the spilled oil drifted.

Review of the hydrocarbon concentration data revealed that results of analyses for PAH by one laboratory were consistently lower than the results produced by other analytical laboratories. When the reasons for these systematic differences were identified, the raw PAH data were reprocessed by the quantification methods used by the other analytical laboratories. This was done in order to make all PAH data for water samples consistent and comparable (reprocessing of PAH data is described below).

Hydrocarbon concentrations in seawater and blank samples collected with the water sampler that tended to contaminate samples were reviewed again. Field protocols for use and cleaning of the sampler also were reviewed. It was reaffirmed that, for the offshore Prince William Sound study, due

Table A-1. Comparison of Numbers of Water Quality Analytical Results Available at the Time of the April, 1990 Report and in this March, 1991 Update.

Study	April 1990		March 1991	
	Water	QC	Water	QC
Prince William Sound Offshore Water Quality	1,878	445	2,319	845
Prince William Sound Nearshore Water Quality	430	261	1,342	690
Prince William Sound Nearshore Sheens	39		81	29
Gulf of Alaska Water Quality			1,356	870
Total	2,347	706	5,098	2,434

to the nature of the sample contamination, analytical data for water samples analyzed for VOA, PHC, and TPH were unreliable and, therefore, not useable. However, the PAH data were marginally acceptable. Therefore, PAH data for subsurface water samples collected with the contaminating sampler were used in the updated report.

AVERAGING SETS OF CONCENTRATIONS THAT CONTAIN VALUES BELOW THE NOMINAL REPORTING LIMIT

In the studies of concentrations of petroleum hydrocarbons in the water column discussed in this report, many analyses yielded results below the nominal reporting limit (similar in magnitude to the method detection limit). These analyses resulted in either no observed signal (non-detects) or a slight signal for which a rough estimate of concentration can be given. The analytical laboratories often report these estimates, called J-values, but they are considered less reliable than values above the official reporting limit. When it was necessary to calculate an average value for a group of analytical results, non-detects were given a value of zero, except when a J-value was given. In these cases, the J-value was used in the calculation of the average.

In calculations of average concentrations, if a fraction of the reporting limit had been used instead of zero, the resulting averages would not have been much higher than the values calculated using zeros or J-values for non-detects, because the reporting limits for the VOA and PAH analyses were so low. Therefore, none of the conclusions about the extremely low concentrations of petroleum hydrocarbons in the water column would have been changed by use of a different method for calculating averages.

HANDLING NONREPRESENTATIVE DATA

Approximately 30 percent of the water samples for VOA, PHC, and TPH analysis from the first and second offshore water quality field surveys, performed in late March and early April, are not included in this report. These samples were collected with a sampling device, widely used in physical and chemical oceanographic sampling, that turned out, with the particular solvent used, to be extremely difficult to clean sufficiently for the types of samples being collected (e.g., samples for analysis of petroleum hydrocarbons present in seawater at ultra-trace concentrations). Reagent-grade hexane was used to rinse the sampler between samples. Although the sampler was rinsed again with water after the hexane rinse, a small amount of hexane sometimes remained adsorbed to the inside walls of the sampler and contaminated the water samples with VOAs and saturated hydrocarbons (components of PHC and TPH). Because of this sampler contamination, the quality control samples for the VOA analyses (often called blanks) obtained with this sampler using high-purity water, contained very high concentrations of VOAs, ranging from 12 to 218 ppb; blanks for PHC and TPH also were high. Because the use of this sampling device resulted in contamination of samples of high-purity water, it was decided to exclude VOA, PHC, and TPH data for seawater samples taken with this sampler on the assumption that they were similarly contaminated. The use of this difficult to clean sampling device was discontinued after the first two surveys. Because the hexane rinse did not contain PAH components, PAH blanks from this sampler did not yield excessively high PAH concentrations. Further, since PAHs were the most useful class of petroleum hydrocarbons for monitoring the distribution and fate of the oil in the water column, it was decided to use the PAH data from water samples collected

with this sampler. This same sampler was used to collect some of the water samples for the Gulf of Alaska Offshore Water Quality Study. However, on these surveys the sampler was rinsed with high-purity methylene chloride which did not result in contamination of the sampler with hydrocarbons. Therefore, results for water samples collected with this sampler during the Gulf of Alaska Offshore Water Quality Study were included in this report.

A similar but less severe problem was encountered with a second type of water sampling device. However, results of analyses of water samples collected with this sampler are included in this report. Use of this device was also discontinued after the second field survey. Surface water samples from all field surveys and subsurface water samples from all field surveys and studies after the second Prince William Sound water quality field survey were collected with a third type of sampler that delivered the water directly into a pre-cleaned sample bottle, substantially decreasing the possibility of contaminating the sample. In addition to the sampling device problems, there was one instance in which two field blanks were incorrectly mislabeled as samples. Associated VOA analyses of these two samples are not reflected in averages included in this report.

REPROCESSING OF PAH DATA

It became apparent when chemists began reviewing the large amounts of water quality data now available, that the results of analyses by different analytical laboratories of PAH in water samples showed systematic laboratory-specific differences. Examination of the detailed data reports produced by the different laboratories revealed that the systematic differences were due in large part to differences among the laboratories in the methods used to quantify individual analytes from the gas chromatograph/mass spectrometer traces.

At the beginning of the water quality studies, standard operating procedures (SOPs) were written giving detailed descriptions of the different analytical methods to be used by the analytical laboratories to analyze water quality samples. One of the analytical laboratories used a slightly different interpretation of the SOP for processing raw data to quantify individual alkylated PAH in water samples. This method yielded slightly lower concentrations than the method called for in the SOP. Subsequently, the raw PAH data from this laboratory were reprocessed and

quantified by the method intended in the SOP, so that data from all analytical laboratories would be consistent. The reprocessed data were used in preparing this revised report. Approximately 20 percent of the PAH data was affected by this reprocessing, most often resulting in slight increases in PAH values.

ANALYSIS OF PETROLEUM HYDROCARBONS (PHC) AND TOTAL PETROLEUM HYDROCARBONS (TPH) IN WATER

For completeness, two methods were used to measure the concentrations of total petroleum hydrocarbons in water samples, even though these types of analyses do not provide as good estimates of concentrations of potentially toxic hydrocarbons in the water as do PAH and VOA analyses. In the PHC analysis method, the concentration of total saturated and aromatic hydrocarbons, including hydrocarbons from natural biological sources such as plant waxes, is measured by a sensitive gas chromatographic technique. The TPH analysis method is a rapid, inexpensive method, useful for sample screening, identification of trends, and rapid estimation of hydrocarbon concentrations. The TPH method, based on infrared analysis, measures all hydrocarbons, including those of biological origin, as well as many other poorly soluble organic compounds. The method is not very sensitive (detection limit of about 1,000 ppb, or 1 ppm) and is highly subject to interference by natural biological organic matter in the water. As a result of these limitations, TPH analysis is unsuitable for monitoring extremely low concentrations of hydrocarbons, such as those existing in Prince William Sound and the Gulf of Alaska following the spill.

Prince William Sound:

A total of 990 water samples (including 210 quality control samples) from the offshore water quality field surveys were analyzed for PHC. Two samples containing more than 450 ppm PHC (described on page 10) were not included in the PHC concentration distribution because they contained mousse or tar balls. As shown in Figure A-1, concentrations of PHCs were below the method detection limit of about 50 ppb in 89 percent of the samples (695 of 778 water samples). Only 23 samples (3 percent) contained more than 100 ppb of PHCs. The highest concentration was

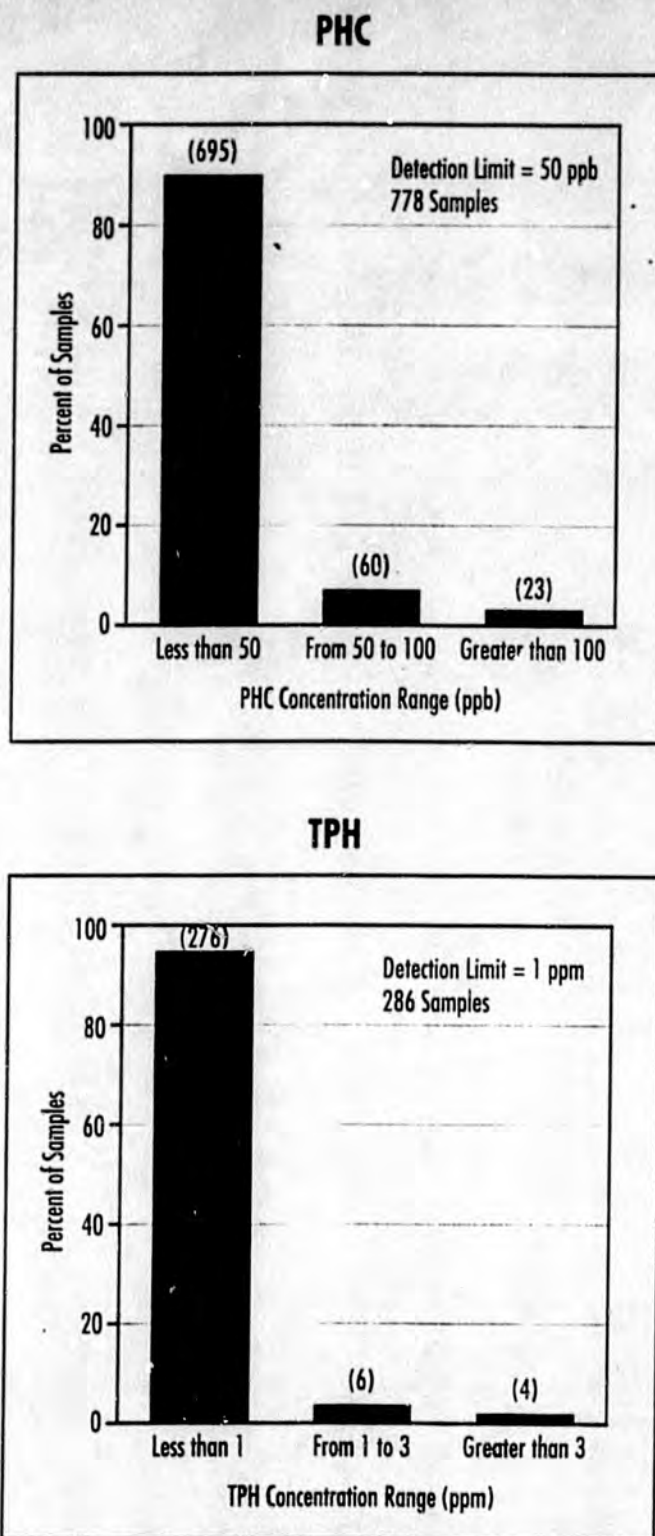
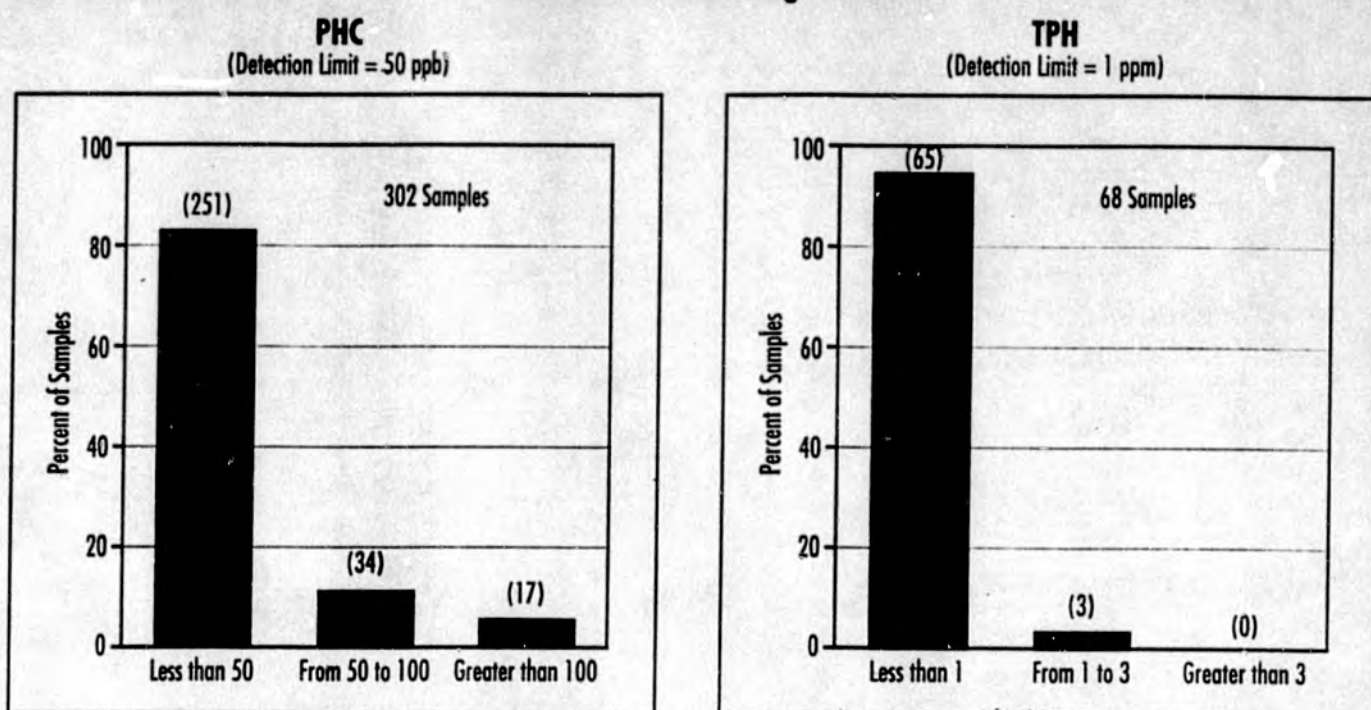


Figure A-1. Distributions of Petroleum Hydrocarbon (PHC) and Total Petroleum Hydrocarbon (TPH) Analyses (Offshore Prince William Sound)

1,000 ppb. Thus, the trend for concentrations of total petroleum hydrocarbons as measured by the PHC technique is similar to the trends in concentrations of VOAs and PAHs. Concentrations of total petroleum hydrocarbons were uniformly low

Shoreline Monitoring Sites



Shoreline Treatment Monitoring Sites

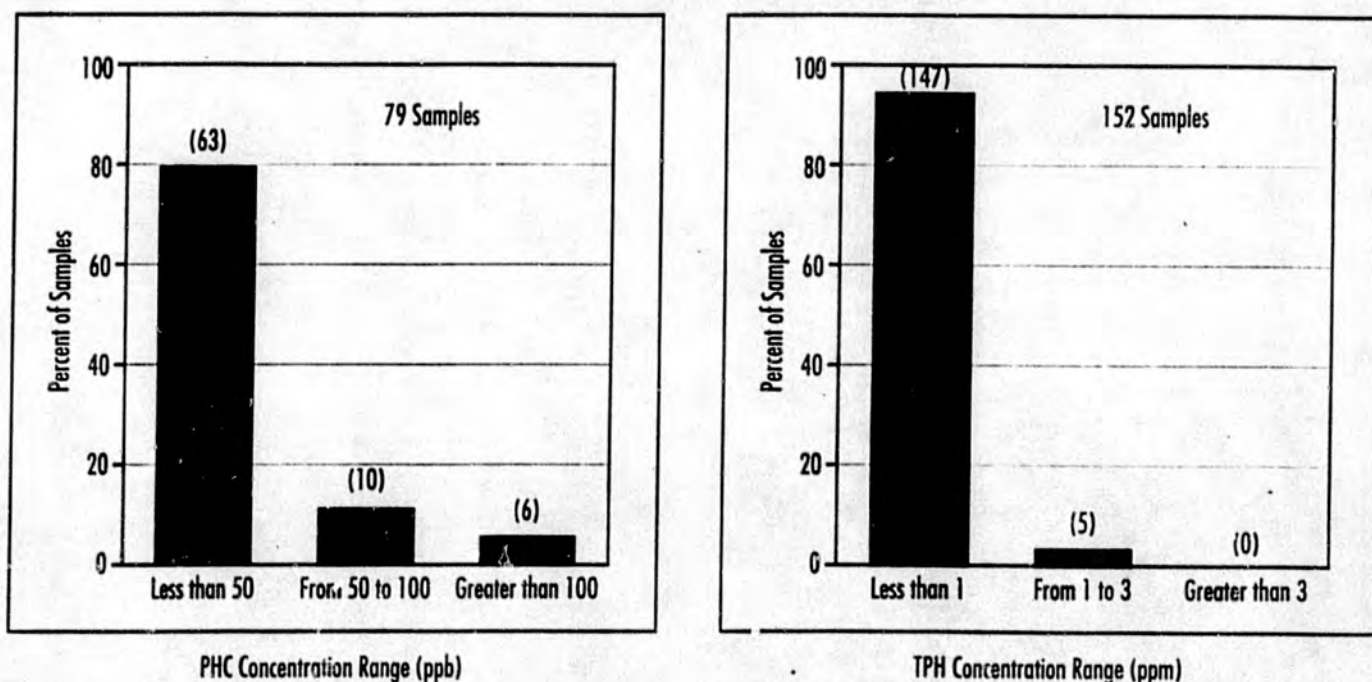


Figure A-2. Distributions of Petroleum Hydrocarbon (PHC) and Total Petroleum Hydrocarbon (TPH) Analyses (Nearshore Prince William Sound)

throughout Prince William Sound, with only a few samples (mostly surface samples) containing detectable concentrations of PHCs.

A total of 416 water samples (including 130

quality control samples) from the offshore water quality field surveys were analyzed for TPH. As indicated in Figure A-1, concentrations of TPH were below the method detection limit in 97

percent of the samples (276 of 286 water samples). Of the 10 remaining samples, 4 contained more than 3,000 ppb (3 ppm) TPH.

Water samples from the nearshore water quality field surveys, at both the shoreline monitoring sites (458 samples, including 156 quality control samples) and shoreline treatment monitoring sites (141 samples, including 62 quality control samples) were analyzed for PHC. One sample from a shoreline monitoring site contained 435 ppm PHC and obviously contained mousse; this sample was not included in the graphic data summary. As shown in Figure A-2, concentrations of PHCs were below the method detection limit of about 50 ppb in 82 percent (314 of 381 samples from both types of sites) of the samples. Twelve percent (44 samples) of the samples contained between 50 and 100 ppb PHCs, and 6 percent (23 samples) contained more than 100 ppb PHCs. The highest concentrations of PHCs in water samples (other than the samples containing substantial mousse or sheen material discussed above) from the shoreline monitoring and shoreline treatment sites were 1,000 and 300 ppb, respectively. Both samples were surface water samples.

A total of 285 water samples (including 65 quality control samples) were collected for TPH analysis during the shoreline monitoring surveys and shoreline treatment monitoring surveys. More than 96 percent of these samples (212 of 220 samples) contained less than 1,000 ppb (1 ppm) TPHs. The highest TPH concentration measured was 2,600 ppb (2.6 ppm).

Gulf of Alaska:

A total of 733 water samples (including 292 quality control samples) were collected for PHC analysis during the three Gulf of Alaska water quality studies. The ten samples containing mousse from the Kenai Peninsula were not included in the data summary (Figure A-3). Almost 92 percent (395 of 431 samples) of the water samples contained less than 50 ppb PHC (Figure A-3). Only 3 percent (13 samples) of the samples contained more than 100 ppb PHC. The highest PHC concentration measured in a water sample from the Gulf of Alaska (other than the samples from the Kenai shoreline containing mousse material discussed above) was 247 ppb. Six samples were analyzed for TPH during these studies; all resulted in nondetectable values.

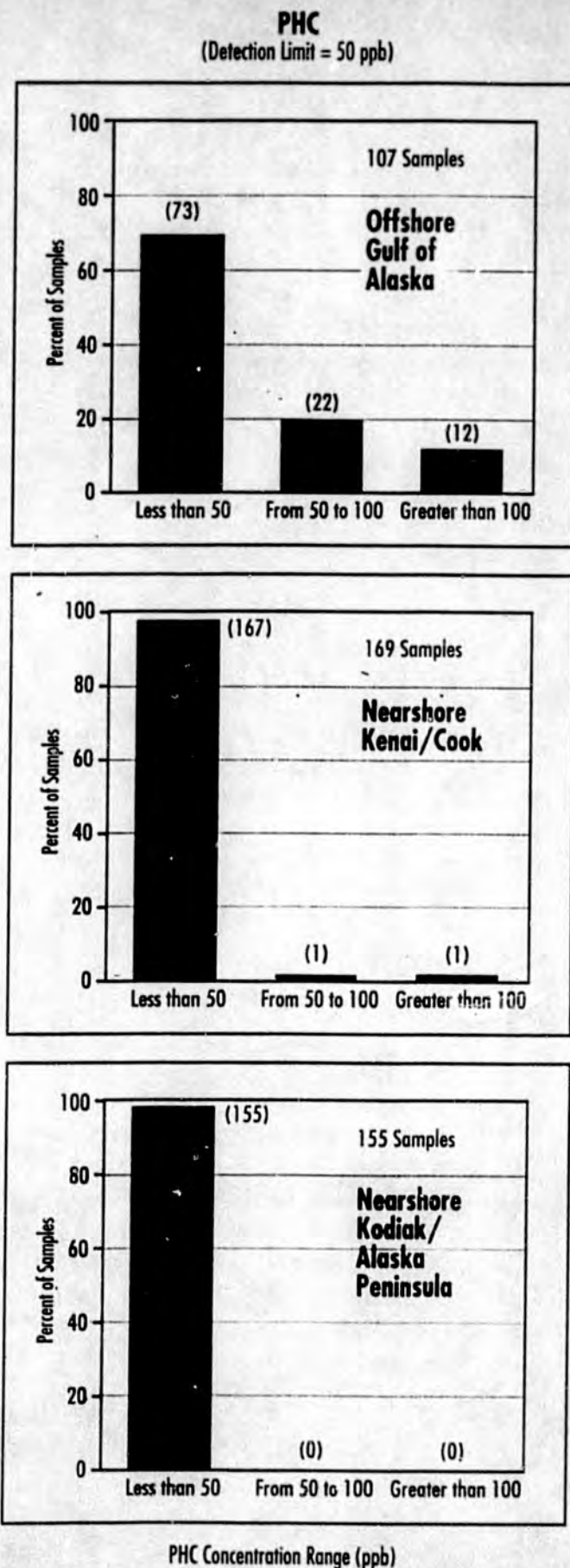


Figure A-3. Distributions of Petroleum Hydrocarbon (PHC) Analyses (Western Gulf of Alaska)

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America North is an environmental consulting company based in Anchorage and Fairbanks, Alaska. Its special services include marine sampling, wetlands delineations, investigations of contaminated sites, scientific database development, oil spill response plans, and industrial health and safety. America North's 50 professionals, who include chemists, marine geologists, hydrogeologists, marine biologists, and regulatory specialists, work regularly throughout Alaska from Prudhoe Bay to Ketchikan.

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Kinnetic Laboratories, Inc. is a specialized firm offering oceanographic and environmental science services in the biological, chemical, and physical disciplines. Their expertise in the biological sciences is particularly comprehensive and widely recognized. Kinnetics has extensive experience in studying trace pollutant problems in marine systems. Kinnetics also has a long history in Alaska, and has the logistical and field capabilities to obtain high quality data.

ABOUT THE AUTHOR

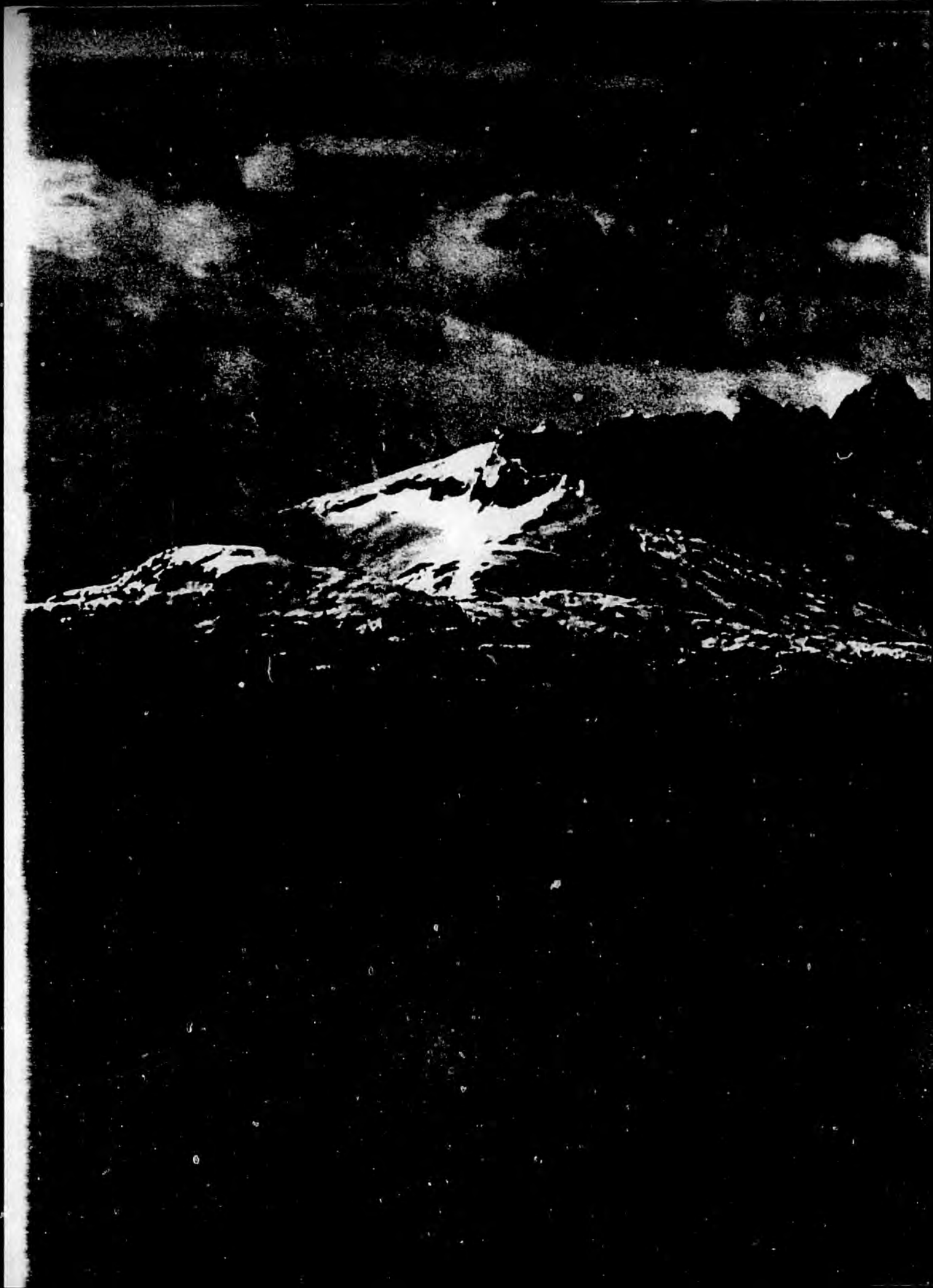


Dr. Jerry M. Neff, Senior Consultant with Arthur D. Little, is an internationally recognized authority on the fate and effects of pollutants in marine and freshwater environments. During the past 20 years he has participated in or managed more than 100 basic or

applied research projects dealing with the effects of pollutants on estuarine and coastal marine ecosystems. Dr. Neff is author or co-author of over 120 articles and reports and has written two books dealing with petroleum and aromatic hydrocarbon pollution of aquatic environments as well as a major literature review on recovery of pollution-damaged marine ecosystems. He has been a member of three review panels of the U.S. National Academy of Sciences, one of which dealt with petroleum in the marine environment.

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Two Years After the Spill: Environmental Recovery in Prince William Sound and the Gulf of Alaska

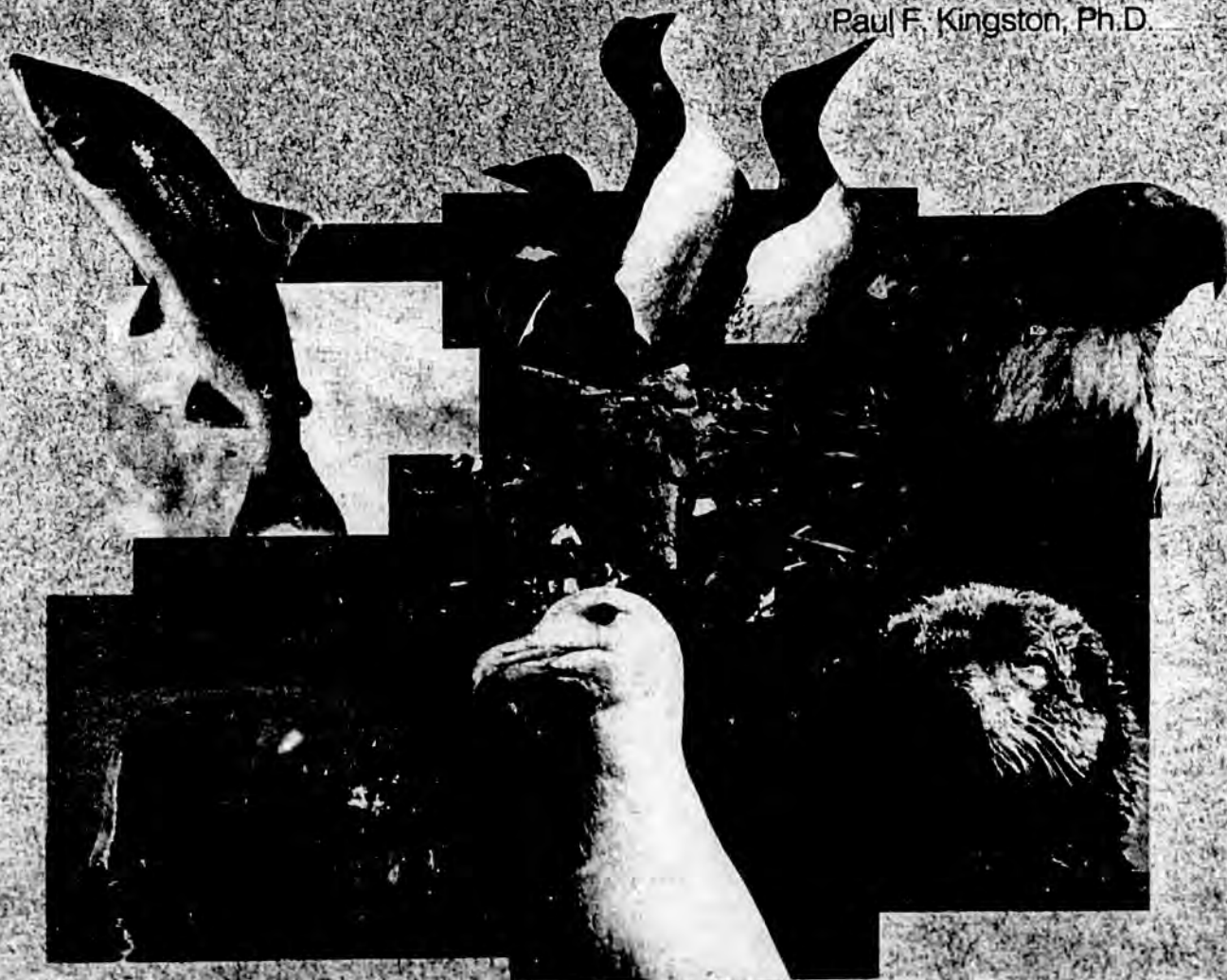
March 1991



Jennifer M. Baker, Ph.D.

Robert B. Clark, Ph.D.

Paul F. Kingston, Ph.D.



INTRODUCTION

A striking feature of the Valdez oil spill and its impact on the environment is the great disparity between public perceptions and fact. In 1989, the public learned from extensive media coverage that the oil spill had fouled beaches, killed seabirds and other sealife and disrupted fishing. As in other oil spills, natural recovery started quickly after the initial impact. The recovery, however, is not such dramatic news and has attracted much less media attention. In 1991, the public is therefore still left with its impression of "disaster," but is less aware that the affected areas are now well on the way to recovery.



The authors (from left to right: Dr. Paul Kingston, Dr. Robert Clark, and Dr. Jenifer Baker) during one of their 1990 visits to Prince William Sound, Alaska. All three have extensive international experience studying the impact of oil on the marine environment.

As James Mielke commented in his report to Congress for the Congressional Research Service, *Oil in the Ocean: The Short- and Long-Term Impacts of a Spill*, this is not a unique situation. Very much the same public misperception of "disaster" followed the wreck of the *Argo Merchant* on the Nantucket Shoals off the Massachusetts coast in 1976, when, in fact, minimal ecosystem damage was caused. The wreck of the *Amoco Cadiz* on the French coast in 1978 was the largest tanker oil spill on record (six times the size of the Valdez spill) and was claimed to be an ecological disaster. Although extensive damage was caused to the coastal environment, recovery in most areas was rapid.

The report we have written here is concerned with the recovery processes that have taken place in Prince William Sound and the Gulf of Alaska since the oil spill. Our observations and conclusions are based on factual evidence and run counter to some public perceptions, but they may help give reassurance that natural recovery is well underway and that the Valdez oil spill has no different implications than those relating to other cold water oil spills that have occurred around the world.

In December 1989, Exxon invited us to prepare a survey of the information in the published scientific literature on the recovery processes and rates of recovery of cold water marine environments following oil spills. At that time, there were no scientific publications relating to the Valdez oil spill and so it did not feature in our report.

Following the preparation of this technical report, we visited Prince

William Sound in the Spring (April, May) and Fall (September) of 1990 to form an impression of the recovery of oiled shores 12-18 months after the spill by "skilled eye" survey. Such surveys, using experienced observers to look for key features to monitor changes in the environment, are commonly used as part of gross environmental damage assessments. Our chief objectives were to discover if the recovery processes on the shores that had been impacted by oil were following the same pattern and were occurring at the same rate as those experienced in comparable situations following oil spills in other parts of the world.

We selected a variety of shore types for examination (including some that one of us, Dr. Baker, had studied in June 1989 before they were cleaned). They included shores that had been heavily oiled, lightly oiled or, for comparison, shores that had not been oiled at all; sheltered beaches and some exposed to severe wave action; and beaches that had been cleaned in various ways or, in one case, not cleaned.

In addition, we were able to form a view about the recovery potential of other elements in the marine environment that were at risk from the oil, based on our observations in the area, experience from previous oil spills, and reported events in the Sound during Summer 1990. We also addressed some of the concerns that have been expressed in public discussion or in the media (which we have followed closely since the event) or which we have encountered in discussions with local officials, other interested parties and members of the public.



Green Island (above) and Smith Island (below) in Prince William Sound, once heavily oiled, demonstrate the degree of recovery experienced by the shorelines in the area.



BACKGROUND TO OIL SPILLS

Oil spills, large and small, have happened in many parts of the world, and there is an enormous amount of scientific knowledge and information about the effects of oil on different types of marine environments, the recovery processes and rates of recovery. This experience has been reviewed and conclusions from it have been drawn several times by various distinguished bodies, including the U.S. National Academy of Sciences in 1975 and 1985, the U.K. Royal Commission on Environmental Pollution in 1981 and the U.N. Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) in 1982 and 1990. One of us, Dr. Clark, contributed to the first three of these reviews and was a founding member of GESAMP.

The consensus from all these overviews is that oil spills always have features in common and these need to be borne in mind when reading this report on the recovery of Prince William Sound following the 1989 oil spill. The features include:

- ▶ **Crude oil loses most of its toxicity within a few days of being spilled at sea.** Weathered oil is unlikely to poison plants or animals, but may smother them, and floating oil, whether still toxic or not, can be damaging to seabirds and sea otters if it contaminates their plumage or fur. In Prince William Sound and the Gulf of Alaska almost all of the oil reaching the shore had weathered at sea for many days or weeks.

Thin sheens may still occur after the bulk of the oil has either come ashore or dispersed at sea, but there is no evidence that they have any significant impact on marine ecosystems.

► **Recovery of the environment depends on the capacity of the unaffected plants and animals to replace the one-time immediate losses.** The speed of the recovery depends, first, on how quickly the damaging effects of the oil are removed, thus allowing recovery to start;



Occasional oil sheens may appear long after the bulk oil is removed. Sheens have little or no impact, as evidenced by the presence of beach plants.

second, on the numbers and species of survivors; and third, on how far the damaged area is from the nearest plants and other marine life available to recolonize it. No area in Prince William Sound was far from an undamaged area which acted as a reservoir for recolonization. Moreover, even on shores that were oiled there were many surviving plants and other marine life.

► **Once the bulk oil has been removed from the environment, either by human intervention or by natural processes, the mortality of marine organisms declines rapidly.** Most mortalities are immediate, but some organisms that have suffered sub-lethal damage may not recover and die after a short interval, or are unable to compete for long in the struggle for existence. Oil impacts are essentially short term. Concerns that damage which is not currently apparent will appear in future years is not supported by scientific evidence from any previous spills.

SURVEY OF SHORES

Following the spill, oiling of shores was an obvious concern because of threats to wildlife using the shores and because of fears that residual oil might be a long-term threat to marine life.

Clean-up operations in 1989 addressed these concerns and were more extensive and thorough than those after any previous oil spill in the world. The successful removal of bulk oil from beaches minimized long-term threats to wildlife, largely averted the formation of asphalt pavements and maximized the benefits of natural clean-up processes. These natural processes substantially reduced the amounts of residual oil during the period September 1989 to March 1990. In April 1990 we observed that shores in Prince William Sound and the Gulf of Alaska had a generally clean appearance but some weathered oil remained, mostly in sheltered inner bays or on upper shores. By September 1990 some of this remaining oil was more obvious, possibly resulting from the higher summer temperatures warming the oil, and allowing it to thin out and migrate through the beach material more easily. Another possibility is that this was the intended result of some types of beach cleaning which aim to expose sub-surface oil to promote its weathering.

In April 1990 we saw that recovery had begun and predicted normal growth and development would take place over the summer season. When we revisited the same beaches in September 1990, our predictions were

confirmed.

We examined the plant and animal life on shores because this intertidal flora and fauna is a good indicator of water quality. The early life stages—spores and larvae—of these organisms float in the surface waters of the sea before settling on the shore and they are particularly sensitive to toxic effects even at low levels of contamination. Furthermore, these shore plants and animals are important because most are low in the food chain and many fish, birds and mammals depend on them for food.

The summer settlement and growth of the organisms we saw was good biological evidence that the sea and the shores were clean enough for recovery to take place. Mussels, barnacles and rockweed that were abundant on the shores as newly settled juveniles in Spring had become established as young adult populations by the Fall. Such development had taken place even where there had been no clean-up or there was still residual oil on the shore. For example:



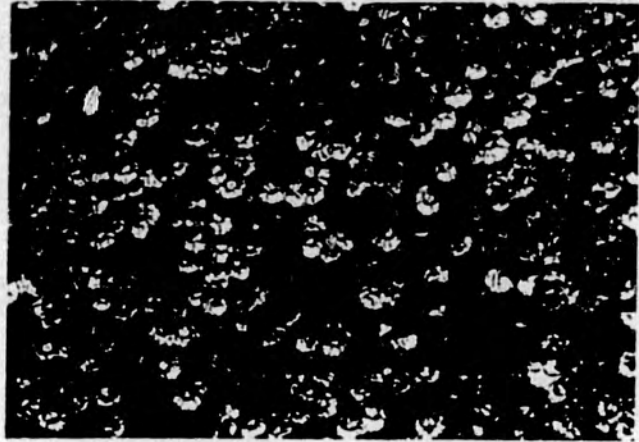
▲ April, 1990



► On the upper shore we found beach grasses in oily sediments sprouting in April and well grown in the Fall showing that there had been vigorous growth in the Summer.

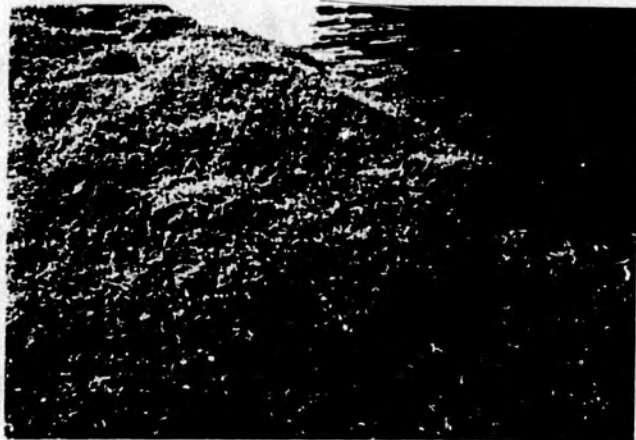
◀ September, 1990

► We saw that there had already been a good post-spill settlement of barnacles by April. In September there were well-established juvenile populations of barnacles on all shores together with



additional settlement of individuals that had taken place during the Summer.

► The rockweed sporelings (newly settled young plants) established in the Spring had developed into healthy stands of young adult plants.



► In the Spring, periwinkles (sea snails) were found under stones on several shores and frequently seen spawning. In September, rocks in most localities visited had large numbers of young individuals indicating a successful breeding season.





► On one beach on Seal Island, we discovered a lagoon in which oil was found under stones. Nevertheless, this lagoon had the richest and most varied marine fauna of any site we investigated. The same elements of

the fauna were present in April and September, a further indication that the presence of residual oil is not necessarily harmful to marine life.

► Mussels that had survived the initial oiling had been joined by newly settled juveniles.

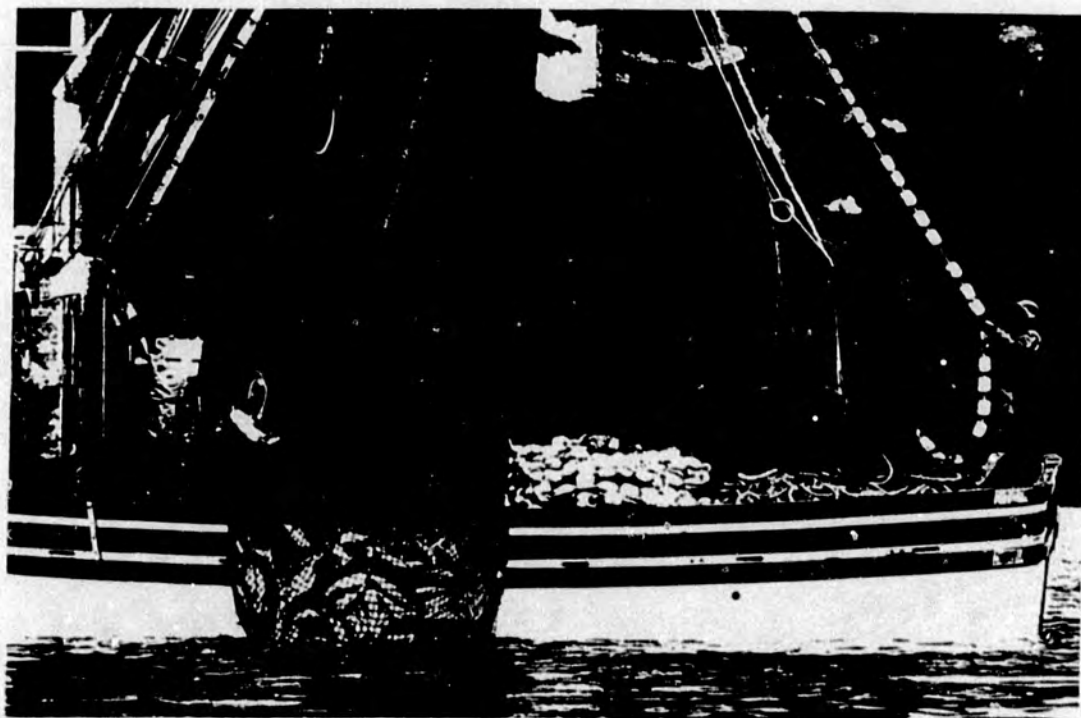
Our observations on the biological status of the shores suggest that the water quality in Prince William Sound is good. This is corroborated by the thorough study on water quality in Prince William Sound done for Battelle Ocean Sciences by Dr. Jerry Neff in which he shows that hydrocarbon levels in the water had returned to normal background levels by Summer 1989. Even at the highest hydrocarbon levels measured, concentrations were so low that they did not exceed the stringent drinking water standards of the U.S. Environmental Protection Agency.

COMMERCIAL FISHERIES

Commercial fishing is the second largest revenue-producing industry in Alaska, primarily involving salmon, herring and halibut.

Both wild and hatchery-reared salmon, as well as wild and pen-reared shellfish (oysters, shrimp and crabs) are harvested commercially. During the oil spill response, high priority was given to these hatcheries and farms as well as to protection and cleaning of the shores near salmon streams.

Except for such hatcheries and farms, observations at oil spills around the world consistently indicate that free-swimming, open-water fish are rarely at risk from oil spills. Fish swim away from floating oil and this behaviour



Prince William Sound fishermen enjoyed record-breaking pink salmon and herring harvests in 1990.

explains why there has never been a commercially important fish-kill of wild species following an oil spill. In fact, the only adult fish-kill on record following an oil spill was on the French coast when several tons of small rock-living fish (not commercial species) were killed at the site of the wreck of the *Amoco Cadiz*.

Fish eggs and larvae are more vulnerable and have often been killed in large numbers by floating oil. However, fish over-produce eggs on an enormous scale and the overwhelming majority of them die at an early stage, generally as food for predators. Even a heavy mortality from an oil spill has no detectable effect on the adult population which is exploited by a commercial fishery. This has been confirmed during the *Torrey Canyon* spill off southwest England and the *Argo Merchant* spill off Nantucket. In both cases a 90% mortality of fish eggs and larvae (pilchard and pollack, respectively) was observed in the affected area, but this had no impact on the local fishery.

Developmental abnormalities occur naturally in wild fish populations, and the frequency of these abnormalities is increased in populations chronically exposed to oil. These abnormal fish do not survive long in the struggle for existence. Such delayed mortality is likely to have an equally negligible impact on a commercial fishery as the immediate mortality following an oil spill.

The Valdez oil spill was no exception to the general experience. No fish-kills were confirmed in Prince William Sound as a result of the oil spill of 1989. There were, however, concerns about the possible impact of the

oil on the breeding cycle of two commercially important kinds of fish—salmon and herring.

Pink Salmon

Unlike the other four species of Pacific salmon, pink salmon have a two-year life cycle and spawn in summer in gravel at the mouth of creeks or in intertidal areas. They spend the following fall and winter developing, to emerge in the spring. They then spend a year offshore to return as spawning adults the following summer. In Spring 1989 when the oil reached the shore, young pink salmon were still in Prince William Sound close to the spawning



Pink salmon have a two-year life cycle. Adults that returned to the Sound to spawn in 1990 swam under oiled waters as juveniles in 1989.

areas, and the concern was that heavy losses of these younger salmon might have a serious impact on the number of fish returning to breed a year later in 1990. The fear was unfounded.

The 1990 pink salmon catch of these returning adults in Prince William Sound broke all records, with over 44 million fish caught compared to the previous record catch of 29 million. Even in September, when the peak of the spawning was over, we observed large numbers of spawning pink salmon at several beaches in Prince William Sound and the Gulf of Alaska.

Other Salmon

Unlike pink salmon, other salmon species spawn in several of the suitable rivers of Prince William Sound and the Gulf of Alaska. They breed upstream and the young fish eventually return to the open ocean for 4-5 years before returning to the rivers to breed. There were no reports of kills of salmon or their young in 1989 when oil was on the water, nor in 1990 when there was no longer oil on the water.

Herring

Herring congregate for spawning in enormous numbers in certain parts of Prince William Sound every April. The 1989 breeding season took place two weeks after the oil spill. There were fears that the spawning fish or their eggs would be damaged, and that the next year's and subsequent years' crops would be severely limited.

These fears fortunately appear to be groundless. We were present at the opening of the fishery in April 1990, one year after the spill. It was widely

reported that the fish were so abundant that the entire year's seine harvest quota was filled in just 20 minutes' fishing with a catch of 8,300 tons.

Halibut

This is another commercially important fish in the area. Halibut are bottom-living fish and there has been no indication that they were affected by the oil or that the commercial catch has suffered in any way.



Over 16,000 sea otters live in Prince William Sound and adjacent areas of the Gulf of Alaska.

SEA OTTERS

Sea Otters are appealing creatures and therefore have a high profile in the eyes of the general public. Although they were reduced to the verge of extinction by fur hunters in the last century, their numbers recovered in Alaska. However, a common public misperception is that they are still an endangered species in Alaska and thus there was great concern at the events following the Valdez spill.

Unlike other sea mammals, sea otters are vulnerable to oil on the sea primarily because if their fur becomes matted with oil, they rapidly lose body heat and die from hypothermia. The total mortality following the spill is unknown, but the best scientific estimate is that only a small fraction of the otter population in Prince William Sound died.

During our aerial surveys in April 1990 sea otters were frequently seen around many islands in Prince William Sound. Numerous other observers have reported frequent sightings of large numbers of otters including juveniles and pups in the Sound. It is apparent that there is a substantial surviving population from which the losses are being restored.

Research reported by Dr. James Estes in 1990 and carried out in Alaska, British Columbia and Washington state since the 1960s has shown that populations of sea otters throughout this region have increased at the very high rate of 17-20% per year until they reach a population limit set by the availability of their food.

Sea otters are abundant in Prince William Sound. With a potential for the population to grow at nearly 20% per year, we have concluded that whatever losses suffered in the oil spill are likely to be rapidly made good by natural reproduction.



Sea lions were not seriously at risk from the spill.

OTHER SEA MAMMALS

Scientific research suggests that whales, dolphins, seals and sea lions are not seriously at risk from oil spills. One of the reasons is that they rely on a layer of blubber under the skin, rather than fur, to insulate them from the cold. Whales and dolphins are hairless and even if they encounter floating oil, the oil does not stick to their bodies. Experiments with seals have shown that oil may stick to the fur but rapidly washes off.

In previous oil spills, there have been occasional reports of very small numbers of oiled seal or seal pup carcasses being found. These reports have generally not been well substantiated and it is not clear that oil was the cause of death. Similarly, whales do not appear to have been affected by oil spills. Gray whales migrated through the Santa Barbara Channel following the blowout of 1969, but there were no reports of casualties. The disappearance of some members of a resident pod of killer whales in Prince William Sound in 1989 and 1990 is therefore unexpected; it is not clear how they could have been affected by the oil, if, indeed, they were.



The abundance of nesting seabirds in the area and the size of their breeding colonies do not support fears of long-term adverse spill impacts.

SEABIRDS

Seabirds, particularly auks, are the most conspicuous casualties from oil spills. There are enormous seabird colonies in Prince William Sound and the Gulf of Alaska so even a small percentage of casualties means large numbers of birds were killed. The important question is how rapidly these losses will be restored by natural processes.

The dominant seabirds in the area are auks (murres, puffins, etc.) and gulls. Gulls are rarely affected by oil and at the time of the oil spill puffins had not yet returned to the Sound from their winter quarters farther south. Therefore, the concern centres on murres.

As in other cold water oil spills, the chief seabird casualties in Prince William Sound and the Gulf of Alaska were murres. There has been a good deal of concern that the damage caused to the murre population in Prince William Sound and the Gulf of Alaska would take decades to restore. Experience in other parts of the world suggests that this fear is not well founded.

Murres have an extremely low reproductive rate and several scientific studies have predicted, on theoretical grounds, that a substantial loss from a breeding colony would take 50 years or more to restore by natural growth. There were natural fears that this would apply to the colonies in the affected area, but this is most unlikely because when the theory has been tested by actually counting the size of breeding colonies in other areas affected by oil spills, it has proved to be wrong.

Murres, like many other seabirds, do not start breeding until they are 5-7 years old and, even then, do not necessarily breed every year. There is therefore a large reserve of non-breeding adults outside the breeding colonies, and this population of non-breeding adults replaces any losses from the breeding colonies. This accounts for the fact that breeding populations are not reduced even after natural disasters caused by severe weather or after oil spills. As an example of a natural disaster, over 100,000 murres died in the severe winter of 1971-72 in southwest Alaska.

Observations from the northeast Atlantic are relevant to Alaska because the same species is involved and because in this area there are long-term data available.

Tens and hundreds of thousands of murres have been killed in the northeast Atlantic *every year* since the 1920's by oil pollution from shipping in heavily trafficked sea lanes. Far from this causing a steady decline in populations, as the theory predicts, murres and other auks have all undergone a population explosion in the northeast Atlantic and are now at the limit of their food supply.

In the Gulf of Alaska the murre breeding season does not begin until May or June, but even in April 1990 we saw large numbers congregating near some of the larger breeding sites, including Barwell Island where the colony had reportedly suffered heavy losses in 1989. Many more murres were widely distributed throughout Prince William Sound and the Gulf of Alaska. To judge from experience in the northeast Atlantic, the size of the

breeding colonies in Prince William Sound and the Gulf of Alaska should be restored within a short time.

A remaining worry is that seabirds might continue to be killed by oil sheens on the water even though most of the oil was removed from the environment in 1989. During extensive overflights of Prince William Sound and parts of the Gulf of Alaska in April, May and September, 1990, we saw very few sheens. These were small, and their silvery colour indicated that they were very thin films of oil. There is no scientific evidence that these are harmful.

Sheens of this type are caused by boats discharging oily bilge water (as we observed on one occasion), by residual oil washing off beaches (as we observed off one beach), but are also produced naturally by algae. Seabirds are constantly exposed to sheens from natural or man-made sources, and spend most of their time, when they are not feeding, preening their feathers to keep them in a clean, waterproof condition.



BALD EAGLES

This noble bird is the national emblem of the United States, so feelings about it run high. It is an endangered species in the lower 48 states where it exists only in very small numbers. There was natural concern that some had been harmed by the oil.

Although there are very few bald eagles in the lower 48 states, they are not rare in Alaska. There are estimated to be 40,000 bald eagles in Alaska, probably the world's largest concentration of these birds. About 5,000 of them are in Prince William Sound.

During extensive aerial surveys of Prince William Sound and the Gulf of Alaska at the start of the 1990 breeding season, we observed bald eagles



Bald eagles are not endangered in Alaska, with more than 5,000 concentrated in the Prince William Sound area.

on prominent look-out trees at regular intervals around all forested coasts. At some sites we observed courtship displays and competition between male birds for territories.

Birds of prey have never before been victims of marine oil spills, but bald eagles are scavengers on the shoreline and presumably this activity resulted in some becoming oiled. Special teams captured 113 eagles in the most heavily oiled areas during the Summer of 1989. Evidence of oiling was noted on 35% of these 113 birds, and all but three of them were cleaned and eventually returned to the wild.

Eagles in the oiled areas had poor breeding success in 1989 with only about 200 young being produced in the Prince William Sound area. Scientific observers have attributed this to the disturbances caused by the clean-up activities and not the oil itself. In contrast, 1990 had a greatly reduced clean-up effort, and there was an active nest count of 1,031 with chicks being reared in previously oiled territories, according to the United States Fish and Wildlife Service.

The habits of these birds make it most likely that the breeding population will be quickly restored to its former level. Bald eagles do not breed until they are 5-6 years old and young non-breeding adult birds are widely distributed along rivers inland. There is competition for the breeding sites and the dominant birds occupy the best situations; any losses among the breeding population are filled by new recruits, at least by the next breeding season.

RESTORATION PROGRAMMES

There has been some public discussion about replanting and restocking damaged areas in Prince William Sound.

Such programmes to hasten biological recovery have occasionally been implemented elsewhere when there have been compelling reasons such as the prevention of coastal erosion. For example, a salt marsh on the French coast that had been severely damaged by oil-spill clean-up measures was replanted with appropriate vegetation, and eel grass beds destroyed by waste discharges in Florida and Australia have also been replanted. The reason for these extreme measures was because the salt marsh and eel grass beds were important in those areas as traps for sediment washed from the land, and without these barriers there would have been severe coastal erosion. That is why priority was given for their rehabilitation.

We have not seen damage requiring such measures in Prince William Sound and the Gulf of Alaska. Salt marshes in the area are very small so their significance in controlling coastal erosion is minimal. Moreover, in 1990 we saw that salt marsh plants, eel grass and beach grasses were growing well even on shores which had been heavily oiled in 1989 and still retained some residual oil.

Other shore organisms showed signs of rapid natural recovery. Many of the shores impacted in Prince William Sound were boulders or cobble stones exposed to severe wave action during storms (high energy beaches). Most of the plants and animals living on these shores are removed each year as a result of this natural turbulence. However, rapid recolonization takes place each season as part of the natural cycle of events in such hostile environments. There is an abundance of recolonizing organisms providing a reservoir from which shores damaged for any reason can be rapidly restored.

In conclusion, we saw nothing to indicate that further human intervention in the marine restoration process would be of any value.

CLEAN-UP

There have been continuing public discussions about whether further clean-up of remaining oil on the beaches in Prince William Sound and the Gulf of Alaska is necessary.

Whether or not further clean-up measures to remove this residual oil are justified largely depends on the human use a beach is put to. Our judgment is that where recovery of animal and plant life is already well established, the residual oil is obviously doing no harm and the organisms



With plant and animal life established, further intrusive clean-up could be counterproductive.

established on the shore will hasten the final removal and degradation of the oil residues. Further intrusive cleaning such as beach excavation and rock washing of beaches would kill the plants and animals already there and set the recovery process back to the beginning .

Experience has shown that after other oil spills, heavily-used tourist beaches may need to have most of the physically detectable oil removed. In that case, drastic measures are needed even at the expense of biological recovery. However, such beaches do not exist in Prince William Sound. Beaches need to be considered one by one, to decide whether there are special considerations which warrant further cleaning even though this could set back biological recovery.

CONCLUSIONS

There is a wealth of information about the recovery of cold water marine ecosystems following oil spills in various parts of the world. In all cases recovery events have been similar to those seen in Prince William Sound. If anything, because of the exceptionally thorough clean-up measures and natural cleaning processes, biological recovery has started sooner and proceeded further in Alaska than might have been anticipated.

There is no reason to suppose that the recovery process in the Prince William Sound oil spill are any different from those following other cold water oil spills around the world, many of them larger and more damaging. Although there have been a number of pessimistic forecasts in the media, there is nothing to suggest that there will be further delayed or long-term effects from the oil now that recovery is well underway.

These conclusions will not surprise any scientist experienced in the recovery of ecosystems following oil spills. In 1985, the U.S. National Academy of Science published an expert assessment of the threat posed by oil spills which is entirely consistent with our judgements, and there have been a number of similar expert reports published by distinguished international bodies to the same effect.

BIOGRAPHIES

Each author has had extensive international experience studying the impact of oil on the marine environment extending back over 20 years. Also, each has acted at various times as an independent scientific consultant to environmental bodies, government agencies or commercial organizations. The authors are all familiar with the scientific literature on oil spills and, indeed, have contributed to it significantly over the years.

Dr. Jenifer M. Baker

Dr. Baker is a marine biologist who conducts research on oil-pollution problems for conservation organizations, corporations, and government and United Nations organizations throughout the world. She is the former research director of the U.K. Field Studies Council, an independent environmental education and research organization. Her doctoral studies at the University of Wales involved research into the effects of oil and cleaning methods for salt marshes, and she later served as a staff member in the Botany Department of the University College, Swansea. She recently helped assess potential oil pollution problems on the great lakes of Africa for a conference organized by the International Association of Theoretical and Applied Limnology. A fellow of the British Institute of Biology and the Institute of Petroleum, Dr. Baker has published numerous papers in the scientific literature on the recovery of impacted shoreline ecosystems.

Dr. Robert B. Clark

*Dr. Clark, professor emeritus of zoology at the University of Newcastle upon Tyne, received his Ph.D. from the University of Glasgow and a D.Sc. from the University of London. He has served as director of the seabird research unit of the British Advisory Committee on Oil Pollution of the Sea (1969-75) and as director of the Natural Environment Research Council's Unit on Rocky Shore Surveillance (1980-87). He has served as member of the zoology faculty of the University of California at Berkeley and has worked with numerous national and international advisory bodies, including the United Nations Group of Experts on Scientific Aspects of Marine Pollution (of which he was a founding member) and the U.K. Royal Commission on Environmental Pollution. Dr. Clark is the author of the textbook *Marine Pollution* and is founder and editor of the monthly *Marine Pollution Bulletin*.*

Dr. Paul F. Kingston

Dr. Kingston is the Assistant Director of the U.K. Institute of Offshore Engineering and a former member of the marine biology faculty at Heriot-Watt University of Edinburgh, Scotland. He obtained his doctorate from the University of London and joined Heriot-Watt University in 1975 following a three-year research fellowship at the University of Newcastle upon Tyne.

*Dr. Kingston has worked in the field of marine environmental monitoring for over fifteen years. His experience covers a wide range of oil and non-oil related issues ranging from the Amoco Cadiz oil spill to the Channel Tunnel project on which he currently acts as Principal Marine Environmental Consultant. He has had extensive experience in assessing the impact of the North Sea industry on the marine environment and has worked on most major North Sea petroleum developments. His research interests centre on the structure and dynamics of seabed communities in relation to industrial and domestic environmental impacts. He has published extensively and currently serves as news editor of the *Marine Pollution Bulletin*.*



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**Excavation and Rock Washing Treatment Technology
Net Environmental Benefit Analysis**

With Contributions From:

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Compiled By:

**Hazard Materials Response Branch
National Oceanic and Atmospheric Admin.
7600 Sand Point Way, N.E.
Seattle, Washington 98115**

July, 1990



**U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration**

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July 9, 1990

RADM David Ciancaglini, USCG
Federal On-Scene Coordinator
601 West Fifth Street
Anchorage, AK 99501

Dear Admiral Ciancaglini:

Enclosed is the Net Environmental Benefit Analysis (NEBA) on excavation and rock washing, my concluding summary, and responses to that summary from the State of Alaska and Exxon. We were delayed somewhat in transmitting this material, awaiting the response from Alaska Department of Environmental Conservation.

It is important to note that the summary and conclusions represent my best judgement as Scientific Support Coordinator for the EXXON VALDEZ spill response. The interpretations therein should not be construed to reflect the opinion of the Agency in any broader context.

As you know, the NEBA studies have been relatively short term and specifically directed to the questions involved in this analysis. In accomplishing this task, we did not have the benefit of the studies being undertaken through the damage assessment programs of the Trustee Agencies or Exxon. Nothing in the attached material should be interpreted to imply an opinion on my part, or on the part of other contributors to this report, as to the extent of damage that may have occurred or may occur in the future as a result of the spill.

Sincerely,

John H. Robinson, Chief
Hazardous Materials Response Branch

Attachments



U.S. Department
of Transportation

United States
Coast Guard



Federal On Scene
Coordinator
U. S. Coast Guard

Key Bank Bldg.
601 W 5th Ave.
Suite 300
Anchorage, AK 99501
(907) 277-3833

16465
16 July 1990

Mr. Otto Harrison
General Manager
Exxon Alaska Operation
P. O. Box 240409
Anchorage, AK 99524-0409

Dear Mr. Harrison:

The Net Environmental Benefit Analysis (NEBA) Committee Report has been reviewed in its entirety. It is my understanding that the data contained in the report and submitted individually by NOAA, the State of Alaska and Exxon was included in toto for my consideration. Based on this data, I have determined that the benefits derived from the wide-scale use of the rock washer would be far outweighed by the detrimental effects caused by its usage. Although there is some disagreement regarding various conclusions in the report, there is sufficient basic information not in contention to support my decision. Therefore, as the Federal On Scene Coordinator, I will not authorize use of the rock washer. Essentially, the reasons for this decision are as follows:

A. With recolonization and a year's natural cleansing, the use of the technology would be detrimental to environmental recovery.

B. Considering the secondary environmental damage associated with the rock washer, damage to the lower intertidal zone and the mid intertidal zone habitats, and the unknown gain by using such an intrusive method, there are much better ways to improve the high human use and subsistence areas.

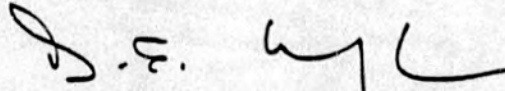
C. On those shorelines which still have significant subsurface oiling, the top 15cm of oiled sediment is of greatest concern. For those shorelines, other alternative treatment methods such as bioremediation, tilling, berm removal, etc. may be used to significantly reduce subsurface oil.

D. Based on the information contained in the NEBA report, the potential environmental hazard posed by the oil in its present state is far less than the certain ecological harm that would be incurred by rock washing. Biological recolonization is occurring, natural cleansing continues to remove oil, sheening is dramatically reduced, and commercial fisheries are taking place.

The process to develop the rock washer and study its effects on the environment is appropriate and consistent with the procedures employed prior to the use of other treatment technology used on this spill response.

A letter similar to this has been sent to ADEC and NOAA.

Sincerely,

A handwritten signature in dark ink, appearing to read 'D. E. C. W. L.', written in a cursive style.

D. E. CIANCAGLINI
Rear Admiral, U. S. Coast Guard
Federal On Scene Coordinator

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UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL OCEAN SERVICE
OFFICE OF OCEANOGRAPHY AND MARINE ASSESSMENT
ROCKVILLE, MARYLAND 20852

JUL 17 1990

RADM David Clancaglini, USCG
Federal On-Scene Coordinator
601 W. Fifth Avenue, Suite 300
Anchorage, AK 99501

Dear Admiral Clancaglini:

I have personally reviewed the recent report of your Scientific Support Coordinator (SSC), Excavation and Rock Washing Treatment Technology: Net Environmental Benefit Analysis, and the summary and conclusions in John Robinson's July 5 cover memorandum. As Mr. Robinson stated in his July 9 transmittal to you, the report and its conclusions were based on the best information available to the report authors and the SSC at the time of their preparation.

The summary and conclusion of the report should not be interpreted as conclusive about the extent of comprehensive damages that have occurred and may continue to occur as a result of EXXON VALDEZ oil spill. In addition, the conclusions of the report should not be interpreted as precluding the need for restoration activities to enhance natural recovery processes. The Natural Resource Damage Assessment Program of the Federal and State of Alaska trustees must make those determinations.

The National Oceanic and Atmospheric Administration fully supports the conclusions reached in Mr. Robinson's memorandum of July 5 with respect to the specific question of the environmental benefits of washing rocks to remove subsurface oil.

Sincerely,

Charles N. Ehler
Director



***Excavation and Rock Washing Treatment Technology
Net Environmental Benefit Analysis***

With Contributions From:

***Exxon Company, U.S.A.
National Oceanic and Atmospheric Administration
State of Alaska***

Compiled By:



***Hazardous Materials Response Branch
National Oceanic and Atmospheric Administration
7600 Sand Point Way N.E.
Seattle, Washington 98115***

July 1990



U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration

NATIONAL OCEAN SERVICE
OFFICE OF OCEANOGRAPHY AND MARINE ASSESSMENT
OCEAN ASSESSMENTS DIVISION
Hazardous Material Response Branch
7600 Sand Point Way NE - Bin C15700
Seattle, Washington 98115

July 5, 1990

MEMORANDUM FOR:

RADM David Ciancaglini, USCG
Federal On-Scene Coordinator

FROM:

John H. Robinson, Chief *John H. Robinson*
Hazardous Materials Response Branch,
NOAA

On April 27, 1990, you requested that NOAA conduct a Net Environmental Benefit Analysis (NEBA) comparing the benefits of excavation and rock washing with the benefits of natural cleanup as augmented by the approved 1990 cleanup methodologies. A committee of technical experts from NOAA, the State of Alaska, and Exxon, was formed to investigate and attempt to reach some resolution of the issues involved.

The committee has worked diligently to define the environmental factors important to the analysis, research the scientific literature to gain insight from past spills, and undertake field programs to obtain additional data where necessary.

The NEBA committee produced the attached report following a mutually agreed-upon outline and technical approach. All members of the committee were provided the opportunity to comment on a draft of the final report and the authors of each section were urged to consider committee member comments in their final manuscripts. The opportunity to append other viewpoints was provided. NOAA then prepared a summary of the report which is included as an attachment to this memorandum. The summary was forwarded to the State of Alaska and Exxon for review and comment; comments received were considered in the final draft.

Many key technical issues surrounding the analysis were partially resolved in the course of this undertaking and on some topics the range of disagreement was substantially narrowed. In accord with your instructions, NOAA attempted to reach a consensus on the question and



reserved our position on the issue until it became clear that the major parties to the matter would be unable to reach agreement on the key issues.

Given the disagreement between the State of Alaska and Exxon on the conclusion of the analysis, we offer our opinion that there is no net environmental benefit to be gained from shoreline excavation and washing — in fact we believe that this technology has the potential of aggravating the injury to the environment caused by the oil spill.

We believe that the data gathered in the process of this analysis support the contention that deeply buried subsurface oil (i.e., oil beyond the reach of near-term bioremediation and other less-intrusive cleanup methods) poses little risk of causing further significant environmental injury. This finding is borne out by the following:

- There is evidence of a substantial reduction (up to 90%) in the top 20 cm of the shoreline since September of 1989. Subsurface oil should continue to be reduced gradually as fall and winter storms scour the coast.
- There is evidence that the frequency and magnitude of sheens have decreased significantly over the past several months and chemical changes in the subsurface oil have rendered it much less capable of sheening. Commercial fisheries closures attributed to sheening are infrequent.
- There is evidence that recolonization of biological communities is proceeding in candidate areas for rock washing. There is no evidence that subsurface oil is causing a serious impact to intertidal or subtidal organisms, either by direct contact or by indirect contact through adverse effects on nearshore water quality.
- There is evidence that the toxicity of subsurface oil is continuing to decline, primarily as a result of microbial degradation.

The case against excavation and rock washing is further accentuated by a review of the negative impacts of that technology:

- Excavation would alter the natural structure and profile of the shoreline, and require one to three years for a return to equilibrium.
- Excavation would eliminate virtually all plant and animal life indigenous to the mid- and upper-intertidal zone and may cause a

significant adverse effect in the highly productive lower intertidal zone. Biological recovery of the shoreline following excavation would require four to eight years compared with two to six years if left to natural processes.

- Excavation would cause numerous large-scale secondary impacts associated with fuel consumption, incidental spills, noise, air pollution, siltation, possible archaeological disturbance, and human intrusion into the affected shoreline areas.

We believe that the only benefit to be derived through excavation and rock washing is the predictability that oil would be promptly removed from the subsurface environment, eliminating the potential for future contamination that might disrupt human use of the shoreline and nearshore waters. This potential benefit, in our opinion, is certainly far outweighed by the ecological disruptions that would be result from use of this technology.

We believe that the conclusions reached through this analysis strongly support natural cleanup processes and continuation of the approved 1990 cleanup program.

Attachments

SUMMARY

A technical committee was formed in May 1990 to investigate the environmental tradeoffs associated with excavating and washing oiled sediments remaining deeply buried along some sections of the Alaskan shoreline affected by the EXXON VALDEZ oil spill. The committee, comprised of Exxon, NOAA, and State of Alaska scientists, was charged with conducting a Net Environmental Benefit Analysis (NEBA) related to the advisability of excavation/washing in comparison to natural cleansing and application of treatment protocols approved by the Federal On-Scene Coordinator for use in 1990.

The NEBA committee selected two shoreline segments, Sleepy Bay on the north coast of Latouche Island and Point Helen on the southeast coast of Knight Island, as candidate locations to pursue field studies associated with the analysis.

The committee collectively outlined the range of environmental issues important to the analysis. The benefits and negative impacts of excavation and rock washing were researched in some detail, using both site-specific data from the candidate beaches and published studies on the fate and effect of oil and the impacts of physical disturbances to the shoreline. The results of these analyses can be summarized as follows.

How much oil is buried at what depths along the most severely affected sections of the coast? What are the prospects for removal by natural processes?

During the March/April 1990 shoreline assessment, 212 of the 1,134 shoreline segments surveyed had subsurface oil deposits thicker than 15cm and buried deeper than 15cm. Of 5,071 pits dug in the assessment, only 279 contained oil that had penetrated greater than 30cm, with 25 that had oil penetration greater than 60cm. The deepest occurrences of subsurface oil were found on coarse-grained beaches (boulder/cobble/pebble) along exposed shorelines.

NOAA studies at 18 stations in Prince William Sound over the six-month period from September 1989 to March 1990 indicated that, on the exposed shoreline segments most likely to be amenable to excavation, sediment reworking resulted in the removal of oil from the top 10-20 cm of

surface sediments. Data taken from Sleepy Bay and Point Helen reflected a 90% oil reduction in the top 30cm, but no discernible trend in oil reduction was evident below this depth. Exxon's winter monitoring study at 18 sites in Prince William Sound concluded that the concentration of total petroleum hydrocarbons (TPH) in subsurface sediments (generally >10cm) declined by 88% over the same period.

Using various survey methodologies, the estimated amount of oil remaining in subsurface sediments at Sleepy Bay, one of the candidate sites for excavation, was:

Gallons/meter of Shoreline	No. of Samples	Source
9.9	43	NOAA Oct-Feb Survey
5.0	13	Exxon Mar Survey
6.1	11	Exxon Jun Survey

Perhaps of more importance than the quantity of subsurface oil is the rate of natural removal which may be expected over the next few years. There have been numerous studies of previous spills in which the persistence of stranded oil has been surveyed. However, there are many factors specific to Prince William Sound that might alter the extrapolation of oil persistence curves from other spills to the EXXON VALDEZ. The factors that may speed natural removal processes in Alaska are:

- 1) Flocculation, the process by which fine-grained sediments adhere to the subsurface oil and make the oil less sticky and more biologically available.
- 2) Enhanced biodegradation, both naturally occurring and stimulated by the addition of nutrients.
- 3) Removal of surface oil during the 1989 treatment, which limited the formation of asphalt pavements.

The factors that may slow natural removal rates in Alaska are:

- 1) The relatively low wave energies relative to the grain size of shoreline sediments.
- 2) The initial high degree of contamination of some shoreline segments.

Oil removal is expected to be most pronounced early in the recovery period; this expectation is clearly being borne out by data gathered thus far through the various monitoring programs. NOAA estimates that virtually all of the oil buried in gravel shorelines should be removed, given no further treatment, in the periods of time indicated below:

Sheltered parts of Prince William Sound	10+ years
Sheltered outer Kenai	3-5 years
Exposed parts of Prince William Sound	2-4 years
Exposed outer Kenai	1-2 years

At what rate is subsurface oil being weathered?

Samples of subsurface oil were collected by NOAA from the two NEBA study areas and analyzed by gas chromatograph/mass spectrometry (GC/MS) to determine both chemical composition and weathering trends. Most of the subsurface oil in these samples was moderately to heavily weathered and altered significantly in both physical and chemical properties from the original state. Physically, the oil had become more viscous, less sticky, and would not readily sheen. Chemically, the oil had lost many of the light- to moderate-weight polynuclear aromatic hydrocarbons (PAHs), components which are of greatest toxicity to aquatic organisms. For example, the naphthalenes and phenanthrenes had been reduced by more than a factor of 100 when compared with fresh EXXON VALDEZ oil. Analysis of the saturate fraction of this subsurface oil showed strong evidence that microbial degradation had occurred. Overall, the subsurface oil had decreased in both concentration and toxicity and showed evidence of significant microbial degradation.

Will subsurface oil become exposed by wave action?

It is likely that there will be further removal of subsurface oil by wave action and shoreline erosion; however, these processes are most likely to

occur in the winter when sediment abrasion and thus natural cleaning of the surface is at a maximum. There is no general agreement as to the rate at which the oiled subsurface sediments would be exposed by these processes. Larger cobbles exposed during severe winter storms may remain with some surface oil contamination; the smaller sand, granules, and pebbles would rapidly be cleaned.

To what degree is water within the beach being contaminated by subsurface oil and thus exposing organisms to toxic hydrocarbon compounds?

Water within the beach ("pore water") comes in contact with subsurface oil as it moves through the interstitial space among oiled sediment particles. The prospect that pore water may become contaminated was investigated by the committee.

An Exxon mathematical model was used to predict the concentration of PAHs in pore water, which contacts subsurface oil deposits, and the rate at which tidal flushing would leach the water-soluble fractions of the oil. Using data on concentrations of PAHs in sediments collected in March 1990, Exxon predicted that concentrations of total PAHs in pore water would be generally below 20 ppb. These model results were confirmed by Exxon analyses of field samples of pore water collected in March at eleven sites in Prince William Sound. Only one sample contained PAH levels greater than 10 ppb and only three reflected levels greater than 1 ppb. Two of the three highest values were for samples collected from Sleepy Bay. All observed levels of pore water contamination are below concentrations known to be acutely toxic to marine organisms.

An additional twelve water samples were collected by NOAA at the sediment/water interface during falling tides from Sleepy Bay in May 1990. Total PAH concentrations in these samples were all less than 1 ppb. The rapid dilution of the pore water as it mixes with clean interstitial and shallow subtidal waters should result in PAH concentrations that pose little or no toxic hazard to marine organisms on the lower shore and in subtidal waters.

To what extent can sheens be produced by subsurface oil? If such sheens are produced, what adverse effects can be anticipated?

The committee investigated the frequency, magnitude, composition, and effect of oil sheens likely to originate from subsurface oil. Observations by ADEC and Exxon show a declining trend in both sheen frequency and volume throughout Prince William Sound. The downward trend in Exxon data is more pronounced, possibly due to the elimination of non-Prudhoe Bay crude sheens from the data set. On a weekly basis, the volume of sheens from EXXON VALDEZ oil is now well below the present level of petroleum hydrocarbons introduced to surface water of Prince William Sound from other sources (vessel traffic, combustion, natural organics, etc.).

NOAA chemical analysis indicates that the natural weathering of subsurface oil has rendered the oil both less toxic and much less capable of producing sheen. As long as the oil remains physically stable in the shoreline, sheen frequency should be minimal. A temporary increase in sheening would likely be produced either by excavation or by intense winter storms. Sheens produced by excavation could be expected to be controlled in light to moderate weather conditions. While control of storm-induced sheens is unlikely, the range and effect of such sheens would be limited by natural dispersion during the storm event. NOAA studies in 1989 indicated that only in unusual weather conditions would convergence zones have the potential to concentrate free-floating oil into popweed windrows to the extent fishing gear might be contaminated. The threat of exposure to birds feeding at these windrows is likely to be small as exemplified by the lack of reports of oiled marine birds this year.

In summary, subsurface oil is relatively stabilized and insulated from exposure to vulnerable resources through sheening. Adverse effects on birds, fish, wildlife habitat, or human uses are not expected to originate from sheens produced by subsurface oil.

What is the near- and long-term fate of subsurface oil?

Subsurface oil that persists in the shoreline will eventually be degraded by indigenous bacteria. However, prior to the complete microbial breakdown of oil buried deep within the shoreline, other processes may be important in controlling the intermediate distribution and fate of the oil.

Flocculation is one process that has been proposed by Exxon as being an important mechanism for enhanced natural removal and dispersal of subsurface oil. The flocculation process has been demonstrated in laboratory studies, and in the field some subsurface oil appears to have taken on a more weathered, smeary texture indicative of floc formation. However, the rate of flocculation and its relative importance, particularly in the removal of heavily oiled subsurface sediments, is not known.

There is some concern that the fine-grained fraction of oiled subsurface sediments may be exposed by erosion and deposited in the nearshore subtidal environment. Since there are few data available to evaluate this potential risk, a diving survey was conducted by ADEC in June 1990 to collect subtidal sediments along a transect out to 100m off both Point Helen and Sleepy Bay. Total PAHs in these subtidal sediments were 0.1-9 ppb off Point Helen and 1-130 ppb off Sleepy Bay. This limited sampling would indicate that deposition of oiled sediments, derived from either subsurface or surface sources, may be minimal.

What are the potential effects of rock excavation on the shoreline substrate?

There is great variability in sediment grain size and shoreline exposure in Prince William Sound, and therefore the effects of excavation and rock washing on the structure of the intertidal zone would vary considerably from location to location. Shoreline segments that contain high concentrations of subsurface oil are also generally exposed to moderate or high wave energy. The upper part of the intertidal zone in these locations is affected by the erosion and deposition of high-tide berms, as shown through analysis of data obtained during the Exxon, NOAA, and ADEC winter monitoring programs. The middle and lower intertidal zones are less affected, particularly if a cobble/boulder armor is present, such as on Point Helen, one of the candidate sites for rock washing.

Using data from the winter monitoring programs and case histories from other studies, it is predicted that, if the material were removed from the upper one-third of the beach and replaced in approximately the same position from which it was taken, the upper berms at Point Helen would reestablish themselves after two or three medium-sized storms. The re-armoring process in the middle and lower part of the shoreline would require a few more storms, possibly covering a period of one to three years.

For Sleepy Bay, which is more sheltered but also is composed of finer-grained sediments, the upper surface sediment resorting should occur in less than one year. However, because the middle portion of the beach changes more slowly, complete reestablishment of the original profile and sediment resorting may require up to three years, though it may take place sooner. Recolonization by intertidal organisms would be delayed during these periods of sediment restabilization.

Loss of fines is not expected to be of concern, mainly because of the relatively small percent of sand-sized materials in the upper zone on most beaches in Prince William Sound. Because the sand exists primarily as a matrix to the already fixed framework of the beach, there should be no impact of its potential loss on beach morphology or erosion. There were concerns that the loss of sand might change the hydraulics of the beach, but the magnitude or consequences of this impact are unknown.

What are the effects of subsurface oil and excavation on the recolonization by intertidal communities?

In the areas where excavation is being considered, the intertidal zone can be divided into three subzones on the basis of the distribution of biological communities. The upper intertidal zone, generally the location of the highest concentrations of subsurface oil, is normally not inhabited by a very rich biological community because of relative dryness, sediment mobility, and lack of food.

The middle intertidal zone contains a more rich and diverse biological community. Observations made this spring and summer indicate that these communities are recovering from the oil and treatment activities. Oil concentrations of the surface sediments in this zone are generally low and, as discussed earlier, toxic impacts from the discharge of groundwater through oil-contaminated sediments across this zone are not expected to be significant. Because most of the plants and animals in this zone live in the top 10-15cm, there is no pathway of exposure to subsurface oil other than oil exposed during erosional events. To the extent the oil remains buried, it poses no serious risk to intertidal communities in this zone.

The lowermost intertidal zone has the greatest biomass and species diversity. In most cases, this zone is showing evidence of recovery and only