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Impact of the Transportation of Petroleum on the Waters of the Northeastern Pacific Ocean

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INTRODUCTION

Petroleum and other hazardous chemical products are shipped in large amounts over the waters of the northeastern Pacific Ocean and along its coastal waterways. The variety and quantity of these toxic materials moving across the oceans are steadily increasing in response to expanding industrial needs. Spills and other accidental discharges of such materials can seriously impair water quality at sites near or remote from the sources of discharge. Since petroleum makes up nearly 95 percent of the bulk of hazardous cargo moved in the northeastern Pacific, this discussion will concern itself with the magnitude and impact of petroleum and its products on the water quality and the living marine resources.

For the last 100 years, petroleum on the west coast has been transported over the waters of the northeastern Pacific—first in small wooden barrels and now in large tankers of 130,000 deadweight tons (dwt) or larger. Until the last decade or so, most of the oil shipped along the western margin of the North American continent was contained in small tankers and barges (18,000 dwt or less), carrying refined petroleum products from southern California refineries to nearby coastal markets.

In the last two decades, the markets for petroleum products have increased in size while the production of crude oil in the southwestern United States has decreased. Consequently, it has become expedient to build new refineries nearer the developing markets, and it has become necessary to transport crude oil greater distances from domestic and foreign oil fields by pipelines and supertankers. This increase in magnitude of the transportation of petroleum and its refined products has magnified the potential risk of oil pollution in the marine environment.

TRANSPORTATION AND PRODUCTION

Historically, petroleum products were refined near the oil fields in California and then shipped up the west coast in small coastal tankers. In the mid-1950's new refineries were built in Washington and British Columbia to produce petroleum products for local consumption from crude oil delivered by pipeline from Alberta, Canada. Oil was discovered in the late 1950's in the Kenai Peninsula near Anchorage, Alaska; two small refineries were built there for Alaskan needs, and the excess crude oil was shipped to California for refining. By the early 1970's the overall production of crude oil on the west coast was declining while the demand for products in the same geographic area was increasing at approximately 4.5 percent annually (Oil and Gas Journal, 1971). Although the petroleum industry has predicted that higher energy costs, conservation efforts, and slower economic growth will reduce the average growth of petroleum use to about 2.2 percent annually over the next decade (Exxon USA, 1976), the projected west coast demand for 1976 is 4.9 percent greater than the use in 1975 (Oil and Gas Journal, 1976). The deficiency in crude oil production (53.3 percent) compared to consumption of refined products has, in the area west of the Rocky Mountains, required the importation of large volumes of foreign (South American, Indonesian, and Middle East) crude oil carried in increasingly larger tankers—in the 100,000-130,000 dwt class—although very large crude carriers (VLCC) of 226,000-400,000 dwt are already in use on other worldwide routes.

The utilization of the large oil reserves (20-40 billion barrels; 1 U.S. barrel is 42 gallons) discovered in the Alaskan Arctic in the late 1960's can decrease the need to import crude oil to the west coast. A 48-inch diameter Trans-Alaska Pipeline System (TAPS) is being completed from Prudhoe Bay to the ice-free port of Valdez, where crude oil will be loaded eventually at 2 million barrels/day into large tankers and supertankers for delivery to refineries in the Puget Sound area of Washington and the San Francisco and Los Angeles-Long Beach areas in California, with possible shipments to the east coast through the Panama Canal (Fig. 1). This system, assuming a completion data of 1977, envisions the use of more than 35 modern tankers ranging in size from 45,000 dwt to 250,000 dwt, many of them yet to be built. All will be U.S. built and manned (Table 1).

PRUDHOE BAY CRUDE OIL

The Prudhoe Bay oil field (Sadlerochit oil pool) is North America's largest known petroleum reservoir; the American Petroleum Institute places the recoverable reserves at a conservative 9.6 billion barrels of oil, and the American Gas Association estimates 26 trillion cubic feet of gas. The initial production is planned at 1.2

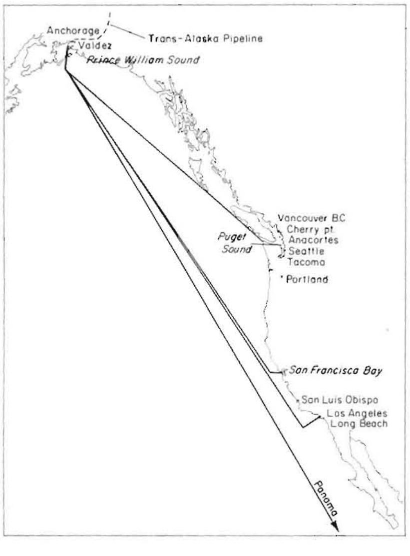

Figure 1.—Crude oil transportation routes from the southern terminal of the Trans-Alaska Pipeline System at Valdez to west coast ports.

Table 1.—Typical tankers to be used on the Valdez-west coast run at 2 million barrels per day [1].

No. of vessels	Tonnage (dwt)	Vessel size: Length (ft)	Vessel size: Draft (ft)	No. of cargo tanks	Crash stopping distance (ft)
1	45,000	—	—	—	—
3	60,000	731	43.2	13	4,300
2	70,000	810	43.5	18	9,000
3	75,000	810	41.5	15	5,225
2	80,000	811	43.2	13	5,000
2	86,000 (&90,000)	892	47.5	14	—
16	120,000	883	51.8	15	10,000
5	130,000	—	—	—	—
1	150,000	—	—	—	—
2	180,000	952	59	—	—
8	250,000	1,143	65.5	15	13,500
0	380,000	1,190	101	20	—

[1] Sources: Alyeska Pipeline Service Co., 1971, Description of marine transportation system—Valdez to West Coast ports. Submitted to U.S. Dep. Interior, 21 July, 65 p.; Final Environmental Impact Statement, 1973, Maritime Administration Tanker Construction Program, Dep. Commerce (NTIS Rep. No. EIS 730725-F); Alyeska Pipeline Service Co., 1973, The marine transportation of Alaska North Slope oil, Anchorage, 24 p.

million barrels/day for pipeline delivery to Valdez. This single 46-square mile field is expected to produce for 10-11 years without secondary recovery (water or gas drive to force the oil from the reservoir rock structure to the well)[1]. There are other geological basins, including Naval Petroleum Reservation Number 4 adjacent to Prudhoe Bay, having sedimentary structures which point to further oil reserves in Alaska; therefore, tanker transport of crude oil from Alaska can be expected to increase beyond the levels predicted for TAPS.

Chemical analysis reveals Prudhoe Bay crude oil to be an average crude oil. Comparisons of chemical analyses of Prudhoe Bay crude oil (Sag River) with typical South Louisiana and one of the Kuwait crude oils is made in Table 2.

SUPERPORTS AND SUPERTANKERS

To meet the energy needs of the western United States and Canada, it is predicted that there will be increasing reliance on sources such as Alaskan and foreign regions, requiring waterborne delivery of petroleum. The increase in tanker traffic can take place by either increasing the number of medium (less than 40,000 dwt), large (around 70,000 dwt), or supertankers (120,000-180,000 dwt) or by turning to very large crude carriers (VLCC—above 200,000 dwt). In general, the cost per unit ton of crude oil decreases with increases in vessel size and route distance up to certain optimum combinations.

As the size of the tankers increases, the requirements for adequate port facilities also increase to the point that existing facilities on the west coast will be inadequate for the size of some of the tankers now under construction or on order. Superports are usually designed to accommodate vessels with drafts up to 100 feet (500,000 dwt vessels or less). The type and geographic location of such facilities derive from three considerations: 1) the depth of the water, 2) the congestion of ship traffic, and 3) the nature of the commodity to be transported through the facility (dry bulk commodities like grain, coal, or ores compared with liquids such as crude oils, refined petroleum products, petrochemicals or liquified gases). The facility must

Table 2.—Analysis of Prudhoe Bay, South Louisiana, and Kuwait crude oils [1].

	Prudhoe Bay	Coastal Louisiana	Kuwait
Gravity, specific, 15°C	0.848-0.893	0.84	0.869
Gravity, °API	27.0-27.8	32-37	31.3-31.4
Pour point, °C	—10	—	—32
Sulfur, wt %	0.82-0.94	0.2-0.3	2.50
Nitrogen, wt %	0.23	0.7	0.14
Viscosity, 38°C, cSt	14.0	—	9.6
Hydrocarbons			
Paraffins, wt %	27.3	28	34
Aromatics, wt %	25.3	19	24
Naphthenes, wt %	36.8	44	20
Others & loss, wt %	10.6	9	22
Nickel, ppm	8-10	2-3	8-9
Vanadium, ppm	16-18	1-2	27-28
Residue, high-boiling, °C	343	315	371
Yield, wt % [2]	52.6	55	50.7
Gravity, specific, 15°C	0.961	(0.90)	0.974
Sulfur, wt % [2]	0.79	0.23	4.15
Nitrogen, wt % [2]	0.189	0.04	—
Nickel, ppm	17	[3] 20	18
Vanadium, ppm	35	[3] 5	53
Viscosity, kinematic, 100°C	36.5	[3] 700	64.4
Pour point, °C	18	—	21
Asphaltenes, wt %	1.7	[3] 0.85	2.7

[1] Brunnock, Duckworth, and Stephens (1968); Rosellus and Steffens (1971); Coleman et al. (1973); Vaughan (1973); Alyeska Pipeline Service Co. (text footnote 3); Pancirov, R. J. 1974. Compositional data on API reference oils used in biological studies: A #2 fuel oil, A Bunker C, Kuwait crude oil, and South Louisiana crude oil. Esso Res. and Eng. Co., Linden, N. J., Rep. AID. IBA. 74, 6 p., 4 app. p.
[2] Based on percent in total crude.
[3] Above 540°C (1,000°F).

[1] State oil and gas division testimony before Legislative Interim Pipeline Impact Committee. *In* The Alaska Series: Special Reports for Management, Ser. Rep. 8, Issue 3 (August) 1971, [Anchorage, Alaska], 4 p. (Processed.)

either be located offshore far enough to obtain the required water depths, or there must be considerable dredging at an inshore (shallower) site; the farther offshore the port facilities are placed, the less the congestion of existing coastal ports and the lower the chances of collision[2].

Deepwater petroleum superports fall into two principal categories: moorings and fixed structures. The conventional anchored buoy mooring maintains a fixed tanker position and orientation by mooring lines to a number of buoys or by a single point anchored buoy system around which the tanker is free to rotate. Fixed structures consist of a single pile mooring pier or they may take the form of artificial or sea islands. Most existing facilities (except for a conventional buoy mooring at San Luis Obispo off California) consist of a pile mooring pier connected to landside storage with a road and pipeway built on pilings.

There are a number of different offshore facilities which may be developed to fill the need for handling supertankers and VLCC's. Such facilities range from a single point mooring buoy, with an underwater pipeline to shore, to a large island with protected berths and storage for oil. Each will have its own environmental impact, determined not only by its design, but also by its location.

There are several potential crude oil superport sites on the west coast having existing facilities, such as oil company-owned refinery docks or moorings at Cook Inlet, Alaska (35,000 dwt, current maximum vessel size); Vancouver, B.C. (44 feet—usual safe operating draft; 125,000 dwt); Cherry Point (42 and 65 feet; 80,000-150,000 dwt), Anacortes (46 and 48 feet; 60,000-80,000 dwt), and Tacoma, Wash. (35 feet; 50,000 dwt); Portland, Oreg. (38 feet; 35,000 dwt); and San Francisco (35 feet; 55,000 dwt), Port San Luis Obispo (32 feet), Long Beach (54 feet; 120,000 dwt), and Los Angeles Harbor, Calif. (51 feet; 110,000 dwt) (International Petroleum Encyclopedia, 1971, 1975; Pacific Northwest Sea, 1974).

[2] Maritime Administration. 1973. Final environmental impact statement: Maritime Administration Tanker Construction Program. U.S. Dep. Commer., Washington, D.C., NTIS Rep. No. EIS 730725-F, p. IV159-IV169.

Various proposals have been suggested for upgrading these facilities to receive the supertankers and VLCC's. A common solution entails extending the terminal pier facilities into deeper water, although in some cases entirely new reception facilities have been proposed, such as a single deepwater oil transfer facility for the Pacific Northwest just inside the entrance of the Strait of Juan de Fuca, off central California, or in the Los Angeles-Long Beach area. Offshore transfer facilities along the exposed coasts of northern California, Oregon, Washington, or British Columbia do not appear to be economically or environmentally attractive.

Due to the increasing petroleum needs of the United States and Canada, it is becoming apparent that the crude oil requirements of the west coast refineries already located near or on tidewater will have to be supplied from the diminishing indigenous pipeline-delivered oil (California and northwestern British Columbia) supplemented by an increasing inflow of tanker-delivered crude oil from Alaska, South America, and the Middle and Far East. It is conceivable that in the next decade most of the existing and planned refineries in British Columbia, Washington, Oregon, and northern California will be receiving all of their crude oil feedstocks by tanker. The west coast could even serve as a transshipment point for forwarding oil to Midwest refineries, either through existing and expanded pipeline systems such as by reversing the present westward flow of Alberta crude oil over the Trans-Mountain Pipeline to Vancouver, B.C., and northern Puget Sound or by the construction of new transcontinental pipeline systems from Puget Sound to the Midwest or from southern California to the southeast and Midwest.

OIL POLLUTION SOURCES

Before considering the potential impact of oil pollution on the marine environment in the northeastern Pacific Ocean, one should consider several estimates of the total amount of oil discharged into the global marine environment (Table 3).

Land-based discharge of petroleum and its by-products comes from untreated and semitreated domestic and industrial wastes, spent marine lubricants, and incompletely burned fuels including those from atmospheric fallout. For instance, the input of oil into marine waters off southern California has been estimated (Table 4).

It is estimated that nearly 2 million tons of used lubricating oil is unaccounted for each year in the United States alone, a significant portion of which reaches our coastal waters. The quantities of oils generated and methods of waste oil disposal for the state of Washington (1971) are given in the following table for comparison. Approximately two-thirds is disposed of directly into the environment or is unaccounted for (Table 5).

In regard to marine operation losses, on the Pacific coast the existing domestic tankers do not use the load-on-top method for cleaning ballast water from the cargo tanks because the west coast runs are too short to

Table 3.—Estimates of annual petroleum discharges into the global marine environment compared with a global petroleum production (1971) of 2,978,400,000 tons.

Type of discharge	Estimated tons of oil contributed annually[1]		
	Wardley Smith	Blumer	Natl. Acad. Sci.
Land-based discharges:			
Refineries, petrochemical	300,000		200,000
Waste oil, runoff, sewage,		2,000,000	
atmospheric fallout	500,000		3,100,000
Marine operation losses:			
Tankers, using load-on-top	100,000	3,000,000	310,000
Tankers, not using load-on-top	600,000	1,500,000	770,000
Bilge discharges	50,000	500,000	500,000
Accidental discharges	200,000	—	553,000
Offshore production		—	80,000
Oil seeps		—	600,000
Totals	1,900,000	7,000,000	6,113,000

[1]Wardley Smith (1973); Blumer (1971); National Academy of Sciences (1975).

Table 4.—Estimates of annual petroleum input in waste waters off southern California [1].

Type of water	Mass emission rate in tons per year	
	Total oil and grease	Petroleum only
Municipal waste water	65,000	32,000
Industrial waste water	2,200	2,200
Runoff	4,400	?

[1]Source: Philip N. Storrs. 1973. Petroleum inputs to the marine environment from land sources. Background papers for Ocean Affairs Board, Natl. Acad. Sci., Workshop on Inputs, Fates, and Effects of Petroleum in the Marine Environment, 21-25 May 1973, Airlie, Va., Vol. 1, p. 50-58.

Table 5.—Quantities of waste oils generated and methods of waste oil disposal employed in Washington State during 1971[1].

Waste oils	Quantity (gallons)
Type generated	
Automotive lubricating oils	10,599,183
Industrial oils	5,871,879
Tank cleanings	2,137,570
Total	18,608,632
Method of disposal	
Returned to California refineries (Ultimate fate unknown)	828,424
Rerefined	2,570,972
Used as road oil	7,609,866
Dumped on ground surface	2,843,419
Disposed of at a sanitary landfill or garbage dump	772,773
Reused as a lubricant or form oil	140,415
Used as fuel	2,735,950
Dumped into sewer or storm drain	27,416
Unaccounted for	1,079,397
Total	18,608,632

[1]Source: A report on oil pollution prevention and control. Washington State Dep. Ecol., Olympia, Wash., 1973, p. 1-6. (Processed.)

allow for proper separation of the oily residues from the ballast water. There are few crude oil loading ports maintaining shore facilities for removing oil from ballast water for these tankers; these tankers now have to discharge some of their oily ballast water directly into the northeastern Pacific Ocean. At Valdez, however, Alyeska Pipeline Service Company will provide ballast water treatment for incoming tankers which will lower contamination down to 10 parts per million oil in the final effluent discharge. Bilge water containing oil can be pumped from any vessel—not only oil tankers. Governmental regulations prohibit pumping bilges within coastal zones from 50 to 100 miles of shore.

Another category of petroleum loss into the marine environment is from accidental discharges: collisions, groundings, structural failures, rammings, fires, explosions, breakdowns, and human error. Although oil discharged accidentally comprises only 10 percent of the global losses, they are more noticeable because most of these accidental discharges occur in port or very near the shore. One study of major marine oil spills indicated that 75 percent were from vessels, 90 percent of which were tankers, and half of the spills were due to tanker groundings. Eighty-five percent of the spills occurred within 50 miles of a port (Gilmore et al., 1970).

Offshore oil production on the west coast is currently concentrated in the Santa Barbara-Long Beach area of southern California and in the Cook Inlet area of south-central Alaska. The Santa Barbara blowout of 1969 is an example of a large-volume, man-caused discharge of oil from offshore production. The total input (including shore-based petroleum recovery resources) has been estimated to be of the order of 0.3 percent of the total oil produced or handled in Cook Inlet (Kinney, Button, and Schell, 1969).

The contribution made by natural oil seeps to the contamination of the northeastern Pacific waters is difficult to estimate, yet the coastal margins of this region contain geological areas capable of measurable oil seepage. Seeps have been reported in the following nearshore areas:

Norton Bay	Bering Sea
Androncia Isl.	Shumagin Islands
Puale Bay to Wide Bay	Alaska Peninsula
Kamishak Bay	Alaska Peninsula
Chinita Point	Alaska Peninsula
Don Miller Hills	South-cent. Alaska
Nichawak Hills	South-cent. Alaska
Robinson Mts.	South-cent. Alaska
Samovar Hills	South-cent. Alaska
Lacey-Hoh River	Washington coast
Coal Oil Point	California coast
La Goleta	California coast
Santa Monica Bay	California coast

While there is moderate to high potential for seepage in these regions, the input is still low compared with man-caused oil pollution (Table 6).

IMPACT OF INCREASED CRUDE OIL TANKER TRAFFIC ON THE NORTHEASTERN PACIFIC

The impact of the increase in marine transportation of petroleum in the northeastern Pacific Ocean following the discovery of oil in Alaska is expected to be considerable, due to an increase in vessel size and traffic, and, consequently, a potential increase in intentional and accidental discharges.

Table 6.—Areas of geological potential seepage in the continental margins of the northeast Pacific Ocean.[1]

Area	Seepage potential	Gross area (1,000 mi²)	Seepage prone area (1,000 mi²)
Bering shelf	Low	656	524.6
Aleutian Chain/Cook Inlet	Moderate	18	12.6
Gulf of Alaska	High	77	53.9
Northeast Pacific margin	Moderate	151	60.4
Southern Calif./Baja basins	High	361	144.4
Central America Pacific margin	Moderate	318	127.2

[1]Source: Richard D. Wilson. 1973. Estimate of annual input of petroleum to the marine environment from offshore production operations. Background papers for Ocean Affairs Board, Natl. Acad. Sci., Workshop on Inputs, Fates, and Effects of Petroleum in the Marine Environment, 21-25 May 1973, Airlie, Va., Vol. 1, p. 59-96.

The prediction of the amount of oil lost and the frequency of accidental oil spills from different causes at different places is an important part of the evaluation of the environmental impact of the marine tankers fed by TAPS. Various estimates of the volume of oil discharges in the northeastern Pacific Ocean are listed in Table 7.

Available information indicates that accidents and intentional discharges of oil will continue to occur in spite of technological advances and the existence of the most stringent regulations. Thus a gradual increase in pollutant hydrocarbons can be expected from the increased tanker traffic in the northeastern Pacific, especially in the nearshore areas (Gilmore et al. 1970)[3].

The northeastern Pacific is relatively unpolluted compared with much of the world's ocean areas (Butler, Morris, and Sass, 1973). The background hydrocarbon level is relatively low in Port Valdez, Prince William Sound, and Puget Sound, and even though it is not clear what the acute and long-term effects of oil upon the marine environment would be, it is expected that where biological effects appear they would be most apparent in areas such as the above, which have restricted circulation[4].

The intentional discharge of ballast water into the Gulf of Alaska beyond the 50-mile limit—as permitted by state, federal, and international regulations, in addition to the accidental loss of oil—poses a threat to the marine ecosystem, if allowed to increase without control; the adverse effects cannot yet be precisely evaluated or predicted because too many variables are involved. It is hoped that the application of modern technology and enlightened regulations will minimize such discharges.

CHEMICAL AND PHYSICAL FATE OF OIL

Crude petroleum is a complex mixture of natural products and includes many thousands of different compounds. Petroleum and its hydrocarbons have been found to be remarkably stable in the marine environment.

Oil spilled at sea undergoes rapid changes which include spreading to form slicks, evaporation of the more volatile components, dissolution of the more soluble components, emulsification, and oxidation by photochemical and microbial processes (Fig. 2). Important in this phase of petroleum dispersion, as well as in the process of emulsification, are the surface-active components of the petroleum—in particular, the nitrogen-, sulfur-, oxygen-containing heterocyclic compounds. Evaporation selectively depletes the most volatile components, but leads to little or no fractionation of different hydrocarbon types having approximately the same boiling points. The dissolving of hydrocarbons into seawater follows the same pattern as evaporation, with the difference that selective dissolution of polar aromatic and oxygenated compounds tends to make them relatively more soluble than nonpolar components with the same boiling point. Oil can adsorb onto particles or be compacted in the fecal matter of small marine organisms; in either case, once the particle becomes heavier than water it sinks and the oil can become incorporated into the sediments (National Academy of Sciences, 1975).

The residue or relatively insoluble and nonvolatile material from petroleum spilled on the sea surface is one source of raw material for pelagic tar balls. Slicks on the sea surface are a transient phenomenon lasting only weeks at most. Pelagic tar balls are also relatively transient, lasting at most for a few years. The ultimate fate

[3]Alyeska Pipeline Service Company. 1971. Supplement to description of marine transportation system—Valdez to West Coast ports. Letter submitted to U.S. Dep. Int., 24 Sept. 1971, 4 p., 6 attachments.

[4]U.S. Department of the Interior. 1972. Final Environmental Impact Statement Proposed Trans-Alaska Pipeline, Washington, D.C., Vol. 4, p. 460-487.

Table 7.—Summary of volume of potential spills associated with the proposed northeast Pacific Ocean marine transportation system at a 2-million-barrel/day pipeline throughput (all volumes in tons/year)[1].

	Contiguous zone						
Type and total discharge	Valdez	Puget Sound	San Francisco	Los Angeles	Total	Open ocean	Total
Intentional discharge							
1. Ballast treatment facility[2]	650-1,300	—	—	—	650-1,300	—	650-1,300
2. Compliance with 1969 amendments,[3] or	—	—	—	—	—	6,650	6,650
3. 100% load-on-top, or	—	—	—	—	—	27,000	27,000
4. Uncontrolled tank cleaning	—	—	—	—	—	74,000	74,000
Unintentional discharge							
5. Transfer operations-PIRS[4], or	150.0	15.0	40.0	57.5	262.5	—	262.5
6. Transfer operations-Milford Haven[5]	70.0	6.5	19.0	27.0	122.5	—	122.5
7. Casualty losses-restricted waters-PIRS, +	90.0	10.0	25.0	35.0	160.0	—	160.0
8. Casualty losses-open waters-PIRS	2.0	—	—	—	2.0	—	2.0
9. Total (7 & 8), or	92.0	10.0	25.0	35.0	162.0		162.0
10. Casualty losses-worldwide analysis[6]	—	—	—	—	—	—	19,200
Total discharge							
Case I : lines 1 + 6 + 9							[7]≈ 950
Case II : lines 1 + 6 + 10							20,100
Case III: lines 2 + 5 + 10							26,100
Case IV: lines 3 + 5 + 10							46,450

[1] U.S. Department of the Interior (see text footnote 4).
[2] Alyeska Pipeline Service Company. 1971. Various submissions to the U.S. Dept. of the Interior.
[3] Not more than 1/15,000 of cargo capacity could be discharged at sea.
[4] U.S. Coast Guard Pollution Incident Reporting System data for 1970.
[5] Beynon, L. R. 1971. Report on oil spill statistics at Milford Haven. Exhibit 48, U.S. Dep. Int. hearings, Trans-Alaska Pipeline, Feb. 1971, Anchorage, Alaska.
[6] Covers all casualty losses, including these in open ocean for 1969-70.
[7] Incomplete, no open ocean amount included.

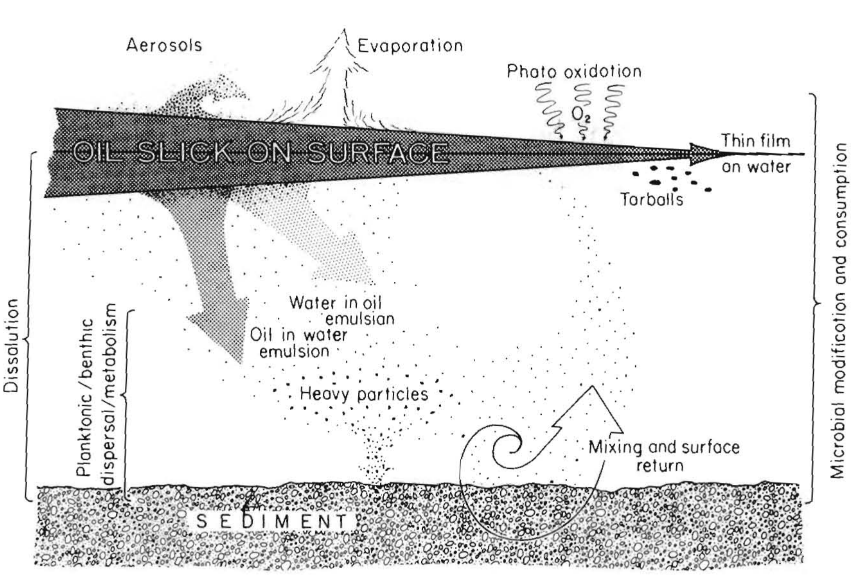

Figure 2.—Diagrammatic summary of the processes leading to the distribution and consumption of petroleum at sea.

of petroleum spilled at sea is dependent upon one or more of the following processes (Butler, Morris, and Sass, 1973):

1) Evaporation and decomposition in the atmosphere.

2) Dispersal in the water column as dissolved or particulate matter.

3) Incorporation into sediments.

4) Oxidation by chemical or biological means to carbon dioxide.

BIOLOGICAL FATE OF OIL

Neither a single rate nor a mathematical model for the rate of petroleum biodegradation in the marine environment can be given at present. On the basis of available information, the most that can be stated is that some microorganisms capable of oxidizing chemicals in petroleum have been found in virtually all parts of the marine environment examined.

Laboratory experiments have demonstrated that the *n*-alkane fraction of petroleum is most easily degraded by microorganisms. In oxygenated marine environments, this type of compound is likely to be degraded in a matter of days or months, depending principally on temperature and nutrient supply. Other classes in petroleum tend to show a greater resistance to microbial action, and considerable lengths of time may be required for substantial decomposition of the extremely resistant components of petroleum in the marine environment—although such refractory components may not be biologically important.

In larger organisms, hydrocarbons are taken up through the gills, by ingestion of food or other particulate matter, or directly from water which passes through the gut. The first two pathways have been demonstrated. Some organisms (e.g., copepods) can ingest large quantities of petroleum and eliminate it directly as fecal matter without substantial degradation. Metabolism of petroleum hydrocarbons in marine organisms and pathways are poorly understood.

Storage of hydrocarbons, including some of those from petroleum, has been found in the lipids of some organisms but its importance as contributing to environmental stress has yet to be established. Biogenic hydrocarbons, particularly di- and triolefins, are clearly distinguishable from petroleum in most cases, while certain saturated and aromatic hydrocarbons have been found to accumulate during short exposure periods with subsequent discharges or loss of the contaminant from the organisms.

Many organisms (e.g., mussels and oysters) can eliminate most of their incorporated petroleum hydrocarbons if placed in unpolluted water. Discharge by vertebrates occurs primarily through the gall bladder and kidney. Paths of discharge for invertebrates are not well established. There is no evidence of food web magnification in petroleum hydrocarbons in the marine environment (National Academy of Sciences, 1975).

DIRECT EFFECTS ON FISHERIES

If large-scale petroleum hydrocarbon pollution occurs in the northeastern Pacific Ocean, the direct effects on fishery species of commercial and recreational value and their food webs can include: 1) direct poisoning; 2) disruption of the marine ecosystem, habitats, and food chains; and 3) general reduction in productivity of the environment on both short- and long-term bases. These biological effects could in turn be related to potential impacts on the commercial and recreational fisheries—resulting in reduced catches, unmarketable catches, or the closure of fisheries due to oil pollution. In addition, benefits from recreational and commercial fisheries could be reduced locally by the 1) physical effects such as gear losses, removal of historical fishery grounds by petroleum-related structures, and interruption in fishing activities caused by tanker traffic, and 2) the diversion of capital and labor force from fisheries and marine recreational development into investment opportunities associated with pipeline construction and operation.

In perspective, large quantities of tanker-carried crude petroleum has been transported along other U.S. coastlines without major environmental degradation to ecosystems, although the impact on some localized shorelines is now being felt—such as tar on Florida bathing beaches and the almost annual spring occurrence of weathered oil residues on the open beaches of the Pacific Northwest. When they occur, the potential biological and physical effects of marine transportation in the northeastern Pacific Ocean will probably be most severe in the coastal and estuarine environments near the terminal areas of the tanker routes. The magnitude of the effects on the recreational and commercial fisheries would depend on the amount of pollutant; the type of pollution (chronic low-level or large isolated spills); the success of prevention and cleanup of both chronic and acute oil pollution; the location, the season, and the frequency of acute losses from vessel operations; and accidents.

A large oil spill could dramatically affect the fishing and aquaculture industries, whose success depends on clean water. The U.S. Department of the Interior estimates that commercial fishing has an annual whosesale value of about $24 million within Prince William Sound, Alaska; and considerable sport fishing also occurs there. The estimated annual commercial and sport fisheries for the greater Puget Sound Basin is of the order of magnitude of $75-85 million; the value for recreational fishing has been placed at about two-thirds of this figure. Recent efforts in aquaculture have shown considerable success and are predicted to add an additional $100 million in the forseeable future (Flajser and Wenk, 1972).

The short-term (in a geological time frame) use of the ocean for vessel traffic during the duration of the pipeline system has a potential for affecting the long-term productivity of the marine ecosystem as well as a possible short-term impact on the industries that are dependent upon a productive ecosystem. Unlike oil and gas, food from the sea is a renewable resource that can be utilized most efficiently so long as the water quality is sufficiently high to allow fish and plant life to enjoy sustained growth, combined with scientifically sound harvesting techniques and global fishery policies.

POTENTIAL EFFECTS OF OIL POLLUTION ON MARINE RESOURCES

Blumer (1971) summarized the potential damage to marine ecology from pollution with crude oil and oil fractions based on isolated field and laboratory studies as follows:

1) Direct kill of organisms through coating and asphyxiation.

2) Direct kill through contact poisoning of organisms.

3) Direct kill through exposure to the water-soluble toxic components of oil at some distance in space and time from the accident.

4) Destruction of the generally more sensitive juvenile forms of organisms.

5) Destruction of the food sources of higher species.

6) Incorporation of sublethal amounts of oil and oil products into organisms resulting in reduced resistance to infection and other stresses (the principal cause of death in birds surviving the immediate exposure to oil).

7) Incorporation of carcinogenic and potentially mutagenic chemicals into marine organisms.

8) Low level effects that may interrupt any of the numerous events necessary for the propagation of marine species and for the survival of those species which stand higher in the marine food web.

The immediate short-term effects of a major oil pollution incident are rather obvious. However, some of the more serious aspects of oil pollution may deal with the low-level toxic effects, particularly on young forms of marine animals, which might result in potentially dangerous situations which could adversely affect our fisheries resources.

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