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ALASKAN OIL, THE ENERGY CRISIS AND THE ENVIRONMENT

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ALASKAN OIL, THE ENERGY CRISIS AND THE ENVIRONMENT

by

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INTRODUCTION

Alaska has become a center of hopeful attention in the energy crisis. A state that encompasses an area greater than 21 of the smaller states combined; 40 percent of the nation's freshwater; over 50 percent of its general coastline; and 65 percent of its continental shelf, Alaska has the nation's greatest oil reserves, mammoth coal reserves, plus unparalleled additional mineral wealth. The state is one of the few remaining resource banks on which the nation can draw for its wealth. Alaska is also a treasure house of natural beauty; it contains huge amounts of fish and wildlife; and many unique geologic, hydrologic, topographical, climatic and biological systems.

These unique arctic-subarctic conditions encourage two opposing strategies. One is exploration; the other preservation. The realities of the energy crisis and the environmental movement however, dictate development with adequate environmental safeguards. The developers are moving ahead with great rapidity and have spent millions of dollars on research. However, most of this research has been to facilitate development and not to protect the unique arctic and subarctic ecosystems: The Federal government still owns most of Alaska and must provide the leadership in environmental protection. EPA has the only Federal environmental research laboratory in Alaska. The Arctic Environmental Research Laboratory, with its Ecological Research Program, is the logical focal point for energy related environmental research in Alaska.

The following information will provide the reader with some background on oil development in Alaska, the probable environmental impact of this development, and what research is desperately needed to safeguard the environment.

BACKGROUND

The oil industry is by no means a newcomer to Alaska. As early as 1853, oil seeps were observed on the west shore of Cook Inlet; similar seeps were noted before 1908 near Barrow by visiting whalers. Alaska's first wildcat wells were drilled in 1902, one near Katalla, the other near Cold Bay on the western end of the Alaska Peninsula. No commercial shows of oil and gas were found at either site. However, drilling continued at Katalla until 1931, at which time 18 of the 36 total wells drilled were low-level producers. A refinery built there in 1911 was operated until destroyed by fire in 1931. In all, 154,000 bbls. of oil were produced from the Katalla field.

In 1957, Richfield Oil Company drilled the first discovery well in the Swanson River unit on the Kenai Peninsula. It flowed 900 bbl/day through an 11/32-inch choke, with an accompanying gas-oil ratio of 140 cu.ft/bbl. By 1959, 17 wells had been spudded; three were major producers. In 1959, 1960 and 1961, the Kenai West Fork, Falls Creek and Sterling gas fields were discovered.

On the other side of Cook Inlet, in 1962, the west foreland and Beluga gas fields were located. Offshore drilling, which began in Cook Inlet in 1962, subsequently located the North Cook Inlet and Middle Ground Shoal gas fields. Development drilling in Cook Inlet followed rapidly. Currently, 15 offshore platforms (Figures 1 & 2) produce oil and gas from the fields in the inlet. Crude is carried by a network of pipelines from the platforms to the Drift River tanker terminal on the west side of the inlet or to the Nikiski terminal, north of the city of Kenai (Figure 3).

In 1971 the Cook Inlet-Swanson River fields produced 77.5 million barrels of oil and 230 billion cubic feet of natural gas. The annual crude

Figure 1. "Monopod" oil drilling platform in Alaska's Cook Inlet

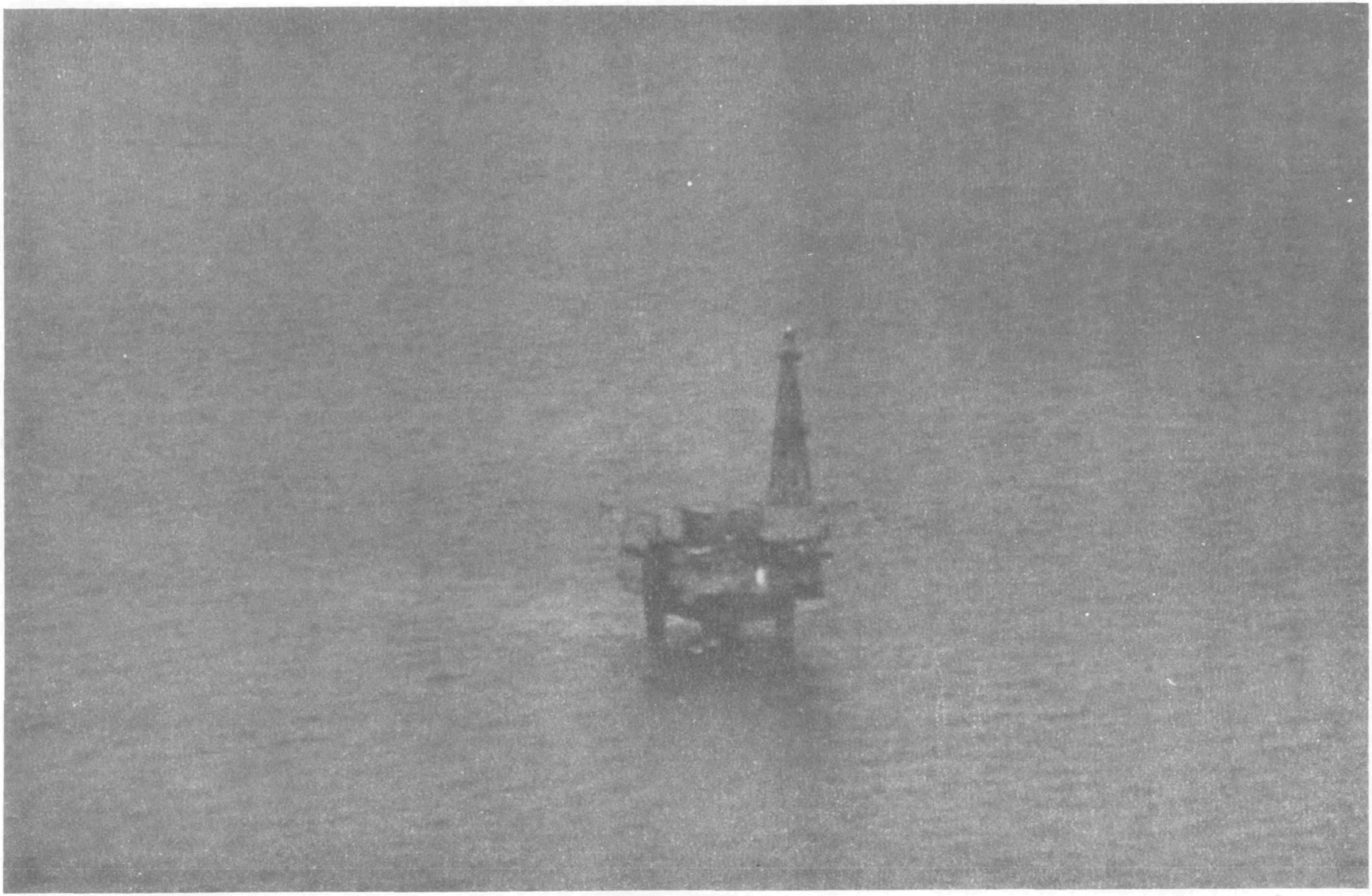

Figure 2. "Quadruped" oil drilling platform in Alaska's Cook Inlet

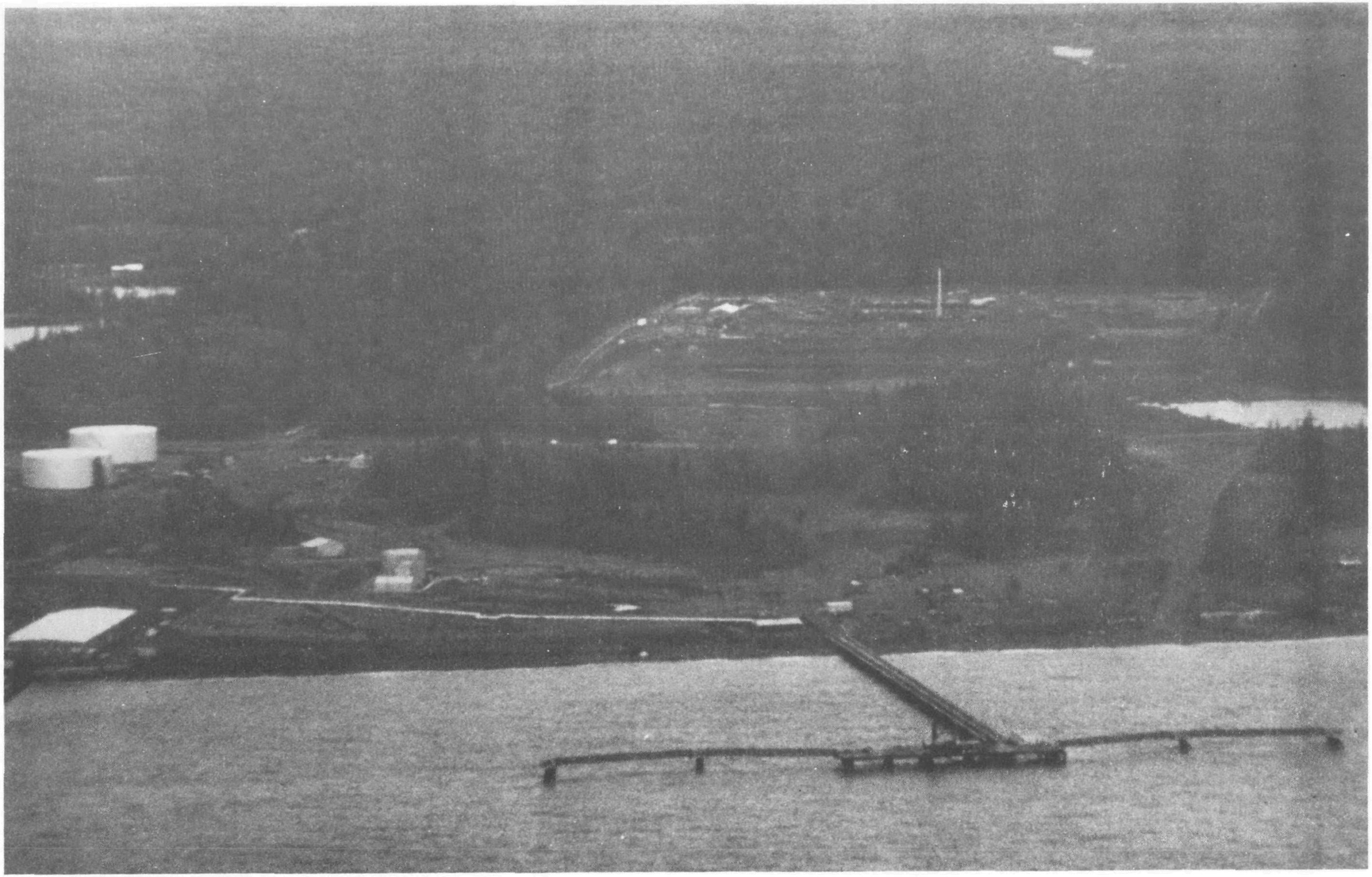

Figure 3. Tanker loading facility in Cook Inlet

oil production figures are not expected to change significantly as the proven reserves in the Cook Inlet basin are estimated at only 550 million barrels.

The oil seeps observed near Barrow inspired the designation in 1923 of a 37,000 square mile area of the northwestern portion of Alaska as Naval Petroleum Reserve #4. From 1944 until 1953, the U.S. Navy drilled 36 test wells and 44 stratigraphic test holes. This exploration resulted in the discovery of an oil field at Umiat, Simpson, and a possible field at Fish Creek. A major gas field was found at Gubik, with small fields near Barrow.

The more-or-less successful exploration by the Navy on Alaska's North Slope inspired commercial exploration. Starting in the early 1960's, Colorado Oil and Gas, British Petroleum, and Sinclair drilled numerous test wells. All these early holes were dry. In 1966, Atlantic Richfield found small gas showings at its Susie Unit #1, using a rig flown in from Fairbanks. Abandoning this hole, ARCO moved the rig to Prudhoe Bay, where its Prudhoe Bay State No. 1 was completed at 12,000 ft in June 1968. On initial tests, this well flowed crude oil at the rate of 2,415 bbls/day from 8,650 ft and gas at the rate of 40 million cfd from 8,200 feet.

This "discovery" well caused extensive additional exploratory drilling, approximately 170 additional wells, exploratory or developmental, have been drilled to date on the Arctic Slope's fields (Figure 4). Proven reserves of the Prudhoe Bay field alone are very conservatively estimated at 10 billion barrels of recoverable crude oil, making it the largest field discovered outside of the Persian Gulf. A prominent geological consulting firm has stated that "the Prudhoe Bay field is one of the largest petroleum accumulations known to the world today."

Five other possible petroleum provinces exist in Alaska besides the Arctic Slope and Bristol-Bay Alaska Peninsula-Cook Inlet areas (none of

Figure 4. Exploratory well drilling operation on Alaska's North Slope.

which have been fully explored). (Figure 5) The Yukon-Kandik area east of Fort Yukon and extending into Canada has been explored seismically in recent years. The Copper River basin had one test well drilled. A small basin exists along the Tanana River near Fairbanks. A much larger area exists east of Nome, extending southwest along the entire Yukon delta. The Katalla region eastward along the Gulf of Alaska coast also shows promise. Although offshore exploration and development has only occurred in Cook Inlet, great interest is shown in the possible offshore areas in the Beaufort Sea, Bristol Bay and Gulf of Alaska that are associated with known land deposits.

Considering these unexplored areas together with the known reserves in Cook Inlet and the Arctic Slope, the present known Alaska oil reserve figure of 11 billion barrels must be conservative indeed. Additional exploration will occur in all of Alaska's petroleum provinces and continue well into the next century. Alaska already has the nation's greatest petroleum reserves and these proven reserves of crude oil and natural gas will probably be increased manyfold.

The key role in Alaska's oil industry is not played by the exploration and development activities, but by the transport of crude oil to the refinery and market. Presently, more than 80 percent of Alaska's oil production is transported outside the state. Two small oil refineries near Kenai, which together have a through-put of 40,000-60,000 bbls/day, produce jet fuel, heating oils, asphalt and some components of gasoline. The remainder of the crude oil production of the Cook Inlet basin is shipped via tanker to west coast ports.

Led by Atlantic-Richfield and Humble Oil, the Prudhoe Bay field's owners in 1969 put together an application for a Department of Interior

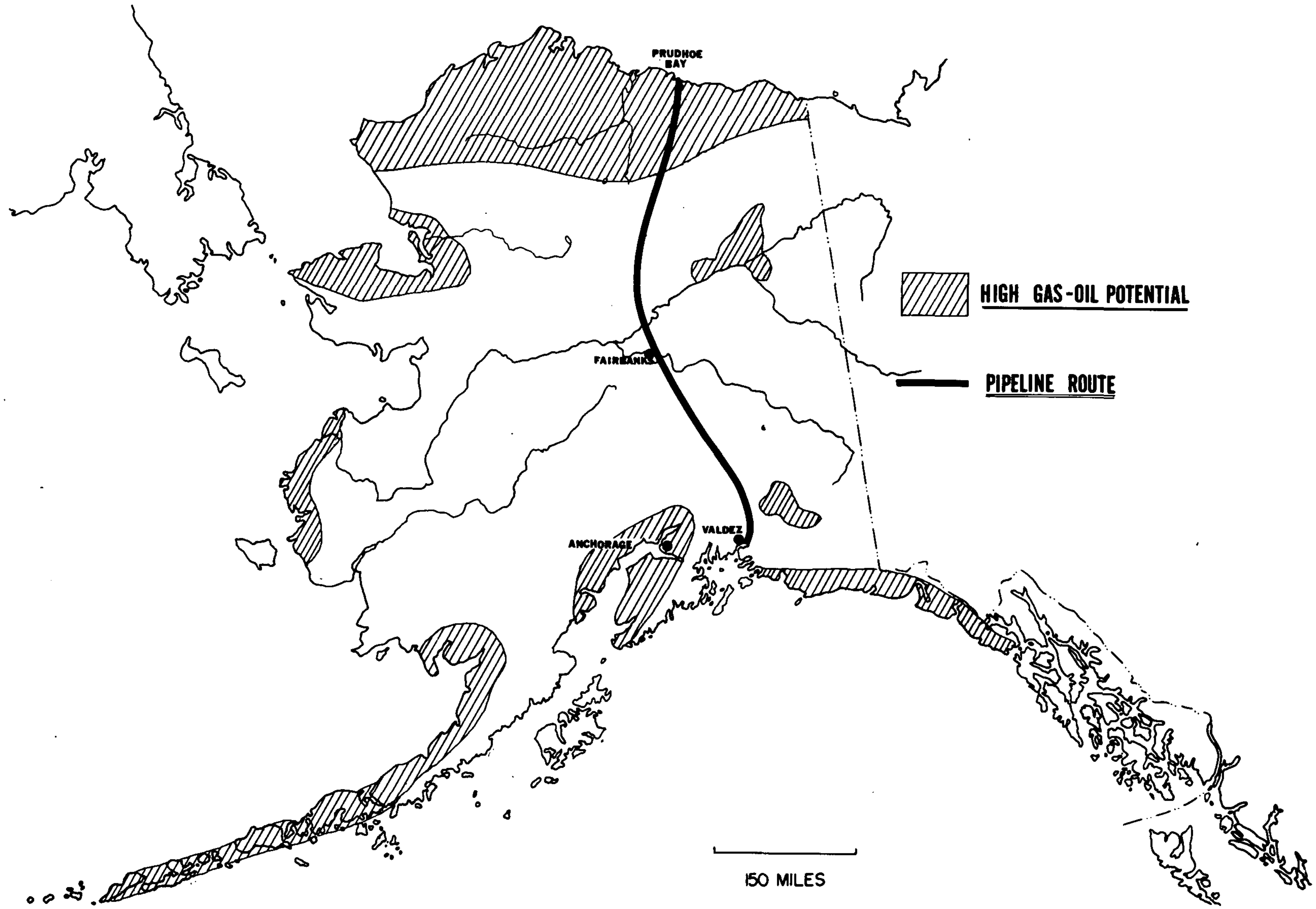

Figure 5. Outline map of Alaska showing areas of high potential for the production of oil and natural gas and the corridor for the Trans-Alaska Pipeline

permit for a Trans-Alaska pipeline. This proposal outlined a 790-mile long, 48-inch pipeline to eventually carry 2 million barrels per day of crude oil from the Arctic Slope to Valdez, a deep-water port in southcentral Alaska. (Figure 5).

The Interior Department carefully scrutinized the proposed pipeline design concept. Major concern was expressed by the U.S. Geological Survey over the effects of the hot (150°) oil pipeline on the permafrost through which it would pass. The Survey published,[1] in late 1969, the result of a computer analysis of the pipeline--an analysis which predicted that severe permafrost melting would occur, causing lateral and vertical movement of the pipe and possible rupture. Also, in December 1969, Congress passed and President Nixon signed, the National Environmental Policy Act,[2] which required an Environmental Impact Statement before a pipeline permit could be issued. Another consideration was the Alaska Native land claims action which was still pending in Congress.

In March 1972, Interior Secretary Morton made available to the public and the Council on Environmental Quality, the final six-volume environmental impact statement,[3] accompanied by a three-volume "Analysis of the Economic and Security Aspects of the Trans-Alaska Pipeline."[4] In the interim, Congress had passed the Alaska Native Claims Settlement Act. However, the case based on NEPA considerations was still in the courts. On February 9, 1973, the U.S. Court of Appeals announced a six-to-one decision that issuance of the pipeline permit would violate the terms of the Mineral Leasing Act of 1920, which limit right-of-way widths leased on Federal lands. This decision was appealed to the U.S. Supreme Court which refused to hear the case. The role to be played was now that of Congress, which alone had the authority to amend the Act. This Congress proceeded to do and on November 16, 1973, Public Law 93-153, "The Trans-Alaska Pipeline Authorization Act," was approved. Not only did this Act allow the Secretary of the Interior to issue the necessary permits, but also essentially waived further review of the project under the National Environmental Policy Act. Interior Secretary Morton issued the long delayed permit for the pipeline construction on January 23, 1974.

While the Trans-Alaska pipeline was being fought out in the courts and the Congress, two consortiums of natural gas distribution companies were surveying routes to bring Arctic Slope natural gas to market. The natural gas that comes up with the crude oil must be separated before the oil can be pumped into the pipeline. In the initial development of the field, this gas must be pumped back into the oil-bearing formation in order to maximize pool efficiency; however, within 2 to 4 years after oil production starts, the gas cannot be further re-injected. Because Alaska State Division of Oil and Gas regulations prohibit "flaring" the excess separated gas, the gas must then be transported to market.

Two major proposals are under consideration to bring the gas to U.S. markets. Since 1970, a consortium of U.S. and Canadian producers, now called Canadian Arctic Gas Study Limited, has investigated the routing of a gas line west from Prudhoe Bay to join a similar pipeline coming from the oil and gas-rich MacKenzie River Delta field. This route would then go south along the MacKenzie River Valley to join existing gas pipeline networks in Alberta, and then to the U.S. and eastern Canada. CAGSL submitted its proposal to the U.S. Federal Power Commission and the Canadian Department of Energy, Mines and Resources in March 1974.[5]

More recently, a consortium of gas distributors led by El Paso Natural Gas Company, has developed a proposal to construct a natural gas pipeline using the same corridor as the Trans-Alaska oil pipeline. The line would end at an open-water port in southcentral Alaska, near Valdez, where the gas would be liquified and trans-shipped in special cryogenic tankers to west coast ports.

Regardless of the route or routes used for shipment of arctic oil and gas to markets in the United States, the projects will be the most ambitious and costly ever undertaken by private industry. The cost of the Trans-Alaska Pipeline System is currently estimated at from 3 to 4 billion dollars; that of the Canadian Arctic Gas Study proposal at as much as $9 billion.

Environmental Impact of Oil Development

Whatever the total economic cost of oil development in Alaska, and it will eventually run into the tens of billions of dollars, this is only part of the total "cost" of this program. The environmental costs are a major consideration, and are required to be established by the National Environmental Policy Act and other Federal and State laws and regulations. No matter how careful industry is, no matter how rigorous the guidelines or stipulations imposed by State and Federal authorities, or how conscientious the surveillance and enforcement activities are, extensive environmental damage will occur. This damage began in the early years of oil development and will continue until the vast petroleum reserves of Alaska are finally utilized.

The probable petroleum provinces and the transport routes cover virtually all major ecosystems in Alaska, from the high arctic offshore zone to the Gulf of Alaska. Each of these ecosystems possesses unique geologic, hydrologic, topographic, climatic and biological characteristics. A complete review of these characteristics is not possible in a paper of this limited extent, and in fact may not be possible at all considering the almost complete lack of baseline information in many of these ecosystems. A general review of some critical ecosystem components is, however, essential to an understanding of research needs related to this development.

The Arctic Coastal Plain and Arctic Foothills areas extend north of the Brooks Range to the coasts of the Beaufort and Chukchi Seas. These areas presently include the majority of the known oil deposits of Alaska. The land is characterized by moist or wet tundra, generally overlying continuous permafrost, which often extends to depths of as much as 2,000 feet. The tundra/permafrost interaction results in surface micro-relief features such as polygons or peat ridges. The many small, shallow, oblong lakes appear to be oriented by the prevailing winds. The major river system is the Colville, which flows west and north to the Beaufort Sea. Minor drainages include the Sagavanirktok, Canning and Kuparuk Rivers, all flowing northward. Offshore, the gently sloping land surface continues into the Arctic Ocean, which is dotted by "barrier islands." This coast is dominated by the Arctic ice pack; tides are minimal--less than one foot. Occasional storms produce great sea waves, which can be quite destructive.

Vegetation patterns are strongly dominated by the harsh arctic climate, which has annual mean temperatures from 10 to 15°F and precipitation of from 4 to 8 inches per year. The impermeable permafrost layer prevents subterranian drainage, resulting in wet muskeg areas over much of the coastal plain, and moist muskeg in the foothills. Mosses and sedges dominate the vegetation, with vast stands of cottongrass in the foothills. Along most drainages, brushy willows can be found, primarily close to rivers and streams.

Waterfowl and seabirds utilize the coastal plain and offshore island areas in large numbers during the breeding and fall molting seasons. During fall migration, as many as two-thirds of the migratory bird populations of the Canadian arctic islands may follow the Alaskan arctic coast flyway. Although population estimates are variable, due to lack of reliable data, average densities of 16 breeding ducks per square mile have been observed. Estimates of the September eider migration range from 800,000 to 1.1 million.

Large mammal populations are dominated by two great caribou herds--the arctic herd which calves in the upper Colville River and the Porcupine herd which ranges over the eastern half of the North Slope to the MacKenzie River in Canada. Population estimates of these two herds indicate an average total size of about 350,000 animals. Wolf populations tend to depend largely on predation from these two herds, supplemented by smaller mammals. The low density brown-grizzly bear population also does some predation, but feeds largely upon vegetation.

The only known denning areas for polar bear in Alaska occur on ten offshore islands from the Colville River east to Brownlou Point, although occasional denning is noted as far southwest as Point Hope. As breakup occurs in spring, polar bears follow the retreating ice north and east, subsisting on the ringed and bearded seal.

Less is known of the fish populations of the Arctic Slope than of the large mammal populations, and even less is known of lower organisms in the aquatic food chain. The Beaufort Sea total fish populations may be small, but do support abundant populations of marine mammals. The only commercial fishery at present is near the mouth of the Colville River, where arctic char and whitefish are taken. The Sagavanirktok River and some adjacent tributaries are known to contain significant arctic char, burbot, and whitefish populations. Some tributary streams of the Sagavanirktok and the deeper tributary lakes are known to contain grayling. Lake trout are found in Galbraith Lake, a medium-size tributary to the Atigun River, which flows into the Sagavanirktok. The Sagavanirktok is probably an important wintering area for arctic char, which are known to spawn in the Atigun.

The presence of man in the arctic coastal plain and foothills area has historically been transitory or on a subsistence level. As oil development proceeds in the Arctic, large populations of wildlife heretofore unaware of man will become threatened. Habitat and food sources will be altered or destroyed and the traditional migratory patterns of caribou and other wildlife may be changed or eliminated by structures that will be erected. As offshore oil development proceeds, waterfowl and marine mammals become threatened by potential oil spills.

Construction of roads and pipelines as well as gravel pads for buildings and drill sites may alter the permafrost regime and change existing drainage patterns, particularly on the low relief coastal plain. Removal of the protective tundra causes melting of ice-rich permafrost areas, resulting in erosion and subsidence, accompanied by siltation of streams. Observations of trails used for cat-trains during exploration by the U.S. Navy indicate that subsidence to a depth of 12 feet may occur over a period of 1 year. Recently, roads have been built on thick gravel pads laid directly on the tundra and summer travel directly on the tundra surface has been prohibited. These practices have resulted in less damage to the tundra permafrost systems, but may have changed existing drainage patterns. The large amounts of gravel needed for construction of roads and pads has generally been derived from stream beds, possibly resulting in destruction of habitat for food chain organisms, and spawning areas for fish. The effects of discharges of municipal wastes and waste heat into arctic waters is virtually unknown.

Increased hunting and fishing pressure will also have definite effects on the populations of arctic animals.

The Brooks Range is the northwesterly extension of the Rocky Mountain system. Although peaks are less than 10,000 feet, its rugged, largely treeless topography has served as an effective barrier between the Arctic Slope and the more developed areas in the south. Through this range must pass any transportation route to provide men and materials to the arctic Alaskan oil fields as well as the most probable route for bringing the arctic oil to market. The proposed TAPS transportation corridor follows the headwater drainages of the Sagavanirktok and Atigun Rivers, by Galbraith Lake, and through the mountains at Dietrich Pass, then down the Dietrich River. An alternative corridor for a linkup with the Trans-Canada Pipeline proposal would go southeast from Prudhoe Bay to the Canning River, south along the Canning to the southern boundary of the Arctic National Wildlife Range, and east along the southern boundary of the range into Canada.

The north side of the narrow, steep Atigun River Canyon is an important habitat for Dall sheep. Through this pass, some north-south caribou movements have been noted. South of the range, the Dietrich River may support only small numbers of fishes, but may serve as a spawning area for grayling. A few thaw lakes near the confluence of the Bettles and Dietrich Rivers serve as a habitat for migratory waterfowl. Moose, bear and wolves are commonly found throughout the Dietrich and middle fork of the Koyukuk River drainages.

The major importance of the eastern upper Koyukuk River system lies in the fact that it is a key watershed to the lower Koyukuk and the Yukon River. These drainages are of high value as habitat for fish, wildlife and waterfowl. Any disturbance to these watersheds from construction activity or an oil spill may have serious consequences to these ecosystems.

The intermontane plateaus of interior Alaska extend southward from the Brooks Range to the Alaska Range. Mean annual temperatures range from 15 to 25°F, mean annual precipitation from 8 to 16 inches per year. The topography consists of rolling, well vegetated hills, some of which extend above timberline. The major drainages through which transportation corridors have been established or in which oil development may occur are the Yukon, Tanana, Koyukuk and Kuskokwim Rivers. The Yukon and Tanana valleys, and the lower drainages of tributaries, are usually flat, broad and dotted with numerous ponds and lakes. Many of these are old oxbow lakes and sloughs left behind by the meandering rivers. In the river valleys, bottomland spruce-poplar forests are found; lowland spruce-hardwood forest is found in the plain areas and upland spruce-hardwoods found in higher elevations. Despite the low rainfall, the area is well supplied with water; aquatic grasses and forbs are common. The entire area is subject to discontinuous permafrost. The Yukon flats area, parts of the Yukon-Tanana uplands, and the Koyukuk flats-Yukon Kuskokwin lowlands areas are all prime waterfowl habitat. Although in summer the larger rivers carry a heavy silt load, the tributaries are most often clear and swift. Many interior Alaska rivers support populations of grayling, burbot, northern pike, suckers and whitefish. The Yukon River is a principal migration route for anadromous fisheries, as well as supporting a major resident fish population. The Chatanika and Tolovana Rivers have runs of chinook, chum and coho salmon as well as sheefish. Many of the rivers in the area support extensive recreational fisheries, and subsistence fisheries are common.

Moose, bear (black and grizzly), wolves, and small furbearers which are common in the Yukon-Tanana uplands, have had severe hunting pressure in recent years and have moved their range to the north and east.

The works of man in the intermontane plateau region of interior Alaska are considerably more evident than in arctic Alaska. This has resulted in considerably more information being available on the populations of commercially and recreationally valuable fish and wildlife; however, these populations are still not well understood. Little information is available particularly on the lower food chain populations of the aquatic organisms, or of the effects of habitat disturbance on fishes and wildlife. Although many streams in the area for some years have been mined as sources of gravel, the effects of this activity on benthic organisms or spawning areas is little understood.

The Pacific Mountain System consists of two series of mountain ranges and is a continuation of the coastal mountain ranges of Canada and the United States. The largest series contains the Alaska Range, the Aleutian Range and the Aleutian Islands. The southern range contains the island of Kodiak, the Kenai-Chugach Range, St. Elias Range, Fairweather Range and the islands of Southeast Alaska. Between these series is a trough containing the Cook Inlet lowlands and the Copper River lowlands. The proposed Trans-Alaska pipeline crosses both these mountain range series, generally following the existing Richardson Highway. The route would cross the Denali fault system near Black Rapids. Precipitation ranges from 12 inches per year on the north side of the Alaska Range and in the Copper River lowlands to 60 to 80 inches per year in Port Valdez. Mean annual temperature varies from 25°F along the headwaters of the Tanana and Copper Rivers to 40°F at Port Valdez.

Vegetation patterns along the proposed pipeline route change from the bottomland spruce-poplar forest of the Tanana River drainage system to the alpine tundra of the passes through the Alaska Range, through a belt of spruce-hardwood forest in the Copper River lowlands. As the route goes through the Chugach Mountains, the vegetation again changes to brush and alpine forms, until the coast is reached, where there is coastal western hemlock-Sitka spruce forest.

In the lower elevations of this section, there is good habitat for moose, bear and wolves; higher elevations provide habitat for Dall sheep. Mountain goats are found in the mountain areas southward from Tonsina. North of Glennallen, part of the Nelchina caribou herd (estimated at 70,000) crosses the route during migration to the wintering range. In this same area, moose, black and grizzly bears, wolves and wolverines are found.

Valuable waterfowl habitat is found in the Copper River lowlands and the Copper River delta. Trumpeter swans are found in both areas. Pothole lakes and other small lakes and ponds serve as nesting habitats for ducks, geese and trumpeter swans.

The proposed pipeline route segment from Isabel Pass to Thompson Pass is within the Copper River drainage system. The annual sockeye salmon run of the upper Copper River averages 250,000. The proposed pipeline will run close to the headwaters of the Gulkana River, a clear-water tributary of the Copper. The Gulkana is one of the most important salmon producers of the entire system, containing tens of thousands of salmon during the spawning season. Chinook and coho salmon are also known to spawn in the Copper and some tributaries. In some of the larger tributaries, steelhead rainbow trout, dolly varden, grayling, whitefish and burbot are found in large numbers. Bald eagles are found in large numbers during the salmon run on the Lowe River.

The Prince William Sound area, including Port Valdez, serves as habitat for many waterfowl, shore birds and sea birds. The Copper River delta to the east of Prince William Sound is the only known nesting area for the dusky Canada goose, and is also a popular waterfowl hunting area.

Large numbers of sea lions and seals are found through the sound; sea otters are relatively abundant in the Hinchinbrook Entrance area. Fur seals and killer whales have occasionally been observed in the area also.

Perhaps the most important renewable resource that will be affected by the oil industry development in Prince William Sound will be the fisheries. All five species of Pacific salmon--pink, chum, coho, sockeye and king are found in Prince William Sound and the Copper and Bering River drainage basins. These support an important commercial fishery with an average salmon take as high as 4.5 million pinks, chums and sockeyes. Halibut, tanner and dungeness crab are also of importance. The U.S. Fish and Wildlife Service has estimated the potential annual harvest value of the Prince William Sound commercial fishery at approximately $10 million.[6] A large number of pink and chum salmon spawn in 32 streams flowing into Valdez Arm. Estuarine and intertidal areas also provide important habitat for spawning pink salmon, as well as habitat for the lower members of the food chain on which the commercially valuable fishes are dependent.

The possible effects of construction activity, as well as possible oil pollution, on the fishery resources of this area are not well understood. Habitat disturbance from siltation or construction on or in the aquatic environment could disturb spawning fishes, as well as eggs or fry. These disturbances, however, will generally be transitory. Spilled crude oil and continuous discharge of treated ballast water could have more lasting effects. At design capacity, 2 million barrels per day of crude oil will be loaded into tankers at Port Valdez. The tank farm at Valdez will hold 10 days through-put of the pipeline--about 20 million barrels. In addition, there will be a ballast treatment facility capable of treating approximately 40 million gallons per day, with a design effluent of 10 mg/liter oil. The acute and chronic effects of crude oil and ballast water discharge on marine and freshwater organisms is not well understood.

Even less understood is the effect of dissolved crude oil fractions on chemoreception mechanisms. Chemoreception is known to be important in the stream identification mechanisms of anadromous fish, and also in prey and mate identification. Dissolved oil fractions may upset these functions, or cause avoidance reactions. Avoidance could, for example, cause juvenile forms to outmigrate from protected zones to areas where they are more subject to predation. The effect is then a secondary one rather than direct toxicity.

A number of areas exist where information must be gathered, and research performed, before the effects of Alaska's petroleum development on the environment are understood, and the means to minimize these effects are developed. In the next section, a review of some of these areas will be made, current research will be matched to need, and areas of further needed research will be developed.

ENVIRONMENTAL INFORMATION REQUIREMENTS

The development of the petroleum industry in Alaska will have extensive effects on the State's many ecosystems. Many of these ecosystems, especially those in the Arctic, have heretofore had only minor incursion by man or his activities. To be able to predict these effects, and to minimize them, a variety of environmental research efforts must be launched.

For the purposes of this paper, the needed research has been developed into two main areas: (1) baseline data gathering and ecosystem analysis, and (2) environmental effects associated with the petroleum development. It should be understood that these two broad areas cannot stand alone. An analysis of the effects must be based on an understanding of the ecosystems involved, and baseline data work and ecosystem modeling must lead to an understanding of the effects of industrial development.

Environmental Baseline Data and Ecosystem Modeling:

The major ecosystems of Alaska have not received much study in the past. Of late, however, increased attention has been paid to these ecosystems, particularly through the IBP Tundra Biome project. Although research agencies in Alaska have conducted environmental research for many years, none has been integrated or comprehensive enough to provide a comprehensive model for any one major ecosystem. Blocks of information are available, however, particularly in the areas of terrestrial vegetation, migratory waterfowl and other birds, and large mammals. The aquatic mammals have been described to some extent, as have the fishes. The Alaska Department of Fish and Game[7] has recently published a comprehensive review of the wildlife populations in the State, including habitat maps and migratory patterns.

A similar effort on fishes would be of great value. The Alyeska Pipeline Service Company has contracted a study, recently published,[8] of the fisheries ecology of the Sagavanirktok River and adjacent drainages. Similar studies have been conducted through the years on the fisheries of other river systems, generally by the Alaska Department of Fish and Game. Additional research needs to be conducted in these areas, particularly in determining the relationships of fish and wildlife to their habitat.

The trees and shrubs of Alaska have recently been reviewed by the U.S. Forest Service[9] in an excellent publication which also contains distribution maps. Intensive work related to major ecosystems is beginning with funds from the petroleum industry or the State and Federal Governments. The

Alyeska Pipeline Service Company has funded "Environmental Studies of Port Valdez," recently published by the University of Alaska's Institute of Marine Science.[10] The Environmental Protection Agency and the National Science Foundations Sea Grant Program have funded "Baseline Data Studies of the Arctic Estuarine Environment,"[11] soon to be completed and published--also by the Institute of Marine Science. These studies were directed toward the entire ecosystem--not a single community or species, and thus are of great value in increasing our total understanding of these systems.

Comprehensive work, however, remains to be done in more accurately defining the community composition of the marine environment, particularly in the coastal areas where offshore drilling will be conducted, or where terminals and transportation routes will be established. Fisheries studies in the marine ecosystems have been generally directed toward species of commercial value; additional work needs to be performed on non-commercial fishes and also the lower trophic level communities.

The freshwater environment has generally received little attention in Alaska. Studies were conducted on some tundra lake ecosystems as part of the Tundra Biome Project,[12] and some small interior Alaska lakes have been studied, particularly with regard to nutrient and trace metal cycling, and primary production; however, larger lakes have been little studied in Alaska. The University of Alaska's Institute of Water Resources is currently conducting an intensive project on Harding Lake near Fairbanks, as part of EPA's research grant program in Alaska. Other lakes in the interior and southwestern portions of the State have been studied with emphasis on sport fisheries potential and fish stocking.

Even less research has been conducted on the flowing water ecosystems, and none of this research has been comprehensive enough to enable adequate understanding of relationships between the various trophic levels. As mentioned previously, the State Department of Fish and Game and the Bureau of Sport Fish and Wildlife have conducted studies into the sport fish distribution in some freshwater streams, and some studies on the feeding habits. Benthic organism populations and stream characteristics of the Chena River drainage were described by the U.S. Public Health Service in the early 1950's, and again by the Alaska Water Laboratory in the early 1970's.[13, 14] Since inception of the Trans-Alaska Pipeline project, both the U.S. Geological Survey[15] and the U.S. Environmental Protection Agency[16] have conducted studies of stream chemistry, and benthic organism populations in areas where the pipeline would cross major drainages. For many years, the Water Resources Division of the U.S. Geological Survey has collected water chemistry and suspended sediment samples in connection with its hydrologic data collection program.

Recently, an experimental watershed project was begun in the Caribou-Poker Creeks subdrainage of the Chatanika River. This project, under the leadership of the U.S. Army Cold Regions Research and Engineering Laboratory,[17] involves a number of State and Federal Agencies including EPA's Arctic Environmental Research Laboratory.[18] Because of its multi-disciplinary approach and long-term baseline data gathering potential, this project promises to be of great value in the development of an understanding of the total ecosystem of these small streams.

The aquatic ecosystems most affected by the development of the oil industry in Alaska will be the streams and estuaries. Lakes may be used as water supply or waste disposal, and may receive drainage from surface activities. However, unless a large oil spill, resulting from a pipeline failure, occurs close to a lake, the direct effects could be minor. Stream systems, however, will be affected by almost any pipeline leak. Many streams will be crossed by oil pipelines and bridges, and bed material will be used as fill for pipelines, roads, airports, drilling pads, and artificial islands. Estuaries are, and will increasingly be, used as tanker loading areas and transport routes, sites for oil drilling platforms and receiving waters for ballast treatment wastes and other industrial and domestic wastes. Both of these major systems need significant additional research if an adequate understanding of their ecosystems is to be developed.

Environmental Effects Research:

Virtually all of the ecosystems that are or will be affected by the oil development in Alaska are, as yet, unaffected by man. With the existing lack of comprehensive baseline data on these ecosystems, the ability to predict or understand the impact of the development on these ecosystems is therefore extremely limited. To better understand these effects, an extensive research program is essential.

The effects of oil development in Alaska can be broken down into three main areas: (a) the effects of exploration and construction, (b) the effects of routine maintenance and operation, and (c) the effects of accidental spills on oil or ballast water.

(a) Effects of exploration and construction:

The exploration and construction phases of oil development in Alaska involve the launching of massive amounts of men and material into a harsh, yet pristine environment. From seismic exploration to construction of well sites, pipelines, pumping stations and camps, this effort involves impacts of little known or understood environments. To only a limited extent can information and guidelines from other environments be extrapolated to fit the far north.

Surface construction in Alaska will often take place on continuous or discontinuous permafrost, occasionally thousands of feet deep. Disturbance of the thin vegetation layer overlying permafrost often results in serious subsidence and erosion into streams and lakes. "Cat trails" used in the exploration of Naval Petroleum Reserve No. 4 are still subsiding 20 years after they have been used. Effects of large scale overland operations on the permafrost itself, on drainage patterns, and on increased siltation in streams have received some attention from the U.S. Bureau of Land Management, the U.S. Army Cold Regions Research and Engineering Laboratory, the U.S. Geological Survey, and the industry itself, as well as research conducted by the Tundra Biome Project. However, the effects of increased siltation from subsiding permafrost on the aquatic ecosystems have been ignored.

Offshore operations currently require seismic exploration techniques to determine geologic formations. Such operations will continue in the Arctic Ocean, particularly in the near shore areas of the Beaufort Sea. The effects of explosive charges on marine life in these areas has yet to be investigated.

Large amounts of stream gravels have been and will be used in the construction phases. The effects of this dredging on the stream flora and fauna have not been well described, although a small project at the Arctic Environmental Research Laboratory should provide some answers to this problem.

Pipelines used to carry oil and gas to market will often cross watersheds in a direction perpendicular to the natural drainage patterns. Planned pipelines will bisect a large number of the major watersheds of the state, including the Tanana and Yukon Rivers. The disturbance of stream beds associated with this construction should be similar to that of the gravel removal operations. However, because much of the pipeline construction will be above ground, using gravel as a support and cover, the effects on watersheds could be much greater than a buried pipeline.

Both the construction of temporary or permanent stream crossings and the removal of gravel from streams could have adverse effects on migratory fishes. Increased sediment concentrations as well as physical disturbance of the spawning area will also have effects on fish populations.

Exploration and construction involves the use of temporary or mobile camps. These may have inadequate sewage treatment and waste disposal systems, resulting in pollution of both the aquatic and terrestrial systems. Although these may be primarily technological problems and ones of relatively short duration, there could be long-term effects.

Following disturbance of the soil and organic layer in temporary road or pipeline construction, revegetation may be necessary to stabilize the soil until natural growth can recur. The Alyeska Pipeline Service Company has sponsored major research by the University of Alaska's Institutes of Arctic Biology and Agricultural Sciences.[19] Although this research has shown that revegetation can be successful on a small plot, the success on larger disturbed areas has yet to be established.

(b) Effects of routine maintenance and operation:

Much of the research necessary in evaluating the effects of exploration has applicability to routine maintenance and operation impacts. For example, the effects on drainage patterns of barriers such as roads or above-ground pipelines would be similar. However, several major areas remain. Roads and other large above-ground structures may serve as an effective barrier to migratory wildlife; particularly caribou. The Alaska Cooperative

Wildlife Research Unit has recently published a report[20] of their investigations into the disturbance of caribou movements by above-ground pipelines. This research was sponsored by industry, and, unfortunately, did not reveal sufficient information to be able to adequately predict effects. Some caribou did cross the simulated pipeline crossings used in the experiment; however, most simply walked around the end. Whether caribou could cross over, or under, such a structure which is long enough to prevent their going around is not known.

Another effect will be from the continuous discharge of effluents from facilities operated by the industry. These will include air pollutants (including ice fog) from the large stationary power plants at the oil fields, at pipeline pumping stations and tanker loading facilities. Another source will be the vehicles used in operation--surface vehicles as well as aircraft. To date, the effects of air pollutants on the tundra vegetation have not been studied. The abatement and control of ice fog, particularly in the Prudhoe Bay and Fairbanks areas should receive immediate attention.

The discharge of effluents into the aquatic environment may have more serious consequences. The discharge of domestic wastes into ice-covered streams with naturally low dissolved oxygen concentrations may cause further depletion of the dissolved oxygen and subsequent damage to the aquatic environment. Studies at the Arctic Environmental Research Laboratory indicate that survival of fecal indicator organisms in cold streams is significantly longer than in warmer climates.[21] Although increased survival has not yet been adequately demonstrated for pathogenic organisms, the possibility of serious contamination of freshwater streams and lakes from domestic wastes does exist.

The discharge of treated ballast water and produced water effluents will also have environmental effects, particularly in the estuarine environment. The planned ballast water treatment facility at Valdez is designed for a 44-million gallon per day capacity with an effluent discharge containing 10 mg/l oil. Water recovered from operating wells, so called "produced water" may be more difficult to treat and may contain as much as 50 mg/l oil.

The Alyeska Pipeline Service Company has contracted with Battelle Memorial Laboratories to conduct toxicity studies with "synthetic" ballast water treatment effluents. The reports of these investigations have been recently published.[22] In addition, as part of the environmental studies of Port Valdez mentioned previously,[10] the University of Alaska's Institute of Marine Science postulated that the influx of treated ballast water would have little or no effect on the primary productivity of the estuary. The effects of these discharges do need significant additional work, not only with relation to toxicity, but also effects on chemoreception and other low-concentration effects.

(c) Effects of accidental spills of petroleum and untreated ballast waters:

Despite all precautions and the advanced technology of the oil industry, major spills of petroleum and untreated ballast water have occurred in the past in Alaska, and will increasingly occur in the future. The recent world increase in tanker traffic has resulted in an increase in accidental spills, and a subsequent international concern over the effects on the marine environment. As a result, a great deal of research has been conducted to determine the effects on marine ecosystems, and some of this work has been done in Alaska. The applicability of research performed elsewhere on Alaska's cold climate ecosystems has yet to be established, however. In addition, the effects on freshwater and terrestrial ecosystems has received little attention in the literature, and only a few studies have taken place in Alaska.

The U.S. Army Cold Regions Research and Engineering Laboratory has conducted studies to determine the effects of numerous pipeline breaks in the Haines-Fairbanks military pipeline on the terrestrial, and to a limited extent, freshwater ecosystems.[23] Although these spills were all petroleum products, the study will find application in evaluating the effects of crude oil spills. CRREL has also conducted a small experimental spill of Prudhoe Bay crude oil in an interior Alaska tundra-tiaga experimental watershed. Experimental spills were also conducted on small tundra lakes and terrain as part of the Tundra Biome Projects in Barrow, Alaska.[12] The effects and fate of oil spills into the flowing water ecosystems of Alaska have yet to be evaluated, however.

Studies concerning the effects of oil spills on marine ecosystems have dealt with only a few species, almost all of commercial interest. The University of Alaska has conducted two studies under grants from the Environmental Protection Agency; one on the effects of large oil concentrations on marine stages of salmon;[24] another, now ongoing, on the effects on intertidal meiofauna in Prince William Sound. The National Marine Fisheries Service has conducted sublethal effects studies on pink salmon and tanner crabs.[25] This work is continuing. However, the fate of oil spills in the arctic and subarctic marine ecosystems has not been defined, nor has sufficient work been done to describe effects on non-commercial marine organisms such as benthic fauna, phytoplankton, and zooplankton.

The U.S. Coast Guard[26,27] has studied to a limited extent the fate of oil spills on and under sea ice, their rate of travel over ice, and the practicability of burning spilled oil under those conditions. The fate of oil spilled into cold climate ecosystems, physical and chemical and microbiological degradation, and the ultimate fate of residual materials ("atmospheric oil residues") has received virtually no attention.

SUMMARY

As can be seen from the above discussion, significant new research is necessary to enable prediction of the effects of oil development activities on Alaska's ecosystems. Not only should this research entail major efforts to determine effects on terrestrial, freshwater and marine ecosystems, but also in fate, pathways and degradation of oil spilled into these systems. Because of the very real lack of baseline information and ecosystem modeling in all of these systems, it is also essential that research efforts in this area be increased.

The oil industry, with all of its attendant environmental problems, is now a reality in Alaska. It will continue to pose a major environmental threat to Alaska through the balance of this century. Yet the ability to predict and control the effects of the industry is presently at a minimum. As the industry expands, so must research efforts expand to meet the growing challenges of petroleum development in the north.

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