Appendix D
Historical Overview of North Slope Petroleum Development and *Exxon Valdez* Oil Spill

By B.J. Gallaway

D.1 Background

The modern history of petroleum development on Alaska's North Slope is generally considered to date from the late 1950s and early 1960s (Gilders and Cronin, 2000). However, oil seepages and oil-rich rocks in northern Alaska were known to Eskimos long before recorded history (Selkregg, 1975). In the early 1900s, E. de K. Leffingwell led a U.S. Geological Survey (USGS) expedition to evaluate the geology of arctic Alaska. Local residents identified the location of surface oil seeps, and this information was used in defining areas that might contain potential oil structures. Reports between 1919 and 1922 by the USGS and other government agencies documented oil seeps in the Smith Bay (Cape Simpson) region of the western Alaska Arctic and concluded that there might be petroleum at many places on the Arctic Coastal Plain and that there might be a more-or-less continuous oil-bearing belt extending across northern Alaska (Martin, 1921). This information contributed to the establishment of Naval Petroleum Reserve Number 4 (PET 4) by President Warren G. Harding in 1923. This area is now known as the National Petroleum Reserve-Alaska (NPR-A) (Figure D-1).

Shortly after Alaska obtained statehood in 1959, a large portion of the eastern arctic region was retained by the federal government with the establishment in December of 1960 of the Arctic National Wildlife Range (Figure D-1). The purpose was to preserve unique wildlife, wilderness, and recreational values while at the same time allowing for oil and gas leasing. The initial withdrawal involved approximately 8.9 million acres. The same land order opened the region between the Colville and Canning rivers to selection under the Statehood Act and to homesteading. The State of Alaska selected considerable acreage in the region, including the lands where the Prudhoe Bay and Kuparuk oil fields were later discovered. Land transfers ceased, however, when the Secretary of the Interior issued a land freeze in 1966, blocking further state selections until Native land claims were settled.

During the eight years between passage of the Alaska Statehood Act and the Department of the Interior's 1966 land freeze, title to approximately 12 million acres of public land was transferred to the state. Further land transfers within the state remained "frozen" until 1971 when Congress passed the Alaska Native Claims Settlement Act (ANCSA). Granting to Alaska Natives land selection rights to over 40 million acres, ANCSA paved the way for construction of the Trans Alaska Pipeline System (TAPS) and allowed state selections to resume. Section 17(d)(2) of the Act, popularly known as "D-2", authorized the Secretary of the Interior to withdraw up to 80 million acres of land for inclusion in national parks, wildlife refuges, forests, and wild and scenic rivers.

Although ANCSA opened Alaskan lands to state and Native selections for a brief time, a series of freezes was imposed on federal land transfers until the D-2 withdrawals were accomplished. After intense debate on management of federal lands in Alaska, Congress passed the Alaska National Interest Lands Conservation Act (ANILCA) on December 2, 1980, ending the uncertainty. ANILCA changed the name of the Arctic National Wildlife Range to the Arctic National Wildlife Refuge (ANWR) and added about 9 million acres to double the size of the refuge to approximately 19 million acres.

ANILCA reiterated the purpose for which ANWR was established including conservation of fish and wildlife populations and their habitats, fulfillment of international treaty obligations relating to migratory wildlife, continuation of subsistence uses by local residents, and maintenance of water quality. Section 304(a) requires that administration of the refuge be in accordance with laws governing the national wildlife refuge system, and Section 304(g) required preparation of a comprehensive conservation plan for ANWR.

In this context, a 1.5-million-acre area — the so-called 1002 Area — of the coastal plain within ANWR was segregated for resource evaluation because of its potential for crude oil deposits (Figure D-1). This area was specifically addressed under Section 1002 of ANILCA, which required the Secretary of the Interior to report to Congress on a number of issues including:

- Identification by means other than drilling exploratory wells of the oil and gas potential of the ANWR coastal plain;
- Description of fish and wildlife, their habitats, and other resources in areas having oil and gas potential;
- Evaluation of adverse effects of further oil and gas exploration and production on wildlife and habitats;
- Identification of transportation systems for oil and gas development;
- Evaluation of the national need for development of ANWR oil and gas resources; and
- Recommendations on whether further exploration for, and the development and production of, oil and gas on the coastal plain should be permitted and, if so, what legal authority would be necessary to avoid effects on wildlife and other resources.

During the winters of 1983-84 and 1984-85, some 1,180 line miles of geophysical data were acquired for the 1002 Area. The U.S. Fish and Wildlife Service conducted baseline studies during 1980 to 1985 to determine the size and diversity of the fish and wildlife populations in the 1002 Area (Garner and Reynolds, 1986). A draft report was issued by the Secretary of the Interior in November 1986 followed by a final report in April 1987. In March 1987, the Secretary of the Interior recommended to Congress that the coastal plain be opened to development and published the final environmental impact statement (EIS) for ANWR exploration. Scientists began additional studies in 1987 to investigate the potential impacts of pending petroleum development in the 1002 Area on key fish and wildlife species and their habitats (McCabe, 1994).

Congress did not immediately take action to allow leasing and petroleum exploration and development in ANWR. From the beginning, petroleum development of ANWR has been a highly contentious issue. In 1995, the U.S. House and Senate finally approved coastal plain development as part of a balanced budget act, but the entire measure was vetoed by President Clinton. To date, Congress has not acted to allow leasing or development.

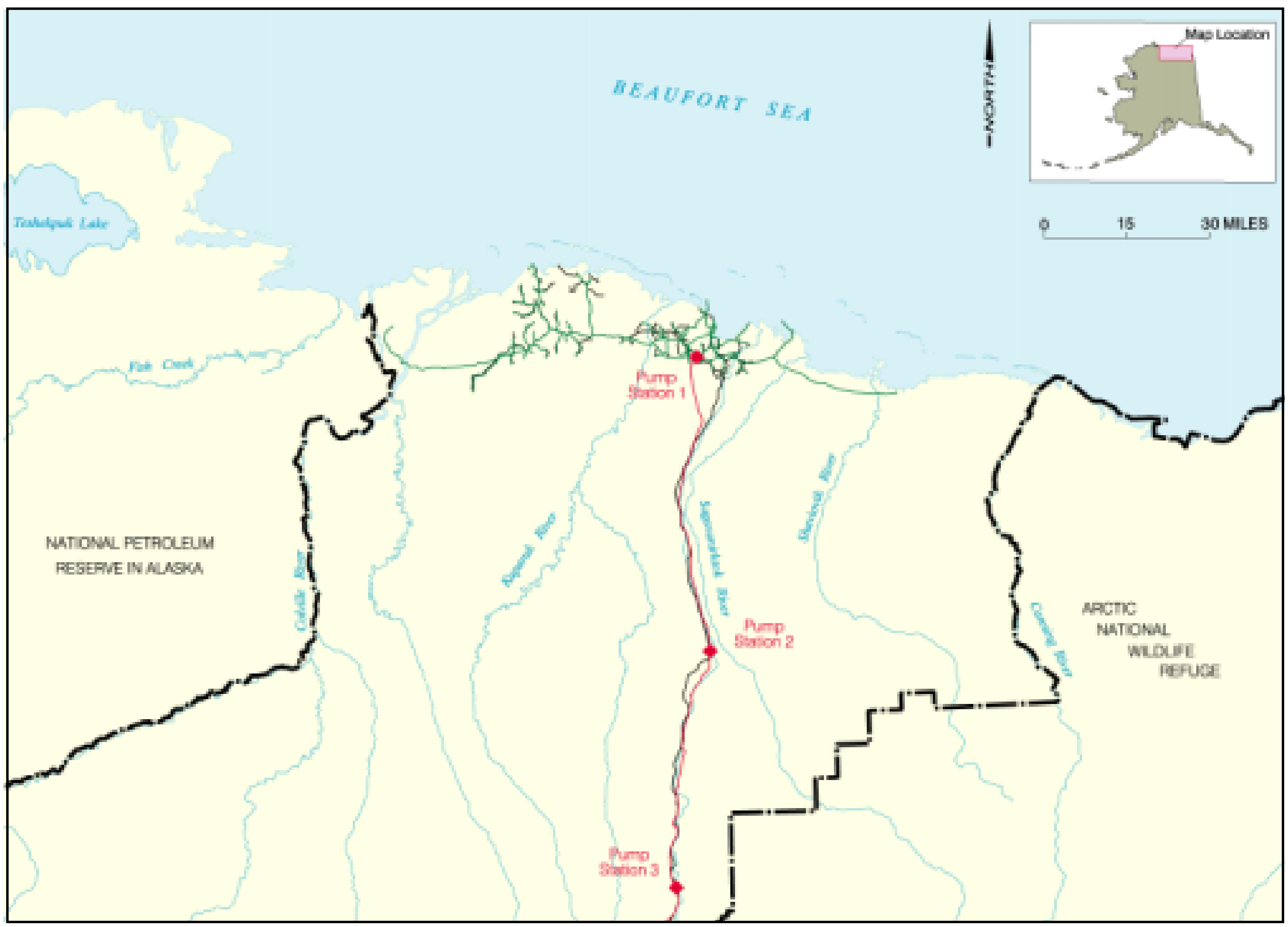

Figure D-1. *The Alaska North Slope in the oil field region.*

As noted above, the State of Alaska selected in 1964 most of the available land between the Colville and Canning rivers (the region between NPR-A and ANWR) and leased these lands for petroleum development. The discovery in 1968 of the Prudhoe Bay oil field has led to extensive oil development in this region and the construction of TAPS. The following provides a synopsis of the history of development in the NPR-A region, the Prudhoe Bay region between NPR-A and ANWR, and TAPS. These sections are followed by a synopsis of the *Exxon Valdez* oil spill.

D.2 Historical Synopsis: NPR-A

As described by the Bureau of Land Management (BLM and MMS, 1998), assessment of NPR-A proceeded in four distinct periods of administration and exploration. These include an early period (pre-1923), the Navy period (1923-76), the Department of Interior period (1976-80), and the private period from 1981 to the present (BLM and MMS, 1998).

The first period begins with Native peoples' use of oil seeps and ends with establishment of PET-4 in 1923. While there are no physical traces of local use of the oil seeps, this use is documented by oral traditions describing the harvest of hardened petroleum or "pitch" from oil seeps. This use continued through at least the 1930s. For example, Libbey (1988-89, p. 524) includes an oral account from a Barrow resident following the introduction of the metal stove for heating and cooking:

> And later on, back in the 1930s, they started to let people go out to the pitch lake out here at Tulimaniq (Barrow TLUI Site #140) and cut up those in blocks and put it in gunny sacks and haul it down to the beach for the Native Store . . . it is the seepage of the oil that surfaces and spreads out. As time goes by it hardens. So they cut it in blocks before the snow goes away.

BLM and MMS (1998) note that the local population required the use of fuels beyond marine mammal oils and driftwood for at least the last 100 years. Pitch was one source of these ancillary fuels.

Before the Minerals Leasing Act of 1920, numerous oil and gas claims were located in what is now NPR-A (BLM and MMS, 1998). Roughly 117 claims were staked before establishment of the reserve. The prospecting permits for these claims were issued by the General Land Office, which became the BLM in 1946. The permits expired 10 years from approval, and no records exist of any exploration under these claims (BLM and MMS, 1998).

The Navy began oil and gas exploration in the reserve in 1944 and conducted extensive exploration between 1944 and 1952 (Selkregg, 1975; BLM and MMS, 1998). The first exploration wells were drilled near oil seeps and on surface anticlines. The approach was simple. A site was prepared, a drill rig erected and drilling commenced. After drilling, the sites were simply abandoned with little or no cleanup. The bulk of material left behind at these early exploration sites was not cleaned up until 1976, when USGS was appointed responsible party for exploration operations in the reserve under Section 104 of the Naval Petroleum Reserves Production Act of 1976 (NPRPA). While most of these abandoned sites today consist of a pipe surrounded by natural vegetation, a number remain in need of maintenance or completion — e.g., reclamation, abandonment, plugging, or other tasks (BLM and MMS, 1998).

The Navy period of exploration resulted in several oil and gas discoveries. Umiat was the first oil field discovered in northern Alaska (1946), although it remains undeveloped. The South Barrow gas field, the first significant gas discovery (1949) on the North Slope, was developed by the federal government in 1958 to supply fuel to Barrow.

By the mid-1970s, the Navy's dependence on and need for oil were dwarfed by that of the entire nation's economy as particularly affected by the oil embargo of 1973. The need to increase domestic oil production was accompanied by a rising environmental consciousness and interest in the variety and richness of wildlife in the NPR-A region still known as PET-4. In 1976, President Gerald Ford signed the NPRPA calling for development of PET-4 and other Naval reserves. This law transferred management of PET-4 to the Secretary of Interior and renamed it as NPR-A.

The Department of Interior, specifically USGS, was charged with exploring NPR-A between 1976 and 1982 under Section 104 of the NPRPA. USGS contracted for exploration with Husky Oil Company. BLM and MMS (1998) note that the wellsites built during this period generally were composed of a camp pad, drilling pad (normally all one pad), reserve/mud pit, a flare pit, a fuel-storage pit, and a wellhead consisting of a pipe (Christmas tree) surrounded by the cellar (corrugated metal chamber or timber cribbing). Although most wellsites were serviced by ice airstrips, three included gravel airstrips. Drilling operations in areas of unknown underground pressures sometimes used pits to allow for a safe way to redirect escaping petroleum. In addition, the pits received expended drilling muds.

This phase of NPR-A exploration resulted in 28 exploration wells and some 14,800 miles of seismic data. Numerous oil and gas shows were reported, but no commercial fields were discovered. Gas fields near Barrow (Barrow and Walakpa) were developed through government subsidies and produced for local use. USGS/Husky exploration ended in 1981. The USGS began continuous wellsite cleanup and rehabilitation in 1978. Solid wastes were disposed at the solid-waste-disposal site at Lonely.

Today, the 28 abandoned wells remain under USGS jurisdiction. All of these wells were the subject of an intensive revegetation program. Since then, the sites continue to be reclaimed naturally by local species. Those sites with compacted gravel pads have taken considerably longer to show signs of natural vegetation takeover than the soil-based pads. The USGS wells have deep permanent plugs generally at about 2,000 ft; in addition, all zones of petroleum fluids or pressure are isolated by permanent plugs. At the surface, the wells have Christmas tree valve (abandonment head) assemblies. This allows a small valve to be opened for temperature logging as part of an ongoing program of climate research.

The private exploration period of the NPR-A began with the passage of the Interior Appropriations Act of December 1980. An oil and gas leasing program was initiated by the Department of the Interior, and the first sale was held in 1982. One well, ARCO's Brontosaurus No. 1, was drilled in 1985 and abandoned in the same year as a dry hole. The Cape Halkett land exchange transferred an existing W.T. Foran well to the Arctic Slope Regional Corporation (ASRC) and allowed ASRC to drill the Livehorse well on private land in NPR-A. Wells in the Barrow area (such as the South Barrow Gas field and the Walakpa exploration wells) that had been developed by the federal government were passed to the North Slope Borough through the Barrow Gas Field Transfer Act. The Walakpa (Ualiqpaa) field now produces more than 90 percent of Barrow's annual consumption of natural gas (NSB, 1998).

A recent EIS (BLM and MMS, 1998) details present-day development requirements for the northeast part of NPR-A now being leased for private development. The leasing plan protects habitats judged important to molting geese and the Teshekpuk Lake caribou herd by making theses areas unavailable for leasing or by strict restrictions on oil and gas surface occupancy. Additionally, surface-use restrictions and other stipulations were applied to other habitats identified as having high surface-resource values, including subsistence use areas, areas along rivers used by raptors for nesting, and "special areas" along rivers. Protection of these areas left some 87 percent of the planning area available for leasing. Leasing stipulations required consultation with affected communities, establishment of a subsistence advisory committee, and creation of an interagency research and monitoring team. This team would coordinate research and monitoring studies related to the effectiveness of stipulations and surface resource impacts. Other than temporary ice roads, no roads connecting outside the planning area are allowed.

Well designs and seismic techniques have evolved since the early days of government exploration in the NPR-A. Modern well designs generally call for recirculating mud systems without pits. The disturbed area is minimal. Modern completed wells under any future leasing should resemble Brontosaurus: a closed pipe marks the location and little else is visible; the ground area has a natural appearance. Seismic exploration programs now use vibrating equipment rather than explosives and benefit from the considerable experience of early government programs.

The acceleration of petroleum exploration in NPR-A between 1944 to 1953 accelerated the cash economy of the Arctic. Additionally, this program led to establishment of the Naval Arctic Research Laboratory (NARL) in 1947 which added employment and resulted in a long-term federal commitment to a quest for knowledge of the arctic region, its people, land, water, resources, and climate. Scientists based at NARL initiated studies of disturbance on soils and nutrient cycling (Shaver, 1996). The NARL facility provided research and logistic assistance to virtually all arctic research programs conducted through the mid-1980s. The facility remains today, but has been transferred to and is operated under the auspices of the North Slope Borough.

The presence of NARL facilitated research in the northwestern Alaska arctic region within and beyond the borders of the NPR-A. Truett (2000) notes that in 1958, the U.S. Atomic Energy Commission authorized environmental studies on the northwestern coast of Alaska in anticipation of an experimental harbor excavation by nuclear blast (which never materialized) (Wilimovsky and Wolf, 1966). In the early 1970s, the National Science Foundation initiated two arctic Alaska programs: (1) the International Biological Program and its Coastal Tundra Biome studies at Barrow (Brown et al., 1980), and (2) the Research on Arctic Tundra program inland from Barrow at Atkasook (Batzli and Brown, 1976). In 1975, the U.S. government started the oil-related Alaska marine-studies program known as the Outer Continental Shelf Environmental Assessment Program, described by its director as "the largest environmental program in the history of our nation and probably of the world" (Engelmann, 1976). This program received logistical and other support from NARL. Also, between 1976 and 1979, the USGS conducted environmental studies in NPR-A in anticipation of potential oil development there following their mandate to explore the region. The NPR-A region

has a long history of scientific research. The NPR-A EIS (BLM and MMS, 1998) contains a comprehensive description of the environment, wildlife resources, subsistence use patterns, human resources, etc. of NPR-A.

D.3 Historical Synopsis: Prudhoe Bay Oil Fields

In 1964, the State of Alaska, largely on the basis of geological surveys, selected a 200-km coastal stretch between NPR-A to the west and ANWR to the east. That same year, competitive lease sales were conducted in the Colville River delta and around Prudhoe Bay (Gilders and Cronin, 2000). Ten dry holes were drilled in the region between 1964 and 1967 — five in 1964, one in 1965, two in 1966, and two in 1967 (Selkregg, 1975). Many oil companies gave up hope of finding commercially viable petroleum deposits on the North Slope. However, Atlantic Richfield Company (ARCO) and Humble Oil and Refining Company (now Exxon Company, USA) announced a major oil strike on March 13, 1968 (Gilders and Cronin, 2000). Ultimately, the total reserves of this strike were estimated at 23 billion barrels of oil and 26 trillion cubic feet of natural gas. Field development began in 1969.

This discovery brought force and economic urgency to settle Native protests and claims regarding federal land set-asides and state-selected lands. The then North Slope Native Association, for example, had claimed virtually all lands north of the 68th parallel. These claims were based on the Omnibus Act of June 26, 1959, which amended the Statehood Act to include "that Alaska and its people disclaim any right to land and property held by Alaska Natives or held in trust by the United States for such Natives." The implications were staggering. Leasing of state lands was suspended by the Secretary of the Interior in November 1966, one month following the state announcement of the opening of large blocks of additional land to oil and gas leasing, and the subsequent Native protests.

Compromise legislation was finally initiated in the form of ANCSA in 1971. President Lyndon B. Johnson had set the framework for the legislation by recommending in 1968 that Congress (1) "give the Native people of Alaska title to the lands they occupy and need to sustain their villages"; (2) give them rights to use additional lands and water for hunting, trapping and fishing to maintain their traditional way of life, if they so choose"; and (3) "award them compensation commensurate with the value of any lands taken from them" (Selkregg, 1975). This act provided the basis for the establishment of the North Slope Borough (NSB) as the local government entity for the entire arctic region, and assured economic vitality of Native communities through monetary compensation and land selection rights. With this action, the Iñupiat of the Arctic moved into a new era of self-assertion and a new cultural, political and economic identity (Selkregg, 1975). Oil-field development in the Prudhoe Bay region was free to proceed on land beyond that which had been leased before the 1966 land freeze. Further, ANCSA enabled development of TAPS.

Gilders and Cronin (2000) list eight producing and four planned oil fields in the Prudhoe Bay region as of 1998 and note that these refer to both "units" and "participating areas". They also note that there were six additional participating areas on the North Slope whose oil is processed by existing facilities (i.e., no additional surface impact). A "unit" is a combination of existing oil and gas leases that, by agreement among the lessees of record and the lessor (State of Alaska in the Prudhoe Bay region fields developed to date), is combined into one lease (or unit) to promote optimal development of the oil and gas resource.

The distribution of producing units presently operating on the North Slope is shown by Figure D-2. The Prudhoe Bay Unit was the first oil-producing area on the North Slope, discovered in 1968. This unit essentially began production as soon as TAPS was opened in 1977. Recent developments in this unit include the Lisburne, Point McIntyre, and Niakuk oil fields which began production in 1986, 1993, and 1994, respectively.

The Kuparuk River Unit, the second oil-producing area in the region, began production in 1981. Production from the Milne Point Unit followed in 1985, establishing it as the third major oil field in the region. Production from this unit was suspended in early 1987 due to unfavorable oil prices, but the unit resumed production in 1989. A seawater treatment plant and waterflooding facility along with a 700-ft dock were established at Oliktok Point in 1985 to support these and potentially other units (e.g., Alpine).

Endicott was the fourth producing oil field on the North Slope, beginning production in 1987 (Gilders and Cronin, 2000). It was notable, however, in that it was the first offshore production facility in the North American Arctic. Built in the winter of 1984-85, Endicott's two artificial islands were connected by a curved, 3.7-mile-long gravel fill causeway, and this segment is connected to shore by a 1.6-mile-long causeway originally constructed with two breaches for fish passage. These breaches provided a total opening of about 630 ft.

The Badami and Alpine oil fields are the most recent developments, beginning production in 1998 and 1999, respectively. These developments reflect the most modern

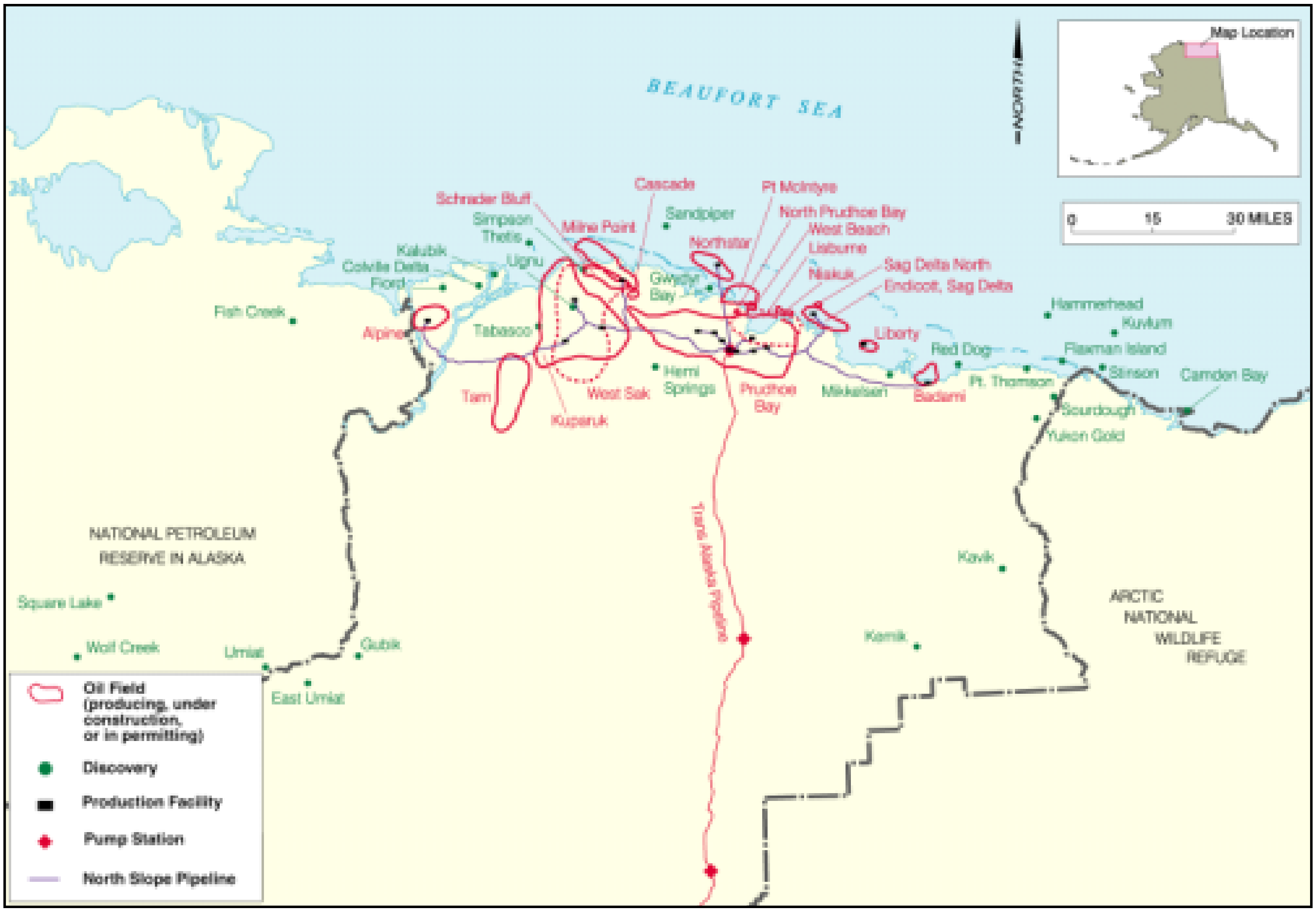

Figure D-2. *Alaska North Slope oil fields.*

technology and are "roadless." Collectively, the oil fields of the Prudhoe Bay region were, and still are, the largest oil and natural gas discoveries in the history of North American exploration. Alaska North Slope oil provides 20 to 25 percent of U.S. oil production, and approximately 85 percent of the Alaskan state budget is derived from taxes and royalties collected on oil production (Gilders and Cronin, 2000).

Disturbances from early oil and gas exploration and development included tracks in the tundra from vehicles during summer, temporary peat roads bulldozed in tundra in both summer and winter (Reed, 1958), and drill sites (Lawson et al., 1978; Ebersole, 1987). The greatest environmental effect of these disturbances was ground subsidence caused by the permafrost thawing ("thermokarst" effect). Many of these thermokarst impacts can be seen even today, and the lessons learned have been applied to modern practices.

Gravel fill has been the solution to the thermokarst problems in the Prudhoe Bay region. It is used to support facilities and vehicular traffic on tundra, providing a dry, stable surface that can be safely used year-round (Gilders and Cronin, 2000). Moreover, gravel fill prevents heat transfer from facilities to the tundra, thus preventing thermokarst and subsidence (Hanley et al., 1981). In the Prudhoe Bay area, gravel is mined from local sources, and most pads and roads are constructed to a height of 5 ft (Walker et al., 1987). The pads, roads, and gravel mine pits provide an infrastructure "footprint" on the moist tundra that can be quantified from aerial photography in terms of acres of fill or gravel mine pits.

Powerlines and pipelines do not presently require gravel pads. Pipelines are typically constructed from ice roads during winter, with a 400-ft or more separation from any adjacent roads. They are usually elevated 5 ft or more above the ground on vertical support members (VSMs) to allow wildlife to freely pass. VSMs produce minimal disturbance to the tundra. Inspections are conducted using aircraft during summer and from ice roads or aircraft during winter. In other cases, pipelines are buried in the roads, and some of the older lines are on gravel pads.

The following describes the incremental development of the Prudhoe Bay oil field from 1968 to 1999. Gravel fill and mine areas measured in acres and miles of common carrier pipelines are used to quantify the rate and amount of oil field expansion. The areas of disturbance and miles of pipelines are based on the calculations of Ambrosius (2000) from existing photography that is adequate for this purpose — namely, photography from 1968, 1973, 1983, 1990, and 1999. These estimates constitute the most accurate totals to date. It should be noted that these areas have been calculated on a unit or oil field basis, but include all these as well as all private and public facilities except for military installations. These facilities would not exist without the oil field and are thus considered part of the overall development. Lastly, note that the TAPS ROW and the Dalton Highway are largely excluded, except for the areas in the oil field region per se. These will be addressed in the following section dealing specifically with TAPS.

In 1968, some 72 acres of tundra in the Prudhoe Bay region exhibited a disturbance or development footprint (Figure D-3). These consisted of the ARCO base camp (including a small landing strip), a peat road extending from the base camp to the discovery site, and the drill site located about 5 km southwest of the Prudhoe Bay shoreline. By 1973, extensive development had occurred in the region, and exploration footprints or tundra disturbance were evident in the discovery area, as well as to the west in the region between Milne and Oliktok Points and to the east in what is now known as the Badami and Point Thomson areas (Figure D-4). Production facilities and pipelines, camps, oil-field service company installations, docks to receive summer barge traffic, a large main and satellite airports, and an industrial highway linking this remote region to Fairbanks had all been constructed by 1973. As late as 1967, this region had been open tundra with scattered Iñupiat seasonal hunting and fishing camps (Parametrix, 1997). The cumulative size of the footprint in 1973 had increased to some 2,445 acres. Peat roads were still prevalent and in use, as well as gravel fill roads and mine sites.

Much of the development during the initial development period and subsequent eras was supplied by “sealift.” Heavy equipment and development modules (complete in every detail) constructed in the contiguous 48 states were and are loaded on oceangoing barges and transported to the North Slope. Marine shipments are limited to seasonal windows between late July and early September when the arctic coast is “ice-free.” East Dock, constructed to receive these oceangoing barges, was the only offshore development evident in 1973. It had been constructed in 1969 on the southeast shoreline of the Prudhoe Bay. The dock consisted of a 1,100-ft-long gravel-fill causeway terminating in a 100-by-200-ft wharf constructed from barges grounded in about 4 ft of water (USACE, 1984; Colonell, 1990). Selkregg (1975) provides photographs of this dock and associated storage yard, noting that “the greatest freight

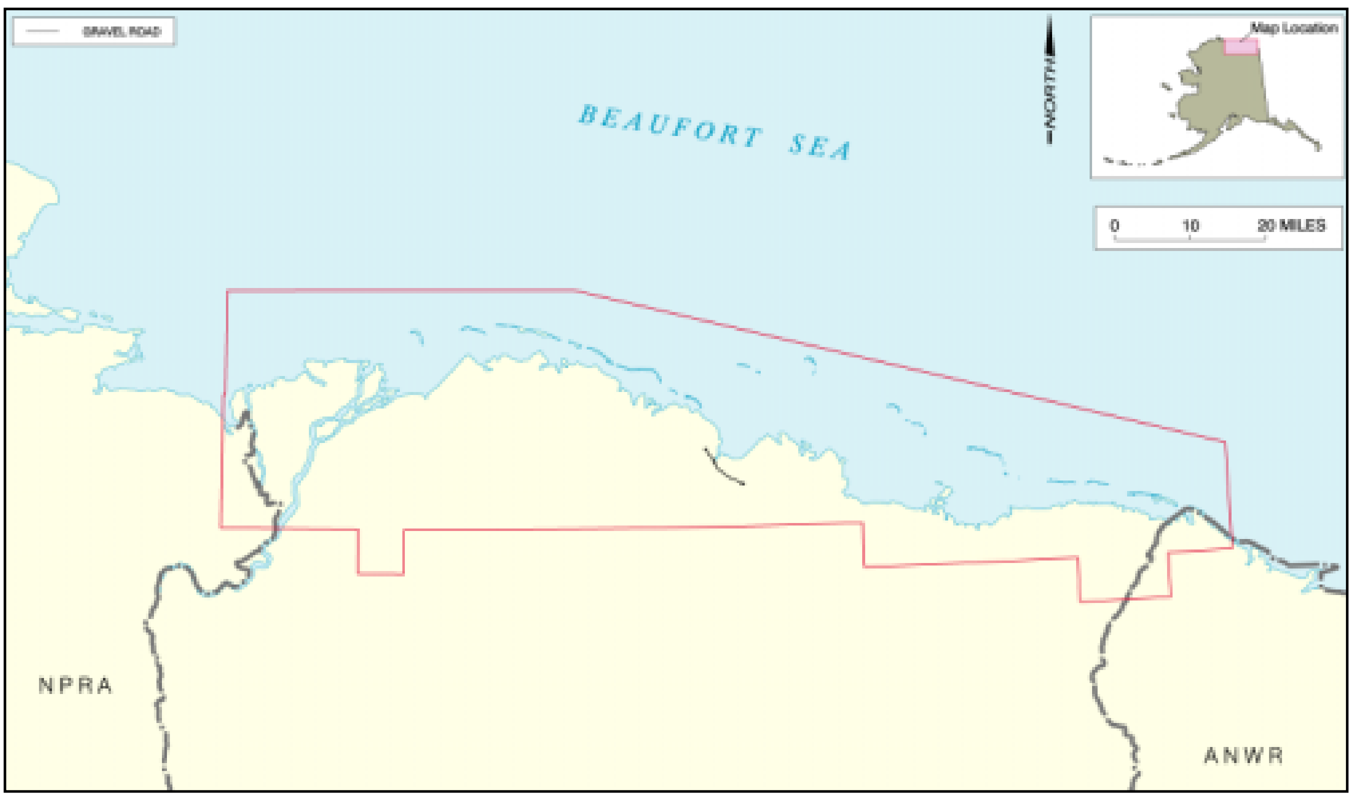

Figure D-3. *Alaska North Slope oil field development footprint in 1968.*

movements in the history of the Arctic passed over this dock."

The largest increment of footprint expansion in the Prudhoe Bay region occurred between 1973 and 1983 (compare Figures D-4 and D-5). The footprint increased from 2,448 acres in 1973 to 8,115 acres in 1985. TAPS, approved in 1973 and built between 1974 and 1977, became operational with the June 20, 1977 delivery of Prudhoe Bay oil to tankers in Valdez (Gilders and Cronin, 2000). Offshore development had increased by 1983 to include artificial gravel islands for exploratory drilling, and West Dock. This dock is located on the northern perimeter or the west side of the bay and effectively replaced East Dock as the main docking facility. This structure has had a most contentious history and was the focal point of offshore development or "causeway" issues for many years.

The structure was originally constructed in the winter of 1974-75 to serve as an alternative to East Dock (Colonell and Gallaway, 1990). The original structure extended about 3,600 ft from the northwest shore of Prudhoe Bay and terminated at Dockhead 2. In the late summer of 1975, the first year of the operation of this new dock, supply barges became trapped in the ice about 4,800 ft offshore of Dockhead 2. Emergency permits were granted to extend the dock to the barges, and this was accomplished in early 1976. Dockhead 3 was established in about 6 to 7 ft of water and was now over 1.5 miles from the shoreline.

The Dockhead 3 extension marked the emergence of pronounced concerns by regulatory resource agencies over potential impacts of solid-fill docks or causeways on coastal and marine resources of the Alaskan Beaufort Sea. The term "causeway" has since been applied to any solid-fill gravel structure that extends from land into the coastal waters of the Beaufort Sea to provide landing facilities for marine-borne cargo, access to gravel island production facilities, shelter and support for seawater intake and treatment plants, safe pipeline routes, etc. Although several studies to assess the impacts of the emergency extension of West Dock were initiated, the results were deemed inconclusive by the regulatory community because agency scientists did not believe the issues of interest had been clearly addressed (Meehan, 1980).

In 1979, another extension of West Dock was proposed for the purpose of waterflooding (a secondary oil recovery process) the Prudhoe Bay oil field. It was proposed that West Dock be extended 4,560 ft due north from Dockhead 3 out to a water depth of 12 ft. A seawater intake and treatment plant were to be installed at the seaward tip of this extension. The third leg of West Dock, known as the Waterflood Extension, was constructed for this purpose in sum-

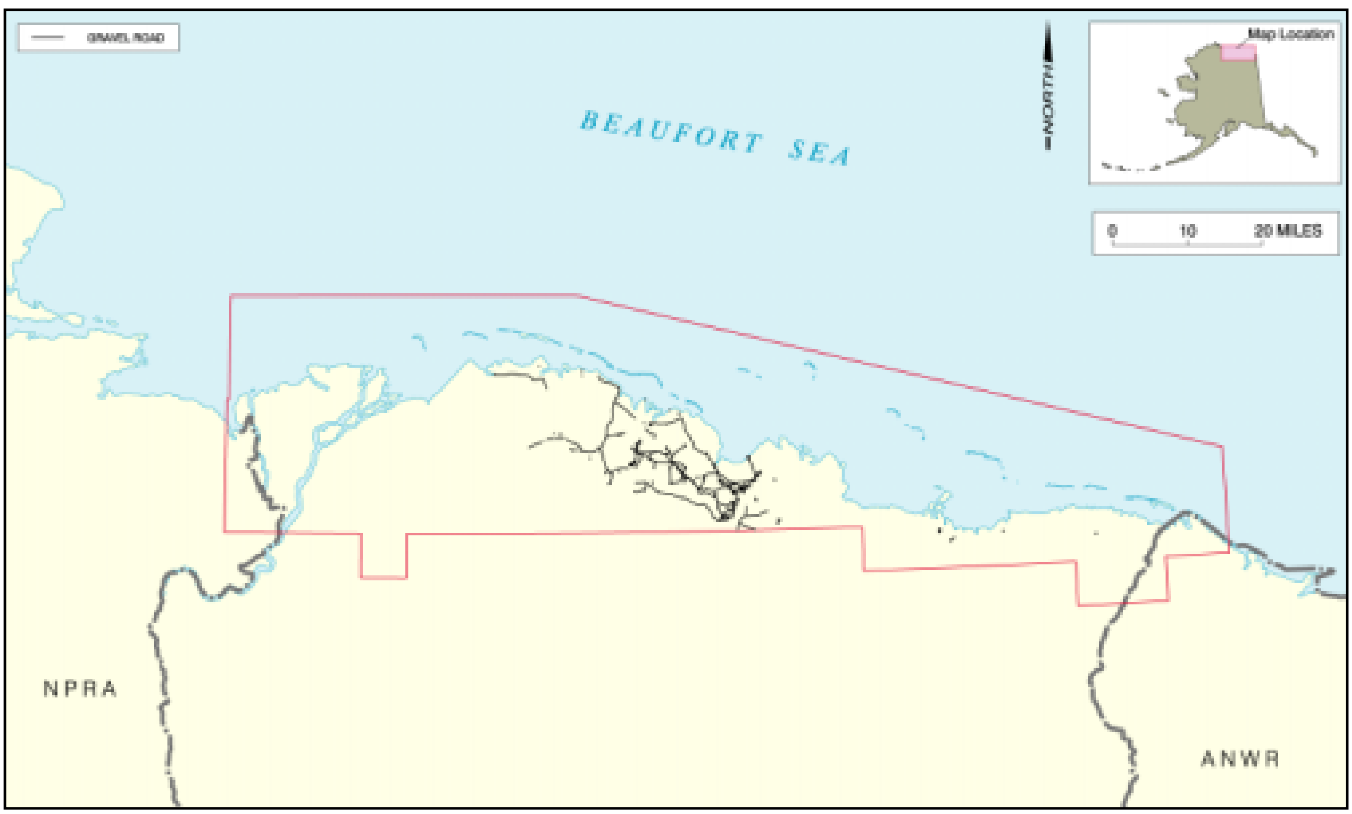

Figure D-4. *Alaska North Slope oil field development footprint in 1973.*

mer 1981, extending the total length of the structure to about 2.5 miles. This leg is connected to the original structure just north of Dockhead 3 by a bridge that spans a 15.8-m-wide breach installed as a passage for fish and small boats. To accommodate additional piping and access requirements, the causeway was enlarged over its entire length to provide a 12-m-wide roadway 5.5 m above mean sea level.

The Waterflood Extension heightened regulatory agency concerns about the impacts of West Dock on the marine environment and resources. The permit stipulated that a comprehensive monitoring program be conducted, called the Waterflood Monitoring Program or Waterflood Studies. Both the terrestrial and marine components of the program were conducted annually from 1981 to 1984. Extensive field studies of oceanographic conditions and anadromous fish use of the coastal zone in the vicinity of West Dock and the Prudhoe Bay region were done under the auspices of the U.S. Army Corps of Engineers (USACE). The goals were to evaluate the predictions that had been made in the project's EIS (USACE, 1980) and establish the actual effects. Colonell and Gallaway (1990) assessed the effects of this structure based on these studies.

Although the North Slope was building a strong tradition of exploration success both onshore and offshore in the late 1970s and early 1980s, it is an interesting historical note that the most spectacular failure in the history of petroleum exploration in Alaska also occurred offshore of the North Slope in 1983. The Mukluk Prospect offshore of the Colville River delta leased in 1982 for total high bids exceeding $1.5 billion, with the highest single bid being $227 million for one outer-continental-shelf tract. The Mukluk well was drilled in 1983 at a cost of $120 million, but then plugged and abandoned as a dry hole. It remains to this day the most expensive dry hole ever drilled (BLM and MMS, 1998).

Analysis of the 1990 photography reflected a total footprint of 10,146 acres, an increase of 2,031 acres from 1983 (Figure D-6). The most notable areas of increased development onshore occurred in the Kuparuk area. Offshore, Endicott is present, having been constructed in the winter of 1984-85. Endicott, like West Dock, was associated with large terrestrial and regional-scale marine monitoring programs. This study effectively replaced the Waterflood

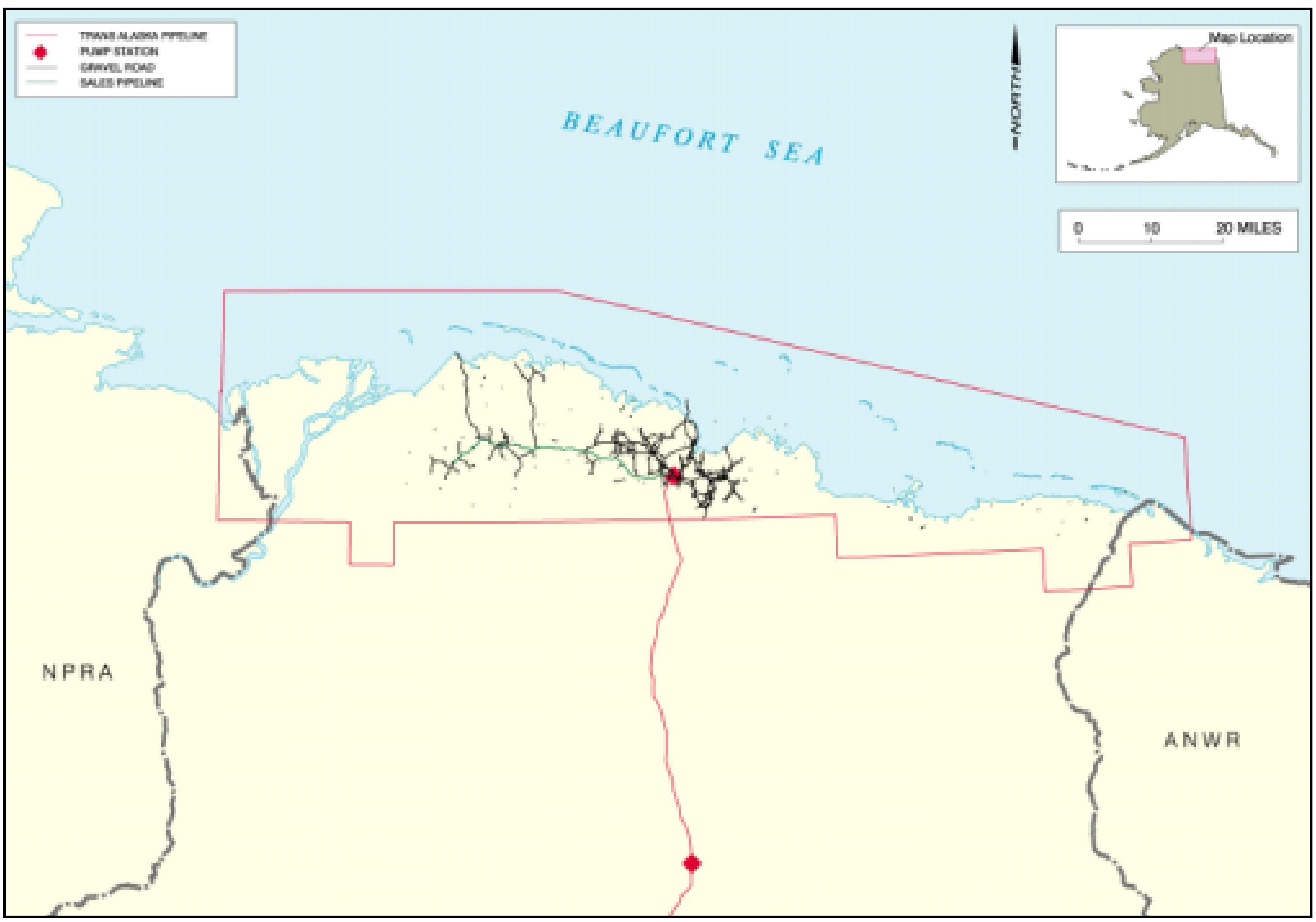

Figure D-5. *Alaska North Slope oil field development footprint in 1983.*

Monitoring Program but included the historical monitoring sites around West Dock along with new sites at Endicott. The oceanography and fish studies were conducted under the auspices of the USACE during 1985 to 1987; the marine studies also included monitoring the Boulder Patch kelp community during 1984 to 1991 for the Environmental Protection Agency (Martin and Gallaway, 1994).

Based on results of the 1985 to 1987 fish and oceanographic studies at Endicott (Hachmeister et al., 1991), the USACE determined in early 1988 that additional breaching of the causeway was required to mitigate perceived adverse effects on broad whitefish habitats and populations. This view was not accepted by the NSB and industry, and a new fish and oceanographic monitoring program was initiated (see Wilson and Gallaway, 1997 for a review). This program ran from 1988 through 1997. Additional breaching for the causeway was rejected as an option until 1991.

The agreement by industry to add 600 ft of breaching in the Endicott Causeway in the winter of 1993-94 as well as 600 ft of breaching at the base of West Dock in the winter of 1995-1996, was a negotiated settlement associated with the development of the Pt. McIntyre oil field drilled from West Dock. Consensus was never truly reached between regulatory agencies and industry on the effects of causeways and the need for beaching in these structures. However, there presently exists a wealth of published scientific information (over 40 articles) regarding these issues for the two causeways, and consensus is slowly emerging. There appears to have been good cause for additional breaching at the base of West Dock, but the additional breaching of Endicott was probably unwarranted (Fechhelm et al., 1999; Fechhelm, 1999).

The development footprint in 1999 was 10,653 acres, only about 500 acres larger than the 1990 footprint (compare Figure D-7 to D-6). The Badami and Alpine developments were the major new oil fields that had been or were near completion in 1999 as compared to 1990. Each was characterized by less than 200 acres in total footprint (184 and 140 acres, respectively), reflecting modern development methods as will be described below. By 1999, there were also some 241 miles of common carrier pipeline (Figure D-7), which had increased from 43 miles in 1983, and 114 miles in 1990.

Since development of the Prudhoe Bay oil field, meth-

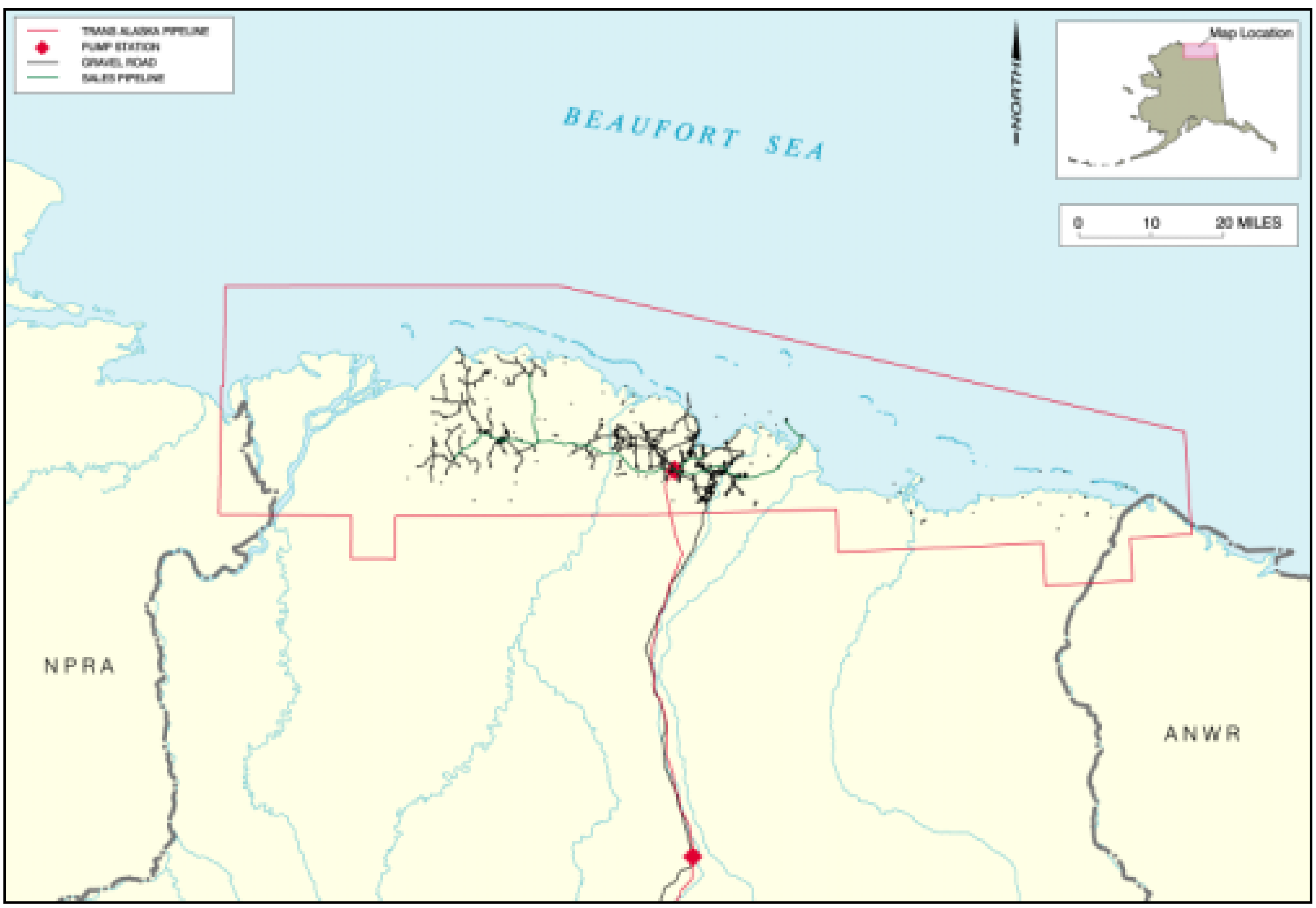

Figure D-6. *Alaska North Slope development footprint in 1990.*

ods of mitigating environmental impacts have focused on reducing the size of oil industry operations. The greatest reduction in the operational footprint has been achieved through the following methods (Gilders and Cronin, 2000):

- Consolidation of facilities.
- Use of ice roads to eliminate gravel roads next to pipelines, and elevating the pipelines 1.5 m above the tundra to allow free movement of wildlife.
- Directional drilling to reduce the number of gravel pads.
- Improved waste handling and the elimination of reserve pits for surface storage of drilling muds and cuttings (these drilling by-products are now reinjected into confining geological formations).

As detailed by Gilders and Cronin (2000), mitigation efforts have minimized changes to the environment that occur during an oil field development; this becomes apparent when past oil field developments are compared with new operations, as in the following examples for selected oil fields. Gravel fill in the Prudhoe Bay oil field directly covers 6,405 acres, or approximately 2.62 percent of the operating unit of 244,787 acres. It has been estimated that if the oil field was developed today, gravel would cover only 1,524 acres, or approximately 0.62 percent of the operating unit. Additionally, the Deadhorse service area (which covers approximately 746 acres of the oil field) would not exist; contractor facilities would be consolidated with oil company facilities, as they have been at the Kuparuk oil field. New field developments show a relatively high level of facility consolidation and technological advances that minimize surface coverage. The facilities servicing the Badami oil field, for example, cover approximately 183 acres (0.49 percent) of its 36,945-acre unit, and the Alpine oil field covers some 140 acres (0.17 percent) within its 80,464-acre unit.

Directional drilling technology permits drilling from a single well pad to reach locations up to 3 miles laterally from the drillsite. Other advances in drilling technology allow wells to be drilled as close together as 9 ft (compared to over 130 ft two decades ago), further reducing the size of the gravel pad needed to access a reservoir. Increased automation and remote-controlled operations have reduced the need for surface connections to all sites, thus eliminating some roads; and pipelines now routinely are built in

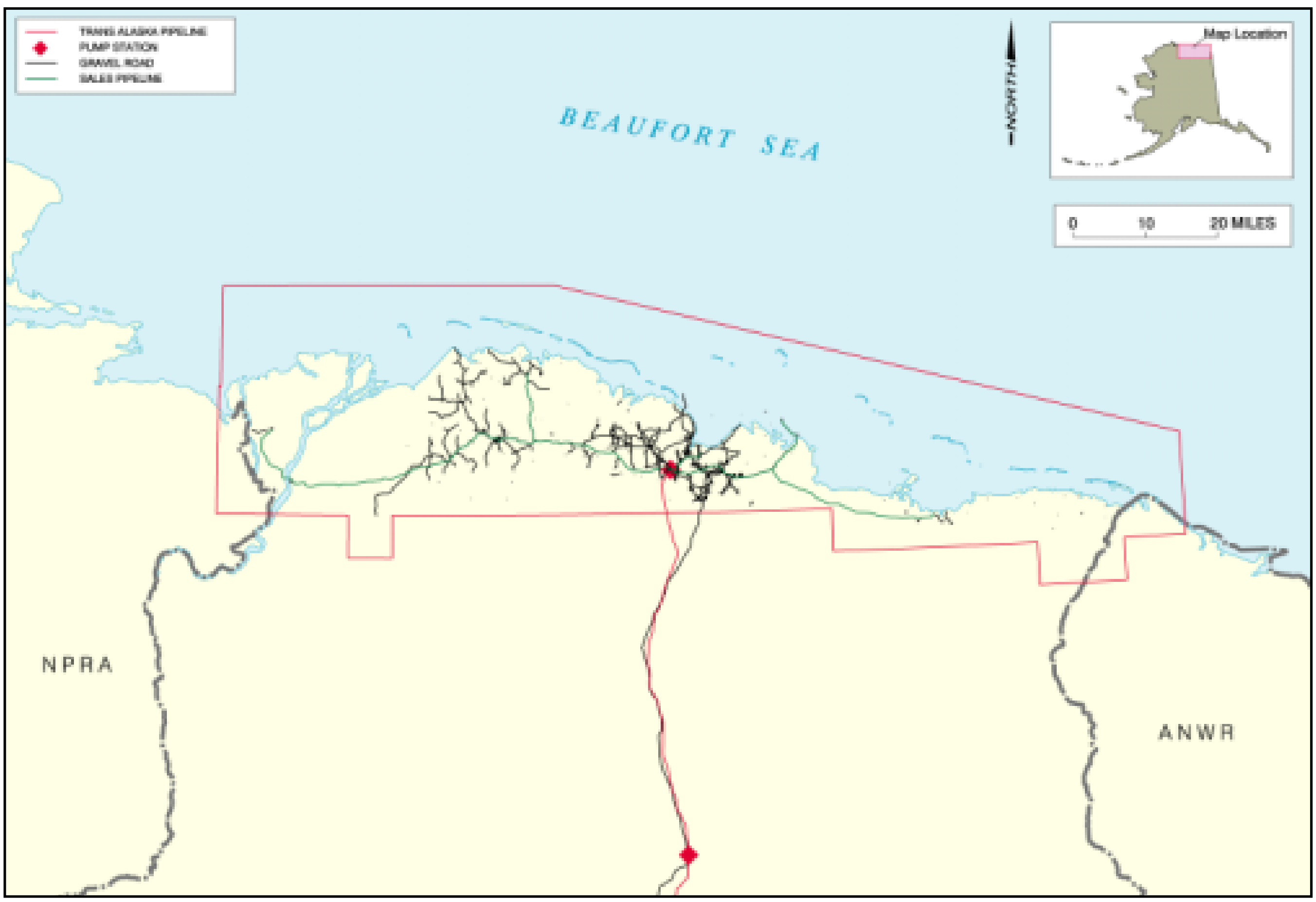

Figure D-7. *Alaska North Slope oil field development footprint in 1999.*

Table D-1. *Average rate of increase in ANS oil field development footprint, 1968-99.*

Oil Field	1968	1973	1983	1993	1999
Prudhoe Bay	72.4	2,322.3	6,093.1	6,367.1	6,406.1
Kuparuk	0.0	10.0	1,557.9	2,476.4	2,554.4
Milne Point	0.0	43.0	204.9	357.4	449.6
Lisburne	0.0	0.0	0.0	248.9	248.9
Endicott	0.0	0.0	74.1	511.6	511.6
Pt. McIntyre	0.0	0.0	0.0	0.0	31.3
Niakuk	0.0	0.0	0.0	0.0	24.3
Badami	0.0	58.3	80.9	80.9	183.8
Pt. Thomson	0.0	14.3	103.7	103.7	103.7
Alpine	0.0	0.0	0.0	0.0	139.5
Total in Acres	72.4	2,447.9	8,114.6	10,145.9	10,653.2

winter from ice roads and surveyed by air, eliminating additional roads and the associated tundra coverage (BP and ARCO, 1997).

Gilders and Cronin (2000) demonstrate the dramatic size difference between "A" Pad built in the 1970's and "P" Pad built in 1990. "P" Pad is 70 percent smaller than its predecessor. The assertions of Gilders and Cronin (2000) regarding mitigation are supported by the average rate of increase in the oil field footprint characteristic of 1968 to 1973, 1973 to 1983, 1983 to 1990, and 1990 to 1999 (Table D-1). Footprint expansion per year peaked at 567 acres per year between 1973 and 1983, but between 1990 and 1999, the rate of expansion declined by an order of magnitude (56 acres per year). As more fields reach the end of production and the footprint areas are reclaimed, a reversal in rate will occur. Given the minimal footprints associated with new developments, the rate of footprint decline will likely be much steeper than the historical rate of increase in footprint area.

Scientific studies accompany virtually every phase of North Slope oil-field operations, as shown in Table D-2 (Gilders and Cronin, 2000). In these oil fields, oil industry and regulatory agency researchers have conducted studies on a variety of species, habitat types, and other topics, including caribou, arctic foxes, brown bears, polar bears, fish and the marine ecosystem, Spectacled Eiders, Common Eiders, Black Brant, Snow Geese, Tundra Swans, shorebirds, wildlife use of disturbed sites (impoundments, gravel pads, peat roads), and the revegetation of abandoned gravel pads (see Truett and Johnson, 2000, for a thorough review).

Environmental studies conducted over the past three decades have provided direct input into the design of new oil fields. They have resulted in long-term data sets (in

Table D-2. *Scientific studies during ANS oil-field development phases.*

Development Phase	Focus of Environmental Studies
Exploration	Baseline studies: habitat and wildlife distribution
Preconstruction	Environmental assessment
	Identification of sensitive seasons and/or habitats
Construction	Avoidance of sensitive seasons and/or habitats
Postconstruction	Monitoring for potential impacts and disturbance
Postabandonment	Site assessment
	Rehabilitation: revegetation, creation of useful wildlife habitat

many cases collected over a decade or more) on such topics as fish, Snow Geese, shorebirds, Black Brant, caribou, and revegetation programs; these permit the establishment of science-based standards for operations. Such studies also help to quantify the level of environmental change that has occurred because of oil development.

As detailed in Truett and Johnson (2000) environmental programs conducted in the oil fields have demonstrated that fish and wildlife populations in the oil fields continue to rise and fall in response to naturally occurring pressures (such as predation and climate); in some cases they also respond to anthropogenic disturbance associated with development activities. Both birds and mammals have been documented using industry-disturbed sites (for example, loons and other waterfowl in impoundments, caribou on gravel pads and roads, Common Eiders on gravel causeways and islands, and shorebirds on abandoned peat roads). Arctic foxes frequently have been observed denning in and

around structures at oil field facilities, raising concerns that their numbers may be elevated in the oil fields because of readily available alternative food supplies and the presence of suitable denning sites in industrial facilities, although other naturally occurring factors may also be involved. Environmental-awareness training in the oil fields has focused on reducing the amount of food that foxes may obtain from field personnel (either by direct feeding or access to vehicles and dumpsters); artificial den sites also have been modified to prevent use by foxes.

In summary, new technologies involving reduced well spacing, elimination of reserve pits, directional drilling, winter maintenance and construction from ice pads and roads, aerial support, and the use of baseline and ongoing biological monitoring programs to facilitate decision-making have combined to reduce the areal impacts of development. Gravel pads can now be built 70 percent smaller than those built in the past; oil fields of considerable size can be accessed with an infrastructure much reduced from that previously required. Additionally, after more than three decades of oil development, the North Slope is one of the most intensively studied regions in North America and the best understood environment in the circumpolar Arctic.

D.3 Historical Synopsis: Trans Alaska Pipeline System

Shortly after the 1968 North Slope oil strike, a team of petroleum company engineers began to evaluate how to deliver the oil to markets. With the discovery, northern Alaska had become the energy storehouse for the nation, but only if this energy could be economically delivered to the marketplace. Virtually every conceivable approach was originally considered, including ice-breaking, double-hulled tankers, rail, tanker trucks, even under-ice transport by a fleet of submarine tankers (Gilders ,1997). Ultimately, a pipeline system was judged the only realistic alternative, and industry announced in 1969 plans to construct a pipeline from the North Slope to the year-round ice-free waters of Port of Valdez, 800 miles to the south. This transportation system (Figure D-8) ultimately became known as the

Figure D-8. *The Trans Alaska Pipeline System (TAPS).*

Trans Alaska Pipeline System. The original proposal called for an all-buried pipeline to be constructed beginning in 1970 and completed by 1972.

Gilders (1997) provides an excellent capsule of the early TAPS period. She notes that to some Alaskans, the coming pipeline was the essential link to an economically secure future and to personal opportunity, whereas to others the pipeline would be an incision that would irrevocably cut the wilderness in two, scarring it forever. Because TAPS would cross 800 miles of wildlands — most of them unprotected by specific federal legislation and many in an unresolved ownership status — the project immediately became the focus of industry, government, and special-interest groups, precipitating a period of national debate.

Gilders (1997) notes that the eventual construction of the pipeline was influenced by a remarkable sequence of landmark legislation. First, the National Environmental Policy Act of 1970 (NEPA) had a significant impact on the pipeline project. NEPA was passed on a tide of rising environmental concern, and its regulatory consequences would be far-reaching. The act required that an EIS be prepared for major activities requiring federal approval or funding, and that all reasonable alternatives be adequately studied. The act's intent was to seek a balance between protection and development and to ensure that environmental concerns were not ignored.

TAPS was the first major project reviewed under NEPA, and it was clear to all the stakeholders that regulatory precedents would be set. The result was an extended period of controversy, lawsuits, and technical reevaluations as industry and government officials alike sought a way through the unmapped territory of the new regulation.

In the year following NEPA, ANCSA created Alaska Native regional corporations and provided almost $1 billion and 44 million acres to Alaska Natives. As part of this legislation, Native land claims along the proposed pipeline right-of-way were resolved, making it possible for the federal and state governments to grant essential licenses and permits. While Congress and the regulatory agencies worked on the finer points of land claims, right-of-way restrictions, and environmental stipulations, Alyeska Pipeline Service Company was established by its owner companies as a nonprofit corporation to build, operate, and maintain the pipeline.

Through all of the delays, Alyeska's engineers continued to work on the design and specifications of the pipeline. This work was performed in coordination with experts of the USGS, the BLM, the USACE, the Alaska Department of Fish and Game (ADF&G), and other federal and state agencies. Data from pipeline field tests, simulation modeling, and an unprecedented detailed study of permafrost were slowly beginning to alter the shape of the project. Where permafrost was mapped as thaw-unstable, and in earthquake zones — both regions mainly south of the Brooks Range — plans for the buried pipeline were changing to an above-ground mode in which the pipeline would be supported on VSMs. The final EIS for TAPS was completed in 1972 (BLM, 1972).

In the meantime, the debate on the pipeline was further complicated by the emerging energy crisis of mid-1973. Under the impetus of this international development and the findings of the final FEIS, the Trans-Alaska Pipeline Authorization Act was passed by Congress and signed by President Nixon on November 16, 1973.

Early in 1974, Alyeska began moving 37,500 tons of equipment by air and truck to the Yukon River, then north by ice road. Construction of TAPS required that 73 million cubic yards of gravel be mined, stockpiled, hauled, and laid down. This meant designing and permitting hundreds of detailed gravel-mining plans. However, construction was finally underway.

Construction of the permanent Haul Road (now the Dalton Highway) was started on April 29, 1974, and completed on September 29 of that year. The first pipe was laid at the Tonsina River crossing of the Richardson Highway, 75 road miles north of Valdez, on March 27, 1975; the final pipeline weld was finished on May 31, 1977. Oil began flowing down the pipeline on June 20, 1977, and on August 1, the *ARCO Juneau* was the first tanker to leave Valdez carrying North Slope crude oil. After six years of controversy, an additional three years of construction, a workforce that ultimately totaled 70,000 people, and eight billion dollars, Alaska's oil was on its way to market.

TAPS and the Valdez Marine Terminal are described in detail in Sections 1 and 2. Some of the key attributes include that the footprint (10,432 acres or 16.3 sq. mi) of the TAPS is essentially the same as the footprint of the North Slope oil fields (10,653 acres). The 800-mi-long pipeline crosses 34 major rivers and some 800 smaller streams and three mountain ranges. The VMT covers an additional 1,000 acres including facilities for crude oil storage, ballast water treatment as well as fixed-platform and floating berths for oil tankers.

The baseline and environmental monitoring studies conducted along the pipeline by industry and agency researchers over the past 20 years have included water quality studies in Port Valdez; long-term revegetation experiments; fisheries investigations of water bodies crossed by or near the pipeline, and surveys of caribou, moose, bear, waterfowl, and other wildlife. The result is that the TAPS corri-

dor, like the North Slope oil fields, is one of the most intensively studied regions in Alaska.

Advances in engineering and construction techniques did not end when the pipeline was built. During the past 20 years, Alyeska's engineers have developed innovative advances in low-temperature engineering (Gilders, 1997). For example, a drag reducing agent (DRA) was initially injected into the pipeline at Pump Station 1 in July 1979, two years after startup. It was considered experimental at the time, and Alyeska pioneered its use to reduce drag in the oil stream. A long-chain polymer with the consistency of cold molasses, DRA dissolves in crude oil and lowers the oil's frictional resistance, increasing its flow rate through the pipeline. Use of this agent is now standard procedure.

With any steel pipe, the potential for corrosion is a significant concern (Gilders, 1997). Corrosion and stability studies are conducted along the length of the pipeline. In 1989, Alyeska began a heightened corrosion inspection program with newly developed "pigging" technology to identify problem areas. Pipeline "pigs" are mechanical devices that are passed through the oil stream — some to clean the walls of the pipeline, some to sense any deformation in the pipe, and others to detect signs of corrosion. Working with Japanese researchers, Alyeska developed the world's first ultrasonic corrosion-inspection pig. This pig measures and records the thickness of the pipeline's walls using ultrasonic transducers, identifying areas of possible corrosion before they become problems.

As Alyeska focused on its investigation of corrosion, it was an external event that soon dominated everyone's thoughts and actions. Just after midnight on Good Friday March 24, 1989, the *Exxon Valdez* strayed off course and ran aground on Bligh Reef in Prince William Sound. The ruptured supertanker spilled 240,000 barrels of oil; a total of over 10 million gallons. As the largest oil spill in North America, this event is discussed separately below.

The spill brought about changes designed to prevent future spills of this magnitude. The Ship Escort/Response Vessel System (SERVS) was established following the *Exxon Valdez* spill in response to an executive order by the Governor requiring every outbound tanker to be accompanied by two escort vessels until the tanker had left Prince William Sound. The primary goal of SERVS is to prevent oil spills; however, it also has more oil spill response equipment than any other entity in the Western Hemisphere, and it is the cornerstone of the Prince William Sound Tanker Spill Prevention and Response Plan (Gilders, 1997). With frequent drills, federal and state agencies gauge marine and shoreline response capabilities using challenging spill scenarios. Other drills are carried out along the pipeline corridor, with an emphasis on areas near rivers and streams.

As an integral part of SERVS, Alyeska has established a unique arrangement in which over 50 privately owned fishing vessels with trained personnel are on contract to provide immediate response support in case of a marine spill; several hundred additional vessels are also available to mobilize spill response equipment.

The 1989 oil spill also gave added impetus to the establishment of a coordinated regulatory body to oversee the planning, construction, operation, and maintenance of all Alaska pipelines and associated facilities. The Joint Pipeline Office (JPO) was established in 1990 and houses representatives from various federal and state agencies, including the U.S. Environmental Protection Agency, the BLM, the U.S. Coast Guard, the Alaska Department of Natural Resources, the Alaska Department of Environmental Conservation, and ADF&G (Gilders, 1997). Agency representatives conduct unannounced inspections of facilities, review permit applications, and oversee every aspect of pipeline operations in Alaska.

In 1991, Alyeska began what was to be the largest post-construction project in the pipeline's history; the Atigun reroute (Gilders, 1997). The reroute began as a result of information supplied by smart pigs used during the first years of the ongoing corrosion investigation. Discovery of corrosion in the buried section of pipe running through Atigun River valley led to the replacement of an 8.5-mile section of pipe in record time. Planning and scheduling for the reroute started in late 1989, construction began in January 1991, and the replacement pipeline was tied in to the system in August 1991. During the tie-in, oil flow was suspended for just 36 minutes. It was a great achievement in project management and execution, requiring careful timing and detailed coordination of some 300 contractor firms and 2,500 personnel. The project was selected as the Project Management Institute's International Project of the year in 1991 (Gilders, 1997).

D.4 Historical Synopsis: Prince William Sound and the *Exxon Valdez* Oil Spill

The supertanker *Exxon Valdez*, carrying a full cargo of over 1.25 million barrels of North Slope crude oil, went off course before midnight on 24 March 1989 after leaving the Valdez Marine Terminal. Shortly thereafter, the ship ran aground on Bligh Reef in northeastern Prince William Sound (PWS). On the order of 257,000 barrels of oil was spilled, or over 10 million gallons. With this event, the

Exxon Valdez Oil Spill (EVOS) was established as the largest oil spill in North America.

The spill was a tragic accident. Exxon immediately took responsibility and committed to cleanup the spill. At the time of the spill, adequate spill response resources were not readily available in Alaska, and they could not be mobilized rapidly enough to contain the spill. Exxon brought in the necessary equipment and people and ultimately spent $2.2 billion on the cleanup. All cleanup activities were conducted under the direction of the Federal On-Scene Coordinator (U.S. Coast Guard) and continued until the U.S. Coast Guard and the State of Alaska declared the cleanup complete in 1992. To mitigate economic impacts of the spill, Exxon set up a claims program within days of the spill to compensate people and businesses that suffered spill-related economic losses. Over $300 million were paid to over 11,000 people and businesses. In 1994 an Anchorage court ruled that the claims program had compensated virtually all the damage claims of individuals and businesses (ExxonMobil, 2000). In 1991, Exxon settled natural resource damage and other claims with the federal government and Alaska for approximately $1 billion (*Exxon Valdez* Oil Spill Trustee Council, 2000). Cleanup activities, environmental impacts, and the status of recovery are discussed below.

At the time of the spill, the PWS environment was generally characterized as "pristine." However, considerable oil spillage had occurred in this region historically, notably during World War II and as a result of the great Alaska earthquake of 1964. The 1964 earthquake dramatically altered vast areas within the intertidal zone by vertically displacing areas of up to 38 feet (Hanna, 1971). Oil and asphalt storage tanks at Valdez and Whittier were ruptured and spilled into the Sound. Thus, the Sound was contaminated with oil residues 25 years before the EVOS, and these residues were still present at the time of the spill (Carlson and Kvenvolden, 1996).

EVOS occurred under calm winds, and the oil spread slowly southwest. Within three days, however, a northerly gale blew the oil slick beyond any hope of containment. The range of the moving oil slick and the dispersal timing are shown in Bernatowicz et al. (1996).

The storm thoroughly mixed the initial slick with subsurface seawater by wave action, promoting solution of sparingly soluble petroleum hydrocarbons into the seawater. Trace amounts of the polynuclear aromatic hydrocarbon (PAH) component of the oil were measured at depths to 15 ft. Subsequently, concentrations of PAHs were highest near heavily oiled beaches. Although PAHs were readily detectable, Short and Harris (1996) noted that concentrations of PAHs were well below levels generally considered toxic to marine fauna. They also noted, however, that PAHs were available to subsurface marine fauna during the first few weeks after the oil spill, especially in nearshore, near-surface waters that they considered to be particularly productive biologically.

By May 1989 — two to three months after the spill — most of the floating oil had either been removed by skimmers, had left the coastal area, evaporated, or degraded, or was stranded on the shoreline (Wolfe et al., 1994). Estimates of the amount of oiled shoreline vary. Exxon Corporation (1992) reported oil on at least 2,090 of the 5,470 km surveyed in 1989, or about 15 percent of the area's 14,480 km, whereas Michel and Hayes (1991) reported some 5,221 km were oiled to some degree, of which 912 km were moderately to heavily oiled. Regardless of the exact measurement, both oiled and unoiled shorelines were home to at least 400 species of marine plants and animals and became the focus of subsequent treatment and cleanup.

As reported by Mearns (1996), the strategy for treating shorelines in 1989 centered on removing as much of the oil as quickly as possible while minimizing impacts to surviving resources. Exxon Production Research Corporation (1990) stated that "the treatment approach was to remove, contain and collect the oil from the shoreline with the least environmental impact, particularly to keep oil off the lower intertidal zone and to avoid oiling other areas." To underscore the drive for an effective response, the U.S. Coast Guard Commandant "made it clear that the administration expected an aggressive and highly visible shoreline cleanup effort" (USCG, 1993).

The shoreline cleanup effort was not only aggressive and highly visible, but diverse. Mearns (1996) provides a detailed synopsis of the treatment methods and a description of the strategy for treating shorelines. He notes that a wide range of methods — from manual pickup and hand-wiping to high-pressure washing — was used to remove oil from the shoreline. In 1989, six task forces, each composed of approximately 1,000 personnel, and more than 100 vessels were deployed in different areas. Several reports discuss operational aspects in more detail (Exxon Production Research Corporation, 1990; Teal, 1991).

Manual treatment included picking up tar balls and pooled oil using absorbent materials; tilling, raking, and shoveling with hand tools; removing oiled debris and tar mats; and cutting and removing seaweed. These efforts were supplemented by mechanical treatment used in 1990 and 1991 to expose buried oil in boulder-cobble beaches. Mechanical treatment involved use of backhoes, tractors, front-end loaders, and other equipment to scoop, dig, and

redistribute beach material. At some sites, tractors pulled steel cable tines to agitate sediment, releasing oil ahead of rising tides (Piper, 1993). In 1990 and 1991, berm relocation was used to open high, intertidal storm berms to expose buried oil and accelerate its weathering (Michel and Hayes 1991). Tractors were also used to dig and flatten storm berms and redistribute the cobble to the mid-intertidal zone. Oil in the open berms was treated with slow-release nutrient capsules in an attempt to accelerate degradation.

Washing coated and remaining pooled oil off rocky surfaces involved use of cold to hot seawater, under low to high pressure, to conduct high-volume flushing (deluge or flooding) of the upper beaches (Exxon Production Research Corporation, 1990; Teal, 1991). For the washing operations, Exxon provided an array of equipment and vessels including more than 600 commercial pressure-washers and 60 landing-craft vessels that supplied either cold water for deluge and hand-held fire hoses or hot water for fire hoses. Generally, multiple hand-held hoses fitted with nozzles were connected in series to delivery barge pumps. In addition, 13 maxi-barges supplied 68°C water through fire hoses mounted on man lifts or cranes to wash vertical rock faces. Finally, 13 Omni-barges were built that supplied 68°C water via spray heads mounted on an articulating crane.

In 1990, a proposal was developed to remove some boulder-cobble beaches, wash the material in a large, specially designed offshore rock washer machine, and then replace the material; the proposal was reviewed in detail and rejected (USCG, 1993).

Bioremediation, to accelerate the chemical degradation of oil not otherwise removed by other treatments, involved application of slow-release pellets containing nitrogen and phosphorus fertilizer, and spraying a liquid oleophilic, urea-based fertilizer (Exxon Production Research Corporation, 1990; Bragg et al., 1992). Despite considerable controversy about results of effectiveness tests and toxicity (Hoff, 1993; Piper, 1993), bioremediation in the form of nutrient applications was approved for use in 1989-92.

Chemicals other than the bioremediation materials were not approved for use during 1989-91, but they were tested. During 1989, at least three sets of shoreline experiments were done to test cleaning agents and dispersants at sites on Disk, Knight, and Smith islands in PWS (Piper, 1993).

The spill was accompanied by large-scale mortality of seabirds and mammals attributable to oiling. Because they rely on the insulating properties of their fur or plumage, some mammals (e.g., otters) and nearly all seabirds are vulnerable to mortality from oiling. In this instance, oiling of the fur and feathers leads quickly to heat loss to the cold water and death due to hypothermia. Additionally, inhalation of fumes, grooming of oiled pelts and plumage, and absorption of oil through the skin may have contributed to the observed levels of acute mortality. Some 36,000 seabird carcasses were recovered after the spill, along with 994 otters (871 carcasses plus 123 deaths at rehabilitation centers). In contrast, only 14 dead seals were recovered. Pinnipeds and cetaceans have layers of subdermal blubber to provide insulation and rely less on their fur.

Loughlin (1994), Wells et al. (1995), and Rice et al. (1996) addressed the acute effects of the EVOS. The consensus of findings was that (1) the EVOS was of sufficient magnitude to be classified as an environmental disaster, but that (2) the estimates of the magnitude of the impact to area resources were very uncertain. Even following extensive research in the 11 years since the spill, there is a high degree of contention regarding the actual level of damage, the recovery standards, and the extent of recovery.

Hilborn (1996) noted that tens of millions of dollars were spent to determine the damage caused by the spill and that most were aimed at detecting population-level impacts on the invertebrates, fishes, birds, and mammals in the spill area. He observed there was a widespread feeling that the studies were not nearly as conclusive as many had hoped and that this had raised concern about the ability to detect oil spill impacts by existing methods. He evaluated five ways to detect population-level impacts, including four that were used predominantly in the EVOS assessments. They were body counts, pre- versus post-spill comparisons, oiled versus non-oiled comparisons of abundance, and oiled versus non-oiled comparisons of vital rates (e.g., growth, egg survival, etc.).

Body counts were available for some bird and marine mammal species. However, body counts by themselves do not provide evidence of population-level impact (Hilborn, 1996). They must be considered in relation to population size, natality, mortality rate, and behavior. For example, even though 902 bald eagles were killed by the spill (11 percent of the estimated population), differences between pre- and post-spill abundance could not be detected. This could be either a result of the high variance in the surveys, or that a one-time mortality was not detectable given year-to-year variation in recruitment and survival, or it could result from compensatory changes in births and deaths.

Any assessment of population-level impacts using body counts needs to be supported by either direct comparisons of pre- and post-spill abundance, oiled versus non-oiled comparisons of abundance, or a population dynamics model that accounts for recruitment and survival (Hilborn, 1996). When pre-spill abundance surveys are available, comparison of pre- and post-spill numbers can be used to assess the change in population. The statistical power of such comparison will depend on the reliability of the census method, the natural variability of the population, and the magnitude of change induced by the spill. This method clearly cannot be used when no pre-spill abundance data are available, as was the case with many fish species affected by the *Exxon Valdez* oil spill. However, pre- and post-spill comparisons were effective in showing changes for many species, including sea otters (Garrott et al., 1993), and pigeon guillemots (Oakley and Kuletz, 1996).

Even when pre-spill data are available, the comparison may be of little value (Hilborn, 1996) Pink salmon, for instance, show very high year-to-year variability, and unless a spill is catastrophic, there is little chance of detecting its impact. In fact, pre- and post-spill comparisons may be deceiving. Geiger et al. (1996) estimated a loss of several million pink salmon because of oiling in 1990, even though the run of pink salmon in 1990 was the largest in history.

Likewise, a significant decline in abundance after a spill is not necessarily evidence of an oil impact (Hilborn, 1996). Populations often vary in abundance, and without evidence of a mechanism for oil impact, such as direct body counts or oiled and non-oiled comparisons, a decline in abundance is not strong proof of an impact of the spill. The disappearance of a number of killer whales from a single pod could be considered evidence of an oil impact, but without supporting mechanisms this evidence of a spill impact is subject to question.

Probably the most common technique used in assessing damage from the *Exxon Valdez* oil spill was post-spill comparison of the abundance of a species in oiled sites to its abundance in non-oiled sites. This technique formed the basis of most intertidal and subtidal assessments (Collier et al., 1996; Highsmith et al., 1996; Jewett et al., 1996). As with pre- and post-spill comparisons, the power of this method depends on the reliability of the census method, the natural variability from site to site, and the magnitude of the change induced by the spill. A key problem is the fact that beaches were oiled as a result of physical processes, whereas in a designed experiment they would have been oiled by random assignment. Thus, post-spill differences may reflect underlying or pre-existing habitat differences rather than the impacts of oiling (Hilborn, 1996). This non-randomization of treatments is in itself not correctable by post-spill analysis, but most investigators attempt to determine if there are other differences between sites and have generally tried to choose control sites that are, to the human observer, as comparable as possible to the treatment sites.

The most convincing data from oiled versus non-oiled comparisons occur when the oiled site recovers to the same abundance as the non-oiled site during the course of the post-spill evaluation (Hilborn, 1996). This set of circumstances strongly suggests that the observed differences immediately after the spill were caused by an oil impact.

An alternative approach to comparing abundance is to measure life history parameters in oiled and non-oiled sites. The estimated parameters are used in a life history model to estimate population-level impacts. The differences in growth observed in oiled versus non-oiled sites (Hepler et al., 1996), and in egg survival for pink salmon (Bue et al., 1996), are examples of how this approach was used to provide evidence of damage even where population-level damage was difficult to measure directly. This approach is weak because it depends on the validity of the population dynamics models used, and in most cases the extent of damage depends on the level of compensatory mortality in the life history after the damage. If there is high density-dependent mortality, the population-level impacts will be much less than the mortality caused by oiling. The potential for compensatory mortality significantly decreases the power of this approach.

Comparison of vital rates between oiled and non-oiled sites also suffers from the weaknesses of non-randomization of treatments discussed above. Again, if vital rates in oiled sites recover to the levels of vital rates in non-oiled sites, the argument that the differences were caused by oil effects rather than pre-existing is much stronger. The continued differences in pink salmon egg survival between oiled and non-oiled sites (Bue et al., 1996) need a more complex mechanism to explain the oil impact and weaken the argument that the differences are attributable to oil.

The assessments of Hilborn (1996) abstracted in the above paragraphs show there is scientific basis for the contention regarding estimates of the magnitude of damage and the status of recovery. The nature of the data allow for legitimate differences in scientific opinion in this regard, and at some point, the arguments transcend what can be addressed by science. Each year, the *Exxon Valdez* Oil Spill Trustee Council provides estimates of the magnitude of the damage and the standard of recovery.

Their opinions regarding damage follow Spies et al. (1996) — namely, that the EVOS resulted in:

- The direct mortality of an estimated 3,500 to 5,500 sea otters, 300 harbor seals, and 250,000 or more birds of 90 species, including Common Murres, and Thick-billed Murres, Bald Eagles, Marbled Murrelets, Kittlitz's Murrelets, Ancient Murrelets, Pigeon Guillemots, two species of puffins, four spe-

cies of loons, and three species of cormorants;
- Significant reductions in the populations of many intertidal organisms, including algae, barnacles, limpets, amphipods, isopods, worms, and fishes, over a very extensive area from PWS to the Kodiak Archipelago and the Alaska Peninsula;
- Significant reductions in populations of subtidal organisms in PWS;
- Increased mortality of Pacific herring eggs in 1989 and increased incidences of aberrations in herring larvae during 1989 and 1990;
- Increased mortality of wild-stock pink salmon eggs in oiled stream beds in 1989-92 and abnormal fry and reduced juvenile growth in 1989, which may have resulted in loss of nearly 2 million pink salmon from the 1990 harvest;
- Poorer growth of Dolly Varden and cutthroat trout for 2 years following the spill;
- Increased vandalism of archaeological resources during the cleanup; and
- Reduced use of subsistence resources.

Spies et al. (1996) note that many of the estimates of injury were very uncertain and that they accrued from a variety of direct and indirect effects.

At present, the *Exxon Valdez* Oil Spill Trustee Council (2000) asserts that of the 28 species/communities/resources injured by the spill, two species (Bald Eagle and river otter) have fully recovered, 13 ecosystem components (species and communities) are exhibiting substantive progress towards the recovery objective, eight species are exhibiting little or no clear improvement since spill injuries occurred, and five system components cannot be characterized in terms of recovery. Further, recreation and tourism, commercial fishing, passive uses, and subsistence uses of the area are considered by the *Exxon Valdez* Oil Spill Trustee Council (2000) to be recovering. The *Exxon Valdez* Oil Spill Trustee Council (2000) notes that it is not clear, however, what role "oil" plays in the inability of some populations to bounce back and that as time passes, separating natural change from oil-spill impacts will become even more difficult.

Exxon and many independent scientists consider the Trustees' conclusions about the status of recovery in Prince William Sound misleading (ExxonMobil, 2000). Exxon suggests that the state of recovery of the Prince William Sound ecosystem cannot be based on the status of the few species investigated by the Trustees while thousands of other species that populate the spill area were either not impacted or were impacted but recovered rapidly. There are also disagreements on the definition of "recovery." The Trustees define "species recovery" as a return to, or increase in, pre-spill population numbers, whereas to many scientists, "recovery" means that a healthy biological community has been re-established with all expected plants and animals present and functioning normally. Under the latter definition, recovery has already occurred, whereas under the Trustees' definition, recovery of certain species might never occur because some populations (e.g., harbor seal, murrelets) were in decline long before EVOS, and a reversal of the trend is questionable even if the spill had not occurred.

The settlement among the State of Alaska, the U.S. government and Exxon was approved by the U.S. District Court on October 9, 1991. It resolved various criminal charges against Exxon, as well as civil claims brought by the federal and state governments for recovery of natural resource damages resulting from the oil spill. Exxon was fined $150 million, the largest fine ever imposed for an environmental crime. The court, however, forgave $125 million of the fine in recognition of Exxon's cooperation in cleaning up the spill and paying certain private claims. Of the remaining $25 million, $12 million went to the North American Wetlands Conservation Fund and $13 million went to the National Victims of Crime Fund. Exxon also agreed to pay $100 million as restitution for the injuries to fish, wildlife, and lands in the spill region (evenly split between the federal and state governments) and $900 million over 10 years as a civil settlement. Exxon also has agreed to provide an additional $100 million if unanticipated losses are discovered.

The *Exxon Valdez* Oil Spill Trustee Council was formed to oversee restoration of the injured ecosystem through use of the $900 million civil settlement. The council consists of three state and three federal trustees. The council adopted a restoration plan in 1994 after an extensive public process including meetings in 22 spill-area communities, as well as in Anchorage, Fairbanks, and Juneau. More than 2,000 people participated in the meetings or sent in written comments. The five-part plan designates $180 million to research, monitoring, and restoration; $392 million for habitat acquisition and protection; $108 million into a savings account to generate long-term funding for restoration after the final payment from Exxon; and $31 million for management and administration including publications and information transfer. The focus of present and future research has been on ecosystem studies and modeling.

Summary

The EVOS was a tragic accident which caused immediate and substantial disruption or harm to the environment, wildlife, and people of the spill area. Exxon immediately accepted responsibility and set out to clean up the oil. Cleanup under the direction of the U.S. Coast Guard continued until 1992 when both the U.S. Coast Guard and the State of Alaska declared the cleanup complete. Exxon spent over $2.2 billion on the cleanup. To mitigate impacts on the people and communities, Exxon set up a claims program within days of the accident to compensate those damaged by the spill and paid over $300 million to 11,000 individuals and businesses. An Anchorage court ruled in 1994 that Exxon's voluntary payments had already compensated virtually all claims. Exxon settled natural resource damage and other claims with Alaska and the federal government in 1991 for approximately $1 billion.

Consensus exists that the EVOS had an immediate and substantial impact on the environment, wildlife and people in the spill area. The extent of initial injury and the status of recovery from the spill are still being debated; however, the following facts are relevant to cumulative effects:

- There are currently no know impediments to the normal use of Prince William Sound and other areas affected by the spill by people or wildlife.
- All cities and villages in the spill area are functioning essentially as they were before the spill.
- Commercial fishing was closed in 1989 as a result of the spill, but it was reopened in 1990 and record and near record harvests of all commercially important species have occurred since the spill (ExxonMobil, 2000).
- Subsistence harvests by Alaska Natives were disrupted by the spill and cleanup but have subsequently rebounded to pre-spill levels.
- Tourism and recreational use of Prince William Sound has increased to significantly greater levels than prior to the spill.
- Trustees claim 13 of 28 species, communities or resources investigated are not recovering or recovery is unknown (*Exxon Valdez* Oil Spill Trustee Council, 2000) while Exxon and many independent scientists assert that the Trustees' claims are misleading because of a flawed definition of recovery and the fact that thousands of other species in Prince William Sound were not impacted by the spill or were impacted and recovered quickly (ExxonMobil, 2000). Regardless of the debate about recovery, no one has claimed that any species is missing that should be in PWS or that any species was permanently injured or decimated by the spill.

Other large spills, some much larger than EVOS, have been studied and characterized by a Congressional Research Services Report for Congress (Mielke, 1990). The report concluded that "past spills have not been long-lived events." Major ecological impacts occur at the time of the spill or within months of it. Longer term ecological impacts have proved fairly insignificant. Effects from EVOS appear to be following the same trends.

References - Appendix D

Ambrosius, K.J. 2000. Area Covered by North Slope Oil Field Development. Memorandum from Aeromap U.S. Inc. to R. Jakubczak, BP Exploration (Alaska) Inc. February 29, 2000.

Batzli, G.O., and J. Brown. 1976. Rate of Influence of Grazing on Arctic Tundra Ecosystems. *Arctic Bull*. 2(9):153-160.

Bernatowicz, J.A., P.F. Schempf, and T.D. Bowman. 1996. Bald Eagle Productivity in South-central Alaska in 1989 and 1990 After the *Exxon Valdez* Oil Spill. Pages 785–797 *in* S. D. Rice, R. B. Spies, D. A. Wolfe, and B. A. Wright (eds.). Proceedings of the *Exxon Valdez* Oil Spill Symposium. American Fisheries Society Symposium No. 18. American Fisheries Society, Bethesda, Maryland.

BLM. 1972. Final Environmental Impact Statement, Proposed Trans-Alaska Pipeline. Prepared for the Federal Task Force on Alaskan Oil Development by the U.S. Bureau of Land Management, Alaska Office, Anchorage, Alaska.

BLM and MMS. 1998. Northeast National Petroleum Reserve-Alaska Final Integrated Activity Plan/Environmental Impact Statement. Volumes 1 and 2. Prepared by U.S. Bureau of Land Management and U.S. Minerals Management Service. General Printing Office, Washington, D.C.

BP and ARCO. 1997. Arctic Oil: Energy for Today and Tomorrow. Prepared by BP Exploration (Alaska) Inc., and ARCO Alaska, Inc., Anchorage, Alaska.

Bragg, J.R., R.C. Prince, J.B. Wilkinson, and R.M. Atlas. 1992. Bioremediation for Shoreline Cleanup Following the 1989 Alaska Oil Spill. Exxon Research and Engineering Company, Florham Park, New Jersey.

Brown, J., P.C. Miller, L.L. Tieszen, and F.L. Bunnell (eds). 1980. An Arctic Ecosystem: the Coastal Tundra at Barrow, Alaska. Dowden, Hutchinson, and Ross, Stroudsburg, Pennsylvania.

Bue, B.G., S. Sharr, S.D. Moffitt, and A.K. Craig. 1996. Effects of the *Exxon Valdez* Oil Spill on Pink Salmon Embryos and Preemergent Fry. Pages 619-627 *in* S.D.

Rice, R.B. Spies, D.A. Wolfe, and B.A. Wright, editors. Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries Society Symposium 18. American Fisheries Society, Bethesda, Maryland.

Carlson, P.R., and K.A. Kvenvolden. 1996. Tracking *Exxon Valdez* Oil from Beach to Deepwater Sediments of Prince William Sound, Alaska. Pages 109-120 *in* S.D. Rice, R.B. Spies, D.A. Wolfe, and B.A. Wright, editors. Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries Society Symposium 18. American Fisheries Society, Bethesda, Maryland.

Collier, T.K., C.A. Krone, M.M. Krahn, J.E. Stein, S.-L. Chan, and U. Varanasi. 1996. Petroleum Exposure and Associated Biochemical Effects in Subtidal Fish After the *Exxon Valdez* Oil Spill. Pages 671-683 *in* S.D. Rice, R.B. Spies, D.A. Wolfe, and B.A. Wright, editors. Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries Society Symposium 18. American Fisheries Society, Bethesda, Maryland.

Colonell, J.M. 1990. What is a Causeway? Pages 11-14 in: *A Synthesis of Environmental Information on Causeways in the Nearshore Beaufort Sea, Alaska*. Workshop Proceedings. OCS Study MMS 89-0038. Anchorage, Alaska.

Colonell, J.M., and B.J. Gallaway. 1990. An Assessment of Marine Environmental Impacts of West Dock Causeway. Final Report for Prudhoe Bay Unit owners represented by ARCO Alaska, Inc., Anchorage, Alaska.

Ebersole, J.J. 1987. Short-term Vegetation Recovery at an Alaskan Arctic Coastal Plain Site. *Arctic and Alpine Research*. 19:442-450.

Engelmann, R.J., 1976. Environmental Assessment Research in Alaska: an Overview. *Sci. Alaska*. 27:83-108.

Exxon Valdez Oil Spill Trustee Council. 2000. *Exxon Valdez* Oil Spill Trustee Council 2000 status report. Anchorage, Alaska.

Exxon Production Research Corporation. 1990. Valdez Oil Spill Technology. 1989 Operations. Houston, Texas.

Exxon Corporation. 1992. Three Years After. Exxon Corporation. Houston, Texas.

ExxonMobil. 2000. Exxon Statements: Valdez Ten-year Anniversary. From web site: http://www.exxon.mobil.com/news/publications.

Fechhelm, R.G. 1999. The Effect of New Breaching in a Prudhoe Bay Causeway on the Coastal Distribution of Humpback Whitefish. *Arctic.* 52:386-394.

Fechhelm, R.G., P.S. Fitzgerald, B.J. Gallaway, W.J. Wilson, and W.B. Griffiths. 1999. Prudhoe Bay Causeways and the Summer Coastal Movements of Arctic Cisco and Least Cisco. *Arctic*. 52(2):139-151.

Garner, G.W., and P.E. Reynolds (eds). 1986. Arctic National Wildlife Refuge Coastal Plain Resource Assessment. Final Report Baseline Study of the Fish, Wildlife, and their Habitats. U.S. Fish and Wildlife Service. Anchorage, Alaska.

Garrott, R.A., L.L. Eberhardt, and D.M. Burn. 1993. Mortality of Sea Otters in Prince William Sound Following the *Exxon Valdez* Oil Spill. *Marine Mammal Science*. 9:343-359.

Geiger, H.J., B.G. Bue, S. Sharr, A. C. Wertheimer, and T.M. Willette. 1996. A Life History Approach to Estimating Damage to Prince William Sound Pink Salmon Caused By the *Exxon Valdez* Oil Spill. Pages 487-498 *in*: S.D. Rice, R.B. Spies, D.A. Wolfe, and B.A. Wright, editors. Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries Society Symposium 18. American Fisheries Society, Bethesda, Maryland.

Gilders, MA. 1997. Crossing Alaska. Essays by Michelle A. Gilders. Graphic Arts Center Publishing Company. Portland, Oregon.

Gilders, M.A., and M.A. Cronin. 2000. North Slope Oil Field Development. *In: The Natural History of an Arctic Oil Field.* Academic Press, San Diego, California.

Hachmeister, L.E., D.R. Glass, and T.C. Cannon. 1991. Effects of Solid-gravel Causeways on the Coastal Central Beaufort Sea Environment. American Fisheries Society Symposium 11:81-96.

Hanley, P.T., J.E. Hemming, J.W. Morsell, A. Morehouse, L.E. Leask, and G.S. Harrison. 1981. Natural Resource Protection and Petroleum Development in Alaska. U.S. Fish and Wildlife Service. Report no. FWS/OBS-80/22.

Hanna, G.D. 1971. The Great Alaska Earthquake of 1964. In: *Biology*. National Academy of Sciences, Washington, D.C.

Hepler, K.R., P.A. Hanse, and D.R. Bernard. 1996. Impact of Oil Spilled from the *Exxon Valdez* on Survival and Growth of Dolly Varden and Cutthroat Trout in Prince William Sound. Pages 645-658 *in* S.D. Rice, R.B. Spies, D.A. Wolfe, and B.A. Wright, editors. Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries Society Symposium 18. American Fisheries Society, Bethesda, Maryland.

Highsmith, R.C., T.L. Rucker, M.S. Stekoll, S.M. Saupe, M.R. Lindeberg, R.N. Jenne, and W.P. Erickson. 1996. Impact of the *Exxon Valdez* Oil Spill on Intertidal Biota. Pages 212-238 *in*: S.D. Rice, R.B. Spies, D.A. Wolfe, and B.A. Wright, editors. Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries

Society Symposium 18. American Fisheries Society, Bethesda, Maryland.

Hilborn, R. 1996. Detecting Population Impacts from Oil Spills: a Comparison of Methodologies. Pages 639-644 *in*: S.D. Rice, R.B. Spies, D.A. Wolfe, and B.A. Wright, editors. Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries Society Symposium 18. American Fisheries Society, Bethesda, Maryland.

Hoff, R. 1993. Bioremediation: an Overview of its Development and Use for Oil Spill Cleanup. *Marine Pollution Bulletin* 26(9):476-481.

Jewett, S.C., T.A. Dean, and D.R. Laur. 1996. Effects of the *Exxon Valdez* Oil Spill on Benthic Invertebrates in an Oxygen-deficient Embayment in Prince William Sound, Alaska. Pages 440-447 *in* S.D. Rice, R.B. Spies, D.A. Wolfe, and B.A. Wright, editors. Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries Society Symposium 18. American Fisheries Society, Bethesda, Maryland.

Lawson, D.E., J. Brown, K.R. Everett, A.W. Johnson, V. Komarkova, B.M. Murray, D.F. Murray, and P.J. Webber. 1978. Tundra Disturbances and Recovery Following the 1949 Exploratory Drilling, Fish Creek, Alaska. Report 78-28. U.S. Army Cold Regions Research Engineering Laboratory, Hanover, New Hampshire.

Libbey, D. 1988-1989. The 1981 Excavation at the Utqiagvik Archaeological Site, Barrow, Alaska, Volume I. In: H.S. Hall, Jr., editor. *Utqiagvik Excavations*. North Slope Borough Commission on Iñupiat History, Language, and Culture. Barrow, Alaska.

Loughlin, T. R. (ed). 1994. Marine Mammals and the *Exxon Valdez*. Academic Press, San Diego, California.

Martin, G.C. 1921. Preliminary Report on Petroleum in Alaska. U.S. Geological Survey. Washington, D.C.

Martin, L.R., and B.J. Gallaway. 1994. The Effects of the Endicott Development Project on the Boulder Patch, an Arctic Kelp Community in Stefansson Sound, Alaska. *Arctic.* 147:54-64.

McCabe, T.R. 1994. Assessing Values of Arctic Wildlife and Habitat Subject to Potential Petroleum Development. In: *Landscape Urban Planning.* 28:33-45.

Mearns, A.J. 1996. *Exxon Valdez* Shoreline Treatment and Operations: Implications for Response, Assessment, Monitoring and Research. Pages 309-328 *in* S.D. Rice, R.B. Spies, D.A. Wolfe, and B.A. Wright, editors. Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries Society Symposium 18. American Fisheries Society, Bethesda, Maryland.

Meehan, R.H. 1980. The Design of a Monitoring Program in the Arctic and its Incorporation into an EIS. Pages 137-144 in: Proceedings of the Sixth Annual Conference on Utilization of Science in the Decision Making Process. The Coastal Society, Arlington, Virginia.

Michel, J., and M.O. Hayes. 1991. Geomorphological Controls on the Persistence of Shoreline Contamination from the *Exxon Valdez* Oil Spill. Report to the National Oceanic and Atmospheric Administration Hazardous Materials Response Branch, Seattle, Washington.

Mielke, J.E. 1990. Oil in the Ocean: the Short- and Long-term Impacts of a Spill. Congressional Research Service, Library of Congress, Washington, D.C. Publication No. 90-358 SPR.

NSB. 1998. Letter dated March 12, 1998, from North Slope Borough, Office of the Mayor, to Bruce Babbitt, Secretary of the Interior. Comments on Draft Northeast National Petroleum Reserve-Alaska Final Integrated Activity Plan/ Environmental Impact Statement. 12 pp.

Oakley, K.L., and K.J. Kuletz. 1996. Population, Reproduction, and Foraging of Pigeon Guillemots at Naked Island, Alaska, Before and After the *Exxon Valdez* Oil Spill. Pages 759–769 *in:* S.D. Rice, R.B. Spies, D.A. Wolfe, and B.A. Wright (eds.). Proceedings of the *Exxon Valdez* Oil Spill Symposium. American Fisheries Society Symposium No. 18. American Fisheries Society, Bethesda, Maryland.

Parametrix. 1997. Alpine Development Project Environmental Evaluation Document. Prepared for U.S. Army Corps of Engineers, Anchorage, Alaska by Parametrix, Inc., Kirkland, Washington.

Piper, E. 1993. The *Exxon Valdez* Oil Spill. Final Report, State of Alaska Response. Alaska Department of Environmental Conservation, Anchorage, Alaska.

Reed, J.C. 1958. Exploration of Naval Petroleum Reserve No. 4 and Adjacent Areas, Northern Alaska, 1944-1953, Part 1, History of the Exploration. U.S. Geological Survey, Professional Paper 301.

Rice, S.D., R.B. Spies, D.A. Wolfe, and B.A. Wright, editors. 1996. Proceedings of the *Exxon Valdez* Oil Spill Symposium. American Fisheries Society Symposium 18, Bethesda, Maryland.

Selkregg, L.L. 1975. Alaska Regional Profiles. Vol. 11. University of Alaska Arctic Environmental Information and Data Center, Fairbanks, Alaska.

Shaver, G.R. 1996. Integrated Ecosystem Research in Northern Alaska, 1947-1994. *Ecol. Stud.* 120:19.

Short, J.W., and P.M. Harris. 1996. Chemical Sampling and Analysis of Petroleum Hydrocarbons in Near-surface Seawater of Prince William Sound After the *Exxon Valdez* oil spill. Pages 17-28 *in*: S.D. Rice, R.B. Spies, D.A. Wolfe, and B.A. Wright, editors. Proceedings of

the *Exxon Valdez* oil spill symposium. American Fisheries Society Symposium 18. American Fisheries Society, Bethesda, Maryland.

Spies, R.B., S.D. Rice, D.A. Wolfe, and B.A. Wright. 1996. The Effects of the *Exxon Valdez* Oil Spill on the Alaskan Coastal Environment. Pages 1-16 *in:* S.D. Rice, R.B. Spies, D.A. Wolfe, and B.A. Wright (eds.). Proceedings of the *Exxon Valdez* Oil Spill Symposium. American Fisheries Society Symposium 18. American Fisheries Society, Bethesda, Maryland.

Teal, A.R. 1991. Shoreline Cleanup — Reconnaissance, Evaluation, and Planning Following the *Exxon Valdez* Oil Spill. Pages 149-160 *in*: Proceedings, 1991 oil spill conference. Publication 4529. American Petroleum Institute, Washington, D.C.

Truett, J.C. 2000. Part I, Introduction to Arctic Ecosystems. Pages 1-13 *in*: J.C. Truett and S.R. Johnson, editors, *Natural History of an Arctic Oil Field; Development and the Biota*. Academic Press, San Diego, California.

Truett, J.C. and S.R. Johnson (eds.). 2000. The Natural History of an Arctic Oil Field: Development and the Biota. Academic Press, San Diego, California.

USACE. 1980. Prudhoe Bay Oil Field Waterflood Project. Final Environmental Impact Statement. U.S. Army Corps of Engineers, Alaska District, Anchorage, Alaska.

USACE. 1984. Prudhoe Bay Oil Field, Endicott Development Project. Final Environmental Impact Statement. U.S. Army Corps of Engineers, Alaska District, Anchorage, Alaska.

USCG. 1993. Federal On-scene Coordinator's Report, T/V *Exxon Valdez* Oil Spill. U.S. Coast Guard, Washington, D.C.

Walker, D.A., P.J. Webber, E.F. Binnian, K.R. Everett, H.D. Lederer, E.A. Nordstrand, and M.D. Walker. 1987. Cumulative Impacts of Oil Fields on Northern Alaska Landscapes. *Science*. 238:757-761.

Wells, P.G., J.N. Butler, and J.S. Hughes, editors. 1995. *Exxon Valdez* Oil Spill: Fate and Effects in Alaskan Waters. ASTM STP 1219. American Society for Testing and Materials. Philadelphia, Pennsylvania.

Wilimovsky, N.J., and J.N. Wolfe, eds. 1966. Environment of the Cape Thompson Region, Alaska. U.S. Atomic Energy Commission, Division of Tech. Inf. Oak Ridge, Tennessee.

Wilson, W.J., and B.J. Gallaway. 1997. Synthesis in Applied Fish Ecology: 20 Years of Studies on Effects of Causeway Development on Fish Populations in the Prudhoe Bay Region, Alaska. Pages 326-339 in: J. Reynolds, editor, *Fish Ecology in Arctic North America*. American Fisheries Society Symposium 19. Bethesda, Maryland.

Wolfe, D.A., M.J. Hameedi, J.A. Galt, G. Watabayashi, J. Short, C. O'Claire, S. Rice, J. Michel, J.R. Payne, J. Braddock, S. Hanna, and D. Sale. 1994. The Fate of the Oil Spilled from the *Exxon Valdez*. In: *Environmental Science and Technology*. 28:561A-568A.