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Filling Knowledge Gaps

The Committee on Cumulative Environmental Effects of Alaskan north Slope Oil and Gas Activities was charged with identifying gaps in knowledge that hinder identification of cumulative effects and with assessment of their causes and importance. Those tasks were made more difficult because data were not always available or were not coordinated or comprehensive, although much is known about the region. This chapter discusses the shortcomings of the data and ways to improve the collection and organization of new information to help future assessments. Specific needs to inform decisions about oil and gas activities on the North Slope also are described.

A great deal of time and effort had been invested in studying North Slope environments and assessing the effects of oil and gas activities there. Some of the research recommendations that follow are for new investigations, but many of them represent a sharpening of the focus and the emphasis of current efforts.

NEED FOR COMPREHENSIVE PLANNING

Decisions about the conditions for and requirements of permitting industrial activities on the North Slope are made by many federal, state, and municipal agencies. Communication and coordination among those agencies have been weak and sporadic. Permitting decisions generally have been made one case at a time without a comprehensive plan to identify the scope, intensity, direction, or consequences of industrial activities that are judged appropriate and desirable. Similarly, the minimal rehabilitation of disturbed habitat has occurred without an overall plan to identify land-use goals, objectives to achieve them, performance criteria, or monitoring requirements. Little consideration has been given to how different future trajectories would be viewed by different groups, including North Slope residents.

In particular, there has been no comprehensive estimate of the costs of dismantlement and removal of infrastructure and subsequent restoration and rehabilitation (DRR) of affected North Slope areas. This is important because although DRR is assumed in some permits and plans, it will almost surely cost much more than the amount of money available. Extrapolation from estimates for individual project plans suggests a total cost of billions of dollars. However, existing state and federal bonding requirements are not even remotely sufficient to underwrite potential DRR costs on the North Slope. Because the obligation to restore abandoned sites is unclear and the financial resources to do so are so uncertain, the committee judges it likely that, absent a change in those constraints, most the disturbed North Slope habitat will never be rehabilitated or restored. What is needed is a slope-wide land-use plan and an understanding of the likely costs and effectiveness of various DRR approaches.

The quality, accessibility, and extent of data to evaluate effects and their accumulation also is inadequate. In many cases, the committee did obtain necessary data, and we are grateful for the cooperation and efforts of state, federal, and local governments; industry; environmental groups; individual researchers; the North Slope Borough, and interested members of the public. But often the committee had difficulties in obtaining data it needed. Sometimes the data did not exist, and other times the data were less useful than they could have been. The reasons for these difficulties included confidentiality, particularly for identifying the locations of seismic exploration; a failure to analyze information from agency or industry files; the lack of comparability of data collected by various agencies; and the lack of long-term data sets that could be used to assess or anticipate future accumulating effects. For example, most of the data acquired from water-quality monitoring programs, which are required by discharge permits, are retained by the principal permitting agency, the Environmental Protection Agency, and are not readily available. Records also are kept by individual operators, but they are not summarized, and there are few annual reports.

Two kinds of comprehensive planning are needed to overcome these shortcomings and to better explain and manage the environmental effects of oil and gas activities on Alaska's North Slope and their accumulation. The first is for a comprehensive slope-wide land-use plan to guide industrial development and assist in planning for the eventual departure of the oil and gas industry from the region. The plan should identify land-use goals and specify restoration and rehabilitation objectives to achieve them. It should include specific performance criteria and monitoring requirements tied to restoration and rehabilitation objectives, and it should provide an inventory of current facilities and gravel fill, including an assessment of the nature and extent of contamination. It should specifically include plans for decommissioning, abandonment, and restoration and rehabilitation once oil and gas production is no longer viable. Even if changing oil prices, new hydrocarbon discoveries, disintegrating infrastructure, changing political arrangements, and other unforeseen factors were to make such a plan obsolete before it could be implemented, the exercises would provide a shared vision of goals for the North Slope, and help to identify areas where knowledge is inadequate and would thus help to guide research and monitoring.

The second need is for a coordinated and comprehensive research plan. This should include the following:

- A regional assessment of ecological and human values that have various degrees of sensitivity to disturbance with a view to ranking their importance and the urgency of addressing them.
- Important research questions developed through collaborative efforts of scientists, local communities, industry, interested members of the public, and regulatory agencies.
- Identification of key indicators of environmental status and trends and how they will be measured.

To increase the likelihood that the research would be of the broadest usefulness in decision making and to have the greatest scientific validity, the following approaches should be incorporated into the research:

- Traditional and local knowledge, especially information gathered by subsistence hunters, should be incorporated into the research plan at all stages of research, from study design through interpretation and presentation of the results.
- Provision should be made for data gathered and managed by various agencies to be comparable and accessible, using the same units and standards of data quality wherever possible. For example, geographic information systems (GIS) are powerful planning tools to help in developing a slope-wide land-management plan. A single site should be established where data are stored and can be accessed.
- Where possible, a hypothesis to be tested should be identified and appropriate controls established before data are collected.
- Thorough, independent peer review should be conducted at all stages of the research, from study design to publication of results.

SCIENTIFIC INFORMATION NEEDS

Ecosystem-Level Research

Most ecological research in the Prudhoe Bay region has focused on local studies of the behavior and population dynamics of animal species. Patterns and processes at landscape scales, as well as nutrient cycling and energy flows, have received relatively little attention. Nevertheless, the research that has been done has identified the need for, and importance of, studies of population dynamics over large areas and the need to assess how industrial activities on the North Slope are affecting the productivity of tundra ecosystems. Alterations of flow patterns of water across the Arctic Coastal Plain, thermokarsting of tundra adjacent to roads and off-road pathways, and changes of albedo attributable to dust are all likely to influence plant community composition; rates of photosynthesis and decomposition; and efficiencies of energy transfer between plants, herbivores, and carnivores. Thus, tundra within an oil field is likely to differ in many ways from that in an unaffected ecosystem, yet the extent of the differences and the processes that cause them are largely unknown.

To assess these differences, protected areas similar to those established by the National Science Foundation's Long Term Ecological Research (LTER) program, accessible to researchers areas should be established in comparable areas within and outside the industrial complex. Currently the LTER site closest to the area of concern is at Toolik Lake site in the foothills of the Brooks Range, about 250 km to the south. Long-term studies should be initiated to assess the influence of industrial activities on fluxes of energy and nutrients in these systems. Particular attention should be paid to those processes most likely to be altered with the objective of identifying ways to reduce the accumulation of undesirable effects, whether by avoiding particularly vulnerable areas or by adjusting the nature of activities to reduce the degree to which ecosystem processes are affected.

Human-Health Effects

The effects of oil and gas activities on human health have not been well documented. Some human-health effects of encroachment of industrial civilization into Alaska Native communities are well known, such as the increased use of alcohol and drugs, increased obesity, and other societal ills. But on the North Slope, it is not possible with available data to say to what degree they are the direct result of oil and gas activities. Other concerns are widespread among Native residents of the North Slope, including concerns about air pollution, contamination of water and food, and noise. To some unknown degree the increased financial resources from oil taxes and royalties have balanced adverse health effects by significantly improving the quality and availability of medical care on the North Slope. The human-health effects of oil and gas activities constitute one of the areas in greatest need of additional reliable information.

Offshore Oil Spills

The committee heard many comments indicating that oil spills are a grave concern among North Slope residents, especially the threat of a large offshore spill. Although there have been no large oil spills in waters off the North Slope, they are such a major concern that we make some comments here about possible research into mitigating their effects, recognizing that this is somewhat beyond our charge. The results of such research would help to refine future assessments of how the effects of major spills accumulate.

Considerable research has been done on methods of cleaning up spills and on mitigating some of their effects (see e.g., Allen 1998, 1999, 2002; Lindstedt-Siva 1992; NRC 1989, 2002). This committee has neither deliberated about the most important research topics for oil-spill cleanup and mitigation, nor has it attempted to reach a consensus on whether, when, and how experimental oil spills might be used in such a research program. Nonetheless, research in a variety of areas seems to be warranted, including the use of noise to move bowhead whales—and perhaps other marine mammals—away from areas affected by a spill. It would also be useful to have the results of research on the effectiveness and environmental liabilities and advantages of nonmechanical methods of cleaning up oil spilled in the sea (e.g., dispersants, in-situ burning), especially in broken-ice conditions. Such research might be of great value in decision making and in formulating the comprehensive plans that the committee identified as being needed.

Research and Human Communities

People and their communities interact with information needs both as consultants and as subjects. As a result, information about the accumulation of effects is missing or sparse in several areas. Therefore, if better assessment is to occur, the following areas need attention:

- Research on the North Slope, regardless of its subject matter, should occur as a cooperative endeavor with local communities. Traditional and local knowledge of the physical environment, the biota, and the human communities on the North Slope is comprehensive and important. This information should be incorporated into research efforts, from the identification of topics and study design through interpretation and presentation of results.
- Balancing economic benefits of oil and gas activities against loss of traditional knowledge and language often is a dilemma for North Slope residents. Research should identify the specific lifestyle benefits and threats that North Slope residents attach to oil

and gas industrial activity. This research should target how much oil and gas activities, as distinguished from other factors, are associated with increasing sociocultural change.

- Research should establish how oil and gas activities and their effects—those deemed positive or negative—have influenced community and individual behavior.
- Research should identify the direct and indirect monetary rewards and costs (including passive-use values) associated with petroleum development on the North Slope. The research should describe rewards and costs for North Slope residents as well as for nonresidents, and it should qualitatively describe effects that cannot be converted to money.
- Research should be conducted on how to best manage effects of rapid social, economic, cultural, and spiritual changes for the Inupiat and Gwich'in of the North Slope and Alaska.

Zones of Influence

Technological developments have greatly reduced the "footprint" of new industrial activities on the North Slope. For example, horizontal drilling and pad refrigeration allow well-heads to be spaced closely on smaller pads. The use of ice roads allows exploration in the winter when its effects on tundra vegetation are greatly reduced. Gravel pads generally are now constructed only for successful exploration wells, and many wells need not be served by permanent gravel roads. Underground injection has eliminated the need for reserve pits to accommodate wastes. Pipelines are still required, however, although fewer than formerly.

Clearly, those advances have greatly reduced the incremental direct effects of new industrial activities on North Slope environments and organisms. Nevertheless, the effects of industrial activities are not limited to the footprints or their immediate vicinity. The committee has identified a variety of influences that extend varying distances from actual facilities. They range from effects on animals that are attributable to gravel roads and pads and that extend a few kilometers, to the influence of industrial structures on visual aspects of the landscape, which can extend as far as 100 km (60 mi).

The examples identified by the committee do not list all of the ways that consequences of activities extend beyond the physical footprint because there are no data to estimate how, why, and to what distance many receptors could be influenced. The full accumulation of the effects of oil and gas activities to date, as well as in the future, cannot be assessed without much better quantitative information about the ways in which effects extend for varying distances.

Current activities should be studied to identify zones of influence of industrial activities and structures on various components of the North Slope environment. Future industrial activities and structures should be studied to generate data showing how and why various receptors are affected by those activities and the distances over which those effects occur.

Air Contamination and its Effects

Air pollution on the North Slope is a concern to residents, and its effects could accumulate. There has been little research to quantify the contribution of local emissions from oil and gas facilities or to determine how local and regional air masses and their contaminants interact. The lack of predevelopment baseline data further hampers assessment of locally and distantly produced pollution on North Slope air quality.

No monitoring system (except for tracking of priority pollutants from 1986 through 2002 at a limited number of sites) has been established to provide a quantitative baseline of spatial and temporal trends in North Slope air quality. The lack of adequate information limits the accuracy and precision of assessments of past and predictions of future accumulation of effects. Given local concerns about air quality and its perceived effects on human health, studies should be undertaken to distinguish between locally derived emissions and long-range transport, to determine how they interact, and if necessary to monitor potential human exposure to air contaminants.

Seismic Exploration and Other Off-Road Traffic

Networks of seismic and other off-road vehicle trails as well as ice roads and ice pads cover extensive areas of the tundra. They are a concern because of the damage they do to vegetation and their visibility from the air. The development of new seismic data-acquisition methods, such as lightweight, rubber tracked equipment, might reduce the effects of those activities by reducing the weight, tracks, or number of vehicles used, but the degree to which tundra damage will be reduced is unknown.

The current regulations governing minimum snow depth (average 15 cm [6 in.]) and frost penetration (30 cm [12 in.]) to allow seismic activities on the tundra are not based on research and do not account for variations in snow depth caused by topography or differential drifting. Thus, the degree of protection they provide to tundra is unknown. Much of the information regarding the location of seismic activities is considered proprietary and is not available to researchers or the public. This information is critical for determining the areas affected and the long-term effects of these activities.

Studies of the effects and persistence of the trails of off-road vehicles are needed, including their long-term visibility from the air. Studies are needed to determine the amount of snow and the frost penetration required to adequately protect the tundra from the effects of seismic exploration.

Exploration is expanding beyond the current area of activity, both southward into the foothills of the Brooks Range and westward well into the National Petroleum Reserve-Alaska (Chapter 5). New areas for oil and gas exploration are likely to differ substantially from current areas of activity. To understand, predict, and manage cumulative environmental effects in the new areas, their environments need to be characterized. This should include descriptions of topography; permafrost conditions; sand, gravel, and water availability; hydrological conditions; and biotic communities.

Caribou and Bowhead Whales

A better understanding is needed of the seasonal habitat requirements of caribou, natural environment constraints, details of the physiology of reproductive tradeoffs, and how disturbance affects them in the Arctic.

Studies are needed to determine the qualitative relationship between the noise generated by offshore operations and the migratory and acoustic behavior of bowhead whales. The studies should include analysis of the effects of multiple noise sources. Better information is also needed about the degree to which bowheads feed in the Alaskan portion of the Beaufort Sea.

Consequences of Water Withdrawals

Water for ice roads, pads, and other purposes is taken from lakes on the North Slope. Because most lakes in the existing development area between the Colville and Sagavanirktok rivers are less than 1.8 m (6 ft) deep, and hence freeze to the bottom, few fish are present and the impacts on them have been minimal. As development spreads into regions with deeper lakes, such as the Colville delta and the eastern portion of the National Petroleum Reserve-Alaska, there is greater potential to affect fish populations within lakes. Under current Alaska Department of Fish and Game policy, water withdrawals from fish-bearing lakes are limited to 15% of the estimated minimum water volume during winter to retain most of the water for wintering fish. The 15% criterion was set arbitrarily in the absence of data to support an alternative, and no research has been conducted to determine what the effects of withdrawals are on populations of invertebrates in the lakes and, hence, food supplies for vertebrates. As of late 2002 there were no restrictions on removal of water from fishless lakes.

An initial study of the 15% criterion should determine the degree to which that criterion prevents harm to fish and invertebrates. A study of the effects of withdrawing water from lakes without fish should be conducted to assess the degree to which current water use affects biota associated with these water bodies.

Dealing with Uncertainties

Actions undertaken to identify and reduce the undesirable effects of interactions among effectors and receptors should greatly improve the quality and quantity of data in future decision-making. However, the information will never be sufficient to eliminate uncertainty in future problem-solving. Some species, such as marine mammals and fishes, are intrinsically difficult to study. Detecting even fairly important changes in their population densities and demographic parameters could be impossible, no matter how much money is available to study them. Also, adequate controls could be impossible to establish. Informative manipulations of populations of rare and endangered species are legally constrained. Experimental oil spills could be politically unacceptable. Distinguishing between changes attributable to specific oil and gas activities and those that are the results of other causes is often difficult because multiple factors typically influence the receptors of interest. Finally, there is uncertainty about reference states or conditions because environmental factors, such as climate change over time and space.

Some of the above problems cannot be solved, but scientific uncertainty can be usefully described by an analysis of the power of the statistical tests being used. When analyzing data collected to test a hypothesis that X has an effect on Y, two kinds of errors are possible. First, one can conclude falsely that there is an effect when actually there is none (a Type I error); second, one can conclude falsely that there is no effect when actually there is one (a Type II error). The likelihood of making either kind of error can be reduced by appropriate analyses, but reducing the likelihood of making one type of error always increases the likelihood of the other. The only way to reduce the likelihood of making both kinds of errors simultaneously is to have more data, either through larger or more samples.

To assess the consequences of making a Type II error, it is helpful to state the magnitude of the effect that could have gone undetected. This is equivalent to asking, "If, on the basis of a statistical test at a chosen significance level, it is concluded that the action has no effect, then how large would an effect have to be for the test to detect it?" The answer is often that the magnitude of statistically undetectable effects is much larger than anyone would have expected. This question should be explicitly considered and described in designing studies to assess the effects of activities already undertaken and the likely consequences of proposed activities on the North Slope. In addition, final results should be accompanied by a statement of the magnitude of effects that would have escaped detection. Those uncertainties should be clearly communicated to decision makers. More detailed discussion of these and related topics is presented in work by the National Research Council (1995) and Simberloff (1990).

No matter how much information would be desirable, decisions often cannot be deferred. How, then, can the best use be made of the information that is available to inform decision-making? This difficult challenge—making environmental decisions in the face of uncertainty—was discussed in detail (with a focus on the Endangered Species Act) by the National Research Council (NRC 1995). The general topic of environmental decision-making under uncertainty often appears under the rubric of the precautionary principle, which says in effect that when there is doubt one should err on the side of the environmental resource. In practice, such an admonition often is not helpful as a guide for making real policy or management decisions. Precaution is a continuous variable, and one person's precaution is another's reckless disregard. The central problem is to characterize people's valuation of risks and rewards and incorporate them into frameworks for risk assessment and management.

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Major Effects and Their Accumulation

The committee on the Cumulative Environmental Effects of Alaskan North Slope Oil and Gas Activities was charged with reviewing information about oil and gas activities on Alaska's North Slope with the objective of assessing their known and probable cumulative effects of those activities on the physical, biotic, and human environments of the North Slope and the adjacent marine environment. The committee also was directed to assess future cumulative effects, based on its judgment of likely changes in technology and the environment. The committee attempted to be thorough in its analyses to reduce the likelihood that important effects—and how they might accumulate—would be undetected. The results of the committee's investigations are detailed in Chapters 6 through 9.

The importance of effects is perceived differently by different individuals or groups. The committee is not aware of a satisfactory way of attributing some absolute degree of importance to effects, and so it attempted to describe the basis on which it assessed importance of the effects. For example, it considered ecological consequences, importance given by North Slope residents, irreversibility, degree of controversy, and economic consequences for North Slope residents.

As described in Chapter 10, there was considerable difficulty with assembling information for some analyses, both because of gaps in data and because of the inaccessibility of some information. Nevertheless, the committee did identify important effects of industrial activities on the North Slope and how they accumulate. Details that support its judgments are provided earlier in the report.

The committee based its projections of future accumulation of effects on a 50-year scenario that assumes political stability and world prices for petroleum products that support the continued expansion of oil and gas activities westward across the Arctic Coastal Plain and southward into the foothills of the Brooks Range (Chapter 5). Some effects are not yet manifest; they will accumulate as consequences of past and current activity. They would occur even if North Slope oil and gas exploration and production ended today. Other effects will accumulate as a result of new activities. Mostly, they will involve increases of current effects, but new effects are likely to be created as well—both by the expansion and by the ultimate retraction of industrial activity.

Assessments of future effects are problematic because of the connection between world politics and the oil market. It is possible to guess, but no one knows for certain how the events of the next decade will affect oil prices or availability. Moreover, future industrial activities will be carried out in a physical climate that will change in ways that are difficult to predict. Nevertheless, if oil activity expands and a gas pipeline is built, the continuing accumulation of effects is virtually certain.

Many laws and regulations affect oil and gas exploration, development, production, and transportation, and many federal, state, and local government offices are involved (see Appendix I). Regulatory oversight can be critical in reducing the accumulation of undesirable effects. The committee's predictions of future effects and their accumulation assume that regulatory oversight will continue at least to the extent of the recent past.

All of the effects identified by the committee accumulated as the result of the actual spread of industrial activity on the North Slope or as responses to the news that such activity was likely to occur.

Since the 1960s, industrial activity on the North Slope has grown from a single operational oil field at Prudhoe Bay to an industrial complex that stretches from the Alpine field near the mouth of the Colville River on the west to the Badami oil field, about 39 km (23 mi) from the borders of the Arctic National Wildlife Refuge in the east. In 2001, oil development on the North Slope consisted of 19 producing fields connected to the rest of Alaska by a highway and a pipeline that cross the state. The network consists of 115 gravel drill sites, 20 pads with processing facilities, 115 pads with other support facilities, 91 exploration sites, 13 off-shore exploration islands, 4 off-shore production islands, 16 airstrips, 4 exploration airstrips, 1,395 culverts, 960 km (596 mi) of roads and permanent trails, 450 mi (725 km) of pipeline corridors, and 219 mi (353 km) of transmission lines. Gravel roads and pads cover more than 3,500 ha (8,800 acres), not including the Trans Alaska Pipeline and the Dalton Highway, and gravel mines have affected nearly 2,600 ha (6,400 acres). Ubiquitous permafrost requires that this infrastructure not thaw its own foundations, imposing an architecture with environmental consequences of it own. Massive gravel fills under roads and other work surfaces are required to raise them 1.8 m (6 ft) above the tundra. Heated buildings and pipeline networks must be elevated on pilings, and the closely spaced oil wells are extensively refrigerated. This network has grown incrementally as new fields have been explored and brought into production (Chapter 4). For a variety of reasons, nearly all roads, pads, pipelines, and other infrastructure—whether in current use or not—are still in place and are likely to remain into the future. Their effects are manifest not only at the physical footprint itself but also at distances that vary according to the environmental component affected. Effects on hydrology, vegetation, and animal populations occur at distances up to several kilometers, and cumulative effects on wildland values—especially visual ones—extend much farther, as can the effects on marine mammals of sound caused by some offshore activities. All effects attributable to the structures and the activities associated with them accumulate, and many will persist as long as the structures remain, even if industrial activity ceases.

SOCIAL CHANGES IN NORTH SLOPE COMMUNITIES

Without the discovery and development of North Slope petroleum, the North Slope Borough, the Alaska Native Claims Settlement Act, and hence the Arctic Slope Regional Corporation, either would not exist or would bear little resemblance to their current form. Petroleum development has resulted in major, significant, and probably irrervisible changes to the way of life on the North Slope (Chapter 9). The primary vehicle of change is revenue that has flowed into communities from property taxes levied by the North Slope Borough on the petroleum industry's infrastructure. Many North Slope residents view many of these changes positively. However, social and cultural changes of this magnitude inevitably have been accompanied by social and individual pathology. Those effects accumulate because they arise from several causes, and they interact. As adaptation occurs, the communities and the people who make them up interact in new and different ways with the causes of social change.

Interference With Subsistence Activities

Offshore exploration and development and the announcement of offshore sales have resulted in perceived risks to Inupiaq culture that are widespread, intense, and themselves constitute a cumulative effect (Chapter 9). The people of the North Slope have a centuries-old nutritional and cultural relationship with the bowhead whale and caribou. Most view offshore industrial activity—both the observed effects and the threat of a major oil spill—as threatening the bowhead population and, thereby, their cultural survival. Noise from exploratory drilling and marine seismic exploration has caused fall-migrating bowheads to avoid noise above 117-135 dB. The distances over which the migratory pathways of the whales have changed are not yet known, but the deflections forced subsistence hunters to travel greater distances than formerly to encounter whales. The results are increased risk of exposure to the dangers of the open sea and the increased likelihood that whale tissues will deteriorate before carcasses are landed and butchered. Recently the Alaska Eskimo Whaling Commission has reached agreements that restrict seismic-vessel operations during the fall hunting period, but they are renegotiated annually.

The threat of a major oil spill also is viewed with trepidation by the coastal Inupiat, even though no such spill has yet occurred. These threats are accumulate because they interact with other factors such as climate change and because they are repeated with every new lease sale.

On-land subsistence activities have been affected by the reduction in the harvest area in and around the oil fields. The reductions are greatest in the Prudhoe Bay field, which has been closed to hunting, and in the Kuparuk field, where the high density of roads, drill pads, and pipelines inhibits travel by snow machine. The reduction in area used for subsistence is most significant for Nuiqsut, the village closest to the oil-field complex. Even where access is possible, hunters are often reluctant to enter oil fields for personal, aesthetic, or safety reasons. There is thus a net reduction in the available area, and this reduction continues as the oil fields spread.

Although there has not yet been industrial activity in the Arctic National Wildlife Refuge, proposals to explore and develop oil resources there have resulted in actual and perceived risks to the Gwich'in culture that are widespread, intense, and themselves are accumulating effects (Chapter 9). The Gwich'in have a centuries-old nutritional and cultural relationship in Alaska and the Yukon Territory with the Porcupine Caribou Herd. Most view petroleum development in the 1002 Area of the Arctic National Wildlife Refuge as a threat to the herd and, thereby, to their cultural survival. The threats accumulate because there have been repeated attempts to develop the area and there is continuing pressure to do so.

Aesthetic, Cultural, and Spiritual Consequences

Many activities associated with petroleum development have changed the North Slope landscape in ways that have had aesthetic, cultural, and spiritual consequences that accumulate.

The consequences have increased along with the area of tundra affected by development, and they will persist for as long as the landscape remains altered.

Roads, pads, pipelines, seismic-vehicle tracks, and transmission lines; air, ground, and vessel traffic; drilling activities; landfills, housing, processing facilities, and other industrial infrastructure have reduced opportunities for solitude and have compromised wildland and scenic values over large areas (Chapter 9). The structures and activities also violate the spirit of the land, a value that is reported by some Alaska Natives to be central to their culture. Given that most of the affected areas are not likely to be rehabilitated or restored to their original condition, those effects will persist long after industrial activity has ceased on the North Slope.

DAMAGE TO TUNDRA FROM OFF-ROAD TRAVEL

The tundra on the North Slope has been altered by extensive off-road travel, some of which may not be directly related to oil and gas activity. Networks of seismic-exploration trails, ice roads, pads, and all-terrain vehicle trails cover large areas. The currently favored three-dimensional seismic surveys require a high spatial density of trails, and the potential damage is substantial because larger camps and more vehicles are used than were used previously for two-dimensional exploration. Although the technology for acquisition of seismic data continues to improve, damage has not been totally eliminated, and some areas have been explored repeatedly—sometimes revisits to gather more complete data using new and better technologies; sometimes to gather data already gathered by a competitor who did not share the proprietary information.

Some seismic-exploration effects accumulate because areas are revisited before the tundra recovers from previous surveys. Seismic exploration can damage vegetation and cause erosion, especially along stream banks. In addition, because seismic trails are readily visible, especially from the air, they affront the residents and degrade the visual experience of the landscape. Data do not exist to determine the period that the damage will persist, but some effects are known to have lasted for several decades (Chapter 7).

Seismic exploration is expanding westward into the National Petroleum Reserve-Alaska and southward into the foothills of the Brooks Range. Current technology and government regulations will not prevent damage to the tundra. Moreover, exploration will be conducted in regions where the topography is more complex and where permafrost conditions are more variable and less well known than on the Arctic Coastal Plain, where most exploration has been done (Chapter 5). The nature and condition of permafrost in the Brooks Range foothills is poorly characterized, and the hilly topography increases the likelihood that vehicles will damage vegetation, especially on knolls and riverbanks, causing increased erosion, exposing bare soil, and promoting development of thermokarst. This exploration will probably be carried out in a warming climate, with milder winter temperatures. It is hard to predict the consequences of vehicular traffic in winter on tundra under those conditions.

ROADS

Roads have had effects as far-reaching and complex as any physical component of the North Slope oil fields. In addition to covering tundra with gravel, indirect effects on vegetation are caused by dust, roadside flooding, thermokarst, and roadside snow accumulation. The effects accumulate and interact with effects of parallel pipelines and with off-road vehicle trails. The measurable direct effects covered approximately 4,300 ha (10,500 acres) in the developed fields, not including indirect effects of the Dalton Highway. Roads also alter animal habitat and behavior and can increase access of hunters, tourists, and others to much of the region; enhance communication among communities; and increase contacts between North Slope communities and those outside the area.

EFFECTS ON ANIMAL POPULATIONS

Animals have been affected by industrial activities on the North Slope (Chapter 8). Bowhead whales have been displaced in their fall migration by the noise of seismic exploration. The full extent of that displacement is not yet known. Some denning polar bears have been disturbed. The readily available supply of food in the oil fields has resulted in the persistence of higher-than-normal densities of predators, such as brown bears, arctic foxes, ravens, and glaucous gulls. Those animals are important predators on nests, nestlings, and fledglings of many bird species, and the reproductive success rate of some bird species in the developed parts of oil fields has been reduced to the extent that it is insufficient to balance mortality. Serious efforts have been made, in the form of educating workers, fencing dumps, and using animal-proof waste receptacles, to reduce the amount of supplemental food available to predators. Those efforts have been only partly successful; some predators have become expert at accessing garbage and it is difficult to persuade people to stop feeding them.

Reproductive rates of some bird species are, at least in some years, insufficient to balance mortality. That is, they are "sink populations" whose densities have been maintained only by steady immigration from "source" areas where reproductive rates exceed mortality. As industrial activities continue to expand, increasing numbers of sink areas are likely to be created and more and more source areas are likely to be depleted. Ecology theory and empirical data indicate that populations can decline suddenly if source areas are significantly degraded.

How industrial activity interacts with source-sink population dynamics is difficult to assess because local population studies alone, no matter how detailed, cannot detect all effects. To anticipate and predict population collapse from disrupted source-sink population dynamics, analyses must focus on those species most likely to be affected, and studies must gather specific kinds of data. The number of vulnerable species cannot be determined because demographic information does not distinguish source and sink habitats, but several species of birds and mammals could be adversely affected.

As a result of conflicts with industrial activity during calving and an interaction of disturbance with the stress of summer insect harassment, reproductive success of Central Arctic Herd female caribou in contact with oil development from 1988 through 2001 was lower than for undisturbed females, contributing to an overall reduction in herd productivity. The decrease in herd size between 1992 and 1995 may reflect the additive effects of surface development and relatively high insect activity, in contrast to an increase in the herd's size from 1995 through 2000, when insect activity was generally low. Although the accumulated effects of industrial development to date have not resulted in large or long-term declines in the overall size of the Central Arctic Herd, the spread of industrial activity into other areas that caribou use for calving and relief from insects, especially to the east where the coastal plain is narrower than elsewhere, would likely result in reductions in reproductive success, unless the degree to which it disturbs caribou could be reduced. Without specific information on the exact nature of future activity and its precise distribution, it is not possible to predict to what degree the migrations and population sizes of caribou herds would be affected.

OIL SPILLS

Major oil spills have not occurred on the North Slope or in adjacent oceans as a result of operations there. There have been three major spills from the North Slope segment of the Trans-Alaska Pipeline. Many small terrestrial spills have occurred in the oil fields but they have not been frequent or large enough for their effects to have accumulated. They have contaminated gravel, which has been difficult to clean up and has made the gravel unavailable for rehabilitation. The threat of a large oil spill—especially offshore—is a major concern among North Slope residents. This continuing concern is an accumulating effect. The effects of a large oil spill at sea, especially in broken ice, would likely be substantial and accumulate because of the fluid environment and the inadequacy of current methods to remove more than a small fraction of an ocean spill.

ABANDONED INFRASTRUCTURE AND UNRESTORED LANDSCAPES

The oil industry and regulatory agencies have made dramatic progress in slowing the accumulation of effects of gravel fill by reducing the size of the footprint required for many types of facilities and by substituting ice for gravel in some roads and pads. They also have directed some attention to rehabilitating or restoring already-disturbed sites. Despite this, only about 1% of the habitat affected by gravel fill on the North Slope has been restored. Other than for well-plugging and abandonment procedures, state, federal, and local agencies have largely deferred decisions about the nature and extent of restoration. The lack of clear performance criteria, standards, and monitoring methods at the state and federal level to govern the extent and timing of restoration has hampered progress in restoring disturbed sites. If restoration would make potential future use of a site more expensive or perhaps impossible, restoration is likely to be deferred. In addition, because so much gravel has been contaminated by petroleum spills, its re-use and the restoration of pads and roads could be constrained because of the added difficulty of restoring contaminated sites. There also is potential liability that constitutes a barrier to re-use of contaminated gravel.

Surface structures pose problems, but there also are portions of the Trans Alaska Pipeline that are buried. The pipeline connecting Alpine to Prudhoe Bay runs under the Colville River. The vulnerability of those buried pipes to shifting river channels and their removal after production ceases could pose serious problems.

By the time restoration becomes more practical because better methods are available and because the operational value of the sites has diminished, the revenue flow from oil and gas also will have declined. The large, well capitalized multinational oil companies are likely to have sold off substantial parts of their operations to smaller companies with more limited resources. Because the obligation to restore abandoned sites is unclear, and because the costs to restore abandoned sites are likely to be very high, the committee judges it unlikely that most disturbed habitat on the North Slope will ever be restored. Natural recovery in the Arctic is very slow, because of the cold; so the effects of abandoned structures and unrestored landscapes could persist for centuries and accumulate with effects of new structures.

RESPONSE OF NORTH SLOPE CULTURES TO DECLINING REVENUES

The standard of living of North Slope communities depends largely on a steady flow of money related to oil and gas activities. This way of life will be impossible to maintain unless significant revenues continue to come into those communities from outside; the prospects of other sources of revenue appear to be modest. Painful adjustments can and probably will be postponed for as long as oil and gas are being extracted, but eventual adjustment is unavoidable. The nature and extent of these adjustments will be determined by the adaptations North Slope societies have made to the cash economy made possible by oil and gas and other activities.

TRADE-OFFS ARE INEVITABLE

Continued expansion will exacerbate existing effects and create new ones. Whether the benefits derived from oil and gas activities justify acceptance of the foreseeable and undesirable cumulative effects is an issue for society as a whole to debate and judge. However, if informed decisions are to be made, the nature and extent of possible effects must be fully acknowledged and incorporated into regulatory strategies and decision-making processes. We hope this report will assist this process.

Appendix A:

Acknowledgments

The following is a list of speakers at the committee's public meetings and contributors of information.

1st Meeting, January 8-10, 2001, Anchorage, AK
George N. Ahmaogak, Sr., Mayor of the North Slope Borough
Maggie Ahmaogak, Alaska Eskimo Whaling Commission
David Allen, Fish and Wildlife Service
Art Banet, Bureau of Land Management
Lucy Beach, Gwich'in Steering Committee
Max Brewer, USGS (retired)
Sara Chapell, Sierra Club
Marcia Combes, Environmental Protection Agency
Pat Galvin, Office of the Governor of Alaska
John Goll, Minerals Management Service
Jeanne Hanson, National Marine Fisheries Service
Taqulik Hepa, North Slope Borough
Mike Joyce, Independent Consultant
Jay McKendrick, Lazy Mountain Research
Rosa Meehan, Fish and Wildlife Service
Pamela A. Miller, Arctic Connections
Gordon Nelson, USGS
Russ Oates, Fish and Wildlife Service
Walter Parker, U.S. Arctic Research Commission
Dan Ritzman, Greenpeace
Ted Rockwell, Environmental Protection Agency
John Schoen, Audubon Alaska
Stanley Senner, Audubon Alaska
Brad Smith, National Marine Fisheries Service
Pat Sousa, Fish and Wildlife Service
Bill Streever, BP Exploration (Alaska) Inc.
Steve Taylor, BP Exploration (Alaska) Inc.
Peter Van Tuyn, Trustees for Alaska

2nd Meeting, April 2-5, 2001, Fairbanks, Barrow, and Nuiqsut, Alaska
George N. Ahmaogak, Sr., Mayor of the North Slope Borough
Maggie Ahmaogak, Alaska Eskimo Whaling Commission
Rosemary Ahtuangaruak, City of Nuiqsut
Kelly Aikins, North Slope Borough
Freddie Aishamma, Whaler
Herman Aishamma, Whaling Captain
Isaac Akootchook, President of the Native Village of Kaktovik
Susie Akootchook, Secretary/Treasurer of the Native Village of Kaktovik
Charlie Brower, Whaling Captain
Eugene Brower, Fire Department, North Slope Borough
Mike Denega, Private Citizen
Nick Dunbar, Ilisagvik College
Charlie Edwardson
Gary Gortz, Ilisagvik College
David Hobbie, U.S. Army Corps of Engineers
Bud Kanayurak, North Slope Borough
John Kelley, University of Alaska Fairbanks
Lenny Landis, Ilisagvik College
David McGuire, University of Alaska Fairbanks
Deb Moore, Northern Alaska Environmental Center
Fenton Rexford, Kaktovik Inupiat Corporation
Marie Rexford
Pat Sousa, Fish and Wildlife Service
Bill Streever, BP Exploration (Alaska) Inc.
Gunter Weller, University of Alaska Fairbanks
Nancy Welsh, Alaska Department of Natural Resources

3rd Meeting, July 9-14, 2001, Deadhorse, Alpine, Arctic Village, and Fairbanks, Alaska
Ken Boyd, Alaska Department of Natural Resources
Sarah James, Gwich'in Steering Committee
Janet Jorgenson, Fish and Wildlife Service
Mike Joyce, Independent Consultant
Roger Kaye, Fish and Wildlife Service
Ryan Lance, Phillips Alaska
Fran Mauer, Fish and Wildlife Service
Jay McKendrick, Lazy Mountain Research
Dan Payer, Fish and Wildlife Service
Evon Peter, Chief of Arctic Village
John Richardson, LGL, Ltd.
Matt Rader, Alaska Department of Natural Resources
Pat Sousa, Fish and Wildlife Service
Bill Streever, BP Exploration (Alaska) Inc.
Steve Taylor, BP Exploration (Alaska) Inc.

4th Meeting, September 6-9, 2001, Fairbanks and Kaktovik, Alaska
Rosemary Ahtuangaruak, City of Nuiqsut
Paul Assendorf, General Accounting Office
William G. Britt, Jr., Gas Pipeline Office
Marilyn Crockett, Alaska Oil & Gas Association
Charlie Curtis, NANA Development Corporation
Charlie Edwardson
David C. Koester, University of Alaska Fairbanks
Jeff Mach, Alaska Department of Environmental Conservation
Joe Mathis, Alaska Support Industry Alliance
Daniel Maxim, Everest Consulting
Colleen McCarthy, Joint Pipeline Office
Debbie Miller
Pamela A. Miller, Arctic Connections
Deb Moore, Northern Alaska Environmental Center
Robin Renfroe, Doyon
Ted Rockwell, Environmental Protection Agency
Stanley Senner, Audubon Alaska
Bill Streever, BP Exploration (Alaska) Inc.
Steve Taylor, BP Exploration (Alaska) Inc.
Nancy Wainwright
Nancy Welch, Alaska Department of Natural Resources

Additional Help
Alaska Native Science Commission
Terry Carpenter, Corps of Engineers
Thor Cutler, Environmental Protection Agency
Glenn Gray, Division of Governmental Coordination
Leon Lynch, Alaska Department of Natural Resources
Dan Maxim, Everest Consulting
Ron Niebo, Everest Consulting
Rex Okakok, North Slope Borough
Evon Peter, Chief of Arctic Village
Judd Peterson, Coordinator, Alaska Department of Environmental Conservation
Gerald Shearer, MMS
Lon Sonsalla, Mayor of Kaktovik
Jeffrey Walker, MMS
Bill Wilson, LGL
Mike Worley, BLM

Appendix B:

Abbreviations and Acronyms

ABSRB: Alaska Beaufort Sea Response Body
ADEC: Alaska Department of Environmental Conservation
ADF&G: Alaska Department of Fish and Game
ADGGS: Alaska Division of Geological and Geophysical Surveys
ADNR: Alaska Department of Natural Resources
AEWC: Alaska Eskimo Whaling Commission
ANCSA: Alaska Native Claims and Settlement Act
ANILCA: Alaska National Interest Lands Conservation Act
ANWR: Arctic National Wildlife Refuge
AOGA: Alaska Oil and Gas Association
AOGCC: Alaska Oil and Gas Conservation Commission
API: American Petroleum Institute
ASRC: Arctic Slope Regional Corporation
ATV: all terrain vehicle
bbl: barrels
BCFG: billion cubic feet of gas
BEST: Board on Environmental Studies and Toxicology
BLM: Bureau of Land Management
CAH: Central Arctic Herd
CBM: coal bed methane
CEQ: Council on Environmental Quality
CFR: Code of Federal Regulations
CIA: cumulative impact assessment
CPF: central processing facilities
CPUE: catch per-unit-effort
DEIS: draft environmental impact statement
DEW: Distant Early Warning
DOE: U.S. Department of Energy
DOI: U.S. Department of Interior
DPF: Division of Parks and Forestry
DRR: dismantlement, removal and restoration
EIA: Energy Information Administration
EIS: environmental impact statement
EOR: enhanced oil recovery
ERR: economically recoverable reserves

FEIS: Final Environmental Impact Statement
FLIR: Forward Looking Infrared Sensor System
GAO: U.S. General Accounting Office
GIS: geographic information system
HDD: horizontal directional drilling
IAI: Inter-American Institute for Global Change Research
IAP: integrated activity plan
IRS: U.S. Internal Revenue Service
ITEX : International Tundra Experiment
IWC: International Whaling Commission
KDA: Kuparuk Development Area
KIC: Kaktovik Inupiat Corporation
LADS: Light Automated Drilling System
LEOS: Leak Detection Location System
LTER: Long Term Ecological Research Program (NSF)
MMPA: Marine Mammal Protection Act
MMS: Minerals Management Service
MOA: memorandum of agreement
MWD: measurement while drilling
NAAQS: National Ambient Air Quality Standards
NARL: Naval Arctic Research Laboratory
NCP: net calf production
NEP: net ecosystem production
NEPA: National Environmental Policy Act of 1969
NMFS: National Marine Fisheries Service
NOAA: National Oceanic and Atmospheric Administration
NPDES: National Pollution Discharge Elimination System
NPP: net primary production
NPR-4: Naval Petroleum Reserve No. 4
NPR-A: National Petroleum Reserve-Alaska
NRC: National Research Council
NRDC: Natural Resource Defense Council
NSB: North Slope Borough
NSF: National Science Foundation
NWPS: National Wilderness Preservation System
OCS: Outer Continental Shelf
OCSEAP: Outer Continental Shelf Environmental Assessment Program
ONR: Office of Naval Research
OOIP: original oil in place
OPEC: Organization of the Petroleum Exporting Countries
PBOC: Prudhoe Bay Oilfield Complex
PBU: Prudhoe Bay Unit
PCH: Porcupine Caribou Herd
PR: partition rate
PRB: Polar Research Board
psi: pounds per square inch

RCRA: Resource Conservation and Recovery Act
RMOL: Realistic Maximum Response Operational Limits
SAC: Science Advisory Committee
SOP: standard operation procedure
STP: seawater treatment plant
TAPS: Trans Alaska Pipeline System
TCFG: trillion cubic feet of gas
TDS: total dissolved solids
TLH: Teshekpuk Lake Herd
TPH: total petroleum hydrocarbons
TRR: technically recoverable reserves
TVD: true vertical depth
UIC: Ukpeagvik Inupiat Corporation
UNEP: United Nations Environment Programme
USACE: United States Army Corps of Engineers
USC: United States Code
USDW: Underground Source of Drinking Water
USEPA: United States Environmental Protection Agency
USFWS: United States Fish and Wildlife Service
USGS: United States Geological Survey
VSR: volumetric spill rate
WAH: Western Arctic Herd
WSA: The Wilderness Act

Appendix C:

Petroleum Exploration and Development

PETROLEUM EXPLORATION AND DEVELOPMENT ON THE NORTH SLOPE OF ALASKA

Oil Seepages, First Indication of Significant Petroleum Deposits

The first evidence of potentially significant petroleum deposits on the North Slope of Alaska came from the oil seepages that can be seen today along the Arctic Coast from Skull Cliff on the Chukchi Sea to Brownlow Point on the Beaufort Sea. Especially notable are the active ponds of oil and layers of tar at Cape Simpson just east of Barrow. It can be assumed that the native inhabitants knew of these deposits long before recorded history. John Murdoch, a member of the U.S. Navy's International Polar Expedition to Point Barrow and vicinity (1881-1883), reported in 1892 that they had heard stories of a lake of tar on an island a days sail east of Point Barrow (Murdoch 1892). This undoubtedly referred to Cape Simpson. The first non-native to see the Cape Simpson seepages may have been Charles Brower and his partner Patrick Grey while on a hunting trip in August 1886 (Brower 1942). In 1922, while on a trip to San Francisco Brower described the site to the Chief Geologist of the Standard Oil Company of California and this resulted in sending a geologic party to investigate the report (G. Dallas Hanna, unpublished report). In 1917, A. M. (Sandy) Smith, prospector, examined the oil seepages along the coast and he also stimulated the interest of the oil industry. A description of the deposits at Cape Simpson was first published by Brooks in 1909 and was based on information and materials collected by E. de K. Leffingwell. Leffingwell published more details, including chemical analyses of the oil in U.S. Geological Survey (USGS) Professional Paper 109, in 1919.

William Van Valin, a U.S. Bureau of Education teacher at Wainwright, had heard stories of an oil lake on the Arctic coast and in the summer of 1914 he traveled to Cape Simpson and staked a claim for a prospecting permit under the old mining laws (Van Valin 1941). He named the claims, the Arctic Rim Mineral Oil Claims. In 1921 several claims were staked, under the old mining laws, in areas near Cape Simpson, Peard Bay, and along the Meade, Kukpowruk, and Kokolik Rivers, by individuals and industry representatives. However, by 1921, large deposits of oil had been discovered and were being developed in Oklahoma and Texas and industry lost interest in the remote Arctic.

Widespread Oil Seepages on North Slope Confirmed in 1943

In response to inquiries by the Alaska Defence Command and officials of the Territory of Alaska, the Bureau of Mines sent a field party to the North Slope in 1943, specifically to investigate oil and gas seepages. The party was transported by float plane, piloted by pioneer bush pilot, Sig Wien, and guided by Simon Paneak, a native from Chandler Lake. They examined and sampled the Cape Simpson seepages and located several additional sites that had been rumored to occur along the Arctic Coast. Reports of seepages along the coast at Skull Cliff, Dease Inlet, Cape Simpson, Fish Creek, Brownlow Point, Manning Point, and Umiat Mountain were confirmed. Samples were collected from 12 separate sites. The descriptions of the seepages and laboratory analyses were published by N.J. Ebbley in 1944 as War Minerals Report 258.

Native Use of Petroleum Resources

The first utilization of North Slope petroleum resources was undoubtedly by the native inhabitants, the Inupiat. To what extent the natives mined and burned oil tars or pitch from Cape Simpson was investigated by G. Dallas Hanna in 1957. Several older natives at Barrow village described to him how they mined the pitch at Cape Simpson in the spring of the year and transported it in 100 lb (45 kg) sacks to Barrow by dog sled and boat. Recollections differed as to when and who began using this material. Hanna notes that in Van Valin's book, "Eskimo land Speaks", he records his sending natives to Cape Simpson for a supply of tar during a fuel shortage in 1918. Ebbley also reported seeing several sacks of pitch at the abandoned Brower Reindeer Station on Dease Inlet in 1943, a further confirmation of the early use of these petroleum resources by the local inhabitants.

Oil Shale Collected on the North Slope in 1886

The presence of oil shale was further evidence of the potential of the North Slope as a significant oil province. In 1886, Ens.W. L. Howard crossed the Brooks Range descending on to the North Slope along the Etivuluk River were he collected an unusual pebble, later identified as oil shale. Howard continued on to Point Barrow and completed what was the first recorded inland crossing of the Brooks Range and North Slope (Smith and Mertie 1930). In 1945, Simon Paneak, led a USGS field party to an exposure of oil shale on the Kiruktagiak River in the central Brooks Range. Simon said that the inland natives occasionally collected and burned oil shale and coal. Exposures of oil shale have been mapped and collected at several localities in the southern foothills of the North Slope.

North Slope Indicated as a Potential Petroleum Province in Published Descriptions of Oil Seepages and Systematic Geologic Reports, Before 1920

By 1920, published descriptions of the oil seepages along the Arctic Coast and of the geography and geology of Alaska's North Slope had indicated the region as a potential petroleum province. The first recorded systematic geologic and geographic traverse to cross the Brooks

Range and the North Slope by way of the John, Anaktuvuk and Colville Rivers was made by Peters (topographer) and Schrader (geologist) in 1901 and was published in 1904. Travel was by dog team, canoe, and umiak, native skin-boat. Schrader named and described the Lisburne Formation of Mississippian age and he named and described in some detail the Cretaceous rocks and noted the broad anticlinal structures in the foothills. Numerous coal seams were noted and described along the Colville and Anaktuvuk Rivers. They also traversed the Arctic coast from the mouth of the Colville River to Barrow and on to Cape Lisburne. Schrader describes in some detail the coal exposures along the northwest coast that had been mined by natives and whalers for many years.

From 1906 to 1914, E. deK. Leffingwell mapped the Arctic Coast east of Barrow and traversed inland over much of what is now the Arctic National Wildlife Refuge. His report was published in 1919 as USGS Professional Paper 109. Leffingwell described and named the rock formations that were to be discovered as the oil-bearing rocks at Prudhoe Bay. He noted the seepages at Cape Simpson and secured a sample "from a keg of the material collected by natives in the employment of Mr. C.D. Brower, of Barrow." He wrote of other reported seepages along the coast. He concluded that, "Even if an oil pool were found in this northern region, there is serious doubt of its availability under present conditions, though it might be regarded as a part of the ultimate oil reserves that would some time be developed." His description of permafrost and discussion of its origin on the North Slope is one of the first and a classic reference on this important subject.

1923, Naval Petroleum Reserve No. 4, NPR-4 Established

In about 1920, ships of the U.S. Navy were converting from coal to oil to fuel their engines and "experts" were already predicting an oil shortage within a few years. To provide for the future fuel needs of the U. S. Navy, Naval Petroleum Reserve No. 4 (NPR-4) was established by President Warren G. Harding, Executive Order, No. 3797-A, dated Feb. 27, 1923. The presence of major oil seepages at Cape Simpson, Ens. Howard's traverse along the Etivuluk River and across the North Slope to Barrow, the pioneering traverse and report by Schrader, and Leffingwell's classic work were major considerations in defining the borders of NPR-4.

1923 to 1926, First Detailed Geographic and Geologic Mapping of NPR-4

In 1923, the geography and geology of the interior areas of NPR-4 were largely unknown. The U.S. Navy recognized immediately that administration of the reserve would require mapping and more information on these subjects. The USGS was asked to examine and map the reserved tract. From 1923 through 1926, seven USGS parties crossed the Brooks Range and NPR-4 and mapped, at reconnaissance scales, the geology and geography along many of the larger rivers including the Kuk and Utukok in the west and the Etivuluk, Ikpikpuk, Killik and Colville in the east. Travel was by dog team, canoe and by foot. The results of the 1923-26 geologic field work were published by Smith and Mertie in USGS Bulletin 815 in 1930.

In addition to mapping the courses of the major rivers and describing the rock units and structure of NPR-4, Smith and Mertie also analyzed the petroleum potential of the reserve. Although they had very little stratigraphic information on the apparently widespread oil shales, they felt that these were the best possible sources of petroleum. They felt that sources of oil in the

Paleozoic rocks were "extremely problematic" and they recognized no abundant source rock in the Cretaceous. They noted the widespread anticlinal structures in Cretaceous rocks but thought that deposits in these rocks were "likely to be small and of extremely sparse distribution."

They recognized and described the faulted and overthrust structure of the Brooks Range but concluded that north of the range the major structure was a regional dip to the north. Thus they felt that at Cape Simpson, 10,000 to 15,000 ft (3,000 to 4,600 m) of Cretaceous was present and that older rocks were beyond practical drillable depth. Smith and Mertie cautioned would-be prospectors against the adverse geographic factors and the consequential high costs. They recommended that the next step in evaluating the petroleum resources of the reserve should be drilling for stratigraphic and structural information in the vicinity of Cape Simpson followed by geologic field studies and then drilling in other areas that appeared favorable.

1944, First Oil Exploration on Alaska's North Slope Began in NPR-4, a WW-II Project

One of the geologists in the 1923-26, USGS, NPR-4 field survey program was William T. Foran. As Lt. Foran in the U.S. Naval Reserves, he was assigned to the Naval Petroleum Reserves Office. He prepared an issue paper on the promising prospects of the NPR-4 and was largely responsible for convincing the U.S. Navy to start a petroleum exploration program in1944, commonly referred to as the Pet-4 program. It was part of the WW-II war effort and the defense of Alaska. Also in recognition of the tightening oil supplies, caused by the war, the Secretary of the Interior issued Public Land Order 82 in January 1943, which withdrew from entry, subject to preexisting rights, for use in the prosecution of the war, all the generally recognized possible petroliferous areas of Alaska including all of Alaska north of the drainage divide of the Brooks Range. This enabled the Pet-4 project, with the consent of Congress, to extend and follow discoveries and favorable trends outside of the boundaries of NPR-4. This Order was not rescinded until 1958 when Alaska became a State.

An earlier war project to supply fuel to Alaska had been initiated just across the border in Canada were oil had been discovered and a small refinery was built in 1920-21 at Norman Wells in the Mackenzie Valley just south of the Arctic Circle. The Canol project, to develop the Norman Wells Oil Field and lay a refined products pipeline to interior Alaska, was approved in February 1942. Sixty-seven wells were drilled by March 1945 and crude oil was delivered to a newly built refinery at Whitehorse, Canada, on April, 1944. The Canol project was abandoned after only one year of operation and the pipeline to Whitehorse was dismantled. The pipeline to Alaska was shut down in 1945 before any refined products were delivered. Construction of the Alcan Highway to Alaska, another war project, also started in 1942.

The wartime urgency of these projects carried over to the Pet-4 program. The initial plan for Pet-4 was to barge drill rigs from Norman Wells down the MacKenzie River and then west to Point Barrow. However, available rigs were located in Oklahoma and that plan was cancelled. But much was learned about construction and oil development in the Arctic by the Norman Wells project and this was passed on to the Pet-4 program.

The first supplies for the Pet-4 program were hauled to the Arctic in 1944 by ships of the U.S. Navy. The first Barrow expedition, Barex, rounded Point Barrow on August 5, 1944 and stood off Cape Simpson in the fog, rough weather and floating ice for five days. A suitable landing site could not be found at Cape Simpson and the expedition returned to the Barrow village site, where supplies were landed on a nearby beach and the Pet-4 headquarters camp was established. The course of the program and the future developments at Barrow would likely have been quite different if the landing at Cape Simpson had been carried out.

Geologic field surveys in support of the Navy's Pet-4 program were begun also in 1944 by USGS. Geologic traverses began along the Colville River and were expanded to all the major north-flowing rivers of the North Slope. The first geologic field parties traveled along the major streams by special collapsible boats, that could be flown out to the field along with supplies for the summer, in bush planes landing on snow. Virtually, every stream capable of floating a boat was traversed by 1950. In 1946 detailed structural geologic mapping was begun using military-style tracked vehicles (Weasels) for overland transportation. Weasels were used to cross the Brooks Range by four different routes, by way of the Okokmilaga River and the Hunt Fork of the John River and return to Umiat through Anaktuvuk Pass, by way of the Kiligwa River into the Noatak River Valley, and to the crest of the range at the head of the Utukok River. Helicopters were first used for geologic studies in the Brooks Range in 1950 in the Anaktuvuk Pass area.

Trimetrogon aerial photography covered all of National Petroleum Reserve-Alaska and special vertical aerial photography was flew over 70,000 mi^2 (181,000 km^2) of the reserve and adjacent areas. These photographs enabled geologist to interpret the possible geologic structure of nearly all of NPR-4. A special series of photo-geologic maps were produced by the USGS and were utilized to analyze and plan field surveys.

Geophysical studies including experimental airborne magnetometer, gravity and seismic surveys were started in 1945 and by 1952 covered a large part of the reserve. Seismic surveys, mostly reflection shooting, along 3,748 line miles covered about 67,000 mi^2 (174,000 km^2), including areas outside of the boundaries of NPR-4. Travel and housing of the geophysical crews was by tractor- sled trains and smaller tracked vehicles. Gravity-meter surveys covered about 26,000 mi^2 (67,000 km^2) and were conducted by small aircraft and small tracked vehicles. Airborne magnetometer surveys covered 75,000 mi^2 (194,000 km^2), nearly all of the coastal plain and much of the foothills of the North Slope.

The presence of the seepages at Cape Simpson and a quick reconnaissance of the Umiat Anticline by Foran in 1944 determined the first drilling locations. It was also decided that drilling should be limited to no more than 10,000 ft (3,000 m), thought to be the economic limit at that time for development in the Arctic. Supplies were sledded to Umiat in February and March of 1945 and a drilling and logistic support camp was established there. Drilling at Umiat began in 1945, but the Umiat Oil Field was not discovered until 1950. Umiat, however, became and is still an important operating base, for air transportation and geophysical and geological operations.

Thirty-one shallow core tests were drilled at Cape Simpson beginning in 1945. Oil was produced but the estimated reserves were considered to be too small to justify further development. By 1948 geophysical surveys had indicated the presence of a large basement high under the Barrow area. Drilling near the top of this high, discovered gas, but no oil and hard rock basement was penetrated at 2500 ft (760 m). The presence of this basement and further geophysical surveys delineated the so-called Barrow Arch, the north limb of the Colville Basin.

In 1949 a test well was drilled near the Fish Creek seepage and a high sulphur, heavy oil was found at about the 3000 ft (900 m). No structure was discernible and no reserve estimate was made. Geophysical exploration around the Barrow high continued and several tests were drilled on small structures around and stepping down from the high, but no significant oil shows were found.

The discovery at Umiat and the mapping of several closed anticlinal structures in and adjacent to NPR-4 indicated further potential in the northern foothills. Ten shallow test holes were drilled on six structures. One gas field and three prospective gas fields were discovered. Two closed structures were mapped by geophysical surveys in the western part of NPR-4 and test wells were drilled. The Meade test had strong gas shows but the Kaolak test was dry.

Thus in the period 1945 through 1952, 45 core tests and 36 test wells were drilled within and adjacent to NPR-4. The results included the discovery of one large oil field, Umiat, one large gas field, Gubik, one small gas field Barrow, three prospective gas fields, Meade, Square Lake, and Wolf Creek and two small oil deposits at Simpson and Fish Creek. When the Pet-4 program was recessed, unexpectedly in 1953, additional drill sites had been selected and some supplies had been delivered to a location east, of NPR-4 in the southern foothills, near the head of the Shaviovik River and another at the head of the Utukok River in the southwest corner of the reserve. Most of these supplies delivered to these locations were returned to Barrow and Umiat.

A comprehensive historical, year-by-year operational report by John Reed was published as USGS Professional Paper 301 in 1958. The 1944 to 1953, NPR-4 exploration program, utilized all of the then available tools and techniques of modern oil exploration and adapted them to Arctic conditions. These special adaptations and their results are described by Reed in some detail. Drilling activities, geophysical surveys, geologic surveys and studies and their results are also published in detail in USGS Professional Papers 302 through 305. Drilling samples and drill cores from the Pet-4 program are still available for study at the Alaska State Core Library in Eagle River, Alaska and the USGS core library in Denver.

North Slope Petroleum Exploration Activities Post Pet-4. 1953 to 1968

In addition to the continuation of USGS geologic field studies, several major oil companies made extensive geophysical and geologic studies throughout Northern Alaska. However no new test wells were drilled on the North Slope until 1963. Seven relatively shallow test wells were drilled from 1963 to 1965 just outside of NPR-4, near Umiat, presumably to explore for extensions and deposits similar to those in the Umiat and Gubik anticlines.

In 1966 ARCO drilled Susie No.1, and this was followed closely by two test wells near the Colville River delta, all east of the National Petroleum Reserve-Alaska. In 1967 ARCO began drilling a test well near Prudhoe Bay that was announced in 1968 as the discovery well of the Prudhoe Bay Oil Field, the largest in North America. This episode of exploration is covered in more detail in the section on industry oil and gas exploration.

Naval Arctic Research Laboratory and Other North Slope Activities Resulting from the PET-4 program.

Naval Arctic Research Laboratory

Equally and perhaps more significantly to the future development of the Barrow village, all the native inhabitants of the North Slope, and to the continuing exploration and development of North Slope Petroleum resources was the establishment and development of a research facility at Barrow. Research by the U.S. Navy, Bureau of Yards and Docks began in January 1947 in a facility of the Seabee (Navy Construction Battalion) detachment. In May 1947 a building program began to provide housing and laboratory facilities for the Arctic Research Laboratory(ARL) of the Office of Naval Research (ONR). In August 1947, ONR occupied these new facilities and ARL was born. The prefix Navy was added in the mid-1960s and ARL became NARL to more fully acknowledge the U.S. Navy's contribution to Arctic research. After the Pet-4 program was recessed in 1953, the entire camp facility was turned over to ONR until December 1954 when the Air Force took over the management of the base camp to support the DEW Line program. The Air Force continued to operate the base camp through a series of civilian contractors until October 1971 when the operation of the base camp was returned to the U.S. Navy. During the period 1954 to 1971, ONR managed the laboratory through a contract with the University of Alaska. That continued until 1980 when the NARL was decommissioned and the camp and all facilities were turned over to the Department of Interior. During the period 1980 to1984, the laboratory and all camp facilities were managed primarily as a base of operation for the Barrow Gas Fields by the USGS and their contractor. In 1984 NARL and the base facilities were turned over to the local native corporation, Ukpeagvik Inupiat Corporation (UIC).

In spite of all the management changes, NARL continued from 1947 to 1980 to serve as the logistic base and support for Arctic research on land, sea and air. Barrow inhabitants were employed at the laboratory and their experience and knowledge was utilized in many aspects of the operation and research. The laboratory, its facilities and personnel were available to the village when needed and this affected the economic and social life and development of the village in many ways. NARL had a long and very productive history of research and operations in the Arctic that contributed positively to the exploration and development of oil and gas resources on the North Slope.

Barrow Gas Field

The discovery of gas at Barrow in April 1949 was probably the most significant result of the Pet-4 project to the people of Barrow village. The Barrow Gas Fields established some interesting records. The South Field is the oldest *producing gas* field in Alaska and the South and East Barrow Gas Fields are the farthest north *producing* oil or gas fields in North America. The Pet-4 base camp, located, only 4 mi (6 km) from the nearest gas well, was fueled, initially, by oil brought in by barge once a year until the season of 1949-50 when the camp was completely converted to using gas.

When the Pet-4 project began in 1944, there were about 400 inhabitants in the Barrow village. The exploration activities provided employment opportunities for the local people and the population increased rapidly. The advantage of making gas available to the village was obvious, but it took permission from the Congress to extend gas supply to the Barrow village beginning in 1964. It was not until 1965 that the village was completely converted to natural gas. The U.S. Navy supplied gas at a subsidized cost and no limits were imposed on its use. The entire Barrow community became dependent on the Barrow Gas Fields for heat and power. The gas fields and all the base facilities and supplies were turned over to the North Slope Borough in 1984

1976, the Naval Petroleum Production Act and the 1974 to 1985 Exploration of the National Petroleum Reserve-Alaska

In 1974, the oil embargo and the discovery at Prudhoe Bay renewed interest in NPR-4 and the U.S. Navy began a new program of geophysical and drilling exploration along the Barrow-Prudhoe trend, the so-called Barrow Arch. From 1974 to 1976 the U.S. Navy drilled seven exploratory wells and found only residual oil in the formations that are productive at Prudhoe Bay.

In 1976 Congress passed the Naval Petroleum Production Act that transferred NPR-4 to the Department of Interior, renamed the reserve as the National Petroleum Reserve in Alaska and authorized the production for sale of crude oil from NPR Nos.1, 2 and 3. Thus the purpose of the reserves was redirected to augment domestic supplies. The Act authorized continuation of a new exploration program begun by the U.S. Navy in 1976, the further development and maintenance of the Barrow Gas Fields, and continuation of the cleanup program, begun by the U.S. Navy in 1975, at the suggestion of Interior Secretary Rogers Morton. The exploration program and the ongoing contract with Husky Oil Alaska Operations LTD. were assigned to the USGS.

The act also required a series of resource and management studies. The special studies were assigned to the Bureau of Land Management (BLM) as part of their regular responsibilities for the management and oversight of public lands.

The USGS took over the U.S. Navy's facilities at Barrow and Lonely on June 30, 1976 and continued the exploration program with the full support of Congress until 1982. Twenty-one exploratory wells were drilled, including two of the deepest holes in Alaska, to test seventeen plays based on the accumulated knowledge of the geology of the North Slope of Alaska and continuing geophysical surveys. From 1974 to 1982 the U.S. Navy and the USGS acquired about 13,200 line miles of additional seismic reflection data and all were made available to the public. Although nearly all drill tests had shows of oil and gas only one new deposit was discovered, the Walakpa Gas Field, about 20 mi (32 km) southwest of Barrow. This deposit was turned over to the North Slope Borough and has been developed for the long-term supply at Barrow.

The cleanup program, the environmental assessments, stipulations, and monitoring during the drilling program and geophysical surveys set a new standard for exploration activities on the North Slope. More than 25,000 fifty-gallon drums left behind by earlier projects were collected, crushed, and buried. More than 12,000 tons(11,000 metric tons) of debris were collected, burned, buried or hauled to disposal sites. Ice pads, airstrips and roads, including a 38 mi (61 km) ice road from the mouth of the Kikiakrorak River to the Inigok test well site, were used to minimize the impact on tundra vegetation. Three permanent gravel airstrips were built at Inigok, Lisburne and Tunalik drill sites and the airstrip at Umiat was extended and upgraded to support the Seabee test. Gravel drilling pads were leveled and most were seeded. The history, technical data, and analyses from this program were released to the public as open files and were published in USGS Professional Paper 1399, in 1988 (Gryc 1988).

Airstrips

Access to the North Slope for hunting by non-Alaska natives increased with the first federal (U.S. Navy) oil exploration program (1944-1953) and with the second federal program (1976-1983). These programs provided four permanent airstrips within the National Petroleum Reserve-Alaska that can be used by large aircraft. These airstrips are at Umiat on the Colville River, Inigok well site, about 60 mi (100 km) north of Umiat, Lisburne well site in the foothills on the southern border of the National Petroleum Reserve-Alaska and Tunalik well site on the far southwest corner of the National Petroleum Reserve-Alaska. Prior to 1944, aircraft access was available only to a few experienced bush pilots flying smaller, single-engine aircraft landing on natural airstrips such as gravel bars.

INDUSTRY OIL AND GAS EXPLORATION ON THE NORTH SLOPE OF ALASKA AND THE ADJACENT BEAUFORT SEA

After the completion of the Navy exploration program, the North Slope remained off limits to the petroleum industry until 1958 when lands were finally made available for industry evaluation by the federal government between the Canning and Colville Rivers. At the same time, the Arctic National Wildlife Refuge was set aside to protect the northeast corner of Alaska for its wildlife, wilderness, and recreational values. The following discussion is about exploration history and potential and is not an analysis of environmental consequences or of competing values for land use.

Factors Encouraging Industry Activity

While the industry had been aware of and interested in the possible potential of the North Slope, the lack of land availability, remoteness, and the cost of operating in this environment precluded industry participation. However, in the middle to late 1950s and early 1960s, a number of developments provided the impetus for the industry to commence active exploration of the North Slope.

Four factors contributed to the entry of the industry into the North Slope exploration scene: (1) encouraging regional geological studies, (2) the NPR-4 exploration program, (3) oil and gas discoveries in Cook Inlet, and (4) the end of the moratorium on land availability on the North Slope. The discovery of commercial quantities of oil and gas in Cook Inlet demonstrated that it was economically feasible to explore for, develop, and market hydrocarbons in and from Alaska. In 1957, Richfield Oil Corporation made the initial Alaskan oil discovery at Swanson River on the Kenai Peninsula. This discovery contributed significantly to Alaska statehood in 1959 and provided industry with the incentive for exploration of the other sedimentary basins in the state.

The North Slope was one of the areas of interest and was highlighted because of the previous work by USGS and the Navy's exploration program. Both of these efforts supported the premise that a significant reserve potential existed on the North Slope. However, the most important factor was the decision by the Federal government through the BLM to make lands available to the industry for leasing.

Pre-Prudhoe Bay Industry Activity

The industry exploration of the North Slope was greatly stimulated by the knowledge that land was to be made available for leasing in 1958, under basically the same conditions that existed in the Lower 48. Leasing and exploration activities are presented separately to provide a less cluttered flow of activity. It should be noted that the various activities are closely related in time and are interdependent.

Leasing

The federal government offered a total of 18,862.116 acres (7,639,157 ha) for lease in sales held in 1958, 1964, 1965, and 1966 (Jamison et al. 1980, Figure 2). Most of the offerings were to the east and southeast of NPR-4 (now National Petroleum Reserve-Alaska) and south of 70° N. latitude, but the lease sale in 1966 contained 3,022,716 acres (1,224,200 ha) to the west of NPR-4. The leases were offer as simultaneous filings and in blocks or tracts consisting of four contiguous sections (2,560 acres (1,040 ha).

Under the Statehood Act, the state of Alaska selected 1,616,745 acres (654,782 ha) across the northern tier between the Colville and Canning Rivers and subsequently offered these lands in three sales between 1964 and 1966. In 1964, the State held its first lease sale on the North Slope. The sale offered 650,000 acres (260,000 ha) in the Colville Delta area and 196 tracts totaling approximately 475,000 acres (190,000 ha) were leased. In July of 1965, the State held its second North Slope lease sale in the area that would eventually include the Prudhoe Bay field. The sale offering was 754,000 acres (305,000 ha) and 151 tracts totaling 380,000 acres (154,000 ha) were leased. Richfield-Humble acquired 28 blocks on what was to be the crest of the Prudhoe Bay field and British Petroleum acquired 32 blocks on the flanks. The State's third sale was held in January 1967, and thirteen tracts were offered and issued. Richfield-Humble acquired seven tracts that covered the remainder of crestal area of the Prudhoe Bay structure. This completed the leasing prior to the drilling of the discovery well at Prudhoe Bay.

Data Acquisition

With the opening of the North Slope to leasing, the industry began to acquire proprietary geological and geophysical data with the goal of better understanding the subsurface geology and the hydrocarbon potential of the region. These companies acquired two fundamental data sets: geological data through summer field programs and geophysical, primarily seismic, data by winter seismic operations. Jamison et al. (1980, Figure 3) provide a chart of exploration activity spanning the interval from 1958 to pipeline startup in 1978.

In 1958, Sinclair operated a three-month field program out of Umiat in preparation for the Federal Sale in September 1958. Sinclair was quickly followed by others, and an average of 5 to 7 companies were in the field during the 1959-1961 seasons. The number of companies continued to increase, and during 1962-1964 up to ten companies per year were operating geological field programs. During the following three years field programs declined markedly with only 2 to 3 companies in the field.

Sinclair and British petroleum operated the first industry program in 1962. (Because of the lack of information regarding the number of line-miles of data acquisition, the number of crew months is used as a gauge of activity.) The first seismic season consisted of 6.5 crew-months. In 1963 the total was 29.25 crew months and activity peaked in 1964 with 53.5 crew months of work. Seismic crew-months decreased to 26.75 in 1965, and there was very little seismic acquisition between 1965 and the season following the Prudhoe Bay Discovery.

Exploration Drilling

Based on leasing, geological field work, and seismic acquisition the industry began a program of exploration drilling in 1963 and eleven dry wells were drilled prior to the Prudhoe Bay State No. 1 (Alaska Oil and Gas Conservation Commission 2001). Colorado Oil and Gas Company drilled the first well the Gubik area. It and the subsequent seven wells were all drilled on leases acquired in the first round of Federal leasing and were located in the foothills within 30 mi (48 km) of either the Umiat or Gubik discoveries. The initial exploration efforts were focused in or near the areas that had shown the most promise in the Navy's exploration effort. All eight wells penetrated the Cretaceous and were dry holes.

With the failure of the drilling programs in the Umiat-Gubik area, the industry's focus shifted to the north and east. Two wells were drilled, one each by Sinclair and Union, during the 1966-1967 interval on acreage acquired in the first State sale in the Colville area. These were both drilled on the eastern flank of the well recognized Colville High and both were dry holes

During the same time frame, ARCO-Humble drilled the Susie No. 1 in the northern foothills of the Brooks Range on acreage leased in the State's second North Slope sale. This well was also a dry hole and presented AtlanticRichfield and Humble with a critical decision: either release the rig and forego further drilling or haul the rig 60 mi (100 km) to the north and drill in the Prudhoe Bay area. Ultimately, the decision was made to drill the Prudhoe Bay State No. 1.

Discovery at Prudhoe Bay and Aftermath

The proposed drilling site for the Prudhoe Bay State No. 1 well was on State of Alaska leases atop the Prudhoe Bay structure. The principal objective was the carbonate sequence of the Mississippian/Pennsylvanian Lisburne Group. Secondary objectives included Cretaceous clastic and the Permian/Triassic Sadlerochit sandstones. The carbonates were the preferred reservoir objective because of the highly indurated nature of the Cretaceous and Permian/Triassic units where see in surface exposures.

The drilling rig was hauled north during the winter and the Prudhoe Bay State No. 1 commenced drilling in April 1967. Drilling was suspended for the summer and resumed in the fall, after freeze-up. ARCO-Humble announced the discovery in January 1968. Upon completion of a confirmation well, the Sag. River State No. 1 7 mi (11 km) to the southeast, the recoverable economic reserve estimate of 9.6 billion bbl (403.2 billion gallons) of oil and 26 tcf of gas was released.

The timing of the well was fortuitous, as other exploration activities had virtually shut down at the time the Prudhoe Bay State No. 1 was drilled. In 1967, there were only three crew-months of geologic field work, no seismic programs were conducted by the industry and other than the Prudhoe Bay State No. 1 all drilling activity had ceased.

With the success at Prudhoe Bay, the State announced an additional sale in the Prudhoe Bay area for the fall of 1969. As a result of the magnitude of the discovery and the pending sale, the industry greatly increased the level of exploration activities on the North Slope. The geological and geophysical programs leaped from the 1967 levels to twelve geological crew-months and twenty-four crew-months of seismic acquisition in 1968 and then to twenty and ninety-seven crew-months respectively in 1969 (Jamison et al. 1980).

In 1969, thirty-three wells were drilled and completed (ADNR 2000). This number is three times the total of all industry wells drilled on the North Slope prior to the Prudhoe Bay discovery.

Alaska State Competitive Lease Sale No. 23 was held in September 1969. The sale offering was 179 tracts totaling 450,858 acres (182,600 ha). The acreage represented the unleased portion of the State's 1,600,000-acre (650,000 ha) allotment from the Statehood Act. High bids on 164 tracts totaled more than $900,000,000.00 with an average price per lease of $2,181.66 per acre ($5,386.81 per ha). This was to be the last sale on the North Slope for ten years (ADNR 2001a).

During the flush of activity immediately after the Prudhoe Bay discovery, several other oil accumulations were discovered. The major fields discovered in 1969 were the Kuparuk, West Sak, and Milne Point fields. These pre-dated the 1969 sale and provided the operators and their partners with additional information and encouragement for the sale.

Post-Prudhoe (1970 To The Present) Industry Activity

The focus of industry activity from 1969 to the present has been determined by land accessibility. There were no lease sales held on the North Slope or in the adjacent waters of the Beaufort Sea between 1969 and 1979. For that ten-year interval, drilling activity was confined to those areas that had been previously leased. Starting in 1979, the shallow State waters and Federal OCS areas of the Beaufort Sea were made available through a series of lease sales and additional onshore sales were held in the Colville-Canning area.

In the 1980s and again in 2000 portions of the National Petroleum Reserve-Alaska were opened to leasing by the Federal Government through the BLM. The Arctic National Wildlife Refuge has never been leased but there are Native inholdings and a land trade with Native corporations was considered in the mid-1980s. At various times the Arctic Slope Regional Corporation (ASRC) has made portions of their lands available to companies under exclusive exploration/leasing agreements.

The discussion of the post-Prudhoe activity will focus on four geographic areas that have different degrees of accessibility and economics. These are the Colville-Canning area/shallow State waters, the Beaufort Sea OCS, National Petroleum Reserve-Alaska, and the 1002 Area of the Arctic National Wildlife Refuge. The onshore areas frequently contain some combination of State/Native or federal/Native land ownership. The Chukchi Sea area to the west of the North Slope will not be included in this review.

Colville-Canning Area/Beaufort Sea State Waters

Through the 1970s the area between the Colville and Canning rivers, from the Beaufort Sea south to the Brooks Range, was the sole area of industry exploration on the North Slope. Because of limited land availability and the success at and near Prudhoe Bay, this area has been the focus of exploration activity since the discovery well was drilled in 1968. The bulk of exploration and drilling has been concentrated in the northern portion of the area, near Prudhoe Bay and east and west along the coastline, following the structural trend of the Barrow Arch. In 1979, the State of Alaska began a leasing program in the State waters of the Beaufort Sea. This acreage is generally confined to a strip 3 mi (5 km) wide seaward from the shoreline and from

Barrow to the Canadian Border. The issue of ownership becomes somewhat irregular in the vicinity of the barrier islands and major inlets.

Leasing

The ten-year leasing hiatus ended with a joint State-Federal Beaufort Sea sale in December 1979. The State offered 71 tracts (341,140 acres [138,162 ha]) and granted leases on 62 tracts (296,308 acres [120,005 ha]). This sale marked the first major venture into offshore leasing in the Arctic by either the State of the Federal governments and signaled the opening of a new, but highly sensitive and expensive, exploration province.

Between 1979 and the present, the State conducted 37 lease sales on the North Slope and the adjacent State waters of the Beaufort Sea (ADNR 2000 and 2001a). The level of leasing activity has varied greatly over this 20-year interval. The State offerings have ranged from as little as 677 acres (274 ha) (1989) to area wide sales, with several million acres available (1998, 1999, 2000, 2001 and 2002).

The total acreage leased was 7,659,536 acres (3,102,112 ha) with 25 onshore lease sales of 6,208,187 acres (2,514,316 ha) and 12 offshore lease sales of 1,451,349 acres (587,796 ha) (ADNR 2001a). (There have been additional State sales since this citation was published and those numbers are not included.) A significant portion of the total leased acreage includes leases that were acquired in earlier sales, subsequently surrendered back to the State and released in later sales. Lease acquisitions per sale have varied greatly during this timeframe. Onshore leasing has ranged from a high of 170 leases and 978,560 acres (396,317 ha) in the 2001 Foothills sale to a low of zero leases and no acreage in 1993 when 1,033,248 acres (418,465 ha) were offered. Offshore leasing has shown similar variability with a high of 162 leases and 323,835 acres (131,153 ha) (in 1997 when 365,054 acres (147,847 ha) were offered to a low of zero leases and no acreage in 1992 when 153,445 acres (62,145 ha) were available.

Much of this variability, especially the low participation in 1992 and 1993, reflects changes in the market and economic conditions rather than lack of success or dearth of ideas and opportunity. This was also a time when staffs were being reduced and acreage was being surrendered to the state as a cost saving mechanism. Currently, the State is holding an area wide lease sale each year and the participation has been high.

Data Acquisition

There was a change in the level and mode of data acquisition after the major discoveries in the Prudhoe Bay area. Following the high level of activity generated by the Prudhoe Bay discovery, geological and geophysical crew activity decreased sharply in the early 1970s and then slowly increased and stabilized by the late 1970s. Seismic activity was at a high in 1970 with 96 crew-months this decreased to 8 crew-months in 1972 and grew back to 54 crew-months in 1974 (Jamison et al. 1980).

In the late 1970s seismic activity averaged about 25 crew-months per year. Since 1980, the level of seismic acquisition has varied but probably averaged less than 20 crew-months per year. One of the major reasons for this decrease has been the departure of several companies and the merger of former competitors. This has resulted in a significant reduction in speculative and group seismic programs. Also, the existing regional seismic grid has been found to be of sufficient quality to allow companies to more finely tune their seismic acquisition and focus on specific areas. The more recent seismic acquisitions tend to be 3-D programs that provide a more detailed image of the subsurface than do the 2-D surveys. Seismic 3-D programs are too costly to be acquired on a truly regional scale and are generally limited to a maximum of 500 to 600 mi^2 (1,300 to 1,600 km^2).

Geological field activity has exhibited a similar profile. In the early 1970s, geological field programs averaged about 20 crew-months per year. By 1974, this had decreased to six crew-months and averaged 5 to 6 crew-months through the remainder of the 1970s (Jamison et al. 1980). During the 1980s and 1990s, the amount of fieldwork varied considerably but the activity never reached the levels seen in the 1960s and 1970s. Over the last decade geological activity has averaged 1 to 3 crew-months per year. This is once again due in large part to the decrease in the number of major companies actively exploring for oil on the North Slope and the data available from earlier field work.

One important aspect of the geological field activity is that, unlike seismic acquisition and exploration drilling, it frequently takes place external to the principal area of exploration interest. Much of the fieldwork was carried out in the Brooks Range to the south and in the Sadlerochit and Shublik Mountains of the Arctic National Wildlife Refuge. The work in the Arctic National Wildlife Refuge was severely curtailed by regulations in the late 1970s and 1980s. Entry into the Arctic National Wildlife Refuge (not the 1002 Area) has become possible in the last decade. Geological fieldwork that may have impact on the OCS and the Arctic National Wildlife Refuge would be included in the previously mentioned programs.

Exploration Drilling

Following the initial flurry of drilling activity associated with the Prudhoe Bay discovery, exploration drilling decreased markedly. The future of the pipeline was uncertain and no lease sales, offering additional drilling opportunities, were held between 1969 and 1979. Only 34 exploration wells were drilled in the five years (1970-1974) following the 1969 sale. This is only one more than was drilled in 1969. An additional 33 exploration wells were drilled during the 1975-1977 interval, prior to the start up of the Trans-Alaska Pipeline System (TAPS) in June 1977 (Jamison et al. 1980).

Between 1977, and the opening of the pipeline, and the end of 2000 an additional 193 wells in the Colville-Canning area and State waters of the Beaufort Sea have been classified as exploration wells by the State of Alaska (AOGCC 2001). This is an average of 8.5 wells per year and ranged from one exploration well in 1988 to 15 exploration wells in 1981. The most recent five-year span (1996-2000) has seen an average of eight exploration wells per year.

It appears that the Alaska Oil and Gas Conservation Commission (AOGCC) has been fairly liberal in its definition of an exploration well, and has apparently classified a large number of delineation wells as exploration wells. According to the AOGCC count, there have been a total of 296 exploration wells drilled on State leases on the North Slope and shallow Beaufort Sea since the State began its North Slope leasing program in 1964 (AOGCC 2001).

Currently, all exploration drilling is conducted during the winter and the drilling site is constructed atop an ice pad that melts away during the summer. Transport to and from these exploration sites is either via an ice road or by air.

Discoveries

From 1970 to the present, there have been 35 discoveries on State lands (ADNR 2001). These range from the currently uneconomic Kavik (1969) and Kemik (1972) gas fields in the east-central portion of the Colville-Canning province to large oil discoveries at Endicott (1978) and Alpine (1994). A very significant undeveloped resource is the Pt. Thomson gas and light oil field (1977). The field is located just to the west of the mouth of the Canning River and contains reserves estimated at 5 TCFG and 360 million bbl (15.1 billion gallons).

A point worth noting is that in the 2000 area wide State lease sale, one of the bidding groups acquired a very substantial tract of leases in the Kavik-Kemik area. They picked up all the leases, except those held by the discovery wells, which had been surrendered by previous leasees. The possibility of a gas pipeline from the North Slope has changed the perception of those discoveries. The winning companies are betting on gas and that the reserves are larger than previously estimated.

Twenty of the 35 discoveries are either developed and on production or currently being developed. Northstar located offshore, is an example of the latter. At least seven or eight of these discoveries are satellite fields and would not have been developed if they were not "immediately" adjacent to a large field with an existing infrastructure. Tabasco and the Midnight Sun/Sambuca fields are satellites each of which has OOIP of 30 to 70 million bbl (1.2 to 2.9 billion gallons).

Since the first commercial discovery at Prudhoe Bay in 1968, a total of 39 discoveries have been made on State leases and twenty-four, nearly all in the immediate Prudhoe-Kuparuk area, have been or are being developed. This area has been and will continue to be the primary exploration grounds until or unless large, attractive areas of the National Petroleum Reserve-Alaska and/or the Arctic National Wildlife Refuge become available for leasing.

Federal OCS, Beaufort Sea

The Beaufort OCS lands were unavailable to the petroleum industry until the joint State/Federal lease sale of 1979. This and subsequent sales provided access to waters beyond the three-mile limit, stretching from Point Barrow in the west to the Canadian border in the east.

Leasing

The Beaufort OCS has been the site of seven lease sales, commencing with the joint State/Federal sale in 1979 and continuing over a 20-year period to the most recent sale held in 1998 (ADNR 2001a, MMS 2001c). These sales were held at two to five year intervals, with sales in 1979, 1982, 1984, 1988, 1991, 1996, and 1998.

The total acreage offered was 54,811,200 acres (22,198,500 ha) in 10,131 blocks (MMS 2001c). The total includes previously unoffered lands, reofferings of surrendered leases, and reoffering of previously offered but unleased acreage.

The offerings ranged in size from 173,423 acres (70,236 ha) in 46 blocks (1979) to 18,556,776 acres (779,384,592 ha) in 3,417 blocks (1991). Issuance of leases ranged from a low of 24 blocks with 85,776 acres (34,739 ha) in 1979 to a high of 227 leases with 1,207,714 acres (489,124 ha) in 1984 (MMS 2001c). The earliest phase of leasing in the late 1970s and early 1980s drew the greatest level of interest with approximately 21 percent of the offered acreage being leased. The large acreage offerings of the late 1980s and early 1990s (7.28 to 18.56 million acres [2.9 to 7.5 million ha]) drew relatively little interest, with only 3.5 percent of the offered blocks receiving successful high bids. Interest may be on the rise once again. At the most recent sale in 1998, 9.3% of the 920,983 acres (372,998 ha) offered were leased.

Interest peaked early not only in terms of the percentage of offerings receiving bids but also in terms of the values bid on the leases. The average per block bid in the first three sales was in excess of $9,200,000. The lease sales in the late 1980s and early 1990s averaged $377,940 per block. The most recent sale averaged $222,822 per block.

These sales resulted in the issuance of 688 tracks and a total of 3,530,514 acres (1,429,858 ha) (MMS 2001c). Of the 688 tracts leased, only 82 leases or 12 percent are active today (MMS 2001c). Most of these leases are clustered around the discoveries or are associated with newly defined prospects acquired in the most recent sales.

Data Acquisition

The data acquisition issue is somewhat different in the case of the OCS regions. There is little or no geologic field work conducted exclusively for the purposes of developing a better understanding of the offshore subsurface geology. Rather, the subsurface well control from onshore drilling activities and secondarily outcrop geology is tied into the seismic grids to extend the geologic interpretations into the offshore areas and assist in the definition of potential prospects.

Seismic acquisition in the OCS is not well documented; however, commencing in the middle- to late-1970s both summer marine and winter ice programs have been acquired to correlate the better explored and understood onshore geology into the Beaufort Sea. Most, if not all, of the existing seismic data are 2-D with little if any 3-D acquisition outside of the areas of existing discoveries or prospects that are being prepared for drilling within the next few seasons. While the per season or total acquisitions are not known, the totals are easily in excess of 5,000 line-miles.

The existing seismic grid extends across state waters and ties into onshore wells or wells in the shallow near-shore portions of the Beaufort Sea. The acquisition area extends from near Point Barrow on the west to near the Canada border on the east.

Exploration Drilling

The Alaska Department of Natural Resources (ADNR), Division of Oil and Gas (2000) states that 27 exploration wells were drilled within the OCS, without providing a listing of these wells. The Minerals Management Service (MMS 2001) counts 30 exploration wells. This discrepancy is probably the result of the Division of Oil and Gas considering wells drilled on acreage jointly owned by the State and Federal governments to not be OCS wells; whereas, MMS considers these same wells to be OCS wells.

The first OCS exploration well was the Beechy point No.1, spud in 1981, and the most recent exploration well was the Warthog No. 1, spud in 1997. The peak of exploration drilling was in 1985-86 when 11 of the 30 exploration wells were drilled. A secondary drilling mode occurred in 1991-93 with 7 wells drilled. Since 1993, only two exploration wells have been drilled, and both of these were drilled in 1997 (MMS 2001). Phillips Alaska, Inc. had planned to drill an exploration well on its McCovey Prospect in 2001 but was unable to drill the well because of permitting problems. AEC Oil and Gas planned to drill this in the 2002-2003 drilling season.

Depending on water depth, the OCS exploration wells are either drilled from man-made ice islands or large, heavy, bottom-anchored, ice-resistant drilling rigs. If a discovery is made and the field developed, a more permanent structure is built to provide the base for such long-term operations.

Discoveries

Eleven of the OCS exploration wells have been determined to be capable of production (MMS 2001). Of these, five have been termed significant discoveries (MMS 2001 and ADNR 2000). Four of these are in OCS waters and are the Kuvlum, Hammerhead, Sandpiper, and Tern/Liberty. The fifth discovery is the Northstar field (Seal well) which underlies federal and state acreage. The first discovery in the OCS was Tern/Liberty in 1983. It was followed by Seal/Northstar in 1984, Hammerhead in 1985, Sandpiper in 1986, and Kuvlum in 1992.

Water depths range from as little as 21 ft (6 m) at Liberty to as much as 110 ft (34 m) at Kuvlum. These depth variations dictate both the type of basic exploration drilling structure to be used and the type of production platform to be built. The costs escalate significantly with incremental increases in water depth.

Three of these discoveries, Tern/Liberty, Sandpiper, and Northstar lie offshore from the well-established Kuparuk and Prudhoe Bay fields and their infrastructure. The Hammerhead and Kuvlum discoveries are well to the east of the Prudhoe Bay field in relatively deep water. Hammerhead is offshore from the Pt. Thomson and Flaxman discoveries. The Kuvlum discovery is to the east of the Canning River and offshore from the 1002 area of the Arctic National Wildlife Refuge.

The Northstar field has been developed and began production in late 2001. The fate of the Liberty field development is unknown at this time.

The OCS lands of the Beaufort Sea, now and in the foreseeable future, provide a modest to good potential for the discovery and development of large fields (≥500 million bbl [21 billion gallons]) and smaller satellite fields supported by these larger discoveries. The McCovey prospect is but one example of such prospects awaiting the drill. However costs, environmental issues, and the regulatory climate will delay drilling of exploration wells and the rapid development of any new discoveries. Lead-time from discovery to first production may be two-four times that of a comparable onshore field.

National Petroleum Reserve-Alaska

After the completion of the second round of federally sponsored exploration in the National Petroleum Reserve-Alaska, the government elected to open the petroleum reserve and encourage industry exploration. The second phase of federal exploration did not yield any significant discoveries but did provide a wealth of information for future operations.

Leasing

The federal leasing program in the National Petroleum Reserve-Alaska commenced in 1982 with two lease sales in January and May. A total of 271 tracts with 5,035,772 acres (2,039,488 ha) were offered in the two sales. Most of the acreage was located in the south and southeastern portions of the National Petroleum Reserve-Alaska. Between the two sales 38 tracts with a total of 927,965 acres (375,826 ha) were leased. The leased activity was focused in the areas west of Nuiqsut, west of Umiat, and west of the Lisburne well. In both sales the leasees appeared to be pursuing Umiat play-types.

A third sale was held in July 1983. This sale offered 84 tracts and 2,195,845 acres (889,317 ha) spread across the northern portion of the National Petroleum Reserve-Alaska. Twenty tracts, totaling 419,618 acres (169,945 ha), were leased (BLM 1990). These tracts appear to have been selected to evaluate Prudhoe Bay play-types and were largely concentrated in the area between Admiralty Bay and the Chukchi Sea.

A fourth sale was scheduled for July 1984. Sale No. 841 was to offer 64 tracts and 1,550,677 acres (628,024 ha). When no bids were submitted for the sale, leasing was cancelled (Weimer 1987, Banet 1991).

During this brief leasing period, the industry acquired 58 tracts and 1,347,583 acres (545,771 ha). None of these leases are currently in force. The last of these leases were relinquished in the early 1990s.

The discontinuance of leasing in 1984 resulted in a 15-year hiatus in leasing activity and exploration in the National Petroleum Reserve-Alaska. It was not until after the 1994 discovery of the Alpine field in the Colville Delta area that the government recognized the renewed industry interest in the National Petroleum Reserve-Alaska and re-instituted leasing in the petroleum reserve.

With the assistance of the MMS, the BLM developed a leasing program in the late 1990s, and the first sale of this new series was held in May 1999. The sale was restricted to the northeastern corner of the National Petroleum Reserve-Alaska, an area comprised of 4.6 million acres (1.9 million ha). The sale was conducted with multiple restrictions regarding drilling locations and presence of surface facilities. Approximately 3.9 million acres (1.6 million ha) were offered. This offering drew 132 high bids on 861,368 acres (348,854 ha). Twenty-two percent of the offered acreage was leased (BLM 2001).

The bulk of the leased acreage is in the vicinity of Nuiqsut and extends from the Colville River westward through Townships 9-12 North to Range 6 West. A second, smaller block of leased tracts lies between Teshekpuk Lake and the Ikpikpuk River (Mapmakers Alaska 2000). These leased areas include lands that were originally leased in the 1980s leasing episode, but they were surrendered without having been drilled.

The leasing pattern indicates that the industry is focused on exploring for Alpine-type plays in the area of eastward migrating Jurassic and Early Cretaceous shelf margins. Additional objectives probably resemble Tarn and Kuparuk plays.

An additional sale was held in the northeastern area in 2002. It was essentially a re-offering of 3,051,500 acres (1,235,858 ha) not leased in the 1999 sale. A total of 60 tracts with 579,269 acres (234,604 ha) were leased. The newly leased acreage is generally to the south and west of the previously acquired leases.

Data Acquisition

The bulk of the data utilized in the industry's evaluations were obtained by federal agencies during their exploration efforts. A total of 16,479 line-miles of seismic data were acquired during the government's exploration effort (Schindler 1988). These data are publicly available and have been extensively reprocessed to enhance their utility.

In the early 1980s, a number of geologic field parties were conducted in the foothills south and southwest of the the National Petroleum Reserve-Alaska, along the Colville River, and in the coastal area from the vicinity of the Corwin Bluffs to Cape Lisburne.

After the discovery of the Alpine field and in preparation for pending sales in the National Petroleum Reserve-Alaska, the major participants in ongoing North Slope exploration began to conduct 2-D and 3-D seismic programs in the probable sale area. The total line-miles of seismic data acquired are not known. There were at least seven 2-D programs acquired between 1992 and 1997 totaling 2,615 line-miles. A single 3-D program was shot in 1996 and covered an area of 152 mi^2 (394 km^2) (Kornbrath et al. 1997). There have been additional 2-D and 3-D programs acquired since 1997; however, the number of programs and coverage are not known.

Exploration Drilling

Leasing in the early 1980s resulted in the drilling of only one industry exploration well within the National Petroleum Reserve-Alaska. This was the ARCO Brontosaurus No. 1. It was drilled in 1985 as a test of the Ivishak truncation—a Prudhoe Bay style prospect. The well was located in the western portion of the National Petroleum Reserve-Alaska about 40 mi (64 km) south-southwest of Point Barrow. The hole was dry and any other plans to drill were abandoned. However, the well was not an entire waste, as it provided a much-needed data point and an additional control for future exploration in the Chukchi Sea. An additional well, the Chevron Livehorse, was drilled on Native inholdings and will be discussed later.

After Sale No. 991 in 1999, the industry commenced an extensive drilling program in the northeastern portion of the National Petroleum Reserve-Alaska. Three wells were drilled in the winter of 2000 and an additional six wells were drilled in 2001. Most, if not all, of these wells are probably targeting Alpine-style prospects. It is anticipated that drilling and additional lease sales will keep this area an active focus of exploration for at least the next six to ten years.

Discoveries

At least five of the wells drilled in the National Petroleum Reserve-Alaska have discovered hydrocarbons. Both oil and gas were found. The size of the discoveries has not been made public. But the operators have indicated that the oil reserves are at least equal to those of the Alpine field. The gas potential is unknown.

Arctic National Wildlife Refuge

The 1002 Area of the Arctic National Wildlife Refuge has long attracted the interest of the petroleum industry. There are numerous active oil seeps, exposures of oil-stained sandstone, and large attractive structures. However, these lands are currently closed to the Industry and can only be opened for exploration and potential development by an act of Congress.

Leasing

Because ANILCA prohibits it, there has been no leasing in the 1002 Area. However, in 1987 the Reagan administration proposed to trade land/exploration rights in the 1002 Area for Native corporation inholdings in National Parks and other sensitive areas. Six Native corporations were found qualified to participate and each chose an industry partner. The industry partners were to supply technical expertise and have exclusive right to explore any lands acquired by their Native corporation partners.

The federal government did propose and develop a tract selection/trade process and the Native corporations and their industry partners proceeded to bid on 71 complete or partial tracts. These tracts were 4 mi^2 (10 km^2) parcels. This land trade was never carried through to completion and the lands were not transferred. As a point of interest, virtually all the prospective trade lands identified in that process were either along the Marsh Creek Anticline or to the east of it. Unpublished industry evaluations have tended to place a greater portion of the areas potential resources in the deformed area. This would include the Marsh Creek Anticline and areas to the east.

Data Acquisition

Data acquisition in the Arctic National Wildlife Refuge has been largely restricted to geological field parties in the Brooks Range, south of the 1002 Area, and to the limited seismic acquisition program conducted under government oversight in 1984 and 1985.

The seismic program was acquired during successive two field seasons (1984 and 1985). A 22-company consortium shared the cost of the data acquisition and processing. These two seasons produced approximately 1,400 line-miles of mostly poor to moderately good data quality. Because of the paucity of seismic control, public and proprietary gravity and magnetic data were used extensively in the Arctic National Wildlife Refuge.

Exploration Drilling

Since there has been no leasing within the 1002 Area, there has been no exploration drilling. However, Kaktovik Inupiat Corporation holds surface title to some lands, and the city of Kaktovik lies within the boundaries of the refuge. British Petroleum/Chevron drilled a well on native lands through an exclusive exploration agreement with the Native corporation. The information from this well has been held confidential since it was drilled in 1986.

Discoveries

Since there has been no drilling within the 1002 Area there have been no discoveries. However, there are two discoveries west of the Canning River that abut the 1002 Area. It is possible that either the Sourdough or Pt. Thomson fields may extend eastward into the 1002 Area. If and when they are developed, they may have the potential to drain oil and/or gas from beneath the Arctic National Wildlife Refuge.

Native Corporation Lands

The Arctic Slope Regional Corporation (ASRC) and its various village corporations have extensive land holdings across the slope. These extend from Barter Island in the east to the Chukchi Sea in the west and from the Beaufort Sea in the North to the crest of the Brooks Range in the south. The regional corporation and several of the village corporations have entered into exploration agreements with various petroleum companies. These agreements have generally required some form of initial monetary commitment, specific work commitments, and an agreement to lease potential acreage or forfeit the right to explore at an agreed upon date. One or more exploratory wells are also required if the company elects to go to lease.

Leasing

There is no competitive leasing process such as the MMS or DOG utilize to make lands available to industry. The negotiations are generally confidential. Chevron, Texaco, ARCO, and Unocal have had such agreements in the past. Anadarko Petroleum and its partners currently have an exclusive exploration agreement with ASRC for nearly 3 million acres (1.2 million ha) in the Foothills area of the Brooks Range.

Data Acquisition

The data acquired on Native corporation lands, especially seismic and other geophysical data are usually kept confidential, and the data are only available to the corporation and its industry partners. Therefore, it is difficult to assess the amount and quality of such data. Geological field programs are in most cases applicable to both State and private lands and have been addressed previously. However, with the recent interest in a gas pipeline, there has been increased activity in the Brooks Range foothills, and the Native corporation lands there are being reevaluated for both oil and gas. This has resulted in a recent increase and refocus of geologic field efforts in the foothills belt. Similarly, new seismic data were acquired during the recent winter seasons. These seismic programs included both 2-D and 3-D acquisition technologies.

Exploration Drilling

Through ASRC's exploration agreements with various companies, eleven exploration wells have been drilled on Native corporation lands on the North Slope (ADNR 2001b). Some of these Native corporation holdings are in the form of inholdings within national parks, national monuments, and wildlife refuges. This has afforded those companies with Native corporation exploration agreements the opportunity to drill and evaluate areas that are not otherwise assessable and are off limits to the rest of the industry. These wells have been drilled on inholdings within the Arctic National Wildlife Refuge and the National Petroleum Reserve-Alaska as well as in the foothills of the Brooks Range south of the State acreage in the Colville-Canning area. There have also been wells drilled on ASRC lands to the west of the National Petroleum Reserve-Alaska.

A listing of these wells, their general location, year drilled and operator is presented to indicate the spectrum of ASRC holdings.

	OPERATOR & WELL	LOCATION	YEAR
1.	Texaco, Tulugak No.1	26-5S-3E (Umiat)	1977
2.	Chevron, Eagle Creek No.1	29-8S-45W (Umiat)	1978
3.	Chevron, Tiglukpuk No.1	15-12S-2E (Umiat)	1978
4.	Chevron, Akuluk No. 1	23-5S-49W (Umiat)	1981
5.	Chevron, Killik No. 1	08-12S-10W (Umiat)	1981
6.	Chevron, Cobblestone No. 1	25-10S-8E (Umiat)	1982
7.	Chevron, Livehorse No.1	13-17N-2W (Umiat)	1982
8.	Unocal, Tungak Creek No. 1	12-6N-42W (Umiat)	1982
9.	Chevron/BP, KIC No. 1	01-8N-36E (Umiat)	1986
10.	ARCO, Big Bend No. 1	24-3S-2W (Umiat)	1993
11.	ARCO, Nuiqsut No. 1	05-11N-4E (Umiat)	1998

The KIC well was drilled on Kaktovik inholdings in the Arctic National Wildlife Refuge and provided Chevron and BP with a source of information unavailable to all other companies. The well is being held confidential. The Livehorse well was drilled on native inholdings in the northern part of the National Petroleum Reserve-Alaska. It provided Chevron a data point that could have been of benefit in the sales held in the National Petroleum Reserve-Alaska during the 1980s.

The Akulik, Eagle Creek, and Tungak Creek wells are located to the west of the National Petroleum Reserve-Alaska and are the only wells in that portion of the North Slope. The information from these wells provides the only subsurface data in this part of the state. There are only two other wells, both within the National Petroleum Reserve-Alaska, within 100 mi (160 km) of these wells.

The Cobblestone, Killik, and Tiglukpuk wells are the southern-most wells on the North Slope. They are well south of the existing leased acreage of the Colville-Canning area and provide key subsurface information for the foothills lease sales, especially with regard to gas potential.

The availability of native corporation lands can provide a company with access to areas otherwise off limits to the industry and may supply data that will give the operator an advantage over competitors in future land acquisitions. Additionally, these wells may lead to large discoveries that lack the problem of joint ownership with those same potential competitors.

Discoveries

There has been one discovery associated with ASRC lands in the Colville River delta. The Alpine field extends beneath leases jointly held with the state. The KIC well has been held confidential by Chevron and BP, since it was drilled in 1986. There has been considerable discussion regarding the stratigraphic succession that may have been encountered as well as speculation regarding the presence of hydrocarbons in either commercial or sub-commercial quantities. If commercial hydrocarbons were found, there is still a major problem confronting any plans for development even if Congress allows oil and gas activity in the Arctic National Wildlife Refuge and/or the ASRC inholdings to oil and gas development and production. To produce any oil that may have been found at KIC, a pipeline to TAPS would have to either pass westward across the 1002 Area or be buried offshore in the Beaufort Sea. The offshore pipeline would need to extend westward beyond the Canning River before it could be brought ashore and tied into future pipelines in the Pt. Thomson/Sourdough area.

To date, the relative remoteness of the native land selections has required very large reserves or has encountered access barriers that have somewhat limited the general industry interest. With the development of a more far-reaching infrastructure and the pending market for natural gas, the native land position may assume a preeminence not seen before on the North Slope.

Future Exploration Potential

There has been concern regarding the long-term viability of the oil and gas industry on the North Slope. The declining production at Prudhoe Bay, Kuparuk and other older fields has led to speculation that the industry will soon turn its eyes and investments elsewhere. However, with the advances in technology, the development of new exploration concepts, and the pending market for gas should be sustained provided that the exploration opportunity exists and that lands are made available for future drilling and development. Within the geographic confines of the North Slope and Beaufort Sea, there are at least four areas of opportunity for the future exploration and development.

Continuation Of Present Exploration Trends

The Colville-Canning area and the Beaufort Sea will continue to be the central focus of exploration for some time. There is little doubt that small satellite accumulations will continue to be found in close proximity to the major facilities at the Prudhoe Bay and Kuparuk fields. However, these will fall far short of offsetting the production declines in the major fields. The major petroleum potential exists in the Federal OCS portion of the Beaufort Sea and to a lesser extent in the State waters.

The Jurassic, Cretaceous, and Early Tertiary age shelf sandstones and lower slope to basin turbidite objectives will continue to be targets and may yield additional Alpine and Point McIntyre size fields. The probability of finding large Prudhoe Bay- or Endicott-type fields in the northern portion of the Colville-Canning area or in the shallow Beaufort Sea is low.

National Petroleum Reserve-Alaska

Early exploration efforts by the Navy and USGS severely damaged the hopes of finding Prudhoe Bay and Lisburne/Endicott style plays along the westward extension of the Barrow Arch into the National Petroleum Reserve-Alaska. However, the Barrow, Simpson, and Walakpa gas fields of northwestern the National Petroleum Reserve-Alaska and the Alpine oil field of northeastern the National Petroleum Reserve-Alaska indicate that these Jurassic/Cretaceous shallow marine shelf reservoirs offer a multitude of opportunities. This trend could potentially be pursued across the entire northern half of the reserve. As seen at Alpine, there is the potential for 500 million bbl (21 billion gallons) fields.

Oil plays may extend well south into the foothills. The Navy's discovery at Umiat demonstrates the potential for reserves in the several tens to a few hundred million barrels range. Recent work by the USGS and DDGS has, shown that even in the southern portions of the National Petroleum Reserve-Alaska and at the same latitudes to the east and west, that source rocks currently in the oil window and oil stained sandstones are not uncommon.

With an ongoing leasing program in place, the National Petroleum Reserve-Alaska may play a significant role in the future viability of the North Slope as a hydrocarbon province. However, it is unlikely that the area will yield fields that will rival Prudhoe Bay or even Kuparuk in terms of recoverable reserves.

Arctic National Wildlife Refuge

The environmentally and politically sensitive 1002 Area of the Arctic National Wildlife Refuge has the greatest remaining potential for the discovery of large oil fields in Alaska. Large structures are evident on the surface and from the limited seismic data. Oil seeps occur at several localities, there are numerous exposures of oil stained sandstone, and several accumulations abut the area on the west and may possibly extend into the refuge.

Several high quality oil source rocks are known to be present within the Arctic National Wildlife Refuge. They are exposed in the front ranges to the south of the 1002 Area and within the 1002 Area itself. These sources are locally sub-mature to mature for oil generation and support the thesis that oil has been generated and may have accumulated in the large structural and stratigraphic traps of the coastal plain.

The technically recoverable reserves attributable to the 1002 Area have been estimated to be as great as 11.8 billion bbl (496 billion gallons) with a mean estimate of 7.7 billion bbl (322 billion gal) (Bird and Houseknecht 1998). There is no comparable publicly available estimate for gas reserves.

Gas Plays in the Foothills and Portions of the National Petroleum Reserve-Alaska

With the possibility of a gas pipeline to transport North Slope natural gas to domestic and world markets, there is increased interest in gas exploration. Without a gas pipeline or the promise of one, gas has had no value and in fact has had negative value in those cases where gas-handling costs are high.

In addition to the major gas reserves associated with the large oil fields along the Barrow Arch, there have been several minor gas discoveries in the Brooks Range Foothills. The best known discoveries are Gubik, Kavik, and Kemik gas fields. The Gubik gas field was discovered during the Navy's National Petroleum Reserve-Alaska exploration program in 1951, and the Kavik and Kemik fields were discovered by the industry in 1969 and 1972 respectively. Each of these fields is estimated to contain 100 to 300 or 400 BCFG.

The southern area has large structures, abundant gas-prone source rocks or overmature oil-prone source rocks, and thick sequences of sandstone with porosities and permeabilities adequate for gas reservoirs. Fracturing tends to be common and is the source of the bulk of the porosity in the Kavik and Kemik wells.

The emerging gas potential of this area can be seen in the bidding trends of the State's 2000 and 2001 North Slope and Foothills area wide lease sales. This strongly implies a very concerted effort to explore the area for gas as well as the more conventional oil plays. This area has the potential to equal the reserve base of the Barrow Arch-associated gas accumulations and would signify a long-term future for gas exploration and production on the North Slope. A gas pipeline along the haul road from Prudhoe Bay would pass through the central portion of this potential gas province. Spur pipelines to the east and west could be constructed to tie into the gas line in the vicinity of TAPS pump station No. 3.

Factors Influencing Future Exploration

The North Slope may continue to play a major role in meeting the energy requirements of the United States well into the twenty-first century, but several key elements will greatly influence the magnitude, stability, and duration of that role. Among the most significant of these factors are oil and gas prices, land availability, regulatory environment, and level of competition.

Prices

The price structure for oil, and to a lesser extent gas, and its stability will play a pivotal role in the future of the petroleum industry in Alaska. Recent low world oil prices have demonstrated just how sensitive the Alaskan oil industry is to fluctuations in price. With low prices, the high cost of producing a barrel of oil in Alaska places North Slope crude at a disadvantage relative to the OPEC cartel and other low-cost producers. It also tends to dry up funding for Alaskan projects by the producing companies who can realize a greater return on investments in those same low-cost environments. With prices that provide a reasonable return on investment, exploration and development opportunities will continue to attract industry to the North Slope.

Land Availability

Even with sustained high oil prices, there will be no significant reserve additions without attractive exploration opportunities. These opportunities only exist when there is a continued and diverse offering of exploration acreage. A successful exploration effort requires that a broad mixture of potential play types of a size sufficient to provide economically viable targets be made available in a predictable and systematic manner. In such a scenario, exploration would provide a spectrum of field sizes such that the larger accumulations generate the demand for the infrastructure, which will in turn create an environment in which smaller fields (satellites) may be profitable to develop.

In the relatively near future, the available relatively low-cost operating areas, near existing infrastructure will have been reasonably well explored. They will be deemed to no longer have the potential to yield discoveries of sufficient size to replace the production lost due to decline of the older major fields. At that point, there will either be pressure to open additional lands to exploration or it will be acknowledged that the region is in decline and that reduced production will ensue and eventually lead to the shutdown of operations and the pipeline.

Prediction Versus Reality

Apparent failure of early stage predictions, regarding reserve size, number of wells to be drilled, size of areas to be affected by development, and miles of roads and pipelines, has caused concern and raised the issue of credibility in some minds. Obviously, if anticipated potential effects are based on the early stage predictions any significant deviation from those forecasts will result in a difference in the magnitude of any activity-associated effects.

The problem lies in the failure to recognize that each of these predictions, whether they are the number of oil fields in an area, the size of the accumulations, or the amount of infrastructure necessary, is based on very little solid scientific data. When exploration begins in a new area, like the North Slope in the 1960s, no one has direct evidence of the true nature and distribution of potential reservoirs in the subsurface, let alone the presence or volume of hydrocarbons that may be present. Seismic data used to determine the presence of potential structures and traps, and outcrop exposures, often tens or hundreds of miles away, are the sole source of possible reservoir data. Based on these bits of information a first prediction is made as to the probability of oil or gas being present, and then if the assumptions regarding structure, trap, reservoir, and source are reasonable, what range of hydrocarbon volumes may the feature contain? As can be readily seen, the reality as revealed by the drill may be very different from the pre-drill predictions.

Prudhoe Bay was a definite surprise, it was far larger than expected and the vast bulk of the oil was found to be in a rock that was not thought to be a reservoir target prior to drilling the well. The first predictions were wrong. The second prediction at Prudhoe Bay was that the field contained 9.6 billion bbl (403.2 billion gallons) of recoverable oil. An independent company based on the evaluation of delineation wells determined this value. Subsequent planning for the field used that reserve figure. Advances in technology, and geologic variability in the reservoir have placed current estimates of recoverable oil in the 13 billion bbl (546 billion gallons) range.

Similar results have been noted at Kuparuk and Endicott fields. The Lisburne field has not met expectations either in terms of daily production rates or cumulative production. This is largely the result of applying the incorrect reservoir model to the field in its early stages.

Predictions made at the time of the discovery of these fields did not recognize the upside that existed (or the downside in the case of the Lisburne). As a result estimates of the life span of the fields, size of areas to be affected, number of wells to be drilled, and other variables were not precise and should not have been expected to be.

Additionally, the development of the infrastructure at Prudhoe Bay and Kuparuk, plus TAPS made exploration for previously unrecognized or ignored nearby small accumulations feasible. This again contributed to a larger area of development than was forecast at the time of the original estimates. Once again is must be recognized that these satellite fields were either unknown, not economic under then present economics, or were known to individual companies as a result of proprietary data which were not shared with competitors for obvious reasons.

These early estimates work both ways, there tend to be more over-estimates of potential than under-estimates. The public generally never hears of these because the either the company drills a dry hole and abandons the project or it acquires additional data that indicates the prospect is invalid or uneconomic and no drilling occurs. The most notable failure in north Alaska was the Mukluk well. The potential of this prospect was thought by many to rival Prudhoe Bay. Exploration, leasing, and drilling costs may have totaled as much as $2 billion. The well was drilled and abandoned as a dry hole.

Uncertainty and risk are the nature of the exploration business. Any company that is willing to spend the money and time to acquire data, lease land, and drill exploration wells is hoping for a discovery of a size sufficient to justify the costs and provide an adequate, competitive return on the investment. That company is also gambling that the field will provide the infrastructure to support possible nearby accumulations when and if they are found.

An observer may note that when an exploration company acquires a new lease or block of leases, it will often permit multiple well locations. In reality, only a fraction of these locations are normally drilled. This is due either to a failure to discover an economic accumulation in the most favored locales or because the initial interpretation of the geology was not correct.

Historically the successful prediction of exploration and development activity in terms of how much, when, and where has been as much an art as it is a science. Recent technological advances have resulted in a much improved exploration success rate, but frontiers areas still bear a high risk and failure rate. With the full awareness of this uncertainty, a range of potential and cumulative effects of future oil and gas activities can be addressed. The best approach is to use the knowledge derived from known activity and its effects and project a likely case into the future, with a series of scenarios that vary the future activity within reasonably constrained limits. This approach still will not guarantee when, where, and how much. However, it should provide the most reasonable range of estimates of the overall effects of future activities.

Appendix D:

Oil Field Technology and the Environment

TECHNOLOGY IN EXPLORATION

Advances in exploration-related technology have been directed toward more precisely identifying subsurface drilling targets in order to reduce the number and cost of exploration wells (DOE 1999) and to reduce the impact on the physical/biological environment. Technologies such as 3-D seismic-data acquisition and 4-D visualization allow for the drilling of fewer wells and the use of ice roads and ice pads, plus remote sensing, can decrease the direct impact on the tundra, although the long-term effects are not fully known. These newer technologies have largely replaced the older, less-efficient and, in some cases, less environmentally friendly practices and techniques.

3-D Seismic-Data Acquisition/4-D Visualization

Improvements in 3-D seismic-data acquisition and other exploration technologies allow geologists to identify higher quality prospects and to improve success rates by as much as 50 percent or more. In 1970, the success rate for exploration wells in the U.S. was about 17 percent. In addition to the advances in data quality and acquisition procedures, there have been important advances in the engineering of the vehicles used to move the camp equipment and to acquire the data. The major changes have been in the development of new "light-weight" rubber tracked caterpillar-type vehicles and vibrators, that do less damage to the tundra and willows than the older vintage steel-tired vehicles. With the use of 3-D seismic-data acquisition, success rate had increased to 48 percent in 1997 (DOE 1999, Revkin 2001). Phillips Alaska, Inc. and Anadarko Petroleum Corporation's recent exploration success in the National Petroleum Reserve-Alaska was an astonishing five successful wells of six drilled (Petroleum News Alaska 2001).

About 25 years ago, 3-D seismic technology was introduced. Data are acquired in a grid-like manner with the individual lines spaced only a few hundred feet apart, and are computer manipulated to create multidimensional representations of the subsurface. The result is a far better understanding of the geologic structures and continuity of the potential hydrocarbon-bearing formations. As with the older generation 2-D seismic data, onshore 3-D seismic data are acquired during winter, after freeze-up to a depth of 12 in. (30 cm) and an accumulation of 6 in (15 cm) or more snow. Vibrators are used and these energy sources and the crews, camps, and other support facilities are carried on and/or are usually towed by low-impact tundra travel vehicles (Lance 2000). Seismic grids may cover an area of hundreds of square kilometers. Most offshore 2-D and 3-D seismic data are acquired during the open water season using airguns rather than vibrators. Some offshore data, in the area of bottom-fast ice, are acquired during winter using land technology. The 3-D data sets are often used throughout the life of a field to plan infill and injection wells.

The older land-based 2-D seismic technology consisted of long, intersecting seismic lines that used either dynamite or vibrators as the energy source. In the early stages of acquisition on the North Slope, much less care was taken to protect the tundra from damage during data acquisition. Damage, then as now, can result from inadequate snow cover and inappropriate equipment. Recent seismic data, both 2-D and 3-D, have been acquired in a much more environmentally sensitive manner.

Offshore seismic data are acquired using patterns and spacing similar to those used in onshore acquisition. These data can be acquired only when the sea is relatively ice-free and boats can maintain long uninterrupted traverses. A high noise level is associated with marine acquisition, and it negatively affects marine organisms, especially whales.

4-D visualization adds the element of time to 3-D seismic databases. A reservoir's fluid viscosity, saturation changes, temperature, and fluid movements can be analyzed by time-lapse monitoring in three dimensions (DOE 1999). The time-lapse picture is built out of data re-recorded, compared, and plotted by computer onto the 3-D model. Additional data, such as well logs, production information, and reservoir pressures, may be integrated into the time-lapse imagery. The resulting information provides geologists and others with data that are valuable for both exploration for and management of existing resources. The exploration element comes from the greater ability to predict the best locations for exploratory drilling.

The 3-D seismic-data acquisition and 4-D visualization technologies provide a number of environmental benefits (DOE 1999). They include more accurate exploration well-siting that reduces the number of dry holes and the number and length of ice roads and the number of ice pads that have to be built; generation of less drilling waste and decreased volumes of materials that are thereby lessening the possibility of a spill or other accident; better understanding of flow mechanics so that less water is produced relative to oil or gas; and increased ability to tailor operations to protect sensitive environments. Overall fewer wells are required in order to evaluate and produce the reserves.

Nonetheless, considerable concern has existed regarding the effects of any seismic activity conducted either on land during winter or at sea during the open water season (Van Tuyn 2000). Land-based seismic-data acquisition with its large vehicles and numerous traverses across the tundra has left scars of the vehicle paths, some of which have been slow to heal and recover. At sea, migrating bowhead whales have been deflected by noises generated by seismic exploration and drilling.

The 3-D seismic-data acquisition programs require more closely spaced grids, a few hundred feet between lines as opposed to several kilometers with standard 2-D seismic programs. This closer spacing has the potential to affect a greater amount of the tundra surface. These trails are often highly visible the following summer, in part because the old dead vegetation has been flattened by the vehicles and the green new vegetation can be more readily seen in sharp contrast to the undisturbed surrounding areas.

The closer spacing of the seismic traverses may also increase the risk that denning polar bears may be disturbed. This risk could be lessened by studies of bear denning sites and planning the acquisition programs accordingly.

Remote Sensing

Remote-sensing techniques such as infrared photography have been used to design and locate roads and facilities, such as development facilities and ice roads and ice pads, to reduce effects on the environment. Satellite infrared photography has been utilized to facilitate habitat mapping in the Alpine field (Lance 2000). The environmental benefits come from the avoidance of critical habitat and better design of facilities that must be placed within less than ideal locations. No negative consequences have been identified with the use of this technology.

Ice Roads/Ice Pads

Arctic tundra is easily disturbed and slow to recover from damage. Disruption of tundra may also have a pronounced effect on permafrost and result in thawing and erosion. Historically, roads to exploration well sites were built of peat, bladed bedrock, or gravel, causing long term damage to tundra that remains evident after forty or more years. Drilling pads were similarly built of gravel or bulldozed bedrock in some areas of the National Petroleum Reserve-Alaska during the Navy exploration efforts in the 1940s and 1950s. Because of these factors and potential damage from transporting equipment across the tundra either in the summer or winter, ice roads have replaced gravel roads and have become the means of access to isolated drilling locations. In a similar fashion, ice pads have become the standard for exploration drilling sites, eliminating the need for gravel to build pads and cleanup after drilling. All onshore exploration drilling is done during winter and all materials necessary for drilling a well, including the drilling rig, are moved to and from well locations on ice roads.

An ice road 6 in. (15 cm) thick and with an average width of 30 to 35 feet (9 to 11 m) would require 1 million to 1.5 million gallons of water per mi (620,000 to 930,000 gallons of water per km) of length (Van Tuyn 2000). BP Exploration (Alaska), Inc. reports that the ice roads are generally 12 to 18 in. (30 to 46 cm) thick. Frequently, exploration activity within a specific area requires more than one drilling season; therefore, more than one ice road may be built from the staging area(s) to the same drilling site or prospect. To avoid possible damage from multiyear usage of the same area, any subsequent ice road is offset by at least a road width from previous ones.

A 6-acre (2.4 ha) drilling pad, 12 in. (30 cm) thick would require approximately 500,000 gallons of water (Van Tuyn 2000). The ice pads provide a solid, stable base from which to drill an exploration well. Upon completion and abandonment or testing of the well, the rig and all support facilities are moved off location and the pad is allowed to melt. The result is a very low impact operation, and usually the only indication of the drilling activity is the abandoned wellhead.

In special situations, specifically where drilling and evaluation are expected to require either an extended drilling season or two drilling seasons, insulated ice pads have been utilized. BP Exploration used such a system when drilling the Yukon Gold No. 1 and Sourdough No. 2 wells in the 1993-1994 drilling season (DOE 1999). A 190 by 280 ft (120 by 85 m) ice pad was built in March 1993 and covered with wind-resistant insulating pads. The pads remained in place over the summer and were removed in October. Drilling began in mid-November, two months ahead of conventional Arctic practice. With this advanced drilling start, the Yukon Gold well was completed, the rig moved to the Sourdough site, and that well completed the same season. This would not have been possible with a conventional ice pad.

There is the potential for some level of short-term damage in areas that have either experienced low snow fall or removal of snow by high winds, thus creating substandard show cover conditions. However, in most instances there is little evidence of either the ice road or ice pad once the snow cover is gone.

The use of the ice-road and ice-pad technology reduces the need for gravel during the exploration phase of oil and gas activity. Smaller volumes of gravel are mined during the history of a given field, less area is covered by gravel, and there is little recognizable damage to the tundra. The use of an insulated pad allows the drilling of more wells in a single season, reducing the need to build ice roads in two seasons to serve the same general area.

The older technologies had greater potential to seriously disrupt tundra, thaw permafrost, and mar the viewscape. These effects can persist for many years and many damaged sites have not been adequately remediated. Although the use of ice roads and pads has largely eliminated those problems, a different set of potential effects has been identified. Insulated ice pads have some degree of influence on the underlying tundra, simply because the area loses a growing season, but these effects have not been studied.

The construction of ice roads and pads relies on a ready and plentiful supply of water. Water is drawn from rivers or lakes, existing ice is crushed or chipped and spread along the prescribed roadway or pad site. Concern has been expressed that the extraction of such large volumes of water may endanger fish and drinking water resources. Areas such as the Arctic National Wildlife Refuge have low lake densities and a reliable source for water to build ice roads/pads may not be present. At this time, there are few reliable data that address the controversy over the appropriate use levels for water in the construction of ice pads/roads.

Rolligons and the Arctic Drilling Platform

Potential problems associated with exploration drilling in areas with limited freshwater supply or shortened ice road seasons may be alleviated by the use of low ground-pressure vehicles (Rolligons) and the Arctic Drilling Platform. Rolligons can extend the drilling and off-road seasons on the North Slope. Current Rolligons put 4 to 5 psi of footprint pressure on the tundra, but that would be reduced to 1 psi per tire, depending on the load and the tire size (Rolligon Corporation web site, www.rolligon.com; Petroleum News Alaska 2002). The vehicles have been used to move drilling rigs to remote locations on the North Slope. Their primary use would probably be to access locations that are far from current infrastructure and where the economics of the operation favors their use over the costs and the associated delays of building an ice road.

The Arctic Drilling Platform is an adaptation to land of offshore technology. The platform is light and mobile. It can eliminate or reduce the need for ice roads or ice pads (Petroleum News Alaska 2002; Anadarko, unpublished material, 2002). The platform is self contained and elevated. It can serve as a temporary drilling facility or a long-term production facility. It is supported by steel pilings that contain coils for circulating hot or cold fluids. The elevated platform consists of interlocking aluminum components (12.5 ft by 50 ft [3.8 m by 15 m]) with reinforcing elements and rests on a base of shallow containers that capture any deck fluids or other spillage. The components are transported by Rolligons, thus eliminating the need for ice roads, as well as ice pads.

A small version of this system is being used by Anadarko during the 2002-2003 drilling season, on a 3,000 to 3,500 ft (914 to 1067 m) gas hydrate core well south of the Kuparuk oil field.

DRILLING AND COMPLETION TECHNOLOGIES

An oil reservoir is part of a porous and permeable layer of rock in which the oil is trapped. On the North Slope, each production well is designed to produce from a subsurface area of at least 80 acres (32 ha). Wells are located on gravel pads and are drilled vertically through approximately 2,000 ft (600 m) of permafrost. Once through the permafrost, the bit is directed toward the desired bottom hole location. The number of wells per pad generally ranges from 16 to 40 (BP Exploration Alaska, Inc. and ARCO Alaska, Inc. 1997). The size of the pad and associated facilities is largely governed by the spacing between wells, and the number of pads is a function of the size of the area that can be drained by the wells on a pad. Historically, production wells were either straight or deviated holes and the number per pad was limited; hence, the number of pads needed to drain a specific area was high. The lateral reach of deviated holes rarely exceeded the true vertical depth (TVD) of the well. New technologies have done much to improve the lateral reach of a well and to reduce the size and number of well pads.

The technologies developed over the last two decades have greatly reduced the size of the "footprint" left by the industry when developing an oil field. Wells may be much more closely spaced, far larger areas developed from a single small pad, the mud systems are less toxic, and reserve pits have been eliminated.

Coiled Tubing

The use of coiled tubing is particularly valuable in sensitive environments such as the North Slope. Coiled tubing technology is quieter and has far less impact on a drilling site than conventional equipment (DOE 1999). The technology dates from the 1950s, but only after rapid technological advances in the late 1980s did it come into common use. The tubing is mounted on a large reel and is a continuous flexible coil that is fed into the hole. The use of coiled tubing does not require the repeated "tripping" out of the hole to add additional pipe segments. One of the byproducts of coiled tubing drilling is a significant reduction in the volumes of drilling fluids compared with conventional drilling. Coiled tubing mud volumes are commonly less than half those required or generated by conventional drilling practices (DOE 1999). In many wells, conventional methods are used to drill the initial hole and then coiled tubing is utilized to drill horizontal segments or multilateral completions. The coiled tubing technology is also commonly used for slim-hole drilling (i.e., a rotary borehole of 5 in. [12.7 cm] or less, or a drill hole of the smallest practical size) and reentry projects.

The use of coiled tubing technology has substantial environmental advantages over the conventional drilling technology, but does have some limitations in its application. The primary benefits include (DOE 1999): reduced mud volumes and drilling waste; cleaner operations, no connections to leak mud; reduced operations noise; minimized equipment footprints and easier site restoration; reduced fuel consumption and emissions; reduced risk of soil contamination due to increased well control; and better well-bore control.

These advantages clearly support the use of coiled tubing whenever it is technically feasible. Many of the newer fields such as Alpine use this technology almost exclusively in conjunction with extended-reach horizontal drilling. No detrimental environmental effects are known to be associated with the introduction of coiled tubing technology to the North Slope.

Horizontal Drilling

Horizontal drilling became a reality in the 1970s due to advances in computers, steerable down-hole motor assemblies, and measurement-while-drilling tools. A horizontal well is drilled from an initially vertical well-bore at an angle between 70° and 110°. Vertical or near vertical wells drain oil from a single hole and have limited contact with the oil-bearing interval (usually limited to the vertical thickness of the rock unit). Horizontal wells penetrate the formation up to 8 km (5 mi) or more from the vertical well bore allowing more oil to drain into the well.

The results are a greater number of wells per pad, closer well spacing on the pad, and fewer well pads than using the old technology. Well spacing has decreased from 120 ft (37 m) or more to as little as 10 to 15 ft (3 to 5 m) between wells (BP Exploration Alaska, Inc. and ARCO Alaska, Inc. 1997). Pad size and radius of reach of the wells on the pad have undergone remarkable changes since the start-up of the Prudhoe Bay field in the 1970s. An example of the reduction in pad size and corresponding area of reach is summarized below (Revkin 2001):

- 1970—Prudhoe Bay Drillsite 1; covers 65 acres (26 ha), has an effective reach radius of 1 mi (1.6 km), and produces from an area of 2,010 acres (814 ha).
- 1980—Kuparuk Drillsite 2B; covers 24 acres (10 ha), has an effective reach radius of 1.5 mi (2.4 km), and produces from an area of 4,522 acres (1,831 ha).
- 1985—Kuparuk Drillsite 3H; covers 11 acres (4 ha), has an effective reach radius of 2.5 mi (4 km) and produces from an area of 12,500 acres (5,100 ha).
- 1999—Alpine Pad #2; covers 13 acres (5 ha), has an effective reach radius of 4 mi (6 km), and produces from an area of 32,154 acres (13,022 ha).

The marked increase in drillable area per pad, as demonstrated at Alpine, is largely due to the extensive use of horizontal drilling technology, although Pad #2 is connected to the rest of the 97-acre (39-ha) Alpine site.

The environmental benefits include smaller footprints requiring less gravel and fewer wells to produce the same volume of hydrocarbons. These more effective drilling programs require less water and subsequently generate less drilling waste. Horizontal drilling results in smaller and fewer pads than did the older technologies, but gravel is still needed and effects on tundra and permafrost may result from gravel mining and emplacement. The closer spacing of well-bores has the potential to increase the rate at which permafrost thaw bulbs form, reducing surface stability and causing subsidence. However, some factors can limit the application of this technology (MMS 2001a, Vol IV, Appendix D).

Multilateral Drilling

Multilateral drilling, a variant of the horizontal drilling technology, creates an interconnecting network of separate, pressure-isolated and reentry accessible horizontal or high-angle boreholes surrounding a single major borehole (DOE 1999). Multilateral drilling is most effective in reservoirs that have isolated accumulations in multiple zones, have oil above the highest perforations, have lens shaped pay zones, are strongly directional, contain distinct sets of natural fractures, and are vertically segregated with low transmissibility.

The environmental benefits are similar to those achieved with horizontal drilling and include fewer drilling sites and smaller footprints, less drilling fluids and cuttings, and protection of sensitive habitats and wildlife. Multilateral drilling poses no recognized risk to the environment other than those associated with horizontal drilling.

Measurement-While-Drilling (MWD)

Conventional down-hole logging practices consist of running a variety of remote sensing tools down a borehole prior to setting the surface casing, before any intermediate casing strings, and prior to completing the well at total depth. These tools are on wire-lines and are lowered into the uncased hole and pulled back to the surface. The tools record specific types of data as they are withdrawn from the hole. These data are then used to evaluate the rock type, reservoir properties, hole integrity, and the other features concerning the physical environment of the well-bore. The procedure is routine, but it can be a risky because irregularities in the hole can result in stuck or even lost tools. Conventional logging can be especially risky in a highly deviated or horizontal hole where there is an increased probability that the tool, while being pulled out of the hole, may become snagged on a resistant rock projection or become buried by loose debris collapsing into the hole.

Additionally, these important data are not available to the geologist until some time after the well or interval has been drilled. This delay may vary from hours to days or even weeks. An example would be the desire to correlate the drilled section with that seen in a well some distance away, in order to predict a coring point or anticipate a stray high-pressure sandstone.

Measurement-while-drilling (MWD) technology can provide data virtually as the intervals are drilled. Additionally, sensors provide directional information and other key data that facilitate more effective geosteering and trajectory control (DOE 1999). The recording sensors and other necessary equipment are housed in the drilling assembly at the bottom of the pipe-string, just a few meters above the drill bit.

Conventional logging tools are still run in many wells and provide a wide range of critical data that are not currently replicated by the MWD tools. Thus, the current technology is a blend of the older wire-line tools and the real-time MWD instruments. Geologists and drilling engineers can benefit from the best of both worlds in today's drilling environment.

Because of its real time capability, the MWD technology can be used to avoid formation damage by alerting the rig crew of problems before they become too serious to correct; similarly there is a reduced possibility of blowouts and improved overall rig safety. This technology is also a contributing factor in the reduction of drilling waste volumes because it facilitates horizontal and multilateral drilling practices and provides better well-bore directional control.

However, the conventional logging package requires long trips to remove pipe from the hole and run a number of wire-line tools down the hole to record data. This process can take several hours to as much as a few days, depending on the number of tools to be run and the depth and condition of the hole to be logged. Repeated flushing of the hole can cause formation or hole damage and result in sloughing of materials into the hole from the walls of the well. The potential for loss of a tool assembly exists. If a tool cannot be extracted or milled up, the hole must be sidetracked and re-drilled, thus creating more waste and extending the duration of the drilling process. The MWD technology significantly reduces this risk and its associated impacts.

Light Automated Drilling System (LADS)

The construction of ice roads and ice pads in remote areas requires an abundant water supply. There is legitimate concern regarding means of access in areas that lack sufficient water and/or fresh-water ice to build roads or if global warming were to prevent the use of ice roads.

A possible solution to this problem, the Light Automated Drilling System (LADS), is in the research phase and is being considered for use on the North Slope. This potential drilling system is expected to be a light-weight drilling rig that can be easily broken down into several components and transported across tundra in winter by light impact vehicles that would not require ice roads. This system or others like it could be adapted to work in areas that lack sufficient water for ice roads or during mild winters when it would not be possible to build an ice road, transport a rig to a drilling location(s), and return it to the staging area.

The principle benefit of LADS would be to reduce the need for water to build ice roads. The primary drawback from the environmental perspective would be the increased risk of damage to the tundra while transporting rigs between locations in the absence of adequate snow cover. The same concerns exist as are presently expressed for seismic activity but on a much reduced scale.

PRODUCTION TECHNOLOGIES

Production and associated operations are the longest-term activities in an oil field. The life of major oil fields on the North Slope is expected to be on the order of 30 to 40 years, occasionally as much as 50 years. During this time pipelines, production facilities, waste disposal systems, water treatment plants, injection facilities, road systems, and other specialized units continue to operate.

Industry attempts to produce the maximum amount of oil (gas) at the least cost in order to remain competitive and viable in the event of competition for funding or a low oil/gas price environment. The most cost efficient technologies are the obvious choice of the operators. It is not surprising that in the early phases of development and production some of these choices have proven to be less than optimal from an environmental perspective. The use of reserve pits for the disposal of used drilling muds, cuttings, and other waste is one such example.

Today, on the North Slope, as fields continue to be discovered, developed and produced, there continues to be the need for new pipelines, production facilities, waste disposal wells, etc. To reduce the environmental effects of these activities, new technologies have been developed or adapted for use on the North Slope. New methods do not eliminate the need for gravel, water, and other materials, but they reduce their use and cause less disturbance, therefore reducing the potential negative effects associated with wastes and road and pipeline construction.

Enhanced Oil Recovery (EOR)

This technology, discussed in Chapter 4, involves the injection of formation/source water, natural gas, and miscible fluids into the producing reservoir to maximize recovery of hydrocarbons. In this process, not only is more oil recovered per well, but much of the waste water associated with oil production is reintroduced into the reservoirs from which it was produced. Many problems that formerly were handled by surface or reserve pit disposal techniques are solved.

The principal environmental benefits are greater recovery of oil without a proportionately greater number of wells and their associated waste, environmentally friendly disposal of produced water, and reduction of emissions that would be associated with the flaring of excess produced gas. Few negative environmental effects are associated with EOR. The primary unease is in regard to spills of produced water and the remote possibility that a reservoir may be over-pressured through the injection process, cause fracturing to the surface, and allow oil and other fluids to escape to the pad and/or tundra.

Waste Disposal

From the 1940s to the 1980s, most well-associated wastes were either stored in reserve pits or handled through other surface disposal means such as incineration. The reserve pits were prone to seepage and spills, and they contained undesirable metals and volatile organic compounds. These did, and still do present environmental risk, especially at old, unclosed remote exploration sites.

The reserve pit closure program was instituted in 1996. To date, fifty percent of approximately 600 reserve pit sites have been closed. The ADEC required submittal of closure plans for all sites by January 28, 2002 (Maham 2001). These plans, which do not require full restoration of the sites, have been submitted (ADEC 2002). Down-hole disposal of wastes by injection into subsurface disposal intervals is utilized in all present-day exploration wells and producing fields.

This mode of waste disposal is an effective and non-contaminating method of removing many unwanted materials from the surface environment. The grind-and-inject project was undertaken to dispose of drilling muds and cuttings stored in reserve pits. Other wastes processed through the grind-and-inject plant include: Class II, RCRA-exempt oily wastes, and drilling muds and cuttings from ongoing drilling operations. As of May 31, 2000, injection at the Surfcote pad included 5.2 million bbl (218.4 million gallons) of water, 16.4 million bbl (688.8 million gallons) of slurry containing 1.1 million tons (1 million metric tons) of excavated reserve pit material and drilling solids, and 166 million bbl (7 billion gallons) of fluid from ongoing drilling operations (Bill 2000).

Annular injection is an environmentally safe method of disposing of drilling muds and cuttings, and the injection of Class I and Class II materials into discrete disposal zones has provided a mechanism for the handling of produced formation waters and other associated wastes (API 1996).

However, a large number of unclosed reserve pits remain at remote exploration well-sites. No adequate plan is in effect to handle the possible pollution and resultant damage from poorly sealed and covered pits. The annular injection process has some potential to create or take advantage of poor casing or cement jobs and result in leakage to the surface. This has occurred on several occasions, but with no contamination of permafrost. Worries regarding subsidence and marine contamination have been expressed, but the existing evidence indicates that subsidence is not a concern and disposal units are effectively and naturally isolated from any contact with the ocean or seafloor.

Roadless Construction

Prudhoe Bay, Kuparuk, Endicott, and other early generation oil fields were developed, facilities and pipelines constructed, and distinct operating areas joined together through a network of gravel roads. This required large volumes of gravel that have been extracted from 13 gravel mines. The U.S. Fish and Wildlife Service has estimated that more than 60 million yd^3 (46 million m^3) of gravel have been mined to supply the constructions needs of the North Slope oil fields (Van Tuyn 2000). Data from the Department of Natural Resources (DNR) place the volume of gravel extracted from 1974 to date at 57,880,481 yd^3 (44,252,803 m^3).

Because of a decrease in scale of facilities and well pads the rate of demand for gravel is decreasing. Also, new roadless construction methods for remote operations have eliminated much of the need for gravel in road construction. As an example, the Alpine construction was done during the winter with equipment, personnel, and modules transported to the site via ice road. Similarly, the pipeline from Alpine back to the existing pipeline infrastructure at Kuparuk was built using ice roads. Gravel was used to build two production pads, a 3 mi (5 km) road between the two Alpine pads, and an airstrip, totaling about 97 total acres (39 ha).

Future oil field development will be based on refined variants of the Alpine model. Pads will be small and few in number and construction will be largely a winter activity with transportation via ice roads. The use of gravel will be appreciably reduced. However, the scarcity of water in some areas, climate change, and other factors could make use of gravel roads more attractive economically and practically in some areas.

The issue of removing and possibly cleaning the existing volumes of gravel, some of it contaminated from spills related to a variety of causes and fluids, is not resolved. In some instances, the operators have removed gravel, cleaned it if necessary, and reused it elsewhere, but the truly massive task of removal or remediation awaits the abandonment of the fields.

The primary environmental benefits are use of less gravel and reduced damage to the tundra. This practice may eventually be efficient enough to be implemented through the reuse of gravel from older abandoned roads and pads.

The environmental concern is the large volume of gravel on existing roads and pads of the major North Slope oil fields. The effects this material has on caribou movements/deflections, especially at roads in close proximity to elevated pipelines; the potential for ponding waters; destruction of the tundra; and long term effects on permafrost may be real and significant. There appears to be a genuine potential for large-scale gravel mining and usage to result in environmental effects that accumulate on the physical and biological components of the region.

Pipeline Construction

Among the standard practices utilized in the construction of pipelines are gravel maintenance/construction roads, elevated river crossings, and block valves to reduce the likelihood and sizes of leaks and spills. Recent developments have lessened the environmental effects of pipeline construction, the hazards to the pipeline due to flooding, the probability and severity of leaks, and impediments to caribou movement. These new approaches were all used in the design and construction of the Alpine oil pipeline (Lance 2000), which was built largely during the winter and construction using ice roads. The lack of a gravel maintenance road removes one potential barrier to caribou movement, reduces the volumes of gravel required for the Alpine-like projects, and the amount of tundra impacted by burial.

The Colville River pipeline crossing posed a considerable challenge. During breakup and the associated flooding, the river is almost a km wide and it could destroy an above ground pipeline or erode deeply enough to expose and rupture a line buried in a surface trench. ARCO Alaska, Inc., elected to use horizontal directional drilling (HDD) to position the pipeline deep beneath the river channel (Lance 2000). More than 4,000 ft (1,200 m) of pipeline were placed 100 ft (30 m) below the river. There was no need to erect pylons for an overhead crossing or trench within the floodplain of the Colville during the winter. However, 8.3 million liters (2.3 million gal) of drilling muds were lost under the Colville River in 1998; its fate is not known.

After conducting an oil-spill isolation strategy study that reviewed ways of meeting federal leak-containment regulations, ARCO Alaska, Inc. elected to use 12 to 14 m (39 to 46 ft) high vertical loops on the Alpine pipeline in lieu of the more conventional block valves. The study concluded that when used in tandem with emergency pressure-letdown valves or divert valves, vertical loops would contain drain-down-related spills as well as block valves, while offering operations and maintenance efficiencies (Pavlas et al. 2000).

The loops are better than manual block valves for reducing catastrophic failures and they provide protection levels similar to those achieved by remotely-actuated valves for leaks of all sizes. They are not themselves potential leak sites, as valves are, but they do not provide any substantial benefit over block valves for pinhole leaks. With approval from the Department of Transportation, the loops were placed at river crossings and high points along the line.

These new pipeline construction methods greatly reduce the environmental effects on tundra, provide for a safer line and lessen the probability of spillage due to river induced pipeline damage. They also more effectively limit the size of catastrophic spills. However, the placement of a pipeline at depth beneath a river could make detection and cleanup of a spill in the buried segment difficult. The preexisting and predominant North Slope pipeline technology presents impediments to caribou movement when in close proximity to roads, and river crossings are sites of potential severe environmental consequences if a spill occurs. The accumulation of effects of continued construction of pipelines and road systems could increase the magnitude of displacement of the calving caribou away from the coastal strip and prime forage/insect relief areas.

Remote Sensing

Satellite infrared photography was used in the Alpine planning and construction phases for selecting the locations of pads and other structures to avoid sensitive, critical habitat. Remote sensing devices have the potential to serve other needs on the North Slope. One of the more recent applications may prove to benefit several diverse areas. A Forward Looking Infrared sensor system (FLIR) can be used to detect pipeline leaks. An airborne FLIR unit is an effective tool in surveying pipelines for potential corrosion and detecting leaks. The system may also have use as a spill response tool for tracking spill movement under ice and snow. FLIR can image a spill site and supply pertinent information either as video footage or as a video frame registered map.

An additional FLIR application is locating large mammals. Although its effectiveness is yet to be fully determined, this system might facilitate the location of polar bears dens. Such an application could be used to plan seismic surveys in such a way as to avoid denning bears.

The potential environmental benefits include avoidance of critical habitat, leak and spill detection, corrosion detection, and planning of seismic and other winter programs to avoid denning bears. There are no obvious environmental drawbacks to these technologies.

Appendix E:

Aeromap Analyses and Data

The information summarized in Chapter 4 on the history of industrial development includes novel analyses created expressly for this report by Aeromap Inc. (Ambrosius 2002). Most of the raw data were supplied by BP, Inc. The methods and details of that assemblage are given here.

AEROMAP U.S.

INTERNATIONAL PHOTOGRAMMETRIC CONSULTANTS

The National Academies
National Academy of Sciences

January 30, 2002

Memorandum:

Calculation of Area Impacted by Oil Field Development North Slope Alaska

Rev.1 02/07/02

This memorandum is a description of the calculations of the area of impact due to oil field development on the Alaskan North Slope.

The impact area was calculated through the use of Industry owned large-scale topographic base maps and historical aerial photography. Area calculations were done for the years 1968, 1973, 1977, 1983, 1988, 1994 and 2001. The geographic area of this project is limited to: north of 70° 5' north latitude, and between 145° 55' and 151° 20' west longitude. A more detailed area description is included on page 7.

For the purpose of these calculations "impact" was defined as the footprint of a gravel facility, the area used for gravel extraction, any overburden piles, or any visible marks or scars on the tundra that persisted for a period of 10 years or more.

All facilities related to the oil field development were included for the purpose of these impact area calculations. No distinction was made between industry owned facilities, contractor facilities, or State of Alaska facilities such as Deadhorse. Those portions of the Trans Alaska Pipeline System and the DOT's Dalton Highway that fall within the study limits are included. Only the Distant Early Warning (DEW Line) military sites and any native owned or other private property sites are excluded.

These area calculations do not include the exploration work done by the U.S. Government in NPRA, exploration wells or seismic camps in the foothills of the Brooks Range, the DOT Dalton highway that falls outside the study area limit, nor any of the Trans Alaska Pipeline system that fall outside of the study area limit. The geographic area of the project was limited to the area for which detailed maps and photos were available for my use.

The area calculations were divided into four geographic regions for each year:

1) West of Kalubik Creek
2) Kuparuk River to Kalubik Creek
3) Foggy Island to Kuparuk
4) East of Foggy Island

Oil field facilities and roads are raised gravel structures that have well defined edges. Deep pit gravel mines (more than 20 feet deep) also have well defined edges. These items are mapped to 1"=500' standards through photogrammetric methods.

Exploration activity before 1978 sometimes took place without raised gravel pads or roads. Prior to 1978 some gravel was extracted from riverbeds by simple grading material into a pile and then hauling it off. Some of these items are well defined in current aerial photos while others are not. The area limits for those items that are not well defined were interpreted from historical photography.

The procedure used for the area calculations involved the following steps:

- A 'footprint' polygon was extracted from the most recent topo map CAD files available from the oil industry. This polygon was placed in a single CAD file and was used as a 'base' for construction of all years studied. The file contained only the areas currently covered by gravel facilities, roads, and mine excavations. Exploration facilities, riverbed gravel extraction, and other impacted areas (disturbed tundra not covered by gravel facilities) were not included.

- The 1968 aerial photos were examined to determine the impact area for that year. The 'base' reference file was used to help locate and define the areas as they appeared in 1968. Well-defined gravel facilities that were a match to what was observed in the 1968 photos were copied from the 'base' reference file into the 1968 CAD file. From an examination of the 1968 photos other impacted areas were then also digitized into the 1968 file with the aid of the current industry topo maps as a backdrop.

- The 1968 CAD file was then copied and renamed 1973. The 1973 photos were examined, those polygons from the 'base' reference file that matched were copied into the 1973 CAD file, and other impacted areas were digitized as above.

- The procedure was repeated for the years 1977, 1983, 1988, 1994, and 2001. A CAD file that contained all impact areas up to that time was created for each year. Each year depicts a cumulative impact up to that time with no consideration for "rehabilitation". These CAD files are the source for the calculations in the accompanying excel tables. Calculations were done using ARC View software in an Alaska State Plane, zone 4, NAD27 projection.

- An additional column was created in the excel tables labeled '2001 current'. Areas that appear to have been rehabilitated through either natural process or through industry efforts have been subtracted from the impact area. This is my best effort at an objective interpretation of the "current conditions"; it does NOT represent the 'Industry viewpoint'.

CALCULATIONS

Exploration Sites

Access to exploration wells from 1963 through 1973 was achieved by three methods each had a varying degree of impact on the tundra. The original table from the project proposal included only Peat Roads; it was expanded it to include all three.

These methods of access were only used prior to 1973. Later permanent production facilities and gravel roads were constructed over some of these early access routes when possible.

a. **Tractor Trails / Tundra Scars** – For some early exploration wells the rig was simple parked on the frozen tundra and shimmed up on timbers to level. Access was from driving over the frozen tundra. By continued use of these routes after spring thaw ruts and tundra scars were produced that have persisted for many years. All of these rutted or scared areas are included in the cumulative impact area calculations.

   Natural processes have since revegetated areas where the routes crossed well-drained high ground. Other low lying wet areas remain marked by well-defined water filled depressions or ditches. In the '2001 current' column of the table those areas that appear to be rehabilitated have been left out.

b. **Peat Roads** – For a few years exploration well access and rig movement was done over peat roads. Peat roads were constructed by using a bulldozer to blade the native soil into a mound, one bulldozer on each side of a route centerline. The result was a pair of parallel shallow ditches on either side of a mound. The mound was graded and packed and when frozen provided a roadbed. Peat roads have left a very well defined mark on the landscape still visible today. The peat roads have become revegetated through natural processes and most have shallow ponds on each side. However, the construction of peat roads has altered the native vegetation patterns and the drainage patterns, it has created a new habitat type that is different than was originally present. Attempts to return these areas to the original state would likely create more impact.

In the '2001 current' column of the table the area covered by peat roads has been retained because they have produced a tangible impact on the native environment that remains today.

c. **Exploration Access Roads of Thin Gravel & Frozen Tundra** – A third method of access was a combination of; a) the placement of a thin layer of gravel over uneven ground and, b) driving over frozen tundra where the ground was already smooth and even. In the areas where no gravel was placed a visible scar on the tundra was observed that persisted for as many as ten to fifteen years, probably a die off of vegetation through repeated passage. All of these areas of thin gravel or vegetation die off are included in the cumulative impact area calculations.

Some of the tundra scars have disappeared by year 1994 or 2001 revegetated through natural processes. Some of the low-lying wet areas where a thin layer of gravel was placed also appear to have become revegetated through natural processes. These may be considered rehabilitated. Other well-drained areas where gravel was placed have remained pretty much as they were when first constructed. In the '2001 current' column of the table those areas that are consider rehabilitated were left out.

d. **Exploration Site - Disturbed Area in Addition to Gravel Covered Area –**

i) Early exploration wells were drilled in winter when the tundra was frozen. For some wells the rig sat on the tundra and was leveled with timbers, no gravel was used at all. Activity around the rig caused some vegetation die off, other areas were rutted and scared by vehicle activity, sometimes pits were dug in the tundra. After the rig was demobilized from the site some pits were filled in, material that was dug up was spread around, some sites appears to have been graded. All of these disturbed areas are included in the impact area calculations.

Over time some of these disturbed areas have become revegetated through natural processes. In the '2001 current' column of the table those areas that are revegetated and considered rehabilitated were left out.

ii) For some exploration wells a thin layer of gravel was used to level the site. Again, activity around the rig caused vegetation die off, other areas were rutted by vehicle activity, and pits may have been dug in the tundra. After the rig was demobilized the thin gravel may have been left in place or it may have been spread around or used to fill in pits. The material that was dug from the pits may have been spread around, some sites appear to have been graded. All of these disturbed areas are included in the impact area calculations.

Over time some of these disturbed areas have become revegetated through natural processes. In the '2001 current' column of the table those areas that are revegetated and considered rehabilitated were left out.

iii) For some exploration wells a gravel pad was constructed, normally 3 to 5 feet thick with a pad and camp area and reserve pits constructed at grade by use of gravel dikes or berms. These sites generally had little to no activity off of the pad that impacted the tundra, however for the few that did these areas are also included in the impact area calculations. Some of these gravel exploration pads have been revisited by industry and 'closed out' to State of Alaska specifications in recent years. The close out procedure may have included regrading some of the gravel found onsite to cover the reserve pits or it may have included breaching the dikes to prevent ponding of water. Sometimes these activities have slightly increased the disturbed area. Some areas have been revegetated through natural processes over time. All of the disturbed areas are included in the impact area calculations.

In the '2001 current' column of the table those areas that are revegetated and considered rehabilitated were left out.

e. **Exploration Site - Tundra Covered by Gravel** – These are the footprint area of those exploration sites that are raised gravel pads. The area calculation is cumulative and includes some sites that are no longer visible on the aerial photography. Some of the sites were located on barrier islands and have since washed away a few others have become thermocarsted and revegetated by natural processes.

In the '2001 current' column of the table any sites that were washed away or that have been revegetated were left out.

f. **Exploration Airstrips Thin Gravel / Tundra Scar** – Some of the early exploration wells were accompanied by airstrips that were a combination of the placement of a thin layer of gravel over uneven ground and a thin ice pad where the native ground was smooth and even. In the areas where no gravel was placed a visible scar on the tundra was observed that persisted for as many as ten to fifteen years, probably a die off of vegetation through repeated passage. All of these areas of thin gravel or vegetation die off are included in the cumulative impact area calculations.

Areas where gravel was placed have remained pretty much as they were when first constructed. The tundra scars have disappeared by year 1994 or 2001, revegetated through natural processes and are considered rehabilitated. In the '2001 current' column of the table those areas that are consider rehabilitated were left out.

g. **Exploration Islands** - The exploration island area calculations are only for that portion of the island that is above sea level in the same manner as was done for "Causeways". For the cumulative figures every island was included, even after an island may have been washed away or removed.

In the '2001 current' column the area of all islands that are no longer in place were left out and those that were changed by erosion were modified to show current conditions.

Production Facilities

h. **Roads** – Gravel roads for general transportation are normally five feet thick and vary in width. Some gravel roads were constructed for pipeline inspection or maintenance and are not intended for general use, these may be less than five feet thick. All of these roads are included in these calculations. Areas were calculated from the toe of the roads.

i. **Causeways** – The causeways are generally constructed to be about twelve feet above Mean Sea Level; side slopes are approximately 7 to 1. The depth or elevation of the seabed beneath any of the causeways varies. The area included in these calculations is only for that portion of the causeway that is above Mean Sea Level, no effort was made to interpolate the area of seabed actually covered. The area of the causeways was reduced from 1994 to 2001 due to the construction of a breach at West Dock and another at Endicott.

j. **Airstrips** – Area calculations include both active usable airstrips and airstrips that were constructed for exploration activities that are no longer in use. All of these airstrips were constructed from gravel and are generally a minimum of five feet thick. Though some of the exploration airstrips have severe thermocarsting and are no longer useable the area of impact numbers remain under this 'airstrip' heading. The gravel from some airstrips has been removed for use in construction of other facilities. In both the '2001 cumulative' and the '2001 current' columns of the tables those area that have been removed and reused were left out. The calculations for those removed areas are recorded under the "Gravel Removed From Tundra" heading.

k. **Production Islands** – Production islands area calculations are only for those portions that are above sea level in the same manner as was done for "Causeways". One production island is incorporated into a causeway; that area was segregated out and reported as a production island.

l. **Production Pads / Drill Sites** – Some production drilling pads were constructed over exploration sites. In these cases the area calculations are reported as 'drill sites' rather than under 'exploration sites'. At the time of construction some facilities were built in such a way as to enclose areas of tundra that are not part of the facility. Other areas that were to be used as flare or reserve pits are completely enclosed, though some were never used and appear to be native tundra with no impact. The drill site areas as calculated here include all of those parts of a facility that were intended for use as a pit as well as the areas of tundra actually covered by gravel. The tundra areas that are not part of the facility but are surrounded by the facility are not included in the area calculations.

m. **Processing Facilities** – Processing facilities are generally large pads with large equipment. In recent years a few very small pads were built in conjunction with the Badami and Northstar pipelines. These small pads are at shore fall and at either bank of rivers, they contain automated valves and a helicopter-landing pad. I included these as process facilities for area calculations, however I did not count each one as a separate facility for purposes of 'number of facilities' due to the relatively insignificant size.

   Some facilities were built in such a way as to enclose areas of tundra that are not part of the facility. Some of these areas are large and have not been visibly impacted; others are small and have filled with storm runoff or snowmelt debris. Areas intended as flare or reserve pits are completely enclosed by gravel dikes. The production facility areas as calculated here include all of those parts of a facility that were intended for use as a pit, the small impacted enclosures, and the areas of tundra covered by gravel pad. The larger tundra areas with no visible impact but surrounded by the facility are not included in the area calculations.

n. **Support Pads** – Support pads include facilities under the control of the oil industry and State of Alaška owned and leased properties that are not under industry's control. In general these facility footprints are well defined, however on occasion they have spread out unto the tundra and have then contracted back to the gravel pad. All of these areas that were used for storage or that appear to have otherwise disturbed the tundra are included in the impact area calculations.

   Over time some of these storage areas have been cleaned up, some disturbed areas have become revegetated through natural processes. In the '2001 current' column of the table those area that are considered rehabilitated were left out.

o. **Gravel Pad Removed - Site in Process of Recovery** – By year 1973 the very first gravel pad constructed, the ARCO base camp, was reconfigured. A portion of the gravel pad was removed and reused elsewhere. In every subsequent year photography examined additional areas of gravel pad or gravel road were found that had been picked up. Some areas have become revegetated through natural processes in a relatively short time. Others take as long as ten to fifteen years, while still others have remained a visible scar to this day. For the years 1973 through 1994 all gravel removed from tundra was placed in this area calculation regardless of status of recovery.

   Note that this category was used only for those areas where a raised gravel pad or road was removed; it was not used for other 'disturbed areas' or thin gravel. Also note that a few of these areas of removed gravel were in riverbeds and the 'removal' may have been caused by erosion rather then by construction equipment.

p. **Gravel Pad Removed - Site Recovered** – Those areas that are appear to be recovered by natural means or rehabilitated by industry are reported here, separately from those that remain visible scars as of 2001.

q. **Gravel Mine on Riverbed** – Gravel for facility construction was removed from the Sagavanirktok and Kuparuk Rivers (typical gravel filled meandering glacier riverbeds) by two different methods:

i) Up to 1978 gravel was removed from some portions of the riverbed by pushing portions of the gravel bars into large piles and then hauling them off with earth moving equipment. The equipment used for this surface mining left some well defined and some not so well defined tracks, pits and piles in the riverbeds. Subsequent spring flooding erased much of the evidence. I suspect that in some areas the river channels changed due to the removal of gravel and this further erased evidence of the gravel removal. From examination of the historical photography I believe that I have accurately defined the gravel removal areas. All of these disturbed areas are included in the cumulative impact area calculations.

Over time evidence of gravel removal for some of these areas has disappeared due to spring floods and the action of the river. In the '2001 current' column of the table I have subtracted out those areas that I consider to be rehabilitated.

ii) From 1973 through 2001 a side channel of the Kuparuk River has been the site of deep pit mining. This side channel floods during spring break up but is otherwise a series of oxbow lakes. From year to year dependent on the results of the spring floods these oxbows are connected by streams. A series of pits were dug from the spine road to the river delta. Some surface mining and surface grading was also done in some of these areas. All of the pits are currently full of water; those that had no surface mining at the edges appear to be natural oxbows and are indiscernible from the natural environment. Some of the pits are currently used as reservoirs and have a flat graded area for vehicle traffic next to them. All of the areas used for mining are included in the cumulative impact area calculations.

I consider the areas that were pit mined and that have no disturbed areas around the edges to be rehabilitated. In the '2001 current' column of the table I have subtracted out those areas.

r. **Gravel Mine in Tundra** – Some gravel mines were situated in tundra areas that are near rivers or streams, these have a very well defined footprint. Typically an overburden layer of mixed organics and gravel was removed and placed to the side of the mine area. The area calculations here include the footprint of the excavation as well as the overburden pile.

s. **Pipelines** – The length and number of pipelines data set was taken from the industry topo maps. On these maps individual pipelines are not shown, pipeline bundles are mapped with an annotation to denote the estimated number of pipelines in each bundle. This is the best data source available to me within the time constraints of this project schedule.

t. **Transmission Lines** – The transmission lines were extracted from the most recent industry topo maps. Theses include all known power lines that are located above ground on poles. No effort was made to research and define the many buried power lines.

u. **Number of culverts** – Culvert locations were extracted from the most recent topo where available and from spill contingency maps for areas not yet covered by topo maps (Tarn, Meltwater and Alpine). The numbers here are for culvert locations rather than for individual culverts. Many culvert locations contain more than one culvert. Large culverts (some as much as eight feet in diameter) are included here and not under 'bridges'.

v. **Number of bridges** – The bridge count includes causeway breaches as well as road bridges. These are from the most recent topo where available and from spill contingency maps for areas not yet covered by the detailed topo maps (Tarn, Meltwater and Alpine).

w. **Number of caribou crossings** – Caribou crossing numbers are from the Industry topo maps. Some caribou crossings have had pipelines built across them rather than under them in recent years. For the purposes of this count these have not been included.

The overall geographic extent of the areas included in this calculation is limited to the extent of the aerial photography and/or current topographic mapping coverage. This geographic extent includes the following townships: T10N-R04E, T11N-R04E, T12N-R04E, T13N-R04E, T10N-R05E, T11N-R05E, T12N-R05E, T13N-R05E, T14N-R05E, T09N-R06E, T10N-R06E, T11N-R06E, T12N-R06E, T13N-R06E, T14N-R06E, T08N-R07E, T09N-R07E, T10N-R07E, T11N-R07E, T12N-R07E, T13N-R07E, T14N-R07E, T10N-R08E, T11N-R08E, T12N-R08E, T13N-R08E, T14N-R08E, T10N-R09E, T11N-R09E, T12N-R09E, T13N-R09E, T14N-R09E, T10N-R10E, T11N-R10E, T12N-R10E, T13N-R10E, T14N-R10E, T10N-R11E, T11N-R11E, T12N-R11E, T13N-R11E, T14N-R11E, T10N-R12E, T11N-R12E, T12N-R12E, T13N-R12E, T14N-R12E, T10N-R13E, T11N-R13E, T12N-R13E, T13N-R13E, T14N-R13E, T10N-R14E, T11N-R14E, T12N-R14E, T13N-R14E, T14N-R14E, T09N-R15E, T10N-R15E, T11N-R15E, T12N-R15E, T09N-R16E, T10N-R16E, T11N-R16E, T12N-R16E, T09N-R17E, T10N-R17E, T11N-R17E, T12N-R17E, T09N-R18E, T10N-R18E, T09N-R19E, T10N-R19E, T09N-R20E, T10N-R20E, T09N-R21E, T10N-R21E, T09N-R20E, T10N-R20E, T09N-R21E, T10N-R21E, T09N-R22E, T10N-R22E, T08N-R23E, T09N-R23E, T10N-R23E, T08N-R24E, T09N-R24E, T10N-R24E, T09N-R25E, T10N-R25E, Umiat meridian.

BASE MAPS

BP Exploration (Alaska) Inc. maintains a set of topographic base maps of the North Slope, Alaska producing oil fields. These maps were produced by photogrammetric methods from 1973 through 2001 aerial photography. The map scale is 1"=500', the horizontal datum is Alaska State Plane, NAD27, based on USC&GS monuments. The vertical datum is Mean Sea Level based on a limited number of tidal observations at East Dock in 1973. The survey of photogrammetric control points was done to third order class two standards. The planned map accuracy is:

90% of the planimetric features are plotted to within 1/40 inch of their true positions.
(At 1"=500' this is ± 12.5 feet.)

Independent ground surveys have shown the horizontal accuracy to be ± 2.0 feet for gravel facilities and pipelines.

The detailed mapping covers all production facilities with the exception of the Phillips Alaska oil fields: Alpine, Meltwater, and Tarn. Less detailed 1:63,360 maps were used for the calculations in these areas.

Ken Ambrosius
AeroMap U.S.

map attachments

The result are the tables below, separated by geographic area, as interpreted in Chapter 4 and displayed in Figures 4-3 through 4-6.

Table A-Aeromap-1. Oilfield infrastructure through time for the entire North Slope.

		1968	1973 cumulative	1977 cumulative	1983 cumulative	1988 cumulative	1994 cumulative	2001 cumulative	2001 current
POINT MEASUREMENTS		:							
	A. Number of gravel pads								
	1. Production pads/ Drill sites	0	16	22	62	95	104	115	115
	2. Processing facility pads	0	6	10	14	18	18	20	20
	3. Support Pads (power stations, camps, staging pads, etc.)	1	36	63	98	108	113	115	115
	4. Exploration sites	3	42	63	103	104	106	103	91
	5. Exploration Islands Offshore	0	0	2	12	13	13	13	5
	6. Production Islands offshore	0	0	0	0	2	3	4	4
	7. Airstrips	1	11	15	16	16	16	16	16
	8. Exploration airstrip - thin gravel / tundra scar	0	4	4	4	4	4	4	2
	B. Number of culverts	no data	no data	no data	no data	no data	no data	1395	1395
	C. Number of bridges	no data	no data	no data	no data	no data	no data	17	17
	D. Number of caribou crossings	no data	no data	no data	no data	no data	no data	50	50
	G. Number of Landfills	no data	no data	no data	no data	no data	no data	1	1
LENGTH MEASUREMENTS									
I. Length of Roads in Miles									
	A. Road	0.0	100.0	138.8	294.2	357.7	370.0	400.1	400.1
	B. Peat Road	29.6	100.7	100.6	100.5	96.3	95.8	95.8	94.9
	C. Causeway	0.0	0.0	1.9	2.7	7.5	7.5	7.7	7.7
	D. Tractor trail / tundra scar	19.0	53.7	58.5	57.1	56.5	56.5	56.4	13.8
	E. Exp road - thin gravel / tundra scar	0.0	35.8	36.4	36.1	36.1	36.1	36.0	27.6
	TOTAL	48.6	290.2	336.2	490.6	554.1	565.9	596.0	544.1
II. Length of Pipeline Corridors in Miles									
	A. 1 pipe	no data	no data	no data	no data	no data	no data	73.2	73.2
	B. 2 pipes	no data	no data	no data	no data	no data	no data	111.9	111.9
	C. 3 pipes	no data	no data	no data	no data	no data	no data	56.9	56.9
	D. 4 pipes	no data	no data	no data	no data	no data	no data	95.4	95.4
	E. 5 pipes	no data	no data	no data	no data	no data	no data	29.0	29.0
	F. 6 pipe	no data	no data	no data	no data	no data	no data	31.5	31.5
	G. 7 pipes	no data	no data	no data	no data	no data	no data	16.8	16.8
	H. 8 pipes	no data	no data	no data	no data	no data	no data	8.4	8.4
	I. 9 pipes	no data	no data	no data	no data	no data	no data	9.7	9.7
	J. 10 pipes	no data	no data	no data	no data	no data	no data	2.9	2.9
	K. 11 pipes	no data	no data	no data	no data	no data	no data	4.1	4.1

	L. 12 pipes	no data	no data	no data	no data	no data	no data	2.0	2.0
	M. 13 pipes	no data	no data	no data	no data	no data	no data	0.8	0.8
	N. 14 pipes	no data	no data	no data	no data	no data	no data	0.7	0.7
	O. 15 pipes	no data	no data	no data	no data	no data	no data	1.2	1.2
	P. 17 pipes	no data	no data	no data	no data	no data	no data	1.0	1.0
	Q. 18 pipes	no data	no data	no data	no data	no data	no data	2.1	2.1
	R. 19 pipes	no data	no data	no data	no data	no data	no data	1.2	1.2
	S. 20 pipes	no data	no data	no data	no data	no data	no data	0.2	0.2
	T. 21 pipes	no data	no data	no data	no data	no data	no data	0.4	0.4
	U. 26 pipes	no data	no data	no data	no data	no data	no data	0.3	0.3
	TOTALS IN MILES							449.7	449.7
III. Length of Power Transmission Lines in Miles									
	A. Major transmission lines with towers	no data	no data	no data	no data	no data	no data	218.6	218.6
AREA MEASUREMENTS									
I. Gravel Roads									
	A. Roads	0.0	677.1	1002.3	2028.7	2448.4	2535.6	2744.7	2744.7
	B. Causeways	0.0	0.0	47.7	81.6	234.5	229.1	226.7	226.7
	SUB - TOTALS IN ACRES	0.0	677.1	1050.0	2110.3	2682.9	2764.7	2971.4	2971.4
II. Gravel or Paved Airstrips									
	A. Airstrip	6.1	135.8	251.6	287.3	313.3	313.0	287.4	287.4
III. Off Shore Gravel Pads / Islands									
	A. Exploration Islands	0.0	0.0	5.4	54.4	56.5	56.5	53.4	16.1
	B. Production Islands	0.0	0.0	0.0	0.0	76.4	92.4	101.1	101.1
	SUB - TOTALS IN ACRES	0.0	0.0	5.4	54.4	132.9	148.9	154.5	117.2
IV. Gravel Pads									
	A. Production pads/ Drill sites	0.0	276.4	647.3	2198.6	2916.9	3019.0	3126.1	3127.1
	B. Processing facility pads	0.0	74.4	389.8	692.2	873.8	889.5	917.4	917.4
	C. Support Pads (camps, power stations, etc.)	14.0	440.6	769.3	1340.1	1444.4	1470.3	1463.1	1463.1
	D. Exploration site - tundra covered by gravel pad	0.0	109.1	175.0	339.0	316.7	313.5	305.0	269.4
	SUB - TOTAL IN ACRES	14.0	900.5	1981.4	4569.9	5551.8	5692.3	5811.6	5777.0
	GRAVEL FOOTPRINT TOTALS IN ACRES	20.1	1713.4	3288.4	7021.9	8680.9	8918.9	9224.9	9153.0
V. Other Impacted Areas and Gravel Removed From Tundra									

	A. Exploration site - disturbed area around gravel pad	55.3	346.3	467.0	613.3	627.4	649.6	644.8	322.3
	B. Exploration airstrip - thin gravel / tundra scar	0.0	68.4	68.4	68.4	68.4	68.4	67.4	16.9
	C. Peat Roads	143.3	546.6	545.7	545.7	520.2	517.4	517.3	512.4
	D. Tractor trail / tundra scar	109.6	249.9	272.1	262.5	258.0	258.0	257.9	52.4
	E. Exp road - thin gravel / tundra scar	0.0	176.5	178.6	177.3	178.3	178.3	177.0	130.4
	F. Gravel pad removed, site in process of recovery	0.0	0.7	20.5	27.0	45.8	80.9	100.3	100.3
	G. Gravel pad removed, site is recovered	no data	no data	no data	no data	no data	no data	94.6	94.6
	OTHER IMPACT AREA TOTALS IN ACRES	308.2	1388.4	1552.3	1694.2	1698.1	1752.6	1764.7	1134.7
VI. Gravel Mines									
	A. In rivers	24.6	4732.0	4995.5	5011.1	5062.5	5060.5	5081.5	820.1
	B. In tundra	0.0	33.8	150.7	745.2	1178.7	1185.6	1282.7	994.8
	GRAVEL MINE TOTALS IN ACRES	24.6	4765.8	5146.2	5756.3	6241.2	6246.1	6364.2	1814.9
	IMPACT AREA TOTALS IN ACRES	352.9	7867.6	9986.9	14472.4	16620.2	16917.6	17353.8	12102.6

Table A-Aeromap-2. Oilfield infrastructure history through time for the North Slope west of Kalubik.

		1968	1973 cumulative	1977 cumulative	1983 cumulative	1988 cumulative	1994 cumulative	2001 cumulative	2001 current
POINT MEASUREMENTS									
	A. Number of gravel pads								
	1. Production pads/ Drill sites	0	0	0	0	0	0	5	5
	2. Processing facility pads	0	0	0	0	0	0	1	1
	3. Support Pads (power stations, camps, staging pads, etc.)	0	0	0	0	0	0	0	0
	4. Exploration sites	2	3	3	6	6	6	5	2
	5. Exploration Islands Offshore	0	0	0	0	0	0	0	0
	6. Production Islands offshore	0	0	0	0	0	0	0	0
	7. Airstrips	0	0	0	0	0	0	1	1
	8. Exploration airstrip - thin gravel / tundra scar	0	1	1	1	1	1	1	0
	B. Number of culverts	no data	no data	no data	no data	no data	no data	119	119
	C. Number of bridges	no data	no data	no data	no data	no data	no data	6	6
	D. Number of caribou crossings	no data	no data	no data	no data	no data	no data	0	0

	G. Number of Landfills	no data	no data	no data	no data	no data	no data	0	0
LENGTH MEASUREMENTS									
I. Length of Roads in Miles									
	A. Road	0.0	0.0	0.0	0.0	0.0	0.0	20.0	20.0
	B. Peat Road	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6
	C. Causeway	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	D. Tractor trail / tundra scar	5.3	7.5	7.5	7.5	7.5	7.5	7.5	0.0
	E. Exp road - thin gravel / tundra scar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	TOTAL	34.9	37.1	37.1	37.1	37.1	37.1	57.1	49.6
II. Length of Pipeline Corridors in Miles									
	A. 1 pipe	no data	no data	no data	no data	no data	no data	28.7	28.7
	B. 2 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	C. 3 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	D. 4 pipes	no data	no data	no data	no data	no data	no data	21.6	21.6
	E. 5 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	F. 6 pipe	no data	no data	no data	no data	no data	no data	0.0	0.0
	G. 7 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	H. 8 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	I. 9 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	J. 10 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	K. 11 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	L. 12 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	M. 13 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	N. 14 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	O. 15 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	P. 17 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	Q. 18 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	R. 19 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	S. 20 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	T. 21 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	U. 26 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	TOTALS IN MILES							50.3	50.3
III. Length of Power Transmission Lines in Miles									
	A. Major transmission lines with towers	no data	no data	no data	no data	no data	no data	16.4	16.4
AREA MEASUREMENTS									
I. Gravel Roads									
	A. Roads	0.0	0.0	0.0	0.0	0.0	0.0	133.1	133.1

	B. Causeways	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB - TOTALS IN ACRES	0.0	0.0	0.0	0.0	0.0	0.0	133.1	133.1
II. Gravel or Paved Airstrips									
	A. Airstrip	0.0	0.0	0.0	0.0	0.0	0.0	24.1	24.1
III. Off Shore Gravel Pads / Islands									
	A. Exploration Islands	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	B. Production Islands	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB - TOTALS IN ACRES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IV. Gravel Pads									
	A. Production pads/ Drill sites	0.0	0.0	0.0	0.0	0.0	0.0	53.5	53.5
	B. Processing facility pads	0.0	0.0	0.0	0.0	0.0	0.0	22.8	22.8
	C. Support Pads (camps, power stations, etc.)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	D. Exploration site - tundra covered by gravel pad	0.0	0.0	0.0	7.0	7.0	7.0	4.4	4.4
	SUB - TOTAL IN ACRES	0.0	0.0	0.0	7.0	7.0	7.0	80.7	80.7
	GRAVEL FOOTPRINT TOTALS IN ACRES	0.0	0.0	0.0	7.0	7.0	7.0	237.9	237.9
V. Other Impacted Areas and Gravel Removed From Tundra									
	A. Exploration site - disturbed area around gravel pad	23.2	44.1	44.1	46.3	46.3	53.4	45.8	16.0
	B. Exploration airstrip - thin gravel / tundra scar	0.0	22.4	22.4	22.4	22.4	22.4	22.4	0.0
	C. Peat Roads	143.3	143.3	143.3	143.3	143.3	143.3	143.3	143.3
	D. Tractor trail / tundra scar	25.7	36.4	36.4	36.4	36.4	36.4	36.4	0.0
	E. Exp road - thin gravel / tundra scar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	F. Gravel pad removed, site in process of recovery	0.0	0.0	0.0	0.0	0.0	0.0	3.2	3.2
	G. Gravel pad removed, site is recovered	no data	no data	no data	no data	no data	no data	0.0	0.0
	OTHER IMPACT AREA TOTALS IN ACRES	192.2	246.2	246.2	248.4	248.4	255.5	251.1	162.5
VI. Gravel Mines									
	A. In rivers	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	B. In tundra	0.0	0.0	0.0	0.0	0.0	0.0	49.9	49.9
	GRAVEL MINE TOTALS IN ACRES	0.0	0.0	0.0	0.0	0.0	0.0	49.9	49.9

	IMPACT AREA TOTALS IN ACRES	192.2	246.2	246.2	255.4	255.4	262.5	538.9	450.3

Table A-Aeromap-3. Oilfield infrastructure history through time for the North Slope between Kalubik and Kuparuk.

		1968	1973 cumulative	1977 cumulative	1983 cumulative	1988 cumulative	1994 cumulative	2001 cumulative	2001 current
POINT MEASUREMENTS									
	A. Number of gravel pads								
	1. Production pads/ Drill sites	0	0	0	28	53	58	62	62
	2. Processing facility pads	0	0	0	3	5	5	5	5
	3. Support Pads (power stations, camps, staging pads, etc.)	0	1	1	5	7	9	10	10
	4. Exploration sites	0	17	24	42	45	45	45	39
	5. Exploration Islands Offshore	0	0	0	0	1	1	1	0
	6. Production Islands offshore	0	0	0	0	0	0	0	0
	7. Airstrips	0	3	4	5	5	5	5	5
	8. Exploration airstrip - thin gravel / tundra scar	0	0	0	0	0	0	0	0
	B. Number of culverts	no data	no data	no data	no data	no data	no data	487	487
	C. Number of bridges	no data	no data	no data	no data	no data	no data	3	3
	D. Number of caribou crossings	no data	no data	no data	no data	no data	no data	12	12
	G. Number of Landfills	no data	no data	no data	no data	no data	no data	0	0
LENGTH MEASUREMENTS									
I. Length of Roads in Miles									
	A. Road	0.0	9.1	15.0	104.0	145.4	153.9	161.5	161.5
	B. Peat Road	0.0	25.4	25.4	25.3	25.0	25.0	25.0	25.0
	C. Causeway	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	D. Tractor trail / tundra scar	0.0	32.1	32.0	31.0	30.4	30.4	30.3	9.5
	E. Exp road - thin gravel / tundra scar	0.0	4.6	4.6	4.6	4.6	4.6	4.4	4.4
	TOTAL	0.0	71.2	77.0	164.9	205.4	213.9	221.2	200.4
II. Length of Pipeline Corridors in Miles									
	A. 1 pipe	no data	no data	no data	no data	no data	no data	10.5	10.5
	B. 2 pipes	no data	no data	no data	no data	no data	no data	38.7	38.7
	C. 3 pipes	no data	no data	no data	no data	no data	no data	33.8	33.8
	D. 4 pipes	no data	no data	no data	no data	no data	no data	51.4	51.4
	E. 5 pipes	no data	no data	no data	no data	no data	no data	13.4	13.4
	F. 6 pipe	no data	no data	no data	no data	no data	no data	12.3	12.3

	G. 7 pipes	no data	no data	no data	no data	no data	no data	3.6	3.6
	H. 8 pipes	no data	no data	no data	no data	no data	no data	3.7	3.7
	I. 9 pipes	no data	no data	no data	no data	no data	no data	0.9	0.9
	J. 10 pipes	no data	no data	no data	no data	no data	no data	0.2	0.2
	K. 11 pipes	no data	no data	no data	no data	no data	no data	1.6	1.6
	L. 12 pipes	no data	no data	no data	no data	no data	no data	0.7	0.7
	M. 13 pipes	no data	no data	no data	no data	no data	no data	0.6	0.6
	N. 14 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	O. 15 pipes	no data	no data	no data	no data	no data	no data	0.7	0.7
	P. 17 pipes	no data	no data	no data	no data	no data	no data	0.4	0.4
	Q. 18 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	R. 19 pipes	no data	no data	no data	no data	no data	no data	0.9	0.9
	S. 20 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	T. 21 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	U. 26 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	TOTALS IN MILES							173.4	173.4
III. Length of Power Transmission Lines in Miles									
	A. Major transmission lines with towers	no data	no data	no data	no data	no data	no data	122.7	122.7
AREA MEASUREMENTS									
I. Gravel Roads									
	A. Roads	0.0	62.6	94.8	692.7	952.9	1015.3	1066.3	1066.3
	B. Causeways	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB - TOTALS IN ACRES	0.0	62.6	94.8	692.7	952.9	1015.3	1066.3	1066.3
II. Gravel or Paved Airstrips									
	A. Airstrip	0.0	15.3	31.2	65.2	65.2	65.2	47.6	47.6
III. Off Shore Gravel Pads / Islands									
	A. Exploration Islands	0.0	0.0	0.0	0.0	3.5	3.5	3.5	0.0
	B. Production Islands	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB - TOTALS IN ACRES	0.0	0.0	0.0	0.0	3.5	3.5	3.5	0.0
IV. Gravel Pads									
	A. Production pads/ Drill sites	0.0	0.0	0.0	484.5	976.9	1028.1	1075.5	1075.5
	B. Processing facility pads	0.0	0.0	0.0	187.1	248.2	248.2	248.2	248.2
	C. Support Pads (camps, power stations, etc.)	0.0	8.7	8.7	136.0	172.2	175.1	175.7	175.7
	D. Exploration site - tundra covered by gravel pad	0.0	55.6	73.2	123.4	121.1	121.1	121.1	107.2
	SUB - TOTAL IN ACRES	0.0	64.3	81.9	931.0	1518.4	1572.5	1620.5	1606.6

	GRAVEL FOOTPRINT TOTALS IN ACRES	0.0	142.2	207.9	1688.9	2540.0	2656.5	2737.9	2720.5
V. Other Impacted Areas and Gravel Removed From Tundra									
	A. Exploration site - disturbed area around gravel pad	0.0	129.2	161.4	228.8	241.1	241.0	241.0	114.2
	B. Exploration airstrip - thin gravel / tundra scar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	C. Peat Roads	0.0	132.9	132.9	132.7	131.3	131.2	131.2	131.0
	D. Tractor trail / tundra scar	0.0	130.4	129.8	130.5	127.6	127.6	127.5	35.6
	E. Exp road - thin gravel / tundra scar	0.0	16.6	16.6	16.6	16.6	16.6	15.5	15.5
	F. Gravel pad removed, site in process of recovery	0.0	0.0	0.0	0.0	10.5	20.0	24.9	24.9
	G. Gravel pad removed, site is recovered	no data	no data	no data	no data	no data	no data	22.6	22.6
	OTHER IMPACT AREA TOTALS IN ACRES	0.0	409.1	440.7	508.6	527.1	536.4	540.1	321.2
VI. Gravel Mines									
	A. In rivers	0.0	451.8	451.9	476.7	476.8	476.8	476.8	9.1
	B. In tundra	0.0	0.0	0.0	362.3	605.7	612.6	627.3	465.7
	GRAVEL MINE TOTALS IN ACRES	0.0	451.8	451.9	839.0	1082.5	1089.4	1104.1	474.8
	IMPACT AREA TOTALS IN ACRES	0.0	1003.1	1100.5	3036.5	4149.6	4282.3	4382.1	3516.5

Table A-Aeromap-4. Oilfield infrastructure history through time for the North Slope from Kuparuk to Foggy Island.

		1968	1973 cumulative	1977 cumulative	1983 cumulative	1988 cumulative	1994 cumulative	2001 cumulative	2001 current
POINT MEASUREMENTS									
	A. Number of gravel pads								
	1. Production pads/ Drill sites	0	16	22	34	42	46	47	47
	2. Processing facility pads	0	6	10	11	13	13	13	13
	3. Support Pads (power stations, camps, staging pads, etc.)	1	35	61	92	100	103	103	103
	4. Exploration sites	1	19	30	39	37	36	36	34
	5. Exploration Islands Offshore	0	0	2	10	10	10	10	4
	6. Production Islands offshore	0	0	0	0	2	3	4	4
	7. Airstrips	1	7	8	8	8	8	7	7

	8. Exploration airstrip - thin gravel / tundra scar	0	3	3	3	3	3	3	2
	B. Number of culverts	no data	no data	no data	no data	no data	no data	772	772
	C. Number of bridges	no data	no data	no data	no data	no data	no data	8	8
	D. Number of caribou crossings	no data	no data	no data	no data	no data	no data	38	38
	G. Number of Landfills	no data	no data	no data	no data	no data	no data	1	1
LENGTH MEASUREMENTS									
I. Length of Roads in Miles									
	A. Road	0.0	90.5	123.4	189.8	211.9	215.7	214.9	214.9
	B. Peat Road	0.0	45.5	45.4	45.4	41.5	41.0	41.0	40.1
	C. Causeway	0.0	0.0	1.9	2.7	7.5	7.5	7.5	7.5
	D. Tractor trail / tundra scar	13.7	14.1	19.0	18.6	18.6	18.6	18.6	4.3
	E. Exp road - thin gravel / tundra scar	0.0	31.2	31.8	31.5	31.5	31.5	31.6	23.2
	TOTAL	13.7	181.3	221.5	288.0	311.0	314.3	313.6	290.0
II. Length of Pipeline Corridors in Miles									
	A. 1 pipe	no data	no data	no data	no data	no data	no data	34.0	34.0
	B. 2 pipes	no data	no data	no data	no data	no data	no data	55.8	55.8
	C. 3 pipes	no data	no data	no data	no data	no data	no data	23.1	23.1
	D. 4 pipes	no data	no data	no data	no data	no data	no data	22.4	22.4
	E. 5 pipes	no data	no data	no data	no data	no data	no data	15.6	15.6
	F. 6 pipe	no data	no data	no data	no data	no data	no data	19.2	19.2
	G. 7 pipes	no data	no data	no data	no data	no data	no data	13.2	13.2
	H. 8 pipes	no data	no data	no data	no data	no data	no data	4.7	4.7
	I. 9 pipes	no data	no data	no data	no data	no data	no data	8.8	8.8
	J. 10 pipes	no data	no data	no data	no data	no data	no data	2.7	2.7
	K. 11 pipes	no data	no data	no data	no data	no data	no data	2.5	2.5
	L. 12 pipes	no data	no data	no data	no data	no data	no data	1.3	1.3
	M. 13 pipes	no data	no data	no data	no data	no data	no data	0.2	0.2
	N. 14 pipes	no data	no data	no data	no data	no data	no data	0.7	0.7
	O. 15 pipes	no data	no data	no data	no data	no data	no data	0.5	0.5
	P. 17 pipes	no data	no data	no data	no data	no data	no data	0.6	0.6
	Q. 18 pipes	no data	no data	no data	no data	no data	no data	2.1	2.1
	R. 19 pipes	no data	no data	no data	no data	no data	no data	0.3	0.3
	S. 20 pipes	no data	no data	no data	no data	no data	no data	0.2	0.2
	T. 21 pipes	no data	no data	no data	no data	no data	no data	0.4	0.4
	U. 26 pipes	no data	no data	no data	no data	no data	no data	0.3	0.3
	TOTALS IN MILES							208.6	208.6
III. Length of Power Transmission Lines in Miles									

	A. Major transmission lines with towers	no data	no data	no data	no data	no data	no data	79.5	79.5
AREA MEASUREMENTS									
I. Gravel Roads									
	A. Roads	0.0	611.7	904.7	1333.2	1492.7	1517.5	1518.8	1518.8
	B. Causeways	0.0	0.0	47.7	81.6	234.5	229.1	222.7	222.7
	SUB - TOTALS IN ACRES	0.0	611.7	952.4	1414.8	1727.2	1746.6	1741.5	1741.5
II. Gravel or Paved Airstrips									
	A. Airstrip	6.1	114.0	205.5	207.2	233.2	232.9	193.3	193.3
III. Off Shore Gravel Pads / Islands									
	A. Exploration Islands	0.0	0.0	5.4	43.4	42.0	42.0	38.9	10.9
	B. Production Islands	0.0	0.0	0.0	0.0	76.4	92.4	101.1	101.1
	SUB - TOTALS IN ACRES	0.0	0.0	5.4	43.4	118.4	134.4	140.0	112.0
IV. Gravel Pads									
	A. Production pads/ Drill sites	0.0	276.4	647.3	1714.1	1940.0	1990.9	1975.9	1976.9
	B. Processing facility pads	0.0	74.4	389.8	505.1	625.6	641.3	645.1	645.1
	C. Support Pads (camps, power stations, etc.)	14.0	431.9	753.1	1196.6	1264.7	1287.7	1273.7	1273.7
	D. Exploration site - tundra covered by gravel pad	0.0	46.5	84.9	135.9	115.9	106.3	100.4	92.6
	SUB - TOTAL IN ACRES	14.0	829.2	1875.1	3551.7	3946.2	4026.2	3995.1	3988.3
	GRAVEL FOOTPRINT TOTALS IN ACRES	20.1	1554.9	3038.4	5217.1	6025.0	6140.1	6069.9	6035.1
V. Other Impacted Areas and Gravel Removed From Tundra									
	A. Exploration site - disturbed area around gravel pad	32.1	149.5	202.3	212.9	214.7	219.6	228.5	107.7
	B. Exploration airstrip - thin gravel / tundra scar	0.0	46.0	46.0	46.0	46.0	46.0	45.0	16.9
	C. Peat Roads	0.0	269.6	268.7	268.9	244.8	242.1	242.1	237.4
	D. Tractor trail / tundra scar	83.9	83.1	105.9	95.6	94.0	94.0	94.0	16.8
	E. Exp road - thin gravel / tundra scar	0.0	159.9	162.0	160.7	161.7	161.7	161.5	114.9
	F. Gravel pad removed, site in process of recovery	0.0	0.7	20.5	27.0	35.3	60.9	72.2	72.2
	G. Gravel pad removed, site is recovered	no data	no data	no data	no data	no data	no data	72.0	72.0
	OTHER IMPACT AREA TOTALS IN ACRES	116.0	708.8	805.4	811.1	796.5	824.3	843.3	565.9
VI. Gravel Mines									

	A. In rivers	24.6	4280.2	4543.6	4534.4	4585.7	4583.7	4604.7	811.0
	B. In tundra	0.0	0.0	116.9	326.9	517.0	517.0	517.0	471.8
	GRAVEL MINE TOTALS IN ACRES	24.6	4280.2	4660.5	4861.3	5102.7	5100.7	5121.7	1282.8
	IMPACT AREA TOTALS IN ACRES	160.7	6543.9	8504.3	10889.5	11924.2	12065.1	12034.9	7883.8

Table A-Aeromap-5. Oilfield infrastructure through time for the North Slope east of Foggy Island.

		1968	1973 cumulative	1977 cumulative	1983 cumulative	1988 cumulative	1994 cumulative	2001 cumulative	2001 current
POINT MEASUREMENTS									
	A. Number of gravel pads								
	1. Production pads/ Drill sites	0	0	0	0	0	0	1	1
	2. Processing facility pads	0	0	0	0	0	0	1	1
	3. Support Pads (power stations, camps, staging pads, etc.)	0	0	1	1	1	1	2	2
	4. Exploration sites	0	3	6	16	16	19	17	16
	5. Exploration Islands Offshore	0	0	0	2	2	2	2	1
	6. Production Islands offshore	0	0	0	0	0	0	0	0
	7. Airstrips	0	1	3	3	3	3	3	3
	8. Exploration airstrip - thin gravel / tundra scar	0	0	0	0	0	0	0	0
	B. Number of culverts	no data	no data	no data	no data	no data	no data	17	17
	C. Number of bridges	no data	no data	no data	no data	no data	no data	0	0
	D. Number of caribou crossings	no data	no data	no data	no data	no data	no data	0	0
	G. Number of Landfills	no data	no data	no data	no data	no data	no data	0	0
LENGTH MEASUREMENTS									
I. Length of Roads in Miles									
	A. Road	0.0	0.4	0.4	0.4	0.4	0.4	3.7	3.7
	B. Peat Road	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	C. Causeway	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2
	D. Tractor trail / tundra scar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	E. Exp road - thin gravel / tundra scar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	TOTAL	0.0	0.6	0.6	0.6	0.6	0.6	4.1	4.1
II. Length of Pipeline Corridors in Miles									
	A. 1 pipe	no data	no data	no data	no data	no data	no data	0.0	0.0
	B. 2 pipes	no data	no data	no data	no data	no data	no data	17.4	17.4
	C. 3 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0

	D. 4 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	E. 5 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	F. 6 pipe	no data	no data	no data	no data	no data	no data	0.0	0.0
	G. 7 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	H. 8 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	I. 9 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	J. 10 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	K. 11 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	L. 12 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	M. 13 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	N. 14 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	O. 15 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	P. 17 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	Q. 18 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	R. 19 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	S. 20 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	T. 21 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	U. 26 pipes	no data	no data	no data	no data	no data	no data	0.0	0.0
	TOTALS IN MILES							17.4	17.4
III. Length of Power Transmission Lines in Miles									
	A. Major transmission lines with towers	no data	no data	no data	no data	no data	no data	0	0
AREA MEASUREMENTS									
I. Gravel Roads									
	A. Roads	0.0	2.8	2.8	2.8	2.8	2.8	26.5	26.5
	B. Causeways	0.0	0.0	0.0	0.0	0.0	0.0	4.0	4.0
	SUB - TOTALS IN ACRES	0.0	2.8	2.8	2.8	2.8	2.8	30.5	30.5
II. Gravel or Paved Airstrips									
	A. Airstrip	0.0	6.5	14.9	14.9	14.9	14.9	22.4	22.4
III. Off Shore Gravel Pads / Islands									
	A. Exploration Islands	0.0	0.0	0.0	11.0	11.0	11.0	11.0	5.2
	B. Production Islands	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB - TOTALS IN ACRES	0.0	0.0	0.0	11.0	11.0	11.0	11.0	5.2
IV. Gravel Pads									
	A. Production pads/ Drill sites	0.0	0.0	0.0	0.0	0.0	0.0	21.2	21.2
	B. Processing facility pads	0.0	0.0	0.0	0.0	0.0	0.0	1.3	1.3
	C. Support Pads (camps, power stations, etc.)	0.0	0.0	7.5	7.5	7.5	7.5	13.7	13.7

	D. Exploration site - tundra covered by gravel pad	0.0	7.0	16.9	72.7	72.7	79.1	79.1	65.2
	SUB - TOTAL IN ACRES	0.0	7.0	24.4	80.2	80.2	86.6	115.3	101.4
	GRAVEL FOOTPRINT TOTALS IN ACRES	0.0	16.3	42.1	108.9	108.9	115.3	179.2	159.5
V. Other Impacted Areas and Gravel Removed From Tundra									
	A. Exploration site - disturbed area around gravel pad	0.0	23.5	59.2	125.3	125.3	135.6	129.5	84.4
	B. Exploration airstrip - thin gravel / tundra scar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	C. Peat Roads	0.0	0.8	0.8	0.8	0.8	0.8	0.7	0.7
	D. Tractor trail / tundra scar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	E. Exp road - thin gravel / tundra scar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	F. Gravel pad removed, site in process of recovery	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	G. Gravel pad removed, site is recovered	no data	no data	no data	no data	no data	no data	0.0	0.0
	OTHER IMPACT AREA TOTALS IN ACRES	0.0	24.3	60.0	126.1	126.1	136.4	130.2	85.1
VI. Gravel Mines									
	A. In rivers	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	B. In tundra	0.0	33.8	33.8	56.0	56.0	56.0	88.5	7.4
	GRAVEL MINE TOTALS IN ACRES	0.0	33.8	33.8	56.0	56.0	56.0	88.5	7.4
	IMPACT AREA TOTALS IN ACRES	0.0	74.4	135.9	291.0	291.0	307.7	397.9	252.0

Appendix F:

Oil Spills

Large oil spills are infrequent events, usually in different locations. They occur, they are cleaned up as much as possible, some restoration may be attempted, and over time, natural recovery may occur. Unless spills occur repeatedly in a location, or are very large, their effects usually do not accumulate. On the North Slope, there have been no major offshore oil spills or large spills—greater than 1,000 bbl (42,000 gallons) according to the Minerals Management Service (MMS) definition—associated with exploration and production. Three large spills from the Trans Alaska Pipeline have occurred on the North Slope (Table F-1). There have been many small spills onshore, however, and the potential for future spills offshore (large and small) exists. This appendix describes the history of spills, spill prevention efforts, response to spills, and the fate and effects of oil spilled on the North Slope.

Table F-1 Ten largest crude oil spills from TAPS: Pump Station 1 to Atigun Pass 1977-2000 (Modified from Maxim and Niebo 2001b).

Number	Date	Volume (bbl)	Description
1	19 Jul 77	1800	Heavy equipment accident caused leak at checkvalve7, milepoint 27
2	1 Jan 81	1500	Check valve 23 malfunctiond and leaked when a drain connection failed.
3	10 Jun 79	1500	Pipe settlement at Atigun Pass caused a leak.
4	16 Aug 77	30	Sump at Pump Station 1 overflowed.
5	24 Nov 94	18	Valve left open after routine maintenance.
6	17 May 84	11	Broken drain plug at the Pump Station 3 tank farm.
7	28 Oct 80	6	Valve malfunction at Pump Station 2.
8	4 May 84	5	O-ring seal failed at Pump Station 4 manifold building.
9	23 Aug 89	5	Discharge relief valve stem failed, Pump Station 2
10	5 Dec 81	5	Check valve leaked, metering building at Pump Station 1

Source: TAPS Owners 2001.

OIL SPILLS

History of North Slope Oil Spills

Spills are unintentional, accidental releases of crude oil or petroleum products. They have been analysed statistically for the Trans Alaska Pipeline System (TAPS), divided into four components (Maxim and Niebo 2001b):

1. Exploration and Production Facilities—well pads, flowlines, gathering centers, base operation centers, power stations, and pipelines which feed into TAPS.
2. TAPS—pipeline, pump stations, storage tanks and associated facilities.
3. Valdez Marine Terminal—storage tanks, pumps, connecting pipes, and tanker berths.
4. Marine Transport—tankers carrying crude oil to destination ports.

Here we focus on North Slope exploration and production facilities, and on TAPS pipeline from Pump Station 1 to Atigun Pass.

Sources of Spills from North Slope Facilities and the Trans Alaska Pipeline to Atigun Pass

Oil is produced from wells on gravel pads onshore or offshore on islands. In-field pipelines (flowlines) carry multiphase slurries containing oil, gas, and water from wellhead to CPFs (Central Processing Facilities), sometimes called flowstations. A CPF is the operational center of the production activities. It typically includes processing equipment, storage tanks for fuel and water, power generators, maintenance facilities, living quarters, and communications facilities. The processing equipment includes three-phase separators. Oil, gas, and water are produced in varying proportions from each well. Gas conditioning equipment removes natural gas liquids from produced gas. Pipeline gathering and pressure regulation systems and well monitoring and control systems are also part of the CPF. Oil is filtered to remove any sand or grit. After processing the oil (now called sales oil) is routed through a sales meter and enters a feeder pipeline (also called sales-oil pipeline) for delivery to a larger diameter pipeline to Pump Station 1 of the Trans Alaska Pipeline.

Natural gas extracted during processing is further processed to remove liquids, then compressed and reinjected into the reservoir through service wells. Water is chemically treated and also reinjected into the reservoir. Reinjection of water and natural gas increases oil recovery by maintaining reservoir pressure.

Pipelines that carry water, gas, crude oil and diesel vary in diameter, and are normally installed above ground on vertical support members. Above-ground pipelines are easier to monitor, repair, and reconfigure when necessary. Offshore pipelines are buried until they reach shore where they join the pipeline system. Spills can potentially occur from pipelines, pump stations, support facilities such as aboveground and underground storage tanks, and support facilities such as tanker trucks. Spills can occur at any place where crude oil or products are handled, stored, used, or transported.

Spill Statistics

North Slope

Spills have been reported and recorded over the years of operation of the oilfields and TAPS. The information discussed here is primarily from the analysis recently prepared for the TAPS Owners (2001) in support of their application for right-of-way renewal. The period covered is from 1977, when the first oil flowed through TAPS, through 1999. The data were compiled by IT Corporation from original source documents with minor adjustments and corrections made more recently by Niebo (2001; Niebo, personal communication 2001), and

Maxim and Niebo (2001). Table F-2 shows spills associated with exploration and production activities on the North Slope; Table F-3 shows spills associated with TAPS pipeline operations from Pump Station 1 to Atigun Pass. Over the 23-year period, there was an average of 70 crude oil and 234 products spills per year associated with North Slope operations and the North Slope segment of TAPS operations. The volume spilled amounts to a yearly average of 523 bbl (21,966 gallons) of crude oil and 278 bbl (11,676 gallons) of products (Niebo, personal communication, 2001).

Table F-2 Numbers and volumes of North Slope crude oil and petroleum products spills. (Modified from Neibo 2001b). Spills from exploration and production activities on the North Slope.

Year	Crude oil		Petroleum products	
	number	volume (bbls)	number	Volume (bbls)
1977	12	75.58	22	163.68
1978	12	47.62	20	82.27
1979	20	101.64	16	25.44
1980	22	50.12	46	236.24
1981	54	57.88	181	1,004.93
1982	59	158.81	91	393.45
1983	62	105.76	120	413.15
1984	48	358.60	23	34.00
1985	91	535.43	168	363.17
1986	91	164.67	145	410.40
1987	97	256.64	137	102.10
1988	129	270.70	312	240.94
1989	163	1,790.05	408	364.64
1990	102	223.50	359	234.85
1991	140	65.56	445	324.86
1992	70	34.80	259	81.80
1993	61	2,230.65	209	65.21
1994	51	298.76	159	54.23
1995	39	33.33	132	115.87
1996	52	46.26	141	97.31
1997	39	97.89	123	321.65
1998	44	118.49	124	40.56
1999	27	6.16	258	49.07
Totals	**1.485**	**7,128.91**	**3,898**	**5,219.81**

Reported volumes of North Slope spills vary by more than six orders of magnitude, from 0.006 to 925 bbl (0.336 to 38,850 gallons). The statistical distribution of the volumes of crude and product spills on the North Slope are approximately lognormal. Relatively small spills are frequent, but there is a long "tail" to the distribution, with total volume dominated by the relatively few larger spills (Maxim and Niebo 2001b). This is typically plotted using a Lorenz diagram (Figure F-1) that graphs the fraction of the spill volume (on the vertical axis) versus the fraction of the number of spills (on the horizontal axis). First, spill data are sorted in ascending order of spill volume. Next the cumulative fraction of the total volume spilled (vertical axis) is plotted as a function of the cumulative fraction of the number of spills (horizontal axis). If all spills were exactly the same size, the fraction of the spill volume would correspond exactly to the fraction of the number of spills. The 45 degree line "AB" depicts this situation. If some spills

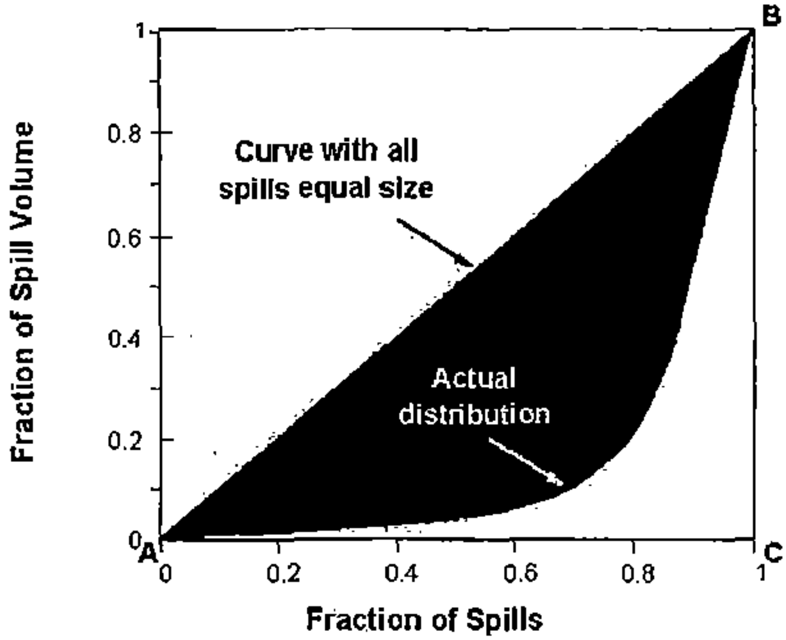

FIGURE F-1. Hypothetical Lorenz diagram. Source: reprinted with permission from Maxim and Niebo 2001.

are larger than others then the fraction of the spilled volume will be less than the fraction of the number of spills, as shown in the curve "AB" beneath the 45 degree line. The area between the curve and the straight line (shaded) illustrates the degree of inequality in spill size distribution. Dividing the shaded area by the area of the triangle "ABC" provides a normalized index or coefficient, denoted L, of the variability in spill volumes. L ranges from 0 (all spills the same size) to 1 (Maxim and Niebo 2001b).

Table F-3 Numbers and volumes of crude oil and petroleum products spills (Modified from Neibo 2001b). Spills associated TAPS from Pump Station 1 to Atigun Pass.

Year	Crude oil		Petroleum products	
	number	volume (bbls)	number	Volume (bbls)
1977	9	1,831.07	771	162.58
1978	3	5.00	17	26.06
1979	7	1,502.67	24	159.78
1980	3	6.28	38	9.14
1981	6	1,505.24	28	13.14
1982	8	4.21	55	93.22
1983	4	2.08	14	4.88
1984	8	16.24	14	12.86
1985	4	0.10	11	4.81
1986	1	0.71	14	90.10
1987	0	0	4	5.39
1988	5	0.24	17	207.21
1989	3	5.72	22	12.30
1990	9	1.10	49	51.16
1991	9	1.92	114	24.30
1992	10	0.42	48	232.47
1993	11	2.66	46	25.61
1994	11	20.84	82	5.16
1995	1	0.71	31	7.12
1996	1	0.07	15	2.68
1997	2	0.12	29	6.19
1998	0	0	18	23.16
1999	2	0.26	12	3.68
Totals	**117**	**4,907.67**	**1,473**	**1,183.00**

The diagram in Figure F-1 is hypothetical; its purpose is to illustrate the concept. The actual curves for exploration and production spills are more extreme. Figure F-2 is a Lorenz plot for North Slope crude oil and products spills over the period 1977-1999. There is substantial curvature in these plots, and the computed Lorenz coefficients are 0.911 and 0.883 for crude and products spills, respectively (Maxim and Niebo 2001b). Thus, a few relatively large spills account for most of the spill volume, as is typical of most oilfields (e.g., Smith et al. 1982, BLM/MMS 1998, MMS 2001). Fifty percent of North Slope crude spills were less than or equal to 0.238 bbl (9.996 gallons). Fifty percent of the product spills were less than or equal to 0.119 bbl (4.998 gallons). The smallest 90% of crude spills accounted for approximately 13% of the total volume spilled in this segment and the smallest 95% of the spills accounted for approximately 20% of the spilled volume. The corresponding percentages for products spills were 16% and 25%, respectively.

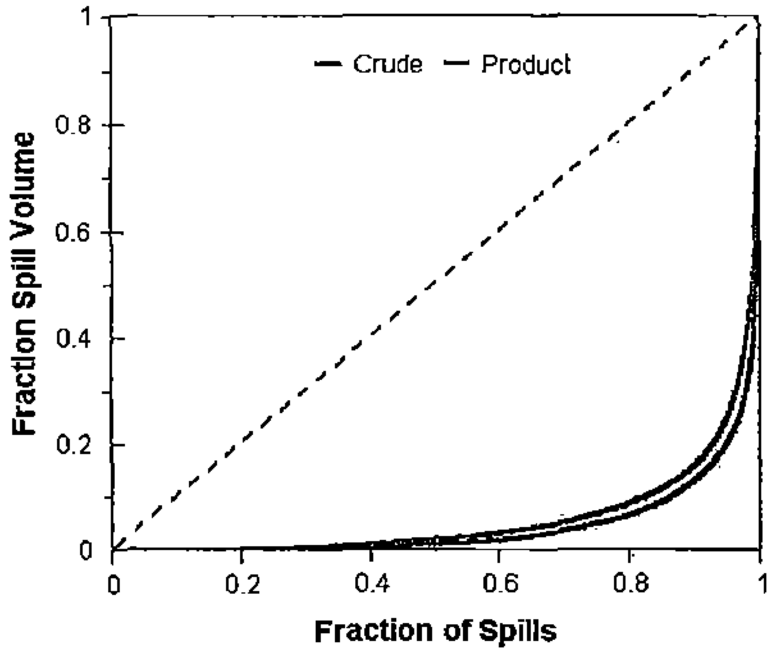

FIGURE F-2. Actual Lorenz diagram for crude oil and products spills associated with exploration and production activities on the North Slope. Source: reprinted with permission from Maxim and Niebo 2001.

From an environmental standpoint, small spills are generally less significant than large spills because they are typically contained and cleaned up at the site of the spill (e.g., drill pad), and therefore, are less likely to cause significant adverse environmental effects. Contaminated gravel cannot be reused before it has been cleaned; current regulations require such cleanup, or disposal, of contaminated gravel. Small spills also account for only a small portion of the total volume spilled.

TAPS: Pump Station 1 to Atigun Pass

Maxim and Niebo (2001) analysed spills along the Trans-Alaska Pipeline using the TAPS (2001) oil spill database. There are 10,588 spill records in the entire database. The North Slope segment from Pump Station 1 to Atigun Pass contains 3,244 records; 232 are crude oil spills and 3,012 are products spills. To identify the spills from Atigun Pass north, spill records were identified by mile marker number on the pipeline or Dalton Highway, pump station number, check valve number, material site number, access road number or landmark name. Using these criteria, 28 spill records did not contain enough information to be positively located north or south of Atigun Pass. Four of them were crude oil spills totalling 303 bbl (12,726 gallons). One spill was 300 bbl (12,600 gallons). The other 24 were products spills totalling 147 bbl (6,174 gallons). These questionable records were not considered part of North Slope segment of TAPS (Maxim and Niebo 2001b).

During the period from 1977 to 1999, 1,590 spills occurred along the pipeline segment from Pump Station 1 to Atigun Pass. Of these, 117 were crude oil spills, and 1,473 were products spills. The total volume of crude oil spilled over the 23 year period was 4,908 bbl (206,136 gallons), and 1,183 bbl (49,686 gallons) of petroleum products, an annual average of 69 spills per year with an annual volume of 265 bbl (11,130 gallons) spilled. For comparison, operation of the entire TAPS during the same period resulted in 3,244 crude oil and products spills totalling 32,092 bbl (1,347,864 gallons), an annual average of 141 spills with an annual volume of 1,395 bbl (58,590 gallons). Spills north of Atigun Pass represent approximately 19 percent of all materials spilled along TAPS. The volumetric spill rate (VSR), i.e., barrels spilled per million barrels of throughput, was 0.477 for the period (Maxim and Niebo 2001b). Figure F-3 shows the annual VSR for this TAPS segment. The spill rate was highest during the early years of the pipeline's operation, dropped in the early 1980s, and has remained relatively constant since then.

Spill records in TAPS segment 1 vary in volume by more than eight orders of magnitude, from 0.00001 bbl (0.00042 gallons) to 1,800 bbl (75,600 gallons). The total spill volume is dominated by a few relatively large spills (Figure F-4). Fifty percent of both crude oil and products spills in this pipeline segment were less than 0.07143 bbl (3 gallons). The smallest 90 % of crude oil spills accounted for approximately 0.5 % of the total volume spilled, and the smallest 95 % of crude oil spills accounted for approximately 1.2 % of the total volume. The corresponding percentages for products spills were 9 and 11 %, respectively (Maxim and Niebo 2001b).

Larger Volume Spills History

Because most oil is released in a few large spills, we highlight the highest volume crude oil and products spills that have occurred over the operating history of the fields, including causes, effects, corrective actions and countermeasures.

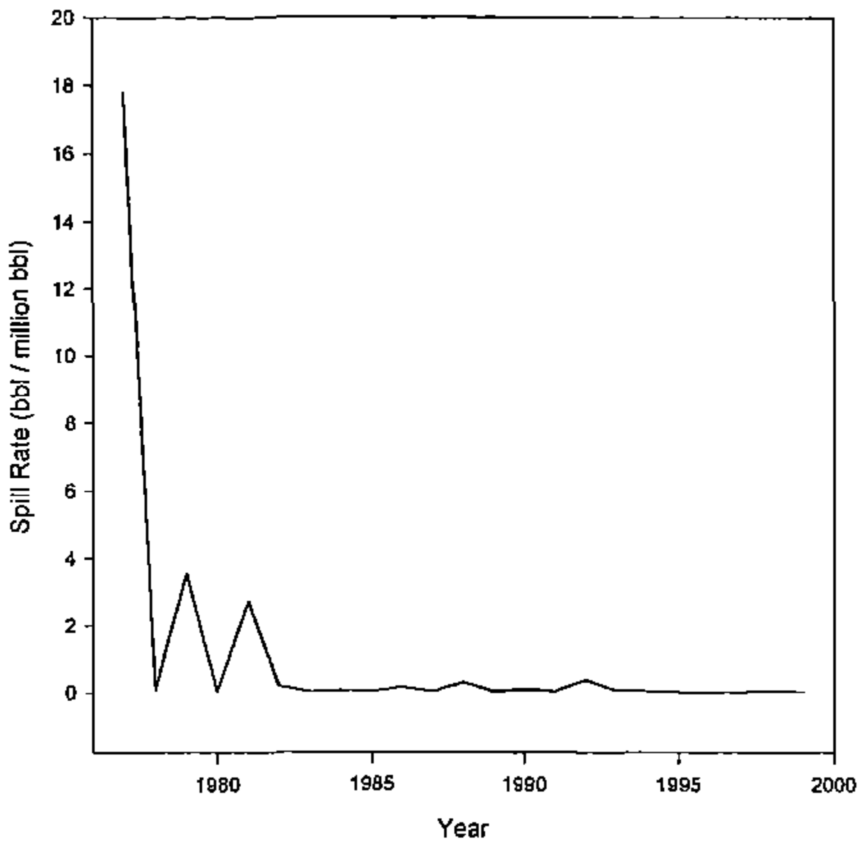

FIGURE F-3. Volumetric Spill Rate (VSR) for crude oil and products spills associated with the Trans Alaska Pipeline System from Pumpstation 1 to Atigun Pass. Source: reprinted with permission from Maxim and Niebo 2001.

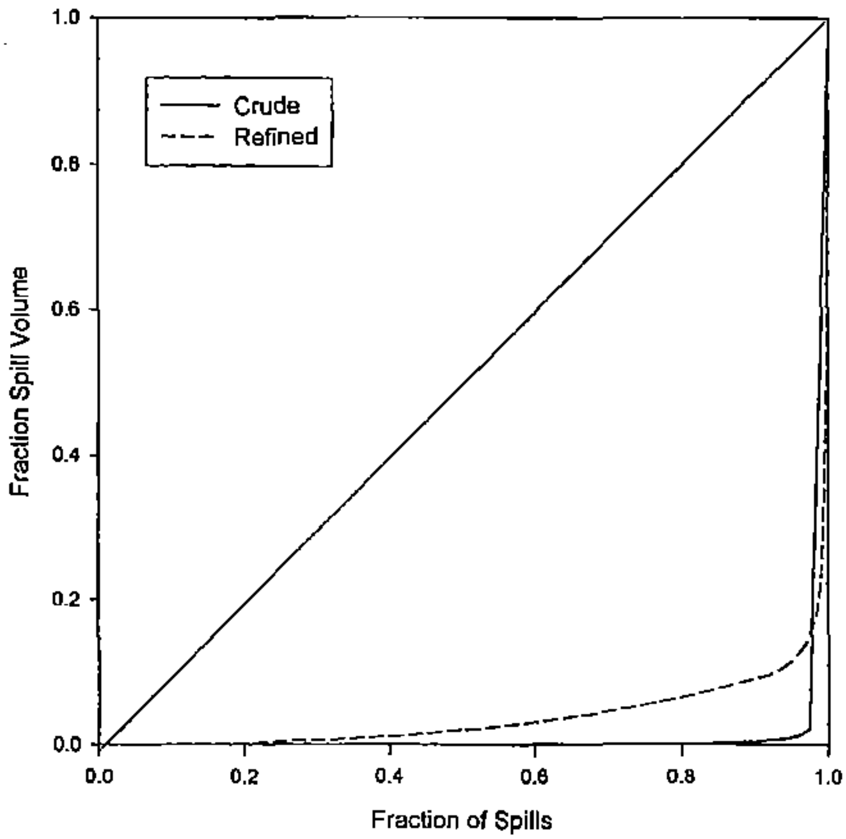

FIGURE F-4. Lorenz diagram of crude oil and products spills associated with the Trans Alaska Pipeline System from Pumpstation 1 to Atigun Pass. Source: reprinted with permission from Maxim and Niebo 2001.

Table F-4 is a list of the 10 largest North Slope crude oil spills (120 to 925 bbl, or 5,040 to 38,850 gallons) during the 1977 to 1999 period. Causes (BLM/MMS 1998, MMS 2001, Parametrix 1997) include leaks from or damage to storage tanks, faulty valves and gauges, faulty connections, vent discharges, ruptured lines, seal failures, explosions, various human errors (e.g., tank overfill, failure to ensure connections).

Table F-4 Ten largest crude oil spills on the North Slope 1977-2000 (Modified from Maxim and Niebo 2001b).

Number	Date	Volume (bbl)	Description
1	28 Jul 89	925	Oil reserve tank overflowed into reserve pit. Alarm system failed.
2	26 Sep 93	650	Pump failure caused tank overflow. Inlet valve was closed and outlet valve opened, allowing oil to spill into a containment dike. High winds carried some oil mist to snow outside containment dike.
3	30 dec 93	375	Wind-induced vibration caused a flowline to crack. Crude oil sprayed from crack. High winds carried some oil away from the pad.
4	10 Jun 93	300	High-level alarm failed on drum.
5	24 Dec 93	180	Level monitor, high-level alarm, and automatic shutoff devices froze on a tank, allowing oil to flow out of the overflow line. Crude oil flowed into the lined area surrounding the tank.
6	8 Nov 89	180	Break in temporary flowline caused by internal erosion. Crude oil was released onto gravel pad.
7	10 Dec 90	176	Explosion and fire caused by fluid leaking from a vacuum truck. Oil was released onto pad.
8	15 Nov 85	175	Faulty valve allowed crude oil to be released into a holding pit.
9	5 Nov 84	125	Bleeder valve was stuck in open position. Oil?
10	25 Mar 87	120	Information pending.

Table F-5 describes the ten largest product spills (71 to 450 bbl, or 2,982 to 18,900 gallons) on the North Slope during the same period. Causes include broken fuel lines, corrosion, faulty valves, and human errors (e.g., accidental overfill). The ten largest crude oil and products spills from TAPS Pump Station 1 to Atigun Pass are listed in Tables F-1 and F-6; most were generally caused by equipment malfunction or operator error (Maxim and Niebo 2001b).

Table F-5 Ten largest products spills on the North Slope 1977-2000 (Modified from Maxim and Niebo 2001b).

Number	Date	Volume (bbl)	Description
1	22 Aug 81	450	Corrosion caused a connection to fail. Material was contained on the pad.
2	31 Oct 82	200	Diesel tank was overfilled, spilling diesel into a secondary containment dike.
3	19 May 97	180	Broken needle valve on the fill line of diesel storage tank. Diesel drained into a lined containment area.
4	19 Jun 83	114	Differential settlement of a temporary holding tank. Released material was released into dike below tank.
5	21 Nov 80	102	Broken fuel line.
6	16 Oct 86	100	Broken fuel line.
7	7 Feb 77	100	Broken fuel line.
8	22 May 85	95	Faulty connection on a diesel tank truck.
9	31 Jul 91	75	Spray from hole in annulus.
10	8 Jun 81	71	Liner cracked due to extreme temperatures. Fluid contained within it seeped into the ground on Challenge Island.

TABLE F-6 Ten largest products spills from TAPS: Pump Station 1 to Atigun Pass 1977-2000 (Modified from Maxim and Niebo 2001b).

Number	Date	Volume (bbl)	Description
1	14 Oct 88	203	Truck overturned at mile point 258 of haul road, spilling diesel fuel.
2	27 Sep 92	190	Tank truck overturned just north of Atigun Pass, spilling turbine fuel.
3	12 Oct 79	95	Gasoline spilled at Ice-cut Hill due to operator error.
4	20 Jun 82	86	Tank valve at Franklin Bluffs camp left partially open, causing diesel fuel leak.
5	12 Sep 77	83	Diesel fuel spill at Pump Station 3, operator error.
6	9 Jan 86	52	Overturned trailer at Atigun pass, diesel fuel spill.
7	19 Dec 90	43	Tanker jack-knifed at mile poing 85, spilling diesel fuel.
8	19 Jun 79	39	Loader caused diesel spill after excavating and rupturing a fuel line near the metering building at Pump Station 1.
9	24 Jun 86	36	Leak in underground gasoline storage tank at Pump Station 1.
10	16 Oct 78	21	Equipment malfunction at Pump Station 4 temporary camp caused a diesel fuel spill.

Source: TAPS Owners 2001

Environmental impact statements contain hypothetical scenarios featuring spills greater than 1,000 bbl (42,000 gallons). Most large spill scenarios involve a "blowout," that is, loss of well control, which can occur due to (1) a failure of a rig's blowout prevention equipment resulting in a surface blowout, or (2) a failure in the well's cemented casing resulting in a subsurface blowout (Mallary 1998). Pipeline failures, accidents, or even vandalism also can result in large spills.

Fairweather (2000) distinguished between and *event* (uncontrolled flow of liquids or gas from the wellbore, at the surface) and an *incident* (when the pressure on the formation fluids exceeds the pressure of downhole drilling fluids, but does not result in uncontrolled flow at the surface). Table F-7 lists all reported events (5) and incidents (6) on the North Slope between 1977 and 2001. The events resulted in the release of either dry gas or gas condensate resulted in minor environmental effects (Mallary 1998). No oil spills or fires resulted from any of the events or incidents. Over this period 4,965 wells were drilled or redrilled (Alaska Oil and Gas Conservation Commission) so the event/incident frequency is 5/4956 or approximately 1 per thousand wells drilled. This is comparable in order-of-magnitude terms to rates in other areas (Mallary 1998, Ross et al. 1998). The conclusion of these analyses is that blowouts that result in

Table F-7 Loss of well control event and incidents on the North Slope, 1977-2000 (Modified from Maxim and Niebo 2001b).

Number	Type	Well Name	Year	Operator
1	Event	CPF1-23	1979	Arco AK
2	Event	F-20	1986	BP AK
3	Event	J-23	1987	BP AK
4	Event	Cirque #1	1992	Arco AK
5	Event	1-53/Q-20	1994	BP AK
6	Incident	Tunalik Test well #1	1978	USGS
7	Incident	DS 15-21	1980	Arco AK
8	Incident	Challenge Isl. #1	1981	Sohio AK
9	Incident	L5-36	1989	Arco AK
10	Incident	3F-19	1996	Arco AK
11	Incident	1H-15	1996	Arco AK

large spills are unlikely. This finding has been affirmed in several recent environmental impact statements, and may be attributable in part to the strengthening of drilling regulations following the Santa Barbara blowout in 1969 (BLM/MMS 1998, MMS 2001, Parametrix 1997).

The environmental assessment for the Alpine field includes a well blowout as a "reasonable worst case" oil spill (Parametrix 1997). Similar analyses were made for both Northstar and Liberty developments (Ross et al. 1998). The spill contingency plan for the Kuparuk oil field includes a hypothetical loss of well control scenario (Alaska Clean Seas 1999). The plan details include a description of the hypothetical event (location, date, duration, type of spill, weather conditions. quantity of oil spilled) as well as descriptions of how the discharge would be stopped, how to prevent or control fire hazards, a well control plan, methods for tracking oil, spill control, containment, and recovery actions. These contingency plan features are now required by the Alaska Department of Environmental Conservation (ADEC).

Table F-8 lists the five largest North Slope oil spills that have actually contacted tundra soil and damaged tundra vegetation during the period from 1977 to 1999. An additional crude oil/produced water spill occurred in 2001. The area of tundra affected by these spills ranges from 125 to 1,700 m^2 (1,350 to 18,300 ft^2) (McKendrick 2000), with a total area of tundra affected by crude oil and products spills on the North Slope of about 20 acres (8 hectares) (McKendrick 2002).

Table F-8 Five largest crude oil or mixed crude oil/water spills that affected tundra vegetation on the North Slope 1977-1999. (From McKendrick 2000).

Year	Oil Field	Containment Area (m)	Tundra Affected (m)
1989	Kuparuk	5,800	1,700
1994	Kuparuk	930	465
1972	Prudhoe	560	220
1993	Kuparuk	400	200
1985	Prudhoe	350	125

AGRA (2000) developed a tundra spills database as part of a contract for ADEC. It contains information on approximately 200 spills of various sizes. Some general conclusions can be drawn from a review of the data. First, large spills tend to cover between 0.1 and 0.4 ft^2 (0.01 to 0.04 m^2) of tundra per gallon of spilled material. Smaller spills have a greater proportional coverage. Second, area coverage and environmental effects vary with season. Spills during summer generally result in greater effects on tundra vegetation. Some spills result from pinhole leaks in pipelines. These may spray oil over a broad area, but oil tends to remain on surface vegetation. These spills have fewer long-lasting effects than spills in which oil reaches sediments and plant root systems.

Approximately 65-80% of all crude oil and products spills were confined to an individual pad (BLM and MMS 1998). Spills not confined to a pad are usually confined to an area adjacent to the pad or roadbeds off the tundra surface. Spills that occur during winter, on snow, are almost completely removed from frozen tundra by spill response activities (BLM/MMS 1998).

Spill Trends

Time trends in the data can reveal if progress has been made in spill prevention. They also provide a basis on which to forecast future spill volumes. It makes most sense to examine the time trend in the volume of crude and product spilled, rather than the number of spills, because the reporting threshold for spills has decreased over time, and spill reporting has improved. Therefore, any trend in the number of spills is confounded with changes in reporting conditions. For North Slope oil activities the most appropriate exposure variable is the volume of crude or product spilled per unit of production or throughput, the volumetric spill rate, the VSR (Maxim and Niebo 2001b).

Figure F-5 shows annual VSRs for the North Slope from 1977 to 1999. The graph shows that there is a great deal of year-to-year variability in VSRs (solid line). The "bad" years result from a few larger spills, and "good" years from the lack of large spills. The large inter-annual variability makes it difficult to detect trends, especially modest trends, but the data suggest that VSRs have decreased over the years since North Slope production began. The fitted trend (semi-logarithmic) for these data is shown by the dashed line in Figure F-5. The slope of this line is negative, suggesting perhaps some progress in reducing spill rates. However, the percentage variation explained by this regression ($R^2 = 0.117$) is relatively low, and statistical analysis of the regression coefficient indicates that such a trend might have occurred due to chance ($P = 0.07$) (Maxim and Niebo 2001b).

Although the apparent time trend is not statistically significant, numerous modifications made to North Slope facilities and operations practices have been designed to reduce spills. In addition, the accuracy of oil spill data may have increased after 1985 (MMS 2001) or 1989 after the *Exxon Valdez* spill (BLM/MMS 1998) and subsequent legislation and regulations. The reporting threshold for spills has decreased over the years, as well. Therefore, by today's standards, spills were probably under-reported in earlier years (Maxim and Niebo 2001b).

The introduction of improved technologies, engineering designs, or operations practices designed to reduce spills have been both continuous processes and triggered by discrete events. Major ("step") changes in technology or procedures often result from specific events (e.g., a large spill or other accident) and regulatory responses to such events. The key event for both regulatory and industry initiatives was the Exxon Valdez spill in 1989. The Oil Pollution Act of 1990 was implemented along with regulations aimed at both prevention and response. At the same time, oil companies examined and strengthened internal prevention and response programs. Figure F-6 shows VSR data with separate average values (dashed lines) calculated for the time periods prior to and after 1990. The average value for the post-1990 time period is 31% lower than for the years 1977 to 1989.

The VSR for the TAPS segment from Pump Station 1 to Atigun Pass (Figure F-7) does show a statistically significant reduction over time.

Spill Prevention

State and federal regulatory agencies and the oil industry have studied each spill incident, to develop "lessons learned," and measures to reduce the likelihood and effects of future spills. For example, the 575 bbl (24,150 gallons) crude oil spill that occurred on 30 December 1993 (Table F-2) resulted when wind-induced vibration caused a crack in a flowline leading from a well house to the manifold building. Although this failure mode was anticipated and "first generation" wind-induced vibration dampers had been developed, they were not installed on this pipeline. Immediately following the spill, the pipeline was fitted with a vibration damper, along with all other pipelines not already fitted. The design was also improved as a result (Norris et al.

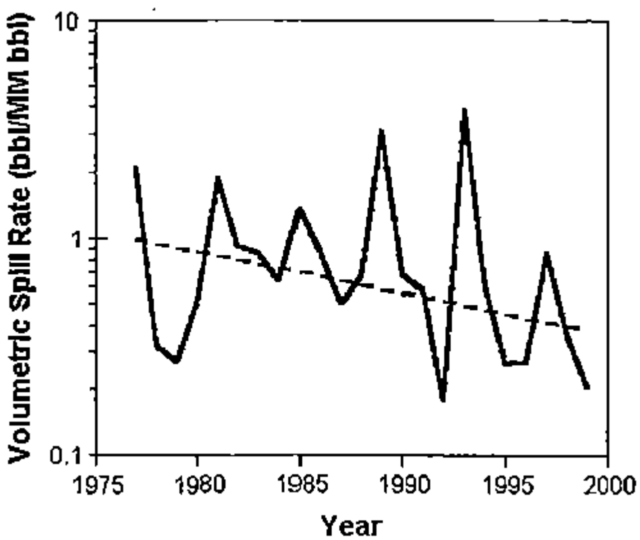

FIGURE F-5. Volumetric spill rates for crude oil and products spills associated with exploration and production activities on the North Slope. Year-to-year variability may mask significance of fit ($p = 0.07$). Source: reprinted with permission from Maxim and Niebo 2001.

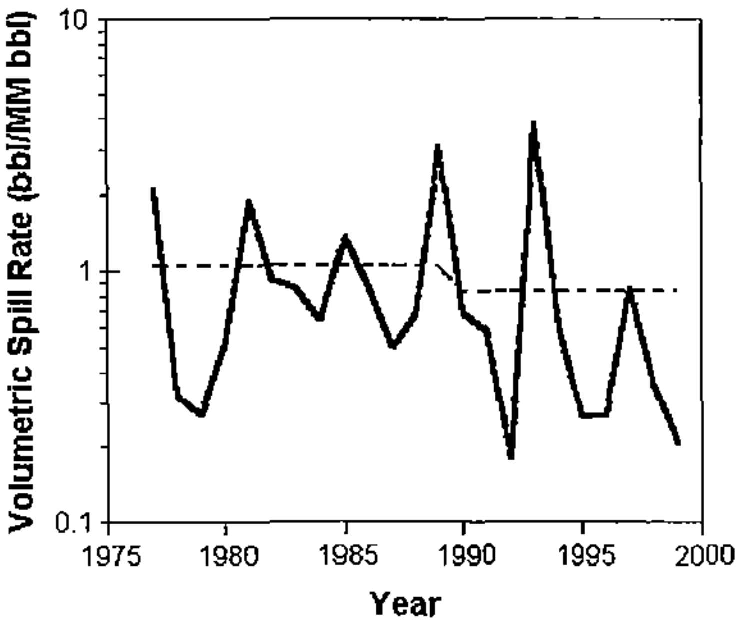

FIGURE F-6. Volumetric spill rates for crude oil and products spills associated with exploration and production activities on the North Slope. Average VSR FRP, 1990-1999 is 31% lower than for 1977-1990. Source: reprinted with permission from Maxim and Niebo 2001b.

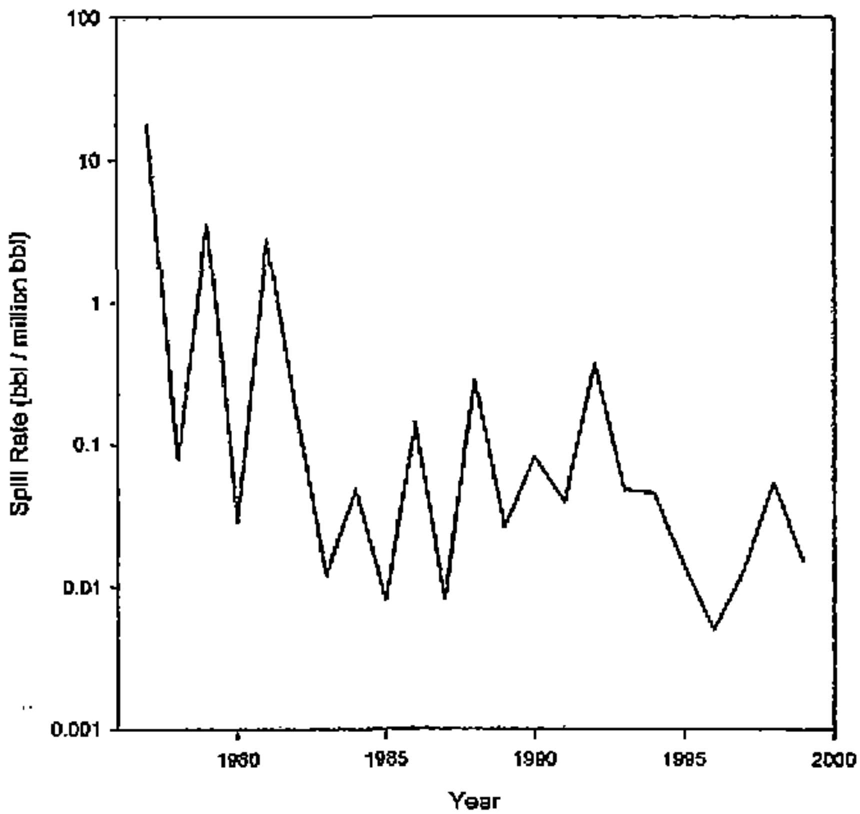

FIGURE F-7. Volumetric spill rate for crude oil and products spills associated with the Trans Alaskan Pipeline from Pumpstation 1 to Atigun Pass (semi-log scale). Source: reprinted with permission from Maxim and Niebo 2001.

2000). Dampers are required only on pipelines less than 24 in. (61 cm) in diameter, oriented perpendicular to prevailing east-west winds and having a specific weld type (Norris et al. 2000).

Prevention of spills can be approached in two ways. The first is changing engineering design and equipment, and the second is changing operating procedures and practices. Table F-9 includes examples of both kinds of changes that have been implemented on the North Slope. The following discussion is descriptive and does not quantitively evaluate the success of those methods.

Table F-9 Spill Prevention on the North Slope (After MMS 2001, Pavlas et al. 2000, Cederquist 2000, Guilders and Cronin, Maxim and Niebo 2001b).

Changes in Engineering Design and Equipment

- Redesign of a component system to reduce probability of leak, e.g., "vertical loops" replace valves in common carrier sales pipeline.
- Use extra thick steel walls, fusion-bonded epoxy coating and cathodic protection to minimize corrosion leaks in pipelines.
- Improve "smart pigs"
- Siemens-developed leak detection and location system
- Use system control and data acquisition system (SCADA) to improve leak detection (similar to TAPS)
- Construct secondary containment around tanks.
- Double-wall storage tanks
- Change pad grading to create a low spot in the center of the pad.
- Development of improved well cellar spill containment system.

Changes in Operating Procedures and Practices

- Location of Major Facilities
  - Avoid environmentally sensitive areas
- Location of storage tanks
  - Avoid river crossings
  - Avoid sensitive wetlands
- Use revised inspection and maintenance procedures (e.g., smart pigs, more frequent inspections)
- Double checking connections before beginning fluid transfer.
- Stepped up monitoring for corrosion.
- Use of corrosion inhibitors
- Use drip pans to collect oil leaks from vehicles.
- More/improved training and classes.

Changes in Engineering Design and Equipment

Changes in engineering design or equipment include new "vertical loop technology to replace block valves, improved leak detection systems, developing and installing double-wall storage tanks and secondary containment structures, alternative design of well cellars, use of "smart" pigs.

The Alpine pipeline uses "vertical loops" in place of block valves (Pavlas et al. 2000, Cederquist 2000). Vertical loops are regular expansion loops of the pipeline with the outboard run lifted to a predetermined elevation. The loops form a terrace structure that, in the event of a leak, limits oil spilled due to drain down effects caused by pipeline elevation differences. Seven 40 to 45 ft (12 to 14 m) high vertical loops were built into the 34 mi (55 km), 12 in. (30 cm) crude oil pipeline. This design was recommended by an oil spill isolation strategy study that systematically evaluated alternatives, including use of conventional block valves throughout. The analysis concluded that, if used with emergency pressure letdown valves or divert valves, vertical loops would contain drain down related spills as well or better than block valves while offering operations and maintenance efficiencies. Use of this technology eliminates the need for remote and manually operated valves that can fail and/or introduce additional leak sources at flanges, valve stems, and fittings. Use of vertical loops is limited to relatively flat terrain, which makes them applicable on flatter areas of the North Slope (Maxim and Niebo 2001b).

Rapid and accurate leak detection can reduce the quantity of crude oil or product spilled. Systems for leak detection include volume balance and mass balance systems (e.g., pressure point analysis). The recently developed Leak Detection Location System (LEOS) for monitoring ethylene pipelines (Comfort et al. 2000; Intec Engineering, Inc. 1999) has been modified for crude oil pipelines. It detects leaks by periodically sampling the vapor within a special, permeable tube strapped to the pipeline. The gas in the tube is sampled by pushing a column of air past a gas "sniffer" at constant speed. The sensor measures vapor concentration and relative distance along the length of the tube, allowing determination of the size and location of the leak.

A well cellar is a cement-lined containment structure surrounding each well. The design was modified to reduce the possibility of subsidence caused by melting permafrost as well as improved containment of leaks and drips from valves or fittings. Each cellar contains a drip pan.

Pigs are mechanical devices that are pushed through a pipeline by flowing crude oil or product. Over the years, pig design has become very sophisticated, leading to various types of "smart" pigs. These pigs are used to monitor the condition of the pipeline, initially establishing a baseline against which future pigging (monitoring) results may be compared. Three types of pigs are used. All can provide early warnings of weaknesses where leaks might occur (Maxim and Niebo 2001b).

- Caliper pig—used to measure internal deformation such as dents or buckling.
- Geometry pig—records configuration of the pipeline system and determines displacement.
- Wall thickness pig—measures thickness of pipeline wall.

North Slope pipelines are insulated to reduce heat loss and reduce the likelihood of corrosion and failure. Weld pack insulation was redesigned, adding a special coating to repel moisture (Maxim and Niebo 2001b).

Containment is one of the generic strategies for spill prevention. Containment prevents further release of spilled material and makes cleanup easier. Measures to maximize containment include double-wall pipes, double-wall tanks, secondary containment structures such as berms and dikes (Pekich, personal communication, 2001, as cited in Maxim and Niebo 2001b).

Changes in Operating Procedures and Practices

Changes in operating procedures and practices include locating storage tanks to avoid environmentally sensitive areas like river crossings, using drip pans to collect leaks, and more frequent inspections. Drip pans are required for all equipment parked on ice pads and roads (including pickup trucks). All stationary tanks greater than 660 gallons have secondary containment (Pekich, personal communication, 2001, as cited in Maxim and Niebo 2001b).

Several spill prevention initiatives are designed to increase spill awareness and reduce human error. These include formal and informal training ("tailgate" or "toolbox" meetings), formation of task forces, appointment of sponsors for various initiatives, and the development and revision of SOPs (Standard Operating Procedures), and checklists (Maxim and Niebo 2001b). Table F-10 is a checklist designed to reduce errors in fluid transfer and transportation operations.

Table F-10 Fluid Transfer Safety Task Assignment (STA) Card Information (Modified from Maxim and Niebo 2001b).

Portable Tank Fluid Transfer Guidelines

Foreman:____________
Date:____________
Location/Job:____________
Truck/Tank #____________
Driver:____________
Volume:____________
Fluid:____________

All lines closed and secured, capped/plugged?	yes	no	
Portable (or permanent) dikes under truck engine?	yes	no	
Portable dikes under all connections?		yes	no
Camlock seal rings checked?		yes	no
Camlock ears locked and wires closed?		yes	no
Assessment of tank condition before transfer?		yes	no
Bonding cables connected?		yes	no
Fluid level checked before loading?	yes	no	
Vents and hatches in proper position?		yes	no
Sumps and accumulators drained?	yes	no	
Will product foam?		yes	no
Frequent straps during transfer?		yes	no
Tank filled to less than 90% capacity?		yes	no
Inspect location prior to departure?	yes	no	

Comments:

Transportation STA Card Information

Tank Tie-in and Rig Checklist
Date:____________
Location:____________
Employee Assigned:____________
Foreman:____________

Inspect and report any existing contamination at site	____________
All hoses and hardline properly connected and diked	____________
All needle valve bleeds closed and capped	____________
Inspect tanks (valves closed/capped, demisters, etc.)	____________
Drip pans beneath all connections	____________
Orange cones placed along hose/piping connections	____________
Pressure test all flowback piping	____________

Spill Response

Response Countermeasures

Research and development on spill response equipment and strategies began after the Santa Barbara spill in 1969. Containment booms, skimming devices, absorbent and adsorbent materials were all developed in the 1970s and have been improved since that time. Since the Oil Pollution Act of 1990 there has been improved design and use of many spill response and logistical support systems. Some of these have been designed or modified with arctic conditions in mind; some may be used anywhere. They include skimmers, fire booms, igniters, air-cushion vessels, airboats, oil/ice processors, oil/water separators, and chemical dispersants. Airborne systems include those that monitor spilled oil, apply dispersants, and ignite oil slicks (Allen 2000). Table F-11 lists major R&D programs for spill prevention and response on the North Slope.

TABLE F-11 Major R&D programs for spill prevention and response (Modified from Maxim and Niebo 2001b).

PREVENTION
1. Corrosion control system (Pekich, personal communication, 2001; Colegrove, personal communication, 2001)
2. Vibration dampers (Carn, personal communication, 2001b; Ford, personal communication, 2001; Henry, personal communication, 2001; Norris et al. 2000)
3. Leak detection and location system (Intec Engineering 1999, Comfort et al. 2000)
4. Expanded vertical loops/antisiphons (Lipscomb, personal communication, 2001; Cederquist 2000; Pavlas et al. 2000)
5. Horizontal directional drilling with remotely located wells (Baker 2000)
RESPONSE
1. Forward looking infrared (FLIR) (Colegrove 2001)
2. Oil recovery from broken ice (Dickens and Buist 2000, D.F. Dickens et al. 2000)
3. In-situ burning (S.L. Ross Environmental Research 1998b)
4. Viscous oil pumping (Majors 2001, S.L. Ross Environmental Research 2001)
5. Oil emulsion breakers (S.L. Ross Environmental Research 2001)
6. Tundra flush programs (Schuyler, personal communication, 2001)
7. LORI stiff brush skimming system (Majors, personal communication, 2001; S.L. Ross/D.F. Dickens 2001)
8. Mutual aid drill (Majors, personal communication, 2001)
9. New trench and weir design (Alaska Clean Seas 1999a)
10. Oil spill response barge for arctic work (McHale 1999)

Much effort has gone into developing these systems, but they are seldom tested or used in training with real oil. Experimental spills have been conducted in other countries, but very few have been permitted in the U.S. since the early 1980s. The effectiveness of that response would likely improve if responders had the opportunity to practice and test equipment on real oil (Allen 2000, Lindstedt-Siva 1995), although broken ice remains a major challenge for response in the Arctic Ocean.

Although all oil spills on the North Slope have been onshore, preparedness is required for both onshore and offshore spills. Alaska Clean Seas, an industry-funded oil cleanup cooperative, is designated as the sole entity responsible for training, purchasing and maintaining equipment, and spill response, including cleanup. Equipment is stored at various locations across the North

Slope. Training and drills are held on a regular basis, including mutual assistance drills, tabletop drills, full-scale spill drills, and safety training.

Onshore Spills

Tundra vegetation can hold large quantities of oil, which prevents oil from spreading over large distances but produces heavy concentrations of oil in the area affected. Standard treatment is low pressure flushing to mobilize the oil and remove it, along with removal of the most heavily contaminated soils. Scraping the surface is designed to leave plant parts (roots, rhizomes) intact so that sprouting will occur the following spring (Cater et al. 1999).

Bioremediation has also been attempted with some success by adding nutrients to the soil and removing snow to increase the growing season (Cater et al. 1999). Most tundra soils contain adequate numbers of hydrocarbon-degrading microorganisms, making in-situ bioremediation possible through addition of nutrients (AGRA 2000).

Most spills during winter on snow have been a light surface aerial spray from a small pin-hole. The pressure and wind blow the oil over a relatively large area, but the coating is light and does not penetrate the snow's surface crust. Vegetation that penetrates through the snow is contaminated. Cleanup is by scraping the snow surface and the affected vegetation, and removing contaminated material. Tundra growth is usually normal the following spring, but there have been minor vegetation effects (Joyce 2001). Cleanup while the ground is still frozen may prevent contaminants from soaking into soil or the tundra mat (AGRA 2000).

Large volume spills on snow melt snow for some distance down drainage. The oil eventually cools and is absorbed by the snow. Cleanup involves making snow berms to contain the oil. Most oil stays on the frozen tundra surface, so scraping the surface is the common cleanup method. The worst-case condition is when some of the oil gets below the frozen surface while it is still warm and can melt the ground and migrate down slope. This kind of spill is cleaned up as if it were a summer condition spill. Down-slope flow is stopped with sheet piling or another barrier. Once contained, contaminated soil and vegetation are removed and remediation takes place in spring. The impacts of such a spill are similar to a spring/summer spill (Joyce 2001).

Burning onshore spills has been tested on tundra, both during winter and the summer growing season. Burning during summer damaged plant communities. Burning during winter had less impact on plants and did not harm permafrost. It may be a viable approach to spill cleanup in winter (McKendrick and Mitchell 1978). Burning was tried recently on a small spill on tundra that the committee observed during a site visit. The spilled oil (from a pin-hole leak in a pipeline) was sprayed over tundra and seemed to contaminate surface vegetation more than soil. Contaminated vegetation was burned.

Spills that flow into running or standing water are contained and removed using booms, skimmers, and sorbent materials (AGRA 2000). Spills on gravel pads are cleaned by removing contaminated gravel according to ADEC standards (ADEC 2001). Contaminated gravel is removed to a central storage location. Periodically this gravel is remediated and reused. Contaminated gravel is rarely left in place but contamination beneath buildings or other structures that prevent immediate removal may remain (van der Wende 2002).

Offshore Spills

Even though there have been no major offshore spills on the North Slope, methods used to control offshore oil spills have been used for 30 years, during which time they have been improved and refined. They are: mechanical containment and recovery, in-situ burning, chemical dispersion. The fate of oil spilled in the ocean is discussed later in this appendix.

Mechanical Control

Mechanical containment and recovery equipment is used to contain oil spilled on water and recover it from the water surface. Containment booms are devices that float on the water surface with an extension (skirt) below the surface. Floating oil contacts the boom that holds it, and may thicken it. Booms are often used in combination with skimmers of various designs that remove oil concentrated within the boom from the water surface. Booms may also be used to deflect spilled oil from a sensitive area. Some booms have been especially adapted for use in ice-infested waters (Abdelnour 2000). The benefit of mechanical recovery is that it removes the oil from the water surface. The disadvantage is that the containment and recovery process is slow, and it usually removes only a small percentage of the spilled oil (Allen 1999).

In most areas of the U.S., mechanical containment and recovery of spilled oil is the first choice of most regulatory agencies. Logistical and efficiency problems increase under the common adverse conditions in the arctic. During freeze-up and break-up unstable ice conditions can significantly reduce chances of reaching and recovering spilled oil safely and effectively (Allen 2000). Much research has been conducted, and design of skimmers, booms, oil/water separators has been improved (Abdelnour et al. 2000, Allen 2000, S.L. Ross Environmental Research 2001a).

In the fall 2000 a series of exercises, using popcorn to simulate oil were held to evaluate the effectiveness of mechanical control and recovery techniques using equipment and methods called for in North Slope contingency plans. Broken ice conditions ranged from 30 to 70 percent ice coverage (Robertson and DeCola 2001). The aim of the exercise was to establish Realistic Maximum Response Operational Limits (RMOL). A barge-based recovery system was tested and RMOL's were determined to be (Robertson and DeCola 2001):

~ 0-1 % in fall ice conditions
~ 10% in spring ice conditions without ice management
~ 30% in spring ice conditions with extensive ice management

These numbers are only estimates, but they strongly suggest that reliance on mechanical recovery to clean up spills on the North Slope is unlikely to be successful.

Since recovery of spilled oil in broken ice conditions remains a major challenge, development of such technology has been an R&D priority (S.L. Ross Environmental Research Ltd. 1998c). North Slope operators established a study team to examine options to deal with oil spills during freeze-up and break-up and define the realistic maximum response operating limitations. The main conclusion of this study team was that "mechanical containment and recovery techniques have limited application for a large spill, especially one from an open-orifice blowout" (D.F. Dickens et al. 2000).

In-situ Burning

If oil is of sufficient thickness and has sufficient volatile components, it can be ignited and burned. On open water, this technique may involve special booms, igniting agents, and methods to deliver them. There has been much research and development on this technique because it is especially applicable in the arctic (Allen 1999). The benefits of burning are that it removes the oil from the environment and it may be more efficient than mechanical recovery, especially in the arctic where a slick may be contained by ice. The disadvantage is that burning oil produces smoke plumes. Another disadvantage is a limited "window of opportunity" when burning is possible. Evaporation of the oil's most volatile components or formation of a water-in-oil emulsion can render a slick not ignitable. S.L. Ross Environmental Research (1998b) studied the "window of opportunity" for in-situ burning of oil on water in the arctic. They found that applying chemical breakers to emulsions contained in fire resistant booms can allow otherwise ignitable slicks burn successfully.

Chemical Dispersion

Dispersants are applied to the surface of an oil slick. They act at the oil-water interface, reducing interfacial tension and breaking the slick into tiny droplets that disperse in the water column (S.R. Ross 2000). Dispersants are most effective if used early, during a fairly narrow window of opportunity. Dispersants are most effective on fresh, low viscosity oils (Ross 2000). The benefits of dispersion are that large slicks can be treated in a short time from the air, and they remove the slick from the surface. Present day dispersants are all less toxic than oil, and applied at lower concentrations than oil. Therefore, dispersant toxicity is less important than toxicity of the dispersed oil (NRC 1994). The disadvantage is that, if effective, dispersion introduces a plume of dispersed oil into subsurface water where it may affect water column and shallow benthic communities. This is usually a very short-term exposure due to the effects of dilution and currents. Dispersents are probably not appropriate for highly viscous oils (Ross 2000). Regulatory agencies generally have not made dispersants a priority for North Slope spills.

Pumping Viscous Oils

Most North Slope crude oils form stable emulsions. Weathered but unemulsified oils may have viscosities as high as 10,000 centistokes (cSt). Emulsions formed from these oils may have viscosities of 100,000 cSt or more. Such high viscosities pose problems for spilled oil recovery activities because pumping these oils is difficult. Solving this problem is another R&D initiative. Several possible techniques might be used to reduce the viscosity of emulsified oils, including heating, use of chemical additives to break the emulsion, and use of chemicals to serve as drag reduction agents. Another technique that has been proposed is annular water injection to reduce line pressures. A relatively small volume of water is injected through a specifically designed flange. The flange causes the water to form a thin layer that coats the inside wall of the hose or pipe, lubricating the flow of fluid and reducing line pressure (Maxim and Niebo 2001b).

Spill Monitoring

Forward Looking Infrared (FLIR) technology was originally developed by the military for reconnaissance and targeting. Since FLIR became available for civilian application it has been adapted for oil spill monitoring. It is carried in an observation aircraft (e.g., DeHaviland Otters) to detect spills along pipelines and pads. It is useful for both prevention and response. It makes possible early detection, and therefore, the ability to minimize the spill volume and extent

(Maxim and Niebo 2001b). It makes it possible to determine the location and extent of a spill, and to distinguish between oil and other substances that may look like oil to the human eye. The airborne FLIR can be used to monitor both onshore and offshore spills.

Research and Development

Restoration/Remediation

The most extensive remediation of a spill on moist-sedge tundra was done following the 2U spill, which occurred in August 1989. This was a spill of 600 bbl (25,200 gallons) of crude oil and produced water that leaked from a valve in the Kuparuk oilfield operated by Arco Alaska. The leak sprayed oil below the pipeline. It pooled and spread downhill, contaminating 1.43 acres (0.60 hectares) of moist and wet tundra, posing several cleanup and remediation challenges (Cater et al. 1999). This was the first relatively large spill on tundra in the Kuparuk oil field, so information was lacking on long term effects of oil spills on tundra, especially the effectiveness and effects of cleanup and remediation methods. The ADEC set stringent standards for remediation, the vegetation in the spill must return to "normal." Normal was to be measured by vascular plant ground cover when compared to adjacent, uncontaminated tundra. The ADEC standard for total petroleum hydrocarbons (TPH) in soil was 500 ppm. After the spill, the most heavily contaminated areas near the pipeline had concentrations of 16,000 ppm TPH (Cater et al. 1999).

During the cleanup, oil sorbents were spread over the area. Low-pressure water flushing with warm and cold water was used to remove oiled sorbent material, along with raking and swabbing. Multiple, short flushes were used to prevent damage to underlying permafrost. Plywood boardwalks were used to prevent trampling. The most severely contaminated soils were removed by scraping off the upper 2 to 5 cm (0.8 to 2 in.), leaving subsurface plant parts (e.g., rhizomes, roots, stem bases) intact. Undisturbed or moderately contaminated areas were not touched. Bioremediation using indigenous microorganisms, adding nutrients, and keeping moisture stable, was also used to reduce oil concentrations in soil. Nutrients and fertilizers were added to enhance indigenous communities of microorganisms. Snow was removed in spring to lengthen the growing season and increase soil temperature. After two summers, the ADEC vegetation requirements were achieved. As of 1996, the hydrocarbon concentrations in the soil were 687 ppm, still exceeding ADEC standards of 500 ppm TPH, although there was a 95 percent reduction from the post-spill concentrations (Cater et al. 1999). Since this was so close to the ADEC standard, the state approved the cleanup (Joyce 2001). Concentrations of oil in soil decreased very rapidly over the first four years, then very slowly after that (Jorgenson, unpublished material, 2001).

As a result of the 2U spill and cleanup, ADEC asked Arco Alaska to do some experiments using surfactants to enhance oil removal from tundra vegetation and soil. Several surfactants were tested, and it was found that small amounts of Dawn® liquid dishwashing detergent mixed with water enhanced oil removal. Multiple, short flushes were used to prevent damage to underlying permafrost. This method greatly enhanced the recovery of spilled oil and had no measurable effect on tundra vegetation (Cater et al. 1999). (Dawn® has also been used to clean oiled birds.)

Seeding has been used to reestablish plant cover in areas where tundra has been damaged by spills. Fertilizer is also applied, with or without seeds. Fertilization accelerated and improved recovery of mosses, grasses, forbs, and shrubs. Seeding may enhance recolonization initially, but natural stocks eventually replace introduced plants (AGRA 2000).

Estimates of Future Spills

Future spill volumes depend on projected values for the VSR and future throughput, neither of which can be forecast with certainty. One projection of future North Slope production is that an additional 7 billion bbl (294 billion gallons) of crude oil will be produced from 2004 to 2034, the anticipated period of the TAPS right-of-way renewal (TAPS Owners 2001). If there is no improvement in the volumetric spill rate (VSR = barrels spilled per million barrels produced), the future value will be equal to the 1977 to 1999 average, approximately 0.86 bbl/million bbl. This amounts to approximately 6,000 bbl (252,000 gallons), an average of approximately 200 bbl (84,000 gallons) per year during the period 2004 to 2034. If the apparent trend is valid, the spill volumes would be lower by 31%. If North Slope production increases, spill volumes will increase accordingly.

An alternate method of forecasting spill volumes is used by MMS (Smith et al. 1982; LaBelle and Anderson, 1985, 1994; Amstutz and Samuels 1984; MMS 1987, 1990ab, 1996, 1999, and 2001a). This method calculates the frequency of large spills (greater than 1,000 bbl) per billion barrels of oil produced. Since no large spills (according to the MMS definition) have occurred on the North Slope, the threshold was reduced to 500 bbl (21,000 gallons) for spill projections for the Liberty field (MMS 2001a). There have been two crude oil spills greater than 500 bbl (21,000 gallons) during the period from 1977 to 1999. Barrels of oil produced over the period were 12.76 billion (535.92 billion gallons), therefore the spill rate is 0.16 spills/billion barrels. MMS (2001a) estimated that there would be 2.74 large spills during the period from 2004 to 2034. These are conservative estimates because they make no allowance for improvement (Maxim and Niebo 2001b).

FATE OF OIL LIKELY TO BE SPILLED ON THE NORTH SLOPE

When oil is spilled into the environment, the fate and effects are determined by the amount and type of oil spilled, the time of year, the environment into which it is spilled, and to some extent, the control and cleanup/restoration methods used. Oil composition and physical characteristics govern its movement, weathering process, and the impacts it has on affected environments. When oil is spilled, it begins to naturally degrade, both physically and chemically. This process is known as weathering and includes spreading, evaporation, dispersion, emulsification, microbial degradation, photo-oxidation. The weathering process is also affected by winds, waves, and currents (BLM/MMS 1998, MMS 2001, USACE 1999).

BEHAVIOR OF OIL IN THE BEAUFORT SEA

Oil spilled during the summer season of open water will spread and weather like other spills in cold waters, influenced primarily by winds and currents. During freeze-up, winter, and break-up, oil will interact with ice and its fate and behavior will be modified accordingly (Dickens and Associates 2000).

Freeze-up

Oil/ice interactions during freeze-up vary with the stage of ice development and ice form (frazil, grease, slush, pancakes, nilas, etc.) as well as the properties of the spilled oil (density, viscosity). All varieties of ice may exist simultaneously, and may change from one form to another rapidly. The progression from less to more mature ice types may be fairly linear at nearshore sites like Endicott and West dock but can be non-linear at locations like Northstar. At nearshore sites, freeze-up progresses from frazil and grease ice to stable new ice in less than a week. Farther offshore, this process may take three weeks or more (Dickens and Associates 2000).

The main factors influencing the degree of oil incorporation into porous developing ice forms (slush, grease, frazil) are oil density and turbulence in the upper water column. The breakdown of oil into suspended particles is also controlled by oil viscosity. Heavier Bunker products are more likely to be break into larger particles, and are less likely to rise to the surface. Most of the oils found in the study area are of lower density and therefore will surface due to buoyant forces (i.e., the density difference between oil and the ice/water mixture). In most situations in the nearshore Beaufort, the turbulent mixing energy in the developing ice field is low compared to open water. Oil droplets or particles of fresh North Slope crude oils will be small enough to rise freely through developing ice (Dickens and Associates 2000).

There have been opportunities to observe oil in developing and broken ice during spills of opportunity and field experiments. Dickens and Associates (2000) describe several of these that, in their opinion, are most applicable to Beaufort Sea conditions. Their general observations and conclusions follow (Dickens and Associates 2000):

1. Landfast ice, when present, provided a protective barrier preventing shoreline contamination.
2. Oil released from under the ice surfaced in leads as they opened.
3. Rough ice such as rubble and rafting ice led to thick oil pools and limited spreading.
4. Crude oil migrated to the surface of slush ice.
5. Barriers of snow and slush in a refreezing lead prevented further oil spreading.
6. Oil continued to evaporate after being mixed or covered by snow.
7. Wind herding created thicker oil layers at the downwind edge of leads.
8. Oil mixed with slush ice and stopped spreading.
9. Most of the spilled oil remained at or near the surface.
10. There is no redistribution of substantial amounts of oil from water onto the surface of ice pancakes or small floes.
11. Oil falling on new or young broken ice under freezing conditions will remain on the ice surface, effectively sorbed by the briny, damp, developing ice and/or snow. In spring,

however, a portion of the oil spilled onto melting ice floes may run off the surface into surrounding water.

12. Most oil spilled subsurface into a developing ice field will be held in concentrated pockets on the underside of the ice. Trapped oil will move with the ice except where there are localized openings in the ice cover or leads where oil can spread on the water surface in the absence of slush. These conditions are short-lived at freeze-up. Open water is unlikely to persist for long at low temperatures.

In the absence of wave action, evaporation is the only significant weathering process that will affect a spill during freeze-up. Evaporation occurs more slowly in the arctic than in temperate climates. However, in a few days to a week, surface oil will lose about the same volume as it would in warmer situations. The result is an increase in density, viscosity, pour point, and fire point of the spilled oil. If pour point exceeds the ambient temperature, the oil will gel. The most likely form of spilled oil remaining after freeze-up is a relatively thick, snow-filled, weathered slick at the ice surface, covered by snow (Dickens and Associates 2000).

Winter

If oil is spilled under stable, land-fast ice in winter, initial spreading will probably be limited to hundreds of meters from the spill source, based on currents and ice storage capacity (Dickens and Associates 2000). Cox and Schultz (1980) found that minimum currents that would move crude oil under a smooth ice sheet were approximately 0.15 m per second (0.50 ft per second), increasing to approximately 0.21 m per second (0.70 ft per second) under the slightly rougher ice representative of midwinter conditions. Under-ice currents in the Beaufort are typically very low (Dickens and Associates 2000).

Another typical phenomenon is encapsulation of spilled oil beneath growing ice that may occur when new ice forms beneath oil trapped under ice. Encapsulation by new ice immobilized the spill quickly, typically within 12 to 72 hours, depending on the time of year. A number of studies have observed this in every month of the ice-growth period from October to May (Dickins and Buist 1981, Norcor 1975).

Oil spilled under ice from a chronic leak may not become encapsulated in the manner described as long as there is a continued source of fresh oil. Although there are no direct observations, it seems likely that frazil present in the water beneath the ice will continue to form and float up into the oil pool as it deepens. At the same time, surrounding unoiled ice will continue to grow and contain the oil from spreading beyond the initial area of oiling. Calculations based on typical ice growth rates show that leaks on the order of 60 bbl (2,500 gallons) per day will be contained in an area approximately 91 m (300 ft) in diameter via this mechanism. The slush/oil mixture will remain a viscous fluid, gradually deepening over time as the cumulative volume increases (BP Exploration 1998).

Normal variations in first-year ice thickness provide natural "reservoirs" that may confine spilled oil to a smaller area compared with an identical volume of oil spilled on open water (Dickens and Associates 2000).

Oil spilled on the ice surface in winter does not spread rapidly due to the presence of snow and natural small-scale ice roughness features. Very little oil is likely to remain under or in the ice at this time.

Vertical migration of oil starts when the expulsion of brine from the warming ice opens pathways to the surface (Dickens and Buist 1981, Norcor 1975). Beginning as early as April, and accelerating through May and June, oil will rise to the surface from wherever it is trapped within or beneath the ice. The rate of oil migration increases once daily air temperatures consistently remain above freezing (Dickens and Associates 2000). The rate of oil migration through an ice sheet is affected by the depth of the oil lens trapped within the sheet (small, isolated oil particles take longer to surface) and the viscosity of the oil (heavier or emulsified oils take longer to rise though brine channels) (Buist et al. 1983, Dickens and Buist 1981, Norcor 1975).

Oil weathering in winter depends primarily on whether or not the spilled oil is exposed to atmosphere. Oil spilled under an ice sheet will not evaporate, but oil spilled on top of ice or into leads does (Dickens and Buist 1981, Nelson and Allen 1982, Norcor 1975).

Oil spilled under ice in winter will be encapsulated into the downward-growing ice sheet. As this process occurs, some oil components may dissolve into underlying water. As is typical, this amounts to only about one percent of the total oil (D.F. Dickens et al. 2000). No further weathering of encapsulated oil occurs until it is exposed to the atmosphere when it appears on the ice surface the following spring.

The formation of water-in-oil emulsion is unlikely with oil spilled under ice since the mixing energy needed to form an emulsion is not present. For the same reason, natural dispersion is expected to be negligible as well (D.F. Dickens et al. 2000).

Break-Up

First ice breakup and the appearance of open water takes place in late May and early June, extending to final breakup in July. The rapid disappearance of nearshore ice in early June is triggered by river overflood (D.F. Dickens et al. 2000). Ice concentrations are highly variable and changeable.

If oil is spilled under ice, it will surface on floes or in leads as ice melts. As the rotting floes fracture and break into progressively smaller ice features, any oil on the surface or in the porous structure of the ice, will gradually enter the water and create localized sheens and patches. Throughout break-up, both residual oil trapped in porous ice and oil on the surface of melting floes will gradually be released to water as sheens and broken thin films. Some oiled floes can strand on shorelines or along barrier islands. The ice will most likely melt in place and release oil into beach sediments (D.F. Dickens et al. 2000).

There is an important difference between oil among broken ice during break-up and freeze-up. There is no slush in the water at break-up. This plus extended daylight, warming temperatures, and decreasing ice concentrations and thickness all combine to make spill response more likely to be effective during break-up (D.F. Dickens et al. 2000).

Once the encapsulated oil is exposed to the atmosphere, it will begin to weather. Evaporation of light components is the dominant process until the ice sheet breaks up, at this time wave action can cause emulsification and natural dispersion of slicks on water (D.F. Dickens et al. 2000).

Oil in meltpools is herded by wind against the edges of the pools. Such slicks may reach approximately 10 mm (0.40 in.) in thickness. Thicker oil will evaporate more slowly than thin slicks and films, but will eventually achieve approximately the same degree of evaporation as slicks on open water. Emulsification of oil in meltpools is not expected to be significant since most are too small to allow generation of wind waves of sufficient size. Rainfall may cause some emulsification but it is likely to be temporary and unstable (D.F. Dickens et al. 2000).

When an ice sheet deteriorates and breaks into floes, oil remaining in meltpools will be discharged onto water between floes primarily in the form of thin sheens trailing from drifting, rotting ice. Once exposed to significant wave action, fluid oil will begin to emulsify and naturally disperse. Weathering occurs more rapidly as temperatures increase (D.F. Dickens et al. 2000).

The implications of these findings for responses to spills are from D.F. Dickens and colleagues (2000).

- Fresh crude oil from both surface and subsurface spills will reside naturally at or near the surface in newly forming ice (grease, nilas).
- Ice acts as natural containment, restricting further spreading from the point where oil contacts the ice surface. However, the presence of ice does not necessarily result in thick films or act to thicken oil once it has spilled.
- All aspects of spill behavior, including spreading and weathering, are greatly affected by the presence of ice. In many cases, the overall effect is to slow or prevent normal weathering and to limit the area of contamination.
- Snow covering oil on ice slows, but does not stop, evaporation.
- Emulsification and dispersion are reduced to almost zero in the presence of any substantial ice cover.
- Attempts at mechanical recovery operations during freeze-up will result in fracturing of the ice and mixing of oil and ice. This would reduce opportunities to recover or burn oil after ice has stabilized.
- Slush or grease ice at freeze-up effectively stops oil from spreading.
- Lack of slush between floes at break-up means the oil is more accessible for recovery and/or burning.
- If the pour point of spilled oil exceeds the ambient temperature, oil on the ice surface will gel. The likely form of most spilled oil remaining after freeze-up is a relatively thick, snow-filled, weathered slick at the ice surface, covered by snow.
- Oil that is spilled under solid, growing ice from freeze-up until April is quickly encapsulated by a new ice layer which grows beneath the oil.
- Oil trapped in ice does not weather (frozen emulsions do not break).
- Oil encapsulated within an ice sheet from a winter spill will naturally rise to the surface beginning in May (exceptions are viscous crudes and emulsions).
- Oil remaining on the ice surface at the downwind edges of meltpools in June and July will be naturally concentrated by wind herding. This facilitates in-situ burning.

Summer

In summer when there is open water, more response options exist. Depending on wind and wave conditions, booming and skimming operations may be effective. In-situ burning using fire booms to concentrate oil is also an option. In some cases, application of chemical dispersants may also be effective, although this does not seem to be a primary strategy on the North Slope.

Offshore

Oil spilled on water spreads due to its relatively low density, and forms an oil slick. The spreading rate and thickness of a slick is influenced by currents, wave action, and the temperature of the water (S.L. Ross Environmental Research 2001a, USACE 1999). Temperature has an important effect on spreading and weathering. At low temperatures, oil is thick and viscous and does not spread as readily as oil spilled in more temperate waters. Viscosity increases as oil weathers, and this can influence the rate of dispersion and emulsification as well (MMS 2001a, USACE 1999).

Evaporation weathers oil by preferentially degrading the lighter hydrocarbons, reducing the overall volume of the spilled oil and increasing its viscosity. Evaporation varies linearly with temperature, faster in warm temperatures, slower in cold temperatures (BLM/MMS 1998). Oil slicks in broken ice or on ice evaporate slowly, while oil encapsulated in ice does not evaporate until it is released during the melting process (BLM/MMS 1998, USACE 1999). Freshwater ice and multiyear ice may not melt during spring thaw and could keep oil from evaporating for years. (The benefit is that the oil is contained and the opportunity exists for a removal project.) For Prudhoe Bay oil, it is estimated that 20% of the oil would evaporate within 30 days following a summer spill or a spring thaw of ice containing a winter spill (BLM/MMS 1998). Similarly, 25-30% of Northstar crude oil released to surface waters would evaporate within the first 30 days based on average temperatures (USACE 1999). The Liberty EIS (MMS 2001a) conservatively estimates that 13-16% of this oil spilled to open water or broken ice will have evaporated. Liberty oil contains more wax and is more viscous than other oils produce on the North Slope (MMS 2001a). Evaporation decreases the toxicity of spilled crude oil as the lighter, more toxic hydrocarbons dissipate. The remaining heavier components may persist in soils and sediments. Even though they are less toxic they may cause chronic, sublethal effects in some instances.

Dispersion and dissolution occurs when oil and water are mixed either by waves, wind, or currents and oil becomes mixed into the water column. Dispersion may also occur when grinding occurs in broken ice conditions forcing water, oil, and ice to mix (MMS 2001a).

Emulsification occurs when water and ice are mixed to form a mousse. This creates two problems regarding spill cleanup. First, emulsification increases the volume of fluid that must be handled, and second, the viscosity of the resulting emulsion can be as much as 1,000 times that of the parent oil, challenging conventional removal and pumping techniques (S.L. Ross Environmental Research 2001b). Emulsification is greatly enhanced in broken ice conditions where grinding ice may form mousse an order of magnitude more rapidly than in open water (BLM/MMS 1998, MMS 2001a).

Microbial degradation may account for a substantial portion of spilled oil removal from marine sediments and shorelines (USACE 1999). Although microbial degradation played a significant role during the Exxon Valdez spill, it is uncertain if it will be as significant in colder North Slope environments. Lower temperatures, limited populations of hydrocarbon utilizing micro-organisms, lack of available nutrients and poor water circulation on the North Slope may hinder microbial degradation of spilled oil (USACE 1999).

Sedimentation and photo-oxidation are other, less significant ways that oil can naturally degrade. Sedimentation occurs when oil particles adsorb to suspended particulate matter and sink to the sea floor. This process can trap oil in seafloor sediments where it may persist (USACE 1999).

Based on their specific gravities and viscosities, none of the crude oils produced on the North Slope will sink naturally, but will remain at the surface when spilled (S.L. Ross Environmental Research 2001). Sinking could occur if oil adsorbs to sediment particles. This has happened in the nearshore waters where there is a high sediment load and mixing energy. It can also result from cleanup activities that mobilize oil that then flows into the nearshore area.

Onshore

Oil spills on tundra are not expected to spread over large areas. The relatively flat coastal summer tundra has a dead-storage capacity of 1.3 to 5.8 cm (0.5 to 2.3 in.), which would retain 74,000 to 370,000 bbl (3.1 million to 15.5 million gallons) of oil per km^2 (BLM/MMS 1998). When oil is spilled on snow-covered tundra, oil spreading is limited because snow acts as a natural barrier. However, if a pressurized pipeline ruptures and oil sprays into the air, it can become widely dispersed on tundra or snow. The nearly constant wind on the North Slope may carry the sprayed oil downwind, depositing it over a large area. BLM/MMS (1998) reported that a spill of 1 to 4 bbl (42 to 168 gallons) of crude oil sprayed mist oil over 100 to 150 acres (40 to 60 hectares).

To better understand the effects of crude oil spills in the arctic, a small amount of oil was intentionally released in a small pond on the North Slope in the summer of 1970. The spill was intended to simulate and average sized spill to a water body during summer. The pond was monitored for nearly a decade. The spill began spreading and evaporating almost immediately. After 24 hours the oil slick had thickened and was pushed by wind to the down-wind side of the pond. Over time the oil spread into vegetation on the down-wind side of the pond and at the end of the first summer was confined to the pond-bottom and vegetation surrounding the down-wind margins. An estimated 50% of the oil evaporated or degraded within a year. During subsequent years, some pond-margin plants were unable to sprout through the oil film there and subsequently died. Additionally, there were measurable, long-term (several year) effects to zooplankton, phytoplankton, and insect population plus shorter-term effects on benthic algae and microbe populations (BLM/MMS 1998).

SCENARIOS OF OIL SPILLS

Beaufort Spill Scenarios

Oilfield operators are required to prepare spill scenarios. Each scenario describes spill location, volume, cause, type of oil, sea, wind, and ice conditions, weather, and spill trajectory. Countermeasures are detailed as well. Scenarios range from small spills to the "realistic maximum oil discharge." The scenarios reviewed were in Oil Discharge Prevention and Contingency Plans required the by Alaska state government.

Pipeline Leak

This scenario is a catastrophic subsea pipeline failure during freeze-up. Spill volume is 2,150 bbl (90,300 gallons). Landfall of the spill on barrier islands is predicted, along with possible impacts on culturally important sites. Shoreline cleanup will be necessary. Some oil will be entrapped in ice. Both mechanical recovery and in-situ burning are recommended spill control measures.

Well Blowout

This scenario is a well blowout during summer, resulting in a 15,000 bbl (630,000 gallons) spill, 1,000 bbl (42,000 gallons) per day over 15 days. Most of the oil (12,800 bbl [540,000 gallons]) spills on tundra. Tundra ponds are also contaminated. Tundra cleanup and rehabilitation are implemented, along with oil recovery from ponds using booms and sorbent materials. Effects on birds are expected, and a bird rescue and rehabilitation program is implemented. The ocean is also contaminated and spill control measures are implemented there. Shoreline cleanup will probably also be necessary.

Chukchi Spill Scenarios

Additional scenarios were prepared for the Chukchi Sea based on assumptions of offshore drill rigs and subsea pipelines (Lewbell and Galloway 1984).

Pipeline Rupture

This scenario is a ruptured subsea pipeline in late summer spilling 5,000 bbl (210,000 gallons) of crude oil in 24 hours. It is assumed the pipeline leak is stopped after that time. There is a 61% chance that landfall of oil will occur between Point Franklin and Point Barrow. Within 30 days, of the oil remaining at sea, 40% would still be on the water surface, 40% dispersed in the water column, 20% evaporated.

Another pipeline rupture scenario, a 500 bbl (2,100 gallons) spill during spring, assumes trapping of some oil under-ice and freezing in place. There is a 61% chance of oil coming ashore within 10 days. Oil trapped in ice could move as far as 480 to 800 km (300 to 500 mi) northwestward.

Well Blowout

This scenario is a June blowout from a wellhead under a drillship, spilling 1,000 bbl (42,000 gallons) per day for 75 days. Landfall of oil is predicted in 33 hours. Under most expected conditions, most of the oil would be transported seaward to the northeast. It could travel 350 km (220 mi) in 75 days.

All of the above scenarios predict oil concentrations in the water column of 1 to 7 ppb (Lewbel and Galloway 1984).

If a spill should occur nearshore, along the Barrow Arch, during winter, the oil might become incorporated within the new ice forming at the edge of the coastal polynya, advected within the polynya, or incorporated into ridges when the polynya closes. Depending on which way the ice is moving at the time, the oil could either be moved offshore with the ice (most likely) or onshore to be released at breakup. The exposure of various portions of the Barrow Arch coastline to spilled oil depends on the site of the spill and the weather at the time. Open coastal areas are more likely to be contaminated by spills than areas protected by barrier islands. Seaward sides of barrier islands are as vulnerable as open coasts. Most lagoons behind barrier islands are protected from oil contamination by these islands. Some lagoons are more vulnerable (Lewbel and Galloway 1984).

North Slope Oil Spill Events Timeline
1977 - 1984
(Modified from Maxim and Niebo 2001b)

	1977 to 1979	*1980 to 1984*
General Events	1968 -Prudhoe Bay discovery announced. 1974 - Prudhoe Bay to Yukon River road construction completed. 1975 - First pipe laid at Tonsina River. 1976 to 1979 – the Petroleum Reserve explored by USGS 1977 - Pipeline completed. 1977 – Oil production at Prudhoe Bay begins. 1977 - 1.800 bbl spill at TAPS check valve 7 1977 - 30 bbl crude oil spill at TAPS Pump Station 1 1977 - One 100 bbl products spill, North Slope 1977 - 83 bbl diesel fuel spill at Pump Station 3 1978 - 21 bbl diesel fuel spill at Pump Station 4 1979 - 1,500 bbl crude oil spill at Atigun Pass 1979 - 95 bbl gasoline spill at Ice-cut Hill 1979 - 39 bbl diesel fuel spill at Pump Station 1	1980 to 1985 – US Fish & Wildlife conducts biodiversity assay in the Arctic National Wildlife Refuge. 1980 -- One 102 bbl product spill, North Slope 1980 - 6 bbl crude oil spill at TAPS Pump Station 2 1981 – Oil production begins at Lisburne Oil Field. Oil discovered- 1967. 1981 – Oil production begins at the Kuparuk Oil Field. Oil discovered -1969. 1981 - 1,500 bbl crude oil spill at TAPS check valve 23 1981 - 5 bbl crude oil spill at TAPS Pump Station 1 1981 -- 71 bbl product spill, North Slope 1982 -- 200 bbl product spill, North Slope 1982 - 86 bbl diesel fuel spill at Franklin Bluffs camp 1983 to 1984 – US Department of energy develops new studies to assess impacts of Arctic Energy development (R&D program). 1984 – August 22, 1984. Largest NS product spill (450 bbl). 1984 - 11 bbl crude oil spill at TAPS Pump Station 3 1984 - 5 bbl crude oil spill at TAPS Pump station 4
Technological Advances	1979 – Alaska Beaufort Sea Response body (ABSRB) is formed as the pre-cursor to Alaska Clean Seas to operate as ANS spill response equipment co-op. 1979? – 'Smart Pigs' are developed as a spill prevention tool.	1983 – Oil companies hold six oil spill cleanup training exercises/ demonstrations. 1983 – ABSRB changes name to Alaska Clean Seas.

Regulatory Events	1969 - TAPS files for pipeline right-of-way permits. 1970 - lawsuits filed to stop pipeline construction. 1973 - Trans Alaska Pipeline Authorization Act becomes law. 1974 - State right-of-way lease issued. 1979 – As a spill prevention policy, the State of Alaska limits seasonal exploratory drilling operations to winter months when the Beaufort Sea is covered by sea ice.	1982 – Original 1979 seasonal drilling laws are revised into two tiers to facilitate exploratory drilling. 1984 – State of Alaska finds: (1) *In situ* burning is the most important component of spill response in broken ice. (2) Volume of oil expected to be recovered by mechanical means is secondary to *in situ* burning. (3) Igniting surface well blowouts can remove the majority of the oil at the wellhead. (4) Seasonal restrictions impact Alaska State economy. (5) Lessees participate in 5-year oil spill research and development program. (6) Increased training for drilling personnel is required. (7) Lessees must be capable of *in situ* burning operations. (8) Drilling is restricted past barrier islands during bowhead whale migration.

Continued -

North Slope Oil Spill Events Timeline
1985 - 1994

Years	*1985 to 1989*	*1990 to 1994*
General Events	1984 -- One 125 bbl crude oil spill, North Slope 1985 – Oil production begins at Milne Point. Oil was discovered there in 1969. 1986 -- One 175 bbl crude oil spill, North Slope 1986 - 52 bbl diesel fuel spill at Atigun Pass 1986 - 36 bbl gasoline spill, underground storage tank at PumpStation 1 1987 – Oil production begins at Endicott oil field. 1987 -- One 120 crude oil spill, North Slope 1987 – Scientific investigation of petroleum development in the Arctic Refuge is done with regard to impact on specific species. 1988 - 203 bbl diesel fuel spill, mile pt. 258 of haul road 1989 – Exxon Valdez spill. 1989 – July 28. 925 bbl crude oil spill at Milne Point Central Processing Flowstation. Largest NS crude oil spill. 1989 – Mixed oil and water spill from production flowline at 2U impacts tundra. Clean-up and remediation. 1989 - 5 bbl crude oil spill at TAPS Pump Station 2 1989 – Industry conducts first mutual assistance drill.	1990 -- One 75 bbl products spill, North Slope 1990 - 43 bbl diesel fuel spill at mile pt. 85, near Pump Station 3 1991 – Oil is discovered at the Badami oil field. 1992 - 190 bbl turbine fuel spill just N of Atigun Pass 1993 – Oil production begins at Point McIntyre. Oil was discovered there in 1988. 1993 -- Four crude oil spills totaling 1470 bbls, North Slope. 1994 – Oil production begins at Niakuk oil field. Oil was discovered there in 1985. 1994 - 18 bbl crude oil spill at Pump Station 1

Years	*1985 to 1989*	*1990 to 1994*
Technological Advances	1985 to 1989 – Alaska Clean Seas focuses on oil in ice spill response. 1989 – Detergent flushing schemes are used on the North Slope to enhance spilled oil recovery. 1989 – First use of wind-induced vibration dampers for spill prevention.	1990 to 1993 – Industry upgrades spill response capability in the state. State focuses attention on shipping in Prince William Sound. 1993 – Wind-induced vibration dampers are installed on some short intra-pad flowlines for leak prevention. 1990 – Alaska Clean Seas charged with slope-wide spill response training and equipment maintenance and inventory. 1994 – Mixed oil and water spill from 1Y1R Flowline. Clean-up response incorporates lessons learned. 199? – Aggressive corrosion control programs are developed. 19?? – Pipeline weld insulation designs are improved. 19?? – Drip pans are used to prevent small spills.
Regulatory Events		1990 – State of Alaska passes oil spill statutes. 1990 – Oil Pollution Act of 1990 passed. 1991 – State of Alaska re-iterates Tier II drilling restrictions. 1991 – Cessation of exploratory drilling in the Canadian Beaufort. 1993 – ADEC promulgates new regulations based on oil spill statutes: (1) Establish a response planning standard of being able to contain and cleanup the worst case discharge in 72 hours. (2) Primary response option is identified as mechanical containment and recovery. (3) *In situ* burning is a response option only if mechanical C&R is not viable.

Continued -

North Slope Oil Spill Events Timeline
1995 - Present

Years	*1995 to Present*
General Events	1996 – Projects to develop the Alpine field are announced.
	1996 – Northstar development begins and issues of response capability in the Arctic offshore during periods of broken ice are re-considered.
	1997 – Oil is discovered at Sourdough.
	1997 -- One 180 bbl product spill, North Slope
	1998 – Northstar oil spill contingency plan submitted.
	1998 – Oil is discovered in the Sambucca and Midnight Sun Prudhoe Bay satellite oil fields.
Technological Advances	1997 – Extended vertical loops and antisyphons are used on the in place of check valves. This reduces the potential for leaks.
	1999 – LEOS system is installed on Northstar to aid in pipeline leak detection.
	199? – Second generation of wind-induced vibration damper is developed.
	199? – FLIR first used on Alaska North Slope.
	2000 – The use of HDD to lay pipe below the Colville River is nominated for ASCE 2000 Outstanding Civil Engineering Achievement of the year.
	2000 – Research and development on spills in broken ice leads to tactics for responders.
	2000 – Studies show that historical loss of well control has lead to no oil spills and minor environmental impacts.
	2000 – By 2000, approximately 30,000 pipeline segments are fitted with wind-induced vibration dampers as a spill prevention technique.
	2001 – Well cellar designs which reduce the potential for spills to the environment are developed.
Regulatory Events	1997 – Joint industry and agency task force is set up to consider North slope oil spill response issues.
	1997 – ADEC identifies oil spills in broken ice as a major issue.
	1999 – Northstar oil spill plan approved by ADEC.
	1999 – Fall testing program conducted as part of North Star, Endicott, and Prudhoe Bay contingency plan conditions of approval.

Appendix G:

Saline Spills

INTRODUCTION

Saline water associated with North Slope oil production comes from water produced with the oil or from seawater used for enhanced oil recovery. The produced water is classified as wastewater and injected into Class I and II wastewater wells. Drilling fluids and cuttings generated by drilling and associated wastes derived from processing facilities are also injected into these wells (Maxim and Niebo 2001a).

Seawater has been used in relatively large volumes since 1984 when the Prudhoe Bay waterflood project began. This is a field-wide enhanced oil recovery system that includes facilities to extract and treat water from the Beaufort Sea and then inject it into injection wells. The injected water maintains pressure within the oil reservoir and flushes oil toward recovery wells (Maxim and Niebo 2001a). When this project began it was estimated to enable the recovery of an additional billion barrels from the Prudhoe Bay oilfields (ARCO Alaska 1984). Seawater is also used other purposes, such as testing pipelines for leaks.

Produced water is considered saline, though salinity is highly variable, depending on the field and the amount of seawater injected into the oil bearing strata (Maxim and Niebo 2001a).

Spills of produced water may occur at the wellhead, along pipelines, and at central processing facilities. They may also come from leaking tanks or, in the past, leaking reserve pits.

Reserve pits have been phased out in recent years, and are being dewatered and restored. A recent progress report on the ADEC reserve pit closure program states that as of mid-January 2002, 184 of 329 reserve pits on the North Slope (56%) have been closed, restored, and approved by ADEC (Peterson 2002a). Judd Peterson, ADEC Reserve Pit Coordinator, stated that plans to rehabilitate remaining reserve pits were due in his office on January 28, 2002. He estimates that completion of remaining pit restorations through closure and ADEC approval will take 6 to 8 years. Mr. Peterson also stated that ADEC requires water sampling adjacent to all remaining reserve pits. According to these data, no substances are being leached from these pits that exceed state water quality standards. Some reserve pits contain diesel-based drilling fluids and produce a visible sheen when muds are disturbed. ADEC requires that these be excavated, dewatered, and backfilled on an accelerated timetable even if the diesel cannot be detected in samples. Accelerated restoration is also required for pits subject to erosion and possible contamination of Beaufort Sea waters. Four such sites are currently being restored and a fifth site is scheduled for restoration in 2003 (Peterson 2002b).

Seawater spills from the enhanced oil recovery process can occur at the seawater extraction plant, the seawater treatment plant, holding tanks, along pipelines, and at seawater injection wells. Less common sources include fire control systems, compressors, pig launchers, and meltwater.

Causes of saline water spills along the pipeline include leaking valves, pump failures, leaking pipes, leaking tanks and drums, transfer hoses, o-ring and seal failures, leaking vehicles, and human error. In the past, leaking reserve pits were also a cause of spills.

SPILL DATA

Maxim and Niebo (2001a) examined water spill data from an unpublished portion of the TAPS oil spill database developed by IT Corporation. This spill database contains information on spills of crude oil, refined petroleum products, water, and other substances from 1977 to 1999. The database covers exploration and production activities on the North Slope and the entire Trans Alaska Pipeline. The crude oil and products spills data were presented in TAPS Owners (2001) environmental report. There was some difficulty distinguishing the saline water spills from fresh water spills.

Maxim and Neibo (2001a) compiled spills listed as water, produced water, seawater, wash water, meltwater, gelled water (seawater mixed with chemical enhancer to thicken it - used in enhanced oil recovery), and chemical mixtures. Any spill record that referred to seawater, produced water, or gelled water was considered to be a saline spill for purposes of the analysis. There was no way to separate out the low salinity from the higher salinity (seawater) spills. Some spills did not contain enough information to identify the material spilled, and these were termed unclassified spills. There were 17 unclassified spills between 1977 and 1985. These were excluded from the analysis. Together, they accounted for 0.9% of the total spill volume. In addition, spill records for that period were less complete, and reporting appeared to be less rigorous than it has been subsequently. Therefore, the detailed analysis covers only the period from 1986 through 1999.

Three spills during this period were water mixed with crude oil. These were considered in the oil spill section, only the water portion was considered in the analysis of saline water spill data.

Over the period 1986-1999, there were 929 seawater spills associated with North Slope exploration and production and the North Slope portion of TAPS. Total amount spilled was 40,849 bbl (1,715,658 gallons). This averages out to 66 spills per year over the period and an annual spill volume of 2,918 bbl (122,556 gallons). (See Table G-1.)

Analyses of the TAPS oil spill data have normalized spills to the amount of oil transported (Maxim and Niebo 2001b). This is appropriate for oil spills in establishing time trends, but may not be the best choice when normalizing saline water spill data. Comparing water spilled to the amount of crude oil produced suggests only how well water is being handled in relation to the amount of oil handled and may mask inefficiencies in the ANS water handling system. A more useful analysis may be comparing the amount of water handled on the North Slope with the amount of water spilled.

Seawater used in the enhanced oil recovery process accounted for the vast majority of water used on the North Slope during the period. Annual data on the amount of produced water and water used for enhanced oil recovery is available from the Alaska Oil and Gas Conservation Commission (AOGCC) (McMains 2001). These data were used to calculate the Volumetric Spill Rate (VSR), measured in bbls of water spilled per million bbls of wastewater handled

Table G-1 Number and volume of saline, freshwater, and unclassified water spills on the North Slope. Modified from Niebo 2001a.

Year	Saline water		Fresh water		Unclassified water	
	no.	vol. (bbl)	no.	vol.	no.	vol.
1986	18	955	8	26,923	16	160
1987	20	177	13	19,758	20	17
1988	52	1,098	15	55	39	45
1989	104	3,336	24	231	41	122
1990	139	772	36	117	24	17
1991	132	9,295	36	227	25	168
1992	80	505	37	227	38	16
1993	73	575	35	52	11	7
1994	63	1,728	44	95	12	3
1995	63	1,057	21	216	14	52
1996	56	652	16	32	8	56
1997	52	18,407	21	60	17	71
1998	41	1,910	39	144	8	16
1999	36	383	26	19	25	58
Totals	**929**	**40,850**	**371**	**48,156**	**298**	**808**

(bbls/million bbls). Table G-2 lists the annual water handled, the annual brine spill volumes, and the calculated VSR. Figure G-1 (3) plots the VSR based on volume of water handled (solid line) as well as the volume of oil transported through TAPS (dotted line). The lines match until 1990 when the volume of water handled increased while the amount of oil transported began to decrease.

Table G-2 ANS E&P Saline Water Spill rates (1986-1999). Modified from Maxim and Niebo 2001a.

Year	Spill Volume (bbls)	Volume of Water Handled (bbls)	Annual Spill Rate (bbls spilled/ million bbls handled)
1986	955	588,243,485	1.623
1987	177	689,765,315	0.257
1988	1,098	726,675,694	1.511
1989	3,336	801,407,354	4.163
1990	772	845,450,781	0.914
1991	9,295	894,098,366	10.395
1992	505	983,579,753	0.514
1993	575	1,038,007,615	0.554
1994	1,728	997,105,134	1.733
1995	1,057	1,001,078,993	1.055
1996	652	1,000,648,796	0.651
1997	18,407	1,031,291,327	17.849
1998	1,910	1,004,600,076	1.901
1999	383	671,552,213	0.571
Total	**90,290**	**12,273,505,602**	**3.30**

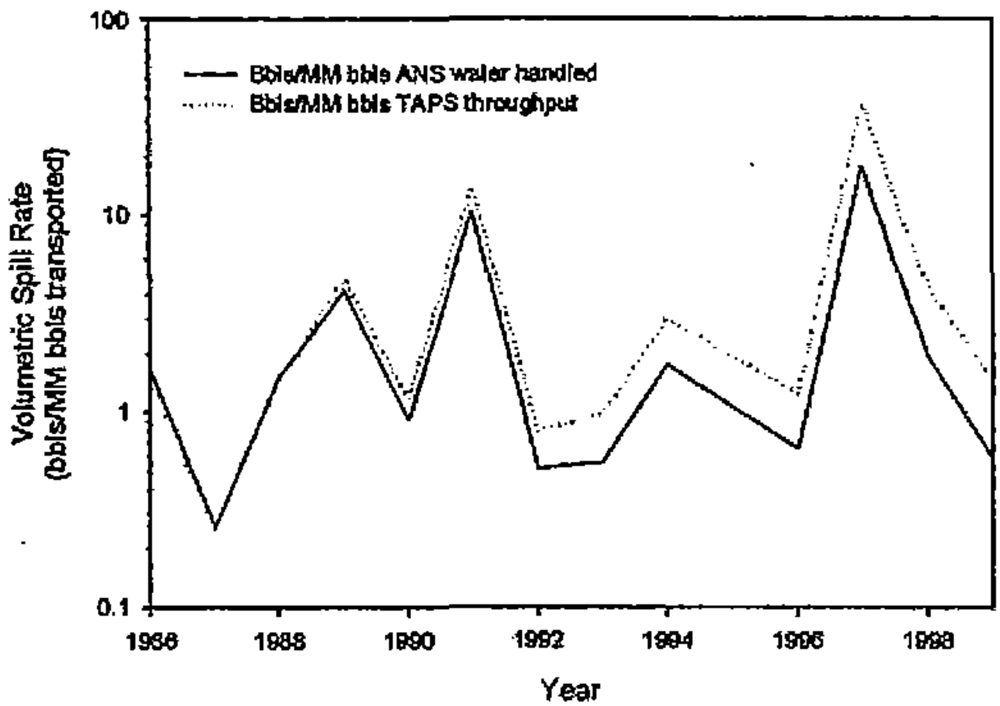

FIGURE G-1. Saline water VSR on the North Slope, 1986-1999. Source: reprinted with authors' permission from Maxim and Niebo 2001a.

Over the period from 1986 through 1999, the average VSR for saline spills based on water handled was 3.3 bbl/million bbl of water handled. If based on the volume of oil transported, the VSR is 5.4 bbl/million bbl transported (Maxim and Niebo 2001b).

As is the case with oil spills, there is substantial annual variability in the VSR for saline water spills—from 0.25 to 17.85 bbl/million bbl. "Bad" years are the result of a relatively few large spills and "good" years result from the lack of large spills, not spill numbers. The years 1997 and 1991 have the highest spill rates (VSRs). In 1997, 18,040 bbl (757,680 gal) of freshwater and diluted seawater came to the surface around several wells. A large spill occurred in 1991 when a valve failed and 8,500 bbl (357,000 gal) of produced water were spilled at Central Processing Facility 2.

The twenty largest saline water spills from North Slope operations during the 1986-1999 period are listed in Table G-3. These range in volume from 210 to 18,040 bbl (8,820 to 757,680 gal). Combined, they account for 85% of the total saline water spill volume.

Table G-3 Twenty largest saline water spills from North Slope operations. Modified from Maxim and Niebo 2001a.

Number	Date	Volume (bbls)	Description
1	17 Mar 97	18,040	Freshwater and diluted seawater surfaced around nine wells at Drillsite 4.
2	01 Jun 91	8,500	Valve failed and leaked produced water at Flowstation 2.
3	16 Dec 89	1,500	Pipeline weld failed, leaking seawater from a seawater injection line along Oliktock road.
4	10 Jan 98	1,500	Pipeline leak spilled produced water.
5	29 Sep 86	500	Fiberglass bypass line on heat exchanger failed, spilling seawater to secondary containment at Seawater Treatment Plant.
6..	28 Jul 89	500	Flowstation 2 actuator bonnet failed spilling produced water.
7	31 Oct 94	385	Crack in pipeline 1Y-1R spilled mixture of crude oil and produced water. Only the volume of spilled water is given for this spill.
8	22 Dec 89	355	Pipeline leaked seawater to drill pad. Corrosion suspected.
9	25 Jun 92	350	Water tank overflowed seawater to a sump when valve leaked at CPF-3.
10	07 Mar 94	320	Seawater spilled to drillpad at Prudhoe.
11	14 Apr 94	310	Seawater valve in pig launcher module leaked into pigging pit and overflowed.
12	15 Mar 95	300	Produced water was released to a drill pad and reserve pit when equipment failure caused pressure change in pipeline.
13	07 Nov 95	300	Seawater spilled onto drill pad during equipment malfunction.
14	08 Feb 88	287	Seawater injection line bled water from a pipe rack on a drill pad.
15	30 Mar 88	281	Corrosion caused a produced water leak in a pipeline.
16	17 May 88	250	Solonoid on seawater line at sw treatment plant failed.
17	06 Oct 88	250	Produced water injection line at drillsite failed due to corrosion.
18	01 Nov 96	231	Leak in seawter line at sw injection plant.
19	12 Dec 91	230	Rod failed on seawater pump at central processing plant.
20	07 Jan 96	210	Produced water spilled from pig launcher after an ice plug melted out of a partially open valve.

The volume of reported saline water spills range from 0.0024 bbl (approximately 1.6 cups) to 18,040 bbl (757,680 gal). As with oil spills, small spills are frequent, large spills are rare, and the total volume is dominated by the few large spills. A Lorenz diagram (Figure G-2) provides a useful depiction of these spills. The fraction of spill volume is plotted against the

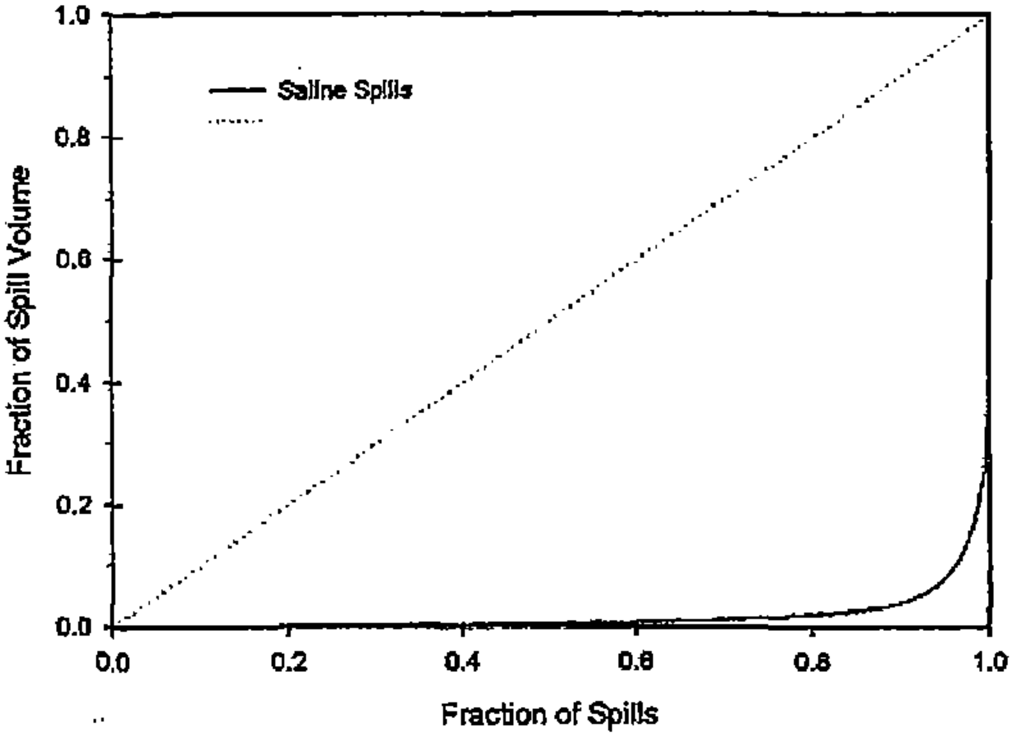

FIGURE G-2. Lorenz diagram of North Slope saline water spills. Source: reprinted with authors' permission from Maxim and Niebo 2001a.

fraction of spills. If all spills were of equal size, the plot would be a straight line. There is substantial curvature in the plot, and the computed Lorenz coefficient is 0.97. It is clear that the relatively few large spills account for the most of the spill volume. In fact, 50% of North Slope saline water spills were less than 0.95 bbls (40 gal), and the smallest 90% of these spills accounted for approximately 3.9% of the total volume, the smallest 95% accounts for approximately 8.2% of the total volume spilled (Maxim and Niebo 2001a).

EFFECTS OF SALINE WATER SPILLS

A study that anticipated potential spills associated with the Prudhoe Bay Waterflood project was sponsored by the Army Corps of Engineering Cold Regions Research and Engineering Lab (CRREL) (Simmons et al. 1984). The purpose was to evaluate the sensitivities of different tundra plant communities to seawater spills. Eight sites representing the range of vegetation types along the pipeline route were treated with single, saturating applications of seawater during the summer of 1980. Each site was examined prior to the experimental spills, monitored closely for 28 days, and visited less frequently over the following year. Symptoms of physiological stress were observed 8 days after the experimental spill. Within 12 days, 17 taxa of vascular plants developed physiological stress attributable to the treatment, ranging from slight chlorosis to total browning and desiccation of all the plants foliage. The impact of seawater treatment was most severe in the mesic and dry sites. The wet sites were less severely affected. Within a month of treatment 30 of 37 taxa of shrubs and forbs in the experimental plots developed definite symptoms of stress, while the 14 graminoid taxa did not exhibit adverse effects. Live vascular plant cover was reduced by 89% and 91 % in the two dry sites and by 54%, 74%, and 83% in the three moist sites. Mosses were unaffected in all but one of the experimental sites. Two species of foliose lichens showed deterioration, while other lichen species were not affected. The absorption and retention of salts by soils is inversely related to soil moisture. In the wet sites, conductivities reached prespill levels in approximately 30 days. Salts were retained in soils at the dry sites, concentrating at or near the seasonal thaw line. Soil enzyme and microfloral activity was reduced for up to one year after treatment (Simmons et al. 1983).

In December 1982 approximately 400 bbl (16,800 gal) of concentrated sodium chloride leaked from a damaged storage tank at a drillsite in the Kuparuk oilfield. The spilled brine spread onto tundra adjacent to the drill pad, covering an area of approximately 0.3 ha (0.7 acre) before freezing (Baker 1985). Soils and vegetation were studied for two years. By the 1983 growing season all plants within 40 to 60 m (130 to 200 ft) of the center of the spill were dead, and up to 30 m (100 ft) beyond the dead vegetation, many plants showed signs of physiological stress. In July 1983, the size of the affected area was approximately 1.6 ha (4 acre). In the fall of 1983 a road was constructed across the western side of the site, altering the local drainage and forming an impoundment in the spring of 1984. By July 1984, the size of the affected area had increased to approximately 4.5 ha (11 acre). Vegetation was dead within 90 to 140 m (300 to 460 ft) of the spill center, and signs of stress were found in plants 40 to 60 m (130 to 200 ft) beyond the dead vegetation (Baker 1985). The study was continued and expanded to map and quantify vegetation types, examine the effects of the spill on thaw depths, document salinity levels in soil and water bodies in the vicinity. Unaffected tundra near the spill zone was used as a reference area.

The area affected by the spill was divided into high- and moderate-impact zones. Forbs and shrubs were most severely affected, graminoids and cryptogams less severely. Some recovery had occurred by 1984, the size of the high-impact zone was decreasing. There was vigorous growth of the sedge species *Eriphorum angustifolium* in the moderate-impact zone (Jorgenson et al. 1987).

In June 2000 approximately 1,200 to 1,500 gallons (28.6 to 35.7 bbls) of low salinity seawater (Electrical Conductivity = 5,020 µmhos/cm; salinity = 3.5 ppt) was leaked from the Alpine oil pipeline during hydrostatic testing. The tundra at this site is moist tussok and wet sedge. The soil active layer was only partially thawed at the time of the spill. The moist tundra was thawed deeper than the wet sedge meadow. The spill site was studied by J.D. McKendrick (2000). As in the previous study, the moist (tussok) community was affected to a greater degree than the wet (sedge) community. Elevated salt levels in surface water bodies were found as far as 58 ft (18 m) from the leak. The area of vegetation damaged by the leak was 6.25 ft^2 (0.1 m^2). In this area salt levels in soil were elevated. Even though plants lost their leaves, they survived and grew normally during the growing season. McKendrick (2000) attributes this to the low salinity of the water spilled. In addition, tundra communities close to the coast may be exposed to seawater during storm surges.

McKendrick (1997) has examined many saline water spill sites, including those treated with fertilizers, or flushed with freshwater or calcium nitrate. He noted much variation in recovery based on such things as grazing pressure. Those sites treated by flushing with freshwater or calcium nitrate recovered faster than non-flushed sites. The calcium nitrate flush was no more effective than freshwater alone. Recovery of flushed sites may still take several years, non-flushed sites may take decades, depending on conditions.

The effects of saline water spills are related to salinity. As expected, low salinity water has less severe initial impacts and more rapid recovery than higher salinity water. Recovery from higher salinity spills may take several years.

Effects of saline water spills can be reduced by flushing with freshwater (Walker 1996). Joyce (2001) reports that the standard response countermeasure in summer is flushing with warm fresh water. In winter, snow berms are constructed to contain the spill and the frozen material is picked up with scrapers.

Appendix H:

Traditional Knowledge

Native American people have since the time of the first European contact struggled with the idea of sharing with the outside world a storehouse of raw information, truisms, philosophies, and ways of life. This storehouse is wrapped in a big blanket and named by the outside world as "traditional knowledge". It has been obtained (as in any culture) over time by observations of nature, trial and error, dogged persistence and flashes of inspiration. In cultures without a written history, such as our Alaskan North Slope Iñupiat culture, this knowledge is passed person to person, through social organizations, individual training, as well as through stories and legends.

Our culture is based on knowledge of the natural environment and its resources. Knowledge of the arctic tundra, rivers and lakes, of the lagoons and oceans, and all of the food resources they provide are our foundation. Further, knowledge of snow and ice conditions, of ocean currents, weather patterns, and their effects on natural systems becomes necessary for navigation, finding and trailing game, and locating shelter and each other. This knowledge has value. First, to pass amongst each other and on to our children, and, second (should we decide to) to pass on to those outside of our culture.

To someone unfamiliar with the Iñupiat culture or the arctic environment (such as a youngster or an outsider) the storehouse of information must seem near infinite and inaccessible. And, stereotypes abound—amongst ourselves and in the eyes of outsiders. Legends of the "hundred different terms for snow… or ice" serve to perpetuate the mystery. Regarding sharing with outsiders, in addition to the stereotypes, there is a stigma: bad experiences too numerous to count that began by good-faith sharing of traditional knowledge and ended by abuses of the sharing process. These range from simple plagiarism to exploitation and thievery. Here, too, legends and stereotypes abound.

Such experiences have led many Iñupiat people first to ask "Why share?" And even if this challenge has been answered sufficiently, an equally difficult challenge remains for both sides: "How to share?"

WHY SHARE?

Why do we share our traditional knowledge? Despite the stigma, our community is proud of a long history of productive cooperative efforts with visiting researchers, and proud of hunters, travelers and other experts lending their support to visiting scientists, map makers and others. Why? We share when we consider others as close enough to be part of our own culture, and we share when we think it is in the best interest of a greater cultural struggle.

Experts Sharing With Each Other

The question of "why" is always easy to answer when two individuals are sharing equally, and the joy of discovery takes place on both sides. Examples in our own hundred-year history of cooperation serve as good models. The wildlife biologist and the whaler, the nomadic traveler and geologist, the archaeologist and the village elders. This two-way exchange has often worked when a given researcher has been around long enough to be considered "one of us," or at least has displayed to the community that he possesses some common values.

Sharing for the Greater Good

For a more locally important reason, we share traditional knowledge when we believe that it will lead to preserving our land, our resources, or our way of life. This reason has prodded us to work hard with regulatory agencies and other organizations to develop policies, to draft environmental impact statements, or to offer even the most specific knowledge of the environment, wildlife, or cultural practice.

Sharing as a Part of Iñupiat Education

A third reason exists: Pure instruction. Like a teacher to a student, our elders and experts teach the rest of our community in any facet of traditional knowledge. We share to perpetuate our culture. How does one become involved in this kind of sharing? The answer is simple: Become a student. However, this can take a lifetime, pairing with a given expert over years of learning. Chances are that the teacher himself is learning, too. This is the method most commonly used by our own people to transfer knowledge amongst ourselves. Our culture has many vehicles to allow this kind of instruction to take place. This method, too, faces challenges due to changing culture, loss of language, and other factors.

HOW TO SHARE?

How can an outsider partake in any of the vehicles of sharing traditional knowledge? Choose one or all above criteria: an exchange among experts, become part of an effort that is of value to our people, or remain in the community and become a real student. Any other method risks lack of context, data gaps from abbreviated efforts, and other such problems.

Current Efforts

Funding exists in many government agencies for programs that elicit traditional knowledge. These programs can be found from NSF to NOAA to MMS. Recently these efforts have drawn praise from outside quarters, as it demonstrates that the government has "validated" traditional knowledge. Yet, even so, we are still struggling with the very agencies that have given traditional knowledge some credibility. Why is this? In many instances the goal of eliciting traditional knowledge is a short-term project objective for an effort that might necessarily take a lifetime.

A common problem many agency efforts face is that they try to gather traditional knowledge in "non-traditional ways." They hold public meetings, offer copies of documents for comment, or rely on whatever political leadership happens to be in place. Another vehicle in vogue for agencies is the contract with a Native organization.

Native tribal organizations, profit and non-profit corporations, and rural and local governments all represent some aspect of a Native constituency. So, because the groups have some legitimacy in attempting to be the bridge between traditional knowledge and the outside world, a contract is developed. The contractor must somehow assimilate, document, and contribute traditional knowledge. Thus, what should take (1) years of heart-to-heart collaboration between experts, or (2) a whole army of local energy focused on a single issue, or (3) years of tutelage under a suite of instructors must now must be completed before the contract deadline, usually a period of weeks to months.

When contracting with a Native organization to elicit traditional knowledge, the government can wash its hands of the issue. It looks appropriate; it's in the Natives' hands. And, the Native organization, hungry as it should be for grants and contracts from the "feds," offers to carry the obligation. Again, contract and project timelines become the targets, and we collect what we can while we can. Quality may suffer, content and context as well.

Knowing that change happens slowly, and that agencies can only do so much, it is reasonable to assume that what is presently occurring will continue. Meetings to assess traditional knowledge will undoubtedly go on. With this in mind, there are a few more cautions to those interested in documenting traditional knowledge, learning about the environment without reinventing the wheel, and working with Native communities on regionally important issues.

Choose the Forum with Care

A meeting's attendees must be matched to the issue. When expertise is really needed, it should be stated. Stereotypes will allow any agency to assume the expertise is there. There is a scene from the movie "On Deadly Ground" where the leading actress (an Oriental woman playing a Yup'ik) jumps on a horse to the surprise of Steven Seagal's character. He asks, "You can ride a horse?" to which she answers, "Of course, I'm Native American!" A comical analogy, but not far from the mark from many real-life stereotypes.

Don't Put Your Eggs in One Basket

Check sources. Stated another way, the most talkative person may not be the most knowledgeable. Ours is a culture of consensus. Agreement is mandatory on nearly every item passed as traditional knowledge. If one person stands alone, he may be an expert, or he may be wrong.

Given the size of the task, it is easy to run away from documenting traditional knowledge, even for our own internal reasons. For many it can be an intensely personal endeavor. Still, such documentation will continue—by our own people as well as by outside groups. Our culture is changing, and some day we may be learning "traditional knowledge" using the same techniques employed by those today who are outside looking in. We may be learning of our own traditional knowledge as if it belonged to others. Just as today in many places we are learning our own language as if it were a foreign language.

As long as we are pledged to the task, we should look past the requirements of this contract or that mandate, and remember the quality of information, time-tested and true. With everything changing, it is a valuable reference plane. If it is not where we are going, at least it is where we are coming from.

Appendix I:

Legal Framework for Activities on State Lands on the North Slope

Source: Final Best Interest Finding, Beaufort Sea Areawide, Appendix B

Laws and Regulations Pertaining to Oil and Gas Exploration, Development, Production, and Transportation

Alaska Statutes and Administrative Code Sections

ADNR

AS 38.05.027	Management of legislatively designated state game refuges and critical habitat areas is the co-responsibility of ADF&G (AS 16.20.050-060) and ADNR. Lessees are required to obtain permits from both ADNR and ADF&G.
AS 38.35.010-260	Right-of-way leasing for pipeline transportation of crude oil and natural gas is under the control of the commissioner of ADNR. The commissioner shall not delegate the authority to execute the leases.
AS 38.05.127	Provides for reservation of easements to ensure free access to navigable or public water.
11 AAC 53.330	Implementing regulations for the reserving of easements to ensure free access to navigable or public water.
11 AAC 83.158(a)	A plan of operations must be approved by the commissioner, ADNR, if (1) state owns all or a part of the surface estate, (2) lease reserves a net profit share to the state, (3) state owns all or part of the mineral estate, but the surface estate is owned by a party other than the state, and the surface owner requests such a plan.
11 AAC 96.010	Operations requiring permits, including the use of explosives and explosive devices, except firearms.
11 AAC 96.140	Land use activities are subject to general stipulations that will minimize surface damage or disturbance of drainage systems, vegetation, or fish and wildlife resources.

ADNR/DO&G

AS 38.05.035(a)(9)(C)	Requires geological and geophysical data to be kept confidential upon request of supplier.
AS 38.05.130	Allows the director, DO&G, to approve oil and gas exploration and development activities in the case where the surface estate is not held by the state or is otherwise subject to third party interests, provided the director determines that adequate compensation has been made to the surface estate holder for any damages which may be caused by lease activities.
AS 38.05.180	Establishes an oil and gas leasing program to provide for orderly exploration and development of petroleum resources belonging to the state of Alaska.

11 AAC 96.010-150	Geophysical Exploration Permit provides controls over activities on state lands in order to minimize adverse activities
ADNR/DL	
AS 38.05.075	Establishes leasing procedures under public auction, including tide and submerged lands, bidding qualifications, and competitive or non-competitive bidding methods.
AS 38.05.850	Authorizes the director to issue permits, rights-of-way or easements on state land for recovery of minerals from adjacent land under valid lease.
11 AAC 80.005-055	Pipeline Right-of-way Leasing Regulations.
11 AAC 93.040-130	Requires a Water Rights Permit for the appropriation of state waters for beneficial uses.
11 AAC 96.010-140	Land use permit activities not permitted by a multiple land use permit or lease operations approval.
ADNR/ DMWM	
11 AAC 93.210-220	Provides for temporary water use permits and procedures for application.
ADNR/DF	
AS 41.17.082	Alaska Forest Resources Practices Act. Requires that all forest clearing operations and silvicultural systems be designed to reduce the likelihood of increased insect infestation and disease infections that threaten forest resources.
11 AAC 95.195	Describes the approved methods of disposal or treatment of downed spruce trees to minimize the spread of bark beetles and reduce the risk of wildfire.
11 AAC 95.220	Requires the lessee to file a detailed plan of operations with the state forester.
ADF&G	
AS 16.05.840	A permit is required from ADF&G prior to obstruction of fish passage.
AS 16.05.870	Provides for the protection of anadromous fish and game in connection with construction or work in the beds of specified water bodies, and calls for approval of plans by the commissioner, ADF&G, for any diversion, obstruction, change, or pollution of these water bodies.
AS 16.20	Management of legislatively designated game refuges and critical habitat areas.
AS 16.20.060	The commissioner, ADF&G, may require submission of plans for the anticipated use, construction work, and proper protection of fish and game. Written approval must be obtained.
AS 16.20.180-210	Requires measures for the continued conservation, protection, restoration, and propagation of endangered fish and wildlife.
5 AAC 95.010-990	Fish and Game Habitat Authority.

18 AAC 50.300	Sets up standards for air quality at certain facilities including oil and gas facilities at the time of construction, operation, or modification.
18 AAC 60.220	Requires proof of financial responsibility before a permit for operation of a hazardous waste disposal facility may be issued.
18 AAC 60.220-240	Requires a Solid Waste Disposal Permit to control or eliminate detrimental health, environmental, and nuisance effects of improper solid waste disposal practices and to operate a solid waste disposal facility.
18 AAC 60.520	General requirement for containment structures used for disposal of drilling wastes.
18 AAC 72	Requires a Wastewater Disposal Permit in order to prevent water pollution (and public health problems) due to unsafe wastewater disposal systems and practices.
18 AAC 75	Provides for oil and hazardous substance pollution control including oil discharge contingency plan (18 AAC 75.305-.395).
18 AAC 75.005-025	Requirements for oil storage facilities for oil pollution prevention.
18 AAC 75.065-075	Requirements for oil storage tanks and surge tanks.
18 AAC 75.080	Facility piping requirements for oil terminal, crude oil transmission pipeline, exploration, and production facilities.
DGC	
AS 44.19.155	Establishes and empowers the Alaska Coastal Policy Council.
AS 46.40	Establishes the Alaska Coastal Management Program.
6 AAC 50	Requires the sale to be consistent with the ACMP, including approved district programs.
6 AAC 80.070(b)(3)	Requires that facilities be consolidated to the extent feasible and prudent.
6 AAC 80.070(b)(10)	Requires that facilities be sited to the extent feasible and prudent where development will necessitate minimal site clearing, dredging, and construction.
6 AAC 80.070(b)(11) and(12)	Requires that facilities be sited to the extent feasible and prudent to allow for the free passage and movement of fish and wildlife.
6 AAC 80.130(c)(3)	Requires that wetlands and tideflats be managed to assure adequate water flow, avoid adverse effects on natural drainage patterns, and the destruction of important habitat.
6 AAC 85	Establishes guidelines for district coastal management programs.
AS 26.23.195	Establishes the State Emergency Response Commission.
AS 39.50.20	Establishes Hazardous Substance Spill Technology Review Council within State Emergency Response Commission for research, testing spill technologies, and to serve as a clearinghouse for containment and cleanup technology.

AS 24.20.600	Citizens Oversight Council established a five-member council to serve as watchdog of state and federal agencies having responsibility for prevention of and response to oil spills, to help ensure compliance with environmental laws and regulations

NSB

19.06 - 19.70.060	North Slope Borough land management regulations, planning, and permitting powers.

Federal Laws and Regulations

Clean Water Act (CWA) - 33 U.S.C. §§ 1251-1387

§ 1343 - Corps permit required to excavate, fill, alter, or modify the course or condition of navigable or U. S. waters.
§ 1344 – Discharge of Dredge and Fill

Oil Spill and Hazardous Substances Pollution Contingency Plan - 40 C.F.R. § 300

EPA Regulations - 40 C.F.R.

§ 109 - Criteria for Oil Removal Contingency Plans
§ 110 - Discharge of Oil
§ 112 - Oil Pollution Prevention. 112.7 - Guidelines for implementation of SPCC plan
§ 113 - Liability Limits for Small Onshore Oil Storage Facilities
§ 114 - Civil Penalties for Violation of Oil Pollution Regulations
§ 116 - Designation of Hazardous Substances
§ 117 - Determination of Reportable Quantities for Hazardous Substances

Coast Guard Regulations - 33 C.F.R.§§ 153-157 Oil Spill Regulation

§ 153 - Reporting Oil Spills to Coast Guard
§§ 155-156 - Vessels in Oil Transfer Operations

Water Quality:

EPA Regulations - 40 C.F.R.

§ 121 - State Certification of Activities Requiring a Federal Permit
§ 136 - Test Procedures for Analysis of Pollutants

NPDES Permit System:

EPA Regulations - 40 C.F.R.

§ 122 - NPDES Permit Regulations
§ 125 - Criteria and Standards for NPDES Permits
§ 129 - Toxic Pollutant Effluent Standards
§ 401 - General Provisions for Effluent Guidelines and Standards
§ 435.10-435.12 - Offshore Oil & Gas Extraction Point Source Category

Ocean Dumping:

EPA Regulations - 40 C.F.R.

§§ 220-225, 227-228 - Ocean Dumping Regulations and Criteria

5 AAC 95.420-430	Requires a Special Area Permit for certain activities within a special area, defined as a state game refuge, a state game sanctuary, or a state fish and game critical habitat area.
AOGCC	
AS 31.05.005	Establishes and empowers the Alaska Oil and Gas Conservation Commission.
AS 31.05.030(d)(9)	Requires an oil and gas operator to file and obtain approval of a plan of development and operation.
AS 46.03.900(35)	Definition of waters.
AS 46.03.100	Accumulation, storage, transportation and disposal of solid or liquid waste standards and limitations.
20 AAC 25.005-570	Requires a permit to drill to help maintain regulatory control over the drilling and completion activities in the state.
20 AAC 25.140	Requires a Water Well Authorization to allow abandoned oil and gas wells to be converted to freshwater wells and to assure there is no contamination of the fresh water source.
ADEC	
AS 46.03	Provides for environmental conservation including water and air pollution control, radiation and hazardous waste protection.
AS 46.03.100	Requires solid waste disposal permits.
AS 46.03.759	Establishes the maximum liability for discharge of crude oil at $500 million.
AS 46.03.900(35)	Definition of waters.
AS 46.04.010-900	Oil and Hazardous Substance Pollution Control Act. This act prohibits the discharge of oil or any other hazardous substances unless specifically authorized by permit; requires those responsible for spills to undertake cleanup operations; and holds violators liable for unlimited cleanup costs and damages as well as civil and criminal penalties.
AS 46.04.030	Requires lessees to provide oil discharge prevention and contingency plans (C-plans). Also, provides regulation of above-ground storage facilities with over 5,000 bbl of crude oil or 10,000 bbl of non-crude oil.
AS 46.04.050	Exemption for above-ground storage facilities for under 5,000 bbl of crude oil or 10,000 of non-crude oil.
18 AAC 15	Requires a Certificate of Reasonable Assurance (Water Quality Certification) in order to protect the waters of the state from becoming polluted. Assures that the issuance of a Federal Permit will not conflict with Alaska's Water Quality Standards.
18 AAC 50	Provides for air quality control including permit requirements, permit review criteria, and regulation compliance criteria.

EPA Regulations - 40 C.F.R.

§ 230 - Discharge of Dredged or Fill Material into Navigable Waters
§ 231 - Disposal Site Determination

Army Corps of Engineers (Corps) Regulations - 33 C.F.R.

§ 209 - Navigable Waters
§§ 320-330 - Permit Program Regulations
§ 323 - Discharge of Dredge and Fill

The Fish and Wildlife Coordination Act - 16 U.S.C. §§ 661-666(c)

Allows comment on § 404 permit applications by USF&WS, NMFS, and EPA.

Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) 42 U.S.C. §§ 9601-9675

EPA Plans - 40 C.F.R.

§ 300 - National Oil and Hazardous Substances Pollution Contingency Plan

Safe Drinking Water Act - 42 U.S.C. § 300

EPA Regulations - 40 C.F.R.

§ 144 - Permit Regulations for the Underground Injection Control Program
§ 146 - Criteria and Standards for Underground Injection Control Program
§ 147 - State Underground Injection Control Program

Coastal Zone Management Act (CZMA) - 16 U.S.C. §§ 1451-1464

NOAA Regulations - 15 C.F.R.

§ 930 - Federal Consistency with Approved Coastal Management Programs
§ 931 - Coastal Energy Impact Program

Solid Waste Disposal Act, as amended by Resource Conservation and Recovery Act (RCRA) - 42 U.S.C. §§ 6901-6991

Clean Air Act (CAA) - 42 U.S.C. §§ 7401-7642

Toxic Substances Control Act - 15 U.S.C. §§ 2601-2655

National Ocean Pollution Planning Act - 33 U.S.C. §§ 1701-1709

National Environmental Policy Act (NEPA) - 42 U.S.C. §§ 4321-4347

Council on Environmental Quality (CEQ) Regulations - 40 C.F.R.

§§ 1500-1508 - Implementing NEPA Procedures

Endangered Species Act (ESA) - 16 U.S.C. §§ 1531-1543

USF&WS Regulations - 50 C.F.R.

§ 17 - Endangered & Threatened Species
§ 402 - Interagency Cooperation

Fish and Wildlife Coordination Act - 16 U.S.C. §§ 661-666(c)

Marine Protection, Research and Sanctuaries Act - 33 U.S.C. §§ 1401-1445

Marine Mammal Protection Act - 16 U.S.C. §§ 1361-1407

Migratory Bird Treaty Act - 16 U.S.C. §§ 703-711

National Historic Preservation Act - 16 U.S.C. § 470

Leases and Permits on Restricted Properties - 25 C.F.R. § 162

Appendix J:

A Method of Addressing Economic Irreversibility

We discuss here an example of calculating the economic cost of long-term or irreversible environmental changes. The method is broadly applicable to the North Slope and beyond; the example of the Arctic National Wildlife Refuge was chosen because it is the only part of the region for which suitable data are available. Chapters 7 and 9 describe physical and biotic effects of seismic exploration and their human effects. Here, the long-term economic costs are considered.

From an economic perspective, damage done to the tundra by seismic explorations and road and pad building is basically economically irreversible. This means that roads, pads, and seismic tracks laid down today are visually very evident for many decades later, as are other long-lived human interventions. Even if an effect does not last forever in a physical sense, it is an economic irreversibility in practice if it lasts foras long as, say, 50. The present value of a dollar every year forever differs by $.002 from the present value of a dollar every year for 50 years at the U.S. Geological Survey's (USGS) use of a 12% rate of interest when analyzing the value of oil in the Arctic National Wildlife Refuge.

Irreversibility is an important ingredient for the accumulation of an effect because the decision to invest in exploration produces visual effects year after year even if no development follows.

Most economic analysis assumes that one readily can undo what one has done. Thus the prospect of irreversibility raises a major concern and requires analysis of the significance of the amount of development and whether development should be prohibited in areas of special value. The following example, calculated using the Arctic National Wildlife Refuge as the example, illustrates an approach for thinking about irreversible accumulated effects. Data on environmental costs would have to be collected to reach a confident conclusion. It does not include any non-economic factors that usually also influence such decisions.

ALL OR NONE?

One piece of relevant data for policy making is how much oil is *economically*, not technically, recoverable in an area. As an example, Figure J-1 illustrates the amount of oil recoverable from the refuge's 1002 Area as a function of price. A price less than $15 per barrel ($0.36 per gallon), makes oil development in the Arctic National Wildlife Refuge unprofitable. If the belief is that $25 per barrel ($0.60 per gallon) will prevail, then the gross value of oil in the refuge would be more than $130 billion if it were extracted and sold today. The cost per barrel in

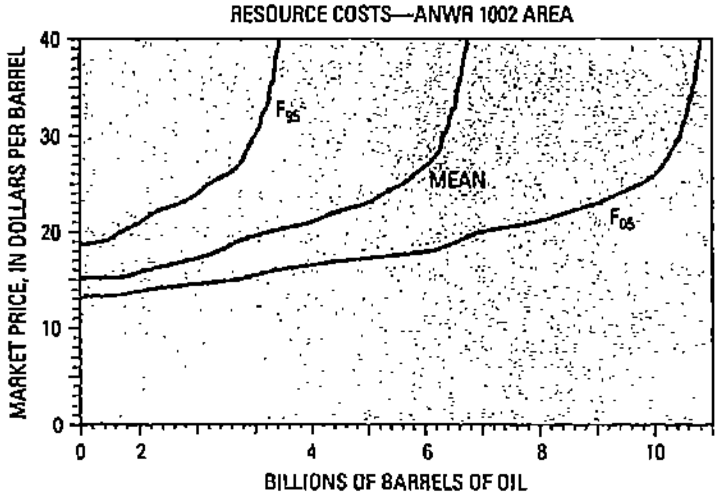

FIGURE J-1. Summary of the USGS estimates of economically recoverable oil that may occur beneath the Federal 1002 Area of the Arctic National Wildlife Refuge. The three curves are based on estimates of economically recoverable oil volumes at the mean (expected value, and at the 95 % (F95) and 5 % (F05) probabilities. Each curve relates market price/cost to the volume of oil estimated to be profitably recoverable. Included are the costs of finding, developing, producing, and transporting oil to market based on a 12 % after-tax return on investment all calculated in constant 1996 dollars. Source: USGS 1999.

Figure J-1 represents discovery, developing, production, and transport costs. The curve should be shifted up for other costs left out, particularly the expected costs due to oil spills, decommissioning, and other environmental damages that can be expressed on a per barrel basis.

The relation of prices and quantities of oil in Figure J-1 provides an estimate of net benefits from extracting oil in the Arctic National Wildlife Refuge as of today and depends on the prevailing price of oil. The figure portrays the incremental or marginal costs of oil. From this, total cost can be calculated. It is the area under the (mean) curve up to a particular quantity of oil. Total revenue is just the product of price and quantity, from which total cost is subtracted to yield a net benefit exclusive of environmental costs for any given expected price.

The expected future price of oil plays a vital role in the evaluation of a "go" or "no go" decision. Figure J-2 illustrates the price of oil per barrel historically. The price of oil is not determined in the market because the oil market is not competitive now. Economists characterize the oil market as a monopoly with a competitive fringe. The Organization of Petroleum Exporting Countries (OPEC) is a collection of nations who seek to control price through collusion. When collusion is successful, the OPEC has driven the price of oil above $35 a barrel ($0.83 per gallon) in the past. However, it has not been possible to successfully collude for very long. The free market, competitive price is believed to be $10 a barrel ($0.24 per gallon), according to the oil minister for Kuwait (NYT, 11/16/01, p.c2)

The ability of the oil-producing countries to collude plays a key role in the potential development of an area. If the chance of persistent collusion is low, a resulting low market price of oil will preclude development.

The second key factor in evaluating development is environmental costs. Among potential environmental costs we focus here on the irreversible nature of the visual impact created by seismic trails, roads and pads. These costs can be treated as the fixed social costs of oil development, which occur at the time of development. It will be assumed that people in general are not pleased with these seismic trails and the imprint of roads and pads, and that they would be willing to pay in principle, to keep them from occurring. One should think of this as an "as if" proposition. It is not that people actually would be asked to pay but rather people are asked to express displeasure in money terms. The thought experiment resembles what we do when we visit a restaurant and express expected gustatory pleasure in money terms by the choices made or not made.

TWO SCENARIOS

The crux question is whether the expected private *net* revenue from oil development, for which there are estimates, exceeds the social cost. Since no such costs have been estimated, a threshold analysis has to be made. Put another way, what is the least amount of money a representative family in the U.S. must be willing to pay annually to make the losses from development exceed the benefits of development?

Two scenarios are developed, one where the interest or discount rate is 12%, following the assumptions of the USGS in estimating the incremental costs of development. The other is a discount rate of 4% which is more in line with what the economics profession would advocate for long lived investment projects (Weitzman 2001).

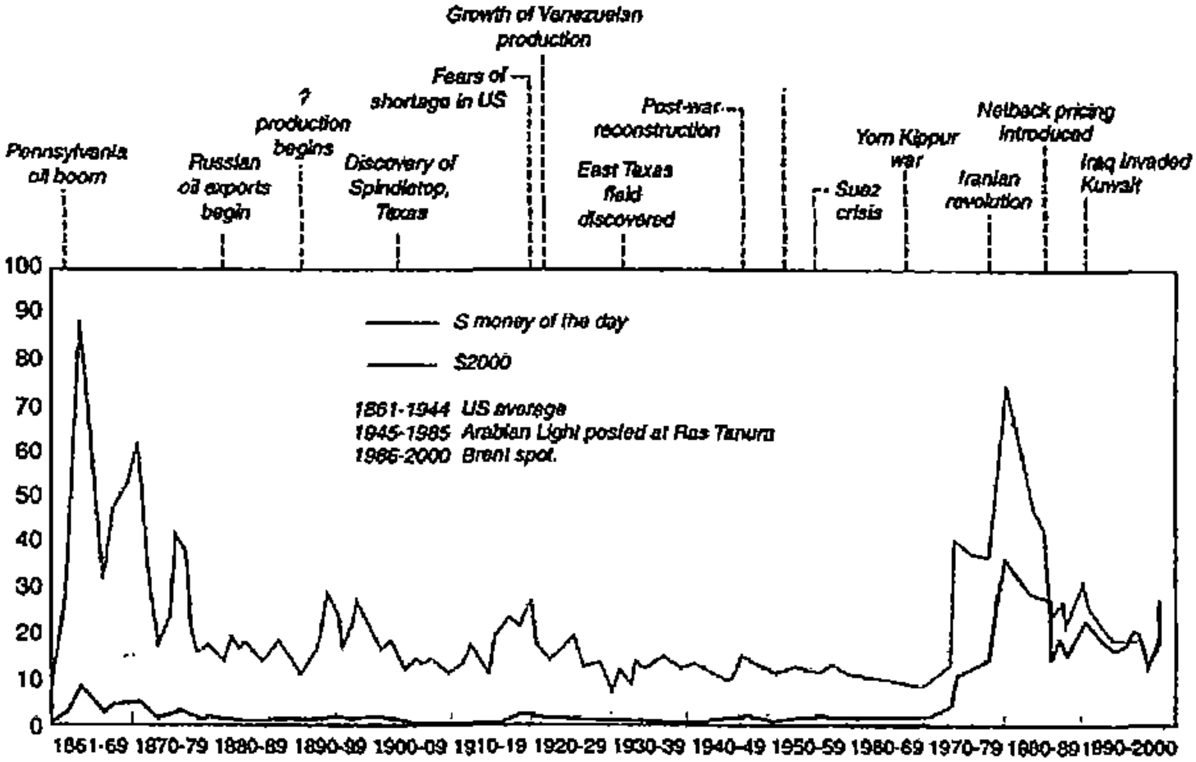

Figure J-2. Source: BP Exploration 2001b

Extraction is not an instantaneous decision. The land must be opened for leasing. It takes time to consummate actual discovery. Facilities have to be built. This process will take 7-12 or more years based on past experience. Here we assume that it takes 10 years before the first field actually produces.[1] Further we assume that it will take 40 years for the oil resources to be depleted.[2] New fields will come on line roughly in decreasing profitability. The extraction period cannot be shortened very much because this reduces the total amount of oil that can be extracted and reduces overall profit to the owner (the public). Prudhoe Bay has been extracting for 24 years and oil specialists expect there are more than 10 years of future productivity. The U.S. Department of Energy expects a total productive life of 65 years with a peak at 18 or 22 years depending on rates of development (DOE). This assumption plays an important role in the economic analysis below. To simplify the analysis, assume that all the oil is extracted at the mid-point of the extraction period—20 years—and that value and costs are discounted back to the present, taken to be 10 years from now. A shorter extraction period entails less discounting and a higher profit from oil development. Discounting back to the actual present reduces the values by one-third.

In the calculations that follow, an exponential function represents the incremental cost curve of the USGS (See Figure J-1).

The estimated incremental or marginal private cost functions (MC) is[3]

$$MC = 0.611Q^{1.725} + 15.$$

Table J-1 is an auxiliary table illustrating the lump sum value of the environment necessary to equal the value of oil development in the Arctic National Wildlife Refuge for three alternative assumptions about the possible prices, conditioned on collusion occurring and two interest rates.

Table J-1 Net value (2011) of Oil Production in the Arctic National Wildlife Refuge Present Value 2011 dollars (billions)

	Interest rate = .12 Price			Interest rate = .04 Price		
Prob of Collusion	20	25	40	20	25	40.
¼	.24	.73	2.1	1.20	3.59	15.28
½	.49	1.4	6.2	2.40	7.9	30.56
¾	.7	2.18	9.3	3.61	10.78	45.84

The formula for calculating this table is the weighted probability of expected net revenues in present value (2011) terms.

[1] The basis for the calculation assumes no lags due to litigation by environmental interests and perhaps others. A lag increases the likelihood that oil development is not economically feasible.
[2] President Bush recently spoke in terms of 47 years (NYT 5/18/01). The longer the depletion period, the more distant are the revenues, so the less valuable is the field, for a given total volume.
[3] A c++ program was written to fit Figure J-1 and close to 600 data points were drawn. A software package, "Kaleida Graph," transformed the data points into the function.

$$E\hat{V}(\overline{P}) = \left\{ \overline{P}Q(\overline{p}) - \int_0^{\overline{Q}(\overline{p})} 0.611Q^{1.725}dQ - 15Q \right\} e^{-rt}(1-\Pi) + \underline{P}\Pi e^{-rt}$$

where $E\hat{V}(\overline{P})$ = expected net present value of oil production in the Arctic Refuge excluding environmental costs

$1-\Pi =$ the probability of successful collusion

$\underline{P} = 0$ because competition drives price below \$15 per barrel. See text.

$Q(\overline{P}) =$ USGS estimate of oil volume when $P = \overline{P}$.

$r =$ the interest rate.

Explaining the equation in greater detail, when the price is high, $\overline{P}$, with probability (1-Π), the revenue is $\overline{P}Q(\overline{P})$, where $Q(\overline{P})$ is computed from the equation for MC. When the price is low, P, with probability Π, there are no revenues because P is the competitive price and is too low to warrant extraction. So the expected revenue is

1) Exp Rev = $\overline{P}Q(\overline{P})(1-\Pi)$.

The private cost = 0, when no oil is extracted, with probability Π. The private cost, when there is extraction is the area under the marginal cost curve in Figure J-1,

2) Exp. Cost = $\int_0^{\overline{Q}(\overline{p})} 0.611Q^{1.725} + 15Q$

which occurs with probability 1 - Π. The expected net revenue is the difference between expected revenue and cost = the difference between equations (1) and (2). The term, e^{-rt}, discounts the expected net revenue back to 2011 from 2031, where the latter date is the midpoint of the extraction period.

The net present value (at a 12% interest rate) at the time extraction is assumed to begin, when the chance of collusion is ½ and it achieves a price of \$25 per barrel (\$0.60 per gallon), is \$1.45 billion. To match this development value requires a lump sum preservation value per family, of about \$14.50 since there are about 100 million families in the U.S. This is less than one-half the value people were willing to pay to avoid another Exxon-Valdez oil spill for 10 years, according to a study done for the state of Alaska. (See Carson et al. 1992)

To capture the idea that some environmental costs are economically irreversible, together with any other credible irreversible environmental cost, it is appropriate to express the threshold environmental values on an annual basis as in Table J-2. If there is a 50% chance of colluding and this market structure could achieve a price of \$20 or \$25 per barrel (\$0.48 or \$0.60 per gallon), then a willingness-to-pay of about \$ .96 or 2.87 annually per family in the U.S. would be necessary to match the value of oil development in the Arctic National Wildlife Refuge at a 4% rate of interest or \$ .58 to \$1.74 annually at the 12% rate of interest used by USGS. Expressed in present day values rather than 2011 values for the 50% chance of \$25 per barrel (\$0.60 per gallon), the threshold values per family are about \$1.89 or \$1.15 annually respectively for interest rates of 4 or 12% (Table J-3).

Table J-2 Per Family Net Value of Oil Production Arctic National Wildlife Refuge (2011 dollars)

$r = 0.12$ and $t = 20$

Probability of Collusion	Price		
	20	25	40
¼	2.43	7.26	30.85
½	4.86	14.51	61.70
¾	7.28	21.77	92.55

Per Family Net Value of Oil Production Arctic National Wildlife Refuge (2011 dollars)

$r = 0.04$ and $t = 20$

Probability of Collusion	Price		
	20	25	40
¼	12.02	35.94	152.79
½	24.05	71.87	305.59
¾	36.07	107.81	458.38

Table J-3 Annual Family Willingness to Pay (2011 dollars)

$r = 0.12$ and $t = 20$

Probability of Collusion	Price		
	20	25	40
¼	0.29	0.87	3.70
½	0.58	1.74	7.40
¾	0.87	2.61	11.11

Annual Family Willingness to Pay (2011 dollars)

$r = 0.04$ and $t = 20$

Probability of Collusion	Price		
	20	25	40
¼	0.48	1,44	6.11
½	0.96	2.88	12.22
¾	1.44	4.31	18.34

If the extraction period were shorter, the threshold willingness to pay would increase as would be the case if more oil was economically available. A lower threshold willingness-to-pay would follow if seismic trails were laid down before extraction began and to the extent that there are other expected environmental costs associated with oil extraction not included in these assumed costs.

Appendix K:

Biosketches of the Committee's Members

COMMITTEE ON CUMULATIVE ENVIRONMENTAL EFFECTS OF ALASKAN NORTH SLOPE OIL AND GAS ACTIVITIES

GORDON ORIANS (Chair) is Professor Emeritus of Zoology at the University of Washington, Seattle. He received his Ph.D. in zoology from the University of California at Berkeley. He has been a member of the faculty of the University of Washington since 1960 and served as Director of its Institute of Environmental Studies from 1976 to 1986. He was elected to the National Academy of Sciences in 1989. His research interests include the evolution of vertebrate social systems, territoriality, habitat selection, and environmental quality. He is a past president of the Ecological Society of America, a member of the American Academy of Arts and Sciences, and a foreign member of the Royal Netherlands Academy of Sciences. He has served as chair of the Board on Environmental Studies and Toxicology since 1997, as a member of the NRC's Report Review Committee, and as chair or member of many other NRC committees and commissions.

THOMAS F. ALBERT has recently retired from duties as Senior Scientist in the Department of Wildlife Management, North Slope Borough, Barrow, AK. He now serves as Senior Scientist with Wag-Hill Arctic Science, LLC. He received a B.S. from the Pennsylvania State University, V.M.D. from the University of Pennsylvania, and Ph.D. in biology from Georgetown University. He is a Fellow of the Explorers Club (New York) and the Arctic Institute of North America and is an honorary member of the Barrow Whaling Captains Association. His major areas of interest are arctic wildlife, environmental biology, and veterinary medicine. He has experience regarding the importance of bowhead whales to the Eskimo people of northern Alaska and the impacts of oil and gas industry activities on whale behavior and habitat.

GARDNER BROWN is a Professor of Economics, specializing in natural resource economics, non-market valuation, and applied microeconomic theory, at the University of Washington, Seattle. He received his Ph.D. from the University of California, Berkeley (1964). Dr. Brown serves on the editorial board of *Environment and Development Economics* and the *Journal of Environmental Economics and Management*.

RAYMOND CAMERON earned a Ph.D. in Zoophysiology from the University of Alaska (1972). He served as Wildlife Biologist for the Alaska Department of Fish and Game for twenty years (1974-94) and is currently Affiliate Professor of Wildlife Biology at the Institute of Arctic Biology, University of Alaska Fairbanks. Dr. Cameron has published extensively on the behavioral, nutritional, and reproductive consequences of petroleum development.

PATRICIA A. L. COCHRAN is the Executive Director of the Alaskan Native Science Commission. She is an Inupiat Eskimo born and raised in Nome, Alaska. Previously she served as administrator of the Institute for Circumpolar Health Studies at the University of Alaska Anchorage; Executive Director of the Alaska Community Development Corporation; Local Government Program Director with the University of Alaska Fairbanks; and Director of Employment and Training for the North Pacific Rim Native Corporation. Ms. Cochran served on the NRC Committee on Management of Wolf and Bear Populations in Alaska.

S. CRAIG GERLACH is an Associate Professor of Anthropology at the University of Alaska Fairbanks. He earned his Ph.D. in anthropology from Brown University (1989). His areas of expertise include archaeology of pastoralists, arctic hunter-gatherers, zooarchaeology, and quaternary paleoecology; arctic oil and gas activities; Native American archaeology and subsistence studies; historic archaeology and anthropology of reindeer herding in Northwest Alaska; analysis of both archaeological and historical resources, as well as subsistence studies on the North Slope and along the TAPS route. He has twenty years of experience involving academic researchers, the native community, the oil and gas industry, and mining companies in the fields of archaeology and cultural anthropology.

ROBERT B. GRAMLING is a Professor of Sociology and Director of the Center for Socioeconomic Research at the University of Southwestern Louisiana in Lafayette. He earned a B.S. in Social Welfare (1965), M.S. in Social Science (1967), and Ph.D. in Sociology (1975) from the Florida State University. His areas of interest include environmental sociology—natural resource development, social impact assessment, and risk assessment. Dr. Gramling is the Principal Investigator for the Louisiana Applied Oil Spill Research and Development Program's study on the "Production and Analysis of an Oil Spill Database for Louisiana" (1999-2001). He is currently the Associate Editor for *Society and Natural Resources* and serves on the Standing Scientific Committee, Gulf of Mexico Fisheries Management Council (1994-present) and National Marine Fisheries Service/Northwest Power Planning Council, Independent Scientific Advisory Board (1999-present). Formerly he served on the Study of the Economic, Social, and Psychological Impacts of the Exxon Valdez Oil Spill (1990-1991); NRC Committee to Evaluate Information Adequacy for the Presidential Task Force on Outer Continental Shelf leasing in Florida and California (1989-1990); and NRC Committee to Review the Department of Interior, Outer Continental Shelf Environmental Studies Program: Socioeconomic Panel (1988-1991). Dr. Gramling has published several books on off-shore oil development including: *Oil on the Edge: Offshore Development, Conflict, Gridlock* (1996) and *Oil in Troubled Waters: Perceptions, Politics, and the Battle Over Offshore Drilling* (1994).

GEORGE GRYC is a geologist, recently retired from the U.S. Geological Survey. He received his M.S. from the University of Minnesota (1941). He has conducted field studies in northern Alaska in support of the U.S. Navy's war-time program to explore Naval Petroleum Reserve. From 1950 to 1960, he was Chief of the USGS, Navy Oil Unit. From 1960 to 1963, he was Staff Geologist to the Chief Geologist, USGS, in the Office of Regional Geology that included geologic studies in Alaska. From 1963 to 1976, Dr. Gryc was Chief of the Alaskan Branch, Geologic Division, in the USGS Regional Center in Menlo Park, California, which was the main operational unit for all USGS mineral, energy and geologic studies in Alaska. In 1976 has was appointed Regional Geologist for the Western Region. From 1976 to 1985, he was head of the new USGS unit, "Office of National Petroleum Reserve, Alaska," ONPRA, in the USGS

Director's Office. As Chief ONPRA, he was in charge of all geological, geophysical, and drilling activities in NPRA. From 1982 to 1995, he was the Director's Representative for the Western Region. Mr. Gryc retired from full-time service in January 1995, but continued USGS activities as a volunteer, first as a Pecora Fellow and now as a Scientist Emeritus. He has served on several NRC committees on permafrost.

DAVID M. HITE is a geological consultant. He earned his M.S. and Ph.D. in Geology from the University of Wisconsin. Dr. Hite has worked most recently as a Geological Consultant for a variety of companies and Alaskan Native Corporations. He has experience in prospect, play and basin analysis in frontier areas (Alaska, Arctic Canada, and OCS) and has been involved in numerous research, exploration, and development activities including: basin evaluation; development of depositional models for sandstone reservoirs; homogeneity/heterogeneity studies of reservoir horizons; and the development of numerous surface geological field programs.

MAHLON C. KENNICUTT, II is Director of the Geochemical and Environmental Research Group in the College of Geosciences at Texas A&M University and a member of the graduate college faculty at the College of Geosciences & Maritime Studies. He received his Ph.D. in oceanography from Texas A&M University (1980). His research interests are in marine chemistry, organic geochemistry, the chemistry of contaminants in the environment, the design and implementation of environmental monitoring programs, the fate and affect of xenobiotic chemicals in the environment, and the development of integrated indicators of ecosystem health. Dr. Kennicutt has significant Antarctic experience, and has participated in 35 ocean research cruises over the past 20 years. He assisted in organizing and writing the workshop report, "Monitoring of Environmental Impacts from Science and Operations in Antarctica," July 1996. Dr. Kennicutt is one of the two U.S. delegates to the Scientific Committee on Antarctic Research (SCAR). He serves on the SCAR Group of Specialists on Environmental Affairs and Conservation and SCAR Group of Specialists on Subglacial Lakes, where he has been key in developing the international science plan for exploration of subglacial lakes.

ARTHUR H. LACHENBRUCH is a Geophysicist Emeritus at the U.S. Geological Survey. He received his B.A. from the Johns Hopkins University (1950), and M.A. (1954) and Ph.D. (1958) in geophysics from Harvard University. He is interested in problems of temperature and stress in the solid earth on a variety of scales ranging from ice-wedge polygons in permafrost to continental tectonics. In 1963, he received the Geological Society of America's Kirk Bryan Award for Geomorphology, and in 1989 the American Geophysical Union Walter H. Bucher Medal for contributions to knowledge of the Earth's crust. Dr. Lachenbruch is also interested in applications to environmental issues such as design of the Trans Alaska Pipeline, implications of borehole temperatures for 20th century climate change, and issues of "sustainability." He has conducted many years of field studies on the North Slope and elsewhere in Alaska, and has served on the Polar Research Board and NRC committees and on science advisory panels for many groups including the Arctic Institute of NA, Los Alamos National Laboratories, U.S. Geological Survey, AEC, University of Alaska, National Aeronautics and Space Administration, and American Association of Petroleum Geologists. He was elected to the National Academy of Sciences in 1975.

LLOYD F. LOWRY is an Affiliate Associate Professor at the University of Alaska School of Fisheries and Ocean Sciences. Previously he was the Statewide Program Coordinator of the

Marine Mammal Division of Alaska's Department of Fish and Game. Mr. Lowry received a B.S. in biology from Southeastern Massachusetts University (1971) and M.S. in marine sciences from the University of California, Santa Cruz (1975). He has extensive experience analyzing human impacts on marine mammals and their habitats in the Beaufort Sea. Mr. Lowry is Chairman of the Marine Mammal Commission's Committee of Scientific Advisors. He has published extensively on seals and other marine mammals and has served on the NRC Committee on the Bering Sea Ecosystem.

LAWRENCE L. MOULTON is the owner of and Senior Fisheries Biologist at MJM Research. He earned his B.S. (1969), M.S. (1970), and Ph.D. (1977) in Fisheries Biology at the University of Washington. His areas of expertise include fishery biology, aquatic biology, and ichthyology. Dr. Moulton has over 25 years experience in North Pacific and Alaskan fisheries investigations. He has managed many studies on freshwater, anadromous, and marine fisheries and the effects of harvest or habitat alteration on aquatic populations. These studies have ranged from large, multidisciplinary field and analytical studies to specialized mitigation and risk analyses. He has also served as an expert witness in arbitration and litigation cases and has been an invited speaker at a variety of symposia and workshops on anadromous, marine, and estuarine fishes.

EVELYN (CHRIS) PIELOU is a retired professor of ecology. She earned a B.S. (1951), Ph.D. (1962) and D.Sc. (1975) from the University of London. Dr. Chris Pielou was a Research Scientist for the Canadian Dept. of Forestry (1963-64); Research Scientist at the Dept. of Agriculture (1964-67); Professor of Biology at the Queen's University, Kingston (1968-71); Killam Research Professor at Dalhousie University, Halifax (1971-74); Professor of Biology, Dalhousie University (1974-81); and Oil Sands Environmental Research Professor at the University of Lethbridge (1981-86). Dr. Pielou is the author of numerous books including: *Introduction to Mathematical Ecology* (1969); *Population and Community Ecology* (1974); *Ecological Diversity* (1975); *Mathematical Ecology* (1977); *Biogeography* (1979); *Interpretation of Ecological Data* (1984); *The World of Northern Evergreens* (1988); *After the Ice Age: The Return of Life to Glaciated North America* (1991); *A Naturalist's Guide to the Arctic* (1994); *Fresh Water* (2000); and *The Energy of Nature* (2001). Other writings include over 60 papers, articles and scientific publications. Dr. Pielou's work has been recognized by several awards including: Fellow, Royal Society of Arts; recipient George Lawson medal of Canadian Botanical Association (1984); Eminent Ecologist Award of Ecological Society of America (1986); Distinguished Statistical Ecologist Award of the International Congress of Ecology (1990); Honorary LL.D. from Dalhousie University (1993); Foreign Honorary Member of the American Academy or Arts and Sciences; Honorary Life Member of the British Ecological Society; and Honorary Sc.D. from the University of British Columbia (2001).

JAMES S. SEDINGER is a Professor in the Department of Environmental and Resource Sciences at the University of Nevada Reno. He is the former Interim Director of the Institute of Arctic Biology and Professor of Wildlife Ecology at the University of Alaska Fairbanks. Dr. Sedinger received his Ph.D. from the University of California, Davis (1983). He is an ornithologist that has worked and published for years on black brant throughout Alaska. His professional interests are in the study of life-histories, population biology, and nutritional ecology of avian species, particularly waterfowl. Before becoming a professor at the University of Alaska Fairbanks, he worked for the U.S. Fish and Wildlife Service as a research wildlife biologist. He is a member of numerous professional organizations, including the American Association for the Advancement of Science and the Ecological Society of America.

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