Chapter 2

Technologies for Oil and Gas Development on the North Slope of Alaska

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INTRODUCTION

If oil and gas leasing is permitted in the Arctic National Wildlife Refuge (ANWR), the exploration for and development of any resources discovered there would likely follow the pattern established over the last two decades of commercial petroleum activities on the North Slope of Alaska. The basic oil exploration and production systems for the Arctic have been adapted from technologies used by the industry in less severe environments. These adaptations make it possible to work successfully in the unique Arctic environment of extreme cold temperatures and harsh weather, and to cope with remoteness and the difficulty of transportation. The need to work on permafrost, tundra, and ice also forced some major technological changes. Substantial engineering development was undertaken by the petroleum industry to produce efficient and effective systems for Arctic use. By the early 1980s, after most of Prudhoe Bay and TAPS had been in routine operation for some time, the industry considered that the technology for onshore Arctic operations was proven and mature.[1]

Four Environmental Questions

The debate about whether or not to allow leasing and petroleum development in ANWR includes four key questions about the impact of technologies and practices on the environment:

1. **To what extent will the physical presence of infrastructure associated with oil development disturb ANWR?** How many gravel pads, gravel roads, pipelines, facilities, etc., will cover the tundra? What will be the effect of erosion, disruption of drainage patterns, dust, etc, on local ecosystems? How long will the facilities operate? What is the potential for long-term growth? What regulations could limit environmental disturbance?
2. **To what extent will gravel mining and other construction practices disrupt ANWR?** How much gravel will be needed? What regulatory limits should there be?
3. **How much waste discharge from drilling and production operations will there be?** Will the practices of (and regulation for) managing those wastes be acceptable in ANWR? Is deep well injection a sound practice? To what extent will environmentally benign muds be used? Will reserve pit containment practices be adequate? Will higher environmental standards than normal be necessary for a wildlife refuge?
4. **Will the fresh water needs for ANWR development and standard industry practices for obtaining water be acceptable, feasible, and controllable by regulation?**

This report has focused attention on the first two areas above because they relate most closely to our main objective of characterizing the technological developments likely to occur should ANWR leasing be permitted. The report only briefly discusses the second two areas above. In addition, air quality issues are not addressed. In commenting on the draft report, environmental groups have called attention to their serious concerns about many environmental issues, but most importantly to questions about waste disposal and fresh water supply. The scope of this study has precluded significant environmental analysis. However, if ANWR leasing goes forward, it is clear that all of these issues will continue to be of concern and will need to be addressed in future environmental studies.

1. National Petroleum Council, U.S. Arctic Oil and Gas, NPC, U.S. Department of Energy Advisory Cemmittee, 1981,

TECHNOLOGY DEVELOPMENT TO DATE

History

Both the present technology in place and the evolution of Arctic oil and gas technology and practices on the North Slope yield important clues to any likely development of the ANWR coastal plain. The Prudhoe Bay oilfield was developed during the 1970s. During that time, the petroleum industry invested in major engineering projects to enable it to modify technologies developed in other areas for Arctic use. Although the Prudhoe Bay field did not begin production until 1977, pioneering efforts on what was then called the Naval Petroleum Reseme in Alaska (now the National Petroleum Reserve-Alaska [NPRA]) at least *20* years before provided much basic information about drilling in permafrost, use of ice roads and platforms, building gravel pads, and other techniques for working in the Arctic. Other fields were discovered in the vicinity of Prudhoe Bay and put into production using the experience at Prudhoe, to advance technology even further.

All of the producing North Slope fields feed into the Trans Alaska Pipeline System (TAPS). TAPS delivers oil in an elevated pipeline along an 800-mile route from Prudhoe to Valdez, an ice-free terminal in southern Alaska. Research on permafrost along the TAPS route was done during the 1950s and 1960s, and TAPS pipeline technology **was** developed during the 1970s.

Photo credit: Standard Alaska

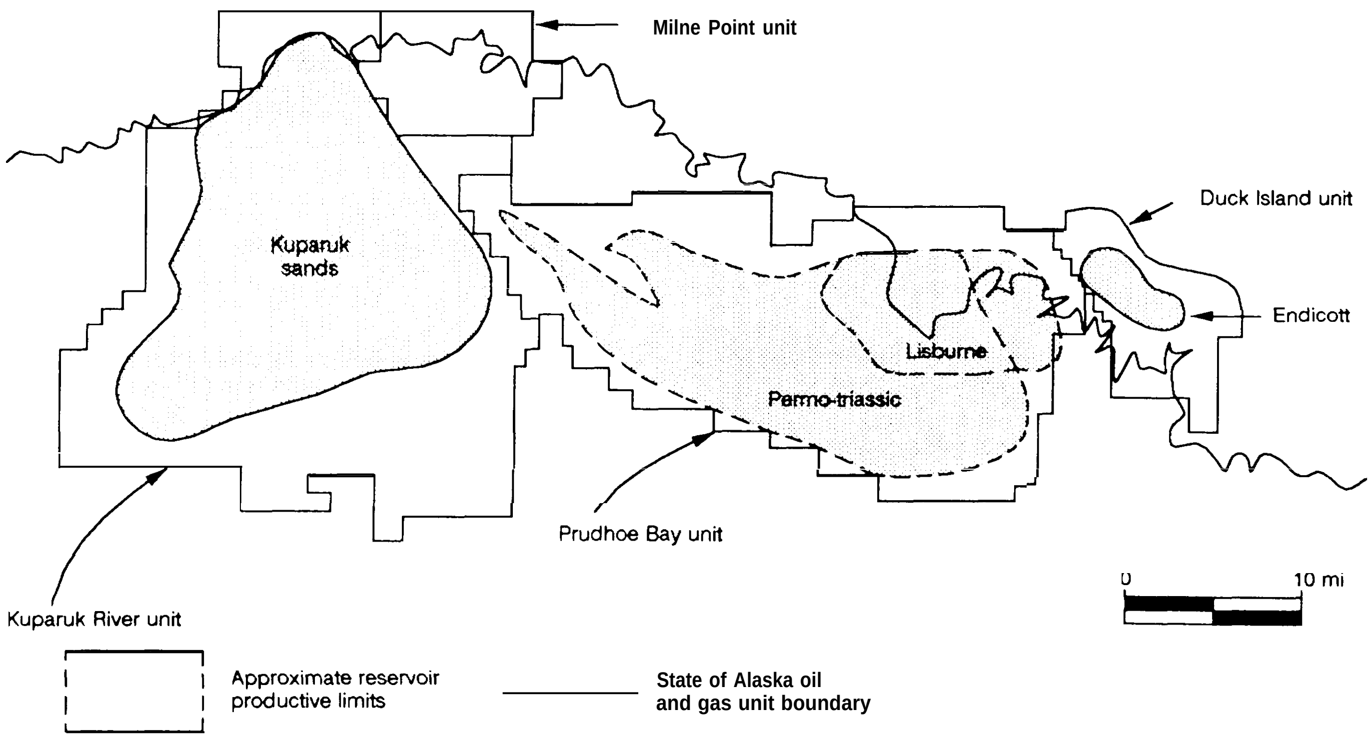
Base Operations Center, Western Operating Area, Prudhoe Bay Field.

Current North Slope Development

Existing North Slope oil and gas development is extensive and still growing.[2] It is concentrated in five fields: Prudhoe Bay, Kuparuk River, Lisburne, Endicott, and Milne Point (Figure 2-l). Currently, all but Milne Point are producing. As a group, the fields are supported by 1,123 miles of pipeline (excluding TAPS) and 346 miles of roads. Some 7,035 acres of land are covered by gravel for facilities, drill sites, roads, and camps. Nine river crossings and three airfields are used for petroleum-related activities. A 370-mile gravel haul road, the Dalton Highway, connects Deadhorse (the operations base for most of the contractors who support the major operations), at the southern end of Prudhoe Bay, with Fairbanks. All the oil is transported via the Trans Alaska Pipeline from Prudhoe Bay to Valdez. The current rate of North Slope oil production is about 2 million barrels per day (mmbd).

Table 2-1 summarizes development activities at the five North Slope sites. Overall, the Deadhorse industrial complex serves as the prima~ support base for North Slope and Beaufort Sea exploration and development. Deadhorse has living quarters, warehouse facilities, and a paved, State-operated airport. It is located in the southern portion of the Prudhoe oilfield. By itself, the Prudhoe Bay field, the Nation's largest, has two adjacent operating areas, one run by Standard Alaska Production Company (SAPC) and the other run by ARCO Alaska. Production

Figure 2-1. –Alaskan North Slope Producing Oil Fields



SOURCE Exxon Co USA, 1988

2. The following description was excerpted from "Five-Year Oil and Gas Leasing Program, " a report of the Alaska Department of Natural Resources, Division of Oil and Gas, January 1988.

Table 2-1 .–North Slope Petroleum Development Summary (as of October 1987)

Field name	Prudhoe Bay	Lisburne	Kuparuk	Milne Point	Endicott
Discovery date	12/67	12/67	4/69	10/69	3178
Size of oil pool (sq. ma.)	400	125	400	45	40
Production start-update	6/77	12/86	12/81	11/85	10/87
Production to date (million bbls)	4,918	5	292	5’	b
1986 average production rate (barrels/day)	1,554,000	40,000	257,000	12,900	100,000
Remaining reserves:					
million barrels (oil)	4,672	395	1,308	55	375
billion cubic feet (gas)	26,000	625	565	0	730
Existing wells	881	51	557	29	30’
Drill sites/pads	38	5	34	4	2
Production centers	6	1	3	1	1
Base camps	2	1	1	1	1
Construction camps	2	0	1	1	1
Power plants	1	1	1	1	1
Topping plants	1	0	1	0	0
Gas compression plants	1	1	1	1	1
Seawater treatment plants	1	0	1	0	1
Enhanced oil recovery plants	1	0	1	0	0
Docks	1	0	1	0	1
Causeways	1	0	0	:	1
Water injection centers	2	0	d		d
Associated support and industrial sites	1	0	1	0	0
Airports and company operated airstrips	2	0	1	0	0
Pipelines (miles)	63’	e	418	15	28
Roads (miles)	218[e]	e	94	19	15
Acreage covered (acres)	5,374[e]	e	1,409	54	198
River crossings (number)	3[e]	e	5	1	1

NOTE: The above does not include the considerable numberof support sites and acreage covered at Deadhorse
aField shut in January 1987
bProduction commenced October 1987
c80-100 wells planned
dwater injection system Included In production centers
eLlsburne numbers Included with Prudhoe Bay

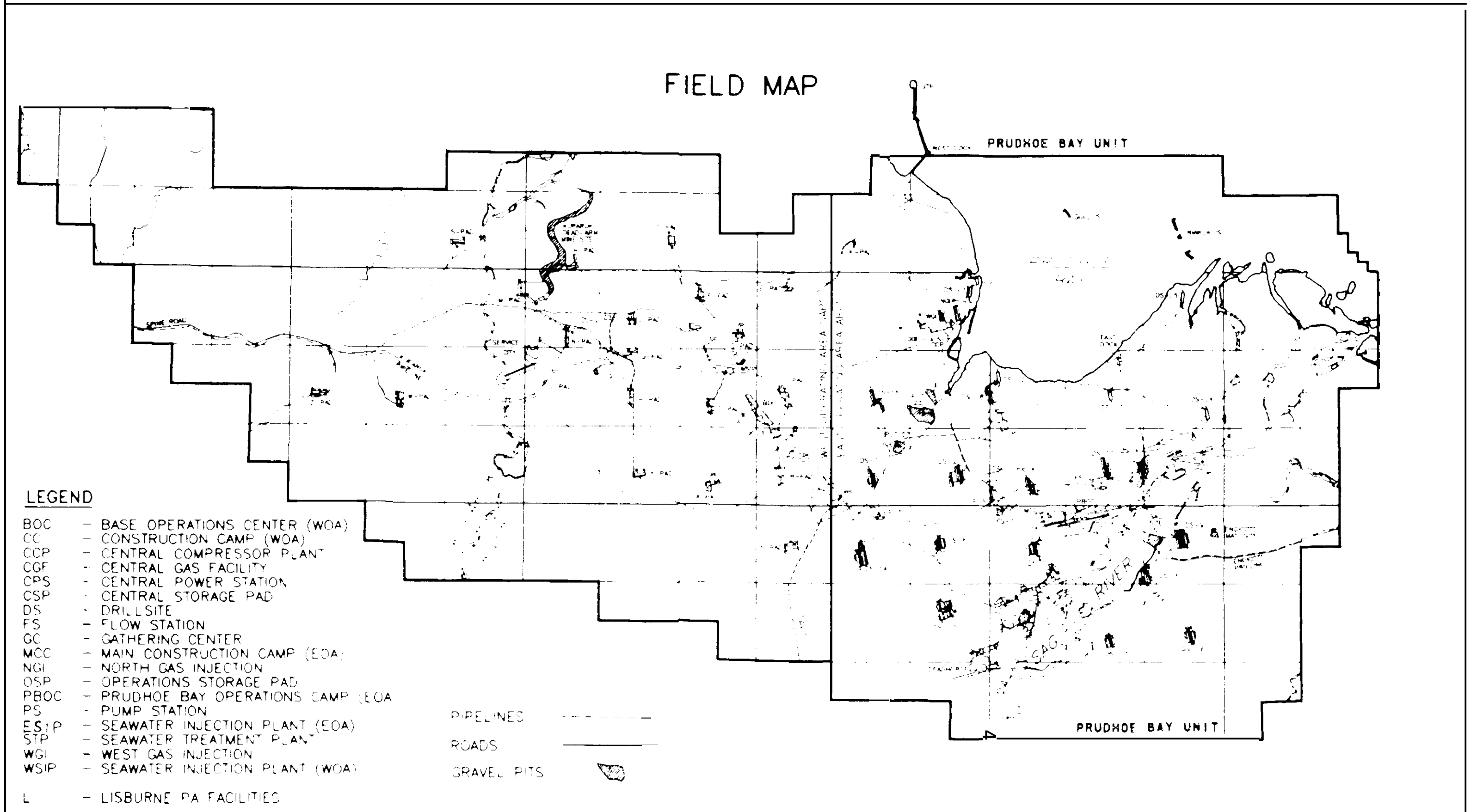
SOURCE Alaska Department of Natural Resources, Division of Oil & Gas and Exxon comments, Apr. 26, 1988.

began in 1977. Today, Prudhoe Bayfacilhies are huge. They are located within a 200-square-mile area of the 400-square-mile Prudhoe Bay Unit, and include six oil/gas separation plants, gathering centers or flow stations, 38 drill pads with a total of 828 wells, a central gas facility, a central compression plant, a central powerplant, afield fuel gasunit, a crude topping plant (refinery), a waterflood seawater treatment facility, a gravel airstrip, 200 miles of roads, permanent living quarters, a dock, two construction camps, offices, and two water injection plants.

Figures 2-2 and 2-3 illustrate the large scale of development at Prudhoe Bay. Figure 2-2 depicts the major field production facilities only (drill pads, airstrips, operations center gas plant, docks, and connecting roads). Figure 2-3 shows more detail of sizes and shapes of facility pads and pipeline networks. while it is difficult to portray the development on this scale, both the extent of coverage and the diversity of the systems in place are evident. Whether (in total) this is a major industrial complex defacing the natural Landscape or whether it is only a small, incidental disturbance in a vast wilderness depends mainly on one’s values and perception.

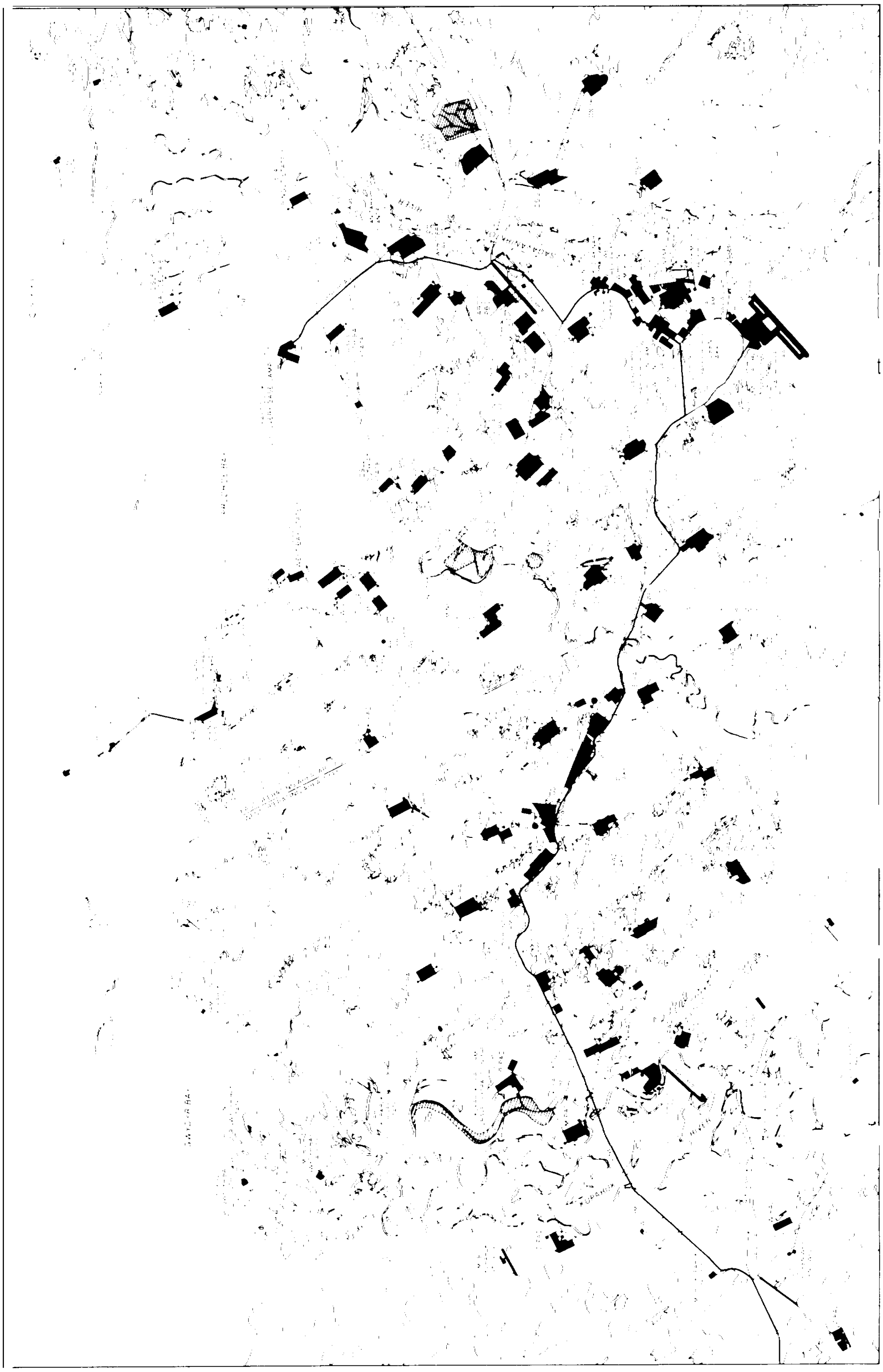
The Kuparuk River field, located about 30 miles west of Prudhoe Bay, is operated by ARCO Alaska. Production began in December 1981. About 500 people will be ultimately employed at the field. Facilities currently include three central production facilities, about 500 wells (800 are planned), the Kuparuk Operations Center (offices and housing for 384 people), the Kuparuk Industrial Center a gasplant, a seawater treatment plant, pipelines (a 26-mile-long, 24-inch-diameter crude oil line, built in 1984, connects to TAPS at Pump Station 1, and a 26-mile-long, 16-inch-diameter converted oil line carries natural gas to Prudhoe Bay for fuel), 94 miles of roads and a

Figure 2-2.—Prudhoe Bay Facilities Map



SOURCE: Exxon Co. USA, April 1988.

Figure 2-3.—Individual Facilities at Prudhoe Bay



LEGEND

Gate

Pad or drill site

Spine road

Pipeline service oad

Road

Trail

Gravel extraction area

SOURCE: Standard Alaska Production Co. January 1987.

300-foot bridge across the Kuparuk River, a topping plant, two construction camps (one accommodates 650 people and the other 360), and one gravel airstrip.

The Lisburne resewoir was discovered directly beneath Prudhoe Bay. ARCO committed to developing Lisburne in January 1984, and initial production began in December 1986. Of 51 total wells, to date 45 are capable of production. The current production is from 37 of these wells. When completed, about 100 permanent employees will work in the Lisburne field, while about 1,000 will be necessary during portions of the construction phase. Lisburne facilities include one central production facility, five onshore gravel pads, 50 miles of pipeline, and a pilot waterflood project.

The Endicott field, discovered in 1978, is located offshore about 20 miles east of Prudhoe Bay. It is the first oil and gas field to be developed in the Alaskan Beaufort Sea. Standard Alaska Production Company is the operator. Production began in October 1987. The field is being developed from two artificial gravel islands, 2 miles offshore. The Islands are connected by 3.1 miles of solid fill causeway and joined to the Sagavanirktok (Sag) River delta by 1.9 miles of gravel causeway with two bridge-type breaches totaling 700 feet and 1.5 miles of onshore causeway through the Sag delta wetlands. A gravel road, 8.7 miles long, connects the causeways with the existing Prudhoe Bay road system at Drill Site 9. An elevated oil pipeline from the field connects with TAPS at Pump Station #1. Other infrastructure includes an onshore gravel pit, a base camp with living quarters for 600 people, a warehouse, offices, fuel tanks, base operations center, seawater intake basin, utilities for the waterflood project, and a dock for sealift operations, Endicott operates with a permit for discharge of drilling effluents into the Beaufort Sea. The North Slope Borough landfill is used to dispose of oil-contaminated drill cuttings, and deep well injection is used to dispose of oil-contaminated fluids.

The Milne Point field was discovered in 1969, and development started in 1979. It is operated by Conoco. The 21 ,000-acre field is located northeast of the Kuparuk River field. Production, which began in November 1985, was suspended in January 1987 pending an increase and stabilization of oil prices. Facilities include 24 wells on two pads, a 50-person permanent camp, and a 300-person construction camp. About 19 miles of gravel roads connect Milne Point to the Kuparuk spine road, and about 15 miles of pipeline are available to carry oil from Milne Point to the Kuparuk Pipeline. Waterflood infrastructure includes a 45,000-barrels-per-day capacity water injection system.

Camp Lonely, located 80 miles west of Oliktok Point and the Kuparuk field, once served as a staging area for western Beaufort Sea activities but is now mothballed. Infrastructure includes a 100-person camp, offices, carpentry shop, communications shop, sewage treatment plant, generating system, vehicle maintenance shop, a large tank farm, and warm and cold storage warehouses.

In addition to these areas, future development is possible from Niakuk, located offshore between the Lisburne and Endicott fields, the West Sak Reservoir in the Kuparuk River and Milne Point Units, Seal Island, Tern Island, Sandpiper Island, Colville Delta, Flaxman Island/Point Thomson, the Hemi Springs Unit, ARCO Alaska's K-10, and Bullen Point Staging Area.

Arctic Conditions Affecting Technologies

Most experts agree that the major differences between North Slope and Lower 48 conditions that affect the choice and use of oil and gas technologies are the very cold weather, the presence of permafrost, and the remoteness of the area. Designs for technologies for operating at subzero temperatures draw heavily on advanced concepts in metallurgy, elastomers (elastic substances), lubricants, and fuels. The harsh cold environment also has demanded development of new survival systems and procedures to assure personnel safety. All drilling rigs and production facilities where people work must be enclosed, insulated, and heated. Exterior steel *structures* need to be built from a special arctic-grade steel to prevent brittleness at very low temperatures. Most pipelines and flowlines are insulated, either to prevent water from freezing or to avoid increased viscosity of the crude oil. Shut-in flowlines must be freeze-protected or evacuated and then filled with inert gas.

Permafrost (see Box 2-A) has forced the development of a number of compatible technologies. Because thawed permafrost lacks load-bearing capacity, special construction techniques are used to protect the permafrost layer so that it remains frozen. Where load-bearing is required, common North Slope practice is to build up a thick gravel pad to insulate the permafrost from warmer summer temperatures and from artificial heat sources. The pads then become platforms for facilities, roads, etc. Ail roads and gravel pads are constructed with a thickness of about five feet of gravel or some alternative, equally effective insulating technique. Flowlines, pipelines, and production handling modules are built above-ground on vertical support

Box 24
PERMAFROST

The entire **Nonth Slope of Alaska, including ANWR,** is underlain **by** permafrost, permanently frozen ground extending just below the land **surface to as much as** 2,000 **feet below the surface. In the Arctic winter, the permafrost** surface is solid and stalble. In the summer, up to several feet of the surface permafrost layer thaw, becoming soft and water-soaked and unable to support even small **structures, but the** remainder stays frozen. Techniques to provide permanently soild foundations for **heated buildings, facilities, roads, etc., on the surface (and to avoid melting the permafrost else-**where where it is frozen) are therefore necessary for ail Arctic operations, With certain types of thaw-stable soils, however, this is less of a problem.

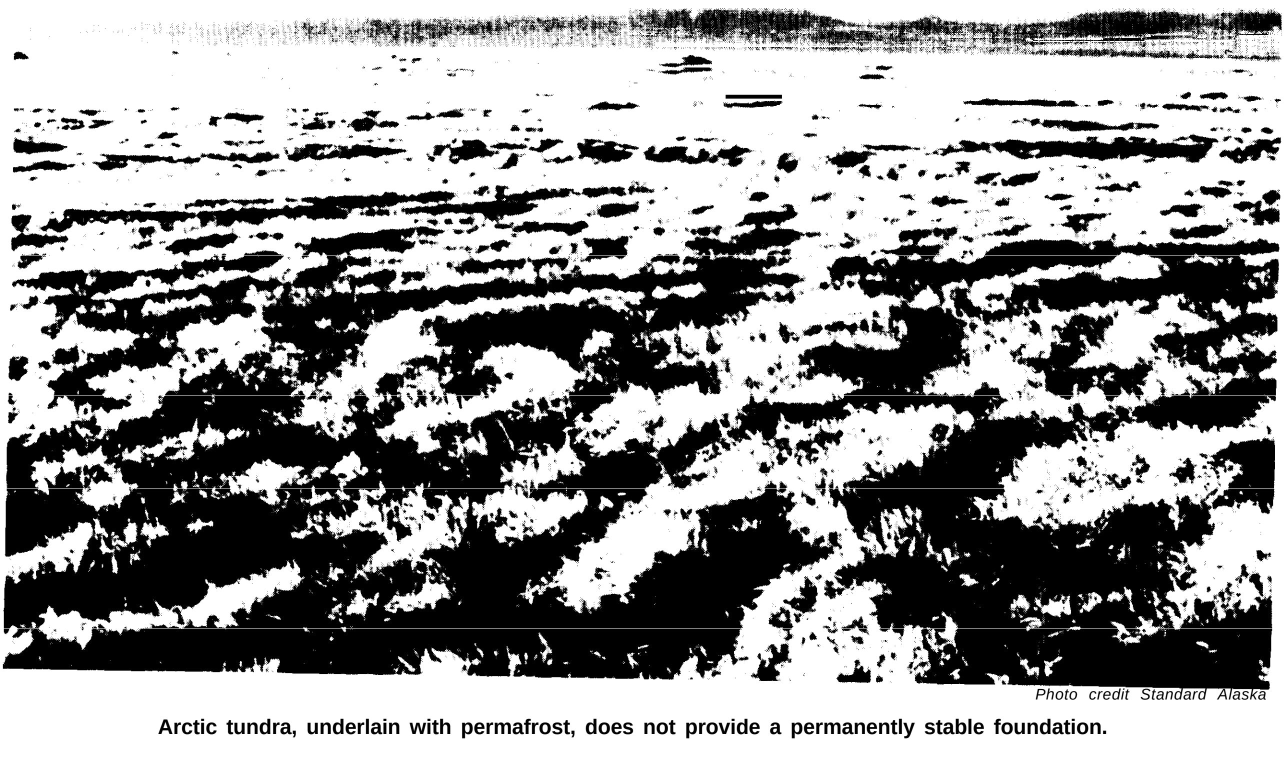


Photo credit Standard Alaska

Arctic tundra, underlain with permafrost, does not provide a permanently stable foundation.

members (VSMs) to insulate the permafrost from the produced fluids. In special cases where lines must be buried in the permafrost, refrigeration is used around the pipeline. To prevent the casing's[3] vertical movement and its collapse due to permafrost freeze-back after drilling or during well shutdown, casing materials are designed to withstand collapse loads, special cold weather cements are used for the surface casing, and "Arctic Pack" (a gelled freeze-proof diesel that has some insulating properties) is used between the surface casing and production casing. Most development drilling is done from drilling pads, and wells are clustered at the surface on these pads and drilled at an angle to the producing formation. This practice minimizes the amount of construction on and coverage of permafrost.

Because of permafrost there generally is a need for elevated foundations for buildings and facilities and for special containment of fluids and waste discharges. As permafrost is impervious to water, there is no downward percolation of water below mud pits, sewage lagoons, etc.

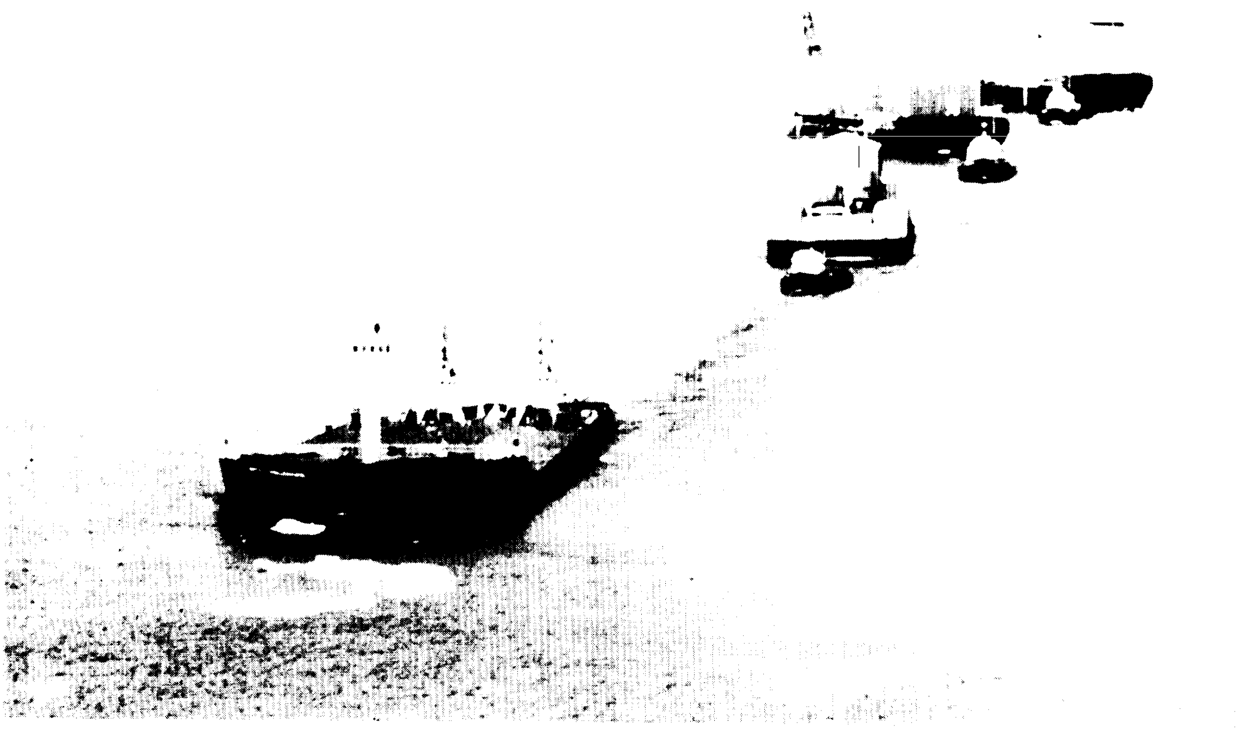


Photo credit Standard Alaska

The annual sealift from the Lower 48 to **the North** Slope brings in thousands of tons of modules,

3. Casing is the large steel pipe that lines an oil well. Some casing is installed during drilling operations and, if a well is used to produce oil, additional casing is installed.

There are indications, however, that permafrost is not impervious to other fluids including, perhaps, waste products, and that the migration of these fluids from some reserve pits is an environmental concern.

The harshness and remoteness of the North Slope make the on-site construction of facilities difficult and expensive. It is more cost-effective to start off-site-to prefabricate, to modularize, and to specially transport the needed structures, from 500 tons to 5,000 tons, to their final destination. For the most part, oil facilities for the North Slope are built in modules in the Lower 48, barged to the Prudhoe Bay dock in late summer, off-loaded and moved by crawlers along a gravel road network to a prepared site, and set on pre-installed large diameter piles. The transportation equipment itself has required the construction of special docks and causeways into the Beaufort Sea, especially where near-shore water depths are very shallow. Typically, 8 feet of water at the dock is needed for barge traffic.

Status and Trends of Arctic Technologies

The status of technologies, new developments underway, and needed improvements in exploration, development, production, and transportation systems or practices are summarized below. Table 2-2 lists some of the technologies for these applications.

Reconnaissance Exploration

Exploration begins with reconnaissance. Geological and geophysical surveys are conducted both on the ground and from the air. Gravity measurements are usually taken at ground stations, and magnetic measurements are commonly made with airborne instruments. Seismic surveys, which probe the shape of underground rock formations by interpreting the reflections and refractions of sound waves traveling through the rocks, are usually conducted with ground-based transmitters and receivers. Detailed seismic reflection surveys commonly use either explosives or vibratory sound sources and, when feasible, are usually conducted on the ice or snow to reduce tundra disturbance. In the past, movement of seismic equipment in wheeled vehicles over the tundra when snow cover is thin has left noticeable tracks. Survey technology advancements that could affect future work are automation of data collection and of transmission, processing, and interpretation of data. While these technologies may contribute to more accuracy in future survey work, they do not have much effect on the environment. Exploratory drilling is the activity of most environmental concern.

Drilling and Drilling Systems

Onshore exploratory or development drilling in the Arctic is now routine, using fairly standard technology. A drilling rig with power supply, pipe, casing equipment, supplies, base camp for personnel, and ancillary equipment must be moved to the drill site. The drilling site may be a gravel pad, ice pad, or insulated timber pad, Depending on rock conditions, depth of target zone, and other well conditions, drilling may be done only in the winter. Winter drilling has advantages for both movement of equipment (using ice roads and air strips) and for the use of ice pads, because ice pads generally harm the environment less than gravel pads. Depending on the well, drilling may also require additional time and cost. Gravel pads are needed for year-round work. Construction equipment is also needed at an exploratory drill site to build gravel pads, construct reserve pits, and install other support facilities.

Concerns about the impact of drilling technology on the environment mainly center on three principal activities: 1) transportation of equipment to and from the site; 2) building of pads, foundations, and pits at the site; and 3) disposal of wastes or removal of equipment and materials

4. Mud is a viscous fluid used to lubricate the drill bit and carry the cuttings to the surface.
5. Cement is used to fix casing pipe in the well,
6. Logging is the practice of making measurements in the well with instruments lowered on a cable from the surface.

Table 2-2.—Arctic Oil and Gas Technology: Composite List From Workshop Participants Answering: "What are the best examples of Arctic 'State-of-the-art' technologies?"

A. Exploration/Development
1. Drilling and Drilling Systems
a. Drilling Rig/Drilling-Lifting-Pipe Handling:
- Cant i lever rig design capable of drilling on close spacing, easily transported.
- Top drive rotary system capable of drilling 90 feet at a time without making pipe connections.
- Automatic pipe-handling systems (off truck and into hole),
- Iron-roughnecks, hydraulically driven make-up and break-out tongs.

b. Drill pipe/Bits/Downhole Drills:
- Improved metallurgy, stronger pipe **and casing.**
- **Diamond bits capable of long run times,**
- **Downhole mud turbines** for directional work.

c. Casing/Cement:
- Finite Element Analysis for casing connections.
- Improved metallurgy,
- Arctic Pak cements for cold hardening.

d. Circulation (Muds, etc.):
- Extensive secondary and tertiary mud cleaning equipment; cones, centrifuges. Dry systems.
- Non-toxic mud systems,
- Annular injection of unwanted liquid Volume.
- Polymer and mineral oil systems,

e. Coring and Logging:
- Improvements in logging tool reliability and capability.
- High angle holes—drillpipe conveyed; coiled tubing conveyed tools.
- Measurement-while-drilling (MWD) capabilities—to measure reservoir properties and to guide directional work.

f. Directional Drilling:
- MWD tools—continous monitoring of inclination and azimuth. Mud pulse telemetry.
- Down hole mud turbines, steerable mud motors.
- Horizontal and near horizontal drilling.

g. Blow-Out Prevention:
- Training simulators and i m proved detection systems.

h. Permafrost Protection:
- Arctic pak—freeze-back protection for casing.
- Arctic cement—set-up prior to freezing; insulates,
- Thaw bulb computer modeling and monitoring,
- Refrigerated conductor pipe systems,

2. Support Systems
a. Transport of Equipment"
- Rolligon.
- Hercules Cl30 air-transportable rigs and equipment,
- Hoverbarge.
- Winter ice road.
- Conventional barge i n summer (offshore island),
- Ice airstrips for exploration.
- Highiy modularized land rigs for fast moves between exploration wells and efficient moving on pads.

b. Personnel Support/Camps:
- Self-contained rig camps (up to 100+- people).
- Construction camps,
- isolation/sociological studies.

c. Supply of Operations: "
- Major equipment and facilities by annual sealift,
- Motor freight **via gravel and ice roads; rolligons.**
- **Air cargo (fixed wing plane via ice or gravel strip; or helicopter).**

d. Construction of Drill Pads/Supply Bases"
- Gravel (5 foot lift for thermal protection).
- Ice pads for single season exploratory wells.
- Foam and timber mats for multi-season exploratory wells.
- "Thin" pads using other insulating materials and less gravel thicknesses,
- Exploration reserve pits below-ground with permafrost for containment,
- Development reserve pits below grade contained in permafrost (proposed).

e. Waste Disposal:
- Annular injection of liquid wastes.
- Backhaul of solid or hazardous waste to approved disposal sites,
- Reduction in waste volumes (distillation),
- Modular and air transported sewage plants,
- Encapsulation and refreezing of drill cuttings and mud solids,
- Washing of cuttings.

B. Production
1. Well Systems
a. Casing/Tubing/Perforat ion/Cementing:
- Special perforating guns.
- "Clean" completion fluids.
- Low-temperature metallurgy.
- Non-freezing annular fluid for freeze back prevention (Arctic pak).

b. Wellhead/Flow Control:
- Computerized gas-lift.
- Ball valves,

c. Permafrost Control:
- Well spacing designed to minimize subsidence due to thaw.
- Permafrost cement.

2. Separation and Treatment
- Compact module designs and overall facility layout.
- Duplex stainless steel separation vessels,
- Control systems highly computerized,

3. Fluid Injection
a. Gas- Prudhoe Bay Unit Central Compression Plant and upgrades of existing equipment; centralized field-wide gas lift system at Prudhoe Bay with interconnecting tieline between operating areas.
b. Water—Seawater Treatment Plants at Prudhoe Bay and Kuparuk; incorporation of waterflood-system with treated seawater intake and related fieldwide processing facilities into initial production facilities at Endicott; source water Injection distribution system with tieline between operating areas at Prudhoe Bay,

4. Auxiliaries
a. Power:
- Generated on site using produced gas/or diesel

(cent/nued on next page)

Table 2-2.—Arctic Oil and Gas Technology: Composite List From Workshop Participants Answering: "What are the best examples of Arctic *State-of- the-art' technologies? ''—Continued

5. Construction Operations
   - a. Gravel Pads/Foundations/Site Preparation:
     - Small pad size (5 feet thick).
     - Winter season preferred for construction.
     - Optimum site location to minimize habitat loss, pending or impoundment, other environmental concerns.
     - Ground surface under some facilities insulated around piles in gravel pads to prevent settlement.
   - b. Transportation of Modules:
     - Sealift for large modules; smaller modules by truck on haul road.
     - Large tractors, crawlers, or multi-tiered trailers to move modules.
   - c. Construction of Docks/Piers:
     - Slope protection sheetpiles and conerete armor/ gravel bags.
   - d. Construction of Drainage Structures:
     - Arctic bridges for stream crossings.
     - Culverts and low water crossings for fish passage and erosion control.

C. Transportation

1. Oil through TAPS
   - a. Construction of Pipelines/Pumping Stations:
     - Winter construction above ground; summer construction for buried line.
     - Earthquake-proof.
     - Insulated (primarily above ground).
   - b. Pipeline Operation:
     - Highly automated.
     - Drag reducing agent to increase throughput.
   - c. Permafrost Protection:
     - Heat pipes i n vertical support members in permafrost.
     - Refrigerated facility pads.
   - d. Controls/Inspection:
     - Highly automated computer controlled.
     - Weekly inspection of line.
     - Automatic monitors and alarms throughout system (leak detection, etc.).
2. Oil Through Norman Wells Pipeline (Canada)
   - a. Construction of Pipeline:
     - Winter construction for buried line.
     - Uninsulated.
   - b. Pipeline Operation:
     - Operated at ambient temperature (25°F to 35°F) due to high API gravity crude.
   - c. Permafrost Protection:
     - Increased pipe wall thickness.
3. Gas
   - a. Overland Gas Pipeline:
     - Engineering studies and environmental impact studies underway.
     - TAPS-operated buried fuel gas pipelinc.
   - b. LNG:
     - Plant under evaluation for Port Valdez to be built in conjunction with gas pipeline from North Slope. provided by local topping plant.
     - Gas-fired or diesel-fired electrical.
     - Large power generation via gas turbines; smaller power needs by diesel fired generators.
     - Kuparuk industrial center for service company support facility.
   - b. Hotel and Base Facilities:
     - Production facilities self-contained and largely self-sufficient re: fuel and power generation, water, waste water, sewage treatment, etc.
     - Interiors designed to avert psychological problems linked to darkness and isolation.
   - c. Resupply and Transportation:
     - Sealift (short time for open water transport), motor freight, air freight.
     - Icebreaking ships for early supply in spring.
   - d. Waste Disposal:
     - Tertiary sewage treatment.
     - Annular injection of liquid wastes.
     - Back haul of solid wastes and hazardous wastes to approved disposal sites.
   - e. Roads and Airfields:
     - Gravel (about 5 feet thick), insulation, and geotex - tile fabric. ,
   - f. Oil Spill Control and Cleanup:
     - Prevention programs and awareness.
     - Specific plans for spill prevention.
     - Environmental response team(s) and equipment trailers.
     - Improved sorbent material and containment booms.
     - Spill reporting procedures,
     - Cleanup and disposal.
     - Revegetation and monitoring.
     - Snow and ice used for containment and sorbent.
   - g. Water Supply:
     - Abandoned and flooded gravel pits.
     - Deep lakes.
     - Seawater treatment.
     - Produced water treatment.
     - Water supply wells from fresh water aquifers.
     - Snow control.

SOURCE Office of Technology Assessment, based on information from: CONOCO; Standard Oil Co.; ARCO Alaska, Inc.; CRREL; and EXXON after the completion of drilling. Practices that minimize such impacts are well-known but may limit exploration flexibility or increase cost. For example, working only in winter months and transporting by vehicles only on ice will minimize impacts but may require extra time and cost for an operator, especially when drilling deep or difficult holes,

Circulation Mud

Most drilling operations use a circulation system with a water- or oil-based fluid, called mud. The mud is pumped down a hollow drill pipe and across the face of the drill bit to lubricate it and to remove cuttings. The mud and cuttings are then pumped back up the annular space between the drill pipe and the walls of the hole or casing. Mud is generally mixed with a weighting agent, such as barite, to: 1) stabilize the wellbore and prevent cave-ins; 2) counterbalance any high pressure oil, gas, or water zones in the formations being drilled; and 3) provide lubrication to alleviate problems downhole (such as a stuck pipe).’

Drilling fluids are selected based on the types of geologic formations encountered, economics, availability, problems downhole, reservoir damage potential, and well data-collection prac-

Photo *credit* Sfandard *Alaska*

Gravel production pad under development on the North Slope. Covered production wells are to the rear of the pad, reserve pits in the center.

7. **U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Management of Wastes from the Exploration, Development, and Production of Crude Oil, Natural Gas, and Geothermal Energy, Report to Congress, December 1987. pp. 2-3 to 2-5**

tices. Water-based mud with 70 to 80 percent water is the most widely used fluid for all types of drilling in the United States. Colloidal materials, primarily bentonite clay, and weighting materials, such as barite, are common constituents of water-based mud, and small amounts of chemical additives may make drilling easier. Oil-based mud accounts for a small percentage of drilling fluids used nationwide,[8] but is essential for certain types of exploratory wells, directional wells, etc.

The composition of drilling mud and the practices of building reserve pits[9] to contain the fluids have improved over the past decade of Arctic oil operations. The size of reserve pits has been reduced in newer designs, and more recent practices have aimed at better control of the waste products. Smaller reserve pits are possible by recycling muds and injecting unusable liquids down the well's annulus. According to current stated industry practice, when drilling is complete the reserve pit contains only drill cuttings that can be buried or used as fill. Smaller reserve pits also mean smaller gravel drilling pads. Major oil companies operating in Alaska usually follow these and other practices to minimize pad size and reduce wastes.

Figures 2-4, 2-5, and 2-6 show typical operations involving drilling mud and reserve pits. Figure 2-4 shows the standard mud flow pattern from mud pump to drill pipe, down the well and up the annulus, to a shale shaker on the surface which screens out cuttings that are put in a reserve pit. The remaining "cleaned" mud may receive some additives and then return to the mud pump for another cycle. The leakage of mud and other wastes out of reserve pits has been a serious environmental concern in the past. New systems have been developed to address this problem. These new systems would be designed to separate the disposal of cuttings from all fluids and from a pit used as a reserve mud source. The rock cuttings are both comparatively benign and simple to contain in a pit. Figures 2-5 and 2-6 show the location of a reserve pit used just for drill cuttings, a practice that some North Slope operators are reportedly beginning. If this type of system proves feasible, the pit may be covered and permanently contained after drilling is completed. Environmental groups stress the-need for long-term monitoring to confirm the permanence of this system.

Directional Drilling

Directional drilling is deliberately drilling at an angle from the vertical to reach a target that is offset from the surface wellsite. Directional drilling was developed specifically for offshore use to allow multiple wells to be drilled from a single platform. Directional drilling on land is used when surface wellheads must be clustered in a small area; one drill pad in the Arctic may contain as many as 40 wells. As directional drilling improves, the number of pads can be decreased and their locations can be more centralized. Currently, North Slope wells are drilled at angles of up to 60 degrees from the vertical with the point of departure from vertical as shallow as 500 feet. Theoretically, a 5,000-acre field, if relatively deep, could be drilled from one site.

Directional drilling to a 60-degree offset is a mature practice on the North Slope. Further developments in directional drilling could allow denser clustering of wells, but changes are expected to be gradual. Continual advancements in offshore extended-reach drilling are helping to cut the high costs of subsea wells; some of these gains may be applied to the North Slope in the future. One North Sea proposal calls for up to a 75-degree angle and as much as 6 mile reach for a research and development well.

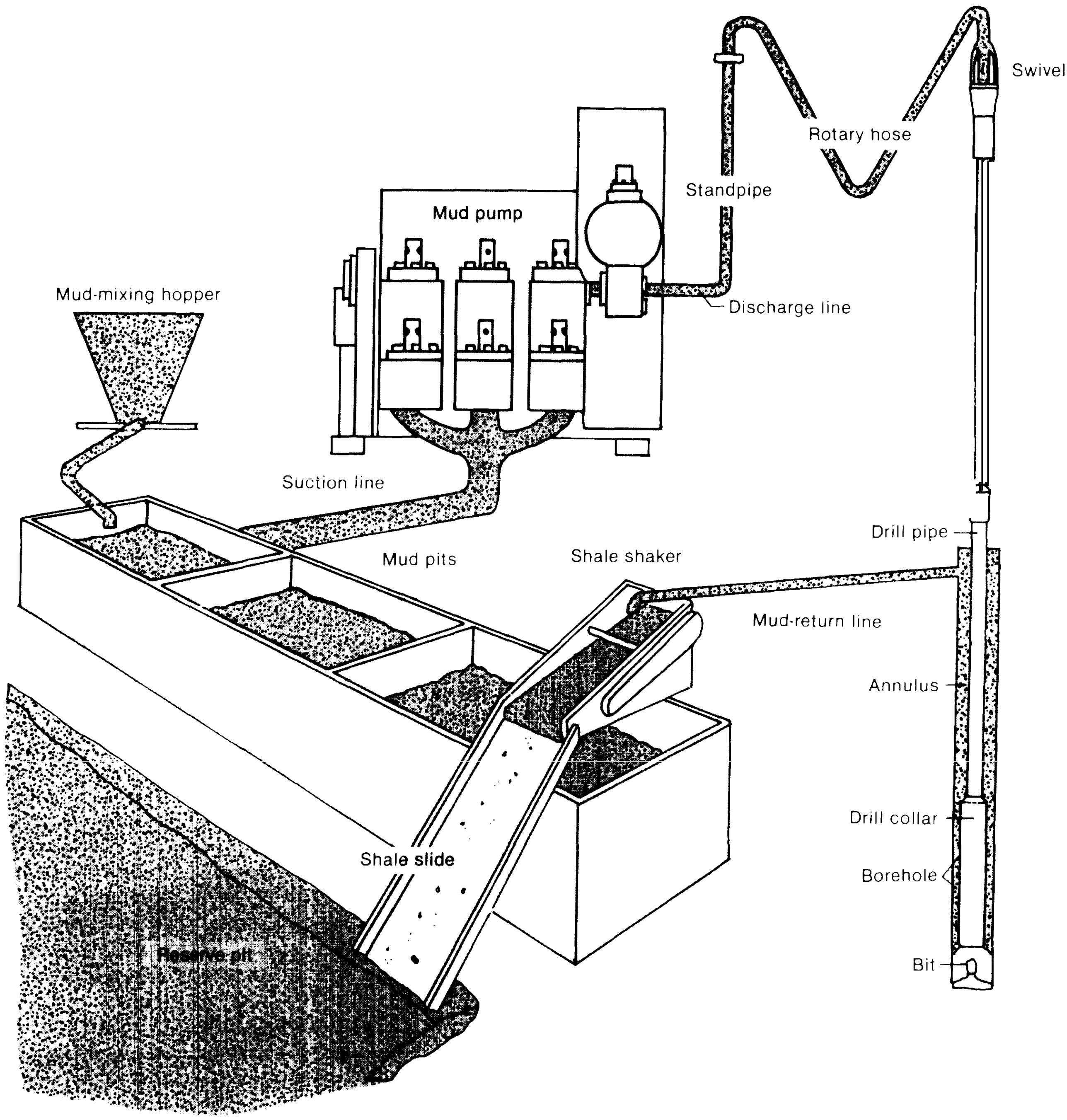
Horizontal Drilling

Horizontal drilling, perfected in South Texas tests, is used to improve well flow-rates, especially for thin formations. A conventional directional hole is drilled to a predetermined depth and then, using another drilling method, the hole is drilled at a 90-degree angle from the vertical, as much

8. Ibid., pp. 2-5 to 2-6.

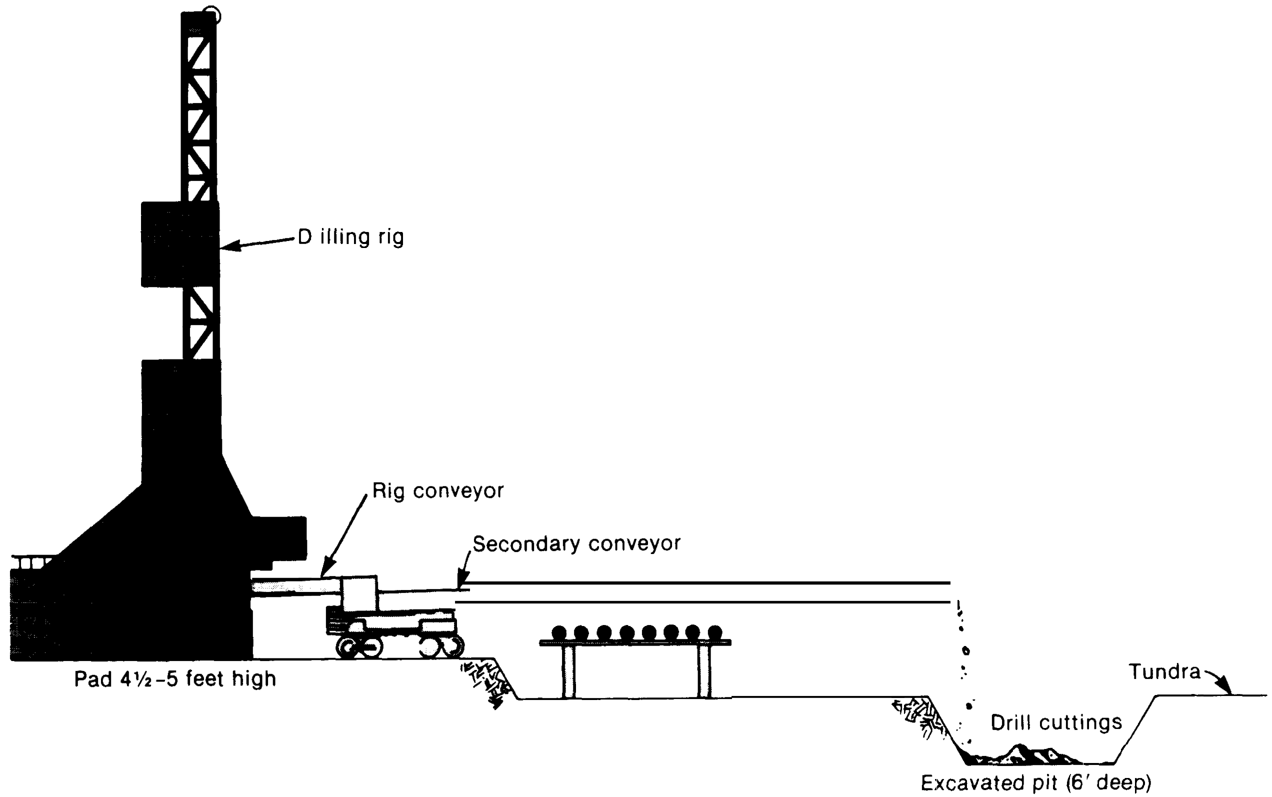
9. Reserve pits are open pits near a well used to hold excess or waste mud made during the drilling operation. The excess mud is sometimes needed to add pressure to a well during drilling. The pits also serve a disposal function.

Figure 2-4.— Drilling Mud Flow Pattern in a Well



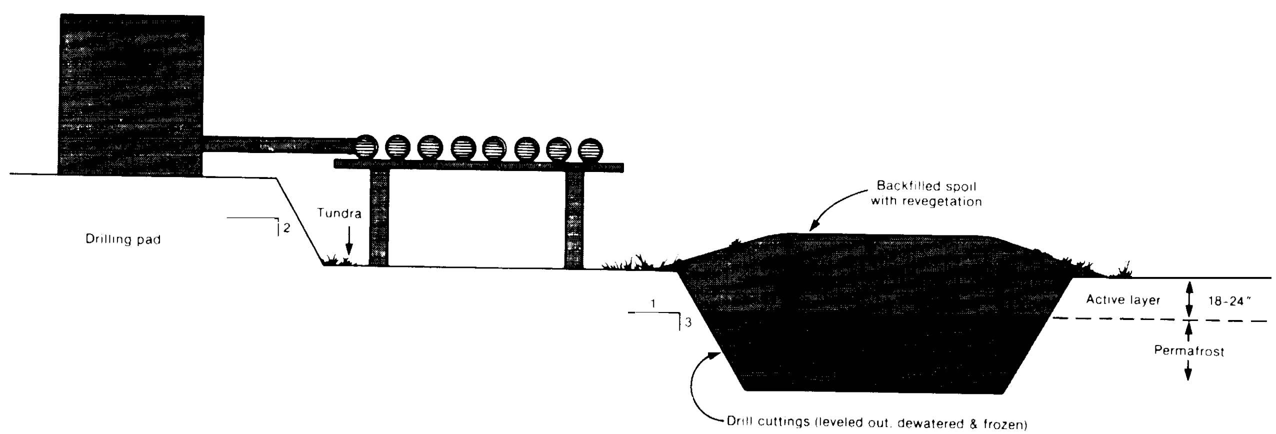
SOURCE: H.R. Moseley, Jr., *Chemical Components, Functions, and Uses of Drilling Fluids*, paper presented at United Nations Environmental Program Environmental Consultative Committee on the Petroleum Industry, Paris, France, June 1981.

Figure 2-5.—Reserve P Operations During Drilling (not o a e



SOURCE: Alaska, Inc. 98

Figure 2-6.—Reserve Pit Operations During Production (not o

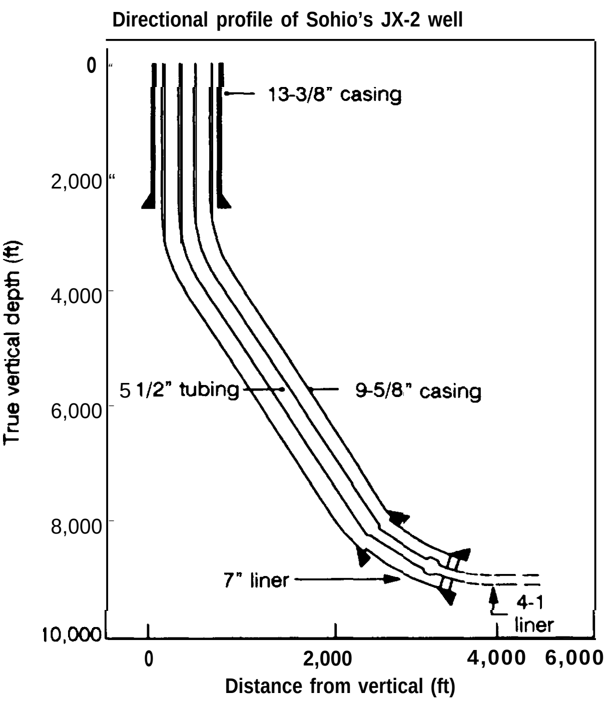


SOURCE: ARCO Alaska, Inc.

as 2,000 feet sideways. In the Prudhoe Bay field, two horizontal wells have been drilled that have substantially increased flow rates and that have recovered hard-to-get oil. Figure 2-7 illustrates one of the horizontal wells drilled at Prudhoe Bay to improve recovery in thin portions of the reservoir near the edge of the field. Horizontal drilling could enhance economic recovery rates in some other North Slope applications.

Both directional and horizontal drilling, however, could have some disadvantageous environmental consequences since oil-based muds are more likely to be used to better lubricate the drilling bit. These oil-based muds are more difficult to dispose of in an environmentally sound manner.

Figure 2-7. -Outline of **a** Prudhoe Bay Horizontal Well



SOURCE: 011 and Gas *Journal,* Feb 17, 1986

Permafrost Protection

The warmth of produced oil flowing through the upper portion of a well drilled through permafrost will eventually melt the permafrost. Hence, the well casing must be properly designed to prevent thaw and subsidence. The area of the melted permafrost may limit close well spacing, as extensive melting could cause subsidence of other nearby foundations. Nevertheless, work on the causes, extent, predictability, and control of permafrost melting problems is continuing in industry Arctic research and development programs. Results of this work could affect designs of future well sites and drill pad arrangements. For example, some closely spaced surface wells (about 10 feet on center) with special casing have been recently instailed at Endicott.

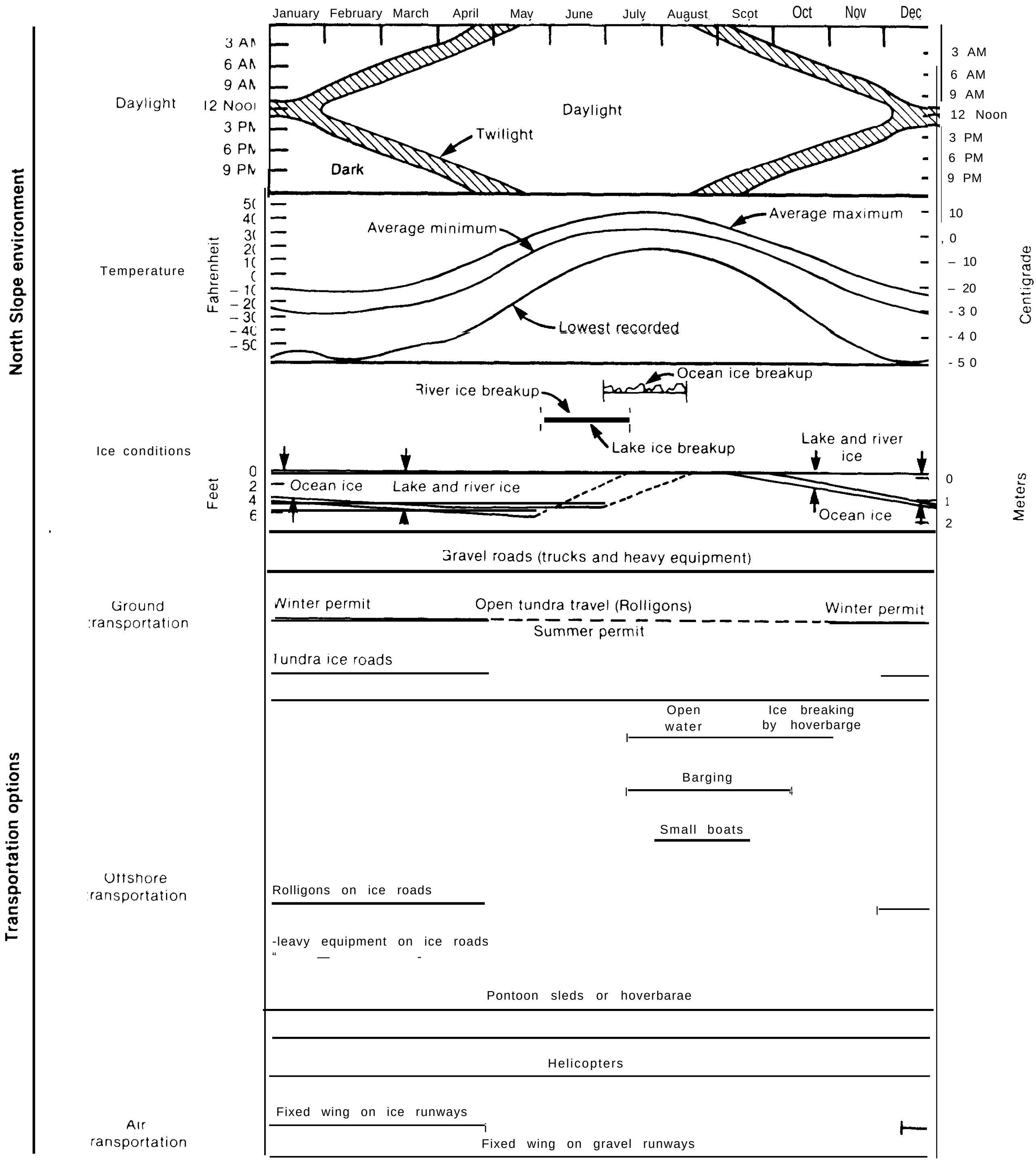
Transport of Equipment

In the early stages of exploratory drilling, transporting equipment is a major activity. To minimize damage to the tundra, winter season movements of heavy equipment on ice roads are preferred. Summer movements may be made by airplane, by barge, or by a specially designed ground vehicle. Vehicles with large, soft tires, called rolligons, have been used, as have air cushioned vehicles. Soft-tired ground vehicle technology is well-established; however, air-cushioned vehicles have not proven very reliable or efficient. Operators usually choose some combination of transport methods to balance cost, environmental protection, and the need for flexibility. Figure **2-8** shows the typical uses of various transportation systems during different Arctic seasons.

New transportation technologies are unlikely anytime soon without more regulatory pressure. Operators may need specific guidelines on the timing or location of movements and on maximum weights, to keep environmental damage down. However, some level of damage to the tundra is unavoidable. Future environmental regulation must evaluate what level is acceptable and what operational controls will assure that operators stay within acceptable limits.

Once a field is discovered and development begins, marine docks and gravel roads needed to receive and transport heavy equipment and

Figure 2-8.—Transportation options Associated with changing North slope physical Environment



SOURCE J. M. Gulick, "Transportation Requirements for Drilling Operations on the Arctic North Slope of Alaska, " *Journal of Petro/eum Technology,* December 1983

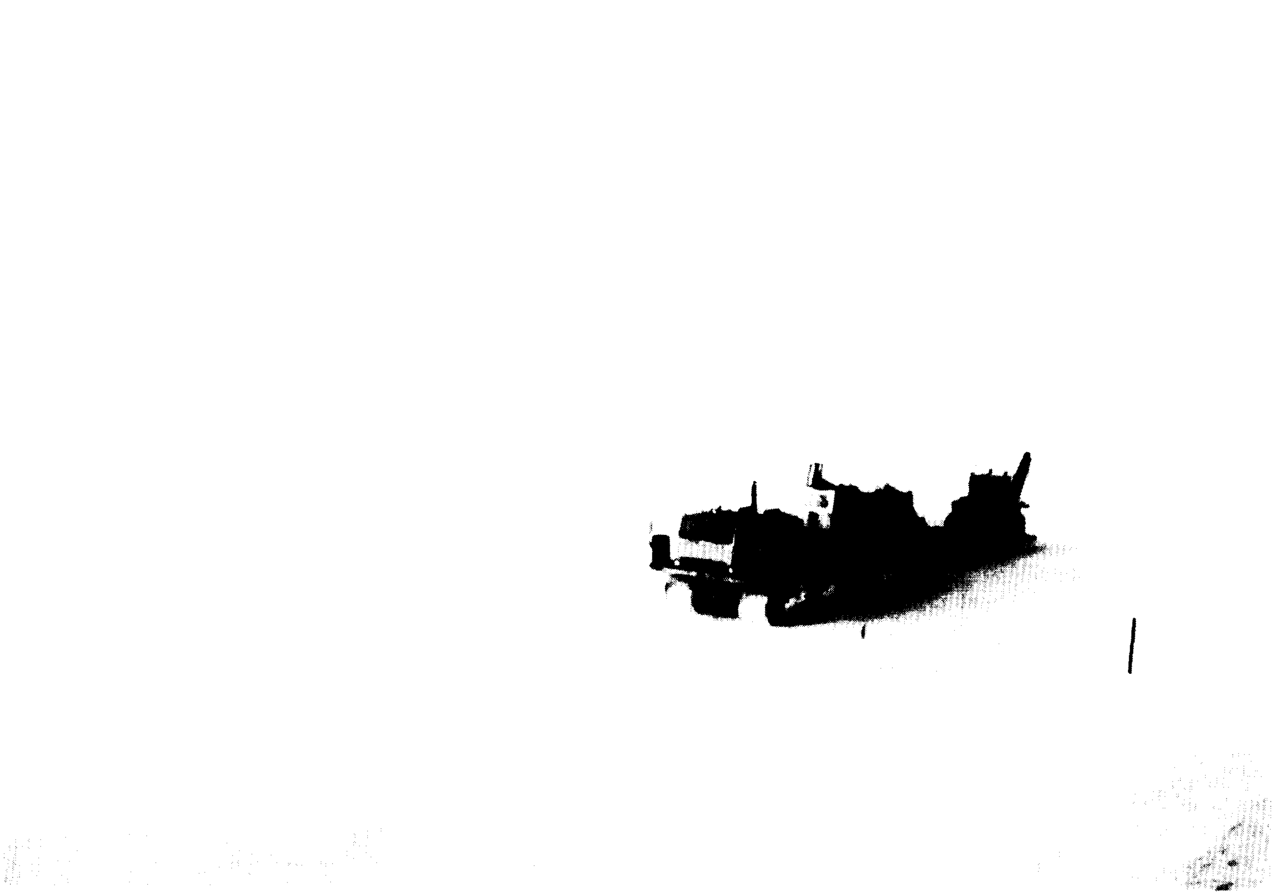


Photo credit *Standard Alaska*

Specialized vehicles **have been developed to protect the tundra during both summer and winter conditions.**

modules to production sites bring more manmade change to the landscape.

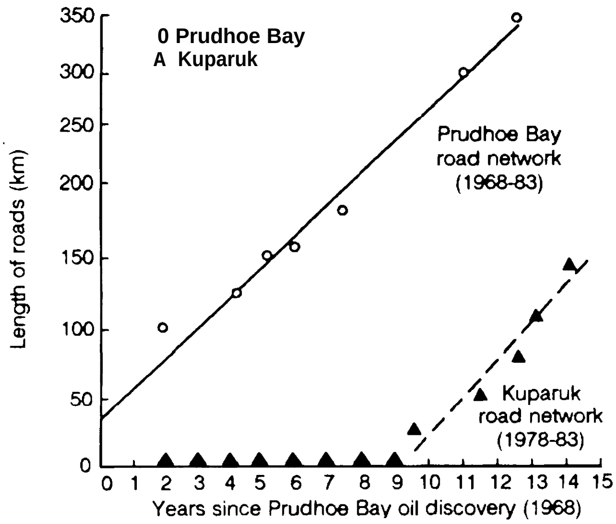
Construction

When a field is developed, onsite construction centers around building gravel pads, roads, culverts, docks, causeways, and foundations (pilings); installing modules; building pipelines, etc. Construction practices have changed over the years since Prudhoe Bay development began–mainly through smaller, more compact drilling pads. However, the typical 5-foot-thick gravel pad, road, or airstrip is reasonably standard and is not likely to be much reduced in size in the near future. Thus, lots of gravel still needs to be mined and moved. Nevertheless, OTA is aware of some insulated gravel pads built in Kuparuk that reduce gravel thickness and, in addition, of the consolidation of facilities to reduce the size of the pads. It is likely that industry's incentive to reduce gravel use is mostly economic. If gravel is easily available and cheap, however, these gravel-reduction measures would not likely be used without regulatory pressure.

Gravel is also used to build roads. Figure **2-9** shows the growth in the length of the road network for both Prudhoe and Kuparuk since they were first developed up through 1983. These data indicate that even 15 years after Prudhoe was discovered, roads were still being constructed at about the same rate as in early years. In 10 years Prudhoe's road mileage tripled. The Kuparuk field is following the same pattern. A corresponding growth in gravel coverage is assumed. While no more recent road coverage data are available, industry claims that gravel coverage leveled off in the last few years.

The continual, long-term growth in the extent of areal coverage of the tundra by manmade facilities follows the gradual and staged nature of the

Figure 2-9.–Growth of the Prudhoe and Kuparuk Road Networks 1968-83



SOURCE: U.S. Army Cold Regions Research and Engineering Lab (CRREL), Disturbance and Recovery of Arctic Alaskan Tundra Terrain," CRREL Report 87-11, July 1987.

development of large oilfields. The first stage of development, when a pattern of primary recovery wells are drilled, can last several years simply because of the large number of wells to be drilled and the economic penalty involved in attempting to complete the drilling quickly by importing large numbers of men and equipment. During this period, the number of gravel pads and the length of the road network grows with the number of wells being drilled. After the initial wells are drilled, after a portion of the field's recoverable resources have been produced, and after the reservoir pressure driving the oil to the wells is somewhat depleted, a second stage of recovery seeks to maintain reservoir pressure by injecting fluids – commonly water, in a "waterflood" operation – into the producing formation. This operation requires additional facilities and (usually) wells for injection, with additional requirements for gravel pads and roads. Further, in a third stage of recovery, heat, fluids, and chemicals are injected into the rock to loosen its hold on the oil not released in the first two stages; these operations may add still further to road and gravel coverage.

Eventually, less geologically attractive drilling targets come into range by using the same infrastructure. New opportunities may open for expanding production through: the development of new, smaller fields; infill drilling; seeking *srrder,* separate reservoirs within the same field; and drilling on the margins of the field where the oil-bearing formation is relatively thin. As these additional drilling targets are pursued, the road and gravel coverage continues to grow.

Wherever construction operations require heavy equipment and major facilities, accidents or carelessness can cause the discharge of pollutants or unnecessary damage to the tundra, natural stream beds, etc. State regulations try to reduce these risks, but some environ mental groups claim that the regulations are not strong enough and that construction over large areas could cause extensive impacts.

Pipelines

Much of today's Arctic pipeline technology was first developed for the Trans Alaska Pipeline System. All developed North Slope fields pump their produced oil by the same kind of elevated pipeline to the TAPS Pump Station #1 at Prudhoe Bay. Refinements have been made in insulation and construction techniques, which make construction more cost-effective. Arctic-grade steel is used for all pipeline vertical support members (VSMs) and other structural components. VSM setting depths are now being adjusted to permafrost characteristics to prevent VSM movement.

Depending on the terrain and excavation necessary, winter-only pipeline construction may be preferred because it offers more tundra protection and, generaily, lower cost. For example, winter work from a temporary ice pad or ice road eliminates some of the need for a gravel construction pad or road parallel to the pipeline; road location becomes more flexible. A gravel access road, constructed later, may follow the pipeline but need not parallel it precisely. (Recent studies of caribou movement through pipeline-road corridors indicate that pipeline and road separation of 600 to 800 feet may be necessary for caribou passage). In addition, VSMs can be more firmly set during the winter anyway, when the tundra is frozen. Summer construction is difficult because heavy equipment cannot

Photo credit BP *America Inc*

Mile Zero, Start of the Trans Alaska Pipeline at Prudhoe Bay. The elevated pipeline rests on structures called vertical support members (VSMs).

operate on the thawed tundra and surface water fills up the VSM holes.

Wastes and Waste Disposal

The generation of wastes during oil production is unavoidable. Waste products can be broadly categorized into three types: air pollutants, liquid wastes, and solid wastes.

The principal air pollutants discharged –mainly by natural-gas-fired turbines and heaters–are sulfur dioxide, carbon monoxide, suspended particulate matter, and nitrogen oxides NOx. Emissions of NOx range from about 60,000 **to** 60,000 tons per year.[10] In comparison, about 600 tons of sulfur dioxide, 17,000 tons of carbon monoxide, and 2,000 tons of suspended particulates enter the atmosphere each year from production activities.[11]

Liquid wastes include reserve pit fluids, domestic wastewater, brine discharges, hydrostatic test discharges, vessel rinsates, excavation discharges, oily wastewater streams, workover fluids, waste oil solvents, and others.

Major types of solid waste include drilling wastes, scrap metal, oily wastes, junked vehicles, construction debris, more than 10,000 used drums per year, and other materials.

10. Larry Dietrick, Alaska Department of Environmental Conservation, Testimony before the Senate Committee on Natural Resources, Oct. 13, 19S7.

11. ARCO Alaska, Air Issues on the North Slope of Alaska, 1987.

Present Alaskan and U.S. Environmental Protection Agency (EPA) regulations govern waste disposal practices. The industry considers its technology for handling waste to be adequate and does not expect major advances in the near future. Environmental groups, however, point to recent charges of violations of the Clean Water Act and consider waste disposal an important unresolved regulatory issue. The Alaska Department of Environmental Conservation has noted that the North Slope has never been subjected to a detailed evaluation of waste management practices or environmental protection measures. it appears that the industry could continue to improve waste handling practices if requirements become more stringent.

Waste disposal methods consist of well injection, reserve pit use, confinement, recycling, incineration, and landfilling. Most waste generated by oil production on the North Slope is either nonhazardous or is currently exempt from hazardous waste regulation under the Resource Conservation and Recovery Act (RCRA). Environmental groups want to see more exempt wastes redesignated as hazardous, but EPA recently concluded that, pending further study, no significant changes are necessary.[13] Existing practice for wastes designated as hazardous is either to recycle onsite or to ship them out of the State for incineration, recycling, or other disposal.

Deep injection of wastes is a source of controversy in arguments about the environmental impacts of current North Slope development and the potential impacts of future development of the ANWR coastal plain. The controversy stems from the contaminants found in the injected materials, the relative lack of monitoring on the North Slope, the lack of detailed understanding of the geology of the coastal plain, and the history of environmental problems associated with deep well injection in the Lower 48. The types of wastes subject to deep well injection in Alaska are produced water and associated oilfield wastes such as mud. The Alaska Oil and Gas Conservation Commission has primary responsibility for regulating deep well injection. State regulations include requirements for casing and cementing wells to ensure initial structural integrity and pressure monitoring to maintain it.

The basic environmental complaint about deep well injection is the potential for migration of the wastes out of the injection zone and for contamination of shallower aquifers or surface waters. Contamination may occur because of structural failures in the injection wells, unforeseen geological pathways for migration, or the existence of undocumented or improperly plugged wells intersecting the injection zones.

The industry claims that the thick permafrost layers on the North Slope are ample protection against “geological” failures, and that the permafrost layer at ANWR will serve this purpose. Despite these assurances, the Alaska Department of Environmental Conservation is concerned about the potential for unforeseen migration of wastes, especially on the coastal plain where detailed geophysical studies and well data are not available. Problems with well failures– either with the injection well, which is usually a converted production well, or with other wells in the vicinity– have been a concern in the Lower 48, where old wells are used for waste injection in many areas, and undocumented and improperly sealed abandoned wells may sewe as pathways to other geologic strata or to the surface. On the North Slope, there are fewer wells, and none are more than 10 or 20 years old. Hence, well failures should not be as big a concern on the North Slope.

Resewe pit wastes, consisting of drilling mud and cuttings suspended in a water or oil base, are another concern. There are over 250 reserve pits in existing developments on the North Slope, with capacities ranging from 4.5 million to 13.5

12. **Letter to OTAfrom Brad Fristoe, Alaska Department of Environmental Conservation, May 12, 1988. Fristoe also noted that DEC is in the process of doing this evaluation, which will be used as the basis for developing appropriate stipulations for new areas like ANWR.**

13. U.S. Environmental Protection Agency, op. cit., footnote 7, p. V21-2.

million gallons of used drilling mud and cuttings and associated wastes.[14] Excess reserve pit fluids are either disposed directly onto the tundra or onto roads, or are injected into subsurface formations. The Alaska Department of Environmental Conservation estimates that 100 million gallons of supernatant (i.e., the liquids forming a layer above settled solids in the reserve pit) are pumped onto the tundra and roadways each year to make room for new drilling waste and to avoid overtopping and/or breaching problems. Additional resewe pit fluids may reach the tundra if reserve pits are breached because of poor construction. Approximately **26** million barrels of muds and cuttings are currently impounded in Prudhoe Bay reseme pits. 15

Liquid reserve pit wastes contain small amounts of metals (e. g., aluminum, arsenic, barium, cadmium, chromium, copper, lead, mercury, nickel, silver, and zinc); aromatic hydrocarbons; and chemical additives. In sufficient quantities and with enough exposure, many of these components of liquid reserve pit wastes can be harmful to aquatic organisms and to waterfowl and other birds (for example, potentially causing bioaccumulation of heavy metals and other contaminants in local wildlife, thus affecting the food chain). EPA notes that the controlled discharge of excess pit liquids has been **a** State-approved practice on the North Slope.

The Alaska Department of Environmental Conservation, the State agency with primary authority to regulate the design, construction, and operation of resetve pits, now requires that discharges meet State water quality standards. Also, the reserve pit must have been stable (no discharges into the pit) for one freeze-thaw cycle before any discharges can take place. Environmental groups assert that these standards are inadequate to protect aquatic species and that effluents have exceeded acceptable levels in the past. Since a National Pollutant Discharge Elimination System's (NPDES) permit does not cover these discharges, EPA is concerned about the long-term effects of discharging large quantities of liquid reseme pit waste on the tundra. While concerned, EPA notes that the existing body of scientific evidence is insufficient to conclusively demonstrate whether or not there are problems resulting from this practice.[16]

A related concern is the potential unintended breaching of North Slope reserve pits, caused by the intense freeze-thaw cycles that can break down the stability of the pit walls, enabling untreated liquid and solid waste to spill onto the tundra. Some observers also question the advisability of underground injection or permafrost burial of reserve pit waste.

OTA has not addressed the environmental impacts of waste generated by North Slope oil production. Generally, neither the fact that these wastes are generated nor the approximate amounts generated is in dispute. However, there is considerable difference of opinion about the environmental impact of the various kinds of air pollutants and liquid and solid waste products.

The environmental community has issued a detailed report documenting what they believe is significant environmental damage caused by development activities. 17 Environmentalists are concerned that air and water pollution and improper management of hazardous wastes threatens aquatic and terrestrial ecosystems in the Prudhoe Bay area and that similar pollution with similar results will occur in ANWR.

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14. Trustees for Alaska, Natural Resources Defense Council, and the National Wildlife Federation, Oil in the Arctic, The Environmental Record of Oil Development on Alaska's North Slope, Januay 1966. January 1966.

15. Standard Oil, Arctic Oil and Gas Exploration and Production Waste, 1967.

16. U.S. Environmental Protection Agency, op. cit., footnote 7..

17. Trustees for Alaska, Natural Resources Defense Council, National Wildlife Federation, Oil in the Arctic: The Environmental Record of Oil Development on Alaska's North Slope, January 1966.

The oil industry, for its part, has attempted to demonstrate that despite some unavoidable consequences of development, “there is no evidence to support the allegation of widespread pollution or to justify claims of significant adverse environmental impact. “[18]

The Environmental Protection Agency is cautious in its recent report to Congress[19] but is generally less alarmed than the environmental community about pollution problems and is also less sanguine than the oil industry that there are no North Slope pollution issues of concern. EPA is concerned primarily about the discharge of supernatant onto the tundra and roads, suggesting that further study of impacts is needed.[20] The State of Alaska has recently adopted more stringent effluent limits and has suggested that zero-discharge of industrial wastewater streams should be carefully considered for ANWR.[21]

Water

Substantial amounts of fresh water are used in drilling and other oil production activities. Water supplies in the Arctic are not easily tapped year-round, and some convenient supplies are environmentally unacceptable to use. It is therefore prudent to first reduce water consumption to the most reasonable practical level. Technologies for ensuring environmentally safe water supplies are important. The methods used by industry include trapping and melting snow; insulating small, non-fish-bearing lakes; flooding gravel pits; and desalting seawater.

Among the most abundant sources of water are the gravel extraction pits that have been converted to water reservoirs. Water for many of the Prudhoe Bay well operations is collected and hauled from the Put River pit, a former gravel source that has been flooded and now sewes as a year-round water source. Similarly, Mine Site C serves as a water source for the Kuparuk oilfield; this pit is replenished annually with overflow from the Ugnuravik River during break-up.

Desalination of seawater is sometimes a practical option for operations near the coast. If the operation is in the winter, an ice road is constructed to **a** point where the seawater is not frozen to bottom, the desalination operation is set up there, and fresh water is trucked to where it is needed. This method was used for operations on Challenge Island #1 in the winter of 1980-81 and for Alaska Island #1 in the winter of 1981-82. Desalination of seawater was also used for all the wells drilled from Endeavor Island and Resolution Island and for most of the Niakuk wells. A large desalination plant has been installed at the Endicott field to support production operations. Conoco also used desalination for their Milne Point operations; however, it desalinated water from a 3,000-foot-deep, brackish water, underground aquifer rather than from seawater.

Many operations have had reasonable access to deep lakes. For example, deep lakes in the Sagavanirktok River delta were used for the first three “Sag Delta” wells in the 1970s. Two deep lakes were approved for water sources for operations to the west of the Sag Delta in the winter of 1981-82. No fish were found in either lake, but draw-down restrictions were still applied to protect the few that might have gone undetected.

Deep holes in a river or an oxbow lake are also valuable sources of water. The Alaska Department of Fish and Game applies withdrawal rate, filter size, and draw-down restrictions to ail river sources to protect fish. Water for the Niakuk #1 well, for example, came from a deep hole in the Sagavanirktok River. Big Lake, the water source for Standard’s Base Operations Camp at Prudhoe, is an example of a lake that has been insulated to minimize freeze-down. For several years it was insulated with styrofoam. Since 1983,

18. Standard Alaska Production Company, Assessing the Impact of Oil Development on Alaska’s North Slope: A Rebuttal of the Claims of The Trustees for Alaska, The Natural Resources Defense Council, and the National Wildlife Federation, February 1988., p. 2-6.

19, U.S. Environmental Protection Agency, op. cit., footnote 7,

20. Ibid., p. V21-3.

21. Dietrick, op. cit. footnote 10.

however, the lake has been insulated by erecting snow fences that collect drifting snow for insulation.[22]

Production Facilities

Production facilities designed to operate for long periods of time with minimal attention must be installed onsite. Directional drilling minimizes the area needed for drill pads and support for wellheads. Characteristics of the oil reservoir will determine the number and location of wells needed, but wellheads can be clustered reasonably close together on individual pads. Wells are needed for both oil production and injection of fluids to stimulate flow. Soil types and permafrost melting characteristics determine the minimum spacing and required support of wellheads on the North Slope.

Production facilities for Arctic use are usually built offsite in large modules (from 500 to 5,000 tons depending on service and distance from dock), in locations such as Washington, Oregon, California, and the Gulf Coast and are moved by barge to coastal docks and then onto pilings and pads at the site. Many kinds of modules are needed to complete a production complex. These include oil/gas/water separation plants, gas injection plants, waterflooding plants, control stations, power-plants, etc. In addition, many support modules are needed, including living quarters, maintenance shops, storage and administrative areas, water and waste treatment, etc. The production field, in time, becomes a network of facility modules resembling a small factory town built on pads and pilings and protected from the harsh environment. Roads, airstrips, and marine docks complete the compiex. All these facilities require considerable acreage and thus need a large source of foundation material to build the 5-foot-thick gravel pads commonly used.

Production facilities are added and modified over time as an oilfield is further developed, with the addition of enhanced recovery systems as needed. Each change is usually accompanied by some increase in size, space, and other material needs.

Summary

Arctic oil and gas technology has evolved over the past decade into today's effective and mature industrial system with its accepted commercial operating practices. The recent development of North Slope fields such as Kuparuk and Endicott are the result of this maturity, and any future ANWR development under similar economic and environmental constraints would probably resemble closely these two fields. The industry is confident that this likely extension of current designs and practices is sound development and offers adequate environmental protection. Some environmental groups, however, contend that today's practices are not acceptable for development of ANWR.

While Arctic oil drilling and production technology has matured, the practices for using the technology have improved even further. These improvements have occurred because of both economic and environmental concerns. Practices are likely to continue to improve in ANWR – if it is developed – if economic factors warrant or if environmental requirements are strong, OTA has not evaluated the specific improvements that may reduce environmental impacts, but it appears that extensive debates about environmental protection versus economics will continue if ANWR is leased. Environmental groups have specific concerns that will need to be resolved during the development of regulations for any development that may occur.

22. Standard Alaska Production Company, letter to OTA, Feb. 23, 1988.

TECHNOLOGY APPLICATIONS FOR THE ARCTIC NATIONAL WILDLIFE REFUGE

If the Arctic National Wildlife Refuge's (ANWR) coastal plain is leased, the oil industry will apply its broad technological and practical experience in Arctic oil development to the specific conditions of ANWR. The industry generally claims that ANWR exploration and development will look pretty much like the most recent operations elsewhere on the North Slope.

ANWR Special Conditions

OTA has attempted to identify any special or unique conditions of the ANWR coastal plain, as compared to Prudhoe Bay and other North Slope areas, that would affect the technology used or practices followed for petroleum development. The primary data source was our Anchorage workshop and subsequent submissions from industry and other participants at the workshop, as well as extensive comments from industry and environmental organizations that reviewed an earlier draft of this report.

Topographic Relief

The southern part of the ANWR coastal plain has moderate topographic relief, with gently rolling foothills. In contrast, Prudhoe is a very flat thaw-lake plain. ANWR's topography has advantages in that there may be fewer problems with standing water and that there may be better elevated sites for facilities. But there are also disadvantages to the greater relief, including the potential for more problems with channeling and erosion (especially if and when east-to-west roads are built, crossing many streams and requiring attention to drainage patterns) and problems with building roads or locating facilities.

For example, in ANWR, a pipeline can cross gullies and hills more or less in a straight line, but a pipeline access road will need to snake along some surface contours to avoid extensive excavation and filling. A road may also create more environmental problems than a pipeline, especially problems related to drainage, mining gravel, etc. Airstrips need to be reasonably flat; hence, suitable locations in the foothills of ANWR would be more difficult to find than they are at Prudhoe, and, even then, some cutting and filling would have to be done. The same considerations are true for a camp or production facility in ANWR. At Prudhoe, a camp or an airstrip can go almost anywhere that is dry and, for a winter-only exploration well, an airstrip can be constructed even on a convenient frozen lake.

Sea Ice and Port Sites

In general, potential ANWR port sites have deeper water than do Prudhoe sites. Deeper water eases the problem of building docks and means the length of causeways, needed to reach the water depths of about 8 feet required for barges and other shipping, could be reduced. Ice conditions in potential ANWR port sites are generally equivalent to those in the Prudhoe region except in the extreme eastern part of ANWR, where more severe offshore ice conditions may cause problems for shipping.

Gravel Availability

Extensive gravel deposits are located within the ANWR coastal plain, a situation that simplifies finding gravel for construction. Gravel availability in ANWR is similar to that at Prudhoe but better than at Kuparuk.

Permafrost Layer

Some experts believe the permafrost layer in ANWR is thinner than at Prudhoe, but the evidence is sketchy. Permafrost thickness may sometimes affect aspects of well drilling (e.g., the starting depth for directional drilling), but other factors could govern drilling decisions and may be more important. This uncertainty will be resolved only with actual drilling. The permafrost situation in ANWR, however, probably will be handled in much the same way as it is at Prudhoe Bay.

Sites for Deep Injection of Wastes

Knowledge of subsurface geologic conditions for deep well injection is sketchy at this time but is important to locating acceptable sites for waste injection. Prudhoe is considered to have good conditions for containing deep injected wastes. Conditions in ANWR are not defined, although experts disagree about the interpretation of existing evidence. Industry is reasonably confident that suitable sites can be found; however, different experts have different opinions on the extent of tests and study necessary to confirm a **"suitable site. "** This ambiguity is one of the chief concerns of some environmental groups.

Potential Developed Area

The ANWR coastal plain covers about **1.5** million acres. This area is about twice the size of the general region covering the Prudhoe, Kuparuk, Lisburne, and Endicott fields, the major producing North Slope fields. The U.S. Department of the Interior has identified 26 faulted structural prospects within the plain. The mapped and areal extent of these prospects is based on structures defined by seismic data. Thus, the prospects contain potential petroleum traps, but the extent of producible oil is unknown. If these prospects contain oilfields, the largest prospect (227,000 acres) would be similar in acreage to Kuparuk and the second largest (about 130,000 acres) would be roughly the area of the Prudhoe Bay field. All 26 prospects are of a size that could contain fields at least the areal size of the smaller known North Slope fields. While these comparisons are not predictive, they are indicative of the possible extent of surface development if major ANWR discoveries are made. The extent of land coverage for development at ANWR would then likely resemble Prudhoe and Kuparuk and perhaps some smaller fields as well. If several of ANWR's prospects contain economically recoverable oil, the total developed area may be equal to or greater than the developed area of all existing North Slope development.

Water

Whereas industry has made extensive use of existing surface water supplies at Prudhoe, ANWR has few large, deep lakes. Substantial water for ANWR development would probably need to come from other sources. Industry could resort to excavating pits, melting snow, and other water collection techniques, but these activities will likely prove to be more extensive in ANWR than they were at Prudhoe Bay. Industry has also claimed that 12 of the large rivers in the ANWR coastal plain could be sources of water in summer. Environmental groups believe that water supply will require regulatory attention to minimize impacts.

Wildlife

Approximately 200,000 caribou of the Porcupine Caribou herd inhabit the Arctic National Wildlife Refuge from roughly mid-May to late July. The ANWR population vastly outnumbers 15,000 - or-so caribou of the Central Arctic Herd that reside year-round in the Prudhoe Bay area; this contrast is probably the most dramatic for wildlife populations in the two areas. Both herds have been increasing in size in recent years. The degree to which the Porcupine herd will be able to acclimate to development compared to the Central Arctic herd is still being debated. The reintroduced musk oxen population in ANWR now numbers about 500 animals; none live in the Prudhoe Bay area. The number of bears and wolves has declined in the Prudhoe Bay area, largely because they are not as tolerant of man as are some other species. Total North Slope wildlife populations however, are not believed to have diminished.

Overview: ANWR Technologies and Practices

The technologies used to explore for and possibly produce any petroleum resources in the Arctic National Wildlife Refuge will most likely resemble those already in place on other North Slope fields. Technology now in use at the most recently developed sites, such as Endicott, has been built to rigid industry design standards for the Arctic environment and is efficient and effective for producing oil from these fields. The industry operators forcefully claim that the technology has been installed and operated with **care to avoid unnecessary environmental** impacts. In opposition to this claim, the environmental community points to a number of instances where habitat has suffered damage.

OTA has not analyzed the history of accidents, spills, violations, etc., on the North Slope[23] but notes that future regulations will need to be based on an objective analysis of these environmental concerns.

Only oil has been produced from Alaskan North Slope fields to date. While substantial gas reserves have been delineated, no system to transport gas to the major markets has been built. Several methods have been proposed to transport gas but favorable economics and other concerns have prevented their adoption. The technology for Arctic gas production, however, has been in use at Prudhoe where the world's largest gas compression facility is operating and considerable gas handling capability is in place to inject the gas back into the formation.

Most industry experts believe that no major technological breakthroughs are needed to safely and effectively explore for and produce oil at ANWR. They say that the production systems have advanced in practice during the past two decades of Arctic work to an acceptable level, which they believe is demonstrated by smooth and reliable plant operations.

The level of environmental damage that has occurred, however, is vigorously debated. Many of the technological advances in the past 10 years have concentrated on improving operational efficiency. Several of these advancements also appear to reduce environmental impacts, but specific measurements of reduced impact are not readily available. Some advancements include improved waste handling, less toxic discharges from drilling, and reduced needs for gravel pads and roads with possible reduced intrusion on wildlife. Other technological advances have led to more cost-effective operations in the Arctic. These advances include substantial automation of oil field operations, more efficient sub-assembly of modules, and systems for controlling permafrost melting. Modules for production plants are built in complete units in the Lower 48 and moved in large pieces on barges to the North Slope, thus eliminating the need for large and costly construction crews working onsite.

More environmentally important than developing new technologies for use in ANWR is controlling the practices used to apply the existing ones. Operating practices include: transportation of equipment; construction of drilling pads, pipelines, and facilities; selection of drilling techniques; controlling the effects of permafrost melting; and containing and disposing of drilling fluids and other waste products.

Equipment transportation involves moving many very large heavy pieces of equipment with large vehicles over long distances. The tundra is very fragile, and it does not support much weight in the summer months. The construction of pads, pipelines, and facilities are also major activities on fragile ground; a considerable amount of gravel must be mined which can alter the landscape extensively. Drilling techniques can be selected to minimize surface disturbance if wells can be closely clustered on the surface and if rigs are easily moved or set up. Permafrost consideration is critical because uncontrolled melting may cause foundations or supports to fail, resulting in accidents, spills, etc. It is also important to keep any waste products contained and/or to dispose of them properly.

Impacts: ANWR Technologies and Practices

Key technologies and practices with potential for significant environmental stress were analyzed in an OTA workshop held in Anchorage, Alaska in November 1987. The following discussion expands on the workshop's views.

Exploratory Drilling

Exploratory drilling practices in ANWR will likely follow those used in recent exploration wells on the North Slope. Considerations that may affect the environment include the ability of drillers to

23, A comprehensive discussion of environmental impacts on the North Slope from the environmental community viewpoint appears in "Oil in the Arctic: The Environmental Record of Oil Development on Alaska's North Slope, " Natural Resources Defense Council, January 1988. Similar discussions from the industry view appear in "Current ANWR Environmental Issues, " The Standard Oil Co., August 1987; "Assessing the Impact of Oil Development on Alaska's North Slope, " Standard Oil Company, February 1988; and "Alaska Oil and Gas Association Response to Oil in the Arctic by Speer and Libenson, January 1988, " February 1988.

move rigs and camps to the site, to build temporary pads and other facilities, and then, when work is done, to remove all material with no damage to the tundra. Practices and equipment have been developed over the years in the Arctic to protect the tundra, but economics and work conditions have sometimes ruled out the ideal approach. In any case, careful set-up and quick removal are keys to environmentally acceptable exploratory drilling. Careful set-up probably can be controlled by regulation, but quick removal will depend on conditions– not always predictable– encountered while drilling.

Techniques have been developed to build ice roads, ice pads, and ice air strips for winter-only drilling in the Arctic. Moreover, water can be obtained from melted snow, and reserve pits can be encapsulated. In these ways, the impacts of a drilling operation can be readily removed, and there could be little need for gravel excavation or any other disturbance of the tundra except for reserve pits. However, winter-only drilling can have economic and operational disadvantages. Given the **added time and costs of winter-only drilling, industry argues** for flexible regulations so that they can judge when such practices are truly warranted. Industry also notes that a small risk of a blowout is always present and, if it occurs, the extra time needed to drill a relief well could extend into the thaw season. Environmental groups argue, however, that, given the unique nature of ANWR, very stringent regulations should be applied with minimal flexibility.

Drilling Systems

Most existing Arctic drilling technology likely to be used in all ANWR exploration, production, workover, and service well drilling has been developed to the point of acceptable efficiency. Use of the most advanced of these systems also may lessen some environmental impacts. For example, directional drilling and the close spacing of wells on the surface contribute to the ability to design fewer and smaller drill pads and thus to reduce the quantity of gravel needed and the spatial impact of development. Directional drilling technology is well developed and continues to improve. In recent years, the development of measurement-while-drilling (MWD) systems,[24] computer analysis, and improved survey techniques have significantly improved directional drilling efficiency and directional limits (the angle off vertical that is possible). Improvements expected in the next decade include more comprehensive logging tools deployed during MWD operations, better directional control from the surface, and improved mud systems for reduced torque or drag.

All of these advancements together may lead to closer spacing of wells on drill pads, and to clustering of larger numbers of wells on each drill pad. However, there are many other factors too that will determine the layout of pads and facilities at ANWR. Well spacing will be determined by a combination of economic, environmental, operational, and safety considerations. Specific conditions such as reservoir depth, well drainage area, and permafrost thaw subsidence also will be factors. Recently drilled wells at Kuparuk and at Prudhoe are spaced as close as 30 feet apart; on the Endicott gravel islands, wells are now even more compact, spaced at 10-foot intervals. Depending on actual conditions, ANWR wells would likely be spaced within this range.

Mud Systems

The most likely mud systems in ANWR are those that have been successful in other North Slope fields. Weighted lignosulfonate, polymer, and oil-based mud have applications in Arctic regions but are not unique to Alaskan oilfields. The majority of North Slope drilling operations use water-based polymer and lignosulfonate muds. However, some drilling operations such as directional, high-angle, and horizontal drilling require the lubricating properties of oil-based mud. Also, some coring [5] operations require oil-based mud to lubricate the bit cutting the core and to minimize damage during drilling. Generally, oil-based mud is used for drilling only the short productive intervals in non-conventional wells.

24. These systems feature remote sensors that measure angle, location, speed of penetration, and other factors at the bottom of a hole and transmit that information to a driller at the surface without interrupting drilling operations.

25. The practice of cutting and retrieving a cylindrical piece of the formation during the drilling operations.

Water-based mud usually would be used until the oil-based mud is required. The anticipated advances from horizontal drilling will possibly increase the need for oil-based mud and, if this occurs, greater attention to suitable disposal of oil-based systems may be needed in ANWR. Environmental groups consider the disposal of mud to be an issue worthy of closer attention.

It is not clear whether more stringent requirements for disposal of used mud and cuttings would be necessary in ANWR. Industry asserts that present State of Alaska regulations are adequate and can be followed in ANWR without much trouble. Alaskan regulations–as they apply in a permafrost region such as ANWR – require that the drill solids be de-watered or frozen in place, covered with a membrane to prevent future fluid entry, and covered with gravel and organic soils of sufficient depth to insure that the drilled solids remain permanently frozen. The liquid drilling mud then would be injected into a subsurface zone. This process is commonly called annular injection because the drilling mud is displaced down the annulus between the surface casing and the production casing. Dedicated injection wells are also used. Some environmental groups have substantial concerns about these practices; they advocate higher standards for waste management in a wildlife refuge.

Fresh Water Supplies

Several techniques for supplying fresh water, developed and used at North Slope production areas, are likely to be used in ANWR. These techniques include: creating deep pools that will not freeze to the bottom in or adjacent to rivers/streambeds, creating deep pools in lakes, desalinating seawater, erecting snow fences to trap snow (and then melting it using snow melters), insulating lakes to keep them from freezing to the bottom, and converting gravel extraction pits to reservoirs. For exploratory sites, water could be hauled from approved locations if necessary. OTA has not evaluated the extent to which the effects of these practices have been monitored.

How much water would ANWR need? Standard Oil Company submitted to OTA the following data as typical of the water requirements that may be expected in ANWR exploration.

- 414,000 gallons of water per mile for construction of an ice road; 4,200 gallons of water per mile for daily ice road maintenance.
- 2,500,000 gallons of water for construction of an ice airstrip;
- 2,100 gallons of water for daily maintenance. (Volume would be less if airstrip is built on a frozen lake.)
- 25,000 gallons of water daily for drilling rig and domestic use.

For a typical exploratory well with about 150 days of operations and about 5 miles of roads, Standard Oil estimates that total water consumption would be about 10 million gallons. The U.S. Department of the Interior estimates 15 million gallons for a similar exploratory well.

For development operations, water requirements would depend on the size of the development, the number of wells, and the size of the support camp. Industry claims that ANWR operations would most likely use developed water reservoirs from former river channels deepened by gravel extraction or from the desalination of seawater. Water withdrawn from gravel extraction pits during the winter would be quickly replenished during the subsequent spring snowmelt. Currently, Prudhoe Bay development drilling operations consume approximately 630,000 gallons of water per well.

The potential for water supply techniques to **damage the environment** would need study at each site. The environmental groups may well urge regulatory attention here.

Gravel Pads/Roads, etc

The most likely number, size, and configuration of **gravel pads** for an ANWR development are difficult to estimate until an actual discovery is made and delineated. Industry believes, however, that less gravel will be required for an ANWR development with today's technology and experience than was required for early Prudhoe Bay development. Most others would agree, assuming equivalent field characteristics and production systems. Improvements in directional drilling techniques and permafrost technology, along with the use of larger, more consolidated and vertically-layered equipment modules and more space-efficient facility designs tend to reduce gravel pad requirements. Improvements in the design of compact pads have already been realized in recent North Slope developments such as Lisburne and Endicott.

Gravel pad design is also affected by the pad's location, insulation needs (to avoid permafrost thawing), stability requirements (to account for permafrost subsidence and requirements for weight support), and site-specific soil conditions.

Characteristics of the actual oil reservoir, however, are the most important factors in determining the most cost-effective design for the total number of wells, the number of wells per pad, and the pattern of positioning well pads over the surface. For example, while compact pad design improvements are evident in Kuparuk, the actual area covered by gravel pads, roads, etc., as a ratio of total field production is much greater in Kuparuk than Prudhoe because Prudhoe is a more productive field with much thicker pay zones, producing higher per-well flows and higher per-pad production. The total area of tundra that would be covered by gravel in ANWR depends most upon whether an ANWR field has characteristics more similar to Prudhoe, with thick, productive reservoirs, or to Kuparuk with relatively thinner and less productive reservoirs.

Pipelines

An elevated pipeline mounted on vertical support members (VSMs) spaced about 60 feet apart with expansion loops every 1,000 feet would be the most likely pipeline design in ANWR. However, Arctic experience in the use of buried ambient temperature lines is growing and may be another option for ANWR, depending on oil characteristics and production rates, environmental impacts, and economics. Depending on soil conditions, it may be desirable to bury the pipeline in some areas and elevate it in others.

Winter pipeline construction practices are likely to be used in ANWR unless a road parallel to the pipelines is needed for other reasons, in which case the road could support summer pipeline construction. The industry favors flexible regulations to allow it to use the best practices for specific circumstances. On the other hand, environmental groups are concerned about excessive flexibility in regulations, especially in sensitive areas.

Construction of Culverts

Construction at ANWR, as with any major petroleum project, is likely to create extensive environmental disturbance, and regulatory controls may be needed, The OTA workshop examined the construction of docks, piers, and culverts– all needed in any plausible ANWR development scenario.

Culvert design and construction, for example, carries several environmental concerns. In the Prudhoe Bay area of the North Slope, drainage patterns are poorly defined and are controlled more by the growth and melting of ground ice than by erosion and transport of sediment. Thus, consideration of thermal as well as hydraulic aspects of drainage design is necessary. ANWR topography is such that drainage design will be very important.

The predominant minor drainage structures are culverts. Culvetts must be designed to prevent thaw settlement of the foundation and to support side loads imposed on the culvert. When culverts are built, unstable material is usually excavated and replaced with thaw-stable material.

Environmental groups point to various past problems with culverts. The most common problem is the restriction of fish passage, which may result from excessively high water velocities or from culvert outlets perched above the streambed. Another problem is pending when culverts are improperly located or placed too high in an embankment and large ponds are formed. Pending has adverse effects on vegetation and, depending on depth, may either increase or decrease the seasonal thaw. These problems can be minimized by careful planning and location of drainage works and by the use of good maintenance programs.

Technological Change

OTA concludes that technologies likely to be used in the ANWR coastal plain will closely resemble the most recent North Slope developments such as Kuparuk or Endicott. Major changes in technologies are likely to be too slow and gradual to alter the big picture for ANWR development, but a number of factors are involved in this judgment: the definition of technologies considered, assumptions about the development process, and observations about past technological change and the underlying causes.

Definition of Technologies Considered

OTA defines technologies to cover all of the equipment and facilities that are used for exploration, development, and production. Technologies are of course dominated by large structures, pipelines, pumps, machinery, etc., to the extent that change in one small part would not have much effect on the whole.

Development Assumptions

OTA assumes that if ANWR is developed, the industry will be just as able to select technologies that best suit its economic needs as it has in the past. OTA also assumes that economic and other constraints will not change drastically. Since ANWR is similar to Prudhoe and Kuparuk, there is little incentive for industry to make major changes in technologies that have worked well in these two other fields. With few new problems to solve, industry will tend to model the next generation of technology after the best of the past. Of course, new regulatory demands could force consequent technological change at any time.

Past Technological Changes

In two decades of Alaskan North Slope oil development, technological advancement has been fast and many systems have reached what the industry considers a mature state. Standard geotechnical design practices for Arctic permafrost conditions have been developed and tested for well casing, roads, facility foundations and pipeline supports. Low-temperature needs are now filled in metallurgy, elastomers, lubricants, and fuels. Modularization of facilities and their transportation can be also considered mature technology. Maturity also applies to those systems adapted from other regions to meet severe Arctic conditions as well as many systems specifically designed to solve unique Arctic problems.

OTA concludes that these technologies will continue to advance, but at a much slower pace because the need for improvement is less urgent. Just a few years ago when oil prices plummeted, cost reduction pressure was heavy as industry re-evaluated the amount of investment that could be justified for future production. Some drilling technology advancements probably can be attributed to the need to reduce drilling costs. This pressure from low oil prices has begun to level off in the past year and will probably continue at a low level. However, there is evidence that industry-wide technological change will continue to occur; and when developments elsewhere can be applied to the North Slope, they will be. This pressure for technological change will probably be the same in the future as in the past but, when combined with the other elements of change, the likely rate of change is likely to be lower in the future.

In OTA's view the challenge of ANWR development, if it occurs, will be met by the petroleum industry with proven technologies rather than with innovative ones. A big unknown, however, is outside forces – such as major regulatory pressures– that could require changes in technologies. Such changes might come first in methods of waste handling or management or in methods to reduce intrusion on wildlife habitat.

Schedule

Projecting a likely schedule for ANWR development is hard. Much depends on the timing and sequence of events. Table 2-3 shows some actual development histories for North Slope oil fields and two current ANWR estimates.

Judging from Table 2-3, the ANWR schedule is likely to be at least as long as the ARCO and Department of Energy estimates of 10 to 12 years from lease sale to production start-up, and possibly even longer. Considering that it will probably take a few years before a lease sale is completed, a reasonable schedule would be 15 years from today for the start of any substantial production. If a major field is discovered in ANWR (equivalent to Prudhoe or even Kuparuk), one could expect production to span at least 25 to *30* years from start-up. If ANWR development follows common experience in other oil producing regions, and if regulations, technology, and

Table 2-3.—Typical Development Schedules

Development	Years from lease to discovery	Years from discovery to start-up	Total years lease to start
Prudhoe Bay	3	9	12
Lisburne	3	18	21
Kuparuk	4	12	16
Endicott	9	9	18
ARCO Estimate for ANWR[a]	3	9	12
EIA Report[b] (assuming existing procedures)	3	7	10

SOURCES: 1. ARCO Alaska, Inc., *Arctic National Wildlife Refuge Coastal Plain 1002 Area: Development Scenarios and Environmental Issues*, Attachment to written statement of Jim Weeks, Manager, Prudhoe Bay Field Operations, before the U.S. House Subcommittee on Water and Power Resources, October 8, 1987.
2. Energy Information Administration, *Potential Oil Production from the Coastal Plain of the Arctic National Wildlife Refuge*, Revised Edition, SR/RNGD/87-01, October 1987.

price-cost relationships allow, more exploration and discoveries will follow, spanning many years. At Prudhoe, new fields are continuing to be brought into production some 20 years after the first strike.

Experience indicates that, should ANWR exploration proceed and lead to discovery of a major oilfield, commercial petroleum activities on the ANWR coastal plain are likely to continue into the middle of the 21 st century. It is also likely that development will use enhanced recovery techniques after production has started.

ANWR Development Scenarios

OTA investigated two plausible scenarios for ANWR development, one done by the Department of the Interior in its LEIS (see Figure 2-10) and one done by ARCO in a presentation to the House Subcommittee on Water and Power Resources in October 1987.

Neither of these two scenarios presents complete details on all major exploration and development steps or activities. For example, neither provides the number of exploratory wells that may be drilled on lease tracts. The ARCO scenario gives only sizes and gravel pad estimates for the drill pads but not for the gravel pads for facilities, pipelines, roads, docks, etc. The ARCO scenario does give an estimate of total affected area. The LEIS details a series of pad areas and gravel requirements but does not relate these to specific facility descriptions, functions, and locations. The LEIS assumes the development of three commercial fields with a total of 3.2 billion barrels of recoverable oil reserves but does not give **a** reserve figure for each of the three fields. It also does not estimate the production rate. It appears that two of the LEIS prospective areas are the same as the ones ARCO uses as hypothetical examples (prospect 19 and prospect 6 in the LEIS). The ARCO scenario with two fields developed assumes a total of 3.75 billion barrels of recoverable oil reserves and a peak production rate of 935,000 barrels per day.

Despite the discrepancies and gaps in these two scenarios, they are generally similar, and the estimates and assumptions are close. For this reason, OTA was able to use the combined data to prepare its own general but more simplified scenario, adding a few assumptions that were missing. The OTA scenario and its assumptions are shown in Table 2-4, and a corresponding development schedule is shown in Figure 2-11.

Exploration

The LEIS states that three of the four blocks in the ANWR coastal plain are assumed to be leased and one discovery will be on each, but the size of each discovery is not given. OTA assumes that two discoveries will be commercial and that the total reserves will be roughly the average of the reserves assumed by the LEIS and ARCO. As in the LEIS, an additional 1,500 miles of seismic data are acquired on the coastal plain.

Neither ARCO nor the LEIS estimates the number of exploratory wells to be drilled after leasing; OTA assumes that 10 to 20 wells will be required to identify the two fields. (It has been reported in the past that Prudhoe was discovered on the 19th exploratory well and that over 250 exploratory and delineation wells have been drilled overall on the North Slope over the past two decades. Therefore, this assumption appears consewative.) The size and location of the two OTA assumed discoveries correspond to the LEIS and ARCO data.

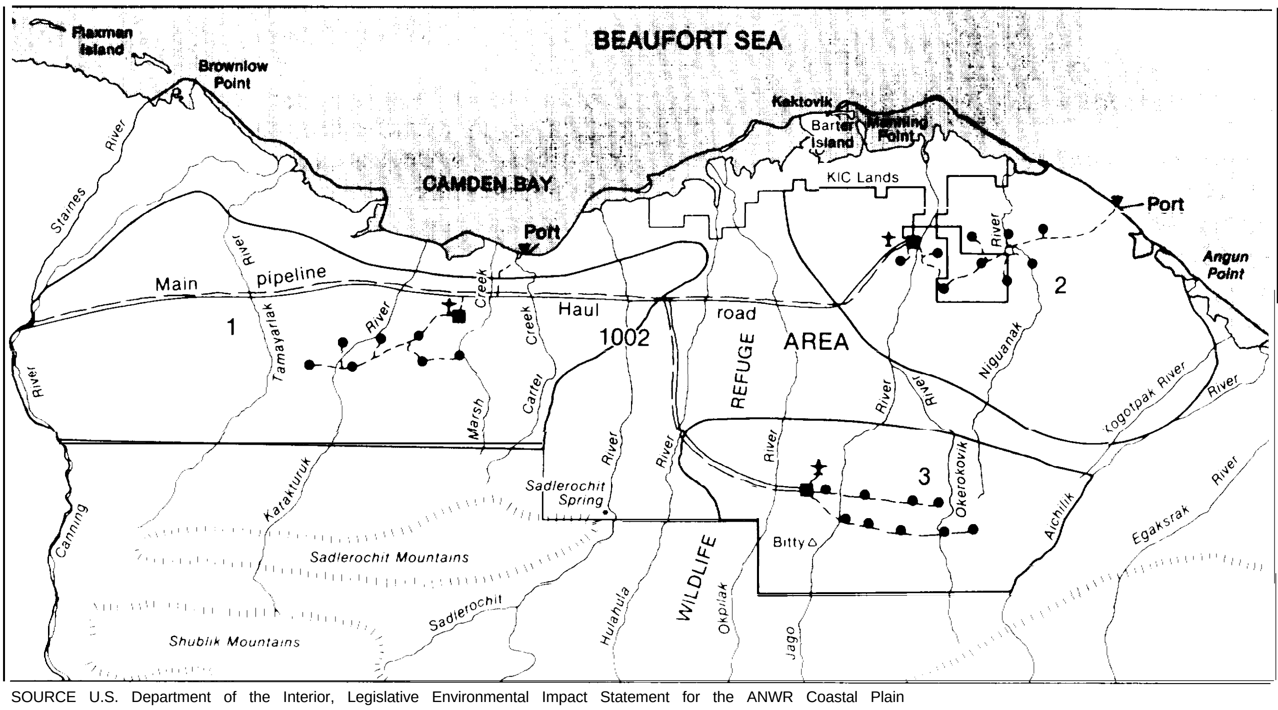
Figure 2-10.— Development Scenario for Three Major Prospects on the ANWR Coastal Plain, Department of the Interior, Legislative Environmental Impact Statement for the ANWR Coastal Plain

Estimated Linear or Areal Coverage by Selected Facilities	
Main oil pipeline within the 1002 area[2]	100 mi (610 ac)
Main road paralleling main pipeline and from marine facilities[2]	120 mi (730 ac)
Spur roads with collecting lines within production fields	160 mi (980 ac)
Marine and salt-water-treatment facilities	2 (200 ac)
Large central production facilities	7 (630 ac)
Small central production facilities	4 (160 ac)
Large permanent airfields	2 (260 ac)
Small permanent airfields	2 (60 ac)
Permanent drilling pads	50-60 (1,200-1,600 ac)
Borrow sites	10-15 (500-700 ac)
Gravel for construction, operation, and maintenance	40 million-50 million cu yds
Major river or stream crossings	Maximum 25

NOTE: Figures given in miles refer to linear miles of the facilities. Areas were calculated on the basis of 50-foot widths each for the main oil pipeline and main road, totaling a 100-foot right-of-way for the main transportation corridor. A 50-foot right-of-way was assumed for spur roads with collecting lines. The numbers of nonlinear units are also provided.

[2]The distance from the 1002 western boundary to TAPS Pump Station 1 [s approximately 50 miles, across State of Alaska land. This 50 miles is not included in the mileage estimates

Location of Selected Facilities in 1002 Area



SOURCE U.S. Department of the Interior, Legislative Environmental Impact Statement for the ANWR Coastal Plain

Table 2-4.—OTA ANWR Development Scenario

Exploration: 3 of 4 blocks leased

Additional seismic survey s-1 **,500** line miles
10-20 exploration wells drilled
Two commercial discoveries—one large/one small field (equivalent to prospect 19 and 6 in EIS)
Air transport exploration drill rigs—ice pads
#1 Large field—eastern end of coastal plain
#2 Small field—western end of coastal plain

Development:	#l	#2
Field size (billion barrels recoverable)	**3.0**	**0.5**
Peak production rate (barrels/day)	**700,000**	**100,000**
Number of well sites (Pads)	**12**	**2**
Total number of wells	**700**	**100**
Central industrial facility	**(One similar to Kuparuk for two fields)**	
Production facilities	**2 large complexes** 4 **satellite**	**1 large complex** —
Airfields	**One large**	**One small**
Port facilities	**Port complex near Beaufort Lagoon**	**Port complex at Camden Bay**
Seawater treatment plant	1	1
Oil transport	**30” elevated main trunk pipeline, 150 mi. to TAPS Pump Station #l**	**Spur Pipeline to Main Trunk**
Gravel pads/roads/etc.	**2,500-3,000 acres**	**500-1,000 acres**
Total “Footprint” incl. main pipeline & road, burrow sites, other disturbances	5,000-7,000 acres depending on final designs	
Total “Sphere of Influence”	150,000—300,000 acres	

NOTE” The assumptions in this table are OTA's but have been reviewed by several industry and government participants in our workshops. While small changes have been suggested, the reviewers generally agree that the numbers are reasonable

SOURCE Off Ice of Technology Assessment

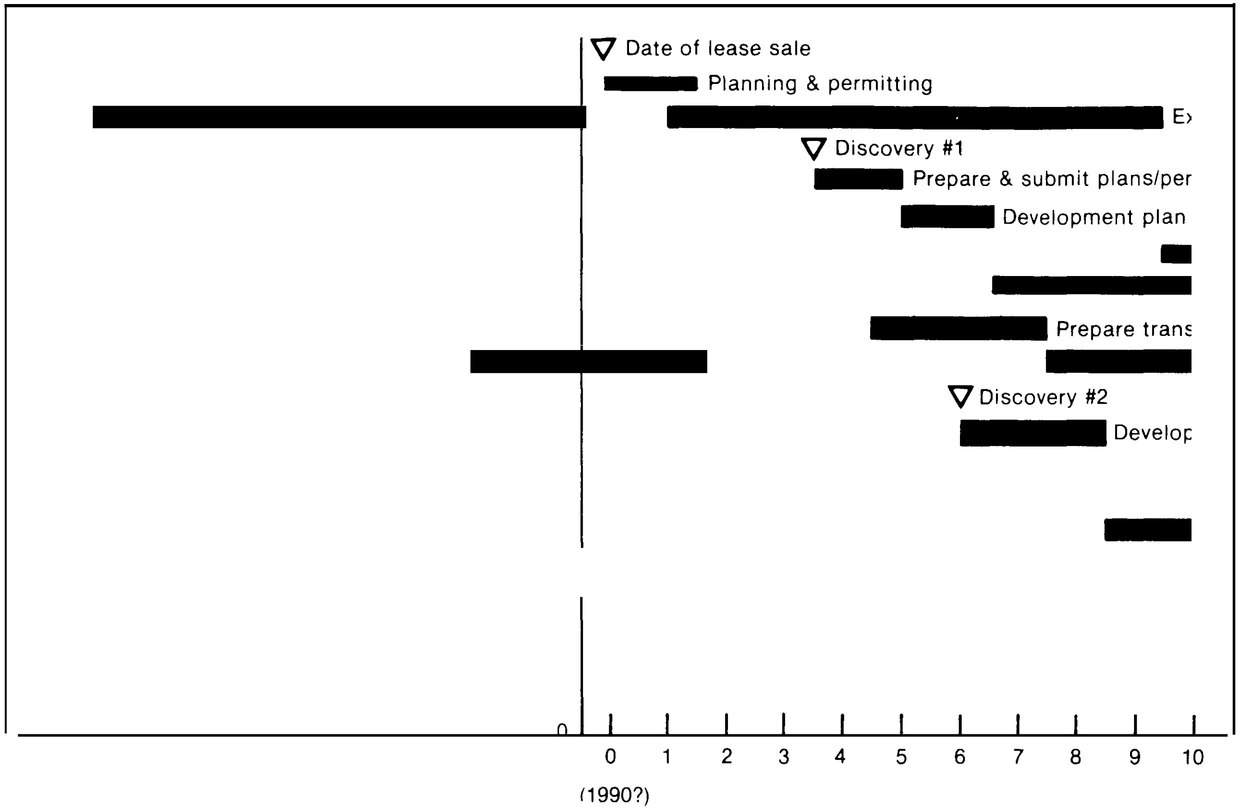
Development

The OTA assumption of peak production rate for the two fields and the total number of wells and well pads roughly corresponds to the ARCO data except that the assumed production rates (as a ratio of recoverable reserves) are somewhat lower. Production rates can be highly variable depending on the actual characteristics of the fields. However, even the OTA numbers correspond to some of the highest production rates from other North Slope fields. For example, discovery #1 is about one-third the size of the Prudhoe Bay field with about half the production rate. It is also about twice the size of the Kuparuk field with about 2.5 times the production rate. Hypothetical discovery #2, on the other hand, is roughly equivalent to the Endicott field which came on-line in 1987.

OTA's assumptions about production facilities are based on both the ARCO scenario and the existing developments at Kuparuk and Endicott. A central industrial facility for the entire ANWR coastal plain would follow the Kuparuk model even though ANWR is somewhat more remote from the other components of the Prudhoe support network. This comparative isolation would probably mean that ANWR would need a larger industrial facility than Kuparuk. Production facilities, airfields, ports, and seawater treatment plants would be similar to those at Kuparuk for discovery #1 and at Endicott for discovery #2. The assumed oil transport pipeline is similar to both the LEIS and ARCO scenarios.

OTA assumptions about gravel pads and road acreage are derived from the LEIS estimates for each field but include neither the main pipeline or road to TAPS nor the other areas of disturbance to the land surface, such as gravel pits. These assumptions, in turn, are all included in the estimate of total “footprint” to be expected from the first development of both hypothetical fields. The projected total “footprint” –area of direct physical coverage –was derived from individual area

Figure 2.1 1.—OTA MNWR Development Scenario



SOURCE: Office of Technology Assessment, 1988.

estimates, but the high end also corresponds to the ARCO estimate of 11 square miles as the total area affected by development.

Finally, OTA made a rough estimate of the total "sphere of influence" to be expected from full development activities. The notion of a sphere of influence appears in the LEIS as that area surrounding a facility or activity where certain wildlife species potentially would be affected. The actual extent of this sphere of influence would vary depending on the species, and specific impacts are not always quantified. This estimated sphere of influence corresponds, on the high side, to an estimate in the LEIS based on an influence zone of about 3 kilometers around all facilities, pads, pipelines, roads, etc. The upper estimate probably would be relevant only for the more sensitive species. The lower estimate corresponds to the total acreage enclosed by the two hypothetical fields in the scenario. In any case, the total area of 150,000 to 300,000 acres assumed in the OTA scenario could be a considerable portion of available habitat for a number of species.

OTA's estimates are only for initial development of the two hypothetical ANWR fields. Based on experience in all of the other developed North Slope oilfields, it is likely that, after the ANWR fields are producing, a series of modifications will be made. Such activities would include routine maintenance, upgrading, and improvement in recovery and production to extend the life of the field, plus well workovers, infill drilling, addition of secondary and tertiary recovery techniques, and many others. Experience at Prudhoe Bay has shown about a 50-percent increase in the coverage of tundra by gravel roads, pipelines, and facility pads from the time of initial production start-up in 1977 through 1988. Experience at Kuparuk is following the same pattern.

The above scenario for ANWR development can be used to project possible changes to the coastal plain environment that may result. It is clear that the changes could be substantial, to some extent, affecting hundreds of thousands of acres and supporting considerable human and mechanical activity for several decades, and that environmental protection issues would continue to be contentious should such development proceed. The four key principal environmental concerns–physical land disturbance, gravel mining and construction, waste management, and fresh water supply–that are listed at the beginning of this chapter, appear to be of continual future concern. OTA has noted industry's approach to addressing these issues and the fact that many environmental critics believe the industry's approach to be inadequate. Further environmental assessment is probably needed, most importantly in the above four areas, to evaluate the effectiveness and adequacy of these approaches.