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[EXTERNAL] Comments on Coastal PLain O&G DEIS - references

1 message

Pam A. Miller <pammillerarctic@gmail.com> Wed, Mar 13, 2019 at 11:02 PM
To: mnhayes@blm.gov, blm_ak_coastalplain_EIS@blm.gov

Please find these references as attachments to my comments and my attached seismic comments.

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pammillerarctic@gmail.com

From: Pam A. Miller [mailto:pammillerarctic@gmail.com]
Sent: Wednesday, March 13, 2019 10:01 PM
To: mnhayes@blm.gov; blm_ak_coastalplain_EIS@blm.gov
Subject: Comments on Coastal PLain O&G DEIS

Please find my comments

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3 attachments

- **Broken-Promises-Report2ndEdTWS2009.pdf**
  2765K
- **BrokenPromises-ReportMiller2003.pdf**
  1223K
- **PAMiller Ltr to BLM on Arctic NWR CP Seismic 8-17-2018.pdf**
  267K

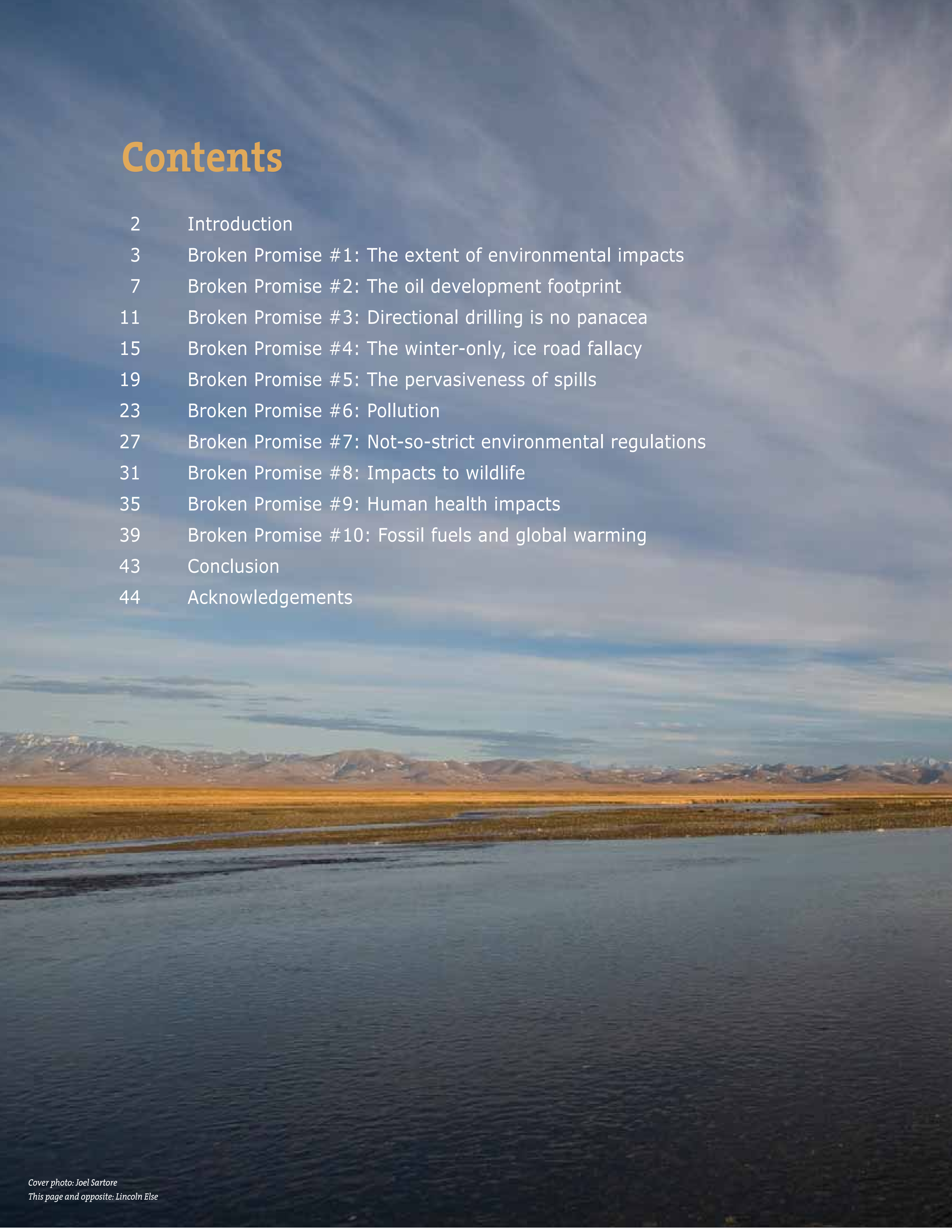
Broken Promises

The Reality of Oil Development in America's Arctic

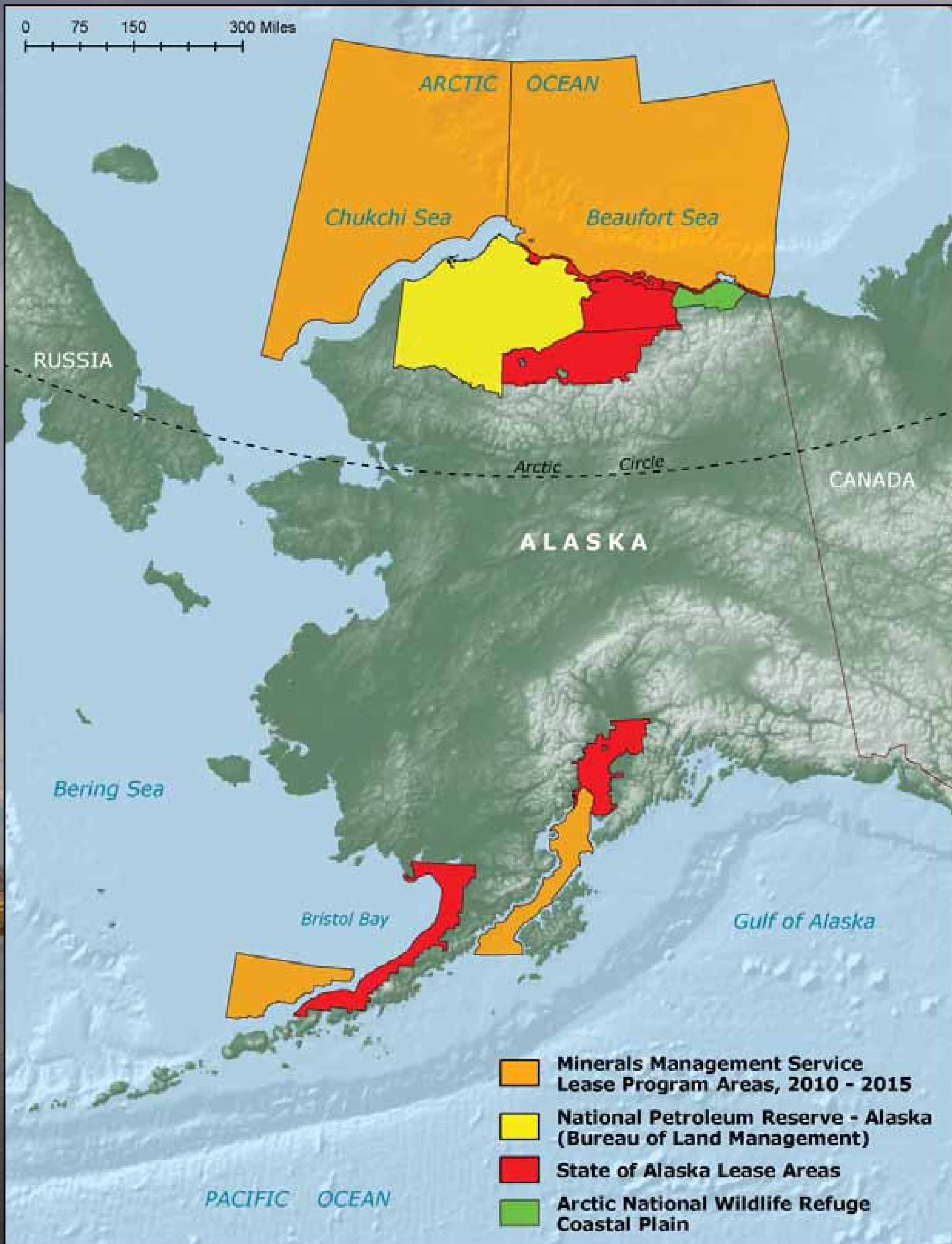
– 2nd Edition –

The Wilderness Society

Contents



Cover photo: Joel Sartore
This page and opposite: Lincoln Else



Significant acreage in Alaska is open to or currently under consideration for oil and gas development, including places of environmental and cultural importance such as the Chukchi and Beaufort Seas, and Bristol Bay. The Arctic National Wildlife Refuge has also been a target for drilling, although it is protected by law from exploration and development.

Introduction

Proponents of oil development in Alaska have been making promises, and breaking them, for decades.

To bolster the case for drilling, especially in environmentally sensitive areas, industry representatives and politicians argue that oil exploration, production and transport activities do not harm the environment. They promote Alaska's North Slope as the gold standard for "clean" oil development, asserting that new technology has shrunk industry's footprint and will make future development environmentally benign.

But the facts tell a different story. More than thirty years of industrial activity in Alaska have demonstrated that oil production is inherently a dirty business. Despite industry's best intentions to minimize impacts, environmental and social effects are accumulating and resulting in lasting harm to ecosystems and indigenous cultures. Opening new areas to drilling will not only add to these impacts but will also contribute to the Earth's warming climate, an increasingly serious concern, especially in Arctic regions.

This report calls attention to the many gaps between promise and reality, casting doubt on the reassurances being made by drilling proponents and their allies. The following chapters will demonstrate that despite advances in some technology, oil and gas development has inherent risks, causes inevitable impacts and is, in fact, taking a toll on Alaska's environment and its people.

At stake are some of Alaska's most extraordinary wildlife values—habitat for migratory birds and fish, globally important marine food webs, hundreds of terrestrial species that are rare elsewhere in the world, and America's only arctic ecosystem. Oil development also threatens the subsistence way of life, which provides not just nutritious food, but also cultural affirmation and continuity.

Rhetoric contending that oil development can occur without harm to the environment and that drilling Alaska's oil will solve America's energy problems has distracted many decision-makers from thoughtful consideration of the facts. Continuing to ignore the realities of oil development in America's Arctic will only further distract from the urgent need to provide real solutions for our nation's energy and climate challenges.

U.S. Fish & Wildlife Service

AK Dept. Environmental Conservation

Subhankar Banerjee

Wayne Todd

AK Dept. Environmental Conservation

Ken Whitten

BROKEN PROMISE #1

The Extent of Environmental Impacts

Subhankar Banerjee

The Promise

Oil development has negligible impacts on the environment.

The Reality

Environmental impacts of oil development are pervasive and lasting, occurring at every stage of oil development and accumulating over time.

Oil companies and politicians insist that it is possible to explore and develop oil fields in Alaska without harm to wildlife and the environment. But oil development is inherently a dirty business. At every stage from exploration to production to transportation, oil development negatively impacts the environment. Impacts occur both in the present and at the source, as in the case of oil spills, as well as in the future and distant from the source, as when oil is shipped overseas, burned, and converted to greenhouse gases.

Some impacts that are not yet manifest will occur as a result of past activity, even if all oil and gas development ceased today.[1] For example, thousands of acres of tundra have been damaged by gravel pads and fill, and much of that gravel has been contaminated by oil spills. These environmental impacts could persist for centuries, especially if vegetation and contaminated sites are not restored.[2]

If oil development continues and expands, existing impacts will be exacerbated and new ones will only compound the environmental damage.[3] If development expands offshore, infrastructure and traffic, noise and air pollution, and oil spills, will impact previously undisturbed ecosystems, interfering with coastal and marine ecosystems and wildlife. The cumulative effects of so many sources of strain, especially when coupled with climate change, are extensive.[4]

- ▷ Environmental impacts occur at every stage of oil development.
- ▷ Past impacts combine with current impacts to produce significant cumulative effects.
- ▷ Future development and expansion will only further compound cumulative environmental impacts.

Impacts at every stage of development

Environmental impacts of oil development occur at every stage of development and include both direct and indirect effects. During exploration, impacts occur from heavy trucks driving across the tundra, damaging plants and permafrost, and disturbing wildlife.[5] Offshore, exploration creates noise impacts that can harm whales and other marine life many miles away.[6]

At the production phase, more equipment, infrastructure and personnel are required, and impacts derive from multiple sources, including air and vehicle traffic; gravel pits and water withdrawals; roads, wells, pipelines, and power lines; construction dust and noise; exhaust from combustion engines; and oil spills, toxic fumes, and drilling wastes. Environmental impacts, especially oil spills, are also a concern during oil storage and transportation, whether by pipeline or tanker.

"Whether the benefits derived from oil and gas activities justify acceptance of the inevitable accumulated undesirable effects that have accompanied and will accompany them is an issue for society...to debate and judge."[7] National Research Council

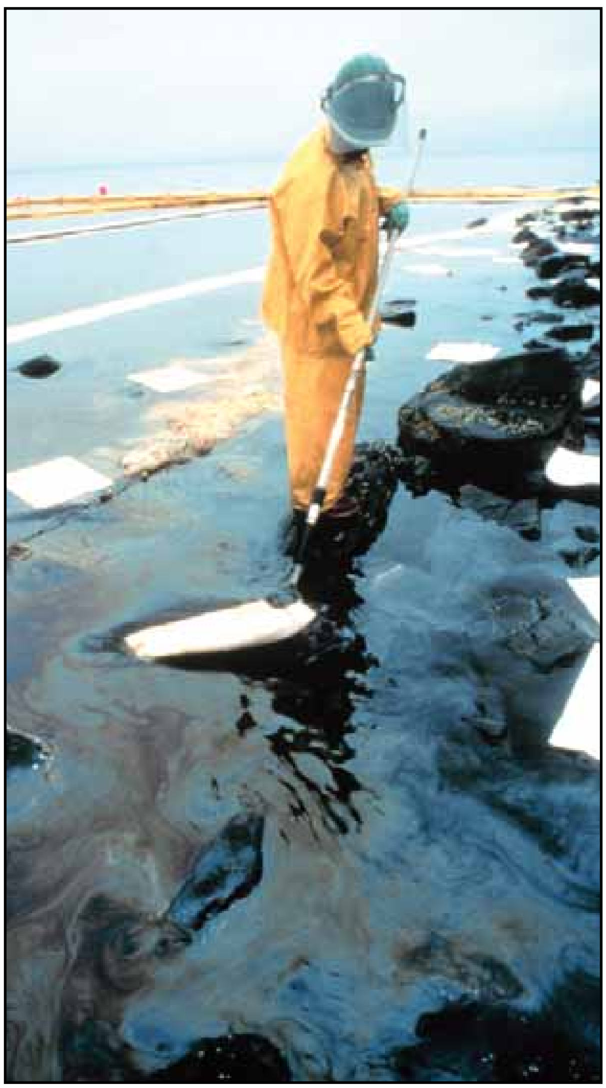
Pamela A. Miller

Exxon Valdez Oil Spill Trustees Council

Oil development activities also contribute to climate change,[8] which is affecting the Arctic more quickly and profoundly than other areas of the world. Arctic ecosystems are highly sensitive to change and pollutants in the Arctic persist longer than they do in warmer climates,[9] further exacerbating the cumulative effects of oil development in America's Arctic.

"…we can produce more energy from my state without harming wildlife or the environment."[10]

Senator Lisa Murkowski, April 29, 2008



National Oceanic and Atmospheric Association

Past and present impacts

The following list describes just some of the ways the oil industry in Alaska has already harmed and continues to harm the environment as a result of past and current development activity.[11]

- Seismic trucks and other off-road travel damage vegetation and affect scenic views
- Off-road vehicles disrupt wildlife, especially in winter when bears are denning and animals are already under nutritional stress
- The noise of trucks and airplanes, construction, and oil production disturbs wildlife, affecting migration and other behavior
- Buildings, powerlines, pipelines, and other structures disrupt the migration of fish, birds, and caribou, and disrupt scenic views
- Gravel roads alter natural water flow and create dust, affecting air quality and roadside vegetation
- Ice roads require drawing millions of gallons of water from lakes and rivers
- Heated buildings melt permafrost
- Hundreds of vehicles, generators, and industrial operations burn diesel and emit other pollutants, including greenhouse gases
- Predator numbers increase near oil fields leaving prey more vulnerable
- The presence of humans and physical structures contributes to direct wildlife mortality
- Hundreds of spills of oil and other toxic substances occur each year [12]
- Drilling waste is discharged directly into coastal waters[13]

Future impacts

The following additional impacts could compound with past and current impacts if oil development is allowed to expand to offshore areas such as the Beaufort and Chukchi Seas:[14]

- Offshore seismic testing will harm bowhead whales and other marine life
- Increased marine traffic and noise will stress coastal and marine wildlife
- Offshore oil and chemical spills will occur

Many impacts of oil and gas development remain unknown. The following are just a few examples recommended by the National Academy of Sciences for further research and study:[15]

- The extent to which fish, wildlife, and plants are contaminated by toxins
- The effects of ice roads on aquatic species and tundra
- The consequences of water withdrawals
- Air contamination and its effects
- Offshore oil spills

To suggest that oil exploration and production can be done with only minimal impacts to the environment is clearly a false promise. According to the National Academy of Sciences, if oil activity expands, the continuing accumulation of effects is virtually certain. Even if development does not expand, the lingering effects of past development will persist for centuries.[16]

Subhankar Banerjee

[1] National Research Council. (2003). Cumulative environmental effects of oil and gas activities on Alaska's North Slope. Washington, DC: National Academies Press, P. 155.

[2] National Research Council. pp. 90, 158.

[3] National Research Council. P. 11.

[4] As goes the Arctic, so goes the planet: Petition for rulemaking under the Clean Air Act to regulate greenhouse gas emissions from mobile and stationary sources to protect the health and welfare of the Arctic and the world. (2008, November). p. 40. http://www.oceana.org/fileadmin/oceana/uploads/pacific/ArcticPetition-FINAL-lowres.pdf.

[5] National Research Council. pp. 76, 84, 96, 117, 157.

[6] Jasny, Michael, J. Reynolds, C. Horowitz, A. Wetzler. (2005, November). Sounding the depths II: the rising toll of sonar, shipping and industrial ocean noise on marine life. Natural Resources Defense Coucil. p. iv. Retrieved July 2009 from website: http://www.nrdc.org/wildlife/marine/sound/contents.asp; National Research Council. P. 156.

[7] National Research Council. P. 11.

[8] ACIA, Impacts of a Warming Arctic: Arctic Climate Impact Assessment (2004). Cambridge University Press. Overview report, executive Summary. p. 2. Retrieved August 25, 2009 from: http://amap.no/acia.

[9] Nuttall, Mark. 2000. The Arctic is changing. Stephansson Arctic Institute, Akureyri, Iceland, in partnership with the EU Raphael Programme. P. 1. Last retrieved July 22, 2009 from website: http://www.thearctic.is.

[10] Murkowski, Lisa. April 29, 2008. Higher Energy Taxes, ANWR One Solution (speech given on Senate floor). Retrieved August 19, 2009 from website: http://murkowski.senate.gov/public/index.cfm?p=Speeches.

[11] National Research Council. pp. 6, 36, 40-41, 47-49, 67-68, 78-80, 117-118.

[12] Alaska Department of Environmental Conservation spill database. (1996-2009). Analyzed and compiled by Pam Miller, Northern Alaska Environmental Center.

[13] Trustees for Alaska. (2008, December 15). Villages, fishermen, and Cook Inletkeeper challenge EPA for allowing oil companies' toxic discharges. Press release retrieved from website: http://www.trustees.org/Supporting%20Documents/CIGP%20press%20release%2012-15-08.pdf.

[14] Harrould-Kolieb, Ellycia, J. Savitz, J. Short, M. Veach. (2009). Toxic legacy: long-term effects of offshore oil on wildlife & public health. http:// www.oceana.org/climate. p. 25; Jasny, M. et. al. (2005, November). p. v.

[15] National Research Council. pp. 9,10,150-153.

[16] Ibid. P. 158.

BROKEN PROMISE #2

The Oil Development Footprint

Roads, pipelines, air landing strips, and other infrastructure spreads across Alaska's industrialized North Slope.

Joel Bennett

The Promise

The oil development "footprint" is smaller than ever.

The Reality

The full impact of oil development extends well beyond physical structures and its footprint is larger than ever.

For years, proponents of drilling in the Arctic National Wildlife Refuge have argued that the development "footprint" will impact only 2,000 acres. According to Sarah Palin, "this is like laying a 2-by-3-foot welcome mat on a basketball court."[1] In fact, oil development impacts are not limited to the area where drill pads and pipeline support beams touch the ground.

Alaska's North Slope industrial complex—a network of roads, pipelines, airstrips, and power lines—sprawls across 640,000 acres, fragmenting the landscape. The aggregate area and impact of this development simply cannot be measured by the physical structures alone. Although the size and number of drill pads required to extract oil may be getting smaller, the true development footprint, measured in the full scope of impacts, is getting larger.

Oil development's footprint spreads across the landscape

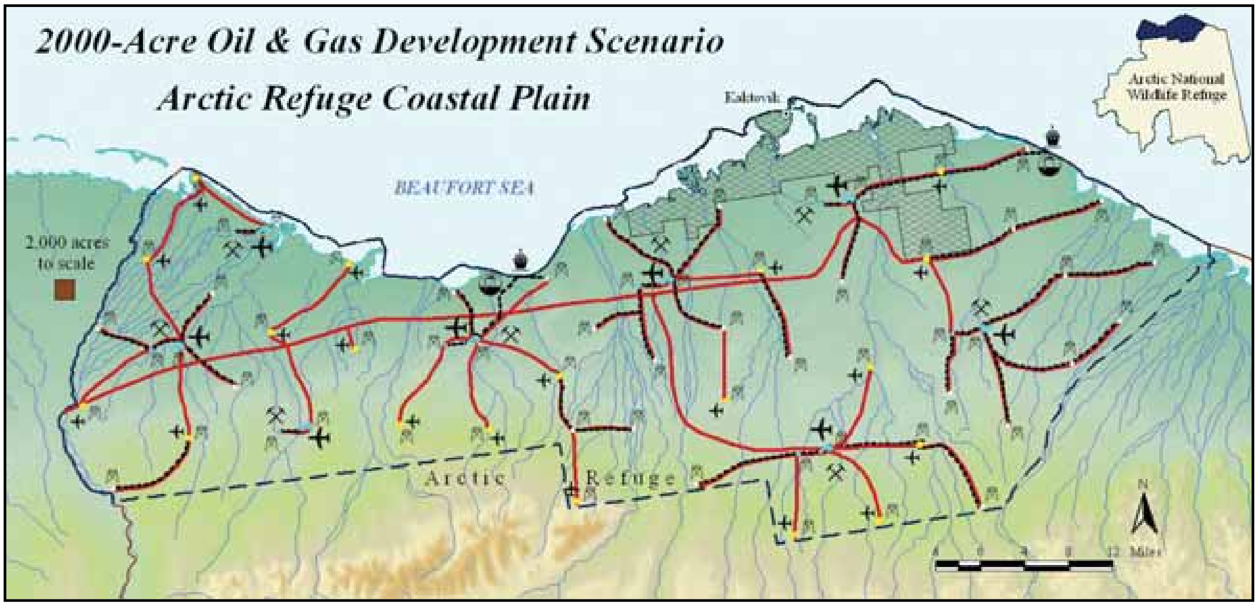
When oil is discovered, one or more production wells are drilled and permanent structures are built to support them. Eventually, development spreads like a web as wells are drilled to tap the full extent of the oil field, and roads and pipelines are built to connect the infrastructure and transport materials and services. According to the National Academy of Sciences, "the common practice of describing the effects of particular projects in terms of the area directly disturbed by roads, pads, pipelines, and other facilities ignores the spreading character of oil development on the North Slope and the consequences of this to wildland values over an area far exceeding the area directly affected."[2]

On Alaska's North Slope today there are 32[3] active oil fields spread across more than 1,000 square miles. Thousands of production wells have been drilled, and these are supported by a vast infrastructure of roads, pipelines and other facilities.

At Alpine, one of Arctic Alaska's newest onshore oil fields, industry initially claimed that directional drilling technology would enable development of this field with only two drill sites and 115 acres or less.[4] That promise was quickly replaced with the usual pattern of incremental sprawl seen elsewhere on the North Slope.

- The footprint of oil development spreads across the landscape.
- The footprint extends beyond drill pads and physical structures.
- The true footprint of oil development includes all of its direct and indirect impacts, as well as cumulative and long-term impacts.

Associated Press Photo/File



Proponents of drilling the Arctic National Wildlife Refuge argue that development would be contained to a 2000-acre footprint. In reality, the aggregate footprint of drill pads, roads, and pipelines could sprawl across 1.5 million acres.

"...the footprint that you put on the ground is a function of the geology of the reservoir that you discover. If that reservoir is spread out over 50 miles, obviously, your footprint is going to be spread out over 50 miles."[5]

Mr. Herrera (British Petroleum geologist)

In 2004 federal agencies approved industry plans to build five more drill sites connecting to the Alpine oil field. In total, Alpine plans now include seven drill sites, 33 miles of permanent gravel roads, two airstrips, two gravel mines, and 72 miles of pipeline covering some 570 acres.[6] To fully develop the oil field, the Bureau of Land Management projects the addition of 24 more production well pads, seven airports, 150 miles of pipeline, 122 miles of gravel roads, and another 1,262 acres of tundra covered by gravel fill or mines.[7]

Oil development's footprint extends beyond physical structures

Oil development's footprint extends well beyond permanent physical structures such as drill pads and wells. On land industry's imprint begins with seismic testing. The marks from heavy vehicles travelling across fragile tundra creates visible lines extending for miles.[8] Other mobile vehicles, including airplanes are also part of the footprint, contributing noise and air pollution beyond stationary structures.

Oil development activities can interfere with hydrologic processes and affect animal populations as much as a few miles from any physical structure.[9] The air pollution generated by stationary sources in Alaska's North Slope oil fields and other emissions from Prudhoe Bay have been detected nearly 200 miles away in the village of Barrow.[10] Carbon dioxide emissions are contributing to climate change and ocean acidification at a global scale.[11]

Offshore, oil development's footprint also extends far beyond any physical structures.[12] Exploratory drills can affect benthic communities for up to a mile.[13] Spilled oil can spread across hundreds of miles[14] and low frequency sonar can travel hundreds of miles through the ocean at considerable intensities.[15] Sound generated by seismic exploration, drilling, and marine vessel traffic can harm whales and other marine animals and drive them away from migration routes and feeding grounds.[16]

The true development footprint

Figure 2.1 lists the physical structures associated with oil development on the North Slope, but these are just one small piece of the overall footprint of oil development. To fully account for oil development's footprint, one must also consider air and noise pollution, water extraction, oil spills and other toxic discharges, gravel pits, habitat fragmentation, and the numerous direct, indirect, and cumulative impacts to wildlife and human populations. These impacts are significant and only growing more so as development continues and expands.

FIGURE 2.1: Oil development's footprint on the North Slope

- **5,549** exploration and production wells[17]
- More than **390** gravel pads[18]
- More than **500** miles of roads[19]
- More than **600** miles of pipelines[20]
- **2** refineries[21]
- **20** airstrips[22]
- **6** docks and gravel causeways[23]
- More than **6,000** acres of gravel mines[24]
- **27** production plants and processing facilities[25]
- The **800** mile-long Trans Alaska Pipeline
- **219** miles of power transmission lines[26]

1 Palin, Sarah. (2009, February 1). Sarah Palin: The case for drilling in ANWR. Minneapolis Star Tribune editorial.

2 National Research Council. (2003). Cumulative environmental effects of oil and gas activities on Alaska's North Slope. Washington, DC: National Academies Press. p. 148.

3 Minerals Management Service. (2008, November). Arctic Multiple-Sale Draft EIS. Beaufort and Chukchi Sea Planning Areas. MMS OCS EIS/EA 2008-0055. Table 3.1.1-1. Vol. IV. Appendix K-Tables.

4 Anadarko Petroleum Corporation. (2000, November 16). Production begins from Alpine field on Alaska's North Slope. Press release. Retrieved August 19, 2009 from website: www.anadarko.com/Investor/Pages/News Releases; Resource Review. (1998, June). State backs ARCO in lawsuit, Knowles says company "doing it right."

5 U.S. Congress, House of Representatives, Committee on Merchant Marine and Fisheries, 102d Cong., 1st Session, Arctic National Wildlife Refuge, Part 1- Consideration of several proposals to authorize oil and gas leasing within the Arctic National Wildlife Refuge. May 1, June 11, and July 16, 1991. Serial No. 102-26, p. 39. Cited in: Trustees for Alaska. 1998. Under the influence: Oil and the industrialization of America's Arctic. p. 34.

6 U.S. Bureau of Land Management. (2004, November). Alpine Satellite Development Plan Record of Decision. Website: http://www.blm.gov/eis/AK/alpine/rod.pdf.

7 U.S. Bureau of Land Management. (2004, September). Alpine Satellite Development Plan Final Environmental Impact Statement. Vol. 1, Sec. 2. Alternative A-Full Field Development. Tables 2.4.1-6, 7, 8. pp. 69,71. Website: http://www.blm.gov/eis/AK/alpine/dspfeisdoc.html; Trustees for Alaska. (2007, June). Sectional Analysis, Stevens/Murkowski Arctic refuge drilling amendment to S.1419. p. 8.

8 U.S. Fish and Wildlife Service. Seismic trails. Retrieved July 20, 2009 from Arctic National Wildlife Refuge website: http://alaska.fws.gov/nwr/arctic/seismic.htm. Jones, B., R. Rykhus, Z. Lu, C Arp and D. Selkowitz. (2008). Radar imaging of winter seismic survey activity in the National Petroleum Reserve-Alaska. Polar Record 44 (230): 227-231.

9 National Research Council. p. 5.

10 Trustees for Alaska. Air pollution fact sheet. Retrieved July 24, 2009 from Trustees website: http://138group.com/alaska/oil_in_the_artic/FSAirPollution.htm; Jaffe, D., R. Honrath, D. Furness, T. Conway, E. Dlugokencky, and L. Steele. (1995). A determination of the DH4, NOx and CO2 emissions from the Prudhoe Bay, Alaska oil development. Journal of Atmospheric Chemistry 20: 213-227.

11 Caldeira, K. and M. Wickett. (2003). Anthropogenic carbon and ocean pH. Nature, 425: 365, p. 365.

12 National Research Council. P.5.

13 Currie, D.R. and L. Isaacs. 2005. Impact of exploratory offshore drilling on benthic communities in the Minerva gas field, Port Campbell, Australia. Marine Environmental Research. 59:3, 217-233.

14 The Exxon Valdez oil spill produced an oil slick that stretched across 460 miles. Source: World Wildlife Fund. (2009). Lessons not learned: 20 years after the Exxon Valdez disaster little has changed in how we respond to oil spills in the Arctic. WWF-US, Kamchatka/Bering Sea Ecoregion, Anchorage, Alaska.

15 Marine Connection. Effects of sonar. Retrieved July 21, 2009 from website: www.marineconnection.org/campaigns/sonar_sonar.html.

16 Siebert, Charles. (2009, July 12). Watching whales watching us. The New York Times; Schick, R., and D. Urban. (2000). Spatial components of bowhead whale distribution in the Alaskan Beaufort sea. 57 Can. J. Fisheries and Aquatic Sci. 2193.

17 Alaska Oil and Gas Conservation Commission. 2009. http://www.state.ak.us/local/akpages/ADMIN/ogc/publicdb.shtml; Alaska Department of Natural Resources. 2009. http://www.dog.dnr.state.ak.us/oil/products/data/wells/wells.htm; Well data compiled by Doug Tosa, Alaska Center for the Environment. July 2009.

18 National Research Council, Table 4-2. p. 43.

19 BLM. (2004, September) Alpine Satellite Development Plan Final EIS. Vol. 2, Table 4G.4.4-2, p. 1246.

20 National Research Council. P. 43.

21 State of Alaska, Department of Natural Resources, Historical and Projected Oil and Gas Consumption, (1999). Appendix B, p.51.

22 BLM. (2004, September). Alpine Satellite Development Plan Final EIS. Table 4G.4.4-2.

23 U.S. Bureau of Land Management. (2003). Northwest National Petroleum Reserve-Alaska, Final Integrated Activity Plan/Environmental Impact Statement. Vol. 3. Table IV-09. Pp. 100-101.

24 National Research Council. (2003). Table 4.4. p. 44.

25 BLM. 2003. Northwest NPR-A, Final Integrated Activity Plan/EIS. Vol. 3. Table IV-09. Pp. 100-101.

26 National Research Council. (2003). P. 44.

BROKEN PROMISE #3

Directional Drilling is no Panacea

One of more than 5,500 oil wells on Alaska's North Slope.

Anne Gore

The Promise

New directional drilling technology enables drilling without any surface impacts.

The Reality

Directional drilling is not new and requires the same infrastructure with the same impacts as all oil development, including surface impacts.

Proponents of oil and gas development in the Arctic National Wildlife Refuge and other sensitive areas of Alaska assert that new advances in directional drilling will reduce, and even eliminate, environmental impacts. In fact, directional drilling has limitations, and its impacts are no different than those of conventional drilling.

"The industry touted roadless development as the way of the future, and is now abandoning the concept."

Community of Nuiqsit, 2004[1]

Directional drilling is not a new practice

According to the U.S. Department of Energy, the first true horizontal well[2] was drilled in 1929 in Texas.[3] Since then, thousands of horizontal wells have been drilled across the world. But as of 1999 horizontal boreholes accounted for only five to eight percent of all U.S. land wells, and extended-reach horizontal drilling is still uncommon.[4] In Arctic Alaska, oil companies have rarely drilled horizontal distances of more than a few miles. Of the 5,549 wells drilled on Alaska's North Slope to date, only 41 have reached horizontal offset distances of three miles or more.[5]

Exaggerated claims

Claims that directional drilling can reach eight to ten miles away are exaggerated.[6] Oil companies have drilled distances over seven miles, but such distances are still extremely rare in the industry.[7] On the North Slope, 94% of all existing wells extend less than two miles from the drill rig, and fewer than 2% extend more than three miles. As of August 2009 the maximum horizontal distance drilled was 4.025 miles. Even at ConocoPhillips' Alpine oil field, which is touted as a model of new directional drilling technology, the average horizontal drill distance is only 1.74 miles.[8]

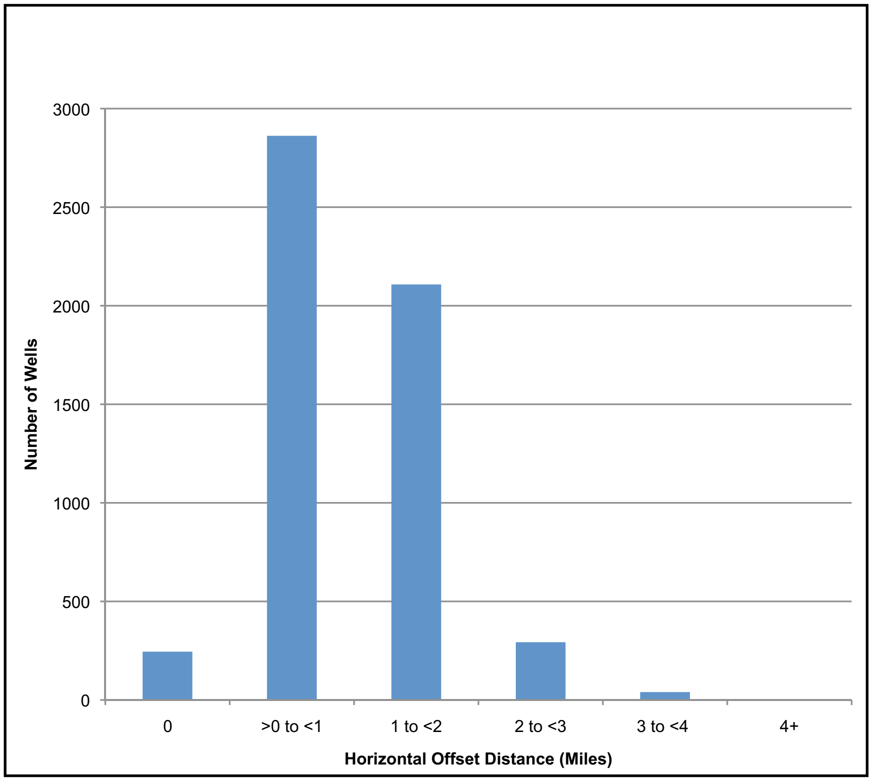
Longer-reach drilling is expensive and often presents geologic and engineering challenges

Truly state-of-the art practices are often impractical if not impossible for oil companies. Factors such as where the oil or gas deposit is in relation to the drilling rig, the size and depth of the mineral deposit, and the geology of the area, are all important elements in determining whether directional drilling is possible.[9] Drilling a horizontal or extended-reach well can cost two or three times more than drilling a vertical well in the same reservoir.[10] In 2000, British Petroleum "stopped drilling extended reach wells—those that reach out a long distance from the pad—after oil prices crashed in the late 1990s, because extended-reach drilling is expensive."[11] In a 2003 draft environmental impact statement for the National Petroleum Reserve-Alaska, the Bureau of Land Management (BLM) wrote:

> *"The cost of extended-reach [ERD] wells is considerably higher than conventional wells because of greater distance drilled and problems involving well-bore stability. Alternative field designs must consider the cost tradeoffs between fewer pads with more extended-reach wells as opposed to more pads containing conventional wells. In most instances, it is more practical and cost effective to drill conventional wells from an optimum site, [than] it would be to drill ERD wells from an existing drill site."*[12]

ConocoPhillips' Alpine oil field is an example of how optimistic claims about directional drilling technology can quickly fall flat. Alpine was advertised in 1998 as a state-of-the-art roadless development. But the oil field already has several miles of permanent gravel road, and plans for expansion could add as much as 122 more miles.[13] In 2004 the federal government approved plans to expand Alpine from two to seven drill sites.[14] Also in 2004 the Bureau of Land Management granted ConocoPhillips an exemption from a lease stipulation that had previously prohibited the company from building a drill site in a 3-mile

Anne Gore



Horizontal drilling distances of Alaska North Slope wells (1969-2009). Source: Alaska Oil and Gas Conservation Commission well database. Data analyzed by Doug Tosa, Alaska Center for the Environment, using known tophole and bottomhole latitude/longitude locations of 5,549 completed wells.

buffer zone along Fish Creek.[15] The agency cited economic and geological limitations of directional drilling as the reason:

> *"Drilling from outside the setback would require directional drilling for long distances through geologically unstable shale. This drilling approach is very problematic because shale in this area tends to collapse holes. Maintaining drill holes would be difficult and expensive."*[16]

In 2008 British Petroleum announced its plans to drill distances of seven miles or more to reach its offshore Liberty oil field. But the technology remains to be proven. It will also demand doubling the size of Endicott Island—an offshore, man-made island—to make room for extended pipe racks, the massive drilling rig, and a worker's camp.[17]

- Directional drilling is not a new practice.
- Claims about distances directional drilling can reach are exaggerated.
- Directional drilling is expensive and often limited by geology.
- Directionally drilled wells require the same infrastructure and have the same environmental impacts as conventional wells, including surface impacts.

Claims that directional drilling will incur no surface impacts are misleading

Before production wells are drilled, seismic testing is conducted and exploration wells are drilled to refine the location of oil deposits. These activities have direct surface impacts.

Seismic exploration typically involves many vehicles driving across the tundra in a grid pattern. Sensitive tundra soil and plants are easily compressed under the weight of these heavy vehicles, even in winter.[18] Seismic lines are often visible on the Arctic tundra for years after exploration, and studies have shown that fragile tundra plants can take decades to recover.[19] Despite industry claims to the contrary, winter exploration can also disturb wildlife.[20]

The notion that directional drilling allows for a smaller footprint is misleading

Although directional drilling may reduce the number of well pads required to access an oil deposit, it requires the same infrastructure and has the same environmental impacts as conventional drilling. Permanent gravel roads and air strips are still used for access, long pipelines are still required to connect the well sites, and pollution and toxic spills are still inevitable.

Oil production is a high-impact activity, regardless of how you drill. New technology has yet to demonstrate that it can minimize, mitigate, or eliminate the inevitable impacts of oil development to America's Arctic and other sensitive ecosystems.

[1] U.S. Bureau of Land Management. 2005, January. Final Amendment to the Northeast National Petroleum Reserve: Integrated Activity Plan/Environmental Impact Statement. Vol. 2, Response to comments. Kuupik Corporation, Native Village of Nuiqsut, City of Nuiqsut, and Kuukpikmuit Subsistence Oversight Panel. Comment Letter No. 197616. P. 6-262.

[2] The terms horizontal and directional drilling are used interchangeably in this document to refer to non-vertical drilling.

[3] Horizontal and Multilateral Wells. Frontiers of Technology. (1999, July). Journal of Petroleum Technology. Retrieved March 18, 2009 from website: http://www.spe.org/spe-app/spe/jpt/1999/07/frontiers_horiz_multilateral.htm#.

[4] Pratt, Sara, (2004, March). A Fresh Angle on Oil Drilling, GeoTimes.

[5] Horizontal offsets calculated by Doug Tosa, GIS Analyst, Alaska Center for the Environment. August 2009. Source data: Alaska Oil and Gas Conservation Commission well database, http://www.state.ak.us/local/akpages/ADMIN/ogc/publicdb.shtml.

[6] Senator Lisa Murkowski's website claims that her directional drilling bill will enable "oil wells to be drilled from the western Alaska state-owned lands, outside of the refuge's boundary, or from state waters to the north, and still to [sic] be able to tap oil and gas deposits located between eight and 10 miles inside the refuge. http://murkowski.senate.gov/public/index.cfm?FuseAction=IssueStatements.View&Issue_id=8160a71d-9c6e-945d-f605-a8959dfbf80b (last visited April 8, 2009).

[7] British Petroleum's Wytch Farm set the current world extended reach drilling record in June of 1999 when its well M16 reached a "horizontal displacement distance of 10,728 m[eters] a total length of 11,278 m[eters] and a depth of 1638 m[eters]." http://www.bpnsi.com/index.asp?id=7369643D312669643D313531 (last visited March 18, 2009).

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BROKEN PROMISE #4

The Winter-Only, Ice Road Fallacy

Tire marks from seismic testing conducted in winter remain visible on the tundra in summer.

Anne Gore

The Promise

Many oil development activities take place in winter months when animals are not around; roads and drill pads built from ice melt away in spring.

The Reality

Oil development occurs year-round and winter exploration and ice roads are not without impacts.

A common misperception about oil development on Alaska's North Slope is that it takes place only in winter and therefore has no impact on wildlife. Ice roads are cited as an example of how oil companies conduct business without damaging the fragile Arctic tundra. These claims not only overlook the fact that oil production requires permanent installations that operate year-round, but they also ignore the full scope of impacts that the oil industry has on wildlife and the environment, even in winter.

"Tussock tundra can be quite easily disturbed by ice road construction techniques [and] disturbance can be of long duration."[1]

Alaska Department of Natural Resources, 2007

Year-round impacts

Although oil exploration in Arctic Alaska is mostly restricted to winter months, once oil is discovered, efforts to recover it take place year-round. Construction, drilling and other operations carry on through every month and season,[2] with attendant vehicle and air traffic, noise and air pollution, and inevitable impacts to wildlife and the environment.

Ice roads

Although touted as such, ice roads are no panacea for development in fragile Arctic environments. According to the Alaska Department of Natural Resources, North Slope oil exploration and development consumed 1.5 billion gallons of water in 2000, mostly for ice roads and pads.[3] Pumping such massive amounts of water not only affects water balance, chemistry, aquatic organisms and fish,[4] but can also limit the ability to use ice roads. Already, in areas where water supplies are scarce, ice roads are not a practical option. At the same time, warming temperatures have reduced the number of days that ice roads can be used.[5] Since 1970, ice road use on the North Slope has been shortened from 204 to 124 days.[6]

Permanent gravel roads already cover more than 8,000 acres of America's Arctic,[7] including three miles and more planned at the Alpine oil field,[8] which industry promotes as a "roadless development." Permanent gravel roads remain a standard fixture on Alaska's North Slope and are likely to remain so as a result of water availability and climate change, which are making ice roads less practical.[9]

- Oil development activities take place year-round.
- Ice roads require massive water withdrawals.
- Most oil fields utilize permanent gravel roads.
- Seismic exploration disturbs fragile tundra, soil, and wildlife.

Subhankar Banerjee

Winter exploration

It is not feasible to use ice roads for 3-D seismic exploration,[10] which requires making multiple passes over land in a grid profile with a line spacing of a few hundred meters,[11] so large vehicles are driven directly across the tundra. Multiple trucks and a large crew of people are typically required to do this exploration work.[12] Fragile tundra soil and plants are easily compressed under the weight of these heavy vehicles, even in winter. Seismic lines are often visible on the Arctic tundra for years after exploration, and studies have shown that tundra plants can take decades to recover.[13]

During the spring of 2006 satellite images were used to monitor the Teshekpuk Lake Special Area for melting ice. During review of these images, scientists discovered that the satellite images could detect features on the landscape associated with winter oil exploration activity. "Focused analysis of the image time series revealed various aspects of the exploration process such as the grid profile associated with the seismic line survey as well as trails and campsites associated with the mobile survey crews."[14]

Oil spills are also a concern with seismic testing. According to WesternGeco, a seismic contracting company:

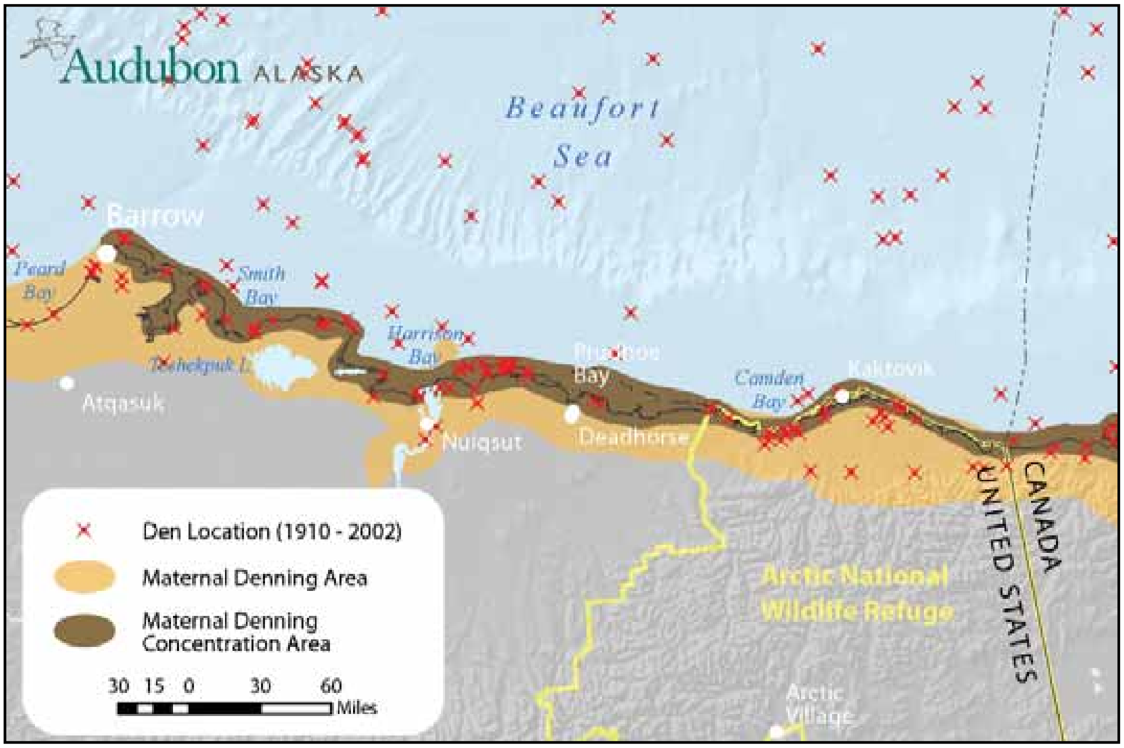
> *"With so many vehicles on hand, special care must be taken to avoid contaminating the snow with…spills of hydrocarbon-based product during refueling, maintenance and ordinary operation. A vibroseis truck circulates hydraulic oil at pressures of thousands of psi to power the vibrator. If a hose breaks, up to 150 liters [40 gal] of oil may escape."*[15]

Winter wildlife

Many species of fish and wildlife, including brown bears, polar bears, caribou, muskoxen, and Arctic cisco, remain in Alaska's Arctic all winter and are subject to impacts from exploration and other oil development activities.[16] Muskoxen, for example, frequently use habitats along or adjacent to rivers—locations that are likely to be gravel and water extraction sites for winter road construction.[17] When muskoxen encounter humans or vehicles, they may expend energy that they need to conserve during the long winter in order to successfully reproduce in spring.[18]

National Oceanic and Atmospheric Administration

Seismic exploration involves caravans of heavy trucks making multiple passes directly across the tundra.



Polar bear denning habitat. Source: Audubon Alaska. 2009. Draft atlas of Chukchi and Beaufort seas.

In 1985, a female polar bear, thought to be pregnant with her first litter, abandoned her den after seismic exploration vehicles tracked within 700 feet of it, although regulations required a half-mile buffer from known dens.[19] Onshore oil development impacts to polar bears in winter may become an increasing concern as sea ice habitat shrinks and these animals increasingly den onshore.[20]

As recently as February 2009, an ice road construction crew encountered a sleeping polar bear. While building the same 50-mile road, Exxon violated a water use permit when it extracted 28,000 gallons of fresh water from a river that is important to whitefish.[21] Less than 5% of stream habitat remains available to fish in winter,[22] making them especially vulnerable to water withdrawals and other oil development activities.

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[12] As one example, BP Exploration Alaska contracted WesternGeco to survey an area of 180 square miles and utilized a crew of 80 personnel and two fleets (5 trucks in each fleet) of rubber-tracked equipment. Source: Gibson and Rice, Oilfield Review p. 20. (Felix and Raynolds 1989; National Research Council, Jones et al).

[13] U.S. Fish and Wildlife Service. Seismic trails. Retrieved July 20, 2009 from Arctic National Wildlife Refuge website: http://alaska.fws.gov/nwr/arctic/seismic.htm.

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[17] Reynolds, P.E., K.J. Wildson, and D.R. Klein. 2002. Muskoxen. Pp. 54-64 in: U.S. Geological Survey. 2002. Arctic Refuge Coastal Plain Terrestrial Wildlife Research Summaries. Biological Science Report USGS/BRD/BSR-2002-0001. p. 60, 62-63; National Research Council. p. 117.

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BROKEN PROMISE #5

The Pervasiveness of Spills

Workers remove oil from the tundra following an August 2006 oil pipeline spill on Alaska's North Slope.

Al Grillo / Associated Press

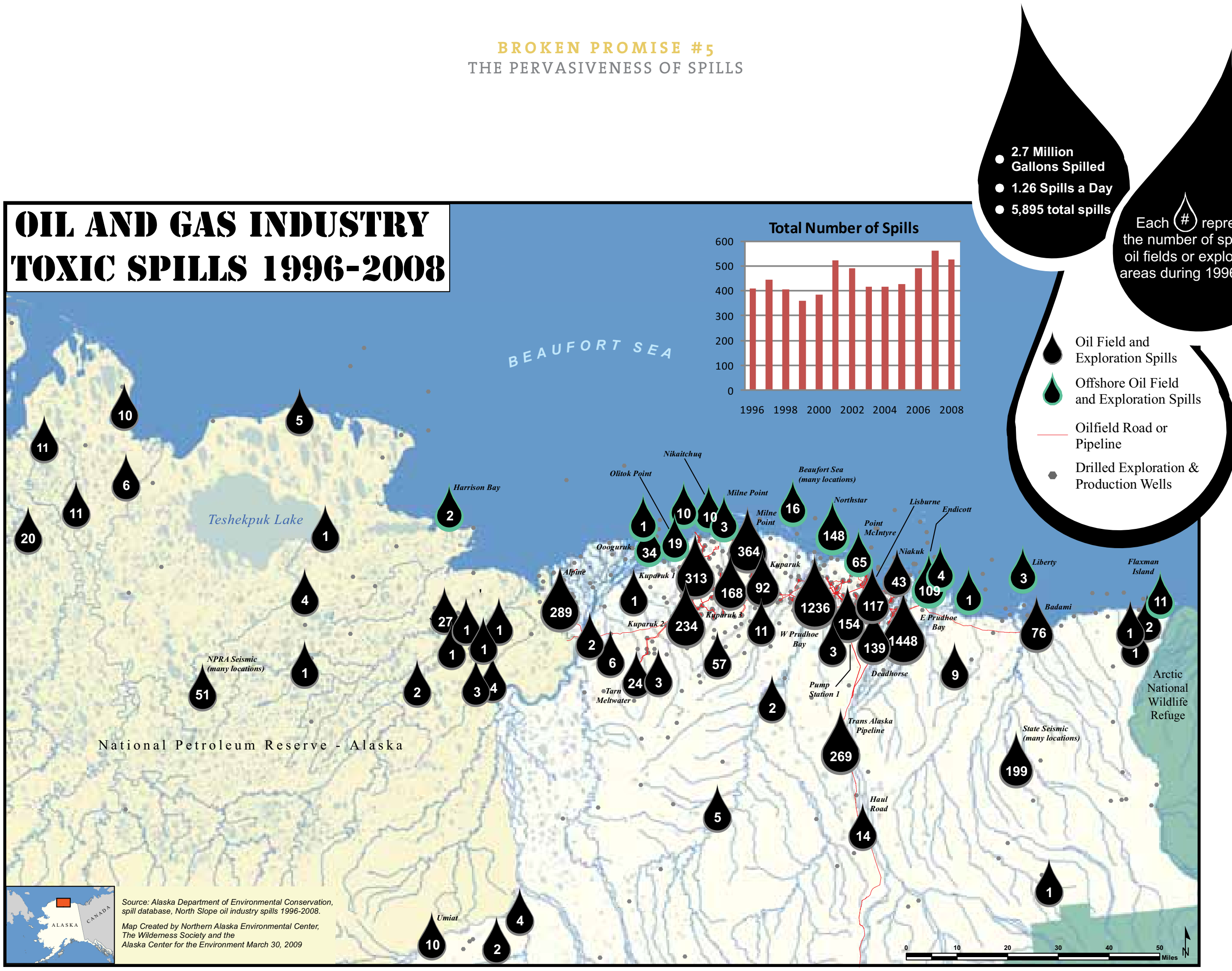
The Promise

Spills can be controlled through operational excellence, environmental safeguards, and spill response. Spills have short-term impacts but no lasting effects.

The Reality

Spills occur frequently, and failures to detect and respond to spills are common. The impacts of oil spills are cumulative and persistent, sometimes lasting for decades.

Each year, an average of 450 oil and other toxic spills occur on Alaska's North Slope as a result of oil and gas activity. More than 45 different toxic substances, including acids classified as extremely hazardous substances, have been spilled during routine operations. Between 1996 and 2008, 5,895 spills occurred totaling more than 2.7 million gallons of toxic substances, more than 396,000 gallons of crude oil, 122,000 gallons of drilling muds, and more than 1 million gallons of process water.[1]



In the 12-year period between 1996-2008 5,895 toxic spills occurred as a result of oil and gas industry activity on Alaska's North Slope. Source: Data compiled by Pam Miller, Northern Alaska Environmental Center. Mapping by Doug Tosa, Alaska Center for the Environment. Source data: Alaska Department of Environmental Conservation spill database.

Spills are common

In March of 2006 the largest crude oil spill in the history of North Slope operations brought national attention to the chronic problem of spills and the glaring discrepancies between oil company promises and the reality of their practices. The spill went undetected for five days.

This spill and many others might have been prevented had the industry not neglected operational safeguards such as corrosion maintenance and leak detection procedures.[2]

Other oil company violations over the years serve to illustrate that neglect and non-compliance are common practice. Violations of federal and state air and water quality regulations, as well as criminal charges for illegal dumping of hazardous wastes are just some of the ways oil companies have failed to live up to their promises.[3]

- Spills of oil and other toxins of the trade occur frequently.
- Oil spills can have lasting impacts.
- Oil spill risks are greater in the Arctic, especially offshore. No known technology exists to clean up offshore spills in broken ice.

"[T]he fact of the matter is that sometimes leaks will occur."[4]

Congressman Don Young, March 2006

OIL COMPANY VIOLATIONS

1998 Doyon Drilling was found guilty of 15 counts of violating the Oil Pollution Act of 1990 and fined $3 million for dumping hazardous wastes.[5]

2000 British Petroleum (BP) paid $6.5 million in civil penalties and $15.5 million in criminal fines, plus five years probation for late reporting of illegal hazardous dumping.[6]

2001 When a vandal's bullet punctured the trans-Alaska oil pipeline, the spill response plans failed, leaving the leak uncontained for 36 hours and spilling 285,600 gallons of crude oil.[7]

2002 Following a 60,000-gallon pipeline spill, BP paid $675,000 in civil fines[8] and $300,000 for delaying installation of leak detection systems for Prudhoe Bay crude oil transmission lines.[9]

2004 ConocoPhillips incurred $485,000 in fines for 470 Clean Water Act violations in five years.[10]

2005 BP was fined $1.3 million by the Alaska Oil and Gas Conservation Commission for safety violations after an explosion and fire at a Prudhoe Bay oil well.[11]

2007 BP was fined $20 million including criminal penalties and probation for knowingly neglecting corroded pipelines, which resulted in spills affecting fragile tundra and a lake.[12]

2009 The federal government and the State of Alaska filed separate lawsuits against BP over March and August 2006 oil spills on the North Slope. The federal government is seeking more than $5 million, and penalties as much as four times that amount.[13] The state suit seeks fines, back taxes and other damages approaching $1 billion.[14]

Spills have lasting impacts

In addition to exaggerating safeguards and controls over oil spills, oil companies often downplay the impact of spills. For example, a spokesperson for Exxon commented that oil spills may have short term impacts, but over the long term "there is full recovery."[15] In fact, the effect of an oil spill will depend on the amount and type of oil or other toxin spilled, where and when the spill occurs, and spill response. Spill impacts can persist for decades, as they have in Prince William Sound twenty years after the Exxon Valdez spill.[16] Scientific studies of the Exxon Valdez spill have also shown that oil is several hundred times more toxic than previously thought.[17]

Pollution in the Arctic has more severe and persistent effects than in temperate regions. Recovery from spills in the Arctic is slower due to cold temperatures, slower growth rates for plants, fewer species and less variety of prey, and longer life spans of animals.[18] Oil takes much longer to break down, in part due to fewer microorganisms, hence oil may persist for decades.[19] Many spills on the North Slope do not spread beyond the gravel drilling pads, but the sites themselves can become contaminated and pose long-term restoration problems.[20] The Alaska Department of Environmental Conservation (ADEC) lists 192 contaminated sites caused by the North Slope oil industry. Fewer than a quarter of these have been cleaned to a level that meets state regulatory standards. [21]

Alaska Department of Environmental Conservation

No technology exists for cleaning spills in Arctic waters

The impacts of an oil spill in marine waters could prove to be much worse than spills on land, especially in the Arctic. No technology currently exists for cleaning oil in the presence of broken ice.[22] Traditional oil spill response methods are ineffective in dynamic sea ice conditions and the kinds of weather conditions that are common in Arctic waters.[23]

Industry leaders eager to begin drilling in the Chukchi and Beaufort Seas cite a December 2007 offshore oil spill in Norway as an example of how cleanups in Arctic waters are possible. But the comparison is misleading. For example, favorable weather conditions made it possible to contain that spill. Conditions in Arctic Ocean waters would be harsher and colder, making a spill harder to naturally dissolve or clean up.[24]

Oil spills can and do occur during any phase of oil development, from exploration to production to transportation. Increased oil and gas exploration in Alaska, especially offshore, will only add to accumulating impacts and increase the chances of a catastrophic spill.

Alaska Department of Environmental Conservation

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[8] State of Alaska. November 14, 2002. BPXA Flowline 86-D Settlement Agreement.

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[21] Alaska Department of Environmental Conservation. Contaminated sites database.

Downloaded March 14, 2009. Data analysis by Pam Miller, Northern Alaska Environmental Center. http://www.dec.state.ak.us/spar/csp/db_search.htm Sorted for only North Slope cities; excluded non-oil industry sites, military and former defense sites, and village sites unless oil industry is responsible party. A total of 192 North Slope oil industry sites are listed in ADEC database; 62 are Open sites (not yet cleaned up); 86 are Cleanup Complete – Institutional Controls (active cleanup ended but contamination still exists and continued monitoring is required); 44 are Closed (however, records show for at least 10 there may be samples with range organics, benzene and other toxics at levels exceeding state regulatory standards).

Alaska Department of Environmental Conservation, January 2007, Alaska's legacy of oil and hazardous substance pollution: Cleanup and management of Alaska's contaminated sites. http://www.dec.state.ak.us/spar/csp/docs/csstory.pdf (accessed July 19, 2009).

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BROKEN PROMISE #6

Pollution

Pamela A. Miller

The Promise

Pollution from oil and gas development is insignificant.

The Reality

Oil development activities generate significant pollution.

More than 2,500 chemicals are used by the oil and gas industry.[1] These chemicals in liquid and gas form, together with dust and particulate matter, pollute the environment and can be harmful to people. Noise is also a significant source of oil industry pollution with impacts to wildlife and people. Although laws are in place to regulate hazardous substances found in oil and used in its production, these laws are often violated and the opportunities for accidents, spills and leaks are significant. Furthermore, the oil industry is exempt from many regulations and is not required to report all information about pollution and toxic waste management, making it difficult to document all the sources and full extent of pollutants.

Many types and sources of pollution

In Arctic Alaska drill rigs, pump stations, refineries, compressor plants, production centers, seawater injection plants, sewage treatment plants, operation centers, power stations, turbines, generators, storage tanks, gravel pits, and gas flaring are all sources of pollution. Quantities of other pollution sources, including buses and trucks, bulldozers and seismic vehicles, small incinerators, fuel tanks, airplanes, and dust from gravel pits and roads, are unknown because they do not require permits. Some of the types, sources, and impacts of pollution that can occur throughout the oil development process, from construction to drilling to waste disposal, are described in Table 6.1.

Drilling muds

Drilling muds are a mixture of water, oil, and chemicals, and are used to lubricate drill bits and prevent pressure blowouts during drilling.[2] When rock cuttings are brought up out of the drill hole they are contaminated with these muds, as well as with hazardous substances found naturally beneath the earth, such as arsenic, mercury, and radioactive materials.[3]

Seawater may also be used to enhance oil recovery, and it becomes what is known as produced water when it is drawn back up a well with the recovered oil and gas. It carries contaminants including radioactive compounds, carcinogens like benzene, naphthalene and toluene, ammonia and hydrogen sulfide.[4] Produced water accounts for up to 95% of waste generated in most oil fields.[5] When spilled on the tundra, produced water kills vegetation and creates long-lasting damage.[6]

In spite of these dangers, drilling muds, produced waters and other wastes resulting from oil and gas exploration or production are exempted from the hazardous waste requirements of the Resource Conservation and Recovery Act (RCRA).[7] If used by drycleaners, these same substances would be classified as hazardous.[8]

- The oil and gas industry generates many pollutants, not all of which are regulated.
- The oil industry enjoys special exceptions to rules regulating drilling wastes and air emissions.
- Oil industry Clean Air Act and Clean Water Act violations are not uncommon.

Exxon Valdez Oil Spill Trustees Council

Pollution	Impacts	Source
Dust	Can stunt vegetation growth, decrease air quality, and contribute to respiratory problems.	Construction activity, Vehicle traffic
Particulate Matter	Contributes to haze. Inhalation of particulates can cause respiratory ailments and cancer.	Vehicles, engines, machinery, gas venting and flaring
Diesel fuel	Fuel and exhaust contain carcinogenic substances.	Drilling muds, vehicles, engines and machinery
Toxic Metals	Toxic health effects.	Drilling muds, produced water, gas venting and flaring, diesel exhaust
Hydrogen Sulfide	Aggravates respiratory conditions, can cause central nervous system and cardiovascular problems.	Gas venting and flaring
BTEX (benzene, toluene, ethylbenzene, and xylenes)	Benzene is a carcinogen. Toulene may affect reproductive and central nervous systems. Ethylbenzene and xylenes have respiratory and neurological effects.	Gas venting, produced water, off-gasing from waste storage
Nitrogen oxides	React with other compounds to form ground level ozone and particulate pollution, and other toxins. Can affect lungs, heart, and central nervous system. May cause biological mutations.	Engine and vehicle exhaust, gas flaring
Polycyclic aromatic hydrocarbons	May be carcinogenic and cause reproductive problems in animals.	Diesel exhaust, gas flaring and off-gasing of stored waste
Methane	A greenhouse gas that contributes to climate change.	Gas venting
Sulfur dioxide	Reacts with other chemicals to form particulate pollution.	Engines, vehicles, gas flaring
Volatile organic compounds	Can combine with nitrogen oxides to form ground-level ozone, which can cause respiratory ailments such as asthma, and decreased lung function.	Gas venting and leaks, off-gasing from stored wastes, gas flaring, vehicles
Noise	Disrupts wildlife behavior and migration.	Air traffic, vehicles, machinery, all operations

TABLE 6.1: Oil Industry Pollution and its Sources [9]

Air pollution

The oil industry in Alaska has permission from the state to extend the official boundaries of its polluting facilities by as much as 250 meters on each side, creating an "air quality exclusion zone." This essentially increases the area that an oil company is allowed to pollute by nearly four times,[10] which allows air emissions to become diluted enough to meet federal standards.[11]

The oil industry on Alaska's North Slope annually generates more than twice the amount of nitrogen oxides than Washington, D.C. and many other U.S. cities.[12] Thousands of tons of sulfur dioxide, particulate matter, carbon monoxide and volatile organic compounds are also emitted annually, along with the greenhouse gases methane and carbon dioxide.[13] The Alaska Department of Environmental Conservation reported in January 2008 that Alaska's oil and gas industry is the single largest contributor of greenhouse gas emissions in the state, accounting for 15.26 Million Metric Tons of carbon dioxide equivalents.[14]

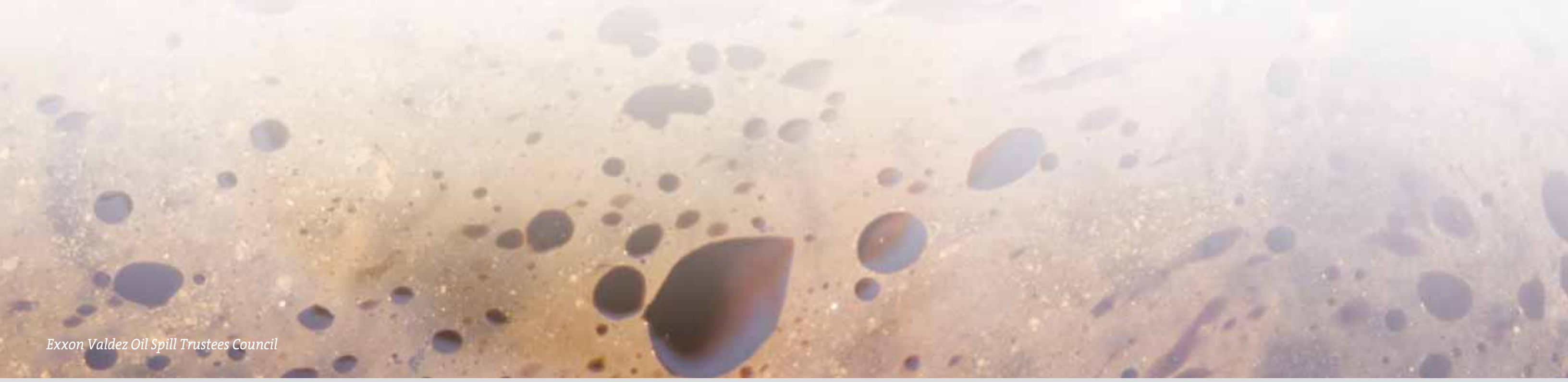
Of all contaminated sites in Alaska, 81% are polluted by petroleum products.[15]

Clean Air and Water Act violations

Clean Air and Clean Water Act violations by the oil industry in Alaska are not uncommon. For example, 470 Clean Water Act violations in five years were incurred by ConocoPhillips in Cook Inlet.[16] The same company violated the Clean Air Act at its Alpine oil field as a result of high carbon monoxide emissions exceeding what was permitted by the air quality permit for a year-long period.[17] British Petroleum is also facing millions of dollars in fines for both Clean Air and Clean Water Act violations associated with a series of oil spills that occurred in 2006 as a result of pipeline corrosion and maintenance problems.[18] And the Environmental Protection Agency is still investigating a 2003 incident where toxic drilling muds were dumped into coastal waters at Prudhoe Bay.[19]

These and many other examples highlight how pollution is a serious problem for the oil industry in Alaska and compliance remains an issue. Both state and federal agencies have resisted tightening rules[20] and oil companies have been permitted to operate with exceptions, exemptions, or in violation of standards.[21]

According to the National Academy of Sciences little research has been done to quantify the effects of air pollution on the North Slope.[22] Especially if oil development expands into new and previously undeveloped areas, it will be important to better understand the full scope and extent of pollution caused by oil and gas development activities and curb its impacts.



Exxon Valdez Oil Spill Trustees Council

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BROKEN PROMISE #7

Not-so-strict Environmental Regulations

Workers test for weakness due to corrosion in a Prudhoe Bay oil pipeline.

Al Grillo / Associated Press

The Promise

The oil industry in Alaska operates under the strictest environmental regulations.

The Reality

Many rules regulating the oil industry in Alaska are already weak, and getting weaker.

Industry and government officials make promises time and again to hold oil development activities to the "strictest environmental standards,"[1] and assure the American people that proposed new development will only move forward in the most environmentally safe and responsible manner possible.[2] But state and federal agencies have actually weakened rules and given exemptions for oil development activities in Alaska.

Oil spill prevention, planning, and preparedness standards weakened

After the Exxon Valdez oil spill the Alaska Legislature enacted laws that revised oil spill contingency plan requirements, specified oil spill response standards, and strengthened the Alaska Department of Environmental Conservation's (ADEC) ability to enforce those rules. Under Governor Frank Murkowski's administration, however, the Alaska legislature adopted amendments to the oil spill contingency plan requirements that weakened them in many respects. Since then, ADEC has been interpreting the regulations so as to further weaken contingency planning.[3] For example, multiple facilities may now be grouped under a single contingency plan;[4] and contingency plans are no longer required to include procedures for controlling a well blowout. Although well blowouts have rarely occurred in Alaska, as long as oil exploration and production facilities operate, they pose a risk for which responders may not be adequately prepared.[5]

Hazardous wastes and toxic releases exempt from regulation

The Resource Conservation and Recovery Act (RCRA) is a federal law that governs the disposal of hazardous waste. But certain oil and gas extraction wastes, including drilling muds and cuttings, rig waste, and produced water, are exempt from regulation by RCRA[6] despite containing many hazardous compounds. Drilling muds may be composed from over 1,000 different chemical compounds, but the formulas are considered proprietary information and are not even made available to the Environmental Protection Agency.[7] If any other industry, such as dry cleaning, produced these same wastes, they would be regulated as hazardous and require special handling.[8]

- Laws regulating the oil industry in Alaska are weak and getting weaker.
- Oil spill plans are less stringent than in the past.
- The oil industry is exempt from some hazardous waste regulation, toxic release reporting, and air pollution controls.
- Laws protecting Alaska's wetlands and coasts favor industry interests.

Pamela A. Miller

The 1986 Emergency Planning and Community Right to Know Act requires many polluters to report annually their toxic releases for inclusion in a public database.[9] In 1996, the oil industry obtained exemption from this Act for most of their exploration and production facilities. No facilities on Alaska's North Slope are required to report their toxic releases.[10]

Air Pollution Exemptions

Diesel exhaust contains pollutants that may increase asthma, respiratory problems, and cancer, and contribute to acid rain and ozone formation. The U.S. Environmental Protection Agency (EPA) passed new rules requiring very low levels of sulfur in diesel fuel.[11] In 2004, the state of Alaska asked for and received some temporary exemptions to the rules, including a 4-year delay for using low sulfur diesel in all on-road vehicles on the North Slope. As part of the agreement, British Petroleum and ConocoPhillips promised to retrofit their small refineries to produce low sulfur diesel starting January 1, 2008 and to use this cleaner fuel more widely than federal regulations required. The companies have since announced that they will not be making low sulfur diesel on the North Slope after all.[12] It remains to be seen how industry will meet the requirement that all diesel powered vehicles use low sulfur by June 2010. Oil companies operating on Alaska's North Slope already have permission to pollute areas larger than normally allowed,[13] and hundreds of "minor" sources of pollution remain unregulated.[14]

Reduced Protection for Wetlands and Coasts

While serving as Governor, Frank Murkowski weakened Alaska water law by eliminating requirements for public notice and comment on temporary water use permits. These 5-year permits enable the oil industry to use hundreds of millions of gallons of water for ice roads, drilling and other uses with potentially serious impacts for wetlands and lake ecology and fish habitat.[15]


Joel Sartore

Oil workers perform a 'work over' on a thirty-year-old well head in Prudoe Bay.

Since 1979, of the thousands of Clean Water Act Section 404 permit applications filed by North Slope operators seeking permission to discharge dredge material, fill, and other pollutants into waters and wetlands, only three had been denied as of 2002. Fewer than one percent of these permits contain specific restoration requirements, and the oil industry is also not required to mitigate any wetlands damage.[16]

Also at Governor Murkowski's request, the Alaska legislature gutted the local community role in its Alaska Coastal Management Program (ACMP), handing over that authority to the pro-development Alaska Department of Natural Resources.[17] The result could have profound impacts for offshore oil and gas development, for example by denying citizens the right to challenge consistency determinations[18] -- special certifications required to ensure that federal projects are in compliance with state coastal zone management programs.

Lincoln Else

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BROKEN PROMISE #8

Impacts to Wildlife

Grizzly bears at Prudhoe Bay oilfield garbage dump.

Joel Sartore

The Promise

Oil development takes place in harmony with healthy wildlife populations.

The Reality

Oil and gas exploration and development harm wildlife and habitat.

Decades of research supports the conclusion that oil and gas development in Arctic Alaska has negative impacts on wildlife and habitat. As early as 1987, the Department of Interior studied potential impacts of oil development on the coastal plain of the Arctic National Wildlife Refuge (Arctic Refuge) and concluded there would be major impacts to the Porcupine Caribou Herd, muskox, water quality and quantity.[1] These conclusions were reiterated in a 1995 science review conducted by the U.S. Fish and Wildlife Service.[2] In 2002, U.S Geological Survey biologists released a report based on 12 years of studies that further substantiated the potential impacts of oil development in the Arctic Refuge on the Porcupine Caribou Herd, and other animals.[3] A year later, the National Academy of Sciences released a major study looking beyond the Arctic Refuge and documenting cumulative impacts of oil development on wildlife across an extensive area of Alaska's North Slope,including offshore areas.[4]

These studies make clear that oil and gas development negatively impacts wildlife through direct mortality and displacement, reduced reproductive rates, and better conditions for predators. Futhermore, significant effects to wildlife and habitat will accumulate as industry expands.[5] To suggest that wildlife and oil development can safely coexist not only ignores the prevailing science, but ignores the additional impacts of climate change, which alone could push wildlife beyond thresholds of survival.

Caribou

Oil development proponents often support their assertion that industrial activity on Alaska's North Slope does no harm to wildlife by pointing to the Central Arctic Caribou Herd, whose calving grounds overlap with the Prudhoe Bay industrial complex. The herd has increased in size since about the time that North Slope development began.

- Wildlife, including caribou, are negatively impacted by oil development.
- Impacts to wildlife are direct, but also indirect as a result of impacts to habitat.
- Impacts from oil development are accumulating, and contributing to climate change, which further stresses wildlife.

"Animals have been affected by industrial activities on the North Slope....It [is] unlikely that most disturbed wildlife habitat on the North Slope will ever be restored."[6]

National Academy of Sciences, 2003

Subhankar Banerjee

But many factors can affect the growth or decline of caribou numbers,[7] and focusing just on numbers, or one herd, fails to tell the whole story. In fact, decades of studies of the five different caribou herds in the Arctic show that:

- Caribou numbers have decreased in developed areas on the North Slope suggesting that they avoid developed areas, especially for calving and during summer months.[8]
- Caribou numbers have been found to decline exponentially as the density of roads increases.[9]
- Larger groups (100 or more caribou) have difficulty crossing roads and pipelines.[10]
- When caribou cows are displaced from preferred calving areas, their calves are smaller at birth and may not grow as fast or survive as well.[11]
- Caribou calves born in an area west of Prudhoe Bay that has seen increasing development since the late 1980s weighed less and were slightly smaller than calves studied in an area east of Prudhoe Bay that is mostly undeveloped.[12]
- Even small changes can have profound effects on caribou populations.[13]

For the Porcupine caribou, a 4.6% reduction in calf survival would be enough to stall the herd's growth.[14] Scientists predict that any development in caribou calving grounds would displace caribou and impact calf survival.[15]

Bears, birds, and other wildlife

In addition to caribou, pictures of bears, foxes, and birds near oil fields are often misrepresented as evidence that wildlife can thrive in the midst of oil development. The real story such pictures tell is not so pleasant.

- Mortality rates for bears feeding on garbage in the oil fields are higher than for bears feeding on natural foods in an undisturbed habitat. Future development will result in destruction of additional grizzly bear habitat,[16] and increased defensive shooting of bears by humans.[17]
- Oil development activities have disturbed polar bears from maternity dens.[18] With sea ice loss, more polar bears are expected to den onshore,[19] thus increasing the likelihood of human-bear interactions and impacts similar to those observed with grizzly bears.
- Fox populations can increase when they establish dens near human settlements. Foxes prey on eggs, and artificially high fox numbers can in turn impact bird chick birth rates.[20]
- Nesting success of spectacled eiders is much lower in the oil fields than in other areas.[21]
- Important wetland habitat for birds has been filled by gravel.[22]
- Roads displace and interfere with wildlife movements, and kill animals in their path.[23]
- Birds are killed by powerlines and other infrastructure.[24]

Wayne Todd

U.S. Fish and Wildlife Service

U.S. Fish and Wildlife Service

Marine life

Offshore development impacts to wildlife can be even more serious. Seismic testing produces sonic shockwaves that can interfere with the way marine mammals communicate and detect prey. In extreme cases seismic testing can damage hearing and even cause death of marine species.[25] Also, both incremental oil spills and catastrophic ones pose threats to seafloor benthic life, fish, walrus, seals, whales, seabirds, and potentially also coastal wildlife.[26] As one example, scientists estimate that if an oil spill were to occur from the Northstar oil field in the Beaufort sea, as many as 70 polar bears could be oiled.[27]

Future development

These and many other impacts to wildlife continue to accumulate on Alaska's North Slope. As drilling proponents press to expand operations offshore, both marine and terrestrial species will face increased impacts from seismic testing, air, land, and marine traffic, and the industrial infrastructure required to support oil development. Oil and gas development not only puts species at risk, but also affects the livelihoods of local people who depend on these animals for food, cultural traditions, and income.

National Oceanic and Atmospheric Administration

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BROKEN PROMISE #9

Human Health Impacts

Inupiat boys watch their elders in a seal skin boat.

Joel Sartore

The Promise

Oil development impacts on subsistence are minor and should not affect human health.

The Reality

Oil development has social, cultural and health effects that disproportionately impact Native people who depend on subsistence.

Alaska Native people have sustained for generations a relationship with the land, water, and wildlife that permeates every aspect of their lives from basic survival, to social norms, to spiritual beliefs. Industrial scale development on Alaska's North Slope has affected this subsistence way of life and contributed to social and health problems. Although oil revenues have helped fund schools and medical clinics, adverse human impacts are accumulating and could further accrue as development threatens to move into the Beaufort and Chukchi Seas, and Bristol Bay.

"Our whole way of life as a people is tied to the Porcupine caribou. It is in our language, and our songs and stories."

Sarah James, Arctic Village[1]

Subsistence

Subsistence activities are very important to Alaska Native people and communities. In Inupiaq villages along Alaska's Arctic coast, "individual and community identity is tied closely to the procurement and distribution of bowhead whales."[2] For the Gwich'in who live further inland, caribou are at the center of cultural traditions. In the Bristol Bay region, salmon are a mainstay for the Aleut, Athabaskan, and Yupik people, representing for some more than half of the wild food consumed.[3] A variety of fish, birds, berries, and other plants are important subsistence resources for all Alaska Native people.

Oil development can impact subsistence resources directly. For example, Native people have reported changes in the size, taste, quality and quantity of fish and caribou in industrial areas.[4] Scientific research supports these claims. For example, one study showed evidence that caribou that spent more time in or near oil fields gained less weight during the summer growing season and had lower pregnancy rates and calf survival than caribou of the same herd that seldom encountered development.[5] Nuiqsut residents have also reported how seismic exploration activities have damaged berries and other plants.[6]

With these direct impacts to subsistence plants and animals comes anxiety that food may not be safe to eat, that game is more difficult to find, and that hunters may not be able to provide for their families.[7] Already, subsistence activities have been affected by the reduction in areas available for hunting as a result of oil field closures, because the high density of roads and pipelines prohibits travel, or simply because hunters are reluctant to enter the oil fields.[8] As oil fields spread, the reduction of hunting grounds will increase.

- Oil development affects subsistence through direct impacts to wildlife and by interfering with hunters' access to species.
- Oil development has brought with it pollution and social changes that have contributed to increased health problems.
- Impacts to people accumulate with increasing development.

Lincoln Else

Oil development can also affect migratory routes of caribou, whales, birds, and other species,[9] driving them further from historic ranges and traditional hunting grounds. At the same time, climate change is affecting species migration and hunting access. For example, hunters in search of seals, walrus and whales are encountering thinner sea ice.[10] Oil development impacts could easily compound these problems, forcing hunters to travel farther distances across already treacherous terrain.


Nicole Whittington-Evans

"The Yupik people depend on seafood caught in Bristol Bay. It's not just our food, it's our livelihood, our way of life. It's everything to us."

– Verner Wilson III[18]

Health

When drilling was proposed just outside the town limits of Nuiqsut in the early 1990s, the oil companies told residents that drilling would not affect the environment or hunting. But residents say "the reality has not matched the promises."[11] Not only have residents observed and reported changes to subsistence resources and their access to these resources, but environmental impacts have also been affecting their health.

The Bureau of Land Management (BLM) reported in a recent environmental impact statement that cancer and chronic diseases such as diabetes, hypertension and asthma, are increasing among Alaska Natives especially on the North Slope.[12] Observations reported by a health aide working in Nuiqsit support this with reports of asthma increasing more than tenfold between 1985 and 1998.[13]

BLM has acknowledged that pollutants prevalent in oil fields, including nitrogen dioxide, sulphur dioxide, ozone, lead, and carbon monoxide are "causing and exacerbating respiratory illnesses" and "have been associated with...excess overall mortality rates among vulnerable groups."[14] The agency also noted that increased levels of oil development activity could result in substantial impacts to human health, primarily as a result of restrictions to subsistence.[15]

Social effects and cumulative impacts

The National Academy of Sciences concluded in its extensive study of cumulative environmental effects of oil and gas development on the North Slope that there has not been adequate attention given to human health and "petroleum development has resulted in major, significant, and probably irreversible changes to the way of life on the North Slope."[16] The study noted that changes to subsistence resources "affects far more than food supplies."[17]

"Social and cultural changes inevitably have been accompanied by social and individual pathology,"[19] including increased problems with alchohol and drug abuse, and domestic violence. Those affects accumulate because they arise from several causes, which interact. The Exxon Valdez spill provides an example of what can happen:

> *"Several studies documented that the social fabric of many communities essentially fell apart following the spill. There were well documented, often dramatic increases in post-spill anxiety disorders, post-traumatic stress, depression, alcohol and drug abuse, domestic violence, conflict among friends and within families, divorce, and even suicides tied directly to the spill. These impacts came mostly from uncertainty about the ecosystem's future, fear of food contamination, the chaos of the cleanup, and the ongoing fish stock collapses. Many residents have moved elsewhere to avoid the ongoing stress and memory of the spill."* [20]

Perceived risks to culture are already accumulating sources of stress for the Inupiat and Gwich'in people.[21]

"The central question when considering the cumulative human health effects of … development is whether it will be possible for the North Slope Inupiat to maintain a culture and way of life based on subsistence. Residents fear that the combination of pressures they now face – modernization, acculturation, global warming and curtailment of subsistence through expanding development threatens the viability of this cornerstone of Inupiat life. Destabilization of the cultural and social systems would be expected to cause serious health consequences. As oil and gas development both on and off shore expands in the region, more villages may face impacts similar to those faced by Nuiqsut."

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BROKEN PROMISE #10

Fossil Fuels & Global Warming

Melting permafrost in the Arctic National Wildlife Refuge.

Brad Meiklejohn

The Promise

Oil and gas can be developed safely and responsibly to provide a bridge to cleaner energy.

The Reality

New oil and gas development will add more stress to a region already experiencing climate change impacts, and will exacerbate global warming.

Oil development interests insist that because "fossil fuels will continue to provide the majority of the world's growing need for energy for decades to come,"[1] the continued development of new oil and gas resources is critical.[2] In fact, the continued expansion of oil and gas development, especially in environmentally sensitive places such as the Arctic Ocean, will only add to the threats Arctic ecosystems and cultures are facing and distract from the urgent need to address climate change.

The primary source of greenhouse gas pollution is the burning of fossil fuels.

Petroleum consumption alone accounted for 44% of U.S. CO_2 emissions in 2006.[3] Scientists believe that to avoid catastrophic changes affecting climate and ultimately life on Earth, we must reduce CO_2 in the atmosphere to 350 ppm, down from current levels of 380 ppm.[4] Only by dramatically reducing the amount of fossil fuels we extract and burn for energy can we meet this goal. According to the Intergovernmental Panel on Climate Change this will require nations like the United States to reduce their carbon emissions by 20-35% below 1990 levels by 2020, and 80-95% below 1990 levels by 2050.[5]

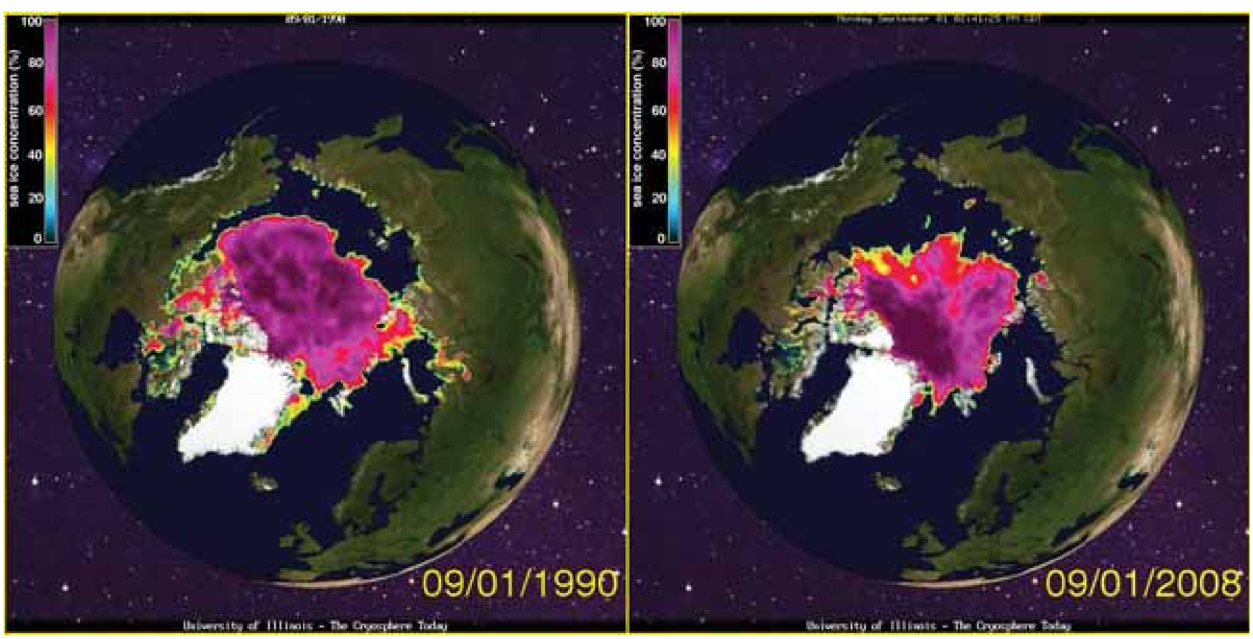
Alaska is one of the top greenhouse gas-emitting states in the nation.[6]

Despite having one of the lowest populations, Alaska released in 2005 the equivalent of 79 tons of greenhouse gases per resident, which is more than three times the national average,[7] and fifteen times more pollution than the average passenger vehicle emits in one year.[8] More than half of Alaska's industrial source greenhouse gas emissions are generated by British Petroleum (BP Exploration Alaska), which operates most of the Prudhoe Bay oil fields.[9]

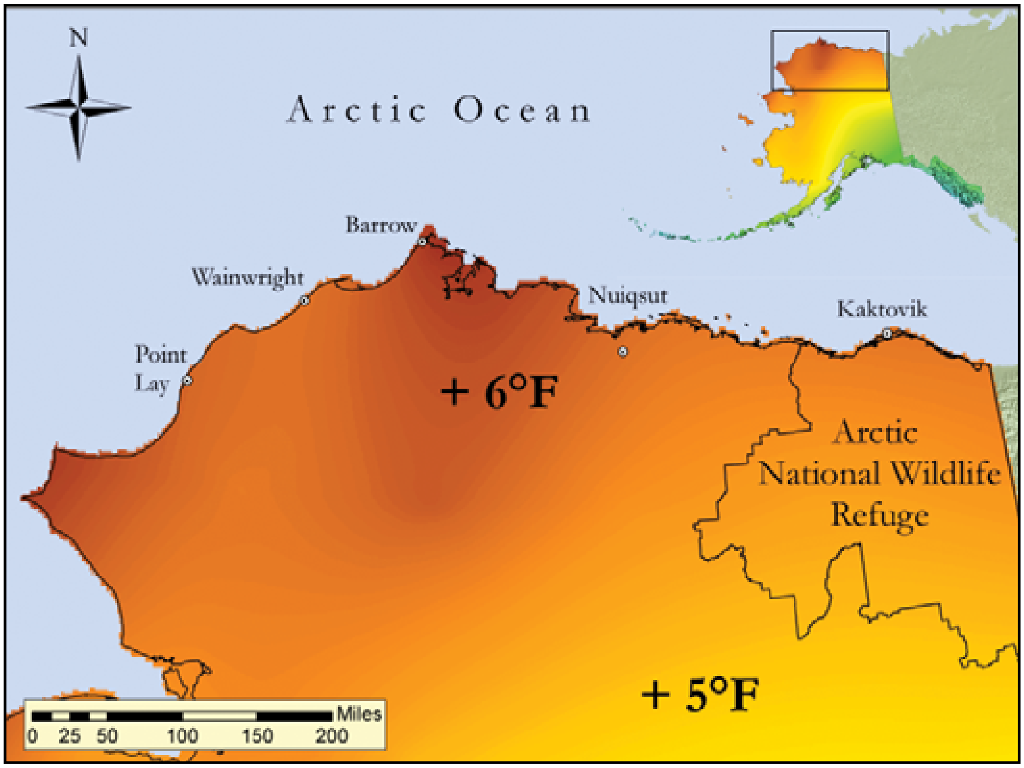
Climate change is already impacting Alaska.

Arctic regions are warming at twice the rate of other places on Earth.[10] Such dramatic increases in temperature have resulted in profound and visible changes to Alaska's land, water, wildlife, and people.

- Oil and gas development is a major source of greenhouse gases and a significant cause of climate change.
- Climate change is already adversely impacting Arctic ecosystems and indigenous people in Alaska.
- Continuing to extract fossil fuels in the Arctic will only add stress to already vulnerable ecosystems and indigenous communities.



Comparison satellite images of summer sea ice cover.
Source: University of Illinois – The Cryoshpere Today, http://igloo.atmos.uiuc.edu/cgi-bin/test/print.sh.



Arctic Alaska is already warming faster than other places in the world, and climate models predict temperatures will increase by as much as 6 degrees by 2040.

Among the more profound changes is the loss of sea ice, which is at the lowest levels in 800 years.[11] As a result of receding and thinning sea ice scientists have observed polar bears drowning and going hungry,[12] walruses forced onto land,[13] and sharp declines in numbers of ice-dependent sea birds.[14] Subsistence hunters have had to travel farther across thinner ice, and sometimes open seas, to access animals.[15] The loss of ice, coupled with melting permafrost, is accelerating coastal erosion, forcing communities to relocate, and threatening habitat for waterfowl, and caribou,[16] which are also important food sources for indigenous people. Also due to coastal erosion, an emergency clean-up was required in 2007 to plug an old oil exploration well after more than 300 feet of shoreline was lost in a few months.[17]

As temperatures continue to rise and precipitation patterns change, scientists expect lakes and wetlands to dry, fires to increase, and plant and animal distributions to change.[18] These anticipated changes have significant health, social and economic implications for people living in the Arctic, and beyond.[19] What is happening in the Arctic affects not just the wildlife and

According to current scientific consensus, it is the burning of oil (and other fossil fuels) that has contributed significantly to the Arctic's warming trend.[20]

people living there, but also has implications for global weather patterns and the survival of species that migrate to the Arctic from other parts of the world.[21]

America's Arctic contains important onshore and offshore feeding, denning, calving, nursery, nesting, staging, and molting habitats for hundreds of species and contains some of the world's last wholly intact ecosystems. If we do not address climate change in the Arctic, and elsewhere, 30 percent of the world's species and one-fifth of the world's ecosystems could be gone by 2050.[22] The result of such losses could affect agriculture, medicines and building materials sourced from plants, jobs, and ways of life that we now take for granted.[23] Even oil production on the North Slope could be impacted by warming temperatures, which have already reduced the number of days that ice roads can be used.[24]

Given what we know about the impacts of climate change to ecosystems, species, and cultures, it would be irresponsible to undertake new drilling activities that would accelerate such change and bring harm to wildlife and people.

U.S. Geological Survey

[1] http://www.shell.com. Online fact sheet. Our approach to climate change. Last visited May 22, 2009.

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[4] http://www.350.org/en/about/science

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[6] Alaska Department of Environmental Conservation. (2008). Alaska greenhouse gas emission inventory. http://www.climatechange.alaska.gov/docs/ghg_ei_rpt.pdf.

[7] Kizzia, Tom. (2008, January 22). Alaska Alaska plays significant role in world's warming. Anchorage Daily News.

[8] Driving one passenger vehicle 12,000 miles per year generates about 5.5 metric tons of carbon dioxide. Source: Environmental Protection Agency, Office of Transportation and Air Quality. (February 2005). Emissions Facts: Greenhouse Gas Emissions from a Typical Passenger Vehicle. EPA420-F-05-004. (http://www.epa.gov/OMS/climate/420f05004.htm).

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[11] Science Daily. (2009, July 2). Sea ice at lowest level in 800 years near Greenland. Journal reference: Macias Fauria et al. Unprecedented low twentieth century winter sea ice extent in the Western Nordic Seas since A.D. 1200. Climate Dynamics, 2009.

[12] Carlton, Jim. (2005, December 14). Is global warming killing the polar bears? The Wall Street Journal.

[13] Joling, Dan. (2007, October 6). Melting ice pack displaces Alaska walrus. Associated Press, USA Today.

[14] The black guillemot colony on Cooper Island off the northern coast of Alaska has declined sharply apparently as a direct result of climate change. Source: Alaska Conservation Foundation. Global Warming: Alaska on the Front Line. (March 2007). Brochure.

[15] In 2002, more than 100 stranded hunters from Shishmaref had to be rescued when the ice they were hunting on drifted too far from shore. DeMarban, Alex. (2009, August 29). Webcam helps Barrow hunters find whales. Juneau Empire. Published in Anchorage Daily News.

[16] Mars, J.C. and D.W. Houseknecht. Geology. July 2007. Quantitative remote sensing study indicates doubling of coastal erosion rate in past 50 yr along a segment of the Arctic coast of Alaska.

[17] Rosen, Yereth. (2007, July 25). Erosion may send Alaska oil wells into the ocean. Reuters.

[18] United States Global Change Research Program.

[19] Because of their deep concern for climate changes they have already observed, some Alaska Natives have joined indigenous people worldwide in a call for a moratorium on new oil and gas drilling through a declaration written and agreed to by participants in the Indigenous Peoples' Global Summit on Climate Change, April 2009, Anchorage, Alaska. http://www.indigenoussummit.com/servlet/content/home.html.

[20] Glick, Daniel. (2005). Degrees of Change. Nature Conservancy magazine. p. 45.

[21] As goes the Arctic so goes the planet. Petition for rulemaking under the clean air act to regulate greenhouse gas emissions from mobile and stationary sources to protect the health and welfare of the Arctic and the world. (2008, November). pp. 12-17.

[22] Intergovernmental Panel on Climate Change. (2007). Summary for policymakers. In: Climate change 2007: impacts, adaptation, and vulnerability. Working group II contribution to the fourth assessment report of the Intergovernmental panel on climate change. P. 792.

[23] United States Global Change Research Program.

[24] National Research Council. (2003). Cumulative environmental impacts of oil and gas activities on Alaska's North Slope. Washington, DC: National Academies Press. pp. 56-57.

Conclusion

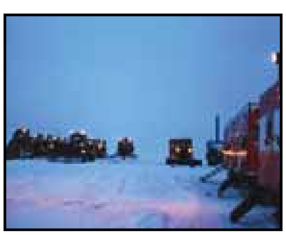
The realities of oil development in America's Arctic are impossible to ignore.

Millions of gallons of oil and other toxic substances have been spilled on Alaska's North Slope—on average, there is more than one spill per day. Seismic exploration leaves visible scars across the tundra. Significant hazardous waste and pollution is either legally permitted, or simply left unregulated and uncontrolled. And greenhouse gas emissions—the ultimate, unavoidable result of oil development—are now profoundly altering Arctic ecosystems and their ability to help cool the rest of the planet.

Still, oil development proponents continue to make the same promises that oil development will not harm Alaska's environment or its people, and continue to press for drilling in some of Alaska's most ecologically and culturally important places. Places like Bristol Bay and the Arctic Ocean have irreplaceable fisheries and wildlife values, which sustain cultural traditions and local economies. The Arctic National Wildlife Refuge is a national treasure and one of the very few areas not open to oil leasing. As policy-makers consider if, when, where, and how to develop energy resources in the Arctic and elsewhere in Alaska, it is critical that they base decisions on the best available science, not on politically-motivated rhetoric.

Especially as the Arctic is facing dramatic transformation as a result of climate change, responsible leaders must protect these priceless places for the lasting benefit of future generations. Industry promises have been and will continue to be broken. But we can no longer afford to ignore the facts and make ill informed decisions or careless choices that place Alaska's—or the nation's—irreplaceable wildlife and cultural values at risk.

AK Dept. Environmental Conservation



NOAA

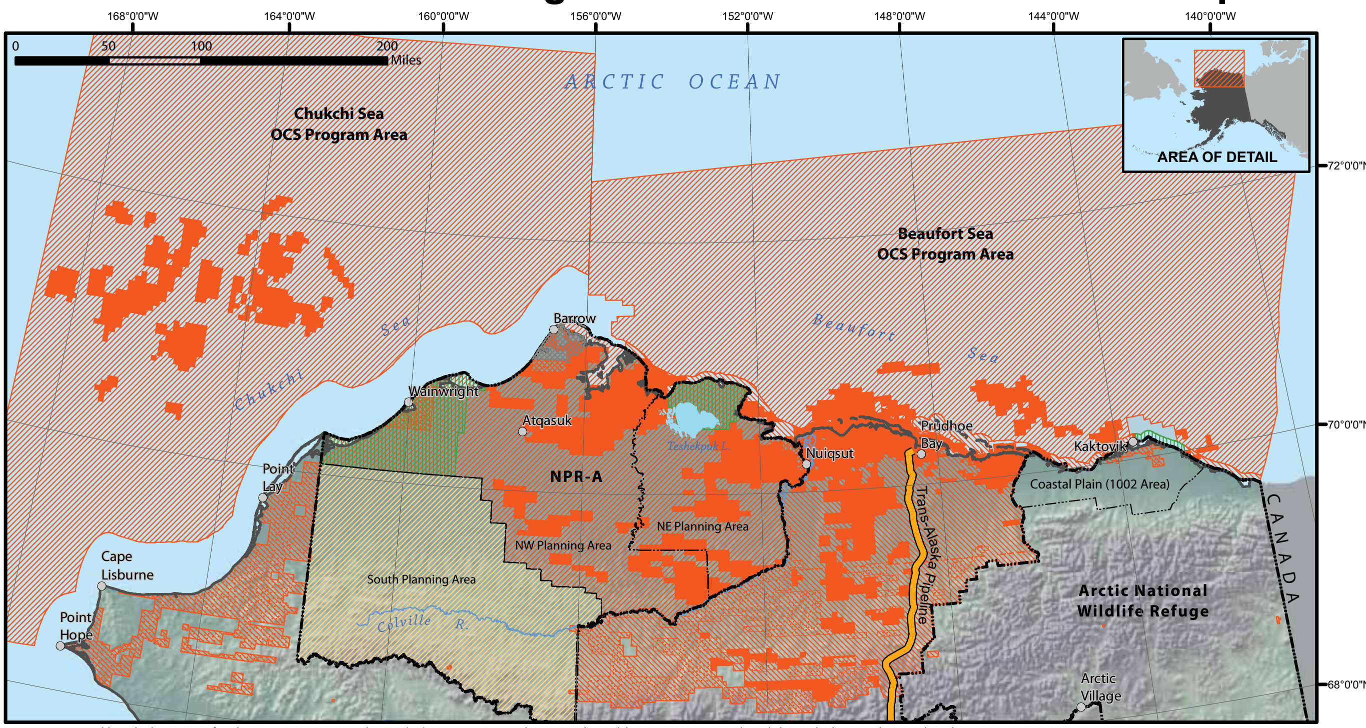
Lincoln Else

AK Dept. Environmental Conservation

U.S. Fish & Wildlife Service

Pamela A. Miller

Oil & Gas Leasing on Alaska's North Slope



*Map composed by Alaska Center for the Environment, Northern Alaska Environmental Center, The Wilderness Society, and Audubon Alaska Map last updated August 11, 2009.

Map Features

- Sold Federal and State Leases
- Active Federal Lease Area
- Potential Federal Lease Area
- Active State Lease Area
- Arctic Slope Regional Corporation (Surface &/or Subsurface Rights)
- Deferred Federal Lease Area (Temporary, Length of Time Varies)
- Barrow Native Lands

National Petroleum Reserve - Alaska (Federal BLM)

** Northeast Planning Area*
4.6 million acres - 95% opened to lease
430,000 acres deferred from leasing until 2018
Next lease sale 2010

** Northwest Planning Area*
8.8 million acres - 100% opened to lease
1.5 million acres deferred from leasing until 2014
Next lease sale 2010

** South Planning Area*
9.2 million acres
Scoping completed 2006

Arctic Ocean (Federal MMS)

** Beaufort Sea Program Area 2007 - 2012*
33.2 million acres
Lease Sale 202 - 97% offered for lease in 2007
Next Lease Sale (209) in 2010

** Chukchi Sea Program Area 2007 - 2012*
39.3 million acres
Lease Sale 193 - 75% offered in 2008
Next Lease Sale (212) in 2010

State

** North Slope Areawide, Foothills, and Beaufort Sea*
14.0 million acres in active lease areas
3.7 million acres in existing leases

Well over 90 percent of Alaska's Arctic, including 70 million acres offshore, is available to oil and gas exploration, leasing, and development. Only the coastal plain of the Arctic National Wildlife Refuge is protected by law from oil development.

Lincoln Else

Author
Anne E. Gore
Alaska Science Education Manager
The Wilderness Society

September 2009

Acknowledgements
The author would like to acknowledge the substantial contributions of Pamela A. Miller of the Northern Alaska Environmental Center, who wrote the first edition of Broken Promises and made available her notes, files and research for this second edition. Pam also contributed many hours of peer review, helped with citations, and updated several analyses and maps for this edition. Other individuals who made valuable editorial and design contributions include: Eleanor Huffines, former director, The Wilderness Society Alaska regional office; Doug Tosa, GIS analyst, Alaska Center for the Environment; and Melanie Smith, staff biologist and GIS analyst, Audubon Alaska. The author also wishes to thank the many colleagues at The Wilderness Society and partner organizations who provided additional review, edits, and other suggestions for improving this report.

THE WILDERNESS SOCIETY

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August 17, 2018

Shelly Jones, Acting District Manager
Arctic Field Office
Bureau of Land Management
222 University Ave.
Fairbanks, AK 99709
Sent to: blm_ak_coastal_plain_seismic_ea@blm.gov

Dear Ms Jones,

I find it inexplicable why and how BLM is rushing forward with a review of the 3D seismic permit application for the entire Coastal Plain "1002 area" of the Arctic National Wildlife Refuge proposed by SAE and partners Arctic Slope Regional Corporation and Kaktovik Inupiat Corporation.

BLM is already rushing the Coastal Plain oil and gas leasing EIS and now spins even faster by jumping ahead by preparing a separate EA for this 3-D seismic exploration. Such pre-leasing seismic will provide private information to corporations to advance their private interests for the broader program of oil and gas leasing and development in the refuge as authorized by the Tax Bill of 2017. BLM should reject the SAE application outright.

BLM has made public statements that it believes seismic exploration in the Arctic Refuge will not be significant and therefore an EIS is not necessary. This ungrounded statement belies common sense for many reasons especially that the Coastal Plain of the Arctic Refuge was protected for the purposes of preserving wilderness, wildlife, and recreation for more than 50 years. The Coastal Plain was recommended for Wilderness designation at the conclusion of a long public conservation plan and EIS process in 2015. The abrupt reversal of the national commitment for protection by the Tax Act with nary a hearing on its provisions in December 2017 requires true public involvement and consideration of the full range of impacts, not a slippery and opaque process like oil seeping on water.

BLM must not separate this NEPA review and potentially allow destructive activities like SAE's proposal without first preparing an EIS that examines the full range of potential impacts from all phases of oil and gas activities. An EIS would need, among other things, to examine how the potential impacts of seismic exploration would combine with those of all other reasonably foreseeable oil and gas related activities in the Refuge—including leasing, exploration, development, production, transportation, and dismantling and restoration—in a single EIS to ensure that BLM will protect the resources of the Arctic Refuge.

In the Arctic Refuge Coastal Plain, significant, long-term impacts to vegetation, including changes in plant species diversity, and permafrost melt lasting decades were documented by the rigorous monitoring studies for the 2D seismic surveys in 1984-85 for the 1002h studies as summarized by the National Research Council (2003)[1] and subsequent scientific studies.

---

[1] NRC 2003, Cumulative Environmental Effects of Oil and Gas Development on Alaska's North Slope.

As a wildlife biologist and seismic monitor as part of the 1002 studies, I witnessed during winter and summer the seismic trails and "cattrain" camp and fuel hauling moves that pressed and rutted into the tundra. I measured snow at -50F in blowing snow and dark and observed and participated in the operational challenges out there and saw how next to impossible it is to avoid sensitive habitats when the program comprises straight lines going east to west across the dozens of rivers flowing from the foothills of the Brooks Range northward to the shorelines of the Beaufort Sea in a complex hydrology. If the mobile camps "cattrains" were routed around windswept Dryas River terraces, riparian willows, or creek and river bluffs by going through deep snow along rivers, they often got stuck. Moreover, the deep snowbanks of rivers, lakes, and the coastline are critical denning habitat for polar bears (despite technology for finding bear dens, not all bear dens will be found). The proposed 3D seismic grid will be far more intensive with the tight grid of 660' wide sources lines on this intricate landscape.

Based on my experience, I am concerned about the impacts on overwintering fish and their habitats including lakes, streams, lagoons, rivers along with associated icings, springs, taliks, groundwater flows above or through permafrost and other hydrology; unique areas like the Sadlerochit Springs area; proposed activities on all fish and wildlife and their habitats, including migratory, resident, and overwintering species, and direct effects on those animals which may be present on or in the vicinity of the Coastal Plain during the timeframe of the proposed activities, including impacts that may result from damage to the Coastal Plain's vegetation and hydrological systems. Major impacts could result to migratory birds, caribou and other wildlife, subsistence, recreation and the environment during the time period outside the window described for the actual seismic surveys (not addressed by SAE). This includes aircraft take-off and landings and overflights and ground work for associated activities such as trash removal "stick-picking," spill response / cleanup, scientific baseline studies and monitoring, inspections, restoration and rehabilitation activities. BLM also should consider impacts to subsistence resources and users, human health, environmental justice, cultural resources, and archeological sites.

I am concerned about the impacts on existing and long-term scientific research including natural (undisturbed) study plots, inventory and monitoring; the impacts to recreation including long-term visual impacts from seismic lines; how rapidly increasing climate change influences seismic operations in the Coastal Plain area such as tundra travel period, snow cover, and heavy vehicle movements across tundra, rivers, and sea ice and the potential significant adverse impacts to fish, wildlife, and the environment, given that the last environmental impact analysis of 2D seismic in this region was done over 30 years ago.

At the onset of the surveys in 1984, inadequate snow cover was documented, but the surveys proceeded nonetheless. At this time, it is important to evaluate assumptions about the adequacy of protective snow. I offer some important considerations: What standards for determining adequate protective snow cover, and studies that document their effectiveness in preventing disturbance to vegetation, soils and permafrost?

- With criteria for opening and closing dates and standards for adequate protective snow cover in NPRA and State lands, what has been the outcome? What long-term studies show how well the standards work in protecting tundra vegetation, permafrost, river, lake and coastal banks? What real-time field monitoring has been done? When operating under the standards, there will always be some impact, was it acceptable or not?
- While there have been improvements in many seismic vehicle types and treads (e.g. from metal to rubber tracks), what tests have been done on vehicle and snow interactions, and for different slopes of terrain?

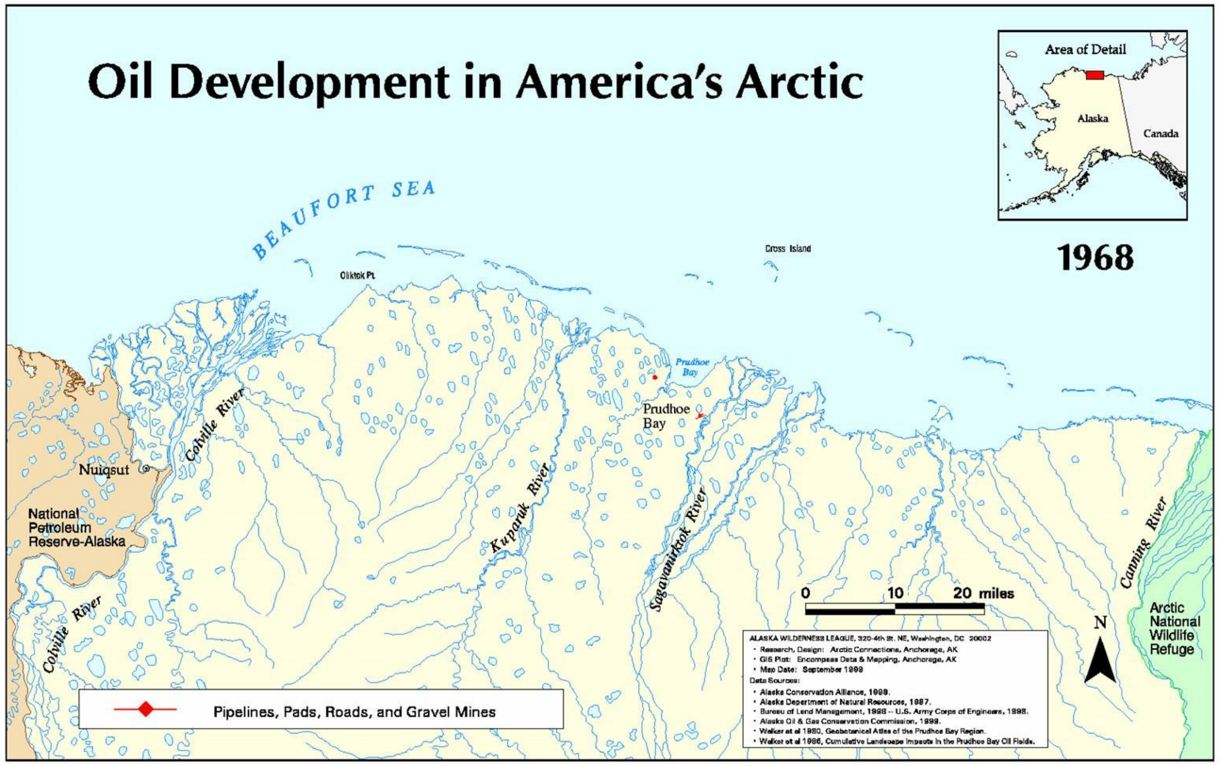
- In the Coastal Plain of the refuge there is generally thin snow cover-- this is not terrain like Prudhoe Bay or the NPRA - and it is very heterogeneous in this narrow band immediately North of the Brooks Range to the Beaufort Sea. The type of snow, density and hardness matters as much as the amount of snow. A stipulation based solely on snow depth not adequate, given that there can be significant differences in quality of protective cover given amount of air and ice.
- How will you determine if there is adequate protective snow cover? What is the protocol for sampling?
- How will the locations where snow measurements are taken be scientifically determined? What is the starting point, how many measurements, what is a sufficient number to get a reliable mean? What geographic unit of the Coastal Plain does each set of measurements cover?
- Depth criteria alone is insufficient, despite being convenient. Whether the snow is new or old affects the density which is a different factor for protection of the tundra. What is the mass of snow that will be between the tundra and the vehicles as it gets packed down? While density is easy to measure, there are not studies of depth and density.

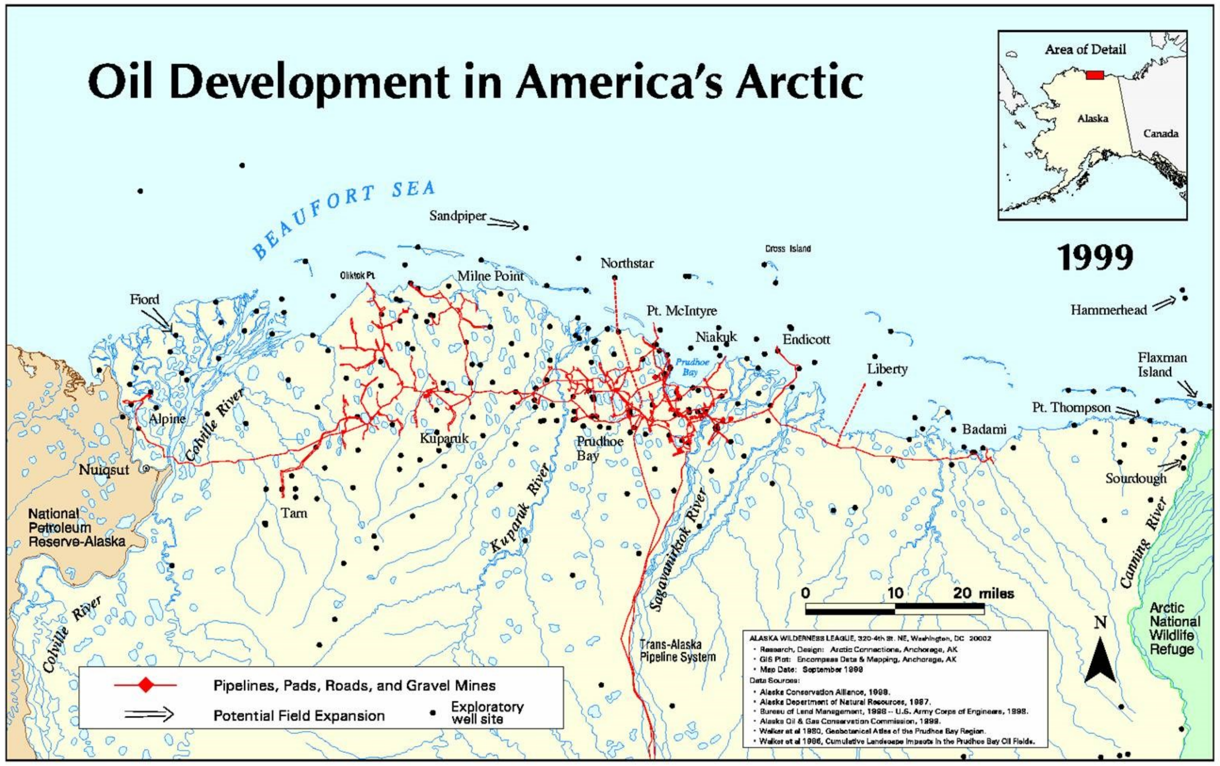
In conclusion, the proposed SAE seismic permit should be rejected because the impacts from the proposed activities will be significant and the grid of heavy vehicles trails that will scar the tundra for my life time will forever degrade the integrity of this remarkable naturally intact ecosystem.

Sincerely,

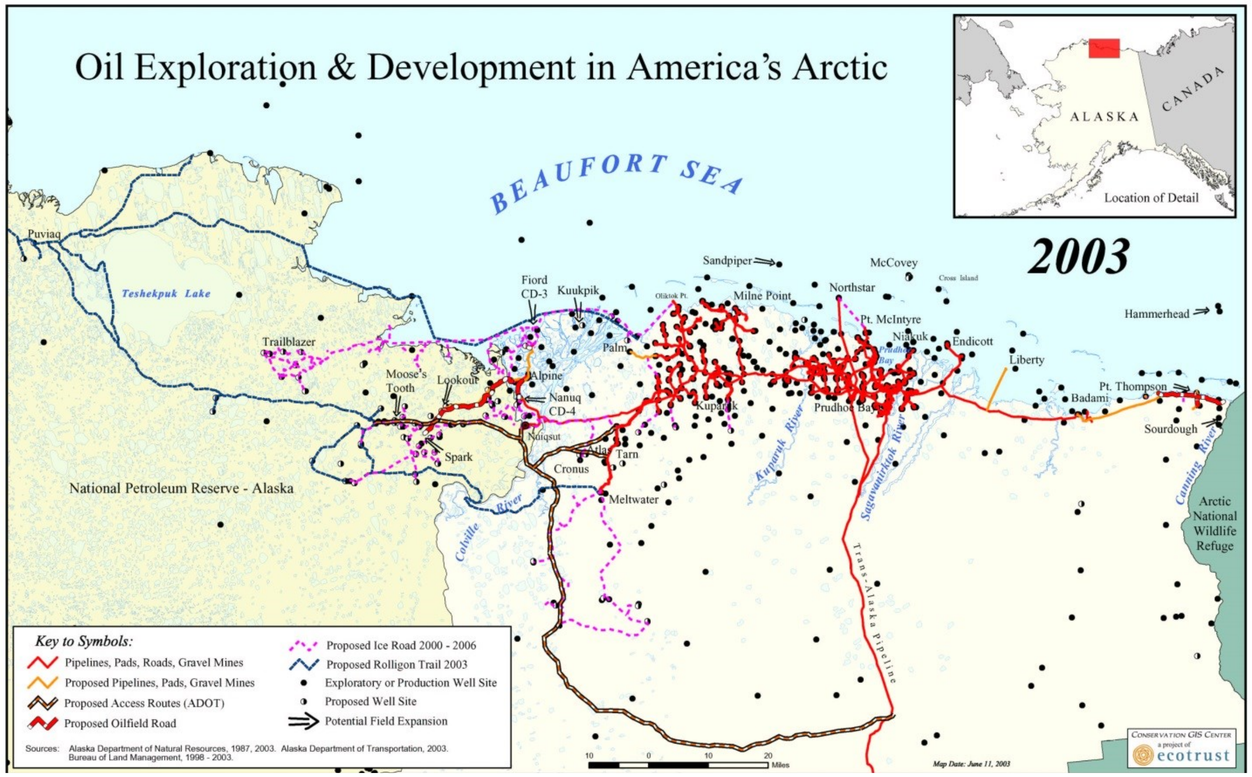
Pamela A. Miller

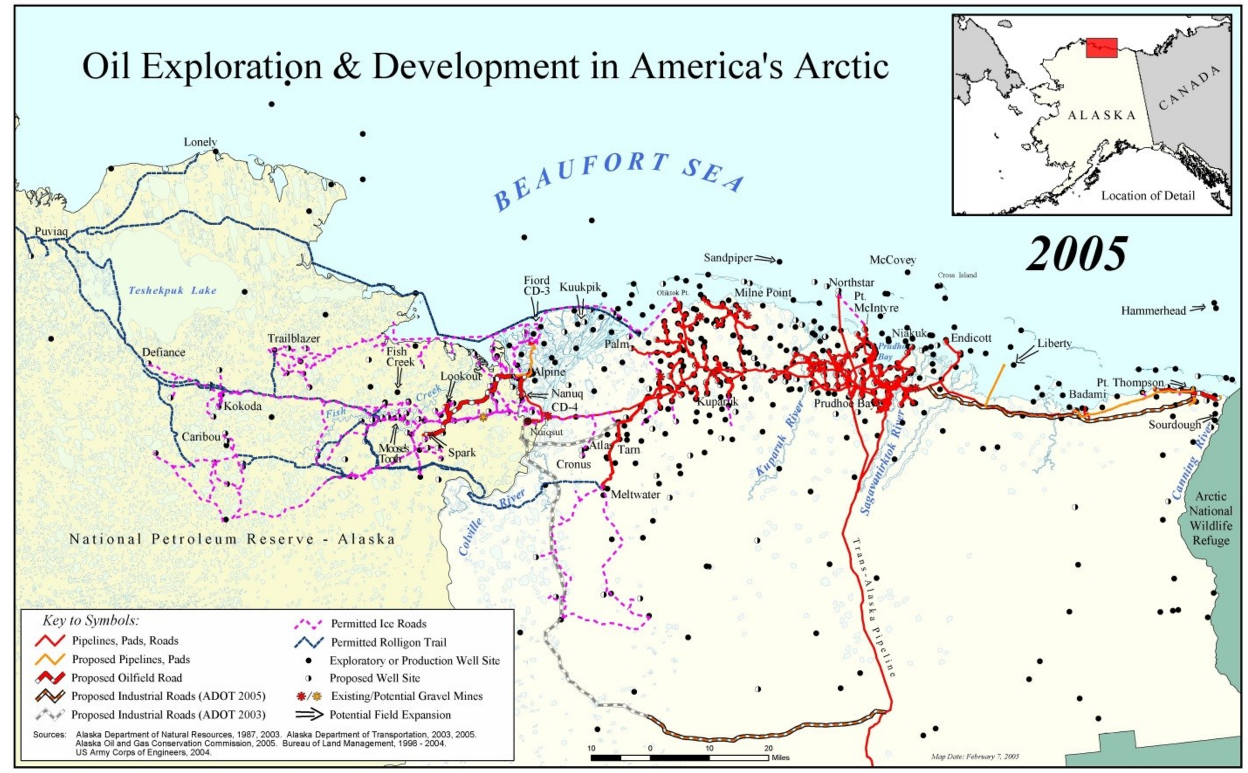
Oil Development in America's Arctic 1968-1999

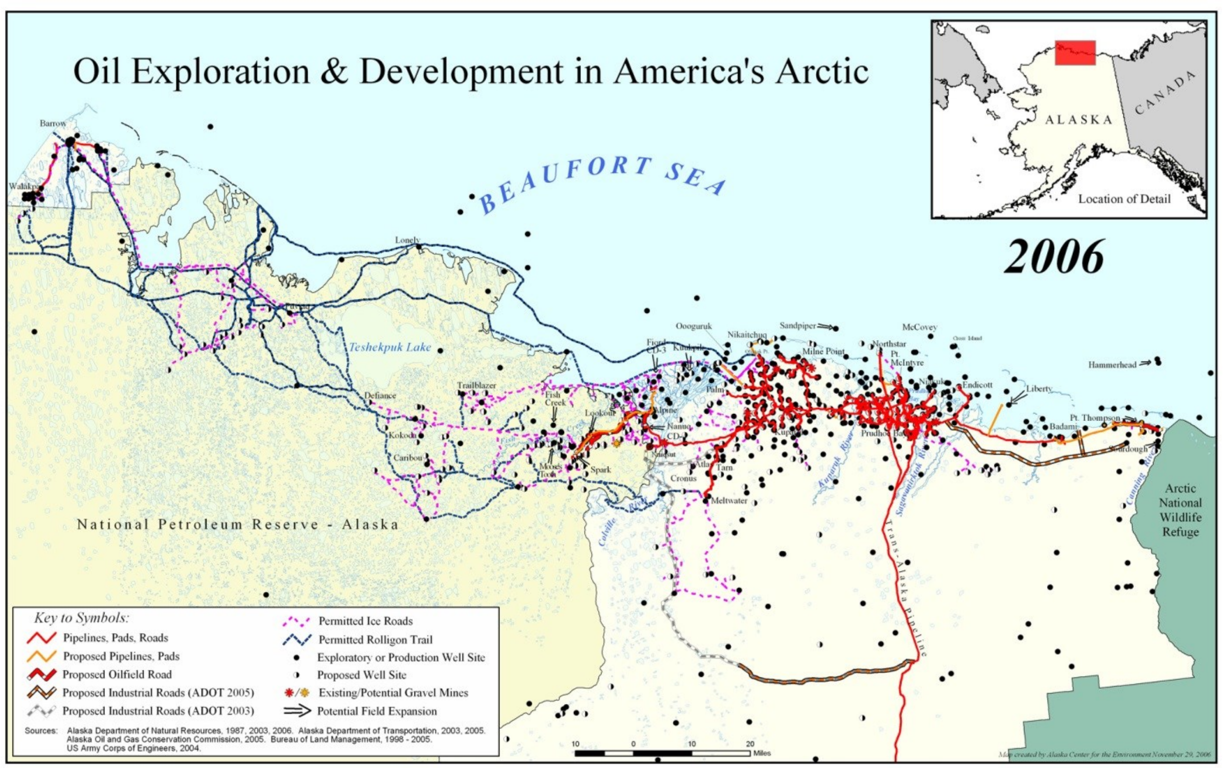


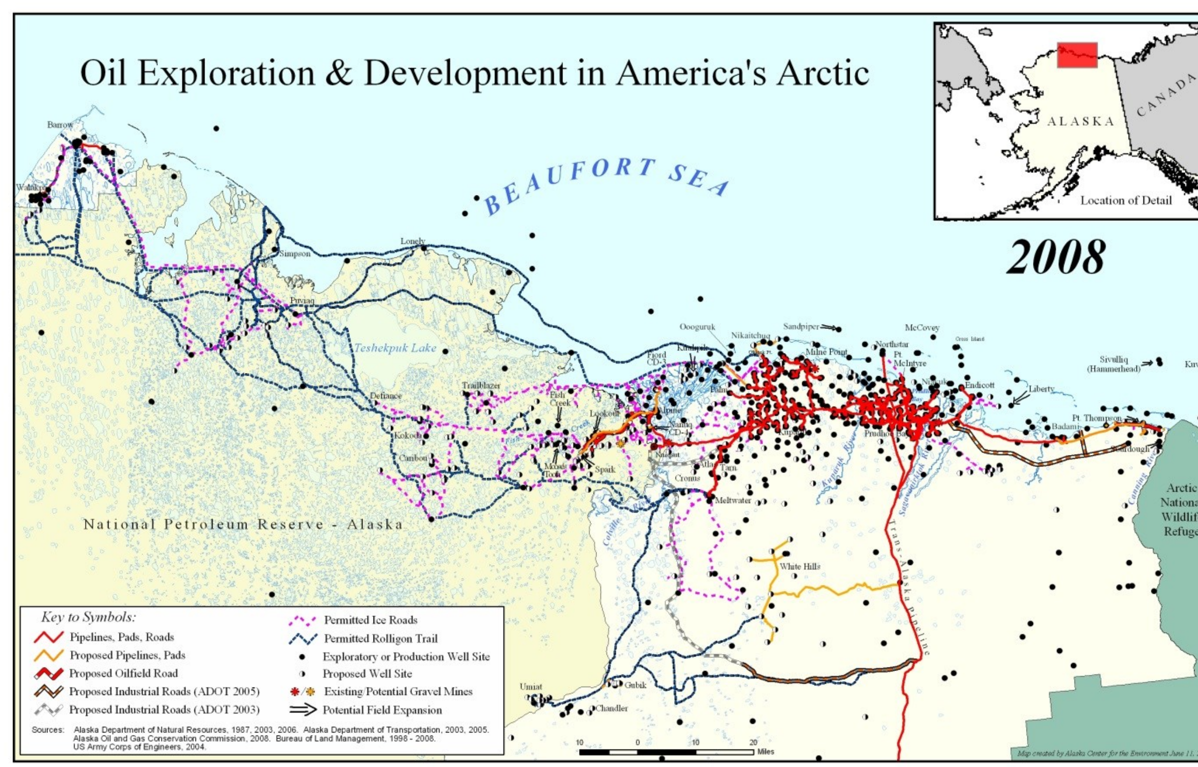


Oil and Gas Exploration & Development in America's Arctic 2003-2008









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CRREL
REPORT 89-7

US Army Corps
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Cold Regions Research &
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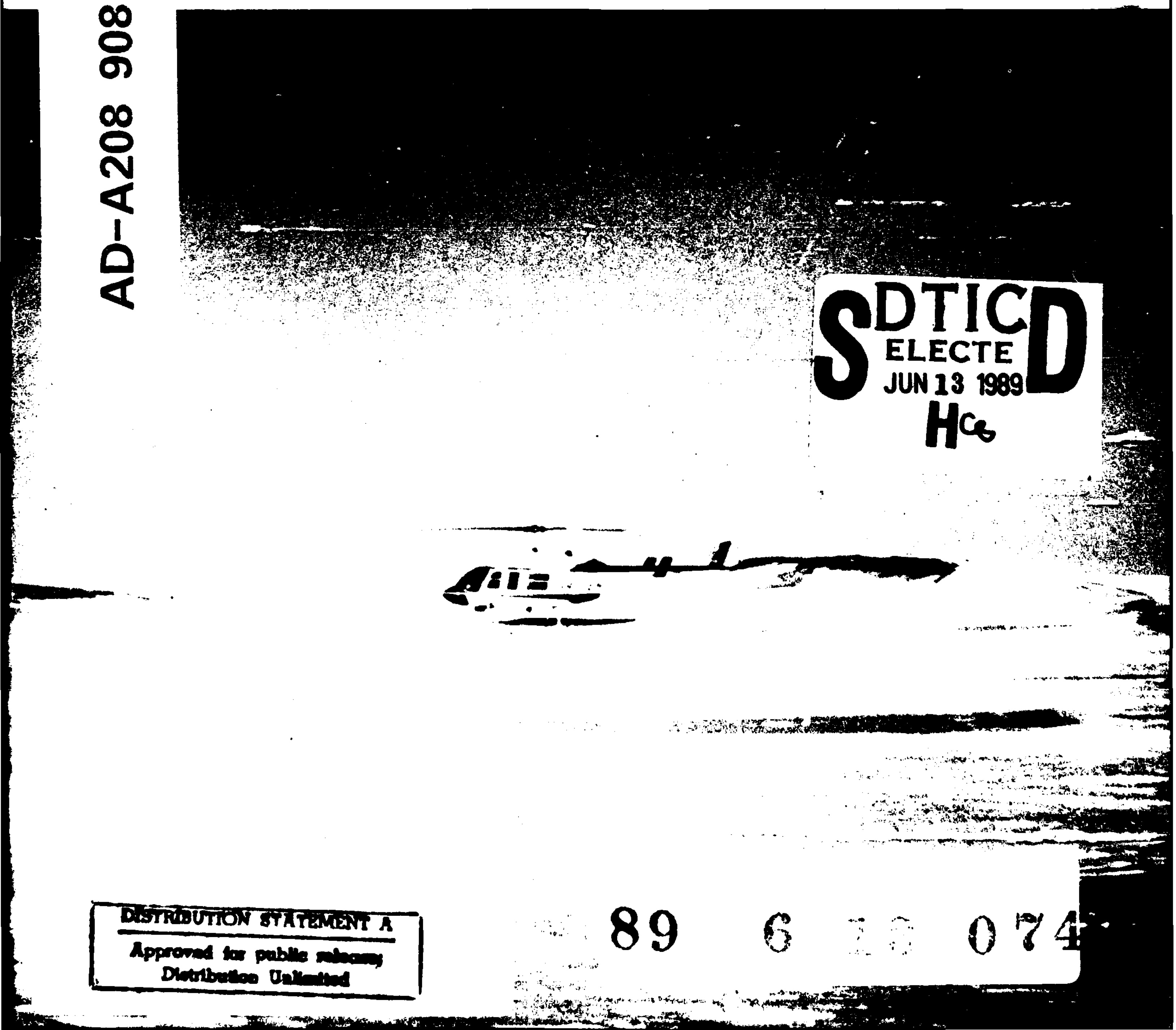
Water detection in the coastal plains of the Arctic National Wildlife Refuge using helicopter-borne short pulse radar

AD-A208 908



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For conversion of SI metric units to U.S./British customary units of measurement consult ASTM Standard E380, Metric Practice Guide, *published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.*

Cover: Ice mound on the Sadlerochit River in the Arctic National Wildlife Refuge. (Photo by D.J. Calkins.)

CRREL Report 89-7

April 1989

Water detection in the coastal plains of the Arctic National Wildlife Refuge using helicopter-borne short pulse radar

Steven A. Arcone, Allan J. Delaney and Darryl J. Calkins

Prepared for
FISH AND WILDLIFE SERVICE
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Water Detection in the Coastal Plains of the Arctic National Wildlife Refuge Using Helicopter-borne Short Pulse Radar

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Arcone, Steven A. ; Delaney, Allan J. and Calkins, Darryl J.

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A helicopter-borne short-pulse radar survey of water resources was performed along the coastal plains of the Arctic National Wildlife Refuge in March 1988 to help evaluate the potential environmental impact of resource exploration. The surveys concentrated on the major rivers and a few lakes of the area and were performed at approximately 5-m altitude and 5-m/s flight speed. The radar antenna was externally mounted on the helicopter skids and emitted 6- to 7-ns pulses whose bandwidth was centered near 500 MHz. The locations of most surveys were determined by a satellite positioning system. The ice cover was generally frozen to the river bed in all areas investigated, except for open water reaches within extensive icings that developed downstream from hot springs. The radar data revealed sub-ice water channels within the icings as well as water beneath ice mound features in icing areas in the delta regions of the major rivers. A systematic radar survey, augmented with drilling, of one chain of three mounds allowed the water volume to be estimated, but did not reveal any external source. It is speculated that a more intensive ground-based radar and drilling survey would clearly identify whether the water source was confined to the talik or was from an aquifer system.

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PREFACE

This report was prepared by Dr. Steven A. Arcone, Geophysicist, and Allan J. Delaney, Physical Science Technician, Snow and Ice Branch, and Darryl J. Calkins, Chief, Geological Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. Funding for this research project was provided by the U.S. Department of Interior, Fish and Wildlife Service, Anchorage, Alaska, Agreement 14-16-0007-08-7719 and by DA Project 4A161102AT24, *Research in Snow, Ice and Frozen Ground*, Task SS, Work Unit 014, *Electromagnetic and Radiative Characteristics of Snow, Ice and Frozen Ground*, and Work Unit 025, *Water Supply Quantification on Winter Battlefields*.

The authors thank Dr. George Ashton and Dr. Lindamae Peck of CRREL for technically reviewing the manuscript of this report. They gratefully acknowledge the assistance given by George Elliot, of the U.S. Fish and Wildlife Service, who was the flight navigator and selected the transect locations. They also thank their pilot, Dean Priddy of ERA Helicopters, for his skillful and safe flying.

CONTENTS

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TABLES

Water Detection in the Coastal Plains of the Arctic National Wildlife Refuge Using Helicopter-borne Short Pulse Radar

STEVEN A. ARCONE, ALLAN J. DELANEY AND DARRYL J. CALKINS

INTRODUCTION

The U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) was contracted by the U.S. Department of Interior, Fish and Wildlife Service (FWS), to conduct geophysical water availability studies in the Arctic National Wildlife Refuge (Arctic NWR) at the end of the 1988 winter season. This information was necessary to determine the environmental impact of possible development of the area's natural resources. The area is frequently referred to as the 1002 area of the Arctic NWR as described in Section 1002(c) of the Alaska National Interest Lands Conservation Act of December 1980.

This report provides the data that were collected during the field work, a description of the equipment and a brief analysis of the techniques used in the study. Typical radar returns obtained during the survey will be discussed to indicate the type of information that may be abstracted from the data, all of which are given in a supplementary data report (CRREL Internal Report 1028).

OBJECTIVE

The objective was to identify the presence of unfrozen water beneath selected rivers and lakes on the coastal plain, Arctic NWR, using both a high frequency short pulse radar mounted externally to a helicopter and a hand-held magnetic induction conductivity meter. Occasional ground truth data of ice thickness and water depths were collected to verify the remotely sensed data.

STUDY AREA

The study sites were confined to the major streams and lakes on the coastal plain of the Arctic NWR. The major streams identified by FWS personnel for sampling were the Canning, Tamayariak, Katakturuk, Sadlerochit, Hulahula, Okpilak, Jago and Okerokovik Rivers and Itkilyariak Creek. Lakes were chosen on the basis of our ability to identify their location on the 1955 topographic maps from visual observation. Figure 1 is a general location map of the area.

The study took place on the Arctic Coastal Plain in Northeast Alaska, with Kaktovik on Barter Island being the major civilian community in the area. We were based at the Barter Island U.S. Air Force Distant Early Warning Radar Station (DEW line). Detailed geographic and climatic summaries of the area can be found in the *Arctic National Wildlife Refuge: Alaska, Coastal Plain Resource Assessment* (US DOI 1987).

Hydrologic and hydraulic information on the streams and lakes is very limited and confined to only spot measurements when available at all. Summer information concerning water flow and quality is available for some streams. Winter documentation, if any exists, on the hydrology, hydraulics or ice conditions of the rivers in the Arctic NWR could not be located at the time of report preparation.

INSTRUMENTATION

Two distinctly different types of electromagnetic equipment were tested. One was a short pulse

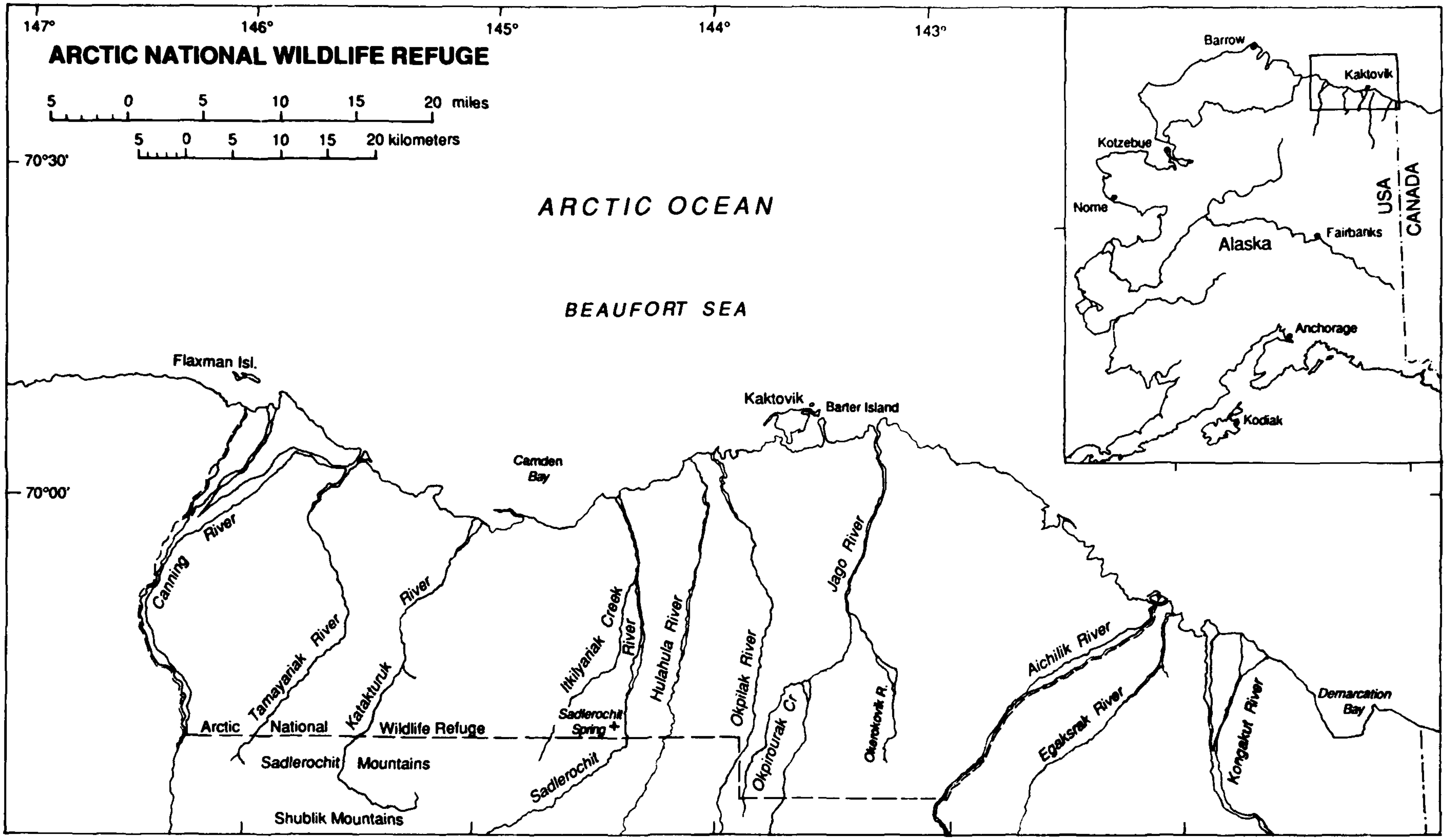

Figure 1. General location map of the study area in the Arctic NWR.

radar system operating near 500 MHz while the second was a magnetic induction conductivity instrument that operates at 39 kHz. The radar technique was used to profile interfaces between materials with different dielectric constants; the conductivity method measures bulk conductivity of the ground in the vicinity of the instrument. Both systems had been used in previous river ice studies to locate unfrozen water beneath ice sheets (Arcone and Delaney 1987, Arcone et al. 1987).

Short pulse radar

Short pulse radar is also known as impulse radar or ground-penetrating radar. The fundamental concept in short pulse radar is to couple some sort of discharge device to a very broadband antenna to radiate a short pulse and receive a reflection whose time of propagation can be measured with suitable clocks in a control unit. The antennas are usually resistively loaded dipoles, the design of which seeks to attenuate the oscillations of the current discharge. Such broadband antennas sacrifice the advantages of conventional radar antennas—high gain, narrow beamwidths, efficiency—to permit this short pulse shape, an example of which is shown in Figure 2. Range resolution is always at a premium; angular location is presumed directly beneath the antenna, for want of any directionality in the beam radiation pattern. Frequency spectra of the pulses in commercial models are centered between 50 and 1000 MHz with usually a 100% bandwidth. Our unit is centered near 500 MHz, reasons for which are discussed at the end of this section. An airborne antenna radiates a single broad lobe with minimal pulse width. The major drawback of airborne antennas is the interference of radiation reflected from the aircraft, examples of which will be shown later. Background removal programs were not yet available for this radar system.

The transmitter and most of the receiver electronics are placed at the antenna terminals to reduce noise, and both antennas and electronics are often placed in one package (Fig. 3) that is shielded to reduce back radiation. The received signals are immediately amplified and then sampled to convert the frequency content into the audio range for tape recording and data display on conventional

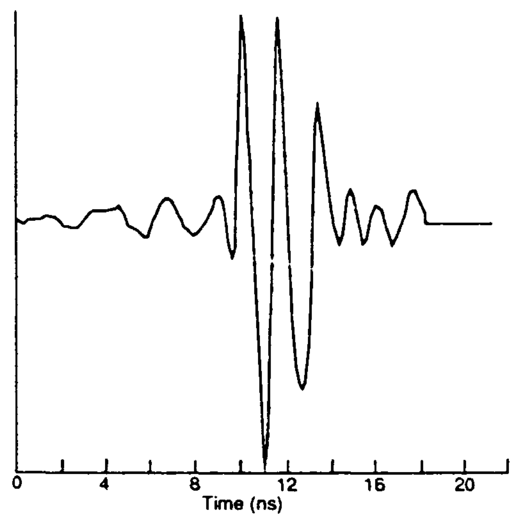

Figure 2. Pulse shape of transmitted signal.

Figure 3. Transmitter and receiver antenna housing assembly mounted externally to a Bell 206L Jet Ranger.

graphic devices. The sampled returns are reconstructed into scans extending over time windows ranging generally from about 50 to 2000 ns.

A control unit sets the scan rate (8/s), time windows, overall gain and the all-important TRG (time range gain) function. This function allows the gain to be varied over the scan to enable suppression of the strong early returns and amplification of the weaker later returns. A small oscilloscope is used for viewing the scans and data are recorded on a cassette tape recorder. A variety of high- and low-pass filter settings are available to exclude most ambient noise. The system is powered by batteries.

The necessary time range window is determined by the expected time of return for the deepest reflection (or "event") sought. The free-space velocity c of electromagnetic waves is 30 cm/ns, so that every meter of altitude adds 6.2 ns to the needed time window. Propagation velocities in earth materials are much slower, varying from about 17 cm/ns in dry soil or ice to about 3 cm/ns in icy water. Pulse distortion and absorption will result when wave velocity in a material strongly depends on the frequency of the radiation because pulses contain a broad spectrum of frequencies. This is not a concern for propagation in ice, but is for water. Only depths to the water surface could be measured; water depths could not be measured because of the extremely high absorption (~24 dB/m) and pulse distortion that occurs in 0°C water at this high frequency.

A basic rule of radar surveying is to go as slowly as possible as this will afford the best quality in the data; in the air 2 m/s is ideal. Data have been successfully recorded at speeds between 2 and 9 m/s at 8 scans/second. Higher scan rates are necessary at greater speeds. Table 1 shows the approximate ground area of sensitivity for one scan as a function of altitude for the GSSI model 3102 antenna (center frequency ~ 500 MHz) operating at 8 scans/s at speeds up to 8 m/s. The calculations are based on a measured transmit-receive 3-dB beamwidth of 70° (Arcone et al. 1986) in both principal radiation planes. Snell's law can be used to compute the area of sensitivity at the bottom of an ice sheet (Arcone et al. 1986). The resulting values are slightly lower than those of Table 1 (considering altitude to equal height above subsurface water) due to refractive focusing of the radiowaves when propagating from air into ice.

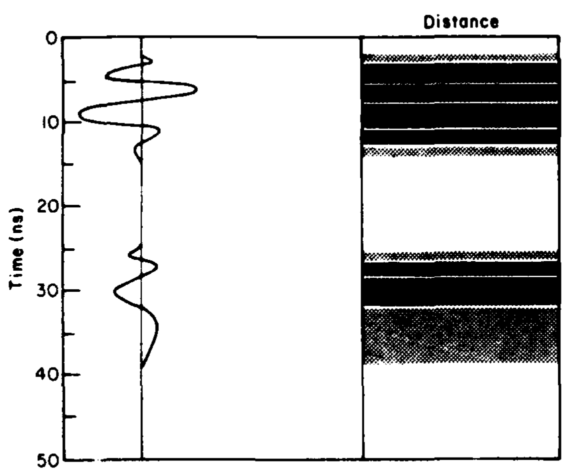

Figure 4. Idealized radar returns and equivalent graphic display, should these returns remain unchanged over a short distance.

Table 1. Approximate ground area of sensitivity as a function of altitude based on the 3-dB beamwidth of the pulse center frequency. Values are good to ±10% for scan rates between 8 and 50 s^{-1} and flight speeds up to 8 m/s.

Altitude (m)	*Area (m^2)*
3.0	16
4.5	35
6.0	60
7.5	90
9.0	130

The most common method of data display is grey-scale intensity modulation on electrosensitive paper, an idealization of which is shown in Figure 4. Darkness is proportional to signal amplitude and the horizontal bands represent the consecutive positive and negative oscillations of the pulse waveform. The chart paper rolls out as fast as the data are recorded on magnetic tape, which means that it takes as long to display data as it does to do a survey. The advantage of this display is that the banding formed by the density of the consecutive scans allows the eye to follow easily the continuity of various events within a profile. The disadvantage is that individual waveforms cannot be readily examined as in a seismic section, but must be retrieved, which is not easy unless they have been digitally recorded and stored, as one manufacturer now offers.

The depth D of a reflection is determined from the time delay t_d between two events (two series of bands) such that

$$D = \frac{ct_d}{2n}$$

where n is the index of refraction of the material (1.79 for ice). The factor of 2 accounts for the round-trip of the echo. In the surveys discussed here, the first event (e.g. Fig. 5) is the ice surface reflection and the second event is usually the reflection from the ice/water or ice/riverbed interface. An ice/water reflection is generally of far greater amplitude than either an air/ice or ice/riverbed interface reflection and is therefore easy to recognize. Theoretically the ice/water reflection is more than 7 dB stronger than an ice/air or ice/gravel interface reflection. In practice, for a snow-covered surface, the ice/water reflections were 20–32 dB greater than the air/ice-snow reflections. This was most likely due to the impedance matching of the air to the ice by the intervening snow layer. Such a layer must have a density of about 0.4 kg/m^3 (n = 1.3) and a thickness of about 15 cm, values that are entirely plausible for this area in late March, to severely depress the dominant frequencies of our radar. Bare ice surfaces gave much stronger reflections.

The choice of a 500-MHz antenna unit was based on our previous experience (Arcone and Delaney 1987) with this unit and on other scientific considerations for this particular task. The 500-MHz unit is small, lightweight and easily mounted on struts. It radiates sufficient power to have allowed airborne penetration of 28 m of ice in an alpine glacier, and provides sufficient resolution to measure thicknesses as small as 30 (±3) cm. Additionally, the unit is shielded to minimize clutter (unwanted reflections) from the aircraft. Lower frequency units are far heavier, poorly shielded, give less resolution and probably would not have provided any additional information, such as water depth, despite the increased power of lower frequency units, and the increased penetration ability of lower frequencies. The reason for this is the high contrast in index of refraction between air and water (considering the ice between). This contrast makes reflections from any bottom slope greater than 6° relative to the ice surface almost impossible to detect. This is because either the returning energy is beyond the angle of critical refraction (i.e. the transmitted energy propagates parallel to the surface) or because the returning energy is refracted beyond the antenna's beam width.

Magnetic induction

Magnetic induction is a ground-based technique for measuring ground conductivity that we implemented in one very limited test during this study using an EM-31, an instrument designed and marketed by the Geonics Co. of Mississauga, Ontario. (See Arcone et al. [1987] for further details of operation on ice-covered rivers.) The instrument is lightweight, consisting of a 3.66-m-long boom with an antenna on each end with a readout device in the center of the boom. The instrument is sensitive to about 7-m depth and was used to search for any subsurface water leading to or present under three ice mounds that were clustered on the Sadlerochit River. Readings were consistently less than 0.1 mS/m (millisiemens/m) everywhere but over the mounds, where readings rose to about 1.4 mS/m, which indicated the presence of water.

After about 1 hour the low temperatures (< –30°C) began to affect battery strength. Therefore the instrument was not used again because of the time it took for obtaining such a limited amount of data.

Water conductivity

This quantity was measured in a few places with a d.c. conductivity meter (Yellow Springs Instrument model 33). The sampling head had to be continuously held in the water to prevent ice from forming within it. This information is needed to evaluate the potential for the radar to penetrate the water depth. The values were 70 μS/cm on the Tamayariak (line GL3) and 26 μS/cm on the Sadlerochit (line IL2), the latter value of which indicates very fresh water and the possibility of a few feet of penetration using our radar. However, none of our data indicated any significant water bottom returns.

Ice augers

A motorized ice auger (a General 21 gas-powered unit) was brought for expediting drilling through the thick ice sheet, but this unit failed in the low temperatures because of loss of resiliency in the diaphragm of the carburetor. Consequently all augering was done by hand. Ice and water depth were measured with a CRREL ice depth gauge, which is a wired tape with a retractable bar at the end.

GPS

The global positioning system (GPS), a Motorola Mini-Ranger with a Motorola Eagle receiver, was battery operated inside the aircraft cabin. The GPS antenna was attached to the top of the radar antenna (Fig. 3) as part of the aircraft external load installation. Mounting directly to the aircraft fuselage would have required additional FAA approval.

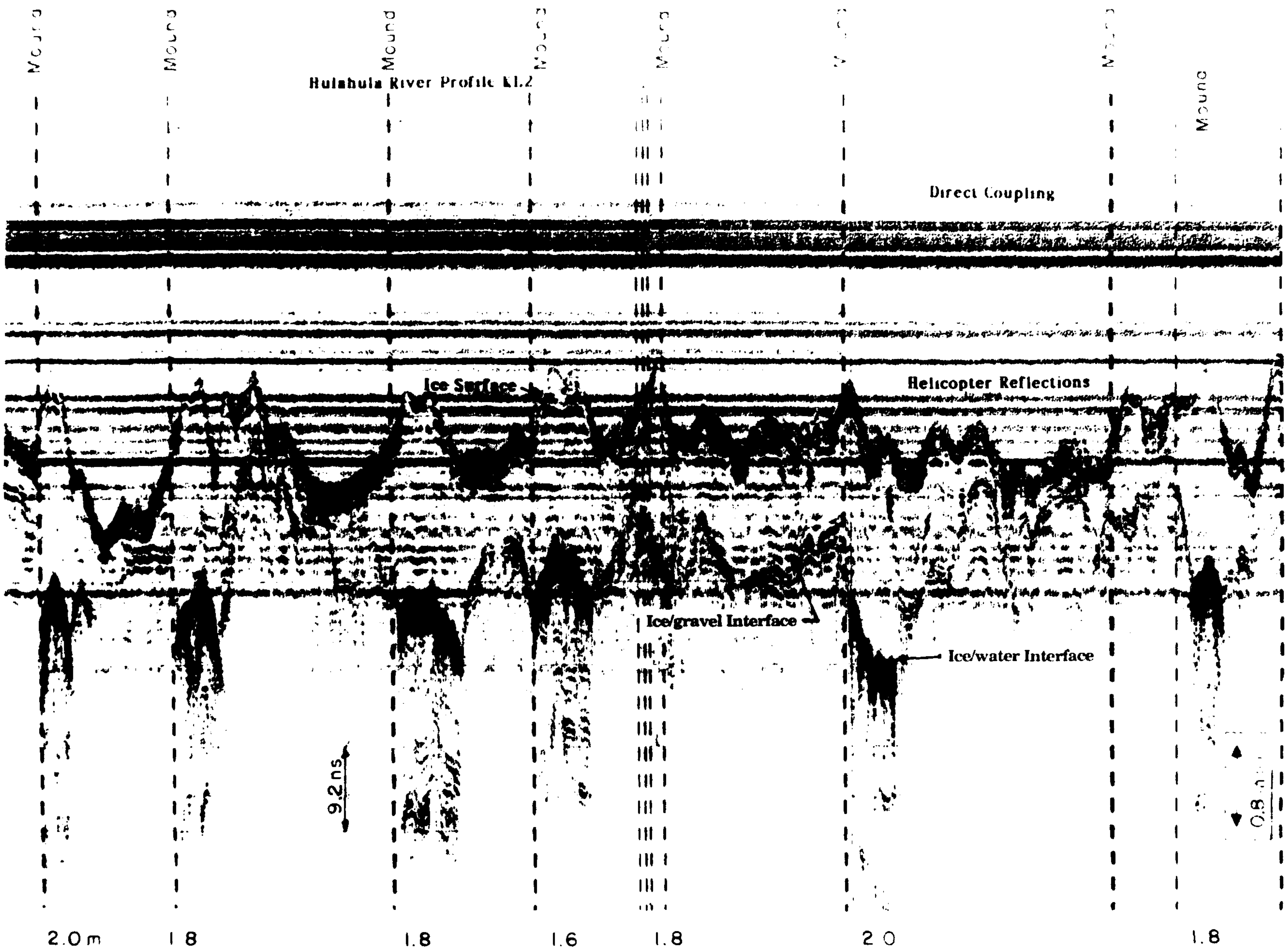

Figure 5. Radar returns over the Hulahula River, profile KL2.

Best operation seemed to occur when the GPS antenna had an unobstructed view to the satellites whose angular elevation above the horizon was always 13–50°. GPS data were read from a Toshiba 1100 lap-top computer. Satellite availability during daylight was generally between 0700 and 1100 local time (–9 hours from GMT). The repeatability of the GPS was checked using the Barter Island aircraft hangar as the reference.

Three satellites were required to start the positioning procedure from an entered, estimated coordinate set, and at least two satellites "locked in" were required to maintain system operation.

At any location, the readings would vary within about ±0.3 seconds of latitude or longitude, which was far more accurate than required. Readings to within about 3 seconds could be made in flight. During sharp turning maneuvers by the helicopter, the GPS would often lose its lock with the satellite signals (possibly due to interference between direct and helicopter-reflected transmissions), which sometimes caused it to compute erroneous coordinates. Difficulties then arose in obtaining accurate coordinates when the GPS tried to redetermine position with only two satellites available.

RADAR DATA COLLECTION

Generally, the aircraft maintained a speed of 5 m/s in a relatively horizontal plane with the radar antennas approximately 3–5 m above the ice surface. Local wind and snow conditions over the rivers on occasions required the pilot to fly at both slightly higher air speeds and higher elevations for safety reasons. The capability to fly relatively level also depended upon the terrain features and wind conditions, the latter of which could influence the direction in which a radar profile was obtained. As the radar data were being collected, event markers were also entered on the recording tape to indicate the location of special terrain or ice conditions. Handwritten notes describing these special features assisted in the interpretation.

POSITIONING

Initial identification of ground position was made from the USGS 1:63360 quadrangle sheets. Coordinates were determined from them at least 50% of the time because of the short time window available for the limited number of satellites. When the GPS was available, coordinate positions were taken at the beginning and end of each transect. The GPS was the preferred method because the 1955 USGS maps in this area do not have the horizontal control precision of the GPS. In addition, stream features identified on the maps such as flow channels, islands, etc., can change from year to year. With the flat terrain, it was difficult to determine position from a USGS map unless a major surface feature could be sighted. Lines for which GPS positions could be obtained are given in Appendix A.

Some transects were flown with no definite control on the end positions or time of the run. These uncontrolled transects were often flown down a meandering channel in a zigzag pattern to detect potential sources of water beneath obvious surface ice features. The location of these transects can be placed only in a general area on the USGS maps.

RESULTS AND DISCUSSION

Airborne radar data (general)

Over 110 cross-sectional and longitudinal surveys were conducted on the rivers mentioned earlier, in addition to survey flights across 16 representative lakes in the region. These locations are identified in CRREL Internal Report 1028. This section will discuss a limited number of examples to show how they may be analyzed for the depth, presence of water, and other factors. The example of Figure 5 is longitudinal profile KL2 on the Hulahula River, which spanned several elongated "ice mounds" (we had no prior knowledge as to which mounds might have water beneath them). The figure is a practical realization of the idealization of Figure 4. Using the typical profile speed of 5 m/s, we judge this record to be about 1200 m long. This distance scale should generally apply to all the radar records, as they have all been displayed at the same chart speed and undergone the same photographic reduction.

There are several radar events in Figure 5 that are labeled. The heavy dark band across the top is the direct coupling between transmit and receive antennas, both of which are contained in the single unit shown in Figure 3. This is followed by several more horizontal bands that are reflections from the helicopter fuselage. The first wavy event is the ice surface reflection. The wavy pattern of this and subsequent reflections is due to gradual fluctuations in helicopter altitude and the sometimes abrupt height of the surface ice features. Beneath this surface reflection is a second reflection that increases dramatically in intensity in seven zones. These zones are reflections from subsurface water. Where the intensity of the subsurface reflection is

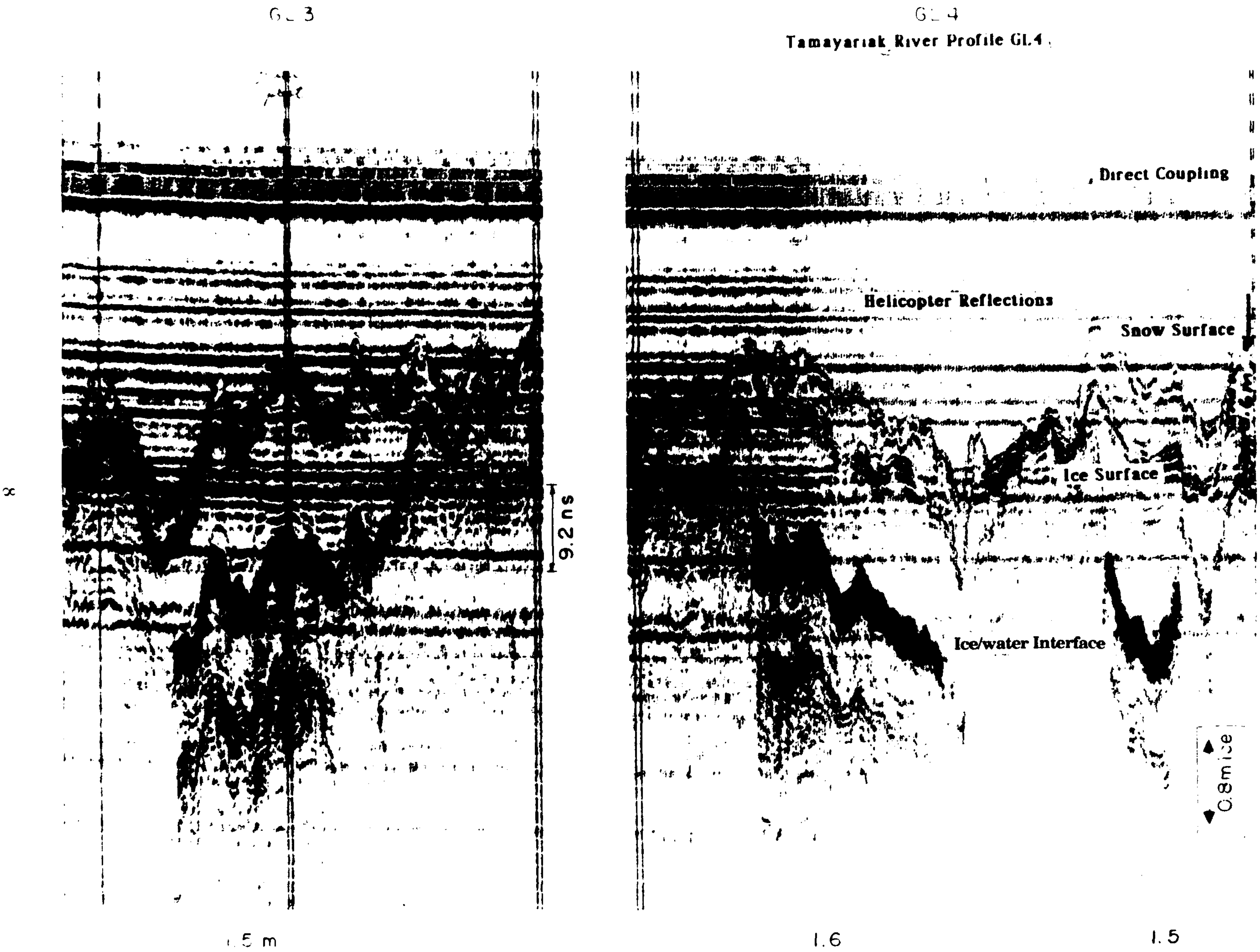

Figure 6. Radar returns over the Tamayariak River, profiles GL3, GL4.

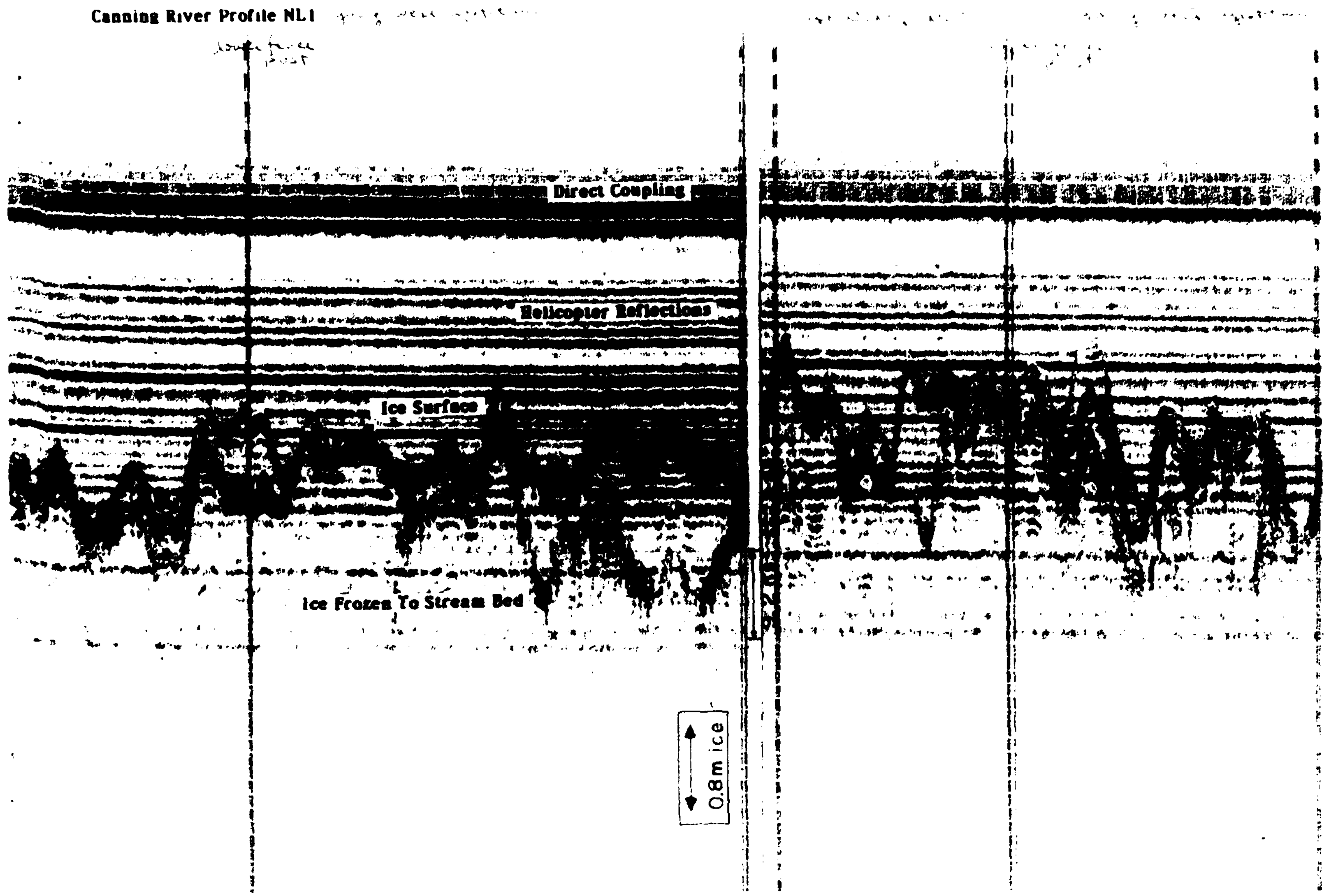

Figure 7. Radar returns over the Canning River, profiles NL1, NL2.

low, the ice is grounded to a frozen gravel bottom. Moderate intensity seen in some of the other data probably indicates ice grounded on an unfrozen bottom.

Figure 5 has an ice depth scale of 0.8 m per vertical division. This scale is to be used only to measure ice depth between the ice surface and bottom reflections. Close examination of the figure between some mounds reveals a very thin ice cover. There are a number of figures in the data set for which a scale of 1.46 m per vertical division applies, including the entire data set for Sadlerochit Springs and Kaktovik Lagoon, plus eleven transects on the Canning River (AX5, BX1, BX2, BX3, BX4, CL1, CX1, E1, E2, E3 and E4). This different scale is easily identified on the figures by the compressed width of the radar reflections. The vertical broken lines indicate features of interest such as an "ice mound" or a channel margin. Ice depths are given beneath some of these lines.

Figure 6 shows a short profile from a section recorded on the Tamayariak River where a thick snow section had accumulated on the outside bend of the river. Clear reflections from both the top of the snow and top of the ice surface can be seen along with bright radar returns from water beneath the ice. Figure 7 shows a profile from the Canning River profile where no water returns are visible and we suspect the ice is frozen to the river bed. A smooth and bare ice surface and placement of the ground returns within the constant amplification region of the radar scan window account for the ice surface reflection appearing darker than all later returns.

River ice mounds—field measurements

On several of the rivers, ice mounds were observed rising above the relatively smooth surface ice. These features were generally elongated, with concave surfaces leading to the top and a surface crack and/or gap along the top of the mound-shaped "icing." However, a few mounds were observed that were circular (Fig. 8), probably rising 1.2 to 2.4 m above the level ice sheet, with radial cracks and gaps extending to the top. The elongated mounds were generally oriented in the direction of the stream channels. The associated ice sheet in the mounds appeared to have crept from an initial horizontal position, with cracks forming along the top surface of the ice sheet. From a qualititative estimate, the large mounds (1.5–3 m in height) generally contained unfrozen water that was detected with the radar.

On the Sadlerochit River, one circular and two elongated mounds were examined in more detail to estimate the extent of the associated water quantities. Figure 9 is a plan view of the three mounds and Figures 10 and 11 give side and longitudinal views, respectively, of the larger mound that was 2.7 m above the surrounding level river ice surface, which itself was 1.2 m thick. Measurements of magnetic induction over the mounds, detailed radar profiles over and adjacent to the mounds and direct drilling of the ice were performed to measure the ice thickness, water depth and the surficial area of water zones.

The Sadlerochit radar transects A1–A4 (App. B) were run perpendicularly while transects B1–B4

Figure 8. Typical ice mound.

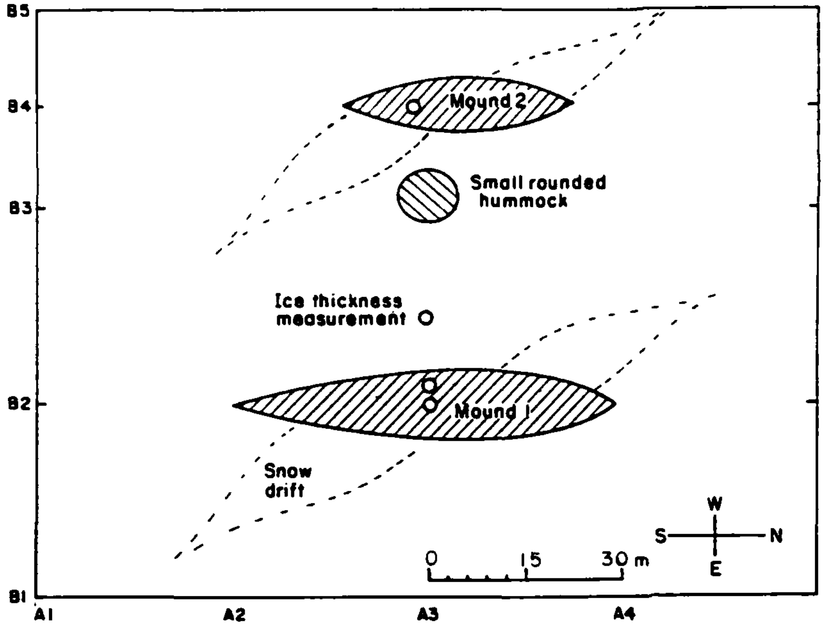

Figure 9. Plan view showing extent of surface area of the three mounds.

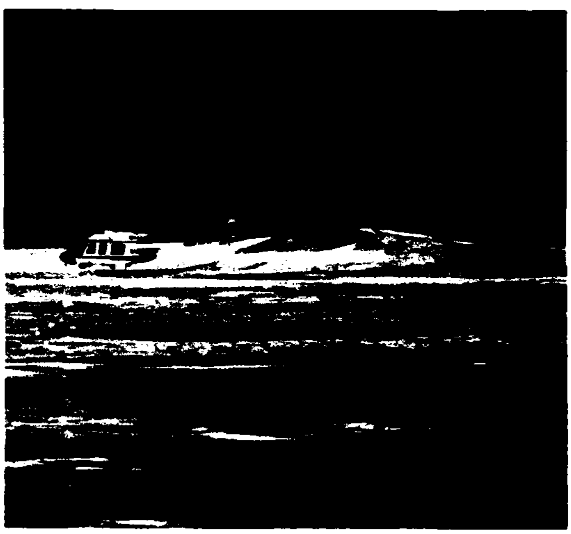

Figure 10. Side views of ice mound 1.

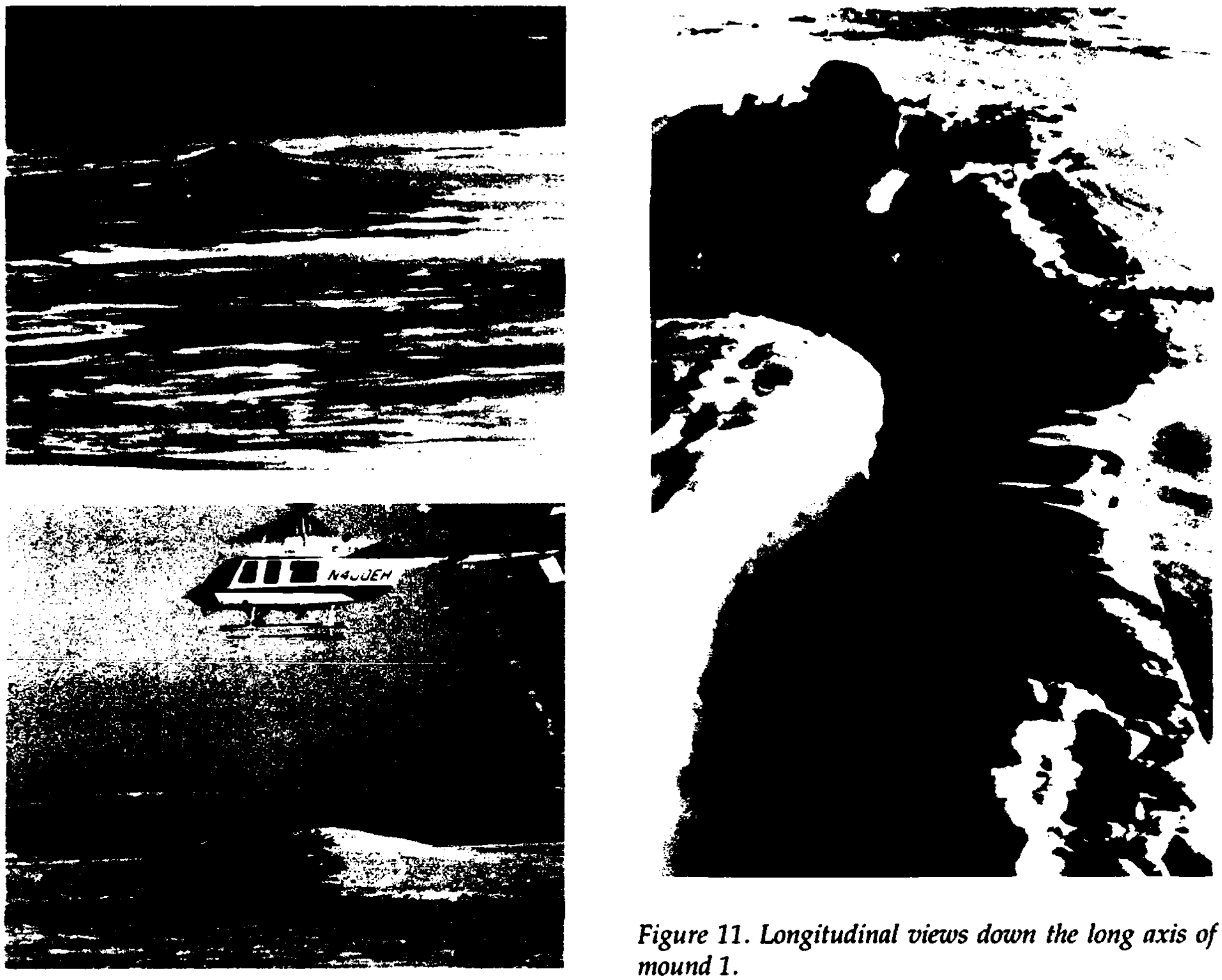

Figure 11. Longitudinal views down the long axis of mound 1.

were taken parallel to the mounds. Transects A1, A4, and B1 were run over the smooth ice sheet upstream, downstream, and on the east side, respectfully, of mound 1 to detect any water that could have been surrounding the study site. A radar transect on the west side of mound 2 was not performed. It can be seen in these transects that no water was detected entering or leaving the control area on three sides in a horizontal direction. The data indicate that the ice sheet was frozen to the river bed in all transects surrounding the mounds.

Transects A2 and A3 were flown perpendicularly to the mounds with A3 directly over the center of both. Transect A2, flown on the upstream end of the mounds, indicates water beneath only one mound, while A3 indicates water beneath both mounds.

Transects B2 and B4 were run parallel over the top of the mounds. The radar returns indicate water beneath a long portion of the mounds. The estimated lengths where water was present are roughly 30 and 53 m for mounds 1 and 2, respectively.

The magnetic induction survey using the EM-31 was also conducted perpendicular and parallel to the mounds. All readings were made with the antennas horizontal coplanar (HCP) with the unit one meter above the surface unless noted otherwise. A transect was run in an east/west direction over both mounds along the same line that radar transect A3 was flown. Starting the survey on the frozen gravel and traversing over smooth ice, we recorded readings of 0.0 mS/m for the ice and frozen ground and only when the unit was directly on top of mound 1 did a reading of 0.15 mS/m register.

The readings for mound 2 (when the unit was on the east-sloping face about 1 m from the top) were 1.0 mS/m HCP and 0.0 for the vertical coplanar direction (VCP). On top of the mound, readings of 0.85 and 0.0 mS/m for HCP and VCP respectively were recorded, while on the west-sloping face readings of 0.2 and 0.2 mS/m were recorded for both HCP and VCP. An HCP profile taken along the top (ridge line) of mound 2 gave readings varying from 0.5 to 1.2 mS/m over a distance of 21 m, which indicated the presence of water. Cross-sectional readings at a second transect approximately 10 m north of the first one indicated the presence of water about 2.0 m from the top on each sloping face, for a total width of about 4.0 m.

Ice thickness measurements were conducted on both mounds. On the level ice surface next to mound 1, the thickness was 117 cm with the ice grounded to the bed, while 4.9 m from the top on the west-facing slope the thickness was 183 cm and the ice was grounded to the river bed as well. The ice condition at the top of mound 1 consisted of a 60-cm-wide crack in which we were able to stand to a depth of about 80 cm. A 3-cm-wide crack extended down about 60 cm more. The total ice thickness was 2.2 m, and the water depth between the bottom of the ice and the gravel bed was 1.2 m. During drilling the water rose about 30 cm above the top of the 3-cm crack and receded in about 2 minutes to no flow out the top as the pressure was relieved. Water also escaped from cracks in the upper 60 cm of the drilled hole and flowed toward both ends of the mound.

The ice thickness in the center of mound 2 was 2.1 m and, again, the water was under pressure as it rose several centimeters above the top of the ice and then stopped flowing after 5 minutes or so. The water depth was greater than 1.2 m below the bottom of the ice and the gravel bed was not reached. Surprisingly, the horizontal extent of the unfrozen water beneath mound 2 indicated by the radar return was greater than that beneath mound 1, even though mound 1 was roughly twice as long and slightly higher than mound 2.

The range in possible volumes of water above the gravel surface for mound 2 can be estimated based on the information from the radar surveys plus the one ground-truth water depth. The length of the unfrozen water zone from transect B4 is roughly 53 m. The range in widths is estimated at 5–10 m and a conservative depth is 1.2 m at the center. If a rectangular section along the entire length is assumed, then the total volume might be between 300 and 600 m^3. The shape of the water cavity over the entire length is probably more elliptic than rectangular, based on observations of frost mound cavities and the expectation that the water depth would decrease toward the elongated ends of the mound. If a pyramidal section is assumed (with a height of 1.2 m) and one side is 53 m long with a "horizontal base," the range in water volumes using widths of 5 and 10 m is 100–200 m^3.

BACKGROUND LITERATURE SEARCH

A computerized search of the CRREL Cold Regions Bibliography Data Base, using key words that could describe these river ice mounds, identified CRREL Draft Translation 399, *Siberian Naleds* (Alekseev 1973). This translation describes river ice mounds, similar to the features we observed on the rivers in the ANWR, which are referred to as "naled heaving hummocks" because of their formation in the river. Individual contributors to this compilation often refer to these river hummocks as mixed naleds, the term "mixed" deriving from the source of water associated with the hummock formation, but no one actually formulates or documents the process that describes the development. Based on English abstracts of untranslated Russian literature, there appears to be additional documentation on the occurrence of river ice mounds.

The natural processes that form these "mounds" appear to be freezing and expansion of ice that totally encapsulates a water body. Freezing from all sides generates sufficient pressure by compressing the water to cause an upward creeping motion of the ice sheet, cracking at the top and possibly subsequent flooding that relieves the pressure, and then refreezing of the crack followed by more creep due to continued confined inward ice growth. It was not possible to determine conclusively if deep sources of water from within the subchannel permafrost may also be flowing toward the surface. Such sources of water could cause additional pressure and supply water for the large extent of the hummocked ice cover.

CONCLUSIONS AND RECOMMENDATIONS

Unfrozen water was found in many sections of all rivers investigated in the Arctic NWR. In the braided channels it was found under ice mounds that occurred throughout the channel. The elongated shapes of the ice mounds were generally oriented along the direction of the stream channels. A realistic volume estimate for unfrozen water above the river bed for one 55-m-long and 3-m-high mound would be no more than about 100 m^3. The quantity of water in the unfrozen gravels beneath the mounds could not be estimated. It is concluded from the radar surveys that near-surface unfrozen water occurs only under about 70% of the mounds in these areas at this time.

Sources for the water are only speculative. Water probably cannot flow through cracks from sources beneath the permafrost because of the extensive depth and temperature of permafrost in the area, although we are unable to prove this. Flows through a thaw bulb or in isolated pockets beneath the river bed are regarded as the probable source and may have gone undetected by our instruments. The exact mechanism for generating the ice mounds is not entirely clear.

The radar unit is much more sensitive to the ice/water interface than is the magnetic induction technique because the former method senses contrasts in electrical properties at interfaces whereas the latter is sensitive to bulk properties of individual media. For example, the results of the EM-31 water detection survey indicated water beneath a 21-m transect along mound 2, whereas the radar gave a distance of 53.3 m.

The following recommendations are made with a view toward understanding the origin and dynamics of mound formation so as to predict water availability in the High Arctic.

1. Given the exact position of many of these features made possible by the GPS data, the mound locations should be examined in late summer to determine the presence of any springs, scour holes or other unusual hydraulic features.

2. A drilling program should be undertaken to assess water volume, rechargeability and water quality. This would best be done in April and May when weather is more accommodating and the ice is still present.

3. Synthetic aperture radar (SAR) imagery of the area should be examined for presence of mounds and their intensity of return as a possible indicator of water. The ice mound texture was very consistent and may be an excellent propagation medium for microwaves, despite the cracks.

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APPENDIX A. POSITIONS OF RIVER CROSS SECTIONS USING GPS

The positions of several cross sections for several rivers and two lakes using the GPS are given below. The stations listed were recorded when two or more satellites were visible to the GPS antenna and stable readings could be observed on the computer. Included in this Appendix are comments by George Elliot of the U.S. Fish and Wildlife Service who was the flight navigator and selected the transect locations. These comments are Mr. Elliot's personal ratings of the accuracy of the transect locations both by reference to USGS topographic maps and by the GPS system. The authors wish to state that the topographic maps were produced in 1955, since when features may have changed, and that the maps themselves state "not to be used for navigational purposes."

Table A1. GPS locations of several river and lake transects.

Location	*Line*		*Latitude*	*Longitude (W. of Greenwich)*
Bar Main Hangar			70 08 11	143 35 24
Refuel position	28-Mar-88		69 57 29	145 40 51
Lakes				
	L3	start	69 59 07	143 39 45
		fin	69 59 18	143 42 40
	L4	start	69 55 53	143 37 51
		fin	69 55 49	143 39 03
Okpilak River	BX1	start	69 51 57	143 45 58
		fin	69 51 52	143 46 42
	CX1	start	69 53 42	143 48 06
		fin	69 53 41	143 49 14
Tamayariak River	CX1	start	69 56 08	145 40 51
		fin	69 56 06	145 41 44
	CX2	start	69 56 ??	145 41 34
		fin	69 56 21	145 42 21
	CX3	start	69 55 28	145 35 31
		fin	— — —	— — —
Canning River	DX1	start	69 52 14	146 19 50
		fin	69 52 11	146 20 36
	LL1	start	70 03 53	145 51 45
		fin	70 04 04	145 50 29
	ED1	start	70 02 28	145 50 45
		fin	70 04 03	145 53 27
	ED2	start	70 01 09	145 50 33
		fin	70 00 56	145 51 08
	ED3	start	70 00 06	145 54 00
		fin	69 59 55	145 54 57
	J1	start	70 03 00	145 58 30
		fin	70 02 04	145 57 36
	J2	start	70 01 55	145 56 20
		fin	70 02 05	145 55 26

Table A1 (cont'd). GPS locations of several river and lake transects.

Location	*Line*		*Latitude*			*Longitude (W. of Greenwich)*		
	K1	start	70	03	49	145	51	27
		fin	70	04	00	145	50	35
	NX1	start	70	04	57	145	43	09
		fin	70	05	30	145	38	46
Hulahula River	LL1	start	70	02	00	144	00	21
		fin	70	02	03	144	01	37
	LL2	start	70	01	31	144	01	50
		fin	70	01	26	144	01	29
	LL3	start	70	01	18	144	01	02
		fin	70	00	39	144	01	44
	LL4	start	70	00	28	144	01	26
		fin	69	59	59	144	02	06
	KL1	start	69	57	50	144	02	37
		fin	69	57	41	144	02	58
	KL2	start	69	57	23	144	03	00
		fin	69	56	45	144	03	34
	KL3	start	69	54	20	144	03	29
		fin	69	53	54	144	04	28
	KL4	start	69	51	04	144	07	37
		fin	69	51	01	144	07	47
	KL5	start	69	49	36	144	07	37
		fin	69	49	16	144	07	47
Jago River	BL1	start	69	44	39	143	35	21
		fin	69	44	36	143	35	34
Sadlerochit River	AX1	start	69	39	30	144	22	59
		fin	69	39	30	144	22	59
	AX2	start	69	38	55.4	144	20	59.9
		fin	69	39	22.7	144	22	43
	AX3	start	69	39	22.6	144	22	43
		fin	69	39	21.4	144	22	46.8
	BX1	start	69	41	51.4	144	23	29.3
		fin	69	41	49.8	144	24	06
	BX2	start	69	41	50.6	144	23	54.1
		fin	69	40	57	144	24	14.1
	BX3	start	69	40	57.1	144	24	22.4
		fin	69	40	53.9	144	24	18.6
	CX1	start	69	42	59.5	144	19	05
		fin	69	43	38	144	16	08
	CX2	start	69	42	49	144	22	01
		fin	69	42	37.3	144	23	18.2
	CX3	start	69	42	36	144	23	14
		fin	69	42	39.6	144	23	33.6

Table A1 (cont'd).

Location	*Line*	*Latitude*				*Longitude (W. of Greenwich)*		
	DX1	start	69	43	37	144	21	(12–26)
		fin	69	43	24	144	19	(22–28)
	DX2	start	69	44	13	144	22	(40–60)
		fin	69	44	(52–58)	144	24	(30–43)
	DX3	start	69	44	12.6	144	20	50.1
		fin	69	44	35.9	144	22	03.9
	DX4	start	69	44	48–49	144	21	(55–58)
		fin	69	45	11.3	144	21	13
	DX5	start	69	44	44	144	22	04
		fin	69	45	14	144	25	(10–16)
	DX6	start	69	45	35	144	27	(24–31)
		fin	69	46	06	144	30	(37–47)
	DL1	start	69	44	05	144	20	44
		fin	69	44	50	144	20	32
	EL1	start	69	45	55	144	17	55
		fin	69	46	53	144	19	07
	FL1	start	69	50	11	144	19	49
		fin	69	50	34	144	23	02
	GL1	start	69	53	21	144	21	16
		fin	69	54	32	144	19	48
Sadlerochit Springs Icing	A	start	70	00	56.2	145	15	44
		fin	70	00	54	145	18	58
	B	start	70	01	10	145	21	12.7
		fin	70	01	(21.6–23)	145	22	(37–44)
	C	start	70	01	(30–31)	145	23	(43–48)
		fin	70	01	46	145	25	(41–50)
	D	start	70	01	58	145	27	12
		fin	70	02	20	145	29	56
	E	start	70	02	29	145	31	09
		fin	69	45	05.2	144	27	28

Table A2. USFWS ratings of accuracy of transect placement.

Location of reference point or flight line	*Rating of transect placement on maps based on visual landmarks*	*Rating of GPS transect placement compared to map features*
Bar Main Hangar	Very good	Very good
Refuel location	Good	Very poor—7 mi. off
Lakes		
L3	Good	Good—within 0.25 mi., direction correct but start may be off
L4	Good	Very good
Okpilak River		
BX1	Good	Good
CX1	Poor	May be good?
Tamayariak River		
CX1	Good	Fair—within 0.5 mi.
CX2	Good	Fair—within 0.5 mi.
CX3 (start)	Good	Poor—2.5 mi. off.
Canning River		
DX1	Good	Poor—1.5 mi. off.
LL1	Poor	May be good?
ED1	Good	Poor—start 1.25 mi. off, fin 3 mi. off, direction 90 deg. off
ED2	Good	Fair—within 1 mi., direction correct
ED3	Fair	Fair—within 1 mi., direction correct
J1	Poor	May be fair?—direction and start in question
J2	Poor	May be good?
K1	Poor	May be good?
NX1	Very good	Poor—2 mi. off, direction 45 deg. off, too long
Hulahula River		
LL1	Good	Poor—direction off, shows cross section not longitudinal section
LL2	Fair	Fair—direction off
LL3	Marginal	May be good?
LL4	Marginal	May be good?
KL1	Poor	May be good:—too short?
KL2	Poor	May be good?
KL3	Poor	May be good?
KL4	Poor	May be good?
KL5	Poor	May be good?
Jago River		
BL1	Good	Poor—Start good but finish too short and in wrong direction
Sadlerochit River		
AX1 (Start)	Very good	Good—within 0.125 mi.
AX2	Very good start Fair finish	Poor—1 mi. off
AX3	Fair	Poor—1 mi. off
Sadlerochit River		
BX1	Poor	May be good?
BX2	Poor	May be good?
BX3	Poor	May be good?
CX1	Poor	May be good?
CX2	Poor	May be good?
CX3	Poor	May be good?
DL1	Poor	May be good?—displaced 0.25 mi. to east of river channels on map
The following DX transects are rated assuming DL1 GPS positions are accurate		
DX1	Poor	Fair/poor—0.5 mi. off, too long
DX2	Poor	Poor—start 0.5 mi. off but wrong direction and too long

Table A2 (cont'd).

Location of reference point or flight line	*Rating of transect placement on maps based on visual landmarks*	*Rating of GPS transect placement compared to map features*
DX3	Poor	May be good?—direction may be off 45 deg
DX4	Poor	Poor—start may be good but direction off 90 deg
DX5	Poor	Poor—wrong direction, too long, fin 2 mi. off
DX6	Poor	Very poor—start 2.5 mi. off, fin 4 mi. off, wrong direction
EL1	Poor	Poor—fin may be good but start 1 mi. from main river channels on map
FL1	Poor	Poor—start may be good but fin 1.5 mi. off, direction 90 deg. off
GL1	Start good Fin fair	Good
Sadlerochit Springs Icing		
A	Fair	Very poor—30 mi. off
B	Fair	Very poor—30 mi. off
C	Fair	Very poor—30 mi. off
D	Fair	Very poor—30 mi. off
E	Fair	Very poor start—30 mi. off, fin good

APPENDIX B: DETAILED RADAR TRANSECTS OF ICE MOUNDS ON THE SADLEROCHIT RIVER

These radar returns represent detailed transects over the three ice mounds on the lower end of the Sadlerochit River near the "lower USGS fence post marker." Transects A1–A4 were flown east to west beginning upstream of the mounds, then over them, and then finishing downstream of them. Transects B1–B4 were flown south to north, parallel to the river, and adjacent and over the ice mounds.

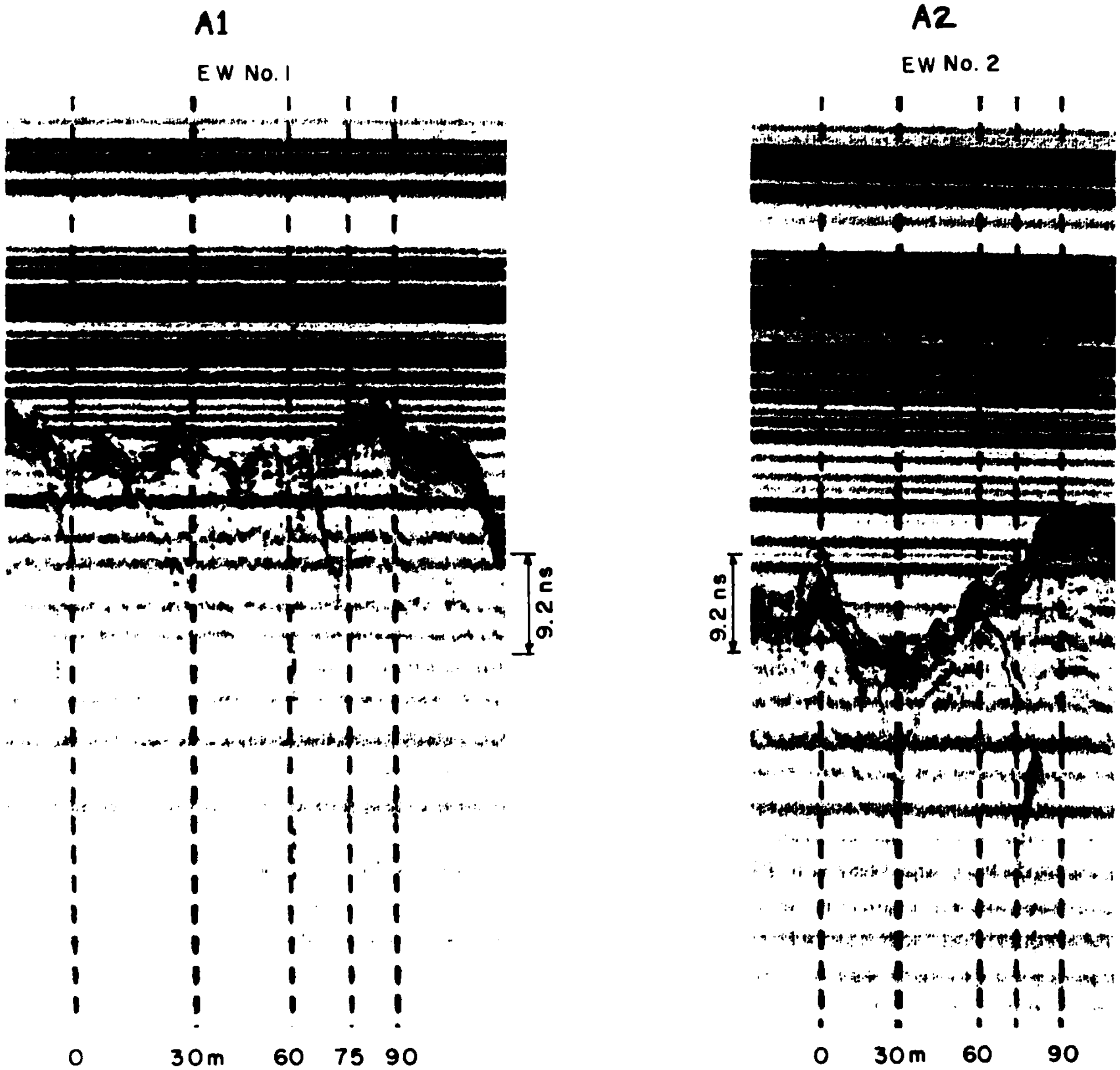


Figure B1. Sadlerochit River, A1, A2.

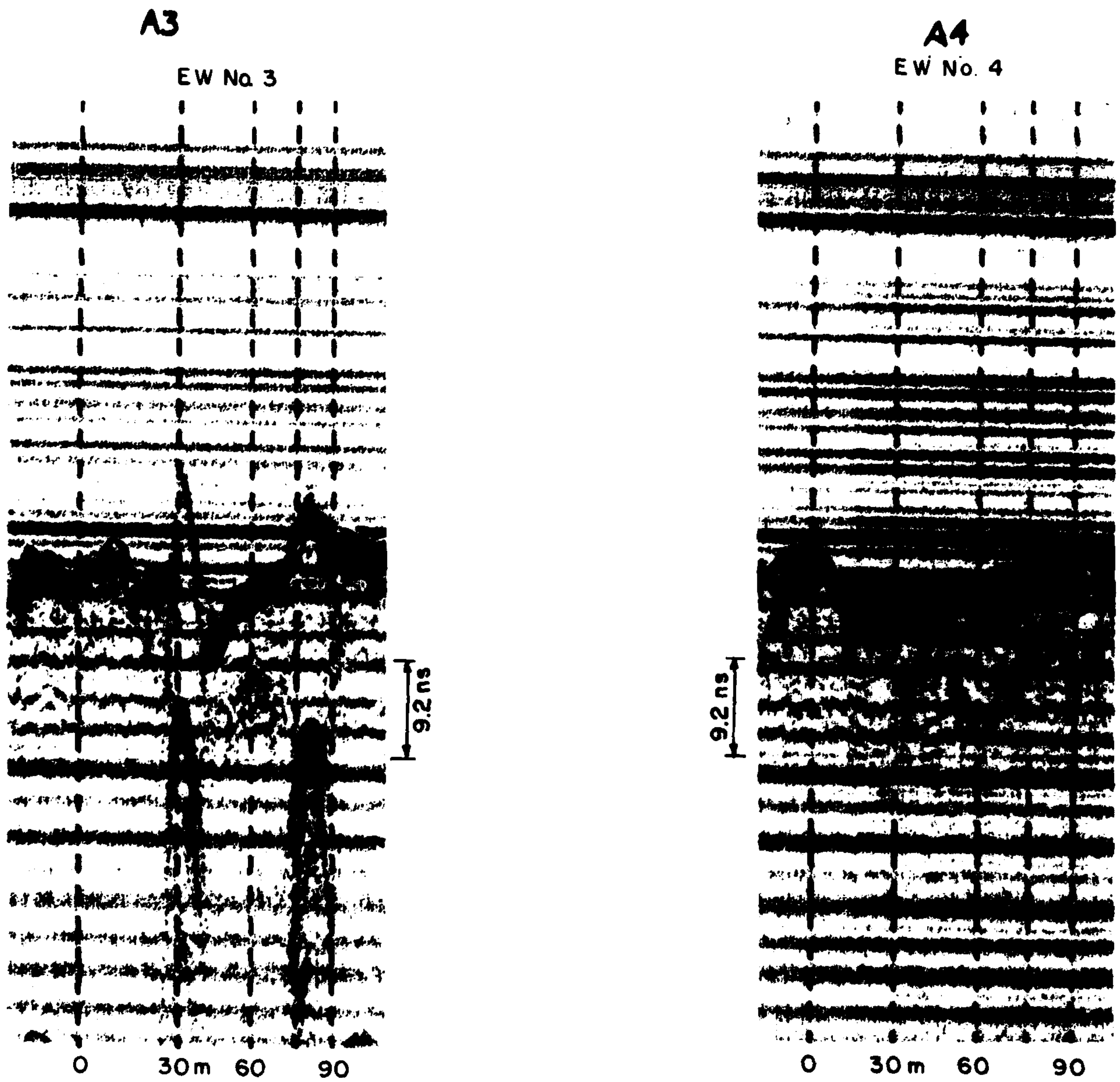


Figure B2. Sadlerochit River, A3, A4.

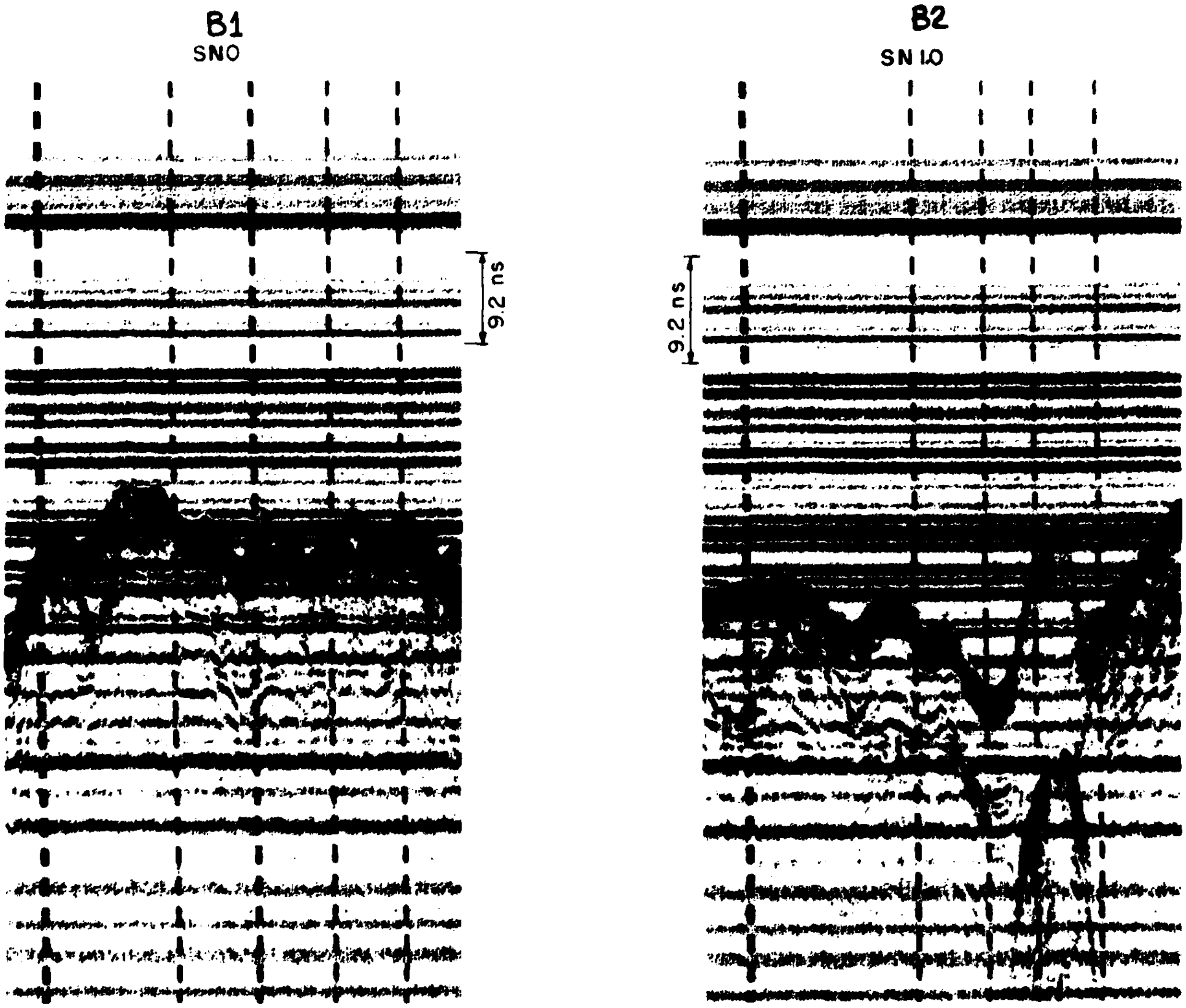


Figure B3. Sadlerochit River, B1, B2.

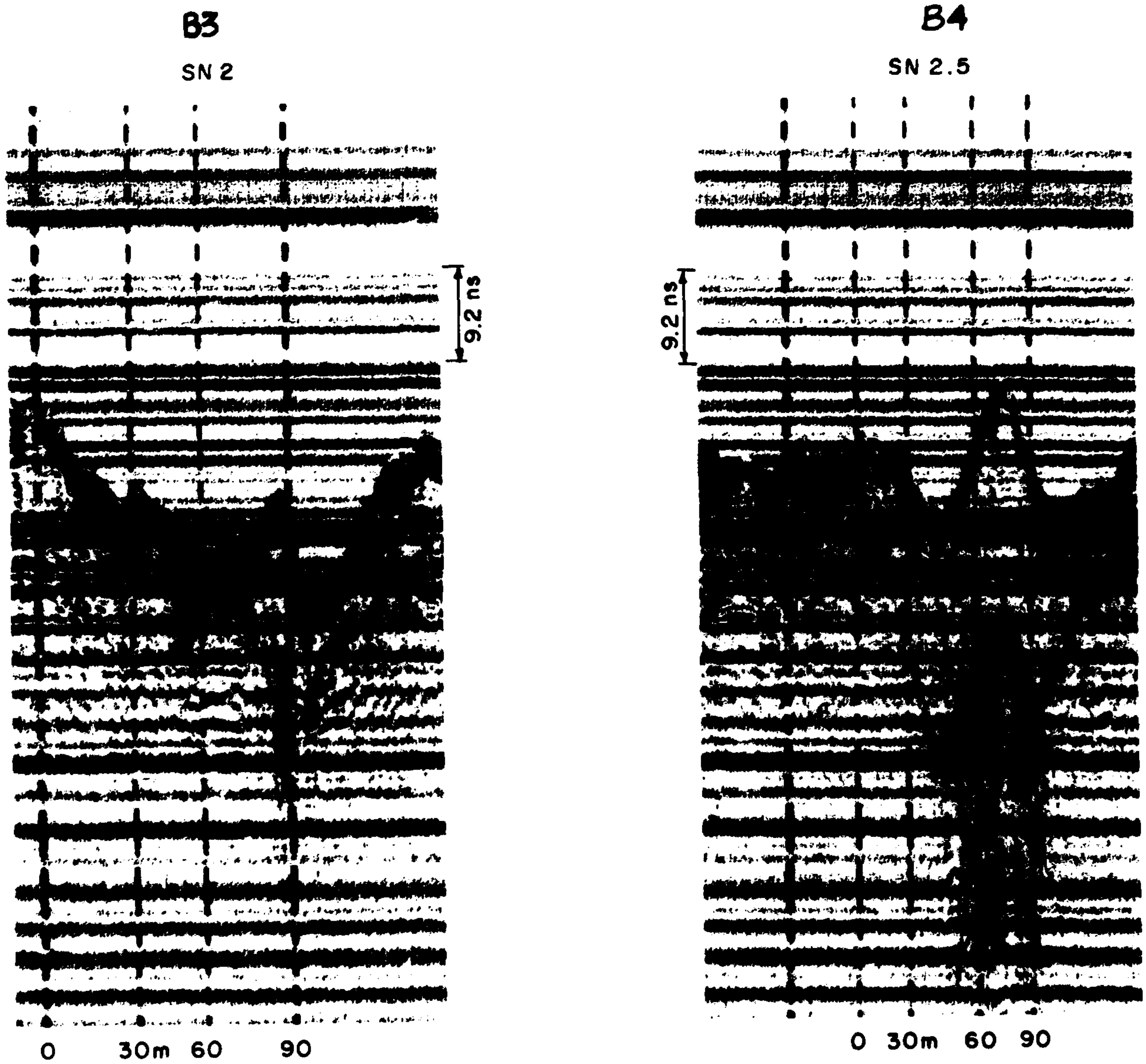


Figure B4. Sadlerochit River, B3, B4.

A facsimile catalog card in Library of Congress MARC format is reproduced below.

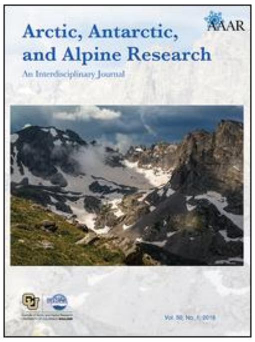
Arcone, Steven A.

Water detection in the coastal plains of the Arctic National Wildlife Refuge using helicopter-borne short pulse radar / by Steven A. Arcone, Allan J. Delaney and Darryl J. Calkins. Hanover, N.H.: U.S. Army Cold Regions Research and Engineering Laboratory; Springfield, Va.: available from National Technical Information Service, 1989.

iii, 31p., illus., 28 cm. (CRREL Report 89-7.)

Bibliography: p. 14.

1. Airborne radar. 2. Arctic National Wildlife Refuge. 3. Freshwater ice. 4. Short pulse radar. 5. Water detection. I. Delaney, Allan J. II. Calkins, Darryl J. III. United States Army. IV. Corps of Engineers. V. Cold Regions Research and Engineering Laboratory. VI. Series: CRREL Report 89-7.



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Classification of Stream Types in Beaufort Sea Drainages between Prudhoe Bay, Alaska, and the Mackenzie Delta, N. W. T., Canada

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CLASSIFICATION OF STREAM TYPES IN BEAUFORT SEA DRAINAGES BETWEEN PRUDHOE BAY, ALASKA, AND THE MACKENZIE DELTA, N. W. T., CANADA

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ABSTRACT

Arctic streams in Beaufort Sea drainages from Prudhoe Bay, Alaska, to the Mackenzie River delta are described and classified. *Mountain Streams* originate in the Arctic Mountain Province and are the largest streams in the study area. These are cold waters (usually less than 10°C) which flow about five months of the year. Arctic char is the common fish species in these streams, and the density of benthic invertebrates is typically low (100 organisms/m^2). *Spring Streams* are small spring-fed tributaries of Mountain Streams. Most are fresh water with temperatures of 3 to 7°C although thermal and mineral springs do occur. The springs are inhabited by Arctic char and high densities of benthic invertebrates (10,000 organisms/m^2). *Tundra Streams* originate in the Foothills and Coastal Plain Provinces and flow for 3.5 to 4.5 months of the year. Their waters are stained brown and have a lower pH, conductance and lower concentrations of calcium than found in Mountain or Spring Streams. Summer water temperatures may exceed 16°C. These streams are used as spawning and rearing areas by grayling. Densities of benthic invertebrates are between the other stream types.

INTRODUCTION

In his review of arctic limnology, Hobbie (1973) states that "there is almost nothing known about the limnology of flowing water in the Arctic." Information is beginning to accumulate, however, due to the current interest in arctic resources. In this paper, information is presented describing the physical, chemical, and biological characteristics of arctic streams in Beaufort Sea drainages in Alaska and the Yukon Territory, from the Kuparuk River west to the Mackenzie Delta.

We have classified streams in the study area into three broadly based categories (Mountain Streams, Spring Streams, and Tundra Streams) largely on the basis of their geographic origin. To a considerable extent, this minimal classification supports the delineation of the Physiographic Provinces described by Payne *et al.* (1952). Each of these provinces "has a unique topography, geology, soil, vegetation" (Spetzman, 1959), and so it may be expected that these differences would be reflected in their flowing waters.

THE STUDY AREA

The study area is shown in Figure 1. The geology and physiography of the area have been described by various authors including Payne *et al.* (1952), Keller *et al.* (1961), Wiggins and Thomas (1962), Wahrhaftig (1965), Bostock (1970), Hughes (1972), and Walker (1973). The North Slope in Alaska has been divided into three Physiographic Provinces: the Arctic Mountain Province, the Arctic Foothills Province, and the Arctic Coastal Plain Province

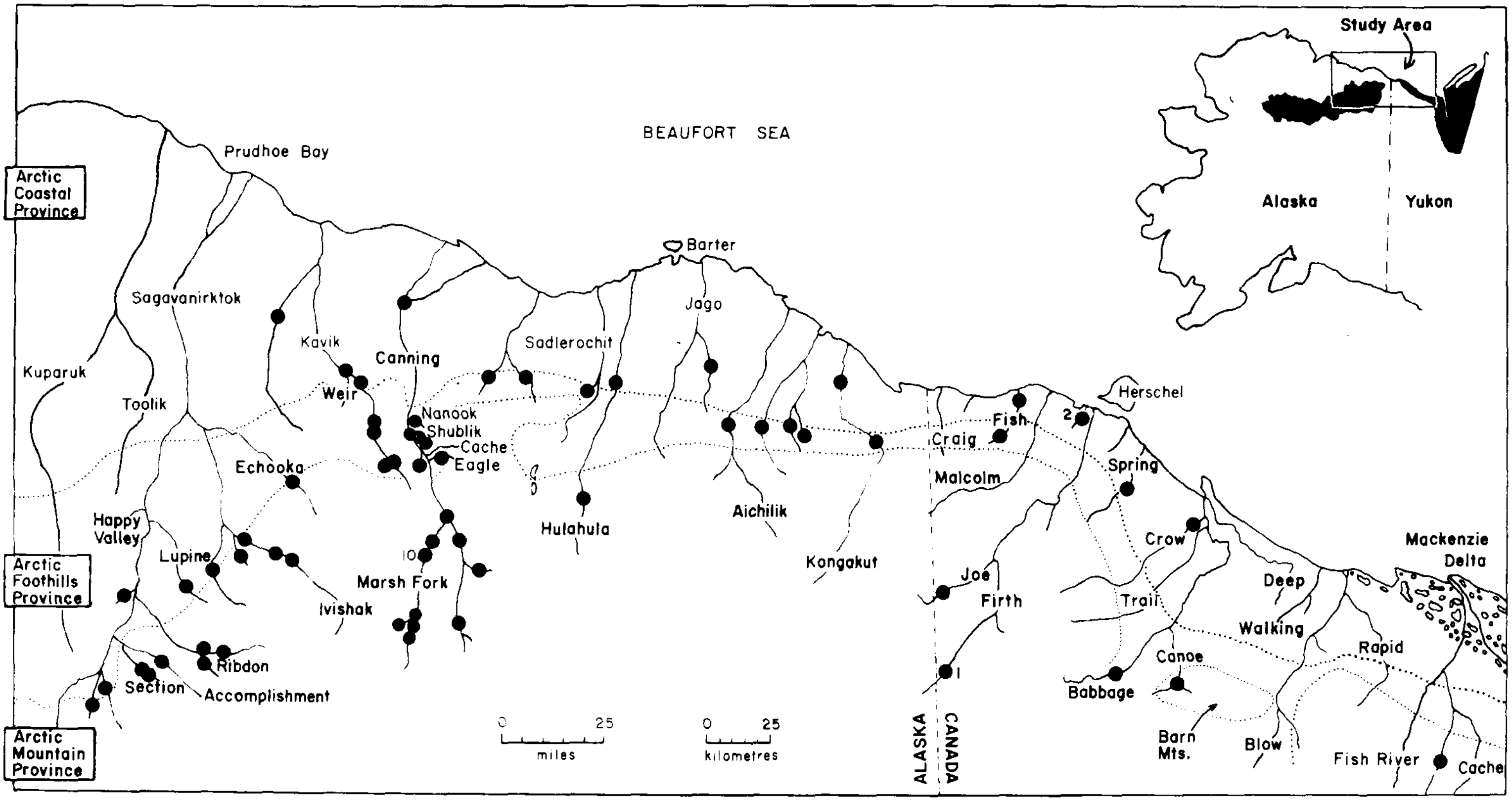

FIGURE 1. Map of the study area in northeastern Alaska and Yukon Territory. Approximate boundaries of the three Physiographic Provinces are shown. Circles show locations of perennial springs. Numbers identify some springs mentioned in the text (i.e., Canning Spring-10, Firth Spring-2). Areas of glaciation are indicated by black areas on the inset map (redrawn from Prest, 1970, and Hughes, 1972).

(Figure 1). Because most of the study area is in Alaska, we have extended the use of the Alaskan terminology into the Yukon Territory. However, geological events were different in this area and different physiographic regions have been described (Hughes, 1972).

METHODS

During the three summers of study, 1971 to 1973, samples of fish, benthic invertebrates, and water were collected from 55 locations in 17 Beaufort Sea drainages: Kuparuk, Sagavanirktok, Shaviovik, Canning, Sadlerochit, Craig, Backhouse, Fish Creek, Malcolm, Firth, Spring, Babbage, Blow, Walking, Fish River, and two unnamed streams. Our principal areas of study were the Sagavanirktok and Canning drainages. Exact locations of sampling sites and original data are presented elsewhere (Craig and McCart, 1974) and these data are summarized from Ward and Craig (1974) and McCart *et al.* (1974).

Benthic invertebrates were collected from the stream bottom with a Surber sampler (9 threads/cm). An average of 5 samples, each 0.09 m^2 (1 sq ft) was taken from a single riffle in each stream, in water depths less than 25 cm. This method provides a useful means of comparing the abundance of stream invertebrates, although its limitations are well known (Chutter, 1972).

Fish were collected by a variety of techniques: seine, dipnet, gillnet, angling, electroshocker, and fish weirs. Two methods were used to estimate fish densities: mark-recapture (Lincoln Index) and removal (Seber and LeCren, 1967).

Measurements were made of pH and dissolved oxygen (Hach Kit, Model RA-2A), conductivity (Beckman Conductivity Meter), turbidity (Hellige Turbidimeter, Model TR 3000; A.P.H.A. turbidity units, ppm SiO_2), suspended sediments (Imhoff Cone), and temperature. Additional groundwater samples were collected and detailed analysis was conducted by R. O. van Everdingen (1973).

Water velocities for discharge estimates were determined with a Gurly Pygmy Current Meter. At two locations (Weir Creek and Canning Spring-10), staff gauges were maintained from late May to September, 1973), and daily discharge rates were calculated.

THE STREAM TYPES

Mountain Streams

Description

The Mountain Streams originate in the Brooks Range and the Barn and Richardson Mountains. In Alaska the upper courses of these streams were glaciated during the Pleistocene giving some valleys a rounded appearance. Where the valleys are broad and flat the streams tend to break up into a number of interconnecting channels forming a braided pattern. Most of these channels are dry except during periods of high water.

Flow Pattern

Flows in these streams derive from two main sources: springs and surface runoff. The springs are perennial and provide the only source of winter flow. Some springs enter the beds of the Mountain Streams directly, others originate some distance away and flow through separate channels (see Spring Streams) before joining the Mountain Streams. One obvious indicator of the presence of spring water sources are the large areas of icings or *aufeis* which build up during the winter in braided areas downstream of springs. Keller *et al.* (1961) reports one of the larger *aufeis* fields as 19 km long with ice up to 6 m thick. Some *aufeis* may persist throughout the summer.

Surface runoff, the second major source of flow in the Mountain Streams, derives chiefly from the melting of ice and snow and reaches a peak during the spring thaw which begins in late May or early June. In the largest river in our study area, the Sagavanirktok River, winter flow at a station 0.6 km downstream of the Lupine River was only 0.4 m^3 sec^{-1} in both 1971 and 1972, but reached peaks of 439 m^3 sec^{-1} (June 8, 1971) and 566 m^3 sec^{-1} (June 1, 1972) during the spring flood (U.S. Geological Survey, unpublished data). During the spring flood, some scouring of streambeds and undercutting of banks occur.

The spring flood normally subsides by early July but marked variations in discharge occur in response to heavy rainfall in the mountain valleys. The silt load varies with flow and is highest during the spring flood (Figure 2). In 1973, maximum levels of turbidity reached 93 units in the Canning River (June 10) and 65

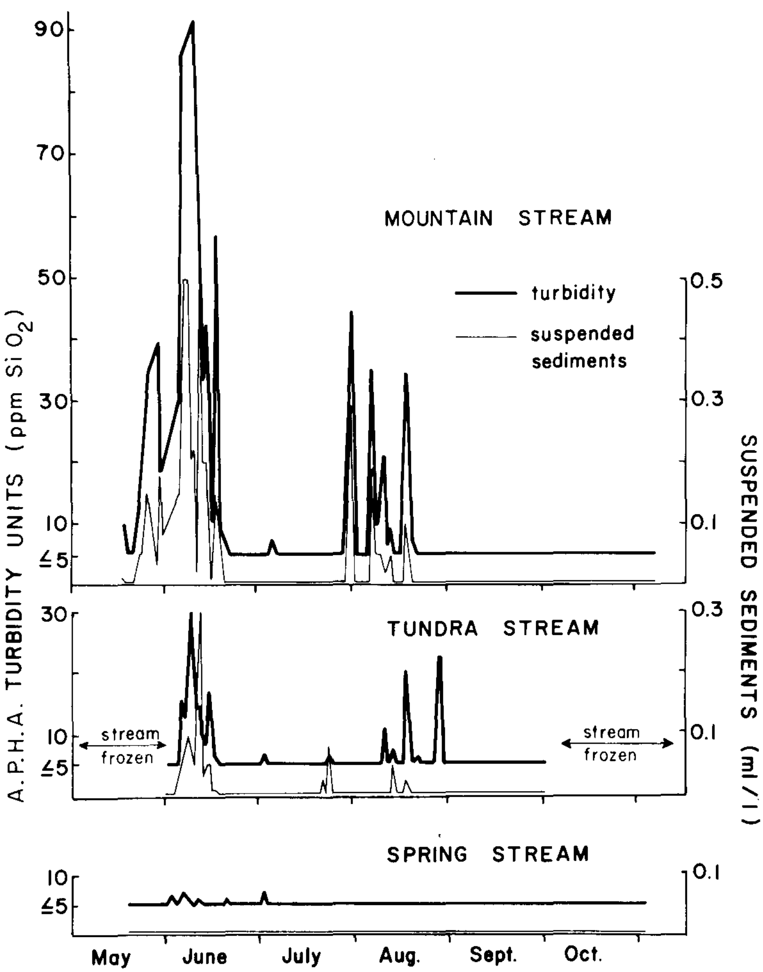

FIGURE 2. Seasonal fluctuations in turbidity and suspended sediments in a Mountain Stream (Canning River), a Tundra Stream (Weir Creek) and a Spring Stream (Canning Spring-10) in 1973. Small peaks in Canning Spring-10 reflect overflow from the Canning River at the sampling site.

units in the Kavik River (June 8 to 11). These levels are two to three times higher than those measured in a nearby Tundra Stream where the maximum value was 30 units (June 8). For comparison, the maximum turbidity level in a Spring Stream was only 7 units (June 4). Turbidity and suspended sediment levels decrease as surface runoff declines in late summer and the bottom can be seen at depths of 2 m.

The Mountain Streams flow for about 5 months of the year. About mid-October surface runoff ceases and the only flow is provided by groundwater sources in localized areas.

Temperature

Summer water temperatures in the Mountain Streams seldom exceed 10°C (Figure 3). The highest temperatures recorded were 13°C in the Sagavanirktok River (June 24, 1969) and 15°C in the Canning River (August 6, 1973). Large masses of melting *aufeis* can influence stream temperatures resulting in considerable longitudinal variation. For example, the water temperature above a large area of *aufeis* on Section Creek was 10°C compared with 4.5°C immediately below (June 21, 1970).

Water Quality

Water samples taken from Mountain Streams reflect the nature of the limestone bedrock in which the streams originate. The water is moderately hard with a predominance of calcium ions. Similar findings were reported for the Sagavanirktok drainage by Shallock (1970) and Nauman and Kernodle (1973), and these values appear to be typical of other Arctic rivers (Brown *et al.*, 1962; Kalff, 1968; USGS, 1969; Kalff and Hobbie, 1973).

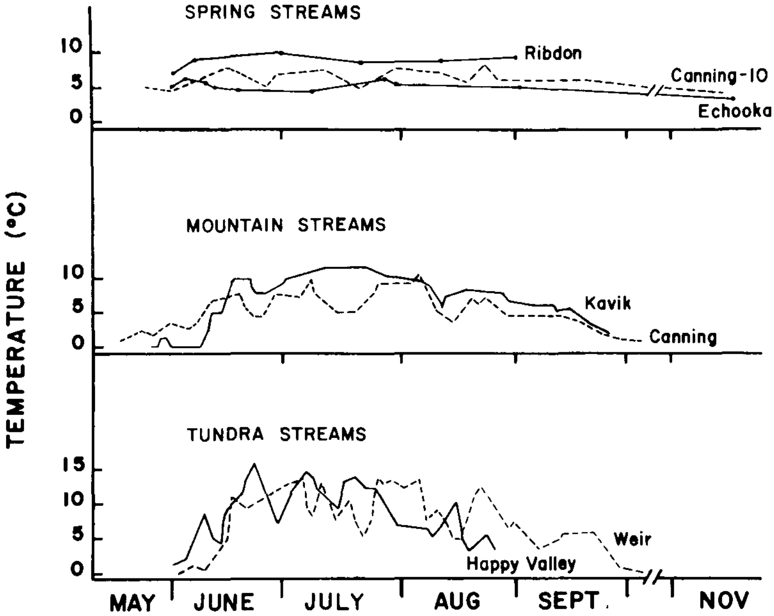

FIGURE 3. Seasonal changes in temperature in the three stream types. Approximate mean daily temperatures are given for Happy Valley Creek (1971) and Canning Spring-10, Kavik River, Canning River and Weir Creek (1973). Temperatures were recorded on several occasions in Ribdon and Echooka Springs (1971).

A comparison of conductivity, pH and calcium concentrations in the three stream types is shown in Table 1.

SPRING STREAMS

Description

As already indicated, the Spring Streams are spring-fed tributaries of the Mountain Streams. Perennial springs have been located in many Mountain Streams (Figure 1) and undoubtedly more are present. Most originate in or along the northern edge of the Arctic Mountain Province and are associated with the Lisburne Limestone Group, but others located in the Arctic Coastal Plain Province, discharge through Tertiary sediments. Several Arctic springs, notably Shublik and Sadlerochit Springs, have been reported by other workers (Leffingwell, 1919; Spetzman, 1959; Williams, 1970; and more fully by Kalff and Hobbie, 1973).

The Spring Stream habitat is one of relative stability and this appears to have a profound biological influence. Kalff and Hobbie (1973) have described these areas as "green oases in the polar environment." Streambanks are often overgrown with vegetation and the streambed is covered in most places with a heavy growth of moss or algae.

These are all small streams, generally less than 1.5 km in length and only a few meters wide. Some Spring Streams are isolated from any influence by other streams. For example, Shublik Springs is separated from the Canning River by a 9 m waterfall and so it is not affected by floods in the Canning River or by channels meandering in the Canning floodplain. Other springs originate in or close to the floodplain of Mountain Streams and have shorter isolated sections. As the channels of the Mountain Stream meander and intercept the Spring Streams, the lengths of the latter change. In many, the lower portions are subject to brief periods of overflow from adjacent Mountain Streams. Groundwater sources which discharge directly into active channels of Mountain Streams have no isolated sections and therefore are not included in the Spring Stream category.

Flow Pattern

Two springs, Echooka Spring (69°16′N, 147° 22′W) and Canning Spring-10 (69°06′N, 145° 59′W), were studied most intensely. The former is approximately 1.6 km long from its orifices to where it enters the Echooka River. The latter averages about 1.0 km in length but this varies as the result of flooding and channel shifting in the Marsh Fork. Throughout the periods of observation, turbidity and suspended sediment levels remained low (Figure 2) and total discharge from these springs was relatively stable (Figure 4).

Temperature

Water temperatures in Echooka Spring re-

TABLE 1

Comparison of conductivities, calcium concentrations, pH values and benthic invertebrate densities in the three stream types. Student's t *test values are given for paired comparisons between Mountain Streams (MS), Spring Streams (SS), and Tundra Streams (TS)*

	Conductivity (μmhos/cm)	Ca (mg/l)	pH	Benthic Invertebrates (no./m^2)
Spring Streams				
n	12	13	13	13
mean	177.1	43.2	8.2	22011
range	(140-240)	(36.3-52.6)	(7.5-8.5)	(1801-84377)
S.D.	31.2	5.0	0.4	27071.0
Tundra Streams				
n	14	6	17	18
mean	115.9	8.8	7.6	1024.6
range	(17-230)	(2.8-15.6)	(6.4-8.5)	(126-2469)
S.D.	64.8	4.22	0.62	673.9
Mountain Streams				
n	25	8	25	26
mean	175.6	28.3	8.0	292.5
range	(78-285)	(16.2-36.8)	(7.0-8.5)	(22-1270)
S.D.	47.4	6.2	0.5	329.9
T Test				
SS $\times$ TS	2.9[b]	13.9[c]	2.6[a]	3.18[b]
SS $\times$ MS	0.09	5.8[c]	0.92	3.98[c]
TS $\times$ MS	3.21[b]	6.2[c]	2.4[a]	4.7[c]

[a]$p < 0.05$
[b]$p < 0.01$
[c]$p < 0.001$

mained within a few degrees of the 4.5°C temperatures at the spring orifices (Figure 3). The maximum temperature range recorded over a 24 hr period was 3.3°C (June 1, 1971). On November 4, 1971, and April 5, 1972, the water temperature was 2.8°C while air temperatures were −28°C and −21°C respectively. The entire length of the stream is free of ice throughout the winter.

Water temperatures at Canning Spring-10, recorded almost daily from May 23 to September 6, 1973, fluctuated more than those at Echooka Spring (Figure 3). Temperatures measured at a site approximately 770 m downstream of the orifices ranged from 1.1°C (July 29) to 11°C (August 23). The typical diel variation was 4°C but differences of 6 to 8°C were recorded on several dates, excluding those occasions when there was overflow from the Canning River.

In general, the water temperatures of most springs in the study area range from 0 to 4°C in the early or late winter to 4 to 11°C in the summer. The exceptions are the two thermal springs, Sadlerochit Spring (13°C on April 14, 1972) and Cache Creek Spring (16°C on November 11, 1972).

Water Quality

Groundwater samples were collected from 19 locations. Most of these springs represent freshwater sources (dissolved solids content less than 300 mg/l) and are of the Ca (Mg)-HCO_3 (SO_4) type (Table 2).

The thermal springs on Cache Creek, NWT, diverge most noticeably from the karst-type groundwater (Table 2). Three additional springs also differ in dissolved solids content. The springs at Firth River-2, Sadlerochit Springs, and Spring River have intermediate values between the karst-type water and the mineral waters found at Cache Creek. These three

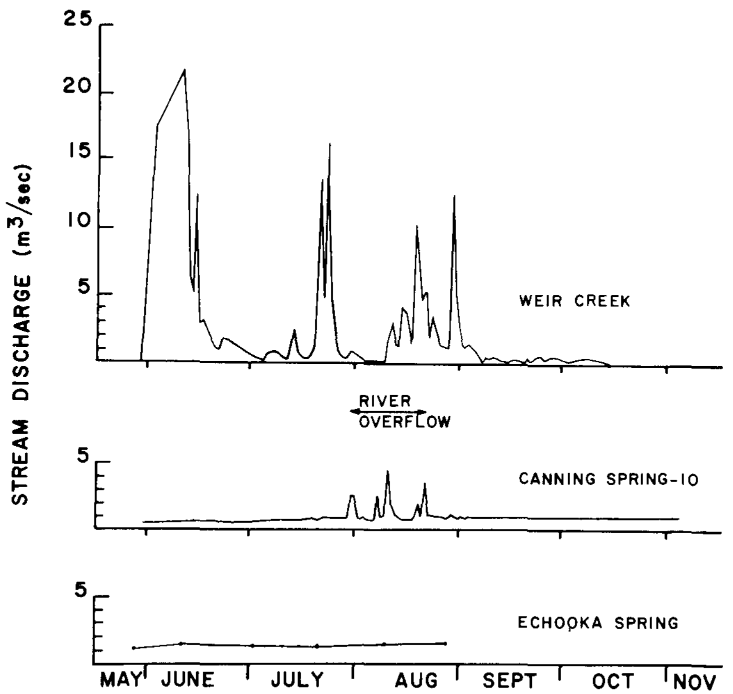

FIGURE 4. Seasonal fluctuations in discharge in a Tundra Stream (Weir Creek) and two Spring Streams (Canning Spring-10, Echooka Spring). Peaks in Canning Spring-10 (1973) reflect overflow from the Canning River. Discharge in Echooka Spring was recorded on several occasions in 1971.

springs originate near the ocean and it is possible that the differences in levels of dissolved solids may be due to passage through evaporites in the Tertiary sediments of the Coastal Plain (R. Mutch, pers. comm., 1973).

During the summer sampling periods, dissolved oxygen concentration in Spring Streams were generally high and saturation percentages were similar to those in the other stream types: Mountain Streams (76 to 100%), Spring Streams (74 to 100%) and Tundra Streams (78 to 100%). However, a considerable variation existed in the dissolved oxygen concentrations measured at the orifices of the groundwater sources. The lowest values were found at the Cache Creek orifice on May 10, 1973, where the dissolved oxygen concentration was only 0.2 ppm (2% saturation at 16°C).

THE TUNDRA STREAMS

Description

These streams drain the tundra-covered slopes of the Arctic Foothills and Coastal Plain Provinces. They tend to be small meandering streams, 30-65 km in length, which flow into Mountain Streams or directly into the Beaufort Sea. For the most part, the streams are confined to a single channel though there are braided areas in the largest of them. With few exceptions, neither *aufeis* nor springs are found on these streams, and flows cease completely during the winter. Many Tundra Streams are of the type known as "beaded" streams.

Few other Tundra Streams have been described in the literature. Ogotoruk Creek, near Cape Thompson in the western Arctic, originates in the Foothills Province and conforms in many ways to the characteristics of Tundra Streams in our area (Lamar, 1966; Likes, 1966; Watson *et al.*, 1966). The hydrology of another small stream, near Barrow has been described by Brown *et al.* (1968).

Flow Pattern

Discharge rate in Tundra Streams are intermediate between those of Mountain Streams and Spring Streams, overlapping both. A spring flood occurs in late May or early June. In Weir Creek, a tributary to the Kavik River, flow began May 30, 1973, one week after the Kavik River itself began flowing (Figure 4). This stream is approximately 39 km in length and has a 155 km² drainage basin. Floodwaters overflowed high banks and across stream meanders. As the bottom ice melted, water levels receded and thereafter, fluctuations in discharge reflected the wet summer of 1973. Flow ceased in Weir Creek about October 15.

TABLE 2

Chemical analysis of water samples from perennial groundwater sources[a]

	Springs: Karst				Springs: Intermediate				Spring: Mineral
	n	mean	(range)	S.D.	n	mean	(range)	S.D.	Cache Creek, N.W.T.
Temp. (°C)	15	2.0	(0-4.5)	1.5	3	1.7	(0.5-2.5)	0.9	15.5
pH	15	7.9	(7.5-8.2)	0.2	3	7.8	(7.3-8.2)	0.4	7.8
Conductivity (μmhos/cm @ 25°C)	15	278.5	(235-322)	24.6	3	368.7	(171-540)	151.8	4546
Ca	15	43.3	(36.3-52.6)	4.8	3	45.8	(21.5-66)	18.4	95.0
Mg	15	7.4	(4-12.9)	2.2	3	10.7	(4.1-16.8)	5.2	22.1
Na	15	0.8	(0.1-3.4)	0.8	3	15.5	(6.1-33)	12.4	824.0
K	15	0.3	(0.2-0.5)	0.1	3	1.2	(0.7-1.8)	0.5	17.5
Fe	6	0.1	(<0.05-0.12)	0.1	2	0.055	(0.05-0.06)	0	< 0.05
Mn	6	0.007	(<0.005-0.015)	0	2	0.0065	(0.005-0.008)	0	0.008
Cu	6	0.002	(<0.001-0 002)	0	2	0.002	(<0.002-0.002)	0	< 0 002
Pb	6	0.006	(<0.004-0.006)	0	2	0.005	(0.004-0.006)	0	< 0.006
Zn	6	0.05	(<0.002-0.19)	0.7	2	0.08	(0.001-0.15)	0.1	0.56
HCO_3	15	139.6	(122-201.3)	39.6	3	135.8	(75.5-167.1)	42.6	267.0
CO_3	15	0.0		0	3	0		0	0
SO_4	15	17.5	(9.1-24.7)	5.5	3	60.9	(13.5-98.3)	35.3	417.0
Cl	15	0.42	(0.1-1.2)	0.4	3	12.3	(4.9-26.2)	9.9	1036.0
F	15	0.2	(<0.05-0.59)	0.1	3	0.24	(0.06-0.57)	0.2	1.2
NO_3	14	0.09	(<0.01-0.23)	0.1	3	0.08	(0.08-0.09)	0	0.04
PO_4	9	0.004	(<0.003-0.007)	0	1	0.003		—	—
SiO_2	15	3.9	(1.9-5.4)	0.9	3	6.5	(3.7-11)	3.2	17.6
Σ	15	221.1	(191.7-278.1)	23.9	3	289	(131.4-408.7)	116.4	2698.1

[a]Figure 1 shows spring locations, most of which are of the karst type. Springs with chemical values intermediate between the karst type and the mineral waters of Cache Creek Spring, N. W. T., are Sadlerochit Spring, Firth-2 and Spring River Spring. Units are mg/l except where noted otherwise.

The open water period extended approximately 4.5 months in 1973, one month longer than in the previous year (May 27 to September 13, 1972).

The Tundra Streams often overflow their banks during the spring freshet but flooding is less severe than that in the Mountain Streams. This is reflected in the lower levels of turbidity and suspended silt loads (Figure 2). There are a number of factors which contribute to this stability: (a) most drainage originates as runoff which passes through the surrounding tundra with its high water absorbing capacity, before entering the streams, and (b) there are lakes, ponds, and marshy areas associated with streams which take up water during periods of heavy runoff and release it slowly.

Temperature

The slow passage of water through shallow ponded areas and superficial ground layers results in rapid warming by the sun, and water temperatures in the Tundra Streams are generally higher than those in either of the other types (Figure 3). A maximum of 20°C was recorded in Happy Valley Creek (July 9, 1971). In this stream there was considerable diel variation (6°C) in water temperatures even during the summer period of continuous daylight. Summer temperatures in other Tundra Streams usually exceeded 10°C, and temperatures exceeding 15.6°C (60°F) were recorded in six additional streams.

Water Quality

Tundra Streams originate outside the limestone areas and the quality of these waters is influenced during its passage through the tundra. These waters have lower concentrations of calcium and a lower pH and conductivity than found in the Mountain or Spring Streams (Table 1). The water is often stained a yellow to brown color.

BENTHIC INVERTEBRATES

A wide range in the numbers of benthic invertebrates was found in the 55 locations sampled. Values ranged from only 22 organisms/m^2 (2/ft^2) in the upper Canning River to over 84,000/m^2 (7,800/ft^2) in Echooka Spring. The greatest densities of benthic invertebrates were found in the Spring Streams (Figure 5). Overlap occurs, but the three stream types are characterized by different invertebrate densities. Spring Streams have significantly greater densities of benthic invertebrates than Tundra Streams, and Tundra Streams have significantly more than Mountain Streams (Table 1). This pattern emerges despite such complicating factors as seasonal and geographic variation.

A further distinction between the three stream types is the kind of benthic invertebrates that are present and the frequency in which they occur. While the specimens were not identified to the species level, a comparison of major taxonomic groups indicates that the greatest diversity occurs in the Spring Streams. These streams contained 22 of the 23 identified taxonomic groups compared to 18 each for the two

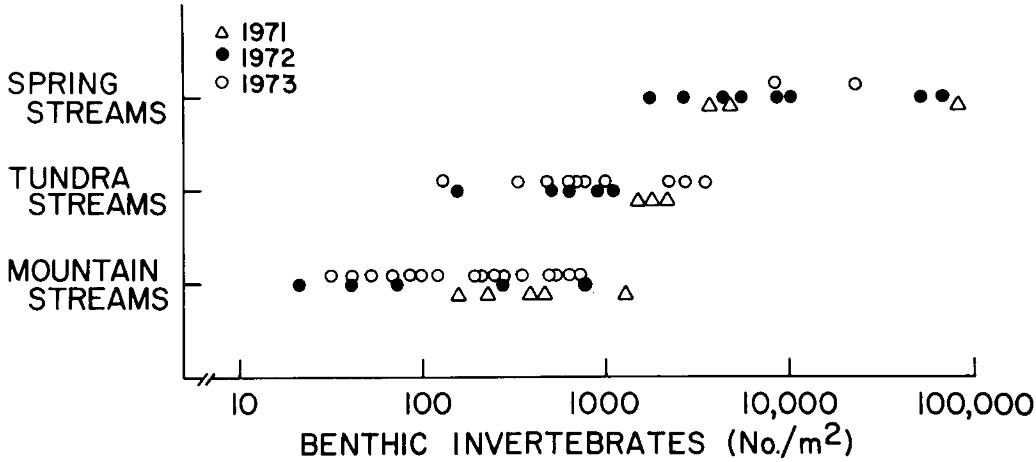

FIGURE 5. Comparison of benthic invertebrate densities occurring in the three stream types, 1971-73.

TABLE 3

Percent occurrence of major taxonomic groups in the total number of Surber samples collected (N) in each stream type

Benthic invertebrates	Spring Streams N=59	Tundra Streams N=98	Mountain Streams N=137
Trichoptera	68%	21%	1%
Plecoptera	95	86	63
Ephemeroptera	85	93	73
Diptera (unidentified)	23	23	16
Simulidae	34	44	9
Dolichopodidae	2	—	1
Tipulidae	58	46	23
Empididae	25	2	3
Chironomidae	100	81	69
Muscidae	6	4	1
Liriopeidae	3	—	—
Ceratopogonidae	2	—	—
Oligochaeta	85	87	59
Nematoda	28	21	6
Arachnida (mites)	38	22	9
Gastropoda	12	9	1
Tricladida	43	22	7
Amphipoda	15	12	18
Coleoptera larva	2	4	4
Lepidoptera larva	2	—	—
Copepoda	2	3	—
Concostracoda	3	—	—
Collembola	—	1	1

other stream types (Table 3). Furthermore, these groups occurred more frequently in Spring Stream samples. For example, 14 of these groups were found in at least 10% of all Spring Stream samples collected compared to 12 for Tundra Streams and 7 for Mountain Streams. The benthic fauna in Mountain Streams was also unique in its lack of certain taxonomic groups. Trichopterans were absent at almost all sites and amphipods and triclads were generally found in rivers only in the eastern portion of the study area.

The observed differences in benthic communities may be due to a variety of factors, some of which have already been noted (e.g., temperature, water quality). Hynes (1970, p. 226) has stated that "in general, small tributaries, being less exposed to the effects of storms covering limited areas, are richer than the larger streams into which they flow." In our area this appears to be especially true of those Mountain Stream drainages which have Spring and Tundra Streams as tributaries. If all streams from all stream types are compared (Figure 6) there is a significant correlation between invertebrate numbers and stream discharge ($r = 0.56$, $p < 0.001$). However, within any single category of stream type, the smaller streams do not necessarily have the richer fauna. When the density of benthic invertebrates is compared to stream size (discharge), no significant correlation exists within any stream type: Spring Streams ($r = 0.25$, $p > 0.1$), Mountain Streams ($r = 0.43$, $p > 0.1$), Tundra Streams ($r = 0.06$, $p > 0.1$).

Field observations in our area suggest that the overall relationship between the size of the stream and the density of benthic invertebrates is due, in part, to factors associated with the stability of stream flow. Spring Streams, because of their perennial flow and relatively constant discharge, might be expected to harbor large populations. Mountain Streams, on the other hand, fluctuate widely and Tundra Streams appear to be intermediate in this respect.

A survey of the literature showed that, in a variety of locations, seasons and substrates, benthic invertebrate densities in streams in

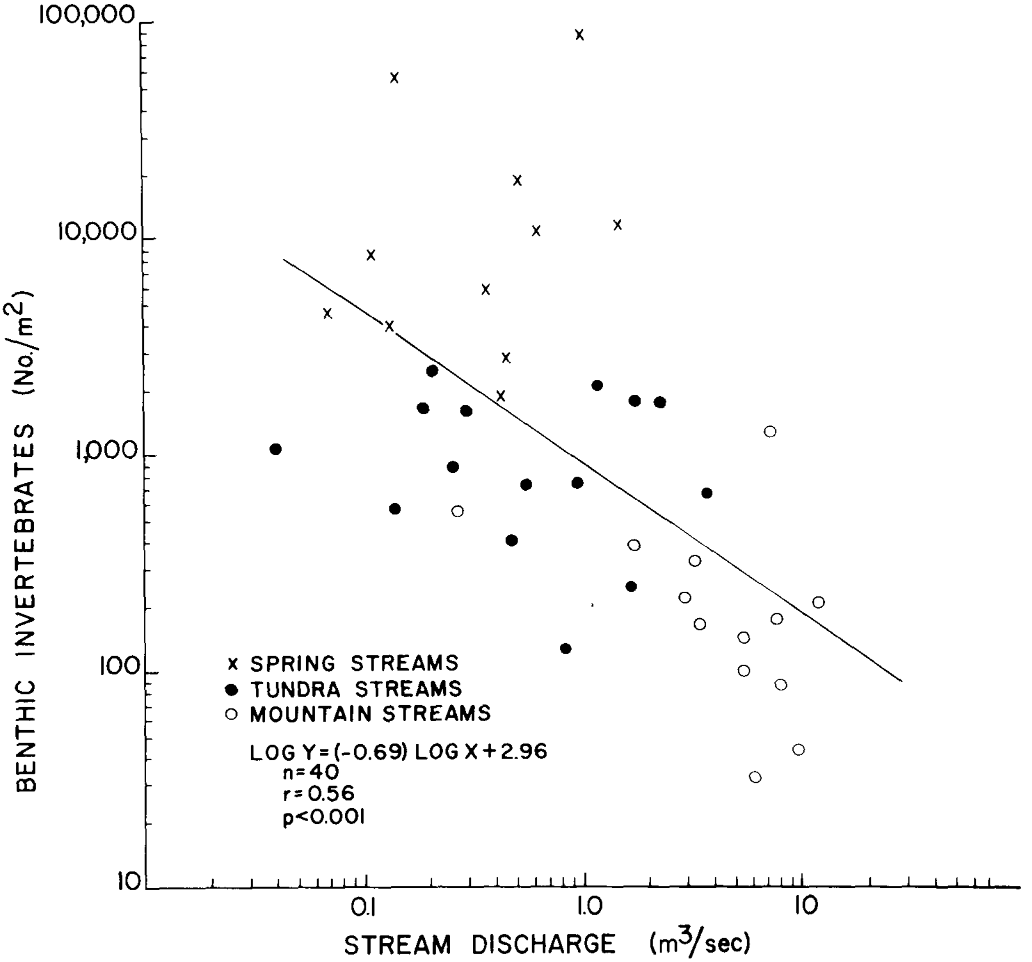

FIGURE 6. Relationship between stream discharge and the density of benthic invertebrates, 1971-73.

temperate latitudes commonly range from 500 to 10,000 organisms/m^2. While such comparisons are tenuous, they demonstrate that Spring Streams support invertebrate populations which are dense even when compared to streams in more southerly latitudes and Tundra Streams are comparable in standing crop to southern streams. Standing crops in the Mountain Streams, on the other hand, are among the lowest recorded in the literature. It should be emphasized that these data describe only the standing crop and not the rate of production which may be substantially lower than in streams in more southerly latitudes.

FISH

The common fish species in the study area are the Arctic char (*Salvelinus alpinus*), grayling (*Thymallus arcticus*), round whitefish (*Prosopium cylindraceum*), slimy sculpin (*Cottus cognatus*), and ninespine stickleback (*Pungitius pungitius*). Two of these, the Arctic char and grayling are of special interest due to their abundance and because they illustrate additional differences between the stream types. The life histories and movements of these species are complex, and detailed information is presented elsewhere (McCart and Craig, 1971, 1973; McCart *et al.*, 1972; Roguski and Komarek, 1972; Yoshihara, 1972; Bain, 1974; Craig and

Poulin, 1974; Glova and McCart, 1974; McCart and Bain, 1974).

The grayling is the most widely distributed fish in our area and it is found in all three stream types. Spawning, however, is largely restricted to the Tundra Streams and grayling fry have been collected in most of these streams. No fry have been found in Spring Streams, and it is likely that those collected in the lower reaches of the Mountain Streams have moved downstream from the Tundra Streams flowing into them.

Adult grayling enter the Tundra Streams to spawn shortly after thawing and flooding begin in early June. The spawing run is frequently followed by an upstream movement of juvenile fish. Many adults may leave the stream immediately after spawning but some adults, along with many juveniles and fry remain throughout the summer and leave just prior to freeze-up. The occurrence of other fish species is incidental in these streams. Arctic char juveniles may enter Tundra Streams but their numbers are small. For example, in Weir Creek, only one percent of the 18,000 fish enumerated at a fish weir were char, the rest were grayling (Craig and Poulin, 1974). The ninespine stickleback becomes more abundant in the Tundra Streams nearest the Beaufort Sea.

The Arctic char is the characteristic species of Mountain and Spring Streams. Spawning occurs in the late summer and fall at which time large numbers of anadromous fish begin gathering in the vicinity of spring sources in the Mountain or Spring Streams. The eggs cannot tolerate freezing and these are the only stream areas in which winter flow is assured. Fry emerge from the gravel in the spring of the following year. Both fry and juvenile char are abundant in the vicinity of springwater sources. Where conditions are favorable, densities may be very high. At Echooka Spring, densities of 5.2 and 3.4 fish/m^2 were recorded (July 20, 1971). In other spring areas, values ranged from 0.1 to 3.1 fish/m^2.

Echooka Spring is primarily a spawning area for anadromous char and a rearing habitat for their young. This situation appears to be typical of those springs with easy access to Mountain Streams and the Beaufort Sea. However, isolated stream-resident populations of dwarf char do occur (McCart and Craig, 1973; Bain, 1974; McCart and Bain, 1974).

The most interesting feature of fish distributions in the study area is the almost complete separation within major drainages, of the spawning and early rearing areas of the two major species, the Arctic char and grayling. The former spawn in the fall in the vicinity of cool, springwater sources on Spring and Mountain Streams, the latter in the spring in the warmer waters of Tundra Streams. When the grayling are still spawning, Arctic char fry have already emerged. Grayling may be unable to compete successfully under these circumstances and require the advantage of the rapid development and rapid early growth which they experience in the warm, food-rich waters of the Tundra Streams.

DISCUSSION

Biologists have long attempted to categorize the kinds of streams that occur in nature. Generally these systems are based on variables such as physical features, water chemistry, or faunal or floral zones (Macan, 1961; Usinger, 1963; Hynes, 1970). Summarizing the situation, Usinger (1963) commented that "such classifications are doomed from the start because they attempt to fit continuously variable and endlessly diverse situations into stereotyped systems. Nevertheless, the urge to classify runs deep in human nature, and useful generalizations and clearer understanding have resulted from certain broadly based ecological classifications."

Table 4 presents some of the characteristic or distinguishing features of the three stream types in the Beaufort Sea study area. The classification is a very broad one with only three stream types in an area of many thousands of square kilometers. What is interesting is the large number of streams that can be included in these categories. There are, however, several sources of variation in this classification system. These include (a) variation in stream characteristics from headwaters to mouth, (b) geographic variation, and (c) temporal variation.

Section Creek exemplifies variation of the first type. This is a small stream in the Sagavanirktok drainage which originates in the mountains. By definition then, it is a Mountain Stream and for most of its length it conforms to this classification. However, one headwater tributary is more like a Tundra Stream. It flows from a small headwater pond and meanders through the tundra before joining the mainstream. Like other Tundra Streams, the

TABLE 4

General characteristics of Spring Streams, Mountain Streams, and Tundra Streams. Mean values are followed by the range of observed values

Features	Spring[a] Streams	Mountain Streams	Tundra Streams
Physical and chemical		late May-	late May-
Flow—Surface	minimal	mid-October	mid-Sept.
Groundwater	perennial	minimal	none
Summer discharge (m^3 sec^{-1})	0.1-1.5	0.3-100+	0.1-7+
Temperature (°C)			
Summer	7(4-11)	10(4-15)	10(5-20)
Winter	2.5(0-5)	0-1 or frozen	frozen
Annual variation	4	10	17
Color	clear	clear/turbid	stained
pH	8.0(7.5-8.5)	8.0(7.0-8.5)	7.6(6.4-8.5)
Conductivity (μmhos cm^{-1})	241(149-322)	176(78-285)	116(17-230)
Ca^{++} (mg/l)	45(35-55)	28(16-37)	9(3-16)
Benthic invertebrates			
Standing crop (no./m^2)	10,000	100	1,000
Relative diversity	high	low	moderate
Fish			
Most abundant species	Arctic char	Arctic char	grayling

[a]Excludes thermal or mineral springs (Sadlerochit, Firth-2, Spring and Cache Creek Springs).

water is stained and the density of benthic invertebrates is high (2.342 organisms/m^2).

The Kuparuk River provides a similar example on a larger scale. It is the largest stream in our area which originates in the Foothills Province. The headwater tributaries are typical Tundra Streams, but the lower reaches of the river are quite different in appearance. Here there are groundwater sources, *aufeis* fields, and large braided channels.

Geographic variation involves discrepancies in the classification system in the eastern portion of the study area. The characteristics used to identify the stream types becomes less distinct towards the Mackenzie River delta. This may be due, in part, to the influence of the Mackenzie River itself and also to changes in the bedrock and surficial geology of this area (Hughes, 1972). Bryan (1972) noted that streams to the east of the Babbage meander more, and had a greater proportion of fines in the substrate and mud in the deltas than did streams to the west of the Babbage.

Temporal variation is a third source of variation that must be considered when the collection periods of benthic invertebrates are separated by months or even years. For example, at Echooka Spring the seasonal variation in numbers of benthic invertebrates ranged from means of 84,377 organisms/m^2 in mid-July to 20.930 organisms/m^2 in late August 1971. Similar comparisons in other streams also demonstrated considerable variability, but the density values obtained generally fell within the range of values characteristic for each particular stream type.

Despite these difficulties in application, we feel that the classification system, and the data on which it is based, will be a useful guide to workers in the area.

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United States Department of the Interior

FISH AND WILDLIFE SERVICE
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IN REPLY REFER TO:

ARW

AUG 29 1995

Memorandum

To: Special Assistant to the Secretary of the Interior for Alaska

From: Regional Director
Region 7

Subject: Arctic National Wildlife Refuge Report

Attached is a copy of "A Preliminary Review of the Arctic National Wildlife Refuge, Alaska Coastal Plain Resource Assessment: Report and Recommendation to the Congress of the United States and Final Legislative Environmental Impact Statement." This report was prepared by staffs of the U.S. Fish and Wildlife Service, with input from the National Biological Service in Alaska.

The report was prepared to determine if the original conclusions of the 1987 LEIS remain valid considering the significant new information that has been collected since the LEIS was prepared. While much new information exists, all studies and analyses have not been completed. This preliminary review can be updated when additional reports are completed. The document is intended to update you, and other Department of the Interior personnel, on the best available information concerning the potential environmental impacts of oil development on the coastal plain of the Arctic National Wildlife Refuge.

Please contact me if you have questions at (907) 786-3542.

Attachment

Executive Summary

Review of Potential Impacts of Oil Development on the Coastal Plain of the Arctic National Wildlife Refuge

The U.S. Fish and Wildlife Service has conducted a preliminary review of the 1987 *Arctic National Wildlife Refuge Coastal Plain Resource Assessment, Report and Recommendation to the Congress of the United States and Final Legislative Environmental Impact Statement (LEIS).* In the eight years following the report, many additional studies of fish, wildlife, and habitats have been conducted to better understand the ecology of the coastal plain of the Arctic National Wildlife Refuge and potential effects of oil and gas development.

The 1987 LEIS assessment of environmental effects of full development of the coastal plain predicted many major impacts. Reviewing scientific information subsequent to the 1987 report, the information provided in this review concludes that the prediction of major impacts is still valid. This review also concludes that the 1987 LEIS adapted a highly comparmentalized assessment, and considered impacts to species in isolation rather than as interconnected components of a complex ecosystem. Further, the major impacts on significant resources predicted in the 1987 report were characterized as acceptable risks in reliance on mitigative measures, some of which are speculative and unproven. An examination of biological and historical data indicate that, contrary to the 1987 conclusion, the Arctic Refuge coastal plain is unique among refuges and parks of the United States.

Caribou - Full leasing and development of the refuge coastal plain would have a major effect on the Porcupine caribou herd (PCH). Research since 1987 has documented that:

- a reduction in annual calf survival of less than 5% would be sufficient to change a positive rate of increase in the PCH population to a declining rate;
- caribou have a broader use of the coastal plain for calving than depicted in the LEIS;
- each year the PCH selects the concentrated calving grounds based on snow melt and rate of plant growth. The primary forage species (*Eriophorum vaginatum*) is higher in nutrition, more digestible, and more available within the 1002 area than in the peripheral areas during calving season;
- the concentrated calving area (where 50 percent of the calves are born) in any year imparts a higher level of predator protection;
- nearly every year, all PCH females and calves use the 1002 area for post-calving activities, and, in most years, the majority of bulls also use the area during late June and early July;
- displacement of the PCH to the foothills south and east of the 1002 area would subject the herd to the area of highest predator density, reduce the amount and quality of preferred forage species available during calving, and restrict access to important coastal insect-relief habitat.

Muskoxen - Major impacts on muskoxen are predicted because:

- they are present in the area year round and would be subjected to cumulative effects in both winter and summer;
- disturbance could increase energetic costs resulting in decreased calf production;
- full development would result in the loss of availability of a large percentage of high use habitat, which would have an adverse affect on muskox productivity and population size.

Snow Geese - Snow geese would be moderately impacted by oil development on the coastal plain. Without controls on aircraft activities, disturbance would have widespread effects on snow goose distribution. Such disturbance would displace geese from feeding habitats, increase energy expenditure, and reduce the ability of geese to accumulate fats.

Polar Bear - The coastal plain of the Arctic Refuge is the most important land denning area for the Beaufort Sea polar bear population. A moderate impact on refuge polar bears is predicted because:

- polar bears might avoid important denning habitat on the refuge if large-scale industrial activity occurs there;
- cumulative impacts of potential off-shore developments is an important concern for the Beaufort Sea polar bear population.

Brown Bear - A moderate decline in the numbers of brown bears using the area or a change in the distribution could result from the additive effects of direct mortality, decreased prey availability, harassment, and disturbance in denning areas.

Vegetation - Impacts on vegetation, wetlands and terrain types would cover far larger areas than the surface areas of the pads, roads and development structures. The most extensive impacts are due to:

- changes in water flow through the area due to "damming" by roads (inundation above roads, drying below them, causing changes in vegetation and distribution of wetlands, wildlife feeding and bird nesting habitat over very large areas);
- road dust on the tundra causing earlier snow-melt in the spring, increased melting of permafrost resulting in thermokarst pits, and increased pH of the soil, which kills many common tundra plants and dramatically changes the plant species composition for about 35 feet on either side of the road.

Fisheries - A conclusion of minor effects on coastal and freshwater fisheries is appropriate only if recommended mitigation measures can be strictly met. With current knowledge, it is uncertain that mitigation measures can be adequately addressed. Fisheries may be affected by:

- decreases in quantity and quality of the coastal brackish water zone, which is used by numerous anadromous fish species as a migration corridor;
- the unknown impact of any specific causeway on the local hydrography, as well as the cumulative impact of additional causeways on migrating fish;
- spring and summer water removal from fish-bearing waters which would adversely affect the quality of rearing habitat.

Water - Water in the 1002 area is very limited and impacts upon water resources should be considered major. Investigations since 1987 substantiate that:

- ice road construction requires 1.35 million gallons of water per mile. It takes 30,000 gallons of water per day to support an oil drill rig - as much as 15 million gallons may be required to drill one exploratory well.
- at the time of maximum ice development, only 9 million gallons of water are available in 237 miles of river across the coastal plain - enough to build and maintain only 6.6 miles of ice road. Gravel roads may be necessary.
- ice mining and water diversion from lakes and rivers results in an increased depth of freezing, which kills invertebrates important to fish and waterbirds.

Wilderness - Full development of the coastal plain would result in the irretrievable loss of the wilderness character of the area. The refuge, including the coastal plain, is a world-class natural area with incomparable and irreplaceable ecological, scientific, historic, and educational values for the American people. It is the outstanding example of remaining American wilderness.

A Preliminary Review of
The Arctic National Wildlife Refuge, Alaska
Coastal Plain Resource Assessment:
Report and Recommendation
To the Congress of the United States
and
Final Legislative Environmental Impact Statement
August 29, 1995

I. INTRODUCTION

In April 1987, the Department of the Interior released the *Arctic National Wildlife Refuge Coastal Plain Resource Assessment: Report and Recommendation to the Congress of the United States and Final Legislative Environmental Impact Statement (LEIS).* The report was prepared in accordance with section 1002 of the Alaska National Interest Lands Conservation Act and the National Environmental Policy Act. The U. S. Fish and Wildlife Service prepared the report in cooperation with U. S. Geological Survey and the Bureau of Land Management. Within the report, sections for each of the features being reviewed contained definitions of major, moderate, minor or negligible impacts for each of the subjects evaluated. The report concluded that the full leasing and development of the coastal plain would have major environmental impacts.

In the eight years following the report, many additional studies of fish, wildlife, and habitats have been conducted to better understand the ecology of the coastal plain of the Arctic National Wildlife Refuge and potential effects of oil and gas development. The Service conducted the following preliminary review of the LEIS to determine if the original conclusions of the 1987 LEIS remain valid, considering significant new data. While all studies and analyses have yet to be completed, additional information strengthens the fundamental conclusion that the Arctic Refuge coastal plain is a vital area for a rich mix of Arctic flora and fauna. This review supports the LEIS finding that there would be major environmental impacts from oil and gas development on the coastal plain.

The following discussion features sections focusing on the biological environment, physical environment, and human environment.

II. BIOLOGICAL ENVIRONMENT

A. Caribou

The LEIS concludes that full leasing and development of the refuge coastal plain would have a major effect on the Porcupine caribou herd (PCH). The impacts described include direct habitat modification, displacement, obstructions to movements which could reduce access to important habitats, and disturbance or harassment. The LEIS predicted a decline in caribou use within 3 kilometers of full development. It further stated that, "Significant declines in use by maternal cows and calves could occur within at least the 2-km zone." These conclusions remain valid for all the reasons cited in the LEIS, and are supported by research since 1987.

1. Caribou Use of the Coastal Plain

The coastal plain of the Arctic Refuge, including much of the 1002 area, is the most important area for high-density, concentrated calving by the PCH. In 1995, 92 percent of the PCH calved in the 1002 area.

The LEIS does not adequately portray the full extent of caribou use on the coastal plain. For example, the LEIS states, "From year to year, the distribution of caribou (PCH) on these calving grounds varies considerably, with most calving usually taking place in the area between the Hulahula River and the Canadian border." This implies that the area west of the Hulahula is of low importance for caribou.

Although from 1972 to 1986, concentrated calving occurred west of the Hulahula River in 4 of 15 years, data collected between 1987 and 1995 show that concentrated calving occurred in this area in 5 of 9 years. In addition, the distribution and habitat of the Central Arctic caribou herd (CAH) includes nearly the entire 1002 area west of the Hulahula. It is significant that additional data collected since 1987 show important calving areas west of the Hulahula River. The generalized development scenario used to assess environmental impacts included three major prospects, one of which is located entirely west of the Hulahula River. These new data indicate that a more extensive area than identified in the LEIS is important to caribou when considering the impacts of oil and gas production.

While the LEIS provides considerable discussion on calving distribution and habitat, very little information is presented regarding caribou use of the coastal plain after the calves are born. The LEIS simply says, "Postcalving movements and aggregations show considerable annual variation." No specific examples or maps are provided. Information regarding caribou distribution and movement during the post-calving period was available in the Baseline Report Series, but was not included in the LEIS. Nearly every year, all PCH females and calves use the 1002 area for postcalving activities and, in most years, the majority of bulls also use the area during late June and early July.

Caribou movements studied after the LEIS illustrates a more extensive and dynamic use of the area by the PCH than the LEIS presents. Large post-calving aggregations of PCH caribou, sometimes consisting of most of the herd, gathered in the Canning River delta area from late June to early July in 6 of the last 9 years.

2. Habitat

The LEIS determined relative habitat values using an aerial approach involving a polygon generated by overlapping multiple years of calving concentration maps. Since only calving distribution maps were used, information about post-calving distribution and movement was not included, and thus the analysis inappropriately truncated the geographic scope and frequency of caribou interaction with the development infrastructure.

Habitat research since 1987 provides new data about the distribution of various coastal plain habitats and the quality of their forage. In addition, use of satellite imagery has permitted study of the movement of caribou on the coastal plain relative to snow melt and vegetation phenology. Although some of these data are still being analyzed, research has documented that:

- the caribou have a broader use of the coastal plain for calving than the LEIS depicted

- snowmelt and "green-up patterns" influence caribou-calving sites each year

- the concentrated calving area, where 50 percent of the calves are born, in any year imparts a higher level of predator protection

- the primary forage species (*Eriophorum vaginatum*) is higher in nutrition, more digestible, and more available within the 1002 area than in the peripheral areas when caribou are present

- caribou seek ridge tops on the coastal plain for insect-relief habitat, in addition to the coastline and mountains the LEIS noted.

Analysis of the multi-year data set from radio-collared adult females indicates that birth sites and caribou distribution are associated with snow melt patterns and early plant phenology. The PCH selects the high density portion of the calving ground annually based on areas with the highest rate of plant growth in the two weeks immediately following calving. The new plant growth is highly digestible with a high protein content. This is the period when protein and energy demands on caribou cows, for lactation, are the highest of any time of the year.

3. Development Impacts

The LEIS assessed the effects of development on caribou as being related to the actual acreage impacted by roads, pipelines, and drill pads, often called the "footprint" of development. The LEIS assumed a 3-kilometer sphere of influence from development would affect 37 percent of the PCH concentrated calving area. Both the effects on calving and post-calving habitats caused by the development infrastructure should be considered. When caribou's complete use of the coastal plain is considered, development affects a larger area than the LEIS depicted by considering only areas of concentrated calving.

By focusing on the "footprint" and a sphere of influence immediately adjacent to it, the real impact of the development infrastructure is minimized and underestimated. The effects the development infrastructure have on movements and access to preferred habitats are the primary factors that will determine the impact to the herd's population dynamics. The development scenario used to assess impacts is oriented on a general east - west axis with two corridors connecting to marine facilities at Camden Bay and Pokok Lagoon. This alignment would interact with caribou movements from uplands to the coast to avoid insect harassment as well as westward movements before calving, and eastward movements when the herd moves toward the British Mountains in Canada. If the infrastructure were oriented north - south, there would also be extensive interaction with these predominant east - west caribou movements. Investigations with the CAH at Prudhoe Bay have shown that the propensity of caribou to cross structures is inversely proportional to the size of the group encountering the structure--that is, large groups have lower success in crossing structures. Since the PCH is 10 times greater in size than the CAH, the probability of large groups occurring in the 1002 area suggests a greater incidence of negative interactions between caribou and the infrastructure. In this case, the "footprint" becomes a barrier and reduces access to habitats beyond the 1-, 2-, or 3-kilometer sphere of influence identified in the LEIS.

In all probability, a barrier effect will occur to some extent, causing displacement of the herd. The LEIS agreed that a change in distribution of the PCH could reasonably be expected. There is limited coastal plain habitat available because of the proximity of the mountains to the sea. Therefore, displacement would be to the foothills south and east of the 1002 area. This would:

- displace the herd to the area of highest predator density
- reduce the amount and quality of preferred forage species available during calving, and
- restrict access to important coastal insect-relief habitat.

The potential increase in predation from this scenario with the herd at its present population level would have a negative, albeit minimal, impact on the population. On the other hand, reduced food resources due to displacement and potential increased energy expenditure, due to encountering the infrastructure, could have a more noticeable impact. Failure to obtain insect relief would contribute to poor physical condition. The Alaska Department of Fish & Game, in conjunction with the 1002 research program, found that viability of the calf was associated with fall weight of the female. Reduced parturition rates or calf survival will have a negative impact on the population dynamics of the PCH.

The LEIS acknowledged the potential for a population decline resulting from loss of habitat and reduction in habitat values. It simply concluded, "No appreciable decline is expected as a result of development." That conclusion is speculative, cannot be substantiated scientifically, and does not logically flow from the concerns about habitat. Likewise, attempts to precisely predict a numerical population decline would also be speculative. Current studies indicate, however, that the ability to freely locate the calving ground where conditions are most favorable influences calf survival. Small disruptions to free calving ground location may have demonstrable repercussions for herd dynamics. A reduction in annual calf survival of less than 5 percent would be sufficient to change a positive rate of increase in the PCH population to a declining rate. It is reasonable to conclude that the cumulative effects of reduced access to habitat providing preferred forage, predator avoidance, or insect relief for the PCH caused by full development of the 1002 area would result in a major, adverse impact on the herd.

B. Muskoxen

The LEIS predicted a major impact on muskoxen as a result of full development. Information gained from 1987 to the present adds to the understanding of the scope of impacts that would be expected. Additional supporting information provides further insights.

The extirpation of the muskox in Alaska and concern that the species might become extinct worldwide resulted in the return of this animal to the State in the 1930's. After 60 years, the species has been reestablished in areas of its former range in northern Alaska. The muskox population centered in the 1002 area of the Arctic Refuge is the source of animals that colonized adjacent areas in northern Alaska and northwestern Canada.

Muskoxen are one of only two ungulate species adapted to arctic conditions, and the only large mammal present year-round in the 1002 area. This important component of the arctic ecosystem provides continuous food for scavengers and predators and contributes to the biodiversity of the system. Muskoxen are energetically conservative, with a high fidelity to relatively small home ranges, limited daily and seasonal movements, and relatively low rates of reproduction. Most females do not reproduce annually. A single calf is born in late April to May under winter conditions. Females must provide milk to sustain the calf for several weeks before green plants are available in early to mid-June.

The portion of the muskox population that resides within the 1002 area increased throughout the mid-1980's, reaching a maximum in 1986, then decreased and stabilized at fewer than 300. Muskoxen have expanded their range both within and beyond the 1002 area. About 100-120 muskoxen currently occupy the portion of the 1002 area between the Tamayariak and Canning Rivers (west), similar numbers occur along the Sadlerochit River (central) and fewer than 60 muskoxen live between the Jago and Aichilik Rivers (east). Regionally, population numbers continue to increase. Over 700 currently live between the Sagavanirktok River in Alaska and the Babbage River in Canada.

The muskox population on the refuge now supports a limited subsistence hunting opportunity for residents of Kaktovik. As many as 10 bulls may be taken each year. Muskoxen provide a protein source during spring when whales and caribou are not present.

Mixed-sex groups have a high fidelity to relatively small geographic areas, and major shifts in distribution are rare. When dispersing, mixed-sex groups move into areas already colonized by bulls; they are unlikely to move into areas devoid of muskoxen.

In winter, muskoxen select locations where snow cover is minimal and dried sedges and willows are available. In winter, muskoxen stay in small areas and reduce their movements and activities to conserve energy. By contrast, in summer, muskoxen are more active, moving longer distances and using larger areas and a greater diversity of habitats as a strategy to regain body weight lost during the long winter, pregnancy, and lactation. Unless females reach a threshold weight before the rut in August, they do not reproduce.

Muskoxen are vulnerable to potential impacts from oil and gas exploration and development because they are present in the area year round and would be subjected to cumulative effects in both winter and summer. Unlike other large vertebrates that migrate or hibernate, muskoxen actively use the arctic coastal plain during winter. This is possible because of their adaptations to cold, their ability to process low-quality forage, and their energy-conserving strategies including low rates of movement and activity. Energetic costs will be increased if animals move or become more active in response to construction or facilities operations, aircraft and vehicle traffic, and other human activities. Shifts in distribution in winter, caused by human activities, are also likely to result in less forage availability and higher energetic costs to obtain food if muskoxen move into areas of higher snow cover. Increased energetic costs will likely result in decreased calf production and may cause some additional winter mortalities.

The discussion in the LEIS about the effects of stress and disturbance on muskoxen and on the effects of habitat loss on ungulates is still valid, but more information is available on the response of muskoxen to oil field facilities. Muskoxen dispersing into areas adjacent to the Trans Alaska Pipeline corridor are found in locations about 5 miles from a pump station, and 2 miles from the haul road and pipeline.

Assuming a 2-mile sphere of influence, the amount of muskox high-use range that could be affected under full leasing exceeds that described in the LEIS, as muskoxen have extended their range throughout the 1002 area. The full development scenario would result in the loss of availability of a large percentage of high-use habitat. This would have an adverse affect on muskox productivity and population size.

Muskoxen are often found along rivers that would likely be used for extensive gravel extraction and creation of water storage basins. These activities in drainages the animals use would result in their displacement and in permanent habitat loss. If muskoxen are displaced from portions of the 1002 area, subsistence hunters will have reduced opportunities. Areas vacated by muskoxen may not be recolonized by mixed-sex groups for some unknown period of time.

Because numbers of muskoxen within the 1002 area are small, and the animals live in social groups, negative impacts on only a few groups could be significant. If only a few groups of animals are displaced or disturbed, a large percentage of the population would be affected. Small increases in female mortalities can cause a decline in population numbers. Muskox distribution, reproduction and survival are influenced by winter weather and snow depth; effects from oil and gas development will likely be additive in severe winters.

C. Polar Bears

The conclusion in the LEIS that development might have a moderate level of impact on polar bears is still reasonable. Since completion of the LEIS, considerable data have been collected regarding polar bears. Results of radio-telemetry studies spanning 11 years indicate that 45 percent of maternal polar bear dens found on land for the Beaufort Sea population were within the Arctic Refuge, and 34 percent were within the 1002 area. Considering the broad region involved (approximately from Wainwright, Alaska to the Bailee Islands in Canada) the refuge coastal plain is a disproportionately small area for the number of dens documented. These results indicate that the coastal plain of the Arctic Refuge is the most important land denning area for the Beaufort Sea polar bear population.

The LEIS does not include a consideration of the effects of a major oil spill (chronic, acute, and secondary) on polar bear populations, nor does it consider the effects of other intensive developments along coastal areas of Alaska and Canada. If oil development occurs on the coastal plain of the Arctic Refuge, it would provide infrastructure that could encourage new drilling in adjacent offshore waters. The cumulative impacts of Beaufort Sea oil development are a concern with the polar bear population.

D. Brown Bears

According to the LEIS, a moderate decline in the numbers of brown bears using the 1002 area or a change in the distribution could result from the additive effects of direct mortality, decreased prey availability, harassment, and disturbance in denning areas. Brown bears use the coastal plain extensively, particularly east of the Sadlerochit River. Development would result in increased encounters with humans causing additional hunting and mortality attributed to defense of life and property. Concerns about reduced prey availability are speculative and are dependent on effects of development on the PCH.

E. Snow Geese

The LEIS predicted that snow geese would be moderately impacted by full development. It further concluded that direct loss of snow goose habitat to infrastructure would be minimal. The major impact would be aircraft disturbance that displaces geese from feeding habitats, increases energy expenditure, and reduces the ability of geese to accumulate lipids. The LEIS noted that impacts would be highly variable each year, depending on the size of the staging population.

These conclusions are essentially correct. The most important snow goose feeding habitats occur in small patches that are widely distributed but comprise <3 percent of the 1002 area east of the Hulahula River. Because of the widespread distribution of these sites, they are not likely to be significantly affected by infrastructure. However, the heterogeneous distribution of feeding habitats requires that snow geese have access to large areas of tundra so that they can search for forage. For that reason, disturbance that displaces geese will have a greater affect than habitat loss to infrastructure.

Without controls on aircraft activity, disturbance would have widespread effects on snow goose distribution. Studies in Canada and our observations on the Arctic Refuge indicate that small fixed-wing aircraft and helicopters flush snow geese at distances of up to 4 miles from the flight line. Larger aircraft associated with petroleum development could flush geese at greater distances. The distance that flocks are displaced following disturbance is highly variable but often exceeds one mile. Distribution of snow geese in areas near flight corridors would likely be significantly affected.

The disturbance of staging snow geese would reduce the time they spend feeding, and the loss of habitat in which to feed would adversely affect their accumulation of energy reserves essential for migration, threatening their survival.

The LEIS suggests that approximately 60 percent of the preferred staging area on the Arctic Refuge lies within the 1002 Area. Using a slightly different analysis based on frequency of use, we concluded that approximately 80 percent of the most frequently used area on the refuge is within the 1002 Area. Because of this larger value, the percentage of preferred staging area impacted by development would be slightly higher than indicated in the LEIS.

The LEIS is correct in stating that impacts would be highly variable among years. The numbers of geese on the Arctic Refuge has ranged from approximately 12,800 to 325,000 individuals. Impacts would be greater in years of larger staging populations.

The conclusions of the LEIS regarding impacts to snow geese are still valid and are supported by additional research conducted since 1987.

F. Wolves

The LEIS predicted that the cumulative impact of full development could cause a moderate decline in the wolf population of the 1002 and surrounding area. The number of active dens adjacent to the coastal plain has varied from 3 to 7. Wolf use of the coastal plain is limited and generally associated with the foothills south of the 1002 area. The conclusion in the LEIS that the wolf population could decline due to reduced prey (e.g., caribou) is questionable, when the LEIS earlier had concluded there would be no appreciable decline in the caribou. Although the conclusion that there will be no appreciable decline in PCH is speculative, it is unlikely, given the present size of the PCH and the relative number of predators, that development would greatly impact wolf populations by changes in herd movement, distribution, or size. The LEIS predicted that additional direct mortality from shooting and trapping could occur because of increased human access. It is reasonable to conclude the effect of development on wolves would be moderate.

G. Wolverine

The LEIS concluded that, "The cumulative effects of displacement, avoidance and reduced food resources could result in localized, long-term changes (a moderate effect) in wolverine distribution. Inadequate controls on access and harvest could possibly reduce by half or more the 1002-area wolverine population. If this occurred, it could result in a major effect on that population." Few data are available on the wolverine population of the 1002 area, and no estimate of total numbers. The conclusion of the LEIS remains a reasonable estimation of impacts on wolverines.

H. Seals and Whales

Since the full development scenario does not involve shipping the oil by tankers, and the development is onshore, the effects on whales and seals is expected to be minor. Barge traffic may increase somewhat during the summer after the whale spring migration has passed and while the seals are pelagic. Seismic work on ice could cause some displacement of ringed seals locally, with the possible loss of some pups.

Again, there is no discussion of the likelihood of onshore production facilities encouraging oil development in adjacent offshore waters. If offshore development is facilitated by the construction of onshore infrastructure, then cumulative impacts need to be considered. Large increases in marine traffic and potential oil spills are the greatest oil development threats to seals and whales.

I. Arctic Peregrine falcon

Since completion of the LEIS, newly collected information regarding status of peregrine falcons in the area indicates the species is increasing and using new nest sites. Pairs with young have been documented at Clarence River, Kongakut River, Ekaluakat River, Hulahula River, Canning River, and on Barter Island, all outside the 1002 area. These locations, except for the Canning River are new nest sites since the LEIS was completed. Adult peregrines have also been observed at locations on the Jago River, and Igilatvik Creek, within the 1002 area, where nesting is likely. Because of the improved status of the Arctic peregrine falcon populations, particularly on habitats located west of the refuge, the species was removed from the threatened list in November 1994. Populations on the refuge coastal plain have been the last to show increase, and are still recovering.

J. Vegetation

1. Landsat-TM Map

The interrelationship of wildlife species and their habitat is complex. The Service conducted many studies examining this interrelationship, including forage availability, snowmelt chronology, phenology, plant biomass and nutritive values. This research was designed to quantify the value of habitats used by caribou and other wildlife species on the arctic coastal plain. The research tried to identify portions of coastal plain that are important during and after calving.

To facilitate this research, the Service produced a LANDSAT-TM map that provides more accurate information on the vegetation types of the coastal plain. Previous maps, from the 1980's, depicted the general distribution of land-cover types. Additional assessment, however, indicated that their site-specific accuracy was inadequate for studies of wildlife habitat. The recently completed LANDSAT-TM map is more accurate. Therefore, the Service now has better knowledge of the distribution and composition of vegetation types of the arctic coastal plain and a better understanding of why these habitats are important to caribou and other species.

2. Seismic Exploration

Previous studies of disturbance from winter seismic exploration on tundra predicted short-term and mainly aesthetic impacts. The Arctic Refuge seismic study has tracked disturbance and recovery from the seismic exploration conducted in 1984 and 1985, with the most recent field data gathered in 1993 and 1994. A random sample of plots on the seismic trails showed that 10 percent of all trails still had measurable disturbance a decade after the exploration. Based on the length of the original trails, including seismic lines and camp-move trails, this translates to approximately 400 kilometers of disturbed trails remaining.

Not all visual impacts are readily apparent to casual observers. Three percent of trails (or 120 kilometers, total) had medium- to high-level disturbance remaining. Recovery of these areas is likely to take many more years. Based on permanent study plots, we found that sites that had been moderately to severely impacted during seismic exploration still showed impacts in 1994. Plots still have changes in plant species composition and increased melting of permafrost, compared to control plots. Over one half of the plots still have increased depth to permafrost a decade after disturbance, even at plots with low levels of initial disturbance where changes to the vegetation were no longer visible, indicating long-term changes to the soil temperature regime.

In some areas, ruts or troughs have formed on seismic trails. This is caused by melting of permafrost and settling of the ground surface, which causes a long-term change in plant composition and the elimination of some plant species.

In the summary of recommended mitigation in the LEIS, no mitigation measures appear to address these concerns. Regulation of any future exploration should include more protective stipulations regarding adequate protective cover of snow, types of vehicles used, and routes used for trails.

3. Rehabilitation (Revegetation)

The summary of recommended mitigation for the 1002 area briefly mentions habitat restoration. However, the document stated earlier that literature reviews of revegetation in Alaska had concluded that areas north of the Brooks Range are the most difficult to revegetate, and successful rehabilitation techniques have not been developed for these areas. This remains true today. Extensive experiments on revegetation techniques at Prudhoe Bay, conducted by contractors for the oil companies, have involved great effort and expense and often have been disappointing or have provided only limited success in small areas. Failure to revegetate naturally or with human help is mainly due to the presence of permafrost, the slow growth and propagation of arctic plants, and the short, cool growing season, particularly close to the arctic coast.

The exploratory drill site that Chevron created on Kaktovik Inupiat Corporation land on the coastal plain in the mid-1980's is the site of the only revegetation effort in the Arctic Refuge. The most advanced techniques were used in this showcase effort, including the construction and later removal (after only a year and a half) of a foam-timber pad on top of flat tundra with no gravel and no disturbance to the tundra surface. Nevertheless, the well-site was still a visible scar on the tundra in 1995.

The pad was reseeded in 1987 when drilling was completed. After that reseeding failed, contractors for Chevron visited the site and continued reseeding almost every summer until at least 1992. Service botanists measured the amount of vegetative cover on the pad as 6 percent in 1990 and 23 percent in 1992. A visual estimate in 1994 indicated 25-50 percent cover. The area of the buried reserve pit adjacent to the pad has much better growth of grasses than the pad. However, the surface, originally dry and graded flat, is now very uneven due to subsurface melting. Ponding of surface water has increased each year since 1987; about 25 percent of the surface area is now covered with ponds. The drilling wastes are supposed to remain frozen to be immobilized, raising the concern that drilling wastes will leach into vegetation and ponds.

4. Cumulative Impacts to Vegetation, Wetlands and Terrain Types

In the LEIS summary of effects, a rating of moderate would be more accurate than minor for impacts on vegetation, wetlands, and terrain types. Studies at Prudhoe Bay have documented extensive cumulative impacts to tundra vegetation from oil development. The impacts cover far larger areas than the surface areas of the pads, roads, and development structures, and have been clearly documented by aerial photographs. The most extensive impacts are due to changes in water flow through the area due to "damming" by roads--that is, inundation above roads and drying below them, causing changes in vegetation, wetlands distribution, wildlife feeding, and bird nesting habitat over very large areas.

Another cause of vegetation change at Prudhoe Bay is the "dust shadow" along roads. Road dust on the tundra causes earlier snow-melt in the spring, increases melting of permafrost resulting in thermokarst pits, and raises the pH of the soil, killing many common tundra plants and dramatically changing the plant species composition for about 35 feet on either side of the road. Replacement plants are often pioneering, "weedy" species.

Studies of the effects of development on a landscape rarely take into account the cumulative impacts of many phases of development. The industrial complex at Prudhoe Bay clearly has had landscape-scale impacts on the ecosystem. Studies mapping historical changes to the Prudhoe Bay oil field found that indirect impacts can lag behind planned developments by many years and the total area eventually disturbed can greatly exceed the planned area of construction. For example, in the wettest parts of the oil field, flooding and thermokarst covered more than twice the area directly affected by roads and other construction activities.

K. Fisheries

A significant amount of fisheries data from inland and coastal waters of the 1002 area has been collected and analyzed since 1987. Most notably, the documented distribution of Arctic char (or Dolly Varden) in freshwater systems has been expanded. We now know that the Okpilak River provides important habitat for Arctic char. Arctic char were also found in the Akutoktak River, a tributary to the Okpilak River, in small numbers. These rivers were not identified in the LEIS as supporting char.

With respect to coastal fisheries, biologists have synthesized a large amount of data since 1987, both on the Arctic Refuge coast and from the Prudhoe Bay development area. The most noticeable shortcoming of the LEIS is the lack of recognition of the importance of the Arctic cisco fishery in the region, coupled with the dependence of Arctic cisco, for migration purposes, on the nearshore environment of the central Beaufort Sea coast. The Arctic cisco is a significant subsistence resource for the villages of Kaktovik and Nuiqsut. Past surveys show that Kaktovik natives often harvest more Arctic cisco than Arctic char/Dolly Varden. As stated in the LEIS, Arctic cisco are known to migrate from Canada's Mackenzie River to the central Beaufort Sea (the Colville River delta) region for rearing. The harvest in Kaktovik occurs as the adults migrate eastward to return to the Mackenzie River to spawn. The size of this return migration run is dependent on the number of juveniles that were successfully recruited to the Colville River region several years earlier. Thus, the original westward migration by juvenile Arctic cisco is an extremely critical period in the fishery. It is essential to maintain the integrity of the coastal brackish water zone, which is used by numerous anadromous fish species as a migration corridor. The effects of any specific causeway on the local hydrography, as well as the cumulative impact of additional causeways on migrating fish, are unknown.

Except for accidental spills, the most potentially threatening aspect of oil and gas development on coastal fishes is the construction of docks or causeways. Their potential for disrupting the integrity of the brackish nearshore corridor during summer has been a focus of study in the Prudhoe Bay region. While much of the literature from Prudhoe Bay suggests minimal effects of causeways, caution is required in directly extrapolating those results to the 1002 coastal area. The coast of the Arctic Refuge is situated differently in the migration corridor than is Prudhoe Bay and presents a different hydrographic regime. The proximity and volume of freshwater input are different for the two areas. As stated earlier, the cumulative effects of additional causeways on migrating fish are potentially significant. Direct *a priori* application of conclusions concerning causeways in Prudhoe Bay to the entire arctic coast is not supported by the recent literature.

The conclusion of minor effects on coastal and freshwater fisheries in the LEIS is inappropriate unless the recommended mitigation measures can be strictly met. With the current knowledge of the potentially affected aquatic systems, it is uncertain that mitigation measures can be adequately addressed. For example, mitigation measure #8 states that docks and causeways are to be constructed so as not to impede fish movement or alter the coastal hydrography. This would certainly be a sufficient measure--if it were realized. Whether this is possible, or feasible, appears uncertain at this time. To biologically demonstrate the "no effect" status of any given causeway, prior to construction, is problematic. Also especially problematic, considering that all the rearing habitat has almost certainly not been identified, is the mitigative measure listed in the LEIS, "Prohibit spring and summer water removal from fish-bearing waters to levels that maintain quality of rearing habitat." The LEIS conclusion of minor effects on coastal and fresh-water fishery resources is dependent on the general premise of maintaining quantity and quality aquatic habitat. There remains, however, great concern about the feasibility and actual compliance with this requirement, as it remains a biological target that has yet to be clearly defined.

III. PHYSICAL ENVIRONMENT

A. Water Quantity

The LEIS concluded that the dedicated industrial use of the limited natural freshwater sources of the 1002 area would be a major effect. Additional investigations since 1987 substantiate the fact that water in the 1002 area is very limited and the impact upon water resources should be considered major. Ice road construction creates the most significant demand on the water resources during oil and gas explorations. Studies show that at the time of maximum ice development in rivers and lakes (March and April) the quantity of available water in 237 miles of river across the coastal plain is enough to build and maintain only 6.6 miles of ice road. Ice mining--scraping and hauling lake and river ice--would be required as a source of ice particles for ice road construction. Ice mining and diversion of water from lakes and rivers earlier in the winter would increase the depth of freezing within the thaw bulb. This deep freezing would kill mud-dwelling invertebrates important in the food chain of waterbirds and fish during the summer months.

In addition, 10 miles has been considered the limit of economic feasibility for hauling ice and water for road construction. There are only 3 or 4 small lakes in the transportation corridor between the Okpilak River to the Canning River, a distance of 60 miles. Sufficient ice and water are not available. Thus, gravel roads may be necessary.

A transportation system consisting of gravel roads would have significant impacts on water resources. Roads through the coastal plain and to Prudhoe Bay would lie across slope. They would dissect the natural flow of water during breakup, melt permafrost, act as dams, trap water upslope, and cause the downslope areas to become dry. Sheetflow across the tundra during spring snow melt is the primary source of water to recharge the lakes and small ponds important to water birds. A road system would interrupt this recharge of the lakes and cause secondary impacts to habitat for waterbirds that breed in the area.

A road system could also have significant effects on the tundra, both downslope and upslope of the roads. When microsite characteristics (moisture and topography) are altered, the resulting species composition differs from the original community. Surface impacts related to gravel fill usually extend beyond the direct loss of the area covered by the fill. These include impoundments of snowmelt, dust, gravel spray from snow removal, small construction spills, thermokarst, and contaminants from road oiling. The recovery of vegetation following disturbance is related to the intensity of the disturbance and the resulting changes in moisture regimes.

During the winter months, water is more abundant in lakes than in pools located beneath ice hummocks along major river drainages of the 1002 area. In April, when ice is at maximum thickness, 90 percent of the available water is contained in 9 of the 119 lakes surveyed. The lakes are not evenly distributed across the 1002 area. Many lakes are congregated near the mouth of the Canning River, and only two lakes are located in the region between the Katakturak and Sadlerochit Rivers. Observation of fish presence in lakes was more frequent and widespread than previously suspected.

Although winter water occurs over a widespread area in most of the major river drainages in the 1002 area, the quantities are low. Ice cover of river channels is generally frozen to the river bed in all areas of the coastal plain. Only 9 million gallons of water were estimated to be available along the 237 miles of river channel inventoried. It takes approximately 1.35 million gallons of water to construct and maintain each mile of ice road used to support oil exploration activities and 30,000 gallons of water per day to support an oil exploration drill.

B. Water Quality

Very little information is provided in the LEIS regarding water quality. Most of the descriptive information, other than that for springs, is based on studies elsewhere on the North Slope. Most of that information, particularly descriptions of seasonal changes in water quality, is accurate. Since the LEIS, the Service has obtained a large volume of data about the water quality of ponds and lakes on the Arctic Refuge and at Prudhoe Bay including impacts of contaminants there. These data provide additional useful information and document the poor buffering capacity (hence susceptibility to water quality changes) of many Arctic Refuge ponds and lakes. These data also disprove one statement made in the LEIS regarding water quality, "Some shallow lakes are turbid during summer, when wind and wave action disturb bottom sediments." Turbidity measurement data from the refuge did not reveal any turbid conditions in any of 36 Arctic Refuge shallow ponds and lakes sampled six times over two years of open-water conditions. The original source of this statement in the LEIS was a study in the National Petroleum Reserve - Alaska and was not supported by any measurement data.

The industrial infrastructure required for oil development would produce sewage that would need to be treated and disposed of properly. Currently 7 large and approximately 10 small sewage treatment plants are working in northern Alaska oilfields. All plants discharge under permits from the Alaska Department of Environmental Conservation (ADEC) and several have NPDES permits from the U. S. Environmental Protection Agency. Six of the large plants discharge into tundra ponds and one, Endicott, discharges to the Beaufort Sea. At the end of 1987, 47 sewage treatment plants were permitted to discharge a maximum of 1,201,650 gallons per day. The reduction in the number of plants is a result of decreased activity in the region and consolidation of some facilities.

Environmental effects of sewage effluent discharges include localized nutrient enrichment of wetland areas, in some instances resulting in algal blooms that increase suspended solids and biochemical oxygen demand, increased metals deposition, and discharges of chlorine.

C. Air Quality

No air quality data for Prudhoe Bay or adjacent oilfields were presented in the LEIS. The close proximity of the Brooks Range to the coast within the Arctic Refuge would create greater chances for inversions and poor air quality episodes and could result in greater entrapment of poor air. The composition of the crude oil and emission equipment design would influence air quality impacts from gas/water/oil separations on the refuge.

Regarding heavy metal and nutrient (nitrogen and phosphorus) impacts, studies have documented enrichment of nutrients and several trace elements in Prudhoe Bay snowpack. The Service has also recently gathered data at Prudhoe Bay and on the refuge to assess the effects of atmospheric deposition on snowpack contaminant concentrations and on the moss, *Hylocomium splendens*. We are still analyzing these 1994 data. However, the snow data indicate significant inputs of some major and trace elements, including heavy metals at Prudhoe Bay at two sites, one near drilling operations and the central compression plant, and the other near the North Slope Borough solid waste incineration facility. Effects appear to be local in that the metal enrichment patterns at the two sites differ substantially and no east-west effects are observed extending into the Arctic Refuge. However, the data suggest significant inputs of nutrients with likely significant effects on the vegetative community. Uptake of certain heavy metals by moss is also occurring.

D. Reserve Pits

The LEIS reviews some of the contaminant impacts of reserve pits and mitigation measures, such as closeout under Alaskan solid waste regulations and requirements. The Service has documented additional impacts of reserve pit fluids. It has also been suggested, but not documented, that caribou may utilize abandoned reserve pits and exploratory sites as salt licks, adding a potential contaminant impact not considered in the LEIS. However, new techniques in waste management now allow for pitless drilling (i.e., no reserve pits). Disposal of drilling wastes can now occur by subpermafrost injection, and drilling cuttings have also been successfully ball-milled, with injection of the fines. If these technologies were to be stipulated for development on the refuge, the impacts from reserve pit fluids would be minimized beyond those estimated in the LEIS.

Statements in the LEIS regarding State of Alaska solid waste requirements for closeout of reserve pits are no longer accurate. The State no longer requires closeout of all abandoned pits, and requirements for closeout have been substantially "loosened" when closeouts are required. To provide the same level of mitigation as described in the LEIS, stipulations would be needed regarding closeouts and solid waste management.

E. Oil Spills

The ADEC has continued to maintain records on the number and volume of oil and other hazardous waste spills on the North Slope since 1987. In general, reporting of spills has increased, indicating a need to revise the description of spills presented in the LEIS. Also, at least two well-blowouts have occurred on the North Slope since the LEIS was prepared. The potential for blowouts and their possible consequences in the refuge were not detailed in the LEIS. Furthermore, the *Exxon Valdez* oil spill occurred after the LEIS was produced and therefore was not discussed in the LEIS.

F. Mitigation

The LEIS relied on mitigative measures to offset many of the adverse environmental impacts of potential oil development within the Arctic Refuge. Many of these mitigative measures are unproven. The LEIS discussion of mitigation states, "Surface effects of seismic surveys can be minimized by confining operations to the winter after the active soil layer is frozen to a depth of at least 12 inches and the average snow depth is about 6 inches." Use of the words "average" and "about" are examples of word choices that reduce the impression of problems. If snow-depth only averages 6 inches, there must be significant areas that have less than 6 inches. In most years that is the case, due to the topography and wind characteristics of the area. The patterns of light snow-cover make it virtually impossible to traverse some areas with surface vehicles without damaging vegetation and soils. The 1984-1985 seismic study resulted in extensive damage precisely because of these factors. In reality, vehicles could not avoid all the areas of light snow-cover as permit stipulations implied. These stipulations are the same ones proposed in the preferred alternative.

Further, statements that the stipulations used for 1984-1985 seismic studies "would result in avoidance or minimization of impacts to vegetation" are optimistic. Experience has shown and extensive data exist to illustrate that damage to vegetation was not avoided in spite of stipulations. Observations at study plot sites in 1994 indicate that the recovery trend at some disturbed sites has reversed towards greater deterioration. This new information requires further study to more accurately predict consequences of future exploration activities.

In terms of mitigating impacts of gravel removal, the LEIS states, "Gravel removal should be prohibited from active fish-bearing watercourses and their tributaries." This does not indicate that it would be prohibited. Furthermore, if removal of gravel were limited to non-fishbearing watercourses, then few riparian gravel sources would ultimately be used, in which case most of the gravel would be extracted from upland sources, resulting in greater impact to landscapes where the visual effects would be very long-lasting.

As for vegetation, the LEIS says, "Localized removal or destruction of tundra vegetation resulting from the construction of gravel pads, gravel roads and gravel mines could occur." Vegetation destruction would occur. The issue of gravel and water required for development and production needs further evaluation. Analysis of data regarding predicted versus actual impacts of Prudhoe Bay oilfields and the Trans Alaska Pipeline completed after the LEIS indicate that the amount of gravel used was 400 percent greater than had been predicted.

In describing surface geological surveys within the 1002 area only, the LEIS does not explain that past surveys have largely focused in the mountain terrain to the south, where various rocks are exposed for investigation and testing. Congress designated this region as wilderness under provisions of the Wilderness Act. It is likely that if full development were authorized, there would be some work in the adjoining Wilderness area. The effect of noise associated with helicopter access in the Wilderness area is not adequately discussed. Accordingly, the LEIS underestimates the impacts to wilderness recreation and the disturbance of wildlife in the wilderness area.

Statements that docks and causeways should be constructed so that along the shore, water transport and water lagoon chemistry are not affected, and fish movements are not impeded, imply that the Prudhoe Bay experience is directly applicable to the Arctic Refuge coast. The coast of the Arctic Refuge is situated differently in the migration corridor than is Prudhoe Bay and presents a different hydrographic regime. Whether such an endeavor is possible, or feasible, is uncertain at this time.

IV. HUMAN ENVIRONMENT

A. Wilderness

The LEIS acknowledged that full development of the coastal plain would result in the irretrievable loss of the wilderness character of the area.

1. Historical Perspective

In the early 1950's, senior National Park Service planner George Collins visited the coastal plain. He found "a magnificent place of beauty . . . not the spectacular beauty of the mountains to the south, but a subtle beauty that comes largely from being part of a much larger, varied and interconnected natural system."

Collins was leading an extensive survey designed to determine which areas in Alaska most deserved formal protection. After traveling extensively throughout Alaska, he concluded that the area now established as the Arctic Refuge provided the nation's finest opportunity to preserve a vast arctic wilderness.

Collins was but the first of many to extol the presence of a complete and undisturbed spectrum of Arctic ecosystems as a primary value of the refuge. Based on Collins' research, in 1957 Bureau of Sport Fisheries Director, D.H. Janzen, declared the proposed range " . . . an ideal opportunity, and the only one in Alaska, to preserve an undisturbed portion of the Arctic large enough to be biologically self-sufficient."

Two years later, before a U.S. Senate hearing on the Arctic National Wildlife Range proposal, Interior Secretary Fred Seaton repeated Janzen's summation, adding,

> "It would comprise one of the most magnificent wildlife and wilderness areas in North America . . . Certain portions of the Arctic coast and the north slope river valleys, such as the Canning, Hulahula, Okpilak, Aichilik, Kongakut, and Firth, and their great background of lofty mountains, offer a wilderness experience not duplicated elsewhere."

Wilderness values, along with wildlife and recreational values, are among the three stated purposes of Public Land Order 2214 that established the Arctic National Wildlife Range in 1960. Those values came into focus again in 1973 when, following an agency wilderness review, the entire Range, including the coastal plain, was recommended for wilderness designation.

The issue of refuge wilderness was extensively debated during the ANILCA hearings of the late 1970's. In 1978 the administration's position was stated by Interior Secretary Cecil Andrus in a speech before the Outdoor Association of America:

> "In some places, such as the Arctic Refuge, the wildlife and natural values are so magnificent and so enduring that they transcend the value of any mineral that might lie beneath the surface. Such minerals are finite. Production inevitably means changes whose impacts will be measured in geologic time in order to gain marginal benefits that may last a few years."

The LEIS acknowledged the 1002 area's "outstanding wilderness qualities: scenic vistas, varied wildlife, excellent opportunities for solitude, recreational challenges, and scientific and historical values." It did not, however, expand on these values, nor discuss the uniqueness and national importance in the area.

2. Wilderness Qualities

The refuge is the only conservation area in the nation that provides a complete range of Arctic ecosystems, functioning in balance to perpetuate wildlife populations. The area offers more wildlife diversity than any other region of the Arctic. The LEIS states that the 1002 area is the most biologically productive part of the refuge and the heart of wildlife activity. This productivity results from the combination of factors that make the area a unique wilderness: the proximity of mountains to ocean, the landscape diversity, the climate, and the permafrost. The coastal plain has unique ecological qualities vital to species such as caribou, brown bears, muskox, wolves, swans, and snow geese. Several species, such as the caribou, use the area during sensitive and critical periods in their life cycle. Many of the species also are of international significance--for example, the massing of the Porcupine caribou herd is one of North America's greatest wildlife spectacles. Many of these species are sensitive to human activities and require large areas of essentially unaltered habitat.

The 1002 area provides more diverse landforms and varied scenery than any other part of Alaska's coastal plain. Here the Brooks Range is only 20 to 40 miles from the Arctic Ocean. From many vistas within this area, visitors can enjoy awe-inspiring views of 9,000 foot snow-clad peaks, glacial valleys, braided rivers, rolling tundra meadows and terraces, shallow lakes, beaded streams, and sea ice--an opportunity not available elsewhere on American soil. The effect of standing water over permafrost adds further interest and dynamic change to the landscape. Rivers rise rapidly, creating cut banks and new gravel bars. In winter, the frozen soil moves and cracks the surface, exposing underground ice structures, forming polygons and other permafrost features, and creating micro-environments for new plants and animals.

Remote and roadless, the 1002 area and the adjacent fragment of refuge coastal plain Wilderness east of the 1002 area comprise the most pristine of any large segment of arctic tundra remaining in the nation.

3. Impacts on the Wilderness Resource

The LEIS states that, "losses in . . . wilderness values on the 1002 area would be the consequence of a long-term commitment to oil and gas development in the area." However, the LEIS did not address, in any significant way, what those losses would be.

Development also would substantially reduce wilderness qualities in large parts of the adjacent Wilderness, significantly reducing its value. An oil field would be seen by recreationists from the many northern foothills and mountains within sight of the 1002 area.

An oil field would destroy the wilderness value that people derive from seeing the coastal plain. Hearing the attendant sounds of the oil industry, the helicopters and aircraft traffic, would erode the sense of wilderness for miles beyond the 1002 boundary.

The LEIS accurately states that "most recreationists currently visit the 1002 area for a wilderness experience." However, the LEIS significantly understates the effects of oil development on their experience. The fact is that an oil field would eliminate the wilderness experience for almost all of the recreationists, primarily hikers and floaters, who currently use the 1002 area and areas in the adjacent Wilderness.

4. Regional Uniqueness

Almost all of the Nation's coastal arctic environment is open to oil development or currently leased. Along Alaska's entire north slope, only the Arctic refuge coastal plain is currently protected from development. The 1002 area represents only about five percent of the Nation's arctic coastal plain. Protection of the area's unique wildlife and wilderness resources would help to ensure a needed balance with current and expanding development of Alaska's north slope. This is especially important because no other coastal areas in northern Alaska or the Nation provide the unique mix of landscapes, wildlife, habitats, and scenery that the 1002 area does. For these reasons, the area has incomparable and irreplaceable scientific, ecological, historical, and educational values for the American people. The LEIS acknowledged that development would result in an irretrievable loss of the wilderness character of the coastal plain.

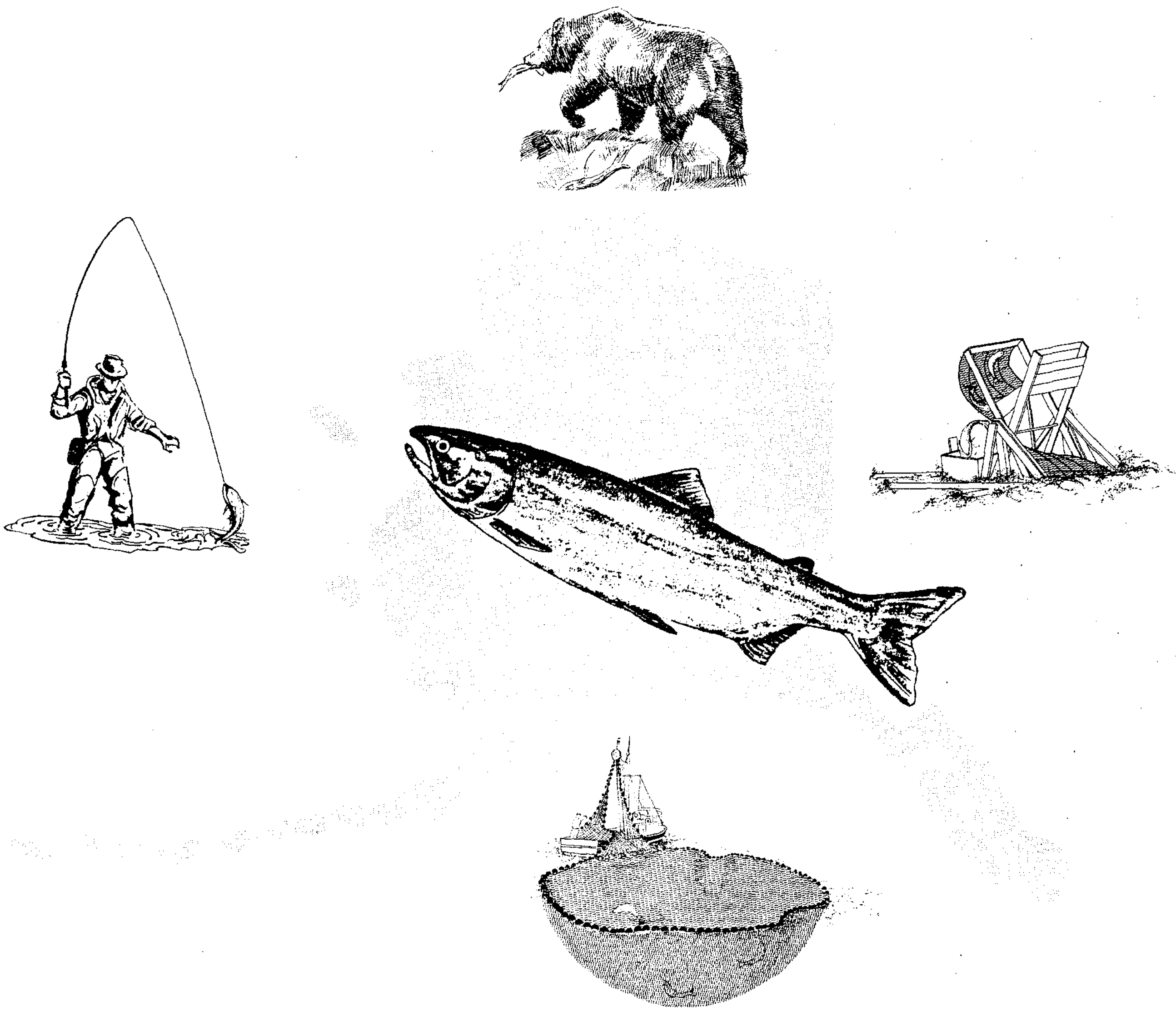
V. CONCLUSIONS

The 1987 LEIS assessment of environmental effects of full development of the Arctic Refuge coastal plain predicted a number of major impacts. Reviewing scientific information subsequent to the 1987 report, the information provided in this review concludes that the prediction of major impacts is still valid. This review also concludes that the 1987 LEIS adapted a highly compartmentalized assessment, and considered impacts to species in isolation rather than as interconnected components of a complex ecosystem; a more scientifically sound evaluation requires consideration of the interrelationship of the species and the surrounding environment of the coastal plain. Further, this review concludes that the major impacts predicted in the 1987 report were characterized as acceptable risks in reliance on mitigative measures, some of which are speculative and unproven. Finally, an examination of biological and historical data indicate that, contrary to the 1987 conclusion, the Arctic Refuge coastal plain is unique among the refuges and parks of the United States.

Information received since the 1987 report confirms that impacts from development would be major, and that measures to reduce or remediate those impacts are uncertain. For its biological richness, undisturbed vastness, and fragility as an arctic ecosystem, the coastal plain of the Arctic National Wildlife Refuge is a national treasure, and would be irreparably altered by development.

Alaska Fisheries Technical Report Number 3

WINTER WATER AVAILABILITY ON THE 1002 AREA OF THE ARCTIC NATIONAL WILDLIFE REFUGE



May 1989

Region 7
U.S. Fish and Wildlife Service
Department of the Interior

WINTER WATER AVAILABILITY

ON THE 1002 AREA

OF THE ARCTIC NATIONAL WILDLIFE REFUGE

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Abstract

During March 25-30, 1988, an inventory of winter water availability was conducted within the 1002 area of the Arctic National Wildlife Refuge. A helicopter mounted radar system was used to identify the presence of sub-ice water. Water was found to be widely distributed throughout much of the 1002 area in several settings: springs and associated aufeis formations; lakes; a deep river pool; and localized pools beneath ice pressure ridges occupying braided river floodplains.

Pressure ridge pools accounted for the most frequent and widespread occurrence of water identified during this inventory. They were identified from portions of river drainages where water was previously undocumented during the winter. These small but numerous pools may greatly expand the known distribution of overwinter habitat for fish in this region, especially for small juvenile fish.

A full inventory of winter water presence within the 1002 area was not completed due to gear limitations and time constraints. Recommendations for further investigation and completion of the area wide inventory are made.

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Introduction

Water on the north slope of Alaska is significantly more abundant in summer than in winter (Wilson et al. 1977). During the winter, stream flow ceases in even the largest rivers and ice thickness on lakes and deep river pools reaches a maximum of 1.6 to 2.4 m by late March or April. Within the 1002 area, most lakes do not exceed 2.0 m in depth (Clough et al. 1987), and therefore freeze to the bottom. River pools with sufficient depth to keep from freezing to the bottom have been documented only from that portion of the Canning River near the southern 1002 boundary (Smith and Glesne 1983). Perennial springs are the only documentated source of flowing water, which rapidly cools and freezes, forming large icings or aufeis areas that may reach a thickness of 4.9 m and cover about 5 km^2. Wilson et al. (1977) identified five springs within the 1002 area; two on the Katakturuk River, Sadlerochit Spring, Hulahula Spring at Fish Hole 1, and Okerokovik Spring. In addition, icings have been identified on the Canning, Tamayariak, and Sadlerochit rivers (Wilson et al. 1977, Dean 1984) that indicate the presence of spring flow.

Overwintering habitat for freshwater and anadromous fishes on the north slope is reported to be restricted to perennial springs and to lakes and river pools with sufficient depth to prevent freezing to the substrate (Bendock and Burr 1984, Clough et al. 1987, Schmidt et al. 1989). Summer fish use has been documented from only six lakes within the 1002 area (West and Fruge in preparation) which may provide overwintering habitat. Water depth in excess of 2.5 m was measured in the largest of the six lakes in September 1987 (Lyons and Elliott 1987). Radio-tagged Arctic grayling (<u>Thymallus arcticus</u>) were described holding in portions of four drainages within the 1002 area during the winter: the Canning, Sadlerochit, Hulahula, and Okpilak rivers (Wiswar et al. in preparation). However, no deep pools have been documented in the vicinity of these areas and the overwinter survival of those fish was in doubt. Within the 1002 area, the Canning River, Sadlerochit Spring, and Hulahula Spring at Fish Hole 1 have been identified as overwintering areas for fish and may be critical for their survival (Wilson and Kelly in preparation).

Proposed oil and gas exploration and development activity on the 1002 area of the Arctic National Wildlife Refuge will require substantial quantities of water. Historically, industrial water needs for oil exploration on the north slope have been highest during the winter, when drilling activities occur. In addition to the water needed for drilling, ice road and airstrip construction and maintenance also require large volumes of water. The quantity of water required for the various exploration activities is reported by Clough et al. (1987).

The greatest potential for conflict between maintenance of aquatic habitat and industrial use of water is during the winter when the amount of unfrozen water is greatly reduced and much of the water is critical to overwinter survival of fish. The U.S. Fish and Wildlife Service, Branch of Water Resources Operations, and the U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, agreed in 1988 to conduct a cooperative investigation of the distribution of water within the 1002 area of the Arctic National Wildlife Refuge during late winter. The objective of this study is to provide a qualitative assessment of the availability of winter water when ice thickness is at a maximum.

Study Area

The 1002 area of the Arctic National Wildlife Refuge encompasses about 627,300 ha of the coastal plain between the Brooks Range and the Beaufort Sea (Figure 1). All rivers in the 1002 area generally flow in a northerly direction. The larger drainages transect the area, originating in the mountains to the south. Smaller drainages originate in the foothill province near the southern 1002 boundary. The drainages investigated during this study were the Canning, Tamayariak, Katakturuk, Sadlerochit, Hulahula, Okpilak, Jago, and Niguanak rivers.

The Canning River, the largest river flowing across the 1002 area, occupies two distinct floodplain configurations. The upper portion, between the southern 1002 boundary and latitude 69°55'N, is characterized by a relatively narrow floodplain confined by the foothills of the Sadlerochit Mountains. The river exhibits some braiding in the upper part of this reach, but is confined to one or two primary channels below the braided portion. North of latitude 69°55', the river spreads out into a broad, highly braided floodplain. Between the lower extent of the highly braided area and its delta, the Canning River flows for about 9.7 km through one to three broad, low gradient channels. The eastern channels of the Canning and the Tamayariak River enter the main channel of the Canning River within the lower 4.8 km of the river.

The Tamayariak River, a tributary to the Canning River, originates in the Sadlerochit Mountains, south of the 1002 boundary. The largest tributary, the West Fork of the Tamayariak River, enters the mainstem about 13 km above its mouth. Within the 1002 area, both the mainstem and the West

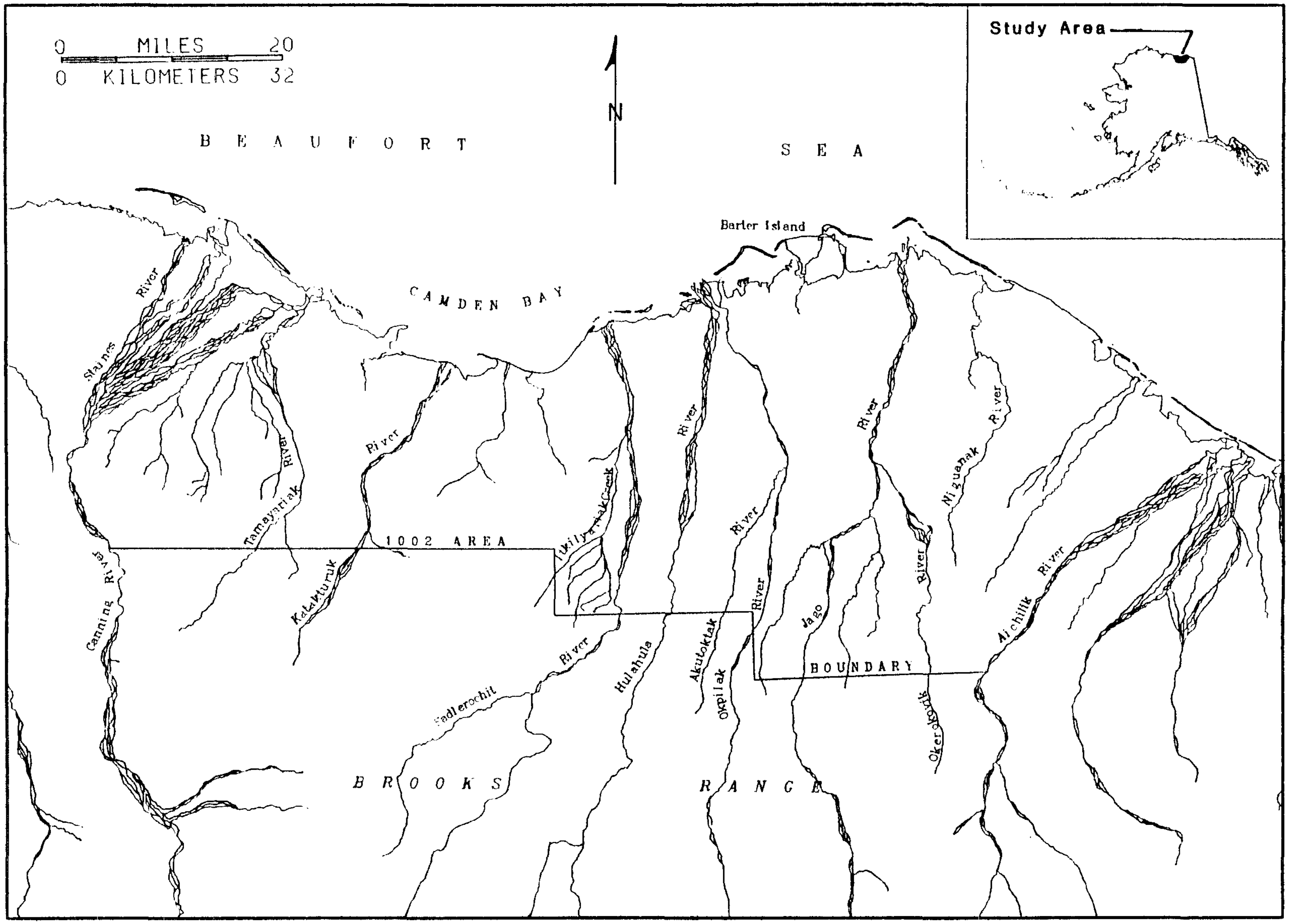

Figure 1.--Location of the 1002 study area and major river drainages.

Fork are characterized by braided channels upstream from their confluence. Below the West Fork confluence, the mainstem is almost entirely confined in a single, broadly meandering channel.

The Katakturuk River originates south of the Sadlerochit Mountains, flows through a cut in the mountain range, then transects the 1002 area. The entire reach through the study area is characterized by a braided channel within an unvegetated floodplain that increases in width to the north.

The Sadlerochit River originates in the Shublik and Franklin Mountains south of the Sadlerochit Mountains, then flows around the east end of the Sadlerochit Mountains where it enters the 1002 area. About 9 km downstream from the 1002 boundary, the river channel becomes extensively braided and this channel configuration continues for the remaining 36 km to the river's mouth. The largest tributary to the Sadlerochit River, Itkilyariak Creek, originates in the Sadlerochit Mountains and flows north, entering the mainstem about 14 km from the Beaufort Sea. The water from Sadlerochit Spring flows into Itkilyariak Creek about 11 km from the spring source and 17 km from the mouth of Itkilyariak Creek. The stream channel of Itkilyariak Creek downstream from the confluence with Sadlerochit Spring Creek is braided.

The Hulahula River transects the central portion of the 1002 area for a distance of 49 km. Between the southern 1002 boundary and Fish Hole 1, the river flows within a confined floodplain, primarily in a single channel. Downstream from that reach the river flows through a highly braided channel for the remaining 36 km to the Beaufort Sea.

The Okpilak River transects the 1002 area to the east of the Hulahula River for a distance of 55 km. The channel is braided for most of that distance, becoming progressively more braided in a downstream direction. The Okpilak and Hulahula rivers share a common delta. The Akutoktak River is the largest tributary to the Okpilak River within the 1002 area and enters the mainstem 31 km from the Beaufort Sea.

The Jago River transects the 1002 area for a distance of 69 km, flowing through a highly braided channel for at least the lower 50 km. There are two major tributaries to the Jago River within the study area. The Okerokovik River enters the mainstem from the east about 33 km from the Beaufort Sea and Okpirourak Creek enters from the west about 15 km upstream from the Okerokovik River confluence.

The Niguanak River originates within the 1002 area about 54 km from the coast. This river flows primarily within a single channel for its entire length.

The largest lakes within the 1002 area are confined to two small lowland areas, within 7 km of the coast. Most are within an area 13 km to either side of the mouth of the mainstem Canning River. The other area is between the mouth of the Okpilak River and Barter Island. Most of the remaining lakes in the 1002 area are within an area of low foothills between the Okpilak River and 8 km east of the Niguanak River, extending inland from the coast for about 32 km.

Methods

Prior to the winter season, permanent steel fencepost markers were placed at six locations to provide reference points near potential sites where winter water presence was suspected (Table 1). In addition, transects

Table 1.--Number, location, and figure reference of fenceposts placed adjacent to three 1002 area rivers during 1987.

Fencepost Number	River	Map Location	Figure Reference
1	Canning	NE1/4 Sec. 20, T6N, R23E	2
2	Canning	SE1/4 Sec. 8, T8N, R26E	2
3	Canning	SW1/4 Sec. 10, T8N, R26E	2
4	Tamayariak	E1/2 Sec. 29, T8N, R26E	3
5	Sadlerochit	NE1/4 Sec. 9, T7N, R31E	6
6	Sadlerochit	NW1/4 Sec. 4, T7N, R31E	6

were marked on 1:63,360 scale topographic maps to be used as a guide for investigation of the water resources of all major lakes and river drainages within the 1002 area.

During March 25-30, 1988, a helicopter mounted, short pulse radar system was used to measure ice thickness and detect the presence of unfrozen water along established transects. The radar system and its use are described in detail by Arcone et al. (in preparation). Radar data was recorded on a cassette tape recorder. The taped data was later used to produce a graphic record from which sub-ice water presence could be visually identified and ice thickness could be measured. The interpretation of the results of the radar data is by the author based on guidance given by Arcone et al. (in preparation).

Established transects were actually used only in portions of river drainages where rivers were confined to a single channel or where water presence was known to occur or was indicated by aufeis formations. After the first day in the field, an association was made between visually identifiable ice formations (pressure ridges) and the presence of water. Most of the transects after that time were flown over these formations in a longitudinal direction with respect to the river channels. Cross sectional transects were used to delineate the location of water within aufeis formations. Transect locations were identified based on visually recognizable topographic features that could be recognized on the topographic maps. A satellite linked, global positioning system operated from a laptop computer was also used to determine the latitude and longitude coordinates of transect locations when the system operated properly.

Ice thickness was ground truthed and water depth was measured at three locations using a hand auger and weighted tape measure. Water conductivity was measured at two of those locations using a Yellow Springs Instruments Model 33[1] salinity-conductivity-temperature meter.

Results

Water was found throughout much of the 1002 area. Open flowing water was observed at two locations in association with perennial springs. The occurrence of sub-ice water was identified in four settings:

1) beneath the ice of 8 lakes;

2) beneath and within the ice of 7 aufeis formations;

3) beneath smooth ice cover over deep pools within the river channel in one drainage; and

4) beneath ice pressure ridges over small localized pools within river channels.

Pressure ridges in river ice were found in the Canning, Tamayariak, Katakturuk, Sadlerochit, Hulahula, Okpilak, and Jago river drainages. After the initial association was made between pressure ridges and the presence of water, water was documented throughout extensive reaches of most of these rivers. The ridges generally appeared to be within the primary channel of these rivers, quite often in highly braided areas. In many instances, a series of ridges were observed following the course of a main channel. Based on radar records, water was confined to the area directly

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[1]The use of trade names of commercial products in this report does not constitute endorsement or a recommendation for use by the Federal Government.

beneath a ridge, and was not present to either side, or immediately upstream or downstream from the ridge.

The following describes the results of the inventory effort by each river drainage investigated.

Canning River

Most of the Canning River between the 1002 boundary and latitude $69^{o}55'$ appeared to be a continuous bank to bank icing (Figure 2). Sub-ice water was identified within the main channel as well as in secondary channels at each of the 13 cross-sectional transects flown across this portion of the river. At several locations water was identified at shallow depths within thick ice, indicating flow through conduits in the icing. Water overflow was observed on the icing surface at several locations in this reach and was readily identified at a distance by rising water vapor.

Water was found at all transects within the highly braided reach north of latitude $69^{o}55'$. All of the sites where water was found within this reach were beneath pressure ridges, with water detected beneath 17 of the 34 (50%) ridges measured. Water was also detected beneath 6 of the 7 pressure ridges measured in the lower portion of the eastern channels. The presence of aufeis was observed only in the upper portion of the braided reach.

Between the lower extent of the major braided area and the Canning River delta, the ice surface was flat, with no evidence of pressure ridges. No definitive indication of sub-ice water was found along any of the four transects in this reach.

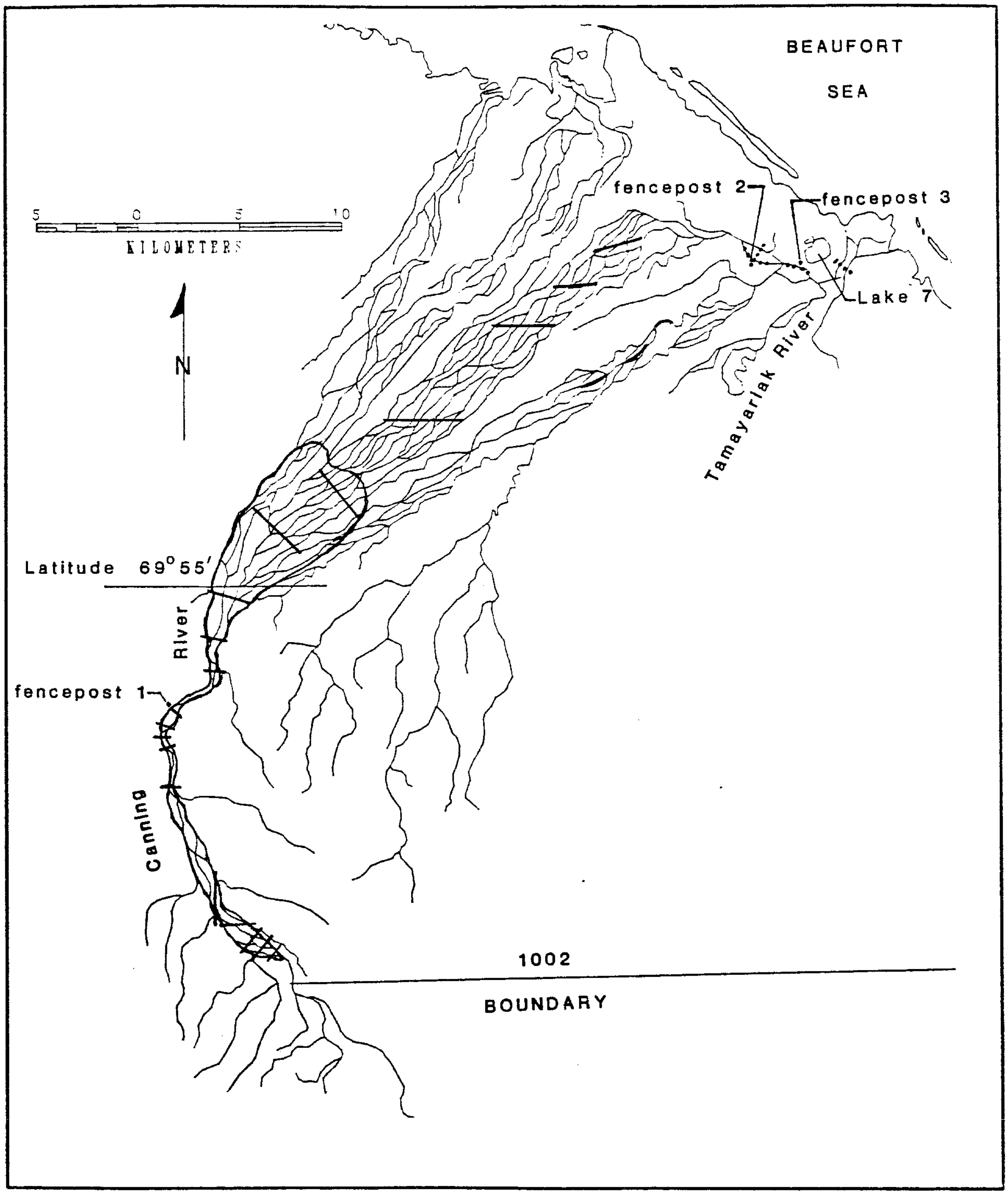

Figure 2.--Canning River drainage within the 1002 area illustrating the location of transects where water was present (solid lines) and not present (dotted lines) and location of icings (closed polygons).

Tamayariak River

Water was found in association with aufeis, river pools, and pressure ridges in the Tamayariak River (Figure 3). Water was detected along all 3 transects flown over the aufeis formation on the mainstem under both flat ice and pressure ridges. Unmeasured pressure ridges were observed in the braided reach between the aufeis and the confluence of the West Fork. Two large pressure ridges were also observed about 16.1 km upstream from the icing. Water was detected beneath 3 of the 6 pressure ridges measured along two transects downstream from the confluence of the West Fork. Water was detected beneath flat ice along two transects near fencepost number 4. The radar record indicated the pools were approximately 150 and 380 m long. At the 150 m pool, 8 cm of water was measured beneath 1.4 m of ice, conductivity was 70 umhos/cm, and salinity was near zero (Figure 4). No water was detected along the transect downstream from fencepost 4.

Water was found in the West Fork of the Tamayariak River in a small aufeis formation and beneath pressure ridges. Between the icing and the confluence with the mainstem, water was detected beneath 14 of 22 (64%) pressure ridges. Unmeasured pressure ridges were observed for up to 5 km upstream from the West Fork icing.

Katakturuk River

Pressure ridges were found at five locations within the lower 16 km of the Katakturuk River (Figure 5). Twenty out of 30 (67%) pressure ridges were found to have water beneath them.

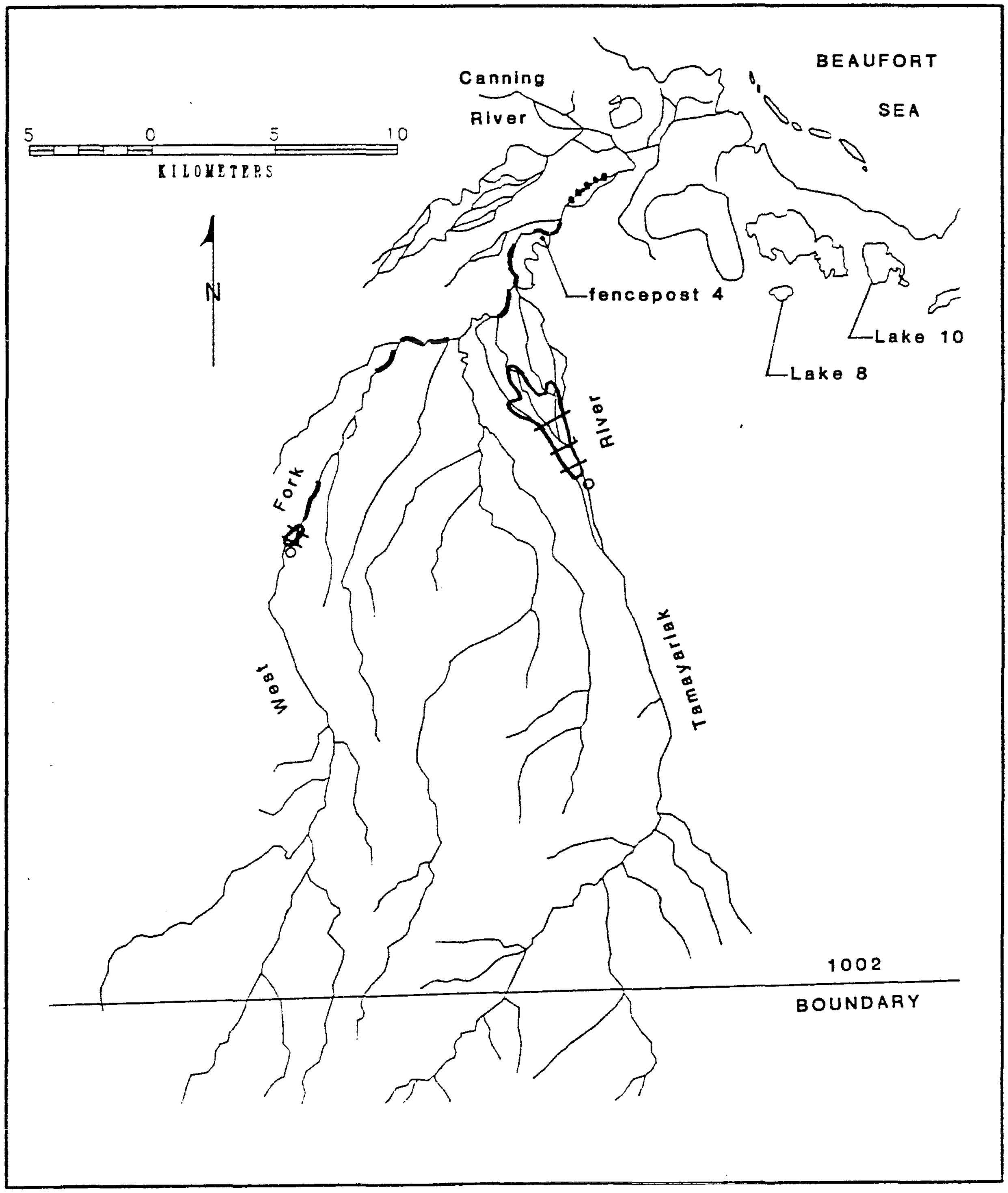

Figure 3.--Map of the Tamayariak River drainage illustrating the location of transects where water was present (solid lines) and not present (dotted line) and location of icings (closed polygons) and springs (circles).

Figure 4.--Ice thickness and water depth being measured at Tamayariak River pool located at fence post number 4 using weighted tape measure. The radar antenna can be seen mounted on the right side of the helicopter.

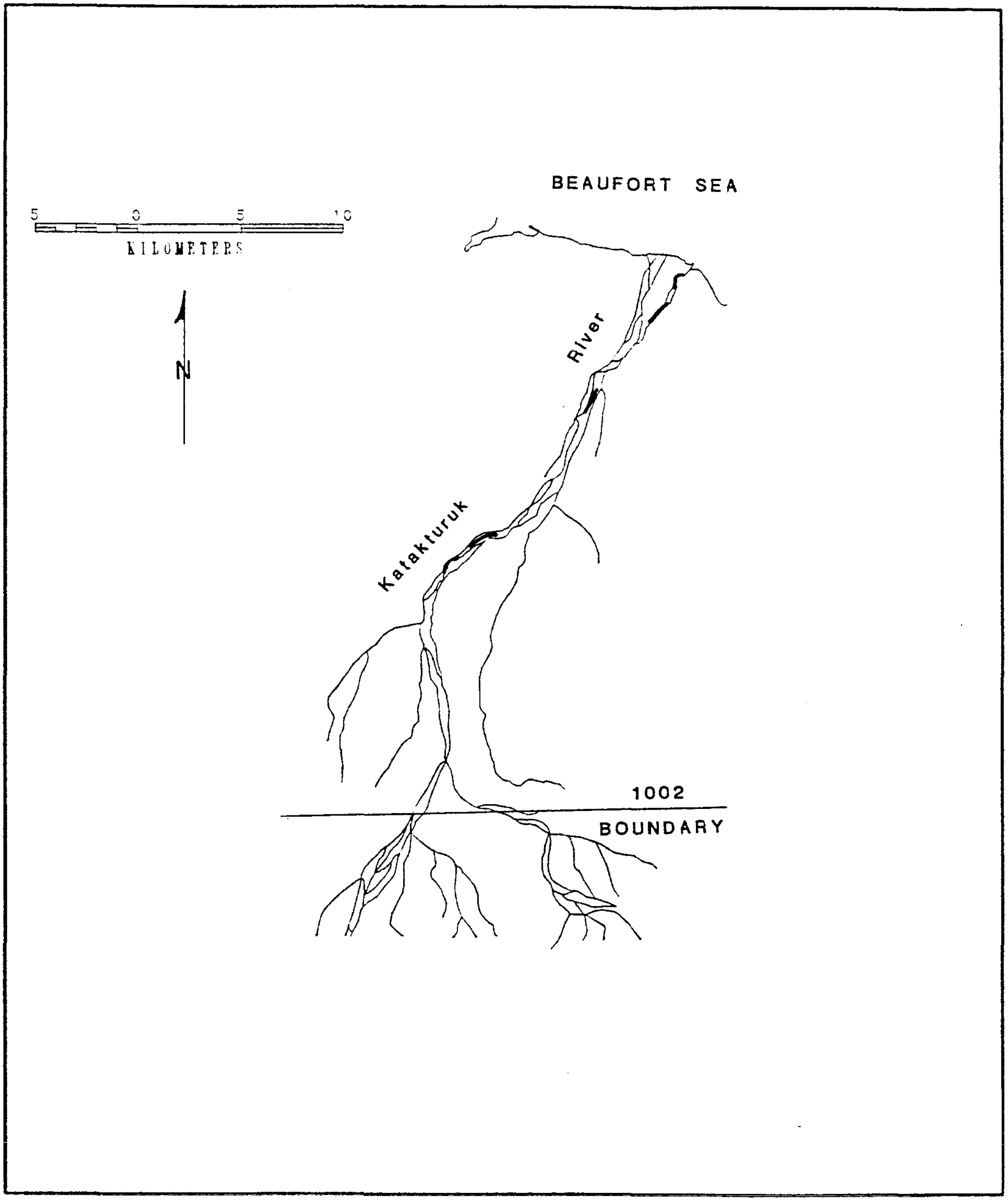

Figure 5.--Katakturuk River drainage within the 1002 area illustrating the location of transects where water was present (solid lines).

Sadlerochit River

Water was found throughout the portion of the Sadlerochit River within the 1002 area (Figure 6). An aufeis formation was identified on the Sadlerochit River about 9.7 km downstream from the 1002 boundary. Water was found throughout this icing, especially beneath pressure ridges. Out of 15 pressure ridges measured along one transect through the length of this icing, 13 (87%) were found to have water beneath them.

Water was identified under the ice at two locations between the icing and the southern 1002 boundary. Between the icing and the mouth of the river, water was identified beneath 26 of 41 (63%) pressure ridges measured.

A transect grid was flown over two large pressure ridges located at fence post number 6 about 3.2 km above the river's mouth. Water was found only directly beneath each ridge, with no water identified immediately upstream, downstream, or on either side of the ridges. The height of these ridges was 2.2 m and 2.7 m above the surrounding level ice surface. Water depths of 1.2 m and over 1.2 m were measured beneath the two ridges through drilled auger holes (Figure 7).

Sadlerochit Spring and Itkilyariak Creeks

Water was found throughout Sadlerochit Spring Creek and downstream through Itkilyariak Creek to its confluence with the Sadlerochit River. Sadlerochit Spring Creek was ice free for approximately 5 km between its source and the large aufeis formation. Water was present at multiple locations along each transect through the central portion of the aufeis formation, some of which were confined in shallow conduits within the icing. Water vapor was observed in patches on the surface of the lower portion of

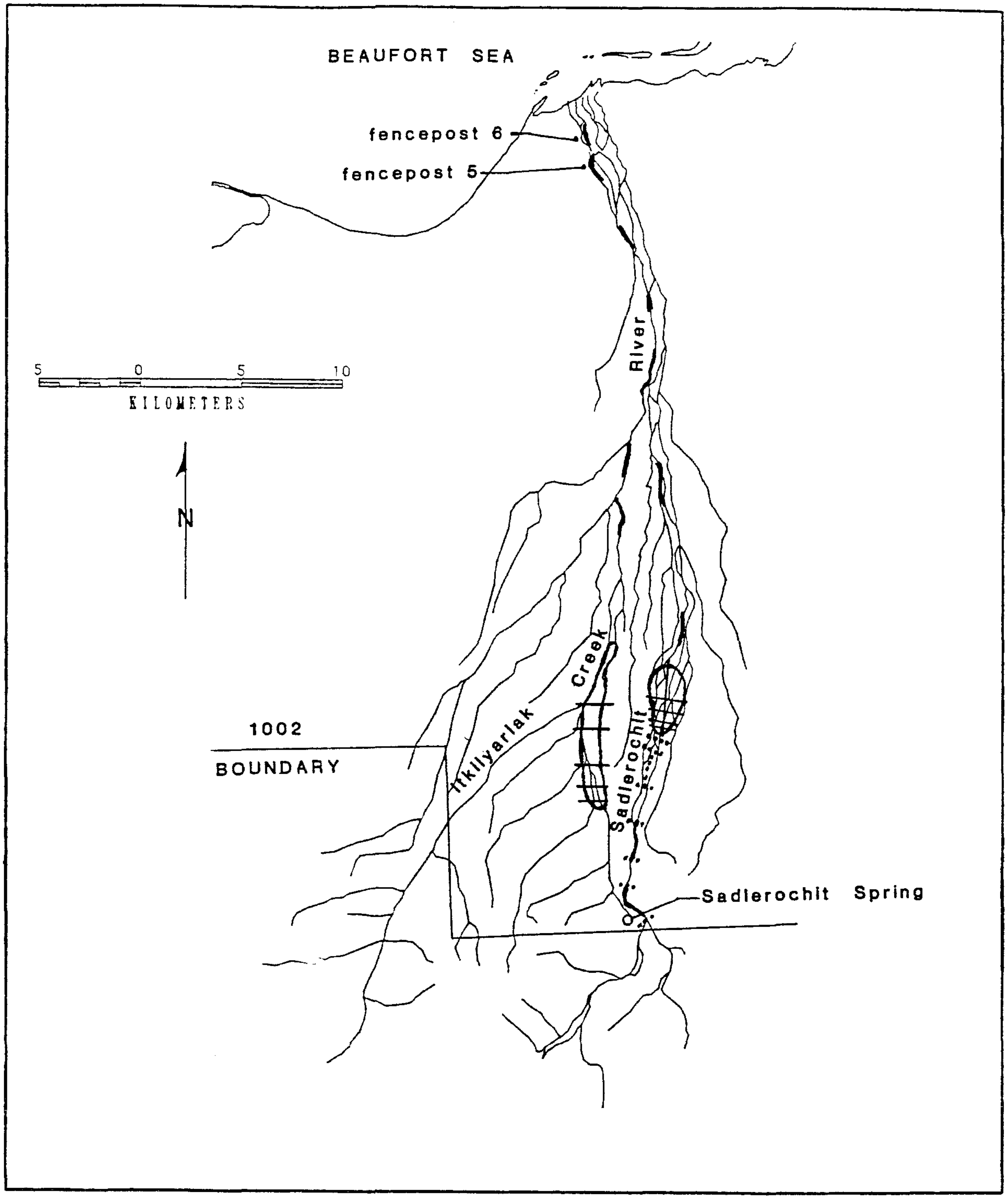

Figure 6.--Sadlerochit River drainage within the 1002 area illustrating the location of transects where water was present (solid lines) and not present (dotted lines) and location of the icings (closed polygons) and spring (circle).

Figure 7.--Ice auger being used to drill a hole through the largest pressure ridge on the Sadlerochit River at fence post number 6. More pressure ridges can be seen in the background looking upstream.

the icing. Pressure ridges were observed throughout the remainder of Itkilyariak Creek and water was identified beneath 9 of 13 (69%) ridges measured in the lower 6.4 km of the stream.

Hulahula River

Water was identified throughout much of the Hulahula River within the 1002 area (Figure 8). At Fish Hole 1, ice-free spring flow was observed along the west bank at the upper end of the aufeis formation within the primary river channel. Several cross sectional transects across the upper and central portion of the aufeis formation revealed the presence of water at several points along each transect.

Pressure ridges were observed throughout the river reach from the aufeis formation downstream to just above the Okpilak River confluence. Water was detected at all 11 transects flown in that reach, with 39 of 52 (75%) ridges measured having water beneath them. Water was also detected beneath 3 of 4 low pressure ridges between the icing and the southern 1002 boundary. No pressure ridges were observed in the Hulahula River delta and upstream for 3.2 km.

Okpilak River

Possible radar reflections from water were noted beneath pressure ridges at two locations on the Okpilak River, about 9.7 km upstream from the river's mouth (Figure 8). The sub-ice reflections on the graphic display of the radar record at these locations were of marginal intensity and may only represent ice grounded on an unfrozen substrate. Pressure ridges were also found at a few other scattered locations in this drainage, but no water was

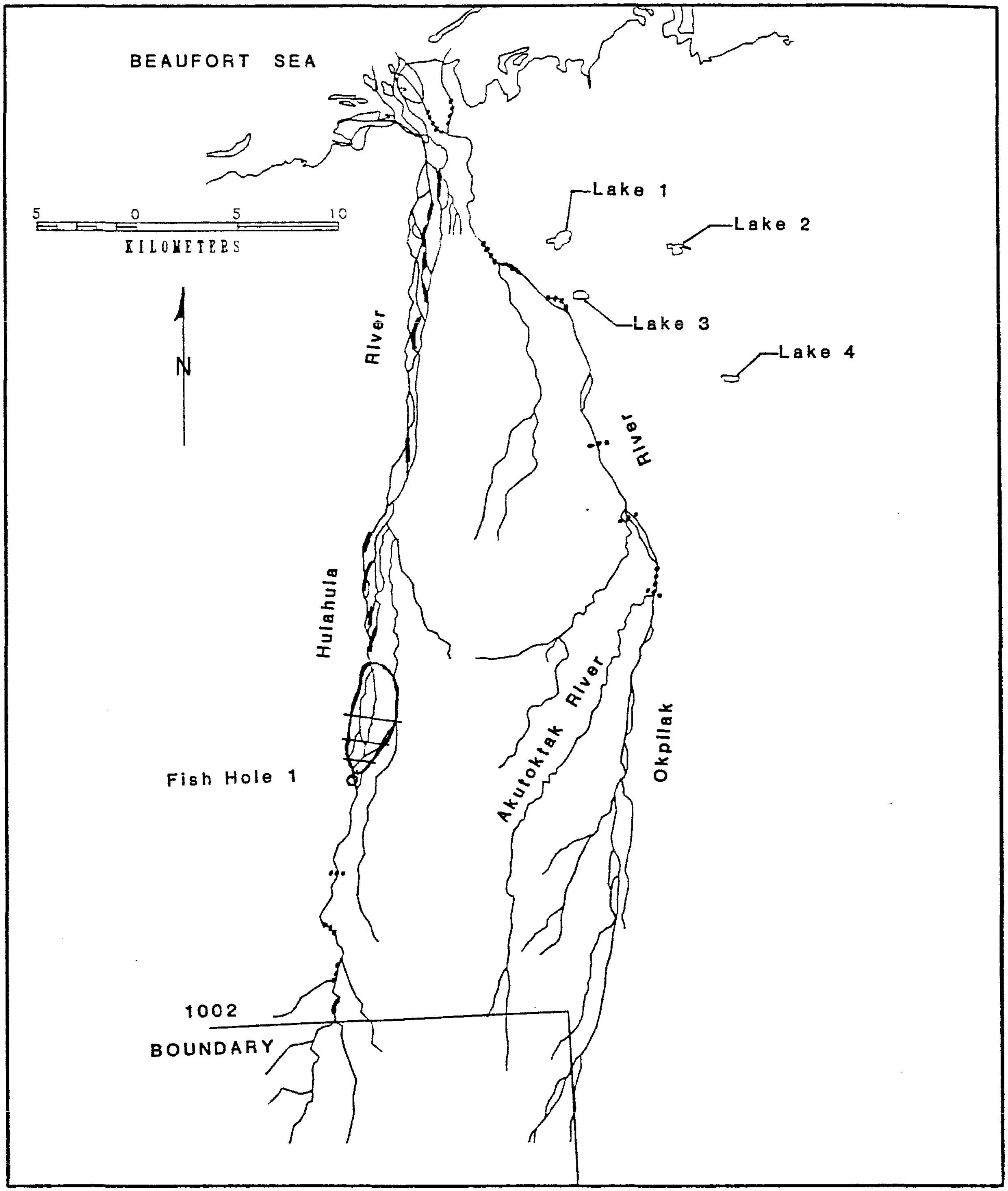

Figure 8.--Hulahula and Okpilak river drainages within the 1002 area illustrating the location of transects where water was present (solid lines) and not present (dotted lines) and the location of the icing (closed polygon) and spring (circle).

identified in association with them. No indication of water was identified at any of the remaining transects in this drainage.

Jago River and Okpirourak Creek

Inventory of the Jago River drainage for the presence of water was restricted to a 14.5 km reach from the confluence of Okpirourak Creek downstream to the confluence of the Okerokovik River (Figure 9). Two longitudinal transects were flown over pressure ridges in this reach, and water was identified beneath 8 of 12 (67%) ridges measured.

No water was detected along two transects flown across meander bends in Okpirourak Creek just above its confluence with the Jago River.

Okerokovik River Spring Icing

Two cross sectional transects across the aufeis formation indicated water was present (Figure 9). Water was present beneath two large pressure ridges in the center of the icing. No open channels were observed in the spring area at the head of the aufeis formation.

Niguanak River

The lower 24 km of the Niguanak River (Figure 9) was visually inspected from the air and no pressure ridges were observed.

Lakes

Water was noted in 8 of 10 lakes surveyed (Table 2). Three lakes near the mouth of the Canning River (lakes 7, 8, and 10) were found to have water beneath the ice (Figures 2 and 3). Out of four lakes (lakes 1-4) surveyed to

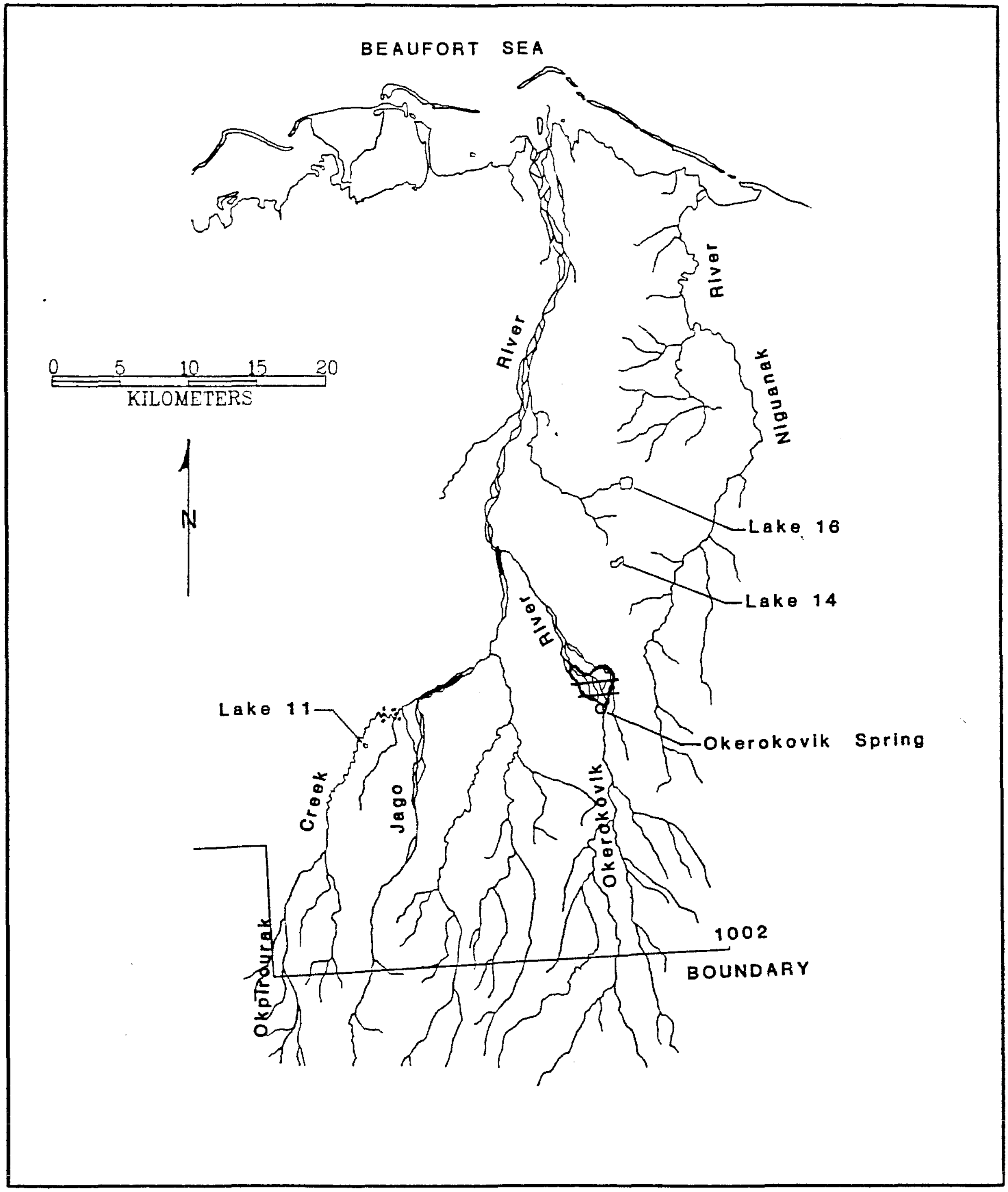

Figure 9.--Jago and Niguanak river drainages within the 1002 area illustrating the location of transects where water was present (solid lines) and not present (dotted lines) and the location of the icing (closed polygon) and spring (circle).

Table 2. Number, location, water presence, and minimum and maximum ice thickness of lakes surveyed by radar, during March 25-30, 1988.

Lake No.	Location	Water Present	Ice Thickness (m) Minimum	Ice Thickness (m) Maximum
1	NE1/4 Sec. 3 T7N R33E	Yes	1.25	1.55
2	SW1/4 Sec. 11 T7N R33E	Yes	1.34	1.43
3	Center Sec. 5 T7N R33E	No	0.73	1.01
4	SW1/4 Sec. 27 T7N R34E	Yes	1.37	1.71
7	E1/2 Sec. 10 T8N R26E	Yes	1.49	1.68
8	NE1/4 Sec. 5 T7N R27E	Yes	1.40	1.55
10	W1/2 Sec. 35 T8N R27E	Yes	1.46	1.65
11	SE1/4 Sec. 11 T4N R34E	No	1.13	1.22
14	SE1/4 Sec. 32 T6N R36E	Yes	1.34	1.65
16	NW1/4 Sec. 16 T6N R36E	Yes	1.31	1.65

the east of the Okpilak River, all but lake 3 were found to have water present (Figure 8). A small lake (lake 11) about 5 km upstream from the mouth of Okpirourak Creek was frozen to the bottom (Figure 9). Two lakes on Niguanak Ridge (lakes 14 and 16) were found to have water present (Figure 9). Ice thickness in lake 16 was measured through two holes drilled through the ice. The ice was 1.75 m thick at each location and water depth beneath the ice was 7.6 and 17.7 cm respectively. For lakes in which sub-ice water was identified, ice thickness ranged from 1.25 to 1.71 m.

Discussion

The presence of water throughout a large portion of the 1002 area was documented during late winter when ice development was at or near maximum. Water was identified in a variety of settings that were both expected and unexpected prior to the inventory.

The presence of flowing water and icings at Sadlerochit Spring and Hulahula Fish Hole 1 Spring and the springs on the Okerokovik, Tamayariak, and Canning rivers have been previously reported (Childers et al. 1977; Dean 1984). However, the icings on the Sadlerochit and West Fork of the Tamayariak rivers have not been previously reported.

The Sadlerochit and West Fork of the Tamayariak icings apparently were not large enough to persist into the summer as residual icings identified by Dean (1984) from satellite imagery. The portion of the Canning River from the southern 1002 boundary downstream to latitude 69°55' contained more extensive icing than expected. Within that reach, the continuous presence of aufeis and the occurrence of water at all of the radar transects indicates that water flow was most likely continuous throughout this area. The winter movement and residence of radio-tagged Arctic grayling within this portion of the Canning River (Wiswar et al. in preparation) and the diversity of fish species inhabiting the Canning River (West and Fruge in preparation) supports the importance of the observed water flow to resident and anadromous fish populations.

With the exception of a few large lakes to the east of the Canning River delta, most of the lakes on the 1002 area are thought to have basins less than 2 m deep and freeze to the bottom by late winter (Clough et al. 1987). The results of the lake surveys conducted during this inventory indicate that water is present beneath the ice of several smaller lakes in the area, although the depth of sub-ice water in all but one and water quality were not measured. The range of measured lake ice thickness (1.25 to 1.71 m) during this survey may be an indication of a mild winter. The average temperature at the Barter Island weather station was 2.8^{o}C above normal for the period from October 1987 through March 1988 (National Oceanic and Atmospheric Administration 1987 and 1988).

The presence of water in deep river pools has been documented in other north slope drainages but not within the 1002 area. Overwintering habitat for fish was suspected in the lower portion of the Tamayariak River (Wilson and Kelly in preparation) but not documented. During this inventory, water was documented in deep river pools at only two sites, in the lower Tamayariak River adjacent to fencepost number 4. The low conductivity and salinity measured at one of these sites indicates that there was no sea water intrusion and that water quality may be suitable for resident fish.

The presence of water in association with pressure ridges was not anticipated prior to this inventory and no documentation of this situation could be found. However, pressure ridge pools accounted for the most frequent and widespread occurrence of water identified within the 1002 area during this inventory.

The documentation of numerous localized pools of water throughout portions of several river drainages where none was previously thought to occur raises some new possibilities regarding the winter distribution of fish in those areas. The fall movements of radio-tagged grayling from the lower Tamayariak and Akutoktak rivers and Itkilyariak Creek involve complex and lengthy migrations to overwintering areas (Wiswar et al. in preparation). It is unlikely that young-of-the-year grayling produced in these streams would be physically able to migrate to the locations documented for adult fish. The pools of water found beneath pressure ridges in the lower Tamayariak, Hulahula, and Sadlerochit rivers and Itkilyariak Creek may provide overwintering habitat for young-of-the-year grayling from those drainages, as well as larger fish, providing water quality and volume are adequate. A population of age 1 and 2 grayling were found residing in an upper Tamayariak River tributary immediately after high breakup flows during 1988 (Corning in preparation). The presence of this population of small juvenile fish within 2 km of the pressure ridges observed in the upper Tamayariak mainstem offers further support to the possibility that pressure ridge pools may provide overwinter habitat.

Several limitations with the gear and time available to conduct the field work restricted the inventory of winter water in the 1002 area. The helicopter mounted radar system used to determine ice thickness and sub-ice water presence was an effective tool to measure those parameters. However, measurement of sub-ice water depth, and thus a means to quantify water volume, was not possible with the antenna configuration used. Time constraints limited the extent of radar coverage of several drainages, notably the upper Tamayariak, Katakturuk, and Jago rivers.

Difficulties with the operation of the global positioning system restricted the acquisition of accurate position locations for many of the transects. Its operation was limited to a 3-4 hour time window when the required number of satellites were "visible" above the southern horizon. The unexpected loss of a "lock" on the required number of satellites during the operational time frame resulted in erroneous positions and a lack of confidence in other positions that could not be verified from topographic features. Drifted snow obscured most of the lake margins, greatly restricting the effort to visually locate many of the lakes intended for survey.

The results of this inventory indicate several gaps in the existing winter water availability data base that warrant further investigation:

1. A more detailed inventory of the distribution of pressure ridges in all drainages in the 1002 area;
2. Quantification of water volumes beneath pressure ridges and investigation of any correlation between pressure ridge size and volume;
3. Investigation of late winter water quality of pressure ridge pools and lakes to ascertain their suitability as fish overwintering habitat;
4. Investigation of the annual reoccurrence of pressure ridges in the same locations; and

5. A complete inventory of all lakes that are deep enough to keep from freezing to the bottom.

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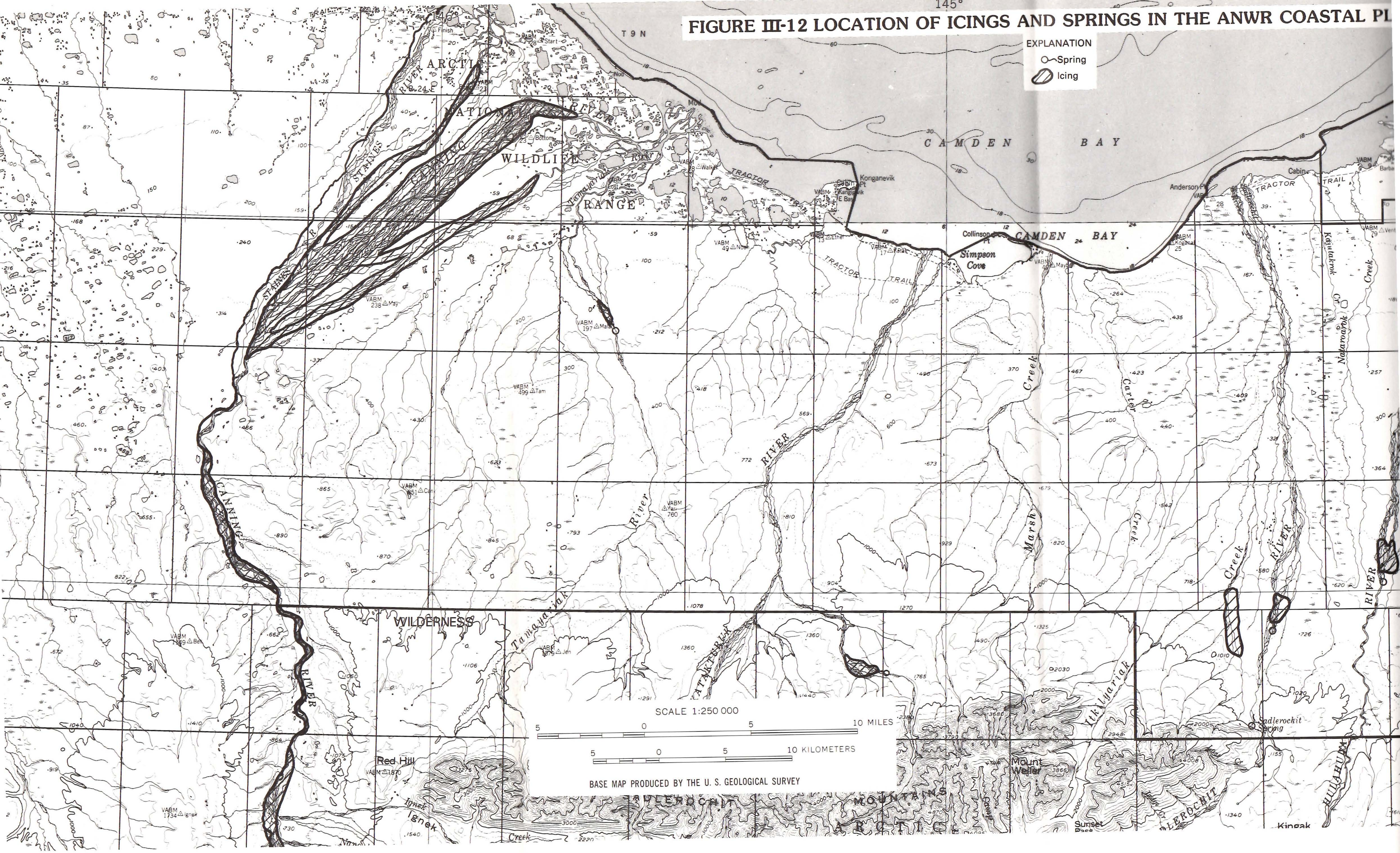
FIGURE III-12 LOCATION OF ICINGS AND SPRINGS IN THE ANWR COASTAL PL




E ANWR COASTAL PLAIN
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143°
142°
70°
69°45'
Kaktovik
Barter Island
Arey Island
Arey Lagoon
Kaktovik Lagoon
Jago Lagoon
Bernard Spit
Bernard Hbr
Kurrtovik Entrance
Tapkaurak Lagoon
Tapkaurak Spit
Tapkaurak Pt
Oruktalik Lagoon
Oruktalik Entrance
Griffin Pt
Pokok Lagoon
Pokok Bay
Humphrey Pt
Angun Lagoon
Angun Pt
Nuvagapak Pt
Nuvagapak Lagoon
Egaksrak Entrance
Egaksrak Lagoon
Beaufort
JAGO RIVER
Niguanak River
Okpilak River
Hulahula River
Sikrelurak River
Angun River
Kogotpak River
Aichilik River
Egaksrak River
Sikutaktuvik
Akootadlak
Okerokovik
Sadlerochit Spring
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TRACTOR TRAIL
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