MISSION 2007: DEVISING AND ANALYZING THE MOST ENVIRONMENTAL CORRECT METHOD FOR DRILLING IN THE 1002 REGION OF THE ARCTIC NATIONAL WILDLIFE REFUGE

Introduction

When the Arctic National Wildlife Refuge was created in 1960, it was established to protect a precious and vulnerable region and the wildlife it harbored and sustained. Less than a decade later the largest domestic oil discovery in history occurred next door in Prudhoe Bay and it became increasingly clear that huge oil potential resided underneath the coastal plain of ANWR. This coincidence of having both a pristine habitat and hydrocarbon wealth set off one of the greater economy versus environment debates in recent times. The ensuing argument has garnered national attention as the issue was rapidly politicized. And somehow, amongst all the clatter, the science behind the issue seems to have been lost.

Mission 2007 had two assignments: to develop a method of extracting hydrocarbon resources from ANWR that is as environmentally sensitive as possible and then to evaluate whether the economic benefit of the oil extracted would be worth the social cost of the environmental damage such extraction would inflict. What follows are the results of that mission.

Geology

Formation of Hydrocarbons

Five Major Types of HydrocarbonsKerogen: Kerogen is a fine-grained, amorphous organic matter. It is not soluble to normal petroleum solvents, like carbon disulfide. Its chemical compositioin is 75% C, 10% H, 15% other (sulfur, oxygen, nitrogen, etc.). It is very important in the formation of hydrocarbons because it is what generates oil and gas. Source rocks must contain significant amounts of kerogen.
Asphalt: Asphalt is a solid at surface temperatures. It is soluble to petroleum solvents. It is produced by the partial maturation of kerogen or the degradation of crude oil.

Crude Oil: Crude oil is a liquid at surface temperatures. It is soluble to normal petroleum solvents. It has four main groups of organic compounds: paraffin, naphthalene, aromatics, and resins.

Natural Gas: Is a hydrocarbon gas. The major natural gases are methane, ethane, propane, and butane.

Condensates: These are hydrocarbons transitional between gas and crude oil.

Five Parameters for Hydrocarbon Accumulation

- Source rocks are required to generate hydrocarbons. Generally, has greater than .5% organic matter (kerogen) by weight.
- Reservoir rocks are required to store hydrocarbons.
- Seal or cap rocks are present to prevent the upward escape of hydrocarbons from reservoir.
- Traps occur where the source, reservoir and seal are arranged in a way that the hydrocarbons can move from the source to the reservoir.
- Source rock must have been heated sufficiently for oil (greater than 60C) and gas (greater than 150C)

Three Phases of Alteration of Organic Matter

Diagenesis: Diagenesis occurs at the surface at normal temperatures. The organic matter goes under bacterial decay, oxidation, dehydration and decarboxylation. The resultant is kerogen. The porosity decreases 60% to 40%.

Catagenesis: Temperatures increase to 250C and kerogen generates oil or gas. The porosity decreases to 10%.

Metagenesis: Occurs at 250C right when the kerogen is going to change into oil or gas.

Catagenesis is the most important stage, and is different for the three different types of kerogen.

Three Types of Kerogen

Type I (Algal): It is very rich in hydrogen, low in oxygen and contains lipids. It generates oil and is present in oil shales.

Type II (Liptinic): It is made from algal detritus, phytoplankton and zooplankton. It has aliphatic compounds and more hydrogen than carbon. It can generate oil or gas.

Type III (Humic): It has more carbon than hydrogen, and is rich in aromatic compounds. It is produced form lignin in higher woody plants. It generates gas.

Type I and Type II are usually found in marine environment and Type III is found in continental environments. That is why there is the generalization that marine produces oil and continental produces gas.

Migration of Hydrocarbons

Primary migration of hydrocarbons is the movement of oil and gas from source rock to permeable carrier beds. Secondary migration is the movement from permeable carrier beds to the reservoir beds. Secondary migration occurs through porous rocks due to buoyancy and capillary and regional pressure gradients.

Geologic History

Geographic Placement

The 1002 area of the Arctic National Wildlife Refuge is a 1.5-million-acre area in northeastern Alaska. It is bounded on the east by the Canning and Staines Rivers, on the north by the Beaufort Sea, on the east by the Aichilik River and the Canadian border, and to the south by Brooks Range, and is roughly 105 miles east-west and 16-40 miles north-south.
Most of the 1002 area lies within the Arctic Coastal Plain physiographic province, a marshy area that slopes gradually towards the Arctic Ocean on the north. A small part along the southern margin that constitutes less than 5% of the total area lies within the Arctic Foothills physiographic province, a series of hills and ridges that descend from more than 500 m in the Brooks Range to 300 m in elevation to the northern foreland. The area is treeless, tundra covered, and 99% wetland.

Topographically speaking, it is comprised of foothills (95% of area), river flooded plains (25%), hilly coastal plains (22%), lagoons and oceans (5%), thaw lake plains (5%) and mountains (less than 1%). It also has beaches, low steep cliffs, barrier islands, shallow lagoons, and river deltas form the coast of the 1002 area, with hills rising to more than 300 m in the south. Many rivers and stream flow between these hills towards the Arctic Ocean.

Origin

The North Slope and its continental shelves, Brooks Range and the northeastern part of Siberia are considered to form the Arctic Alaska microplate, a small lithospheric plate with boundaries that are not clearly known. One hypothesis for the plate tectonic history of northern Alaska suggests that the region was originally next to the Canadian Arctic Islands. Creation of oceanic crust in the Canada basin during the Jurassic and Early Cretaceous caused the microplate to rotate 60 degrees counter clockwise, placing it in its current position.

Surface Geology

Nearly all of the surface of the 1002 area is covered by a thin layer, less than 30 m thick, of unconsolidated, frozen silt- to gravel-sized sediments of nonmarine origin. They originated from the erosion of the Brooks Range during the late Cenozoic.

The surface exposures of rock formations inside the 1002 area are mostly restricted to deposits of the Sagavanirktok, Jago River, and Canning Formations of Tertiary age. There are some smaller outcrops of Hue Shale, pebble shale unit, and Kingak Shale from the Cretaceous and the Jurassic. To the east of the Sadlerochit Mountains, in the southern border of the 1002 area, some of the oldest exposures, of limestones from the Mississippian Lisburne Group, are found.

Subsurface Structure

- Tectonics

During the rifting that separated northern Alaska from the Canadian Arctic Island, the Barrow arch, a structural high, was formed. The northern side of the Barrow arch formed the continental margin, while the southern flank received the thrust of the formation of the Brooks Range orogen.

The part of the 1002 area located to the south and east of the Marsh Creek anticline and north of 69-degrees is the Brooks Range orogen. The Brooks Range is more than 1000 km long and up to 300 km wide, and the distribution and character of its major structures is not symmetrical. Deformations in this region occurred during the Cenozoic era, forming both east-northeastward and eastward structures. Parts of Jurassic to Cretaceous shales, Mississippian shales, and of a horizon in the pre-Mississippian basement rocks were separated from their source due to extreme folding and compression.

The structure of the Brooks Range is formed by a series of broad anticlines with a core of pre-Mississippian rocks and younger rocks deformed on the borders. To the north of the Brooks Range, the structure, called thin-skinned deformation, is composed of numerous folds and faults developed in rocks of Cenozoic and Mesozoic age. Several broad domes are present in pre-Mississippian rocks in that area.

- Stratigraphy

The stratigraphic record of the North Slope is divided into three sequences: Franklinian, Ellesmerian and Brookian.

The Franklinian sequence comprises a thick succession of mainly sedimentary rocks with a minor amount of igneous rocks of Cambrian to Devonian age that lie beneath the pre-Mississippian unconformity, where a gap in the geologic record exists.

Two separate layers of rock are present in northern Alaska. The shallow marine carbonates are composed of rocks of Proterozoic age and rocks of Lower Devonian age, separated by unconformities where Silurian strata are missing. They are composed of quartzite (metamorphic rock consisting of quartz grains, formed by recrystalization of sandstone), argillite compact rock derived from mudstone or shale, product of weak metamorphism), and basalt (dark-colored igneous rock), with intrusions of sandstone (the consolidate equivalent of sand, with 85-90% quartz), and shale (fine-grained sedimentary rock, formed by clay, silt or mud). The deeper marine layers include quartzite, conglomerate, phyllite (metamorphic rock, finer than schist), argilite, limestone (sedimentary rock formed by calcium carbonates), and granite (light-colored, coarse-grained igneous rock). The compression, uplift and erosion of this sequence during the Ellesmerian orogeny formed the pre-Mississippian unconformity.

The Ellesmerian sequence is hundreds of meters thick, and is composed of layers of marine and nonmarine sedimentary rocks of Middle Devonian to Triassic age, that rests on top of the pre-Mississippian unconformity. The lower unit of this sequence is the Endicott Group, which, in the 1002 area, consists of Mississippian coal-bearing sandstone, conglomerate, and shale of the Kekiktuk Conglomerate and Kayak Shale, of Devonian and Mississippian age. The Kekiktuk Conglomerate is a proven oil-bearing reservoir. Large amounts of limestone and dolomine of the Lisburne Group were deposited in the North Slope up to a thickness of 500 to 1000 meters during the Mississippian and Pennsylvanian. It is separated from the overlying Sadlerochit Group by an unconformity formed during the Middle Pennsylvanian to Early Permian in when sea level fell.

Hydrocarbon Reserves

Brief procedure to determine the amount of oil and gas in a certain trap:

- Determine the range of drainage area. Drainage area is from where oil and gas flow to the trap.
- Find out the loss of oil and gas during migration. This process is generally more complex for gas because gas can move more freely and can be absorbed by oil and water.
- Compare the volume of the trap with the volumes of oil and gas and determine the remaining amount of oil and gas in the trap.

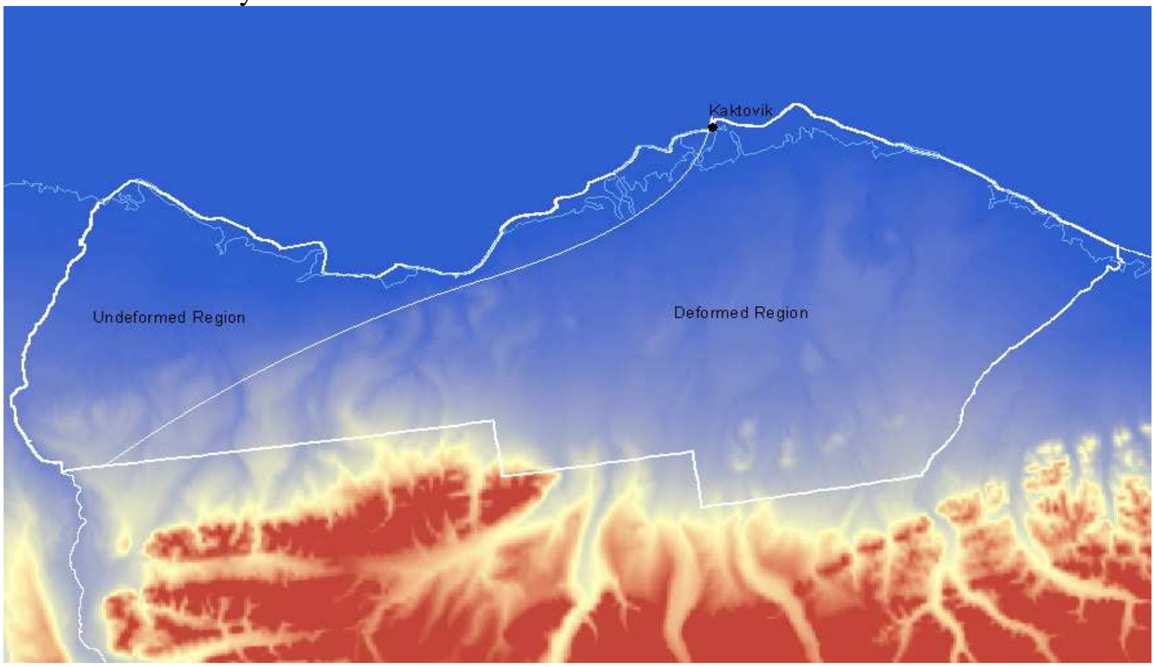
For the real calculation, some geological information on the region is needed. We can get some factors from that information and estimate the amount of petroleum resource in a specific trap.

However, this procedure is actually a simplification of the real process, and the point is that it deals the process of formation and migration of oil and gas as if it were an event that happened in a moment. So, actually the geological factors in the calculation should be able to reflect the difference made by the time taken for formation and migration. It takes the assumption that it is possible to make this simplification, and we should think about its validity.

Division in plays

The total area considered for study in the 1999 hydrocarbon potential assessment of the ANWR 1002 Area by the USGS considers Federal lands, Native lands, and State waters up to the 3-mile boundary under Federal jurisdiction.

The 1002 Area was divided by a line along the Marsh Creek anticline on its western half and along other geologic elements on its eastern half. The area to west is the undeformed region, with rocks that are generally horizontak, and to the east is the deformed region, which is crossed by faults and folds.



Only potential accumulations larger than 50 million barrels of oil (MMBO) in-place were considered. Smaller accumulations of hydrocarbons were not included in the assessment because it is non-economic to produce them.

Technically recoverable oil is not evenly distributed through the territory. Nearly 80 percent of the resources are expected to be concentrated in the north-west undeformed area of the 1002 area.

Region	95-percent probability	5-percent probability	Mean
Undeformed area	3.4 BBO	10.2 BBO	6.4 BBO
Deformed area	0 BBO	3.2 BBO	1.2 BBO
1002 area*	4.3 BBO	11.8 BBO	7.7 BBO
Total assessment area	5.7 BBO	16.0 BBO	10.4 BBO

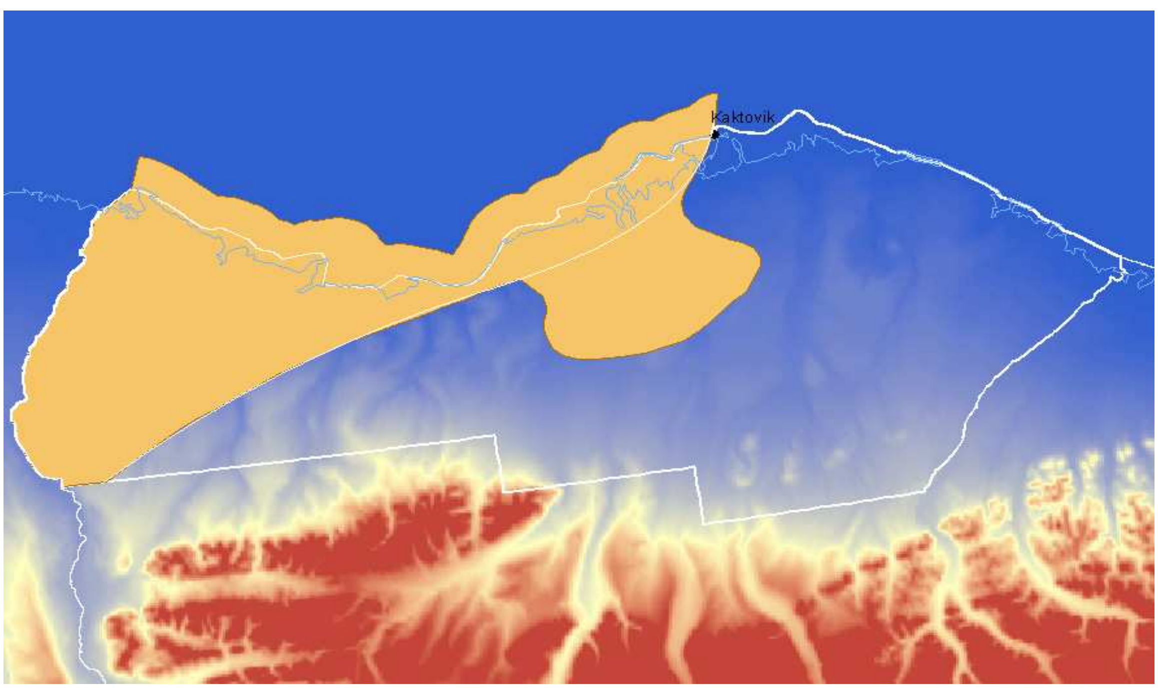
BBO: Billion barrels of oil
*: excluding State and Native areas

Source: BIRD, K. (1999). Geographic and Geologic Setting. In The Oil and Gas Resource Potential of the 1002 Area, Arctic National Wildlife Refuge, Alaska. By ANWR Assessment Team, U.S. Geological Survey Open-File Report 98-34.

It is expected to find most of the oil in several accumulations of over 100 million barrels (the size of already developed accumulations in north Alaska), not on a single large reservoir.

Plays:

Topset Play:



Source: HOUSEKNECHT, D.W. & SCHENK, C.J. (1999). Topset Play. In The Oil and Gas Resource Potential of the 1002 Area, Arctic National Wildlife Refuge, Alaska. By ANWR Assessment Team, U.S. Geological Survey Open-File Report 98-34.

Source: The most likely hydrocarbon source rocks are Hue Shales in the Hue-Thompson petroleum system, and Tertiary mudstones in the Canning-Sagavanirktok petroleum system. It is also possible that hydrocarbons generated in the Shublik formation of the Ellesmerian petroleum system migrated and accumulated in the Topset play.

Reservoir: Sandstones in the Topset reservoir were deposited in both marine-shelf and non-marine environments and are the best reservoir rocks in the 1002 area. Their porosity commonly ranges between 20 to 30%, and their permeability between 500 and 1,000 millidarcies.

Traps: There are several types of traps in the Topset play. Anticlines with four-way closure are few but they are the largest structures observed in the play; they are located just north of the trend of the Marsh Creek anticline and farther north in the 1002 area. Growth anticlines, product of the rollover of strata and rotational growth folding, appear on the edges of Eocene and Oligocene shelves; many have four-way closure. Growth faults are the most common structure in the area, and their presence increases towards the north-east. There are also up-dip shelf-edge pinchouts and stratigraphic lenses, but they are difficult to detect using existing seismic data.

Timing: The generation of oil in the Hue Shale unit probably occurred 40 Ma in the southern border of the Topset play, migrated northward through time, and occurred 10 Ma in the northern boundary. The generation of oil in the Canning Formation probably started 10 Ma in the north and east of the play and continues to the present.

Reservoir thickness: Minimum: 50 feet; median: 150 feet; maximum: 500 feet.

Trap depth: Minimum: 1,000 feet; median: 5,000 feet; maximum: 10,000 feet.

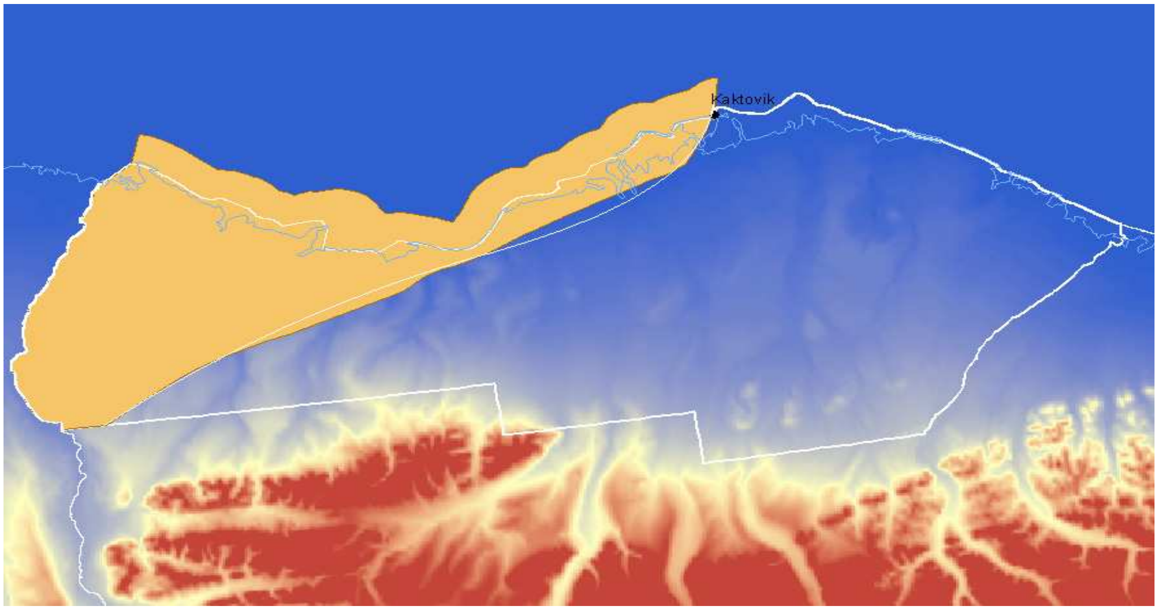
Water saturation: 5%, corresponding to fine- to very fine-grained sandstone.

Number of prospects: (Number of traps with four-way closure, capable of holding hydrocarbons) Minimum: 40; median: 80; maximum: 125.

Types of Hydrocarbons: Mean total volumes of in-place resources: 15,447.05 Million Barrels of Oil; 4,259.66 Billion Cubic Feet of associated-dissolved and non-associated Gas; 35.33 Million Barrels of Natural Gas Liquids from all types of

Gas. Comparison to other plays: Oil is the dominate resource with a relativistic factor of 1.959. It is the type of petroleum of most significance in this play.

Turbidite Play:



Source: HOUSEKNECHT, D.W. & SCHENK, C.J. (1999). Turbidite Play. In The Oil and Gas Resource Potential of the 1002 Area, Arctic National Wildlife Refuge, Alaska. By ANWR Assessment Team, U.S. Geological Survey Open-File Report 98-34.

Source: The most likely hydrocarbon source rocks are Hue Shales in the Hue-Thompson petroleum system, and Tertiary mudstones in the Canning-Sagavanirktok petroleum system. Turbidite rocks (sedimentary deposits from turbid currents) are ideally placed to receive oil migrating from Hue-Thomson and Canning-Sagavanirktok petroleum systems since they are directly in contact or a short distance above these source rocks.

Reservoir: The sandstones in the Turbidite play are of moderate to good reservoir-quality. The best ones are amalgamated channel facies, which are a concentration of relatively clean (clay-free) sandstone. They can be very thick but relatively narrow and thus hard to detect. Their porosity is usually between 10 and 20%, and their permeability between 100 and 500 millidarcies.

Traps: The traps in the Turbidite play are hard to define because of their stratigraphic nature. There are two major indicators of the presence of traps, mounds and channels. In both of them, it is inferred that sandstones are encased in mudstones, therefore forming a stratigraphic trap.

Timing: The potential rocks of this play are Paleocene and Eocene aged turbidite facies. Formation in the Hue Shale probably started 40 Ma (late Eocene), and more recently in the Canning Formation.

Reservoir thickness: Minimum: 50 feet; median: 120 feet; maximum: 400 feet.

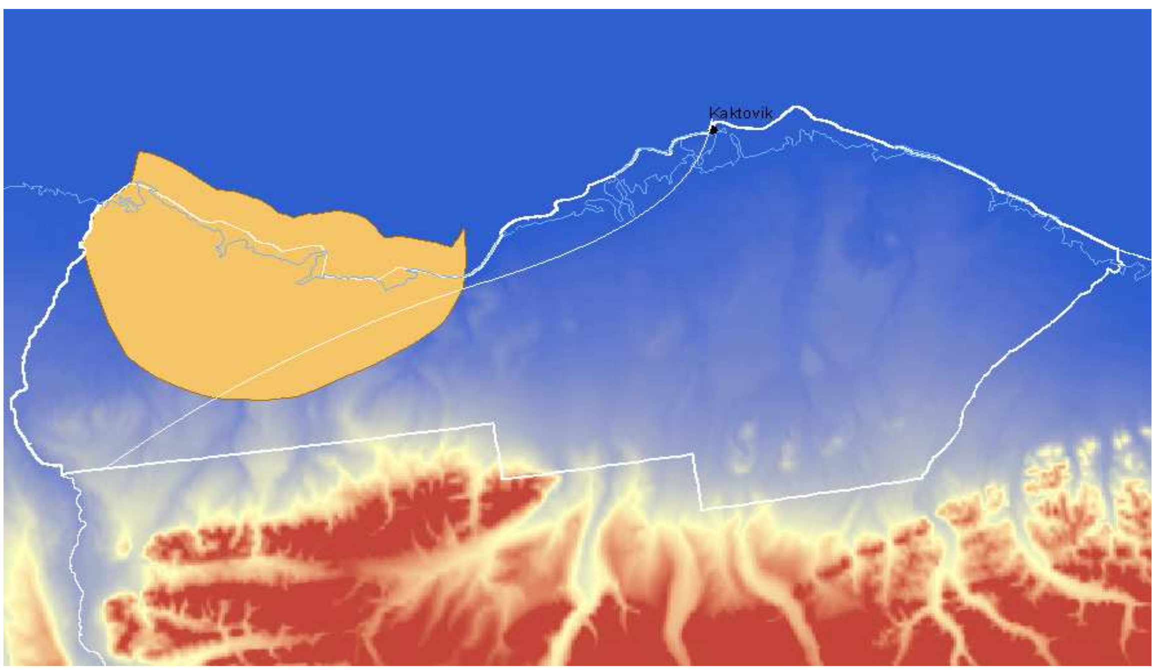
Trap depth: Minimum: 7,000 feet; median: 12,500 feet; maximum: 18,000 feet.

Water saturation: 6%, corresponding to very fine-grained sandstone.

Number of prospects: Minimum: 25; median: 60; maximum: 100.

Types of Hydrocarbons: Mean total volumes of in-place resources: 5,328.05 Million Barrels of Oil; 4,665.20 Billion Cubic Feet of associated-dissolved and non-associated Gas; 272.50 Million Barrels of Natural Gas Liquids from all types of Gas. Comparison to other plays: Oil is the dominate resource with a relativistic factor of 1.299. The three resources in this play, however, have similar comparative ratios so they are all fairly significant as petroleum resources in the Turbidite play.

Wedge Play:



Source: HOUSEKNECHT, D.W. & SCHENK, C.J. (1999). Wedge Play. In The Oil and Gas Resource Potential of the 1002 Area, Arctic National Wildlife Refuge, Alaska. By ANWR Assessment Team, U.S. Geological Survey Open-File Report 98-34.

Source: The most likely hydrocarbon source rocks are Hue Shales in the Hue-Thompson petroleum system, and Tertiary mudstones in the Canning-Sagavanirktok petroleum system. It is also possible that hydrocarbons generated in the Shublik formation of the Ellesmerian petroleum system migrated and accumulated in the Wedge play. This play is ideally placed to receive oil migrating from Hue-Thomson and Canning-Sagavanirktok petroleum systems because hydrocarbons formed in lower strata may migrate along the erosional surface at the base of the Wedge play, directly on top of which lie the reservoir rocks.

Reservoir: The nature of the sandstones in the Wedge play is unknown. It is possible that sediments eroded from the Staines tongue of the Sagavanirktok Formation deposited in the wedge, but their structure is uncertain. There is no direct evidence for the quality of the reservoirs, but it is inferred that it may be intermediate between turbidite and Topset sandstones because of the close relationship between their depositional environments. There are no samples available, but from similarities with the Turbidite play, the porosity was given the values: minimum: 10%; median: 18%; maximum: 30%.

Traps: Traps are thought to be stratigraphic, consisting of mudstones embedded and/or overlying reservoir rocks.

Timing: The potential rocks of this play are Paleocene and Eocene aged turbidite facies. Formation in the Hue Shale probably started 40 Ma (late Eocene), and more recently in the Canning Formation.

Reservoir thickness: Minimum: 50 feet; median: 100 feet; maximum: 400 feet.

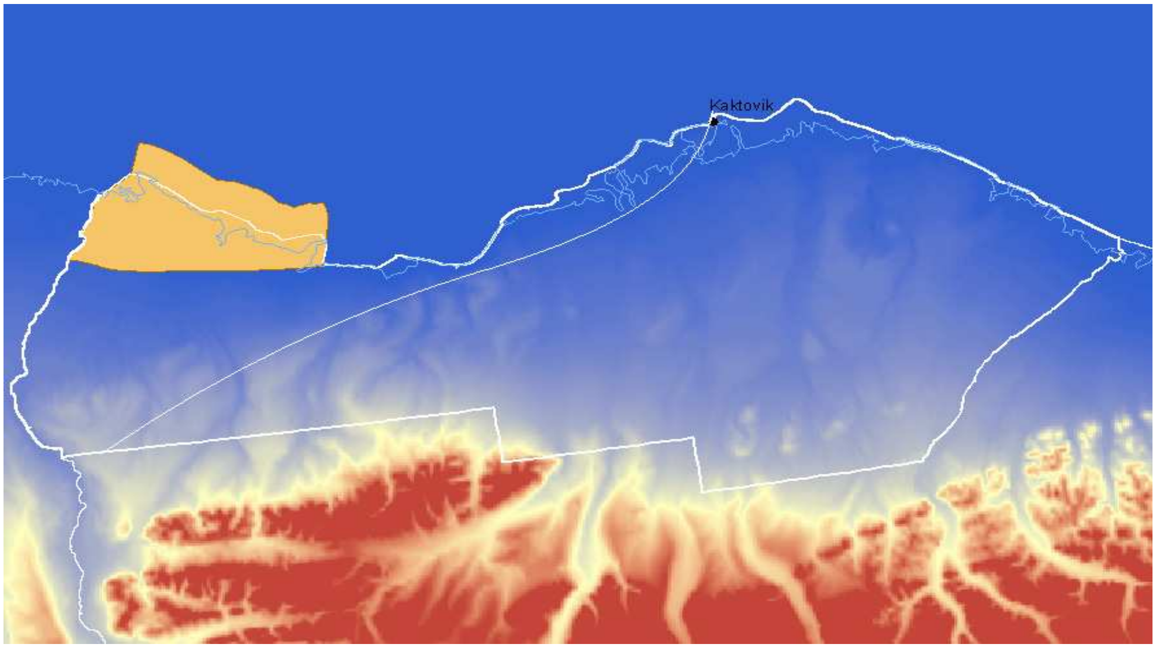
Trap depth: Minimum: 5,000 feet; median: 9,000 feet; maximum: 14,000 feet.

Water saturation: 4%, corresponding to fine-grained sandstone.

Number of prospects: (All traps were counted based on the assumption that they are all stratigraphic and don't need four-way closure to hold oil) Minimum: 10; median: 15; maximum: 35.

Types of Hydrocarbons: Mean total volumes of in-place resources: 1,677.69 Million Barrels of Oil; 864.32 Billion Cubic Feet of associated-dissolved and non-associated Gas; 19.94 Million Barrels of Natural Gas Liquids from all types of Gas. Comparison to other plays: Oil is the dominate resource with a relativistic factor of 1.639. Oil is the predominate resource in this play, but there are relatively significant amounts of Gas as well.

Thomson Play:



Source: SCHENK, C.J. & HOUSEKNECHT, D.W. (1999). Thomson Play. In The Oil and Gas Resource Potential of the 1002 Area, Arctic National Wildlife Refuge, Alaska. By ANWR Assessment Team, U.S. Geological Survey Open-File Report 98-34.

Source: The Thompson play is formed by porous sandstones composed of carbonate clasts of Franklinian age. The source of hydrocarbons is considered to be the Hue Shale of the Hue-Thomson petroleum system and the Shublik Formation of the Ellesmerian petroleum system. They are in close proximity to the reservoir rocks, so migration of oil to them could have easily happened. Hydrocarbons are present in the Point Thomson area, immediately west of the play, so there is a high probability for the presence of hydrocarbons in this region.

Reservoir: The reservoir rock for this play is the Thomson sandstone, from the early Cretaceous, which lies directly over the Lower Cretaceous unconformity. It contains large quantities of carbonates, and is very uniform in character. The depositional environments probably range from trenches to shorelines. The porosity is thought to have a minimum value of 10% and a maximum value of 30%.

Traps: There are several types of traps in the Thomson play, all related to the method of deposition of the sandstones over the Mikkelsen High. The sandstones could have been deposited as blocks, as it is observed in the Kuparuk River Field in Prudhoe Bay. It could also have been deposited in the valleys formed by the channels that drained the Mikkelsen High during the Lower Cretaceous, or as a sheet of sediments resulting from a rise in sea level that caused marine sediments to be deposited over terrestrial strata.

Reservoir thickness: Minimum: 40 feet; median: 120 feet; maximum: 340 feet.

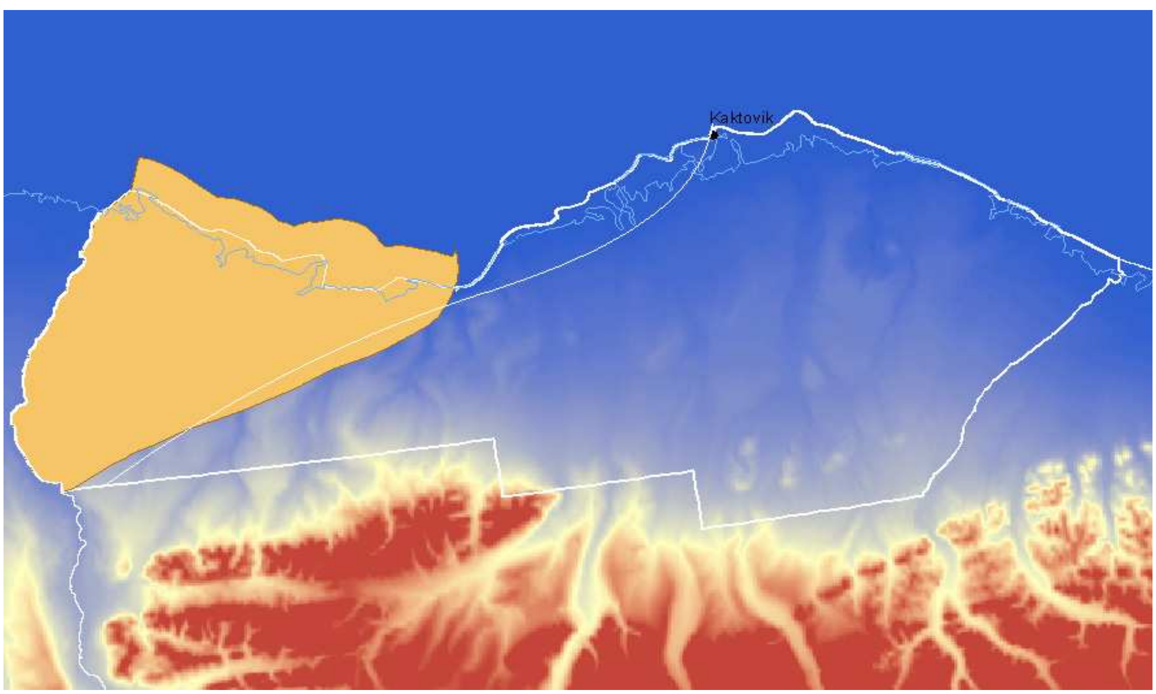
Trap depth: Minimum: 12,000 feet; median: 15,000 feet; maximum: 18,000 feet. They provide an estimate for the hydrocarbon proportion in the play (90% oil, 10% gas)

Water saturation: 6%

Number of prospects: Maximum: 15.

Types of Hydrocarbons: Mean total volumes of in-place resources: 805.10 Million Barrels of Oil; 1,332.28 Billion Cubic Feet of associated-dissolved and non-associated Gas; 111.51 Million Barrels of Natural Gas Liquids from all types of Gas. Comparison to other plays: NGL is the dominate resource with a relativistic factor of 1.679. Compared to the amounts of NGL in other plays, this play has NGL as its predominate resource.

Kemik Play:



Source: SCHENK, C.J. & HOUSEKNECHT, D.W. (1999). Kemik Play. In The Oil and Gas Resource Potential of the 1002 Area, Arctic National Wildlife Refuge, Alaska. By ANWR Assessment Team, U.S. Geological Survey Open-File Report 98-34.

Source: The Kemik play is composed of sandstones deposited in a shallow marine environment. The Kemik Sandstone is a lithic arenite, with chert and quartz as the main lithic grain types. It was probably formed from the the Ivishak Formation, the Lisburne Group and the Kekiktuk Formation. Hydrocarbons probably migrated into this rocks from the Hue Shale of the Hue Thomson petroleum system. There are traces of hydrocarbons in Kemik Sandstone in several outcrops, indicating that they either migrated through or have been reservoired in these rocks.

Reservoir: The Kemik Sandstone may be coarser-grained in the north of the 1002 area, indicating a nearshore marine depositional environment, than it is on the south, where it is a fine-grained shallow-marine sandstone. The sandstone is probably present as valley fills and depositions from rivers and estuaries. There may also be little reservoir-type sandstones as much of the area was thought to be a lagoon during the depositional time; this increases the risk associated with the play. The porosity is estimated by the values: minimum: 10%, median: 16%, maximum: 26%.

Traps: Traps in the Kemik Play are possibly large stratigraphic structures from the pinch-out of the Kemik Sandstone to the north of the outcrop belt. They could also be valley-fill reservoirs with overlying mudstones. There is also the possibility of finding structural traps created when the Kemik Sandstones were involved in the displacement of normal-faulting.

Reservoir thickness: Minimum: 40 feet; median: 70 feet; maximum: 180 feet.

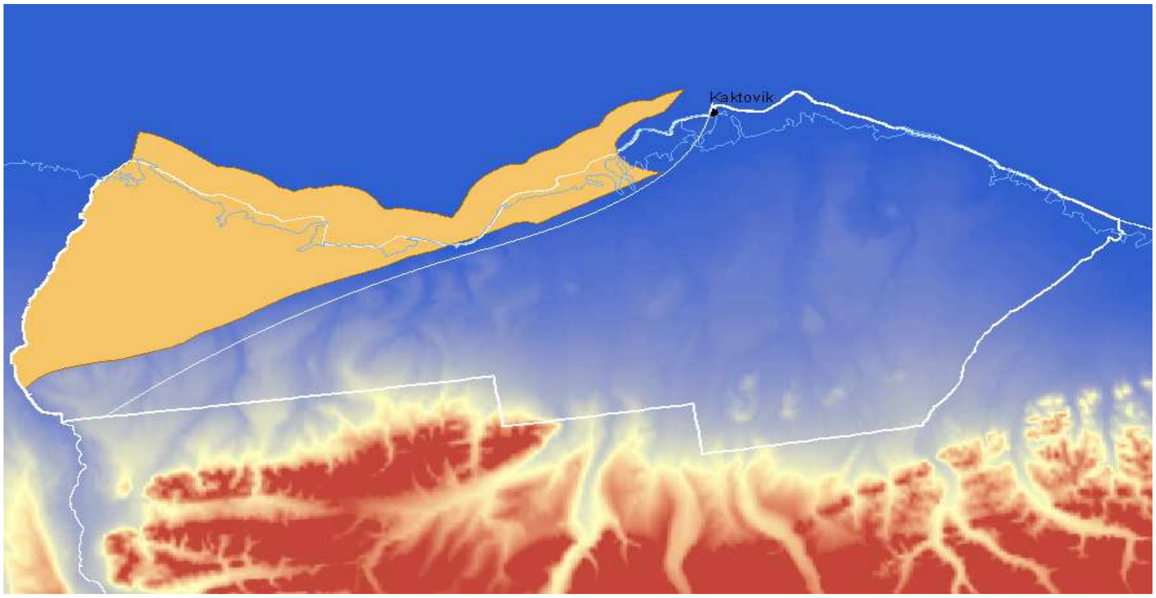
Trap depth: Minimum: 12,000 feet; median: 15,000 feet; maximum: 18,000 feet.

Water saturation: 6%, corresponding to very fine-grained sandstone.

Number of prospects: Minimum: 15; median: 24; maximum: 40.

Types of Hydrocarbons: Mean total volumes of in-place resources: 173.78 Million Barrels of Oil; 305.38 Billion Cubic Feet of associated-dissolved and non-associated Gas; 25.59 Million Barrels of Natural Gas Liquids from all types of Gas. Comparison to other plays: NGL is the dominate resource with a relativistic factor of 1.717. Compared to the amounts of NGL in other plays, this play has NGL as its predominate resource.

Undeformed Franklinian Play:



Source: KELLEY, J.S., GROW, J.A. & NELSON, P.H. (1999). Undeformed Franklinian Play. In The Oil and Gas Resource Potential of the 1002 Area, Arctic National Wildlife Refuge, Alaska. By ANWR Assessment Team, U.S. Geological Survey Open-File Report 98-34.

Source: There are no known source rocks in the Franklinian sequence, so any hydrocarbons would have to come from overlying younger formations. The Cretaceous Hue Shale and the Canning Formation of the Brookian Sequence, which lies directly on top of Franklinian rocks, are the most probable source rocks and seals for this play. It could also have been charged from the Triassic Shublik Formation to the west.

Reservoir: The predominant rock type in this play is the Proterozoic Katakturak Dolomite (Sedimentary rock with more than 90% mineral dolomite, $CaMg(CO_3)_2$) , which dips uniformly to the south. Good reservoirs in the Undeformed Franklinian Play could exist in fractured carbonates with increased porosity due to dissolution of minerals. This porosity, along with porosity due to fracture of the rocks, is probably of Cretaceous age. It ranges from 8 to 20%, with a median of 14%.Because of the poor quality of the seismic data available for the Franklinian rocks, it is difficult to assess this play.

Traps: There are only two possible locations in the Undeformed Franklinian play where a fault could have caused a fold capable of holding hydrocarbons.

Other possible traps are buried hills with heights that range from 100 to 400 feet. Stratigraphical and structural traps are also possible bit there are not observable with the current seismic data.

Reservoir thickness: Minimum: 50 feet; maximum: 300 feet.

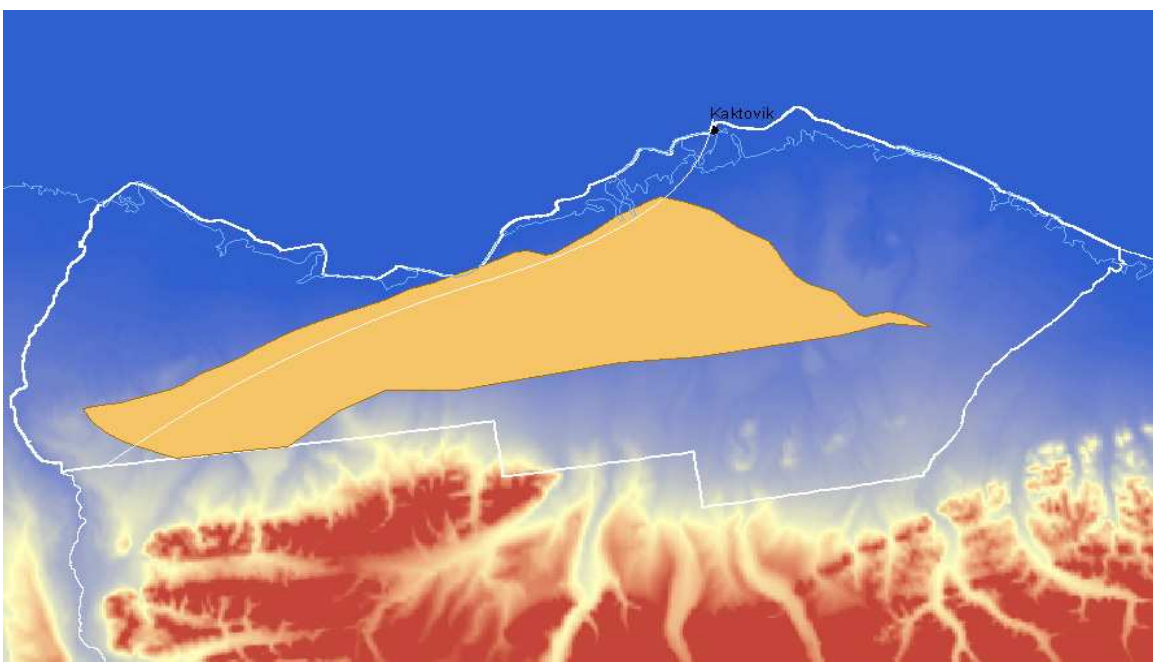
Trap depth: Minimum: 13,000 feet; median: 17,000 feet; maximum: 21,000 feet.

Water saturation: 2%, corresponding to carbonates.

Number of prospects: Minimum: 6; median: 12; maximum: 24.

Types of Hydrocarbons: Mean total volumes of in-place resources: 286.71 Million Barrels of Oil; 740.46 Billion Cubic Feet of associated-dissolved and non-associated Gas; 71.37 Million Barrels of Natural Gas Liquids from all types of Gas. Comparison to other plays: NGL is the dominate resource with a relativistic factor of 2.20. Compared to the amounts of NGL in other plays, this play has NGL as its predominate resource.

Deformed Franklinian Play:



Source: GROW, J.A., POTTER, C.J., NELSON, P.H., PERRY, W.J. & KELLEY, J.S. (1999). Deformed Franklinian Play. In The Oil and Gas Resource Potential of the 1002

Area, Arctic National Wildlife Refuge, Alaska. By ANWR Assessment Team, U.S. Geological Survey Open-File Report 98-34.

Source: There are no known source rocks in the Franklinian sequence, so any hydrocarbons would have to come from overlying younger formations. The Cretaceous Hue Shale and the Canning Formation of the Brookian Sequence, which lies directly on top of Franklinian rocks, are the most probable source rocks and seals for this play. It could also have been charged from the Triassic Shublik Formation to the west, or footwall source rocks (rocks beneath a fault) of the Hue Shale and Canning Formation could have charged the hanging walls (rocks above a fault).

Reservoir: The predominant rock type in this play is the Proterozoic Katakturak Dolomite (Sedimentary rock with more than 90% mineral dolomite, $CaMg(CO_3)_2$), like for the Undeformed Franklinian play. Because of the intense faulting and folding in this area, fractured carbonates reservoirs are probable in this play, facilitating the formation and access to potential reservoirs. The values for porosity range from 8 to 20%, with a median of 14%.

Traps: On the top, the Brookian Turbidite and the Hue Shale are the most likely seals. Most of the prospects mapped in this play were bounded by faults and needed sealing faults to achieve a significant size, but studies of carbonate reservoirs have shown that faults in carbonate rocks are not good seals, giving a low probability of trap formation. There are a few four-way closures mapped on this play.

Reservoir thickness: Minimum: 160 feet; median: 300 feet; maximum: 800 feet.

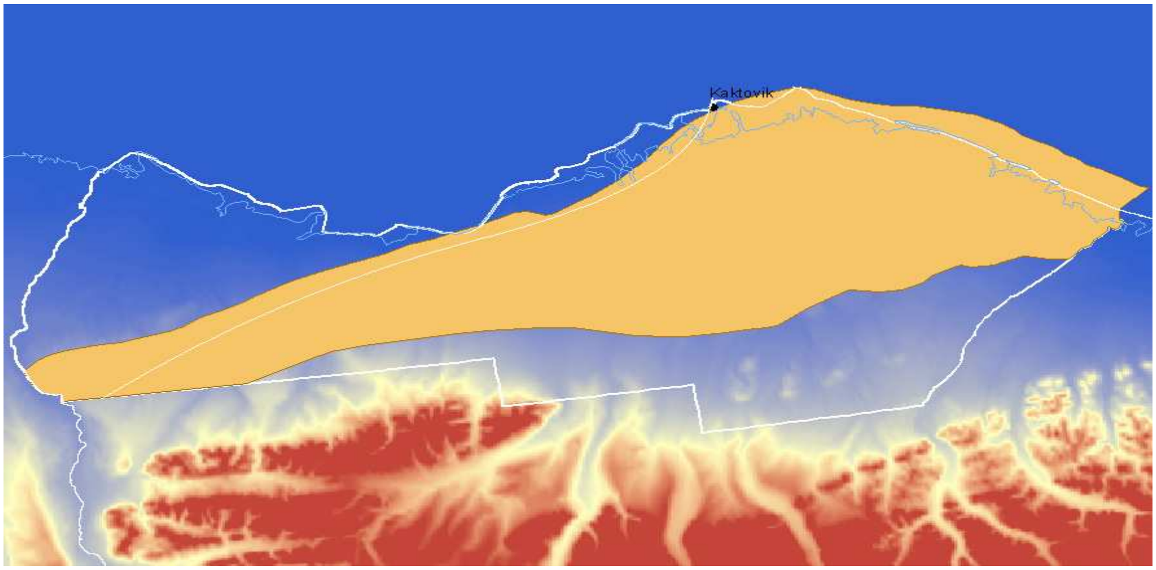
Trap depth: Minimum: 9,000 feet; median: 10,500 feet; maximum: 13,000 feet.

Water saturation: 2%, corresponding to carbonates.

Number of prospects: Minimum: 5; median: 12; maximum: 20.

Types of Hydrocarbons: Mean total volumes of in-place resources: 130.55 Million Barrels of Oil; 1,213.86 Billion Cubic Feet of associated-dissolved and non-associated Gas; 66.18 Million Barrels of Natural Gas Liquids from all types of Gas. Comparison to other plays: NGL and Gas are the dominate resources with relativistic factors of 1.507 and 1.589. Compared to other plays, Oil is not very significant in this play, although there is a greater quantity of it than both NGL and Gas.

Thin-Skinned Thrust-Belt Play:



Source: PERRY, W.J., POTTER, C.J. & NELSON, P.H. (1999). Thin-Skinned Thrust Belt Play. In The Oil and Gas Resource Potential of the 1002 Area, Arctic National Wildlife Refuge, Alaska. By ANWR Assessment Team, U.S. Geological Survey Open-File Report 98-34.

Source and Reservoir: The Thin-Skinned Thrust-Belt Play consists of a region of Brookian strata within the thin-skinned thrust belt. When the Brookian rocks lie directly on the pre-Mississippian basement, the region is composed of Cretaceous Hue Shales or mud-rich Paleocene rocks; when Ellesmerian or Beaufortian rocks are present, it lies between the Kingak and pebble shale interval. The structures in this play are younger than the generation of hydrocarbons, but they may have been charged from the undeformed area, or Tertiary source rocks could have generated hydrocarbons.

Traps: Seismic profiles show several four-way closures in this play, and anticlinal and overlapping structures in two dimensions that could form prospective traps if they present four-way closure.

Reservoir thickness: Minimum: 90 feet; median: 130 feet; maximum: 700 feet.

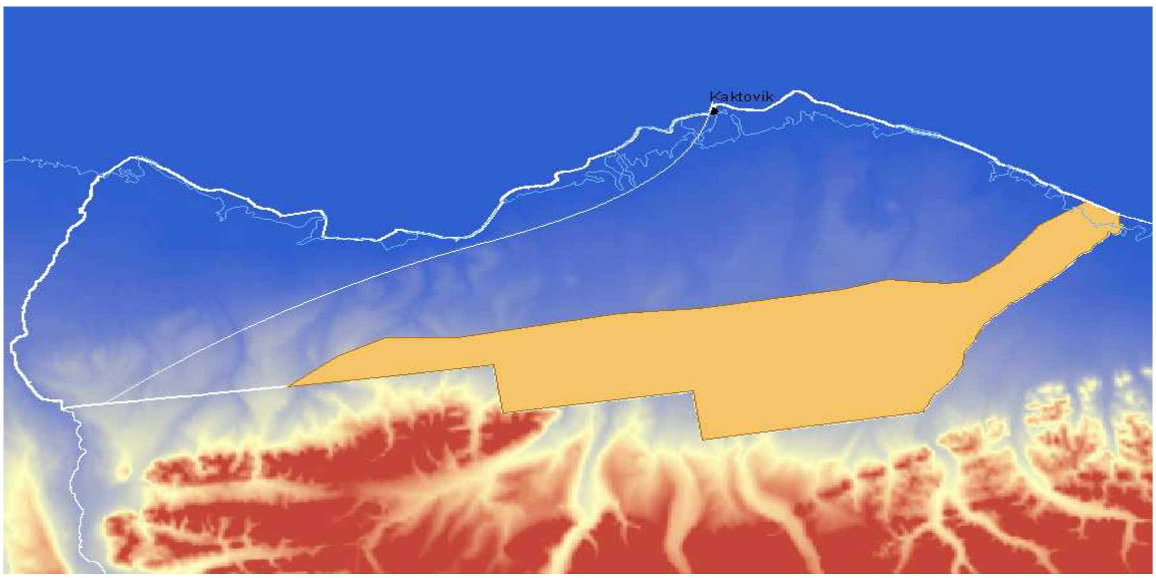
Trap depth: Minimum: 1,000 feet; median: 4,000 feet; maximum: 12,500 feet.

Water saturation: 6%, corresponding to very fine-grained sandstone.

Number of prospects: Minimum: 17; median: 40; maximum: 60.

Types of Hydrocarbons: Mean total volumes of in-place resources: 2,883.88 Million Barrels of Oil; 2,749.66 Billion Cubic Feet of associated-dissolved and non-associated Gas; 28.51 Million Barrels of Natural Gas Liquids from all types of Gas. Comparison to other plays: Oil is the dominate resource with a relativistic factor of 1.275. This play also contains relatively large quantities of gas as well, at a factor of .851.

Ellesmerian Thrust-Belt Play:



Source: GROW, J.A., POTTER, C.J., NELSON, P.H. & PERRY, W.J. (1999). Ellesmerian Thrust-Belt Play. In The Oil and Gas Resource Potential of the 1002 Area, Arctic National Wildlife Refuge, Alaska. By ANWR Assessment Team, U.S. Geological Survey Open-File Report 98-34.

Source: Source rock prospects for this play include the Shublik Formation, Hue Shale, and Canning Formation, charging the reservoir rocks from footwall source rocks (rocks beneath a fault) to hanging wall reservoirs (rocks above a fault). From vitrinite reflectance mapping, it was concluded that most of this play lies below the oil generation window, making this a 100% gas play.

Reservoir: Potential reservoirs for the Ellesmerian Thrust-Belt play only include the sandstones of the Ivishak and Sag River Formations, Kekiktuk

Conglomerate, and carbonates in the Lisburne Group because the Jurassic and Lower Cretaceous rocks of the Ellesmerian formation (Kingak Shale, Kemik Sandstone, and Pebble Shale) are too thin. The mean value for porosity is 11%.

Traps: The subsurface continuations of the Sadlerochit Mountains, two anticlines dipping to the east, are large prospect traps in this play. There are four others, and they all require cross faults for closure, as well top seals. Possible top seals are the Kingak Shale, Hue Shale or silstones of the Canning Formation.

Reservoir thickness: Median: 300 feet; maximum: 1,500 feet.

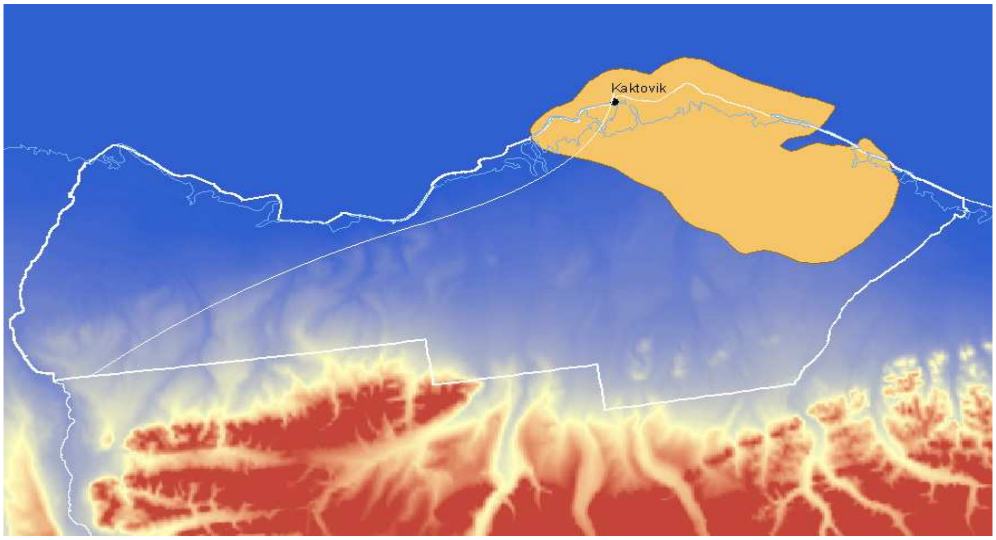
Trap depth: Minimum: 2,000 feet; maximum: 17,000 feet.

Water saturation: 3.5%, corresponding to an intermediate between fine sands and carbonates.

Number of prospects: Minimum: 4; maximum: 8.

Types of Hydrocarbons: Mean total volumes of in-place resources: 0 Million Barrels of Oil; 1,167.65 Billion Cubic Feet of associated-dissolved and non-associated Gas; 23.76 Million Barrels of Natural Gas Liquids from all types of Gas. Comparison to other plays: Gas is the dominate resource with a relativistic factor of 1.716. There is no Oil resource in this play, but there are the largest Gas resources of all the plays.

Niguanak-Aurora Play:



Source: GROW, J.A., POTTER, C.J., NELSON, P.H. & PERRY, W.J. (1999). Niguanak-Aurora Play. In The Oil and Gas Resource Potential of the 1002 Area, Arctic National Wildlife Refuge, Alaska. By ANWR Assessment Team, U.S. Geological Survey Open-File Report 98-34.

This play is composed of two very large structures, the Aurora dome and Niguanak high, located to the north-east of the 1002 area. The uncertanties of the structures present caused the play to be assessed in two scenarios: one with two large prospects, one for each structure, and another with multiple prospects inside each structure.

Source: Lower Cretaceous Pebble shale, Hue shale and the Tertiary Canning Formation, all of the Brookian sequence, may occur around over and on the flanks of the two structures that compose the play, and may have charged them.

Reservoir: The internal deformations in these two structures make it difficult to determine their composition, but the high densities and velocity values measured suggest that they are composed mainly of Franklinian rocks, with some components of Beaufortian and Ellesmerian rocks. The porosity has a minimum value of 5%, a mean of 10% and a maximum of 20% for both scenarios.

Traps: The north-verging Niguanak thrust fault system separates the Aurora dome on the north and the Niguanak dome on the south. There may be stacked thrust sheets of rock within both structures where hydrocarbons could be trapped in basement carbonates or sandstones of the Franklinian, Beaufortian and/or Ellesmerian origin.

Reservoir thickness: Minimum: 50 feet; median: 150 feet; maximum: 300 feet (both scenarios).

Trap depth: Minimum: 2,000 feet; maximum: 17,000 feet.

Water saturation: 2.5%, corresponding to carbonates.

Number of prospects: Many prospect scenario: Minimum: 1; median: 10, maximum: 20. Two-dome scenario: 2.

Types of Hydrocarbons: Mean total volumes of in-place resources: 1,107.04 Million Barrels of Oil; 1,178.96 Billion Cubic Feet of associated-dissolved and non-associated Gas; 51.49 Million Barrels of Natural Gas Liquids from all types of Gas. Comparison to other plays: Oil is the dominate resource with a relativistic factor of 1.185. Compared to other plays, there are also large volumes of both NGL and Gas as well in this play.

Hydrocarbon Values

Value of the hydrocarbons

A major component in determining the 'potential' of a region is to determine its economic potential: the value of what is there.

The price of the hydrocarbon's in the world market is a crucial determining factor in the 'value' of the 'potential' for the ANWR region, as this is the factor that will ultimately make the distinction between drilling or not drilling in a cost-benefit analysis.

According to the Bloomberg energy prices, the current value of hydrocarbons are:

Petroleum ($/bbl)

Type	Price	Change	% Change	Time
Nymex Crude	30.16	-0.14	-0.46	10/24/03
IPE Crude	28.58	-0.05	-0.17	10/24/03
Dated Brent	30.02	0.55	1.87	10/24/03
WTI Crushing	29.98	-0.14	-0.46	10/24/03

Natural Gas ($/MMBtu)

Type	Price	Change	% Change	Time
Nymex Henry Hub	4.79	-0.13	-2.58	10/24
Henry Hub	4.8	-0.11	-2.24	10/24
NYC Gate	5.12	-0.4	-7.25	10/24

As the numbers above demonstrate, there are different types of oil and natural gas that sell for different prices. These prices are, however, very near each other, and so in the long run can be considered the 'same price.'

According to the OPEC tables of 'global oil trends' the lowest value of oil is around $20 a barrel and the highest value peaks nearer to $35 a barrel. This figure is subject to change due to political events, fluctuating oil reserves/ production, and to the health of the oil market at the time.

When coupled with the volume estimates for the 1002 region of ANWR, the value of oil in billion of dollars is

	5% probability	50% probability	95% probability
Higher end	412.97	268.38	148.89
Current value	366.83	238.40	132.27
Lower end	294.98	191.70	106.35

For natural gas, in trillion cubic feet, is

	5% probability	50% probability	95% probability
Higher end	61.17	16.57	0
Current value	54.61	14.80	0
Lower end	44.45	12.05	0

The values used for the above price estimates are

Oil ($/barrel)		Natural Gas ($/MMBtu)	
Higher end	$35	Higher end	$5.5
Current value	$31.09	Current value	$4.91
Lower end	$25	Lower end	$4

The above tables give an idea of how much revenue can be expected from ANWR, bearing in mind that it is a probabilistic estimate and should be treated carefully.

Comparison with other world sources

To get a general idea of the placement of the hydrocarbons in ANWR in the context of the international oil market, a comparison of the the proven reserves of different regions of the world and of the expected reserves of the 1002 area was set up.

Region	Natural Gas (billion cubic meters)	Crude Oil (million barrels)
North America	6898	27646
Latin America	7507	111173
Eastern Europe	57493	79190
Western Europe	6955	18268
Middle East	71546	698906
Africa	13207	93550
Asia and Pacific	14118	38434
1002 Area	**301.9**	**11790**

Expected Recovery

Technically recoverable resource is the volume of petroleum which is recoverable using current exploration and production technology without regard to cost, which is a proportion of the estimated in-place resource. Oil recovery factor is the percent of in-place oil resource which can be technically recovered, without regard to cost.

The USGS Open File Report 98-34 values are used as the baseline estimates for our drilling proposal's values. Our drilling proposal is for oil resource in the undeformed region of 1002 only. The oil values for the undeformed region, from the 1998 USGS assessment, yield the following oil recovery factors.

Undeformed Region Oil volumes by Probability Fractilesbility Fractiles

	Mean	95%	50%	5%
In Place Oil (MMBO)	17483	9428	16880	27435
Tech. Recov Oil (MMBO)	6420	3403	6186	10224
Oil Recovery Factor (%)	36.72	36.09	36.65	37.27

These oil recovery factors are slightly less than the recovery factors for the entire 1002 area, which has a mean recovery factor of 37.1%. In 1998, the oil recovery factor for the undeformed region was 36.7%.

Improvements In Technology

Technically recoverable resource analysis assumes that technological improvements will be made to exploration and production technology over time, resulting in increased technically recoverable resource. Current technological improvements include 4D time-lapse seismic surveys, 4C multi-component seismic imaging, directional and multilateral drilling, logging tools for more accurate well placement, thermal enhanced recovery by steam injection and in situ combustion, and many forms of chemically enhanced oil recovery by polymer addition. These methods add between 5-15% to the oil recovery factor.

The trend for increasing technically recoverable resource over time is an average annual increase factor. Studies have been done by the National Petroleum Council (NPC) and DOE Energy Information Administration (EIA) which include data on this research. From the 1999 NPC study, there is an annual technically recoverable resource increase of 1.3-1.5% due to improvements in technology.

The Statfjord and Gullfaks oilfields in the Norwegian North Sea, however, have different trends for increase in oil recovery.

Increase in Oil Recovery Factor over Time

	1986	1996	2000	Increase/Year
Statfjord	49.4%	61.4%	65.6%	About 2.05%
Gullfaks	46.5%	49.4%	54.5%	About 1.15%

Sources:
http://www.mafhoum.com/press4/117T41.htm
http://www.statoil.com/fin/nr303094.nsf/Attachments/gullfaks.pdf/$FILE/gullfaks.pdf

These oilfields respond differently to improvements in technology with respect to oil recovery factor. Data from all of these different trends, combined by taking the average of the rates of increase, yields a technically recoverable resource annual rate of increase of 1.53% per year.

Changes in Technically Recoverable Resource Due To Water Saturation

Water flooding is one of our proposal's most important methods of enhanced oil recovery. To minimize environmental damage, water used for reservoir flooding must either come from the saturated water content of the reservoir, or must be shipped in to the site by vehicles. The water saturation percent for the entire 1002 area and the undeformed region are given in the table below.\

Water Saturation (%) @ Fractile 50 (1:2 Probability)

Play	Entire 1002	Undeformed Region
Topset	20	20
Turbidite	33.3	33.3
Wedge	22.2	22.2
Thomson	33.3	33.3
Kemik	37.5	37.5
Undeformed Franklinian	14.3	14.3
Deformed Franklinian	*14.3*	-
Thin-Skinned Thrust-Belt	*40*	-
Ellesmerian Thrust-Belt	*31.8*	-
Niguanak-Aurora	*25*	-
Averages	***27.17***	***26.77***

There is slightly less average water content in the undeformed region than there is in 1002. This fact, however, is already taken into account in the slightly lower oil recovery factors for the undeformed region than for the entire 1002.

Reservoir flooding for enhanced oil recovery is used to a large extent in our proposal. Therefore, the effect of percent water saturation on our technically recoverable resource will be significantly different than for the USGS report's technically recoverable values. The limited volume of available water will increase the cost of reservoir flooding. But since cost is no object, as much water can be shipped in as necessary. Water saturation values, therefore, do not affect our oil recoverability factor, but do affect the economically recoverable values.

Results

Technically recoverable resource depends on improvements in E & P technology over time. The USGS report's recovery factors were made without regard to cost. So the current technically recoverable resource is given by the USGS oil recovery factor for the undeformed region, adjusted for improvements in E & P over time. The mean undeformed region oil recovery factor: 36.72%. The increase in technically recoverable resource per year: 1.53%. The current oil recovery factor is then

.3672*(1.0153)^(2003-1998) = .3962 = 40%

The technically recoverable resources for the Undeformed Region are, for 2003:

	Mean	95%	50%	5%
In Place Oil (MMBO)	17483	9428	16880	27435
Oil Recovery Factor (%)	40	40	40	40
Tech. Recoverable Oil (MMBO)	6993	3771	6752	10974

There is a mean technically recoverable oil resource of 6993 million barrels of oil in the undeformed region, which is an 8% increase from the 1998 assessment.

Environment

Physical Environment

The Arctic National Wildlife Refuge spans 9.6 million acres and lies on the edge of the Artic Ocean and, bordered by Prudhoe Bay to the West and the Canada to the East. The 1002 area, 1.5 million acres of northeastern ANWR, lies on the Coastal Plain of ANWR and is situated in the 100 miles between the Aichilik River to the east at 142º 10' W and the Canning River to the west at 146º 15' W. It is trapped between the Brooks Range Mountains located at 69º 35' N and the Beaufort Sea at 0º 10' N, and its close proximity to the two ecoregions produces a variety of ecological conditions and habitats which support a wide spectrum of vegetation.

The entirety of ANWR spans many regions, including the Arctic coast, the tundra plain, the Brooks Range Mountains, and the Yukon basin forests. It contains over 20 rivers, including National Wild Rivers the Sheenjek, Ivishak, and Wind; North America's largest and most northerly alpine lakes Peters and Schrader; warm springs; lagoons; and glaciers. In the 1002 area, specifically, there are also many rivers that run northward and a few large lakes which freeze all the way to their bottoms by winter. Polygonal patterns on the ground across the region are formed by the seasonal thawing of the surface which will be explained in greater detail in the hydrology section. The disturbance of the surface tundra results in permanent alteration of the terrain, including the creation of ponds, ice wedges, vegetative cover and erosion.

Climate

The climate of Northern Alaska can be divided onto three different zones: Arctic Coastal, Arctic Inland and Arctic Foothills. Extending 20 km from the ocean, the 1002 area falls under the category of Arctic Coastal, which is characterized by cool summers and relatively warm winters, due to the impact of the ocean. Partially due to the rain shadow created by the Brooks Range just south of the coastal plain, the region has the lowest precipitation, 50 percent of which falls as snow. The air temperatures remain below freezing through most of the year and snow covers the ground surface for more than 8 months from October through April (Zhang, Osterkamp 1996).

Temperatures

Temperatures reach a high of about 86 degrees F in the summer (averaging about 41 degrees) yet drops to well below zero (averaging -4 degrees) in the winter. The global warming trend has already increased temperatures in the Arctic by 5 degrees F and 8 degrees in the winter since the 1960s, leading to shorter ice seasons, glacier melting, permafrost thaw, and increased precipitation. The inevitable change in climate may lengthen the growing season, but it will also alter the delicate ecological balance in ANWR (anwr.org).

Precipitation

Measuring precipitation in a wind-swept region, especially where the total quantity is small and more than 50 percent comes as snow, is a complicated problem. ANWR has an average rainfall of about 25cm, and solid winter precipitation for coastal areas averaged 15.3cm for the three years of study 1994-97. Out of this 34 percent of the precipitation sublimed (Sturm 2002).

During the winter months, virtually all precipitation falls in solid form. The low-growing vegetation and high wind speeds that characterize the domain allow significant wind redistribution of snow throughout the winter. This means that snow depths can be quite variable and, under appropriate conditions, some of the snow cover is returned to the atmosphere by blowing snow sublimation. Winter precipitation measurements do not exist in wind-blown arctic regions (Sturm 2002).

Snow cover

Snow cover possesses certain thermal properties which compete with air temperature on the ground thermal regime. It has high reflectivity and emissivity that cool the snow's surface; snow cover is a good insulator that insulates the ground; and melting snow is a heat sink, owing to its latent heat of fusion (Zhang et al., 1997). In spite of the high albedo from spring and early summer snow and cloud cover, net radiation is positive throughout the year (Hare, F. K. 1972).

The microclimate of an environment, or the climate near the ground, is largely a function of energy exchange phenomena at the ground-air interface. The average maximum thickness of the seasonal snow cover varied from about 30cm along the Arctic coast to about 40cm inland for the period from 1977 through 1988 (Zhang et al., 1996a). The thickness of seasonal snow cover, however, can vary substantially on a micro scale due to the impact of wind, ground surface morphology, and vegetation. Along the Arctic Coastal Plain, the ground surface is relatively flat and mainly occupied by low-center polygons. Vegetation is poorly developed, and the region experiences high wind speeds during the winter months (Haugen 1982).

In this setting, the snow can be either blown away or well packed by strong wind, reducing the insulating effect. Inland, the ground surface becomes rough and vegetation changes significantly as a result of increased summer warmth. Wind redistributes the snow which is better trapped in the troughs and depressions created by rough micro relief and the taller vegetation. The trapped snow increases the insulating effect of the seasonal snow cover, which, in turn, influences the permafrost conditions that determine vegetation of the area. On a monthly basis, seasonal snow cover warms the ground surface during winter months but cools it during the period of snowmelt. On an annual basis the seasonal snow cover definitely warms the ground surface. (Zhang et al., 1997)

In contrast with the Arctic coast, the Arctic inland and Arctic foothills feature lower wind speed, a very rough surface with tussocks, troughs and depressions, and well-developed vegetation. Snow can be interrupted and trapped by vegetation and rough surface, increasing the insulating effect and permafrost temperatures.

Effects of Global Warming

Climatic warming associated with elevated levels of greenhouse gases in the atmosphere is predicted to be greater in the Arctic than elsewhere, almost two to three times more than the global average (Osterkamp 1982). The impact of climatic warming on the Arctic ecosystem is uncertain, as are the feedback processes to potential changes in the exchange of greenhouse gases between the polar soil and atmosphere. This will be discussed further with relation to soil and the carbon cycle. One of the main reasons is that climatic conditions on the north slope of Alaska are not well understood owing to the sparsity of meteorological stations and discontinuity of observations.

Analyses of data collected by a number of studies done from the late 1940s onwards at and around Barrow and Prudhoe Bay showed that the permafrost surface has warmed 2º to 4º C in the Alaskan Arctic over the last century (Lachenbruch and Marshall 1986; Lachenbruch et al., 1988). Since then, the rate of increase in temperature has accelerated greatly, to about 1º C per decade. Snow and shrubs form a positive feedback loop that could change land surface processes in the Arctic. The increased subnivian soil temperatures that are observed would produce conditions favorable to shrub growth (i.e. more decomposition and nutrient mineralization) (Strum et al., 2001). Aerial photographs taken of Alaska's North Slope during the 1940s offer some of the best evidence of such change: a dramatic increase in the growth of trees and shrubs in the Arctic.

Hydrology

Water Availability

The Arctic Coastal Plain may seem to be abundant in water resources. In actuality however, the low precipitation limits the amount of readily available water. Most of the available water resources come from snow melt, runoff, rivers, and lakes within the area. In arctic and subarctic areas, rivers typically carry 55 to 65 percent of precipitation falling onto their watersheds. The reason for that is that the permafrost prevents the downward percolation of water and forces it to run off at (and very near) the ground surface. Consequences of the high runoff include the fact that northern streams are much more prone to flooding and that they have higher eroding and silt-carrying capabilities (Bowling et al., 1997).

Critical to the control of water runoff in the north is the cover of moss and other vegetation of the tundra, bogs and forests. A thick layer of moss acts much like a sponge lay over the permafrost to slow down the movement of water across the ground surface.

Frozen Water Formations

One primary source of water is in thermokarsts or thaw lakes. These lakes are actually thaw basins: low areas in the tundra where water from melting snow and ice collects. Thousands of square miles in the Arctic are covered by ground which has been segmented into what are called tundra polygons or ice wedge polygons. This pattern is caused by intersecting honeycomb networks of shallow troughs underlain by more or less vertical ice wedges. The ice wedges are formed when the ground contracts and splits in a manner analogous to the formation of cracks on the dry lake bed. This allows water to enter, and successive seasons of repeated partial thawing, injection of water, and refreezing cause the wedges to grow. As they grow, the strata to either side turn up to enclose the polygon, and a lake may form in the center with the raised troughs at the margins. Above the frozen region, unfrozen water saturation increases due to low hydraulic conductivity, which prevents the melting ice from draining, thus causing accumulation of water above it (Panday and Corapcioglu, 1995). During this process, pingos are sometimes formed when the pressure from the contraction of the unfrozen water pushes it up until it collects and freezes under the root mat.

All of the thaw lakes studied were very shallow; even though the lakes could be several thousand feet long, most were no deeper than 10 feet (Bowling et al., 1997).

Drainage patterns typically follow the troughs, and where they meet, small pools may form. These are often joined by a stream which causes the pools to resemble beads on a string - in fact, this type of stream form is called beaded drainage. Thaw lakes tend to be elongated perpendicular to prevailing winds caused by subsurface currents. The waves caused by crosswinds may be eating away at the peat more aggressively along the edges creating a pattern of elongation that all arctic lakes share(Bowling et al., 1997).

The amount of available water in the 1002 area has been estimated to be around 9 billion gallons.

Water Usage in the 1002 Area

Water resources are limited in the 1002 Area. In winter, only about nine million gallons of liquid water may be available in the entire 1002 Area, which is enough to freeze into and maintain only 10 miles of ice roads. Although such exploration is conducted only in winter, snow cover on the 1002 Area is often shallow and uneven, providing little protection for sensitive tundra vegetation and soils. The impact from seismic vehicles and lines depends on the type of vegetation, texture and ice content of the soil, the surface shape, snow depth, and type of vehicle.

Oil companies are withdrawing surface water faster than it can be replenished, says Steve Lyons, hydrologist with the U.S. Fish and Wildlife Service (USFWS). When an ice road melts, the water runs over the surface into streams, usually outside the original watershed from which it was withdrawn, he explains. Because the 1000-ft-thick permafrost does not allow groundwater movement between water bodies, lakes are filled only by snowmelt and may take more than two years to refill after the permitted 15% of their liquid volume is withdrawn for ice road construction (Pelley, 2001).

Surface water will also be used for potable purposes at manned facilities, equipment washing, tank cleaning, dust abatement on roads and workpads, and hydrostatic testing.

Permafrost

Examining the soil and water cycles of the 1002 region, one cannot ignore the presence of permafrost, or "permanently frozen soil," which underlies 80% of Alaska and remains a central issue in the debate about oil drilling. Permafrost has been defined as frozen ground in which a naturally occurring temperature below 0° C (32° F) has existed for two or more years (Bowling et al. 1997). On the North Slope, permafrost ranges in thickness from about 700 to as much as 2,240 feet thick, and may be as cold as -8° to -10° C.

Permafrost can be either thaw-stable or non thaw-stable, depending on the type and percentage water of the soil it is made of. Permafrost in more fine-grained soils like loess (silty) tend to thaw, sink, and create thermokarsts more often. Permafrost thaws from heat input, such as global warming or human activity, as well as the clearing of vegetation which insulates the ground.

Permafrost is affected by road dust generated by traffic on unpaved roads; snow melt due to dust deposition can lead to flooding, ponding, and hydrological changes in oil. Continuing oil and gas exploration, development, and production, construction of a natural gas pipeline, the operation and maintenance of facilities, and other activities requiring road travel would add cumulatively to the volume of road dust generated on unpaved roads (BEST, PRB, 2003). Regions of ice which have been wind-dusted are likely to undergo localized melting earlier than the neighboring non-dusted ice (Bowling et al. 1997).

There are three approaches to dealing with the permafrost problem in the construction practice. The first and most obvious is to avoid it entirely. The second is to destroy it by stripping the insulating vegetative cover and allowing it to melt over a period of years. This has the obvious drawback of requiring a considerable period of time to elapse before construction can begin, and even then, it is a good idea to excavate the thawed ground and replace it with coarse material.

The third approach, and one which is becoming more widespread, is to preserve it. This can be accomplished by building on piles to allow cold air to circulate beneath heated structures, by building up the construction site with gravel fill which insulates and protects the permafrost below, or by refrigeration to maintain low ground temperatures. This is done by utilizing thermal piles or freeze tubes, such as those used by the trans-

Alaska pipeline. These devices are filled with a non-freezing liquid and act like coffee percolators. They are cooled during the winter months and draw heat from the ground to retard thawing during warm weather (Bowling et al. 1997).

In nearshore areas, ice-bonded permafrost is probably present and must be considered in the design of an offshore pipeline. But nearshore ice-wedge permafrost under shallow water, particularly along a rapidly receding coastline, is even more critical for design. Oil pipelines placed in areas of ice-bonded or ice-wedge permafrost must be heavily insulated to limit thawing of permafrost. The best location for an offshore platform is at water depths of 6.5-65 feet, to minimize ice gouging. Beyond the 6.5 foot water depth the top of the ice-bonded permafrost generally is below the surface of the seabed. Inshore of the 18-foot bottom-depth contour, ice gouging is typically less than 1.6 feet (Kutasov, 1997).

Important aspects of disturbance and recovery in permafrost regions

The physical system

Ice-rich permafrost is a major factor controlling disturbance and recovery in the Arctic. If the permafrost thaws, thermokarst can be initiated on a large scale, and a critical point is reached where it is difficult or impossible to return the site to its original state within a few decades because of continued subsidence (Walker)

Thawing of ice causes:

- hydrologic changes(impoundment of water or creation of flowing water
- thermal changes by decreasing the albedo of the surface and increasing heat flux to the site
- geochemical changes(usually increased nutrient availability)

Attributes that contribute to thermokarst

- volume of ground ice in the near surface sediments
- steepness of the terrain
- grain size of the sediments

Disturbance in areas with high amounts of ice, rolling topography, and fine-grained sediments may not stabilize even 30 years after the disturbance. Grain size and steepness can be determined from surficial geology maps and digital terrain models(DTMs)

Overall oil production and industrial activity will melt permafrost, affecting plant growth in the area.

The thawing of ground ice causes hydrologic changes due to the impoundment of water or creation of flowing water. There are also thermal changes by decreasing the albedo of the surface and increasing heat flux to the site. Geochemical changes is usually in the form of increased availability of nutrients. All of these have serious implications on the entire ecosystem. Therefore, it is not without reason that scientists have formulated the following:

The fragility of tundra to destruction is directly proportional to the ice content of the permafrost and inversely proportional to the mean ground temperature (Arctic and Alpine Vegetations: Similarities, Differences, and Susceptibility to Disturbance, Billings).

Modification of the site following disturbance

If heat flux to ice-rich terrain is increased, such as by changes in surface albedo, hydrologic conditions, thermal conductivity of the active layer, snow regime, or local sources of heat(eg. from drilling machinery or hot oil) thermokarst might likely result. The control on heat flux are complex. The radiation balance and thermal properties of the soil are affected by position, depth of the moss carpet, bulk density of the soil, vegetation cover, snow cover, and moisture regimes. Deep organic layers and thick moss carpets are good insulators against heat flux unless the organic material is saturated, as is often the case in low microsites. Physically based models of heat flux now offer predictions of changes to annual thaw depth in response to climate change. The time required for vegetation recovery and the type of vegetation that will reoccupy the site is also controlled by the thermal stability of the site. (Walker 1991).

Relation of oil drilling, permafrost and vegetation

Permafrost layer restricts the drainage of water through the soil, making it moist in the short summer growing season. It is easily broken by road construction or the seismic explosions used in oil exploration, changing the water drainage patterns of the soil and thus retention of moisture. Melting permafrost has also led to widespread damage of buildings, costly road repairs, and increased maintenance for pipelines and other infrastructure impacts that will continue to grow in magnitude. Permafrost also stores large amount of ancient carbon and methane; thawing is likely to release some of this stored carbon and methane back into the atmosphere, amplifying the risk of further climate change. The boreal forest will advance northward into present coastal plain tundra, and mixed forest into present boreal forest. Forest fires and insect outbreaks, both of which have increased sharply in recent years, will further increase. If the permafrost thaws, the vegetation will in the long term dries out, altering plant communities and use by wildlife.

It has been observed that in areas where the permafrost thaws, there is a sudden rapid growth of plants, which attract more animals to feed on. However, this is only momentary. Once the permafrost thaws, temporarily there is much water for plants to grow well for like a month or two, but then the water is continuously used up and drained away as there is no layer to prevention drainage now; yet the permafrost, once destroyed, take years to resume. Therefore, a few months after destruction, water will finally be deficient and no plants can grow well even during summer when water has already been used up, drained away but no permafrost exists to trap them for the growing season. This detrimental effect on vegetation is permanent, while the vast growth of plants is just transient.

Soil

The Arctic Coastal Plain consists of marine (carried into seas by streams and beach erosion), fluvial (carried by flowing river water), alluvial (carried by river water that gradually loses velocity), and aeolian (carried by wind) deposits from the rising of the Arctic Sea on the plain in the mid/late Quaternary Age.

The Coastal Plain is dominated by lakes and poorly-drained soils, while the Brooks Range has less lakes and more well-drained soils (due to river flow). Poorly-drained soils mostly result from the predominance of permafrost, which restricts water flow in and out of the soil, as well as impermeable bedrock in more upland areas.

Active Layer

During the short summers, the active soil layers above the permafrost table thaws briefly to depths of 20-75 cm and allows root penetration, growth and nutrient uptake by the tundra vegetation.

Soil Types of the Area

- Pergelic Cryaquepts: low-lying, seasonally flooded, shallow surface mat of partially decomposed organic matter grading into dark gray sandy loam.
- Histic Pergelic Cryaquepts: lowlands, slightly to moderately decomposed organic matter grading into dark green-gray silt loam.
- Pergelic Cryofibrists: poorly-drained, organic, made of thick layer of sedge and moss

peat.
- Typic Cryochrepts/ Alfic Cryochrepts/ Aeric Cryochrepts

"Histic" indicates that the soil is shallow with poorly aerated organic material; "Pergelic" refers to temperature "regime," indicating the presence of permafrost; and "Aquept" suggests poor drainage. The soils of the 1002 region are generally loamy, gravelly, and from nearly level to hilly/steep association.

Vegetation vs. Soil

Site	Dominant Vegetation	Soil Suborder	Max thaw depth (m)	pH
Tussock Tundra	Eriophorum Dwarf Shrubs Sphagnum	Pergelic Histic Cryaquept	.4	6.4
Heath	Dryas Betula Salix Ericads	Pergelic Ruptic Entic Cryumbrept	2-5+	4.2
Shrub-Lupine	Salix Cassiope Lupinus	Pergelic Histic Cryaquept	1-2+	6.9
Equisetum	Lupinus Grasses, Sedges Equisetum	Pergelic Histic Cryaquept	0.45	7.4
Wet sedge	Carex Eriophorum	Pergelic Cryohemist	0.55	6.6
Willow	Salix Betula Lupinus Sphagnum	Pergelic Cryofluvent	+	7.8

(Valentine 1992)

pH

The soil pH ranges from approximately 4-8, depending on the soil type, topography, and amount of disturbance to which it was subject. High weathering and cryoturbation generally makes the soil less acidic, introducing more basic materials to the soil matrix.

Frost boils, on the other hand, lowered the pH by moving the organic layer deeper in the soil and increasing the depth of thaw. The pH of the soil has a clear relation to the species diversity and density within the area. (Valentine 1992)

Element/Nutrient Composition and the Issue of Heat

Arctic soils consist of many trace elements, as well as very large quantities of the carbon, nitrogen, and phosphorous very important to the ecosystem. These elements are essential to processes of mineralization and respiration and nutrient distribution, and because decomposition processes of Arctic tundra soils respond to temperature increase more than other types of region soils, they stand to be very greatly affected by both global warming and other sources of heat input. Increased water flow which can result from melting of permafrost also temporarily increase nutrient distribution and lengthen the growing season for certain plants, particularly *E. vaginatum*, a species of cottongrass sedges. Increased soil flow increases heat flux, which leads to deeper thaw and therefore magnifies the effect.(Chapin 1988)

Concern also arises that the Arctic soils may contribute to greenhouse gas emissions due to this increase in decomposition of organic matter. Most soil organic carbon is found in the active layer of the soil, and it varies in amount depending on such formations as ice wedges, which melt to form polygons with either "high-centers" or "low-centers" that drain in different ways. The proportion of soil organic carbon in the upper permafrost is directly related to the influence of soil moisture on active-layer thickness in that better drained soils have more carbon in the active layer. With global warming and increased heat, the active layer thickness may increase by 20-30%, increasing cryoturbation, thermal erosion, and intensified thaw-lake cycles. Thaw lakes contain peat in frozen subsoil which would also decompose when melted, increasing emissions.

Permafrost

Examining the soil of the 1002 region, one cannot ignore the presence of permafrost, or permanently frozen soil, which underlies 80% of Alaska and remains a central issue in the debate about oil drilling. The surface soils are frozen all but three months of the year, and the permafrost below them penetrate the ground to an average of about 660 m deep.

Permafrost can be either thaw-stable or non thaw-stable, depending on the type and percentage water of the soil it is made of. Permafrost in more fine-grained soils like loess (silty) tend to thaw, sink, and create thermokarsts more often. Permafrost thaws from heat input, such as global warming or human activity, as well as the clearing of vegetation which insulates the ground.

More on permafrost can be found in the Hydrology section

Soil Microbial Processes

Microbial Processes and Plant Nutrient Availability in Arctic soils

Several characteristics of arctic soils influence microbial activity, nutrient mineralization, and nutrient availability to plants and will certainly figure prominently in changes in these processes in a warmer arctic climate. Arctic soils are generally overlain by a dense mat of organic matter and vegetation, wet for at least part of the year and permanently frozen at some depth. These factors combine to lower summer soil temperatures, impede the progression and decrease the depth of seasonal thawing, and maintain relatively high soil moisture content. Cold, wet soil environments and short summers slow organic matter decomposition and nutrient mineralization and severely restrict nutrient availability to plants.

The accumulation of organic matter in arctic soils is determined largely by the combined effects of temperature and moisture on decomposition and primary production. Because of climatic variation among arctic regions, the amounts of organic matter and nutrients in tundra soils vary across broad geographic scales. Organic matter often accumulates at depth in permanently frozen peats in relatively wet arctic regions such as the coastal plain on northern Alaska.

Organic carbon increases with moisture, from low amounts in well-drained beach-ridge ecosystems with cushion plant-lichen communities. Such an overall pattern of organic carbon increasing with moisture from well- to poorly drained ecosystems also occurs in Alaska's coastal and foothill tundra regions

Well-drained soils are less common in patterned ground regions with little relief, such as the Alaskan coastal plain, where more than 85% of soils are moist to poorly drained. Moist soils with dense organic mats(5-40cm thick), intermediate thaw depths, and divers plant communities dominated by tussock-forming sedges occupy gently sloping land in much of the Low Arctic.

Organic matter and moisture content are important determinants of soil temperature, thaw depth, cation exchange capacity, aeration, redox potential, and other properties affecting biological processes in soils. Decomposition rates and soil moisture balances will likely be affected by the warmer temperatures predicted for the Arctic. The resulting changes in soil organic matter, moisture and microbial processes in ecosystems will alter the amounts, seasonality, and forms of mineral nutrients available to plants. A warmer climate will likely have different overall effects on soil properties and on nutrient cycling in dry, moist, and wet arctic ecosystems..

Microbial and soil Processes

Nutrient cycling and fertilization studies in arctic ecosystems show that plant growth is strongly limited by nutrient availability. Primary production is often nitrogen-limited, but phosphorus (especially in organic soils) or nitrogen and phosphorus together can also limit production.

Arctic ecosystems are generally conservative of nutrients accumulating large amounts in soil organic matter pools with very long turnover times. Because of these characteristically slow turnover rates and, in some ecosystems, the gradual burial of organic matter in permafrost, nutrients become available to plants at very low rates. Long turnover time result from slow decomposition, which can become a bottleneck in nutrient cycling rates. Differences among ecosystem types in soil microclimate and decomposition may explain the inverse relationships between soil nutrient stocks and nutrient cycling rates or primary productivity as reported, for example, on Alaska's northern coast. Slow decomposition leads to greater accumulation of organic matter in soil and can lower nutrient mineralization rates, thereby decreasing primary productivity.

Nutrient Cycles

In order to understand the ANWR ecosystem, it is also necessary to investigate the energy and nutrient cycles. The carbon balance of the ecosystem has been highly influenced by global climate changes and CO2 content changes. The arctic contains 11% of the world's organic matter pool, and within the arctic tundra ecosystems, there are both carbon sinks and carbon sources. Vegetation changes in the Alaskan tussock tundra over the past decade has brought about important feedbacks on the region's biogeochemical cycles, mostly through altered rates of carbon and energy exchange between biosphere and atmosphere. Modeling analysis suggests that the source/sink strength of tundra depends on changes in photosynthesis that result from the partitioning of nitrogen between vegetation and soils, and on changes in soil moisture, which affect soil respiration rates. All of these factors may be affected by machine and human activity in the region and disturbances in the permafrost.

Nutrient cycling and fertilization studies in arctic ecosystems show that plant growth is strongly limited by nutrient availability. Such activity depends highly on decomposition, nitrogen mineralization, phosphorous availability, and controls on carbon and nutrient cycles, which in turn depend on temperature, moisture, decomposability of litter inputs, depth of thaw, etc.

Current Net Ecosystem Carbon Storage and Flux

Carbon pools and rates of carbon accumulation vary, depending on vegetation type and environmental conditions.

More than 90% of the carbon in arctic ecosystems is located in soils, with even higher percentages (98%) in soils of northern peatlands. In upland boreal forest, in contrast, only about 55% of the ecosystem carbon is found in the soil. Not only is the proportion of soil carbon substantial, but so are the absolute amounts. Arctic tundra has 55 Pg (petagrams) of carbon stored as soil organic matter in the A horizon, compared with 87.5 Pg in non-peatland boreal forest and 122 Pg in forest peatlands and Gorham's estimates of 455 Pg C are considerably higher (1991).

Tussock and wet sedge tundra soils account for the bulk of circumpolar tundra carbon stores because they have large amounts of carbon per square meter and cover large areas. Although per unit area carbon storage in polar semi-deserts is only about one-half that in the wet sedge tundra, the greater extent of these semi-deserts results in carbon stores approaching those of wet sedge tundra.

For these large stores of soil organic matter to have accumulated in northern ecosystems, production must have exceeded decomposition at some time in the past. Recent estimates indicate that northern ecosystems still constitute a small net sink for atmospheric carbon; current accumulation rates, however, are difficult to assess (Post, 1990; Gorham, 1991). Because the rates vary with conditions and ecosystem type, soil carbon accumulation is positive in some areas and negative in others. The overall balance is still uncertain (Chapin 1991).

Carbon Balance of Arctic Plants and Ecosystems(and the relation with global warming)

The carbon cycle is strongly correlated with climate in the region, as well as the global climate dynamics. Because of the large amount of carbon present in northern soils and the presumed sensitivity of soil carbon accumulation or loss to climate change, northern ecosystems may be particularly important to global carbon balance in the future. Between 250 and 455 petagrams of carbon are present in the permafrost and seasonally thawed soil layers -- about one-third the total world pool of soil carbon. Warmer soils could deepen the active layer and lead to thermokarst and the eventual loss of permafrost over much of the Arctic and the boreal forest. These changes could in turn alter arctic hydrology, drying the upper soil layers and increasing decomposition rates. As a result, much of the carbon now stored in the active soil layer and permafrost could be released to the atmosphere, thereby increasing CO2 emissions and exacerbating CO2-induced warming. Alternatively, plant communities and vegetation can be changed because of the increase in atmospheric CO2 and nutrient availability. New communities might be taller and have higher rates of primary productivity than does extant vegetation. The net result could be higher primary productivity, increased carbon storage in plant biomass, and a negative feedback on global atmospheric CO2.

Arctic and boreal forest ecosystems are unique in their potentially positive and negative response to elevated CO2 and associated climate change. The arctic ecosystem is alsounique in its capacity for massive continuing, long term carbon accumulation because of its permafrost, and they are also particularly sensitive to global warming. Thus it can be seen that it is important to discuss the major processes and controls on carbon cycling in arctic ecosystems, and the likely effects of elevated atmospheric CO2 and concomitant climate change on carbon storage" (Chapin 1991).

Global warming, vegetation changes, and the nutrient cycles

Under global warming, temperature and precipitation changes in arctic regions are occurring already. In much of Alaska, approximately 1ºC per decade of warming has been observed. Vegetation changes have been recorded in Alaskan tussock tundra over the past decade (Chapin et al. 1995), and these changes are expected to have important feedbacks on the region's biogeochemical cycles through altered rates of C exchange between biosphere and atmosphere, and changes in the region's energy balance.

The arctic tundra ecosystem consists of both C sinks and sources. Detailed modeling analysis of arctic biogeochemistry (McKane et al. 1997) suggest that the source/sink strength of tundra depends on changes in photosynthesis that result from the partitioning of nitrogen (NO) between vegetation and soils, and on changes in soil moisture, which affect soil respiration rates.

From Arctic Ecosystem in a Changing Climate: An Ecophysiological Perspective : "The limitations of photosynthesis by low temperatures and low solar radiation has been clearly demonstrated and simulated for arctic vascular plants(Miller et al. 1976; Limbach et al. 1982; Tenhunen et al. 1994) But, because of the saturating response of photosynthesis to light, day length is an additional important limiting factor to productivity." "While moisture stress has no impact on productivity at some of the mean climate conditions, photosynthesis is vulnerable to changes in soil water potential and hydraulic constraints on water transport." A reduction in soil water potential can cause stomatal closure, to balance transpiration against reduced soil water intake. Lower hydraulic conductance can lead to stomatal closure and reduce gross primary productivity as rates of water supply are constrained by the characteristics of the vascular system.

Photosynthesis in arctic ecosystems is linked closely to the hydrological cycle. C loss from ecosystems is also linked to soil moisture (Oechel et al. 1993).

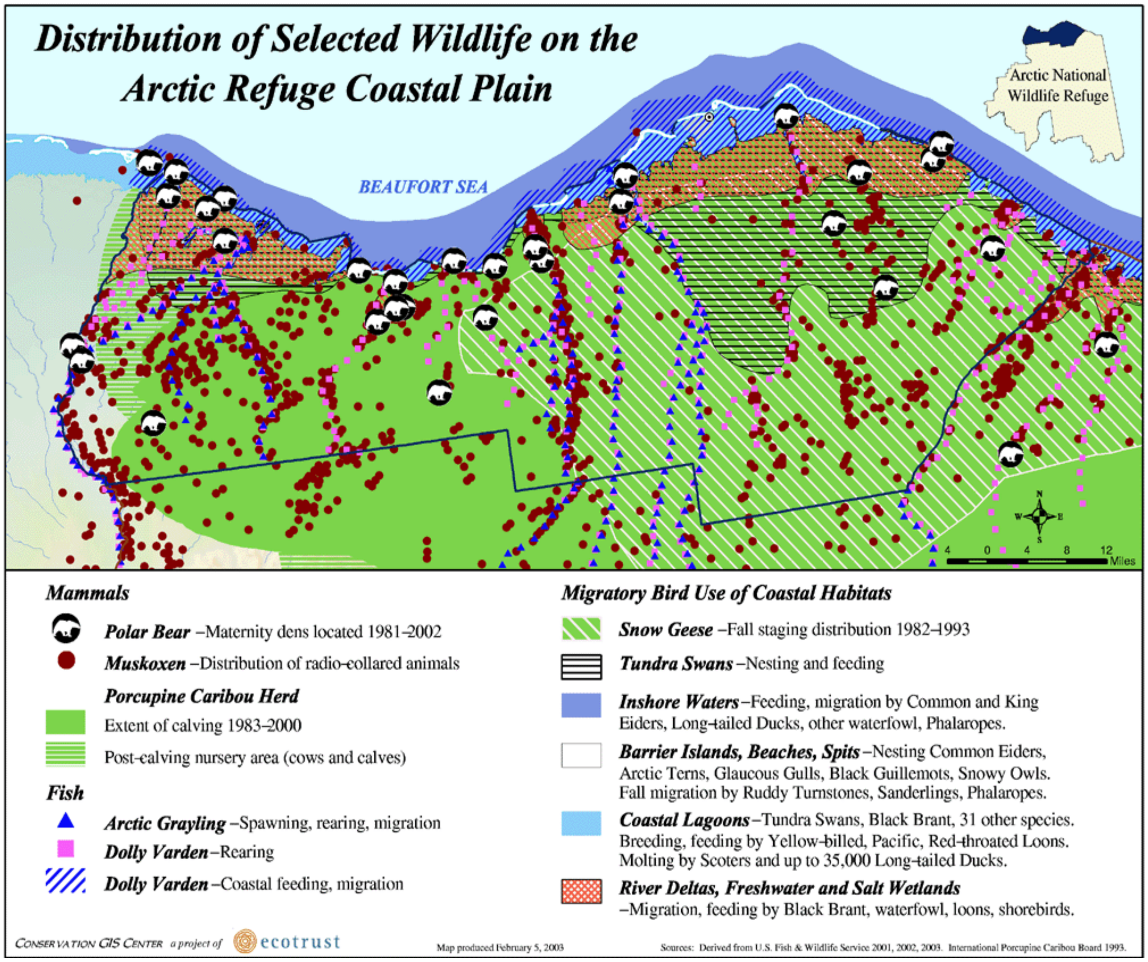
Terrestrial Life

Many terrestrial species can be found in the 1002 region due the abundant food source available on the coastal plain. The forage quantity and quality supports the different species that stay in the area all year round, or come during summer to feed, breed, and raise their young. Migratory species such as the caribou (the Porcupine Caribou Herd PCH in 1002) can be found. Non-migratory species include muskoxen, polar bears, arctic foxes, wolves, wolverines, and other small mammals such as lemmings, voles and shrews.

Vegetation in the area are mainly moist herbaceous/shrub tundra, tussock sedges and wet sedge tundra. The limited precipitation and low temperature in the area limits the variety of plants that can survive there. Mostly, it is vascular species low in height

The Caribou, as a migratory species, mainly uses the 1002 area as a staging ground. The central southern portion of the 1002 area is a core calving ground for the PCH. It also uses the western portion of 1002 as a post-calving ground, and migrates through the area yearly.

Other species such as the muskoxen and arctic foxes stay in the area year-round. Collectively though, the critical time periods of these species would still be summer from May to October, when the weather is warmer and insects are less abundant, allowing calving and breeding to take place for different species. However, polar bears den there during the winter as well, and disturbance to their dens may lead to abandonment of the dens by mothers, endangering the survival of cubs.



Main concerns for terrestrial species would be noise pollution from exploration, which could be particularly significant for polar bears, and blockades and fragmentation of habitat by pipelines and oil-drilling infrastructure.

Polar Bears (*Ursis arctos*)

Habitat

Polar bears can be found along the Coastal Plain and on Arctic Ice. Although Polar Bear breeding occurs on ice, once pregnant, the females migrate to the Coastal Plain in order to make dens, give birth to and nurse their young. Arctic Refuge's coastal tundra provides America's only land denning habitat for polar bears, serving primarily the Beaufort Sea population. It's also one of the world's largest polar bear denning sites

Dangers

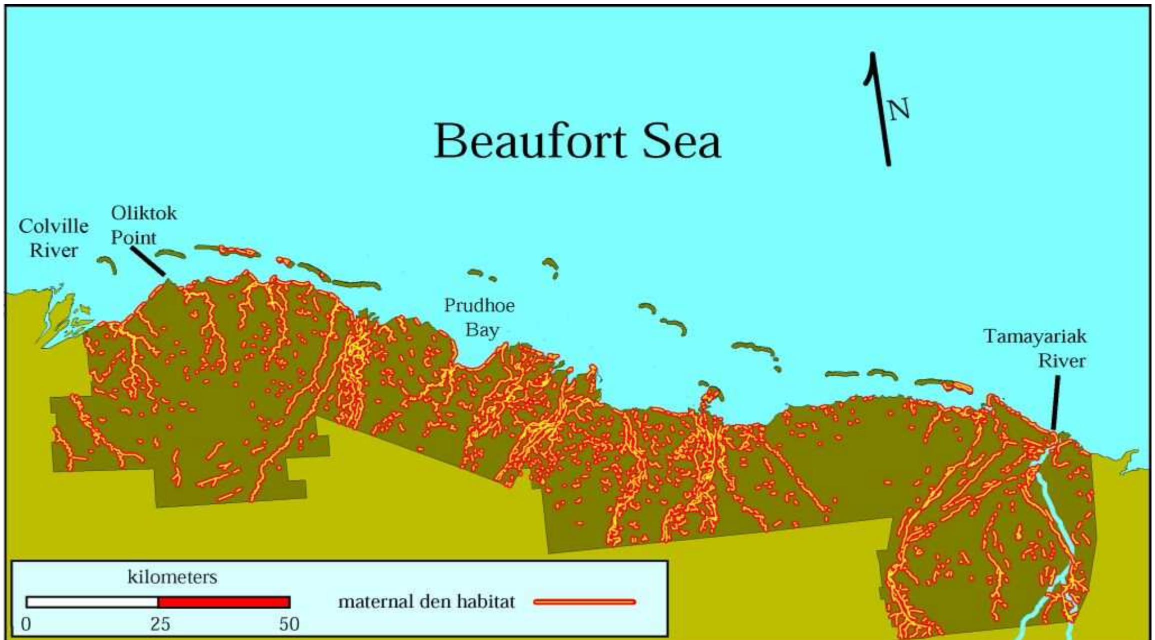
- hunted throughout most of their range.
- polar bears of the Beaufort Sea region are exposed to mineral and petroleum
- extraction and related human activities such as shipping, road-building, and seismic testing (Stirling 1990).

Movement

- Polar bears were observed to move more than 4 km/hr for extended periods, but mean hourly rates of movement varied from 0.30-0.96 km/hr.
- Movement rates varied significantly among months: they generally were lowest in spring and late summer and highest in early winter (Amstrup 1995, Amstrup. Geographic displacements from the beginning to the end of each month were smaller for females with cubs of the year than for single females, and larger in November than in April.
- Total annual movements ranged from 1,454-6,203 km. Bears that spent part of the year in dens moved less than others, but non-denning classes of bears did not differ in total annual movement (Amstrup 1995, Amstrup et al. 2000).

- Beaufort Sea polar bears kept their movements within boundaries outside of which they seldom ventured. Annual activity areas ranged from 12,730 km2 to 596,800 km2. Monthly activity areas ranged from a mean of 344 km2 for females with cubs in April to 11,926 km2 for females with yearlings in December (Amstrup 1995, Amstrup et al. 2000).

Polar Bear Denning Sites:



Distribution of polar bear maternal den habitat in northern Alaska. For more details see:

Durner, G.M., S.C. Amstrup and K. J. Ambrosius. 2001. Remote identification of polar bear maternal den habitat in northern Alaska. Arctic 54(2): 115-121.
Durner, G.M., S.C. Amstrup, and A.S. Fischbach. 2003. Habitat characteristics of polar bear terrestrial maternal den sites in northern Alaska. Arctic 56(1): 1-8.

Source: USGS, Alaska Science Center. Prepared 28 February 2003.

Breeding

-Amstrup et al. (2001) and McDonald and Amstrup (2001) suggested that the number of polar bears in the Southern Beaufort Sea population grew at more than 3% per year between 1967 and 1998, reaching an estimated population that could be as high as 2,500 animals.
-Survival of adults, as calculated from life tables, was higher and survival of young lower when the population was large. Survival rates of adult Beaufort Sea polar bears, however, were as high or higher than those measured anywhere else.
-Although numbers of young produced per female when the population was small (<0.40) and when it was large (<0.38) were similar, litters of more than one yearling were more frequent when the population was small.

Death

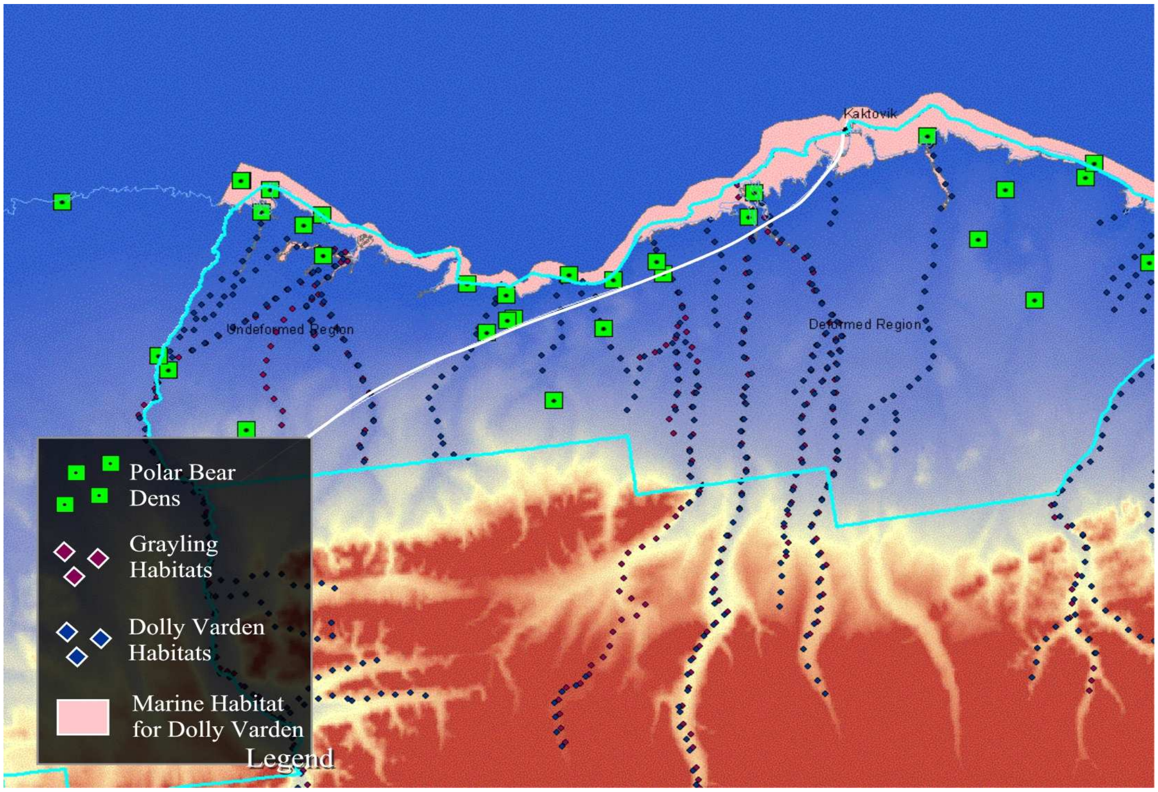
-In this study hunting explained 85% of the documented deaths of adult female polar bears (Amstrup and Durner 1995). Natural mortalities were not commonly observed among prime age animals (Amstrup and Nielsen 1989), and we still know little about the proximate causes of natural deaths among polar bears.

Critical Time Periods:

In research conducted on the Beaufort Sea Region, it was discovered that in the months of May through August the bears shifted locations to the north and remained there till October.

Sensitivities:

Although hydrocarbons have serious ramifications on all wildlife, polar bears reproduction rates and rapid growth will not be severely altered if oil is to be extracted (Amstrup et al. 1989) as can be seen in prior cases. The available data suggests that polar bears are pretty resilient to environmental disturbances (Amstrup 1993).



Effects of Petroleum on Polar Bears

- Although contact with hydrocarbons can have serious ramifications for polar bears (Amstrup et al. 1989), the polar bear's apparent rapid population growth has spanned the entire history of petroleum development in arctic Alaska (Amstrup 2000, Amstrup et al. 2001, McDonald and Amstrup 2001). This suggests that managed resource development can be compatible with healthy polar bear populations. Also encouraging is the new ability to estimate potential impacts that oil spills may have on polar bears. That ability has major ramifications for assessing risks of a variety of potential developments (Durner et al. 2001b).
- Effects of the increasing human intrusions into the polar bear environment have not been observed at a population level, suggesting that proactive management can assure coexistence of polar bears and human developments.

Endangered?

- Estimated numbers of bears at the close of the study were relatively large. Early estimates suggested the additional loss of as few as 30 bears each year might push the total take from the population to the maximum sustained yield (Amstrup et al 1986, Amstrup and DeMaster 1988). Excess take did precipitate a decline in the 1960s and 1970s. Hence, although populations may now be near historic highs, managers must be alert to possible changes in human activities, including hunting and habitat alterations that could precipitate future declines.
- because polar bears have a low rate of reproduction and a greater success of cubbing in land-based dens, onshore denning habitat is crucial to the survival of the species.

Porcupine Caribou (*Rangifer tarandus*)

General Information

The porcupine caribou herd can be located at many plant communities throughout ANWR. The herd is made up of an estimated 129,000 members and spends winters in the southern portion of the refuge (as well as outside of refuge). The herd migrates twice a year more than 700 miles to ANWR's Coastal Plain. The pregnant cows normally reach the calving areas in the Coastal Plain by early June and give birth. (Hank Lentfer and Carolyn Servid, 2001). Soon afterwards, the rest of the herd joins the cows in their calving ground. About a month afterwards, when the climate gets slightly warmer and mosquitos hatch, the caribou will migrate north seeking relief from these tormenting insects. They will travel along the coast, and to the uplands in Brook's Range. (Kaj Birket-Smith)

Porcupine Caribou Herd
(Photo: http://www.r7.fws.gov/nwr/arctic/caribou.html)

Critical Time Periods

Between the months of August and October insects are less abundant, the caribou still travel in search of nutrition but do not have the need to congregate in areas where swarms of insects can be avoided. (Lentfer and Carolyn Servid, 2001) Therefor, the caribou disperse widely and cover a large area but along parallel paths. By October, the Porcupine caribou herd has moved to the boreal forest. The critical time period for the caribou is when migrations is at its greatest in April and during the first week after the calves are born. The cows are the first to arrive to the Coastal Plain (USGS Fish and Wildlife, 2003) and 1002 region and normally arrive in early June although harsh weather conditions can delay their arrival. The most critical time period is in the calves first week in the world.

The Coastal Plain is vital to the calves' survival for two main reasons:

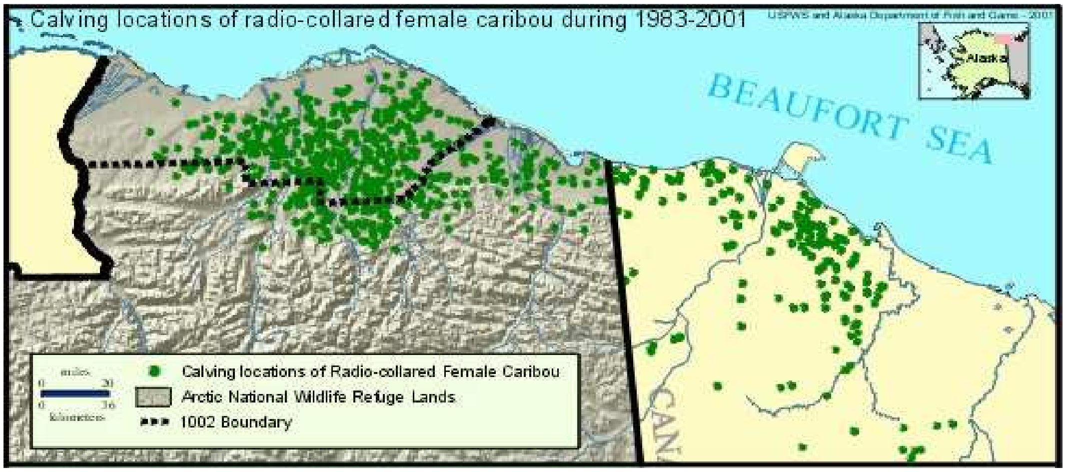
1) fewer brown bears, wolves, and golden eagles live on the coastal plain so newborns have greater chance of survival in their first week until they are strong enough to outrun their predators. (USGS Fish and Wildlife, 2003)

2) Coastal Plain provides proper nutrition needed for calving. There is an abundance of plant species and after a long winter, the cows need to have good nutrition

Calving grounds:

the northern foot hills of the Brooks Range and the arctic Coastal Plain from from the

Tamarayiak River in Alaska to the Babbage river in Canada. Most often used calving grounds are on the Coastal Plain between the Katakturuk and Kongaut rivers where normally, 50% - 75% of the herds' calves are born.



Calving Locations of Radio Collared Female Caribou
(Map: http://www.r7.fws.gov/nwr/arctic/caribou.html)

Proposal

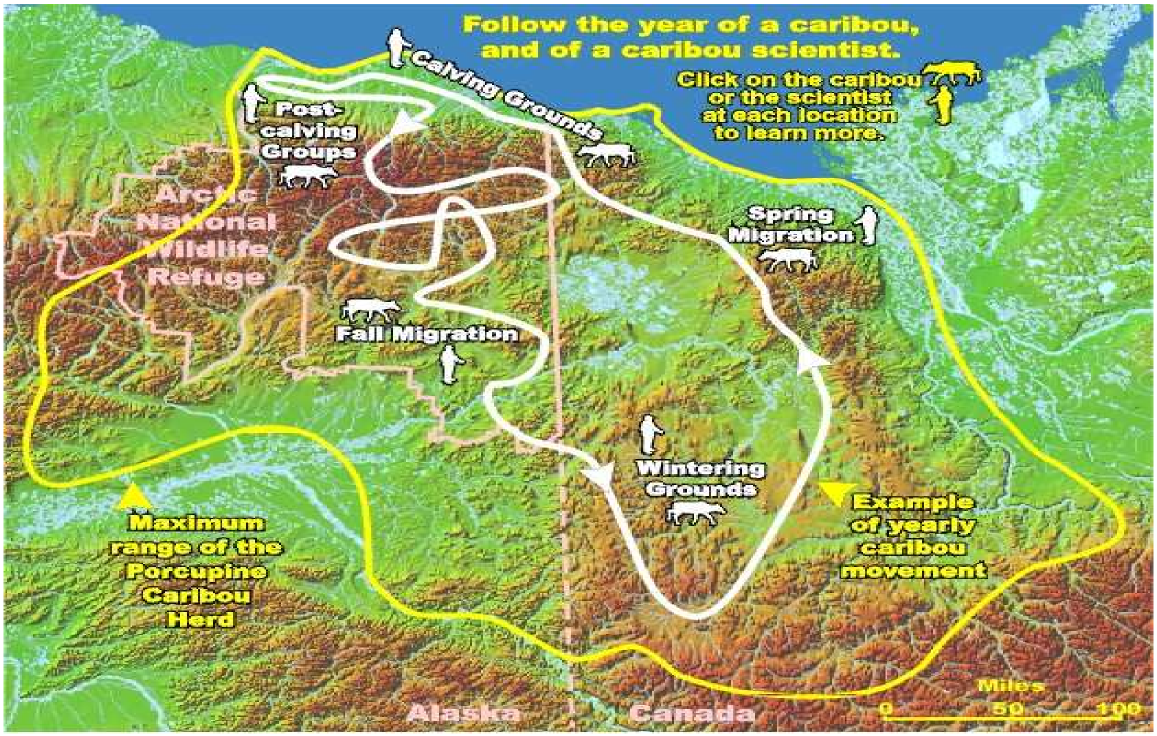
The porcupine caribou herd are a vital part of ANWR's eco-system and therefore must be taken into great consideration when planning the most environmentally efficient way to extract oil . The porcupine' caribou herd's relation to the Coastal Plain is part of an unaltered system which brings new life to the Caribou after a long and harsh winter.

It is vital to take into grave consideration the migratory paths of the Porcupine Caribou Herd before formulating a plan to extract oil. Precautions should be made with utmost carefulness in order to mitigate as much as possible the effects on the herd's migratory paths which have gone undisturbed for centuries.

Suggestion

The fact that this important species is migratory is a major asset in formulating an environmentally efficient method of oil extraction. The oil drilling should occur between the months of October and April when the the caribou are not in the 1002 area.

Caribou's Migratory Paths:



(Map: http://www.r7.fws.gov/nwr/arctic/caribouyear.html)

Central Arctic Caribou

General Information

Success in reproduction is mainly related to the females' nutrition and calf production is highly positively correlated to fat content of sexually mature females during the autumn . As researched near the Sagavanirktok River near the petroleum extraction zone, due to the roads built the herd was not able to reach their usual habitats and food supply thus leading to a reduction of female body fat and calf production. (Remon Pelinsky, 1986) The reduced nutrition of the females near the oil production areas reduced the amount of pregnancies one year after another.

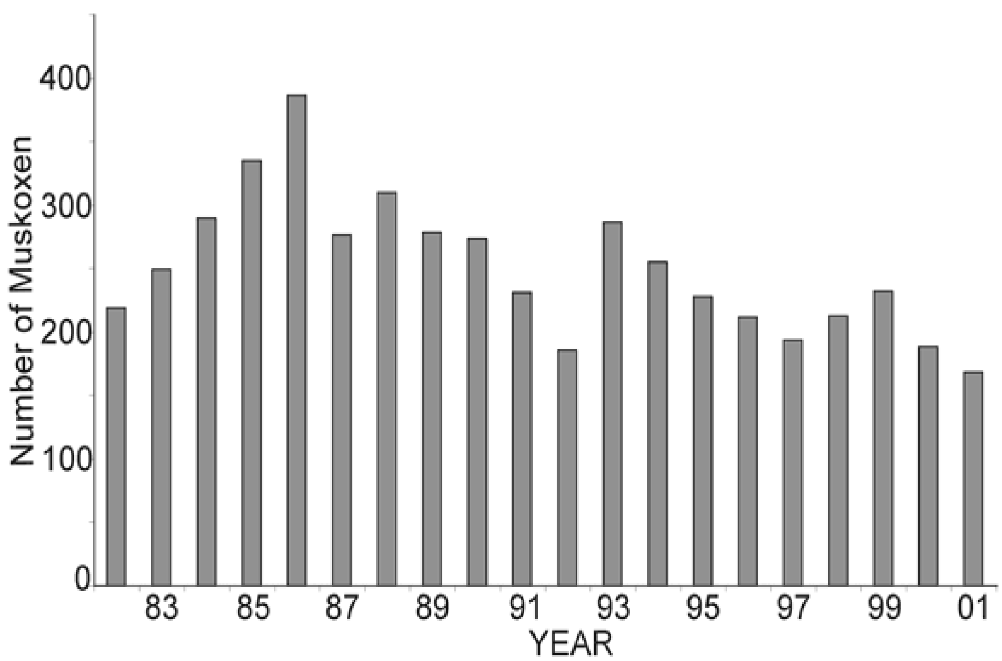
Sensitivities

Evidence from oil extraction in Prudhoe bay has demonstrated its drastic effects on the caribou's habitat. From the 1970s to 1980's the Central Arctic Caribou made use of the areas of the coastal plane near drilling sites (Remon Pelinsky, 1986) During the calving period, caribou showed increasing avoidance of areas near drilling sites and changed their migratory routes accordingly. Within the main industrial complex, the number of caribou severely decreased by an estimated 78% in Caribou use and 90% in migratory paths. These were only some of the effects Prudhoe Bay drilling had over the past few decades

Proposal: Like all the species in the 1002 region, calving and natural habitat will change. The Central Arctic Caribou's migratory paths and calving productivity will most likely decline as was the case near the Prudhoe bay's drilling sites. With the loss of their preferred habitat, sexually mature females will have less body fat and thus have lower reproduction rates. Exactly how much impact there will be depends on the methods of oil extraction and the amount of roads built and the location of those roads.

Muskoxen

Muskoxen (*Ovibos moschatus*) were driven to extinction before the 20th century. They were reintroduced in 1969 and their numbers reached a peak at almost 400 individuals in 1986. Since then, the muskoxen population has declined to around 200 individuals. Reasons for this population decline include emigration, increased predation by grizzly bears, and severe winters. Also, hunting by humans has increased since their reintroduction. (Patricia E. Reynolds, Kenneth J. Wilson, and David R. Klein, 2002)



Population dynamics of Muskoxen
Graph: http://www.absc.usgs.gov/1002/images/Fig07-01.gif.

Muskoxen conserve energy by limiting their movement; they tend to stick to a core area about 50 km^2 in the winter and 200 km^2 during the calving and summer seasons. Calving occurs from March to June, so it is especially important for mothers to build up enough reserves during the summer to last the winter and to feed the newborn. Thus, a prolonged winter would have significant negative impacts on calf survival.

Muskoxen depend on riparian cover along river corridors, floodplains, and foothills year-round. During the winter, it seeks out areas of soft shallow snow. Its winter diet consists mainly of low-quality forage such as sedges, grasses, mosses, and forbs. In the spring, it feeds on high quality flowering sedges. Muskoxen tend to be very loyal to a particular spot, returning there year after year. (Patricia E. Reynolds, Kenneth J. Wilson, and David R. Klein, 2002)

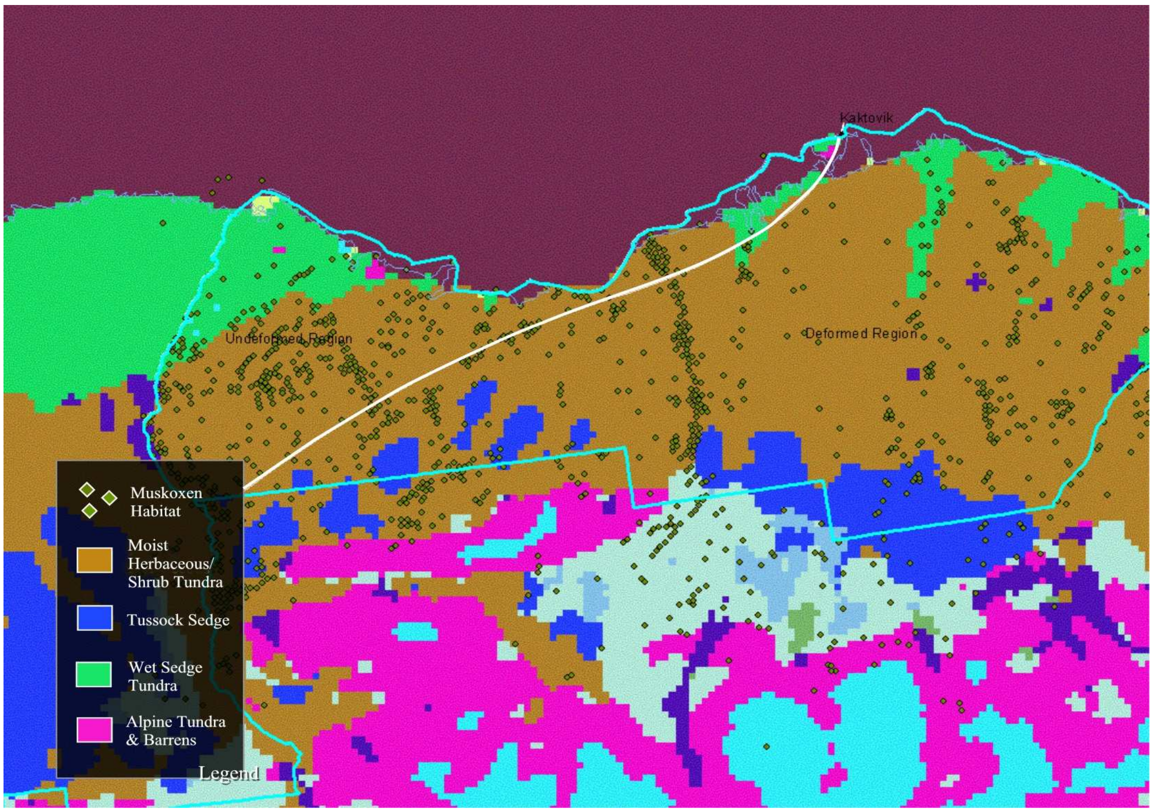
Muskoxen herd
(Photo: http://www.saskschools.ca/%7Egregory/arctic/Amuskox.html)

Any human activity should stay away from the muskoxen habitats, including adjacent uplands. The areas that muskoxen frequent are places often used for gravel and water extraction for roads and/or platforms. Muskoxen congregate into larger groups in the winter, and large groups of animals are more likely to be disturbed by human activity because they tend to have more sensitive individuals.

Muskoxen groups that have moved west tolerate the Trans-Alaskan pipeline and the Dalton highway, but it is due to the wider area of habitable land available to the animals.

Muskoxen remaining in the 1002 coastal plain are in a more geographically constricted habitat, with the Beaufort Sea to the north and the Brooks Range to the south. Eastern muskoxen populations are likely to suffer if human activities displace their territories and there are few alternative habitats available. (Patricia E. Reynolds, Kenneth J. Wilson, and David R. Klein, 2002)

Muskoxen habitats and vegetation in ANWR:

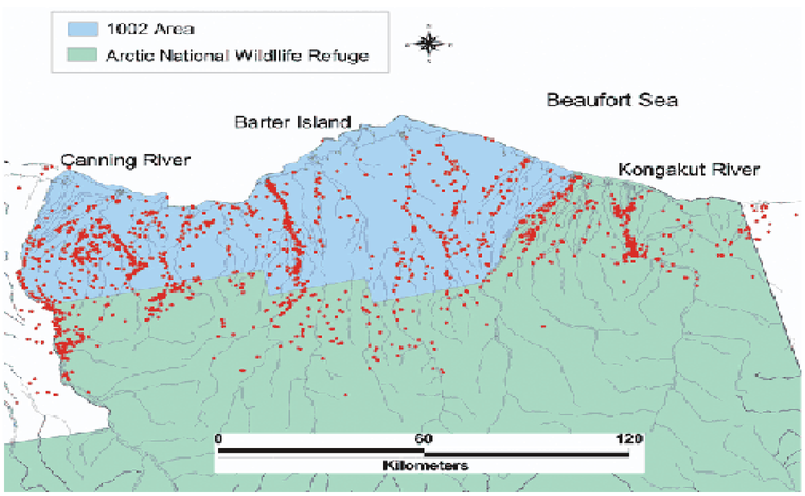


As muskoxen populations in the far west have coexisted peacefully with the Trans-Alaskan pipeline, a similar pipeline through the 1002 region should have little impact as well-- if it is built with the same environmental precautions. For example, the Trans-Alaskan pipeline has 579 animal crossings over its 800 mile span.

Helicopters and low-flying aircraft have been noted to cause some herds to stampede and abandon their calves. Some herds have been agitated by 3-D seismic exploration as far as three kilometers away; other herds seem unperturbed as close as 300 m. Generally, noise produced by traffic, etc will have a negative effect on the animals. (Patricia E. Reynolds, Kenneth J. Wilson, and David R. Klein, 2002)

Little data are available on the interaction between muskoxen and human settlement associated with oil development. This is because drilling platforms have been built in regions rarely visited by muskoxen. However, the nature of the muskoxen's normal food source is such that its scavenging among human waste is unlikely. The major concern is the gravel used for the platforms, which would have to be extracted from muskoxen habitats.

Locations of mixed-sex groups of muskoxen seen during winter and summer surveys in the Arctic National Wildlife Refuge, Alaska, USA, 1982-1999:



(Map: http://www.absc.usgs.gov/1002/images/Fig07-06.gif)

Wolves and Arctic Foxes

Wolves and Wolverines

Wolves primarily den in the foothills and mountains south of the coastal plain in the refuge. Wolverines are infrequently observed but travel in all types of arctic terrain, and females may use snowdrifts along small tundra streams for dens. During spring, wolves roam out to the coastal tundra where they prey on newborn caribou. Population declines or changes in distribution of wolves are results PREDICTED from the increased mortality, decreased prey, harassment, and disturbance in denning areas caused by oil development. The cumulative effects of displacement, avoidance, and reduced food resources could result in long-term changes in wolverine distribution. (2)

The following article is directly quoted from the official website of ANWR: http://www.r7.fws.gov/nwr/arctic/wolf.html

"Wolves have long been a lightning rod for controversy. They evoke passionate feelings in many of us. Some people love them, a few fear them, others prefer that they be shot. On the Arctic Refuge, however, these differences are seldom voiced. Why? The wolf is wild, beautiful, and inspiring. So is the Refuge. The two belong together. People know it and expect it.

Cousin to the dog, the gray wolf is a highly social animal, preferring to live in packs. The pack, dominated by a male/female pair, may include their pups of the year, wolves born the previous year, and other adults.

Gray wolves may be shades of gray, brown, black, or white. Wolves of all these colors roam the Refuge. Some five packs totalling 25 to 30 animals live on the Refuge's north slope east of the Canning River. The wolves are found primarily in the mountains and foothills along major rivers.

The makeup of wolf packs on the Refuge's north slope varies. In summer, many wolves hunt alone or in pairs. Some are "drifters." Others may switch packs or move to new areas, perhaps following the caribou migration. In winter the packs stay together more to hunt.

Gray wolves mate in late February and March. The pairs then move to maternity dens near rivers in the foothills and mountains. About four to seven pups are born in late May or early June. The pups are weaned during the summer, and the dens are abandoned in July or August. By early winter, the pups can travel and hunt with the adult wolves.

Although to date, no dens have been found on the Refuge coastal plain, wolves make frequent trips there from May to July when the Porcupine caribou herd is present. After the caribou leave the coastal plain, the wolves stay in the mountains and foothills hunting caribou, along with Dall sheep and moose. Wolves, however, are opportunistic feeders. They will catch small rodents, birds, and ground squirrels if they can.

Natural relationships between predator and prey still prevail on the Arctic Refuge. Here the wolf's connection to the caribou and the land continues as it has for centuries. Untamed and free, the wolf is a symbol for the Refuge - a truly remarkable place."

Arctic Foxes

From recent studies it has been seen that, "past and current industrial activities on the North Slope have probably increased the availability of shelter and food for the arctic fox" (1, pg. 117). Like bears, these animals too use oil fields for foraging on garbage, or resting. Foraging of these sites is more likely to occur in the winter when food is more scare than in the summer. It has been observed that "foxes do not avoid human activity" (1) raising their young in the proximity of traveled roads and operating drill rigs. Over the years it is remarked that, "the density and the rate of occupancy of dens and the sizes of litters are greater in oil fields than in adjacent areas" (1). These increasing fox numbers have a negative impact on bird population, which are extensively hunted by these. This can be especially "devastating to colonial birds" or to birds that migrate to the area (1). An increase number of roads, has also allowed foxes to access other bird populations that were before inaccessible to them. Thus, it has been seen that oil exploration in the Alaskan region increases fox population which has an adverse effect on other species, such as birds.

Lemmings and Voles

Lemmings and Voles tend to be more abundant and have less survival issues than muskoxen. In the winter they live in large underground burrows that may be as close as two inches from the permafrost. There are two species of lemmings in the area: the brown lemming (*Lemmus sibiricus*) and the collared lemming (*Dicrostonyx groenlandicus*). The brown lemming prefers wetter environments like damp meadows and river or lake shores, while the collared lemming prefers rockier places. Lemmings live on plants, roots, berries, and lichens, and stored seeds in the winter. (John Whitaker Jr.*, 1996)*

There are two species of voles in the 1002 area: the northern red-backed vole (*Clethrionomys rutilus*) and the singing vole (*Microtus miurus*) . The northern red-backed vole feeds on leaves, buds, and twigs. They are active all winter, making the most of their short lives: by the end of the summer, all those born before the last year have died. The signing vole is known for its alarm call, a high pitched trill. Singing voles are colonial, behaving much like prarie dogs. They feed on stored tubers during the long winter season. Burrows of singing voles are often raided by native peoples, who pilfer the stored tubers for their own use. (John Whitaker Jr.*, 1996)*

Because of their numbers lemmings and voles are not likely to be wiped out by human activity in the region. However, they are an important source of food for higher lever consumers, including polar bears, wolves, and foxes. Lemming cycles-- population booms and busts every four to five years-- for example, are closely tied to the population cycles of various predators. A sharp drop in their numbers could potentially cause a population decrease in many other, higher-level consumers. (John Whitaker Jr.*, 1996)*

<u>Singing Vole</u> (Microtus miurus)

The singing vole is so-named for its high-pitched trill, used to warn members of its social group. It is a food source for the common avian and mammal predators of the area. Singing voles dig burrows with ~1" diameter entrances that may be up to 3' long. This includes a large nest that may be up to 1' long, and a storage chamber for extra food. Burrows are typically only 2" from the surface, and are often raided by Native peoples for the stored tubers.
The singing vole eats lupines, arctic locoweed, horsetail, and sedge. Its range encompasses Alaska, Yukon, and the Northwest Territories. It breeds from May to September. Gestation is 21 days. The singing vole may have up to 3 litters/year, with 4-12 young/litter. (John Whitaker Jr., 1996)

<u>Northern Red-backed Vole</u> (Clethrionomys rutilus)

Northern Red-backed voles like to eat green herbacious plants and underground fungi. They store bulbs, stems, tuber, and nuts in their burrows. Burrow entrances are characterised by pieces of cut vegetation among boulders and logs. Its range encompasses Alaska and northwest Canada. It breeds from late May to early September. Gestation is 17-19 days. Females typically have 2 litters/year, with 4-9/litter. (John Whitaker Jr., 1996)

<u>Brown Lemming</u> (Lemmus sibiricus)

Brown lemmings live in surface nests made of woven balls of grass 6-8" wide. They also dig tunnels with chambers 6" diameter. Frequently will a tunnel or nest be abandoned and a new one created. Brown lemmings feed on grasses, sedges, and leafty plants during summer. During the winter months it relies on the bark and twigs of willow and birch. They have very small home ranges, about 3.5 - 6 sq yds. Lemmings mate typically from the spring to fall, though sometimes there is breeding throughout winter as well. There are typically 1-3 litters/yr, with 1-13/litter. Population fluctuates dramatically, peaking every 3-4 years due to winter breeding. Then, the lemmings become nervous and hyperactive, and are prey to the various predators of the area. Brown lemmings inhabit the wet tundra of Alaska, northern Canada, and northern British Columbia, including the ANWR region. (John Whitaker Jr., 1996)

<u>Collared Lemming</u> (Dicrostonyx groenlandicus)

Collared lemmings live in surface nests 6-8" wide among rocks and snowdrifts. They dig tunnel systems with resting chambers as deep as the permafrost line. During the summer, collared lemmings feed on grasses, sedges, bearberry, and cotton grass. They also feed on willow twigs and buds year-round. With a range that spans northern and western Alaska as well as northern Canada, collared lemmings are a major food source for arctic carnivores including Arctic foxes, wolves, wolverines, snowy owls, gulls, jaegers, etc. Collared lemmings breed from March to September. A femal has several litters a year, with ~7/litter. Gestation is 21 days. (John Whitaker Jr., 1996)

Impacts of Oil Exploration and Drilling

Lemmings and Voles tend to be more abundant and have less survival issues than muskoxen. In the winter they live in large underground burrows that may be as close as two inches from the permafrost. They subsist on willow twigs, sedges, and stored tubers during the long winter season. Burrows of voles are often raided by native peoples, who pilfer the stored tubers for their own use. (John Whitaker Jr., 1996)

Because of their numbers lemmings and voles are not likely to be wiped out by human activity in the region. However, they are an important source of food for higher lever consumers, including polar bears, wolves, and foxes. Lemming cycles, for example, are closely tied to the population cycles of various predators. A sharp drop in their numbers could potentially cause a population decrease in many other, higher-level consumers. (John Whitaker Jr., 1996)

Shrews

Overview ("Shrew," Microsoft® Encarta® Online Encyclopedia 2003)
-Shrews are small mouselike mammals, related to the mole, with a long, pointed snout and soft, gray-brown, velvety fur
nocturnal animals that feed primarily on insects and worms but also eat mice equal to their own size, as well as plants and occasionally fish and other aquatic animals.
-Many species have glands from which a fluid with a disagreeable odor is secreted, and some species have a poisonous saliva.
-Members of one subfamily of shrews hunt by means of echolocation, although this sense is relatively crude compared to its development in bats.

Common Characteristics ("Shrew," Microsoft® Encarta® Online Encyclopedia 2003)
-In the United States:
- most common are the long-tailed shrews
- slightly less than 7.5 cm (less than 3 in) long.
- ears are larger than in some other shrews, and the teeth are brown at the tip.
- five to seven young are produced in a litter each spring.
-short-tailed shrews.

- mole shrew, the most common shrew in the eastern United States,
- about 11.4 cm (about 4.5 in) long.

Aquatic Life

The major species found in Alaskan waters in the undeformed region of the 1002 area are the arctic grayling and Dolly Varden. They are both quite migratory and can be found both in Alaska streams as well as the coastal waters. They are important components of the aquatic food web, providing food to animals such as bears.

Other species are found in the coastal waters offshore, such as the bowhead whale, important culturally to the Inupiats, and ringed seals, an important food source to polar bears.

Bowhead Whale

Bowhead whales are large, robust whales that are more contoured than other whales: they have the largest head and mouth in the animal kingdom (around six feet); their upper jaws are arched forward and their blowholes are located at a peak of their crown. (Board on Environmental Studies and Toxicology (BEST), Polar Research Board (PRB), 2003)

Adult bowheads have smooth skin that is free of external parasites. Because they are black with differing amounts of white on their chins, bellies and tails, airborne researchers are able to identify individual bowheads by studying the white markings in addition to scars. At birth, bowhead whales are 14 feet long and weigh about 2000 pounds. Bowheads give birth every three to four years during spring migration. Calves grow to 26 feet during their first year, and then slow down to reach 40 feet in twenty years. Females reach sexual maturity at 41-6 feet in about 15 years. The largest recorded bowhead is about 60 feet and 120,000 pounds, and while it is unknown how old the whales are, it is estimate that they have a lifespan similar to that of humans. (Board on Environmental Studies and Toxicology (BEST), Polar Research Board (PRB), 2003)

Bowhead whales are very vocal and use underwater communication while traveling, feeding, and socializing. The most noticeable use of sound combined with playful behavior is while mating, in which the whales produce long repetitive songs and breach, tail slap and spy hop their potential mates. (Board on Environmental Studies and Toxicology (BEST), Polar Research Board (PRB), 2003)

Migration

The only bowhead whale stock that survives in significant numbers are the Bering Sea stock, and they follow a 3,600 mile migration yearly. They spend the winter in areas of open water within pack ice (polynyas) in the Bering Strait. During late March and April, bowhead moves north through the Bering strait, following cracks (leads) in the ice, sometimes breaking through ice of up to 2 feet with their hummocks to breath, and reaching Beaufort sea by mid-June. These bowhead spend the summer- from June until October- in the Beaufort Sea and swim south along the Russian coast to pass back at the Bering Strait in November. (Board on Environmental Studies and Toxicology (BEST), Polar Research Board (PRB), 2003)

Sensitivities

Sound

"The activities most likely to affect the bowhead are marine seismic exploration, exploratory drilling, ship and aircraft traffic, discharges into the water, dredging and island construction, and production drilling." (Board on Environmental Studies and Toxicology (BEST), Polar Research Board (PRB), 2003)

Marine seismic exploration produces the loudest industrial noise because most exploring is done during summer-autumn months open water period and the bowheads and seismic boats occupy the same water. Bowheads will not come into an area within 12 miles of an operating vessel, and avoid the vessels starting at 21 miles. Bowheads also avoid drilling noises; they avoided the 1992 Kuvlum oil drilling site by 19 miles. During the 1986 open-water drilling site at Hammerhead no whales were found within 6 miles of the site; the area of avoidance seem to extend between 15 to 25 miles. The sound frequency that the whales avoided are between 105-130 dB. (Board on Environmental Studies and Toxicology (BEST), Polar Research Board (PRB), 2003)

The excess noise created by the drilling is dangerous because it might lead whales to take paths they normally would not take, for instance, a path with thicker ice. When two or more types of disturbance occurred at the same time the effects are more pronounced than when there is only one source. (Board on Environmental Studies and Toxicology (BEST), Polar Research Board (PRB), 2003)

Oil Spill

Since oil spill can't be effectively cleaned up on ice, an oil spill is regarded as the largest potential threat to bowhead whales. The whales do not avoid oil contaminated waters because they cannot detect it, and inhaling oil vapor has toxic effects on the skin, eyes, baleen (food filter) and the lining of the gastrointestinal tract of bowhead whales. Although the skin of bowheads are generally smooth, they have roughed areas in which oil can adhere. In these roughened areas, bacteria with tissue-destructive enzymes can react with the oil to harm the whale. The eye is another area that oil can severely damage. The space between the eyeball and lid is large enough to allow a human hand to pass two thirds of the way around- this large surface allows for oil to touch sensitive eye structures. In a study of the baleen, oil stuck to the filaments and affected with filtering efficiency. The baleen filaments that normally break off during feeding and enter the stomach can combine with swallowed oil to form a sticky mass. This sticky mass can block passages between a bowhead whale's four stomach chambers.

Ringed Seal

Ringed seals are most common and widespread seals in the artic, spreading in the northern Bering, Chukchi, and Beaufort seas and staying on shore ice during the winter. They are the smallest of all pinnipeds, rarely exceeding five feet and hundred fifty pounds. (Board on Environmental Studies and Toxicology (BEST), Polar Research Board (PRB), 2003)

Critical Time:

"Females give birth to single, white-coated pup in snow dens on either land or drifting ice during March and April." The mother nurse the pups in the dens for about two months; these dens are used for protection against severe weather and from predators. (Board on Environmental Studies and Toxicology (BEST), Polar Research Board (PRB), 2003)

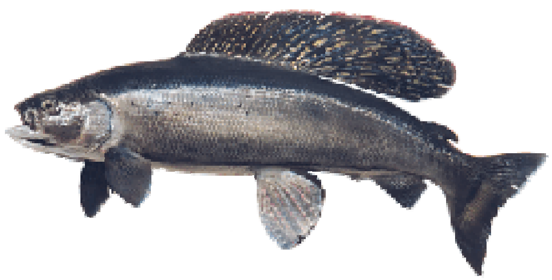
Sensitivities

Noise:
Pinnipeds react to noise from aircraft and ocean vessels. Mothers and pups are less likely to stay in their natural dens if there is noise. Although there is no broad scale difference noticed by aerial studies in regards to ringed seal distance from industrialization, it was noted that the seals were less frequently sighted around areas with industrial noise. (Board on Environmental Studies and Toxicology (BEST), Polar Research Board (PRB), 2003) Ringed seals are more likely to abandon their breathing holes if the holes are close to seismic survey lines, lines likely to have noise due to exploration.

Oil:
Drastic consequences occur when putting mammals in oil. In an experiment, three seals were placed with a pool filled with oil. After 24 hours, the blood and tissues of the seals showed "hydrocarbons that had been incorporated through inhalation," (Board on Environmental Studies and Toxicology (BEST), Polar Research Board (PRB), 2003) resulting in liver and kidney damage. However, there has been no evidence of such effects of industrial oil on seals.

Fish

Artic Grayling



(Photo: http://www.r7.fws.gov/nwr/arctic/fish.html)

General Information
The artic grayling is one of the most abundant freshwater fish in the oil field region, and is found on all the major river systems. (Inaru River, Meade River, Topagoruk River, Chipp River, Ikpikpuk River, Colville River, Kuparuk River, Sagavanirktok River, Shaviovik River, Canning River.)
"Grayling can be highly migratory, using different streams for spawning, juvenile rearing, summer feeding, and over winter survival. Or, in other areas, they can complete their entire life without leaving a short section of stream or lake. Their tolerance of low dissolved oxygen levels allows grayling to survive the long winters in areas where many other salmons would die. With the coming of spring, grayling begin an upstream migration to spawning grounds. Like salmon, grayling faithfully return every year to the same spawning and feeding areas. Grayling spawn for the first time at an age of 4 or 5 years and a length of about 11 to 12 inches.
About one month after spring breakup, adult grayling begin their post-spawning migration to summer feeding areas. Depending on where they have spawned, the distance traveled can be up to 100 miles. By the middle of summer, grayling will segregate within a stream according to age and maturity. The older adults will be found in the upper reaches of river and stream systems, the sub-adults in the middle, and the juveniles in the lower ends. Grayling fry hatch about three weeks after spawning, and they tend to occupy the quieter waters near where they were spawned. In the early fall, grayling again begin a leisurely downstream migration to reach over wintering areas." (Rocky Holmes, 1994)

Critical Time Periods
During the summer the grayling use the glacial rivers as summer migration corridors and feast on hug numbers of drifting insects; they need this energy to survive the frozen and foodless months of winter.
During the winter streams are largely emptied of the artic grayling, and in fact of most fish. The lack of circulating oxygen in the frozen over streams makes it difficult for the fishes to breathe. The best time to build anything would be during winter.

Sensitivities/Proposal
"The distribution of artic grayling has expanded because of habitat alterations in the oil field region. Large deep gravel pits excavated to meet the needs for oil field construction material have filled with water after abandonment and formed large artificial lakes that provide abundant wintering habitat.
The populations of arctic grayling were reduced in the surrounding streams when pipelines and oil fields were first developed in Alaska. The culverts in the roads were of the wrong size, blocking upstream spawning migrations; this problem can be prevented by using smaller culverts and designing culverts based on grayling swimming performance." (Rocky Holmes, 1994)

Dolly Varden

(Photo: http://www.r7.fws.gov/nwr/arctic/fish.html)

General Information

"Two basic forms of Dolly Varden occur in Alaska waters and both are common in all local coastal waters. The southern form ranges from lower Southeast Alaska to the tip of the Aleutian Chain, and the northern form is distributed on the north slope drainages of the Aleutian Range northward along Alaska's coast to the Canada border. Anadromous and freshwater resident varieties of both forms exist with lake, river, and dwarf populations being found among the freshwater residents.

Young Dolly Vardens rear in streams before beginning their first migration to sea. During this rearing period, their growth is slow, a fact which may be attributed to their somewhat inactive habits. Young Dolly Varden often remain on the bottom, hidden from view under stones and logs, or in undercut areas along the stream bank, and appear to select most of their food from the stream bottom.

Most Dolly Varden migrate to sea in their third or fourth year, but some wait as long as their sixth year. At this time, they are about 5 inches long and are called smolt. This migration usually occurs in May or June, although significant but smaller numbers have been recorded migrating to sea in September and October. Once at sea, they begin a fascinating pattern of migration. After their first seaward migration, Dolly Varden usually spend the rest of their lives wintering in and migrating to and from fresh water. Southern form Dolly Varden over winter in lakes, while most northern Dolly Varden over winter in rivers. Those hatched and reared in a lake system carry on annual feeding migrations to sea, returning to a lake or river each year for the winter. However, southern Dolly Varden originating from nonlake systems must seek a lake in which to winter. Recent research indicates that they find lakes by random searching, migrating from one stream system to another until they find one with a lake. Once a lake is found, these fish may also conduct annual seaward migration in the spring, sometimes entering other stream systems in their search for food.

At maturity, Dolly Varden return to spawn in the stream from which they originated. The fish possesses the ability to find their "home" stream without randomly searching, as was the case in their original search for a wintering area. Those of the southern form that survive the rigors of spawning return to the lake shortly thereafter, while northern form Dolly Varden usually overwinter in the river system in which they have spawned." (Dennis Hubartt, 1994)

Critical Time Periods/ Sensitivities

"Dolly Varden spawn in streams, usually during the fall from mid-August to November. The female, depending on her size, may deposit from 600 to 6,000 eggs (2,500 to 10,000 in the northern form) in depressions, or redds, which she constructs in the streambed gravel by digging with her tail fin. The male usually takes no part in these nest building activities and spends most of his time fighting and chasing other males. When the female is ready to deposit her eggs, the male moves to her side and spawning begins. Sperm and eggs are released simultaneously into the redd.
The eggs develop slowly in the cold water temperatures usually present during the incubation period. Hatching of the eggs may occur in March, four to five months after fertilization. After hatching, the young Dolly Varden obtain food from their yolk sac and usually do not emerge from the gravel until this food source is used. Emergence usually occurs in April or May for the southern form and in June for the northern form." (Dennis Hubartt, 1994)

Avian Species

Every year, thousands of avian species migrate to the Coastal Plain of ANWR. There they find a prime, pristine arctic breeding ground that exists as an abundant source of nutrition and nesting territory. Many of the birds that travel up to thousands of kilometers to this land are threatened or endangered species. Five species that fall into this category are the tundra swan, buff-breasted sandpiper, pigeon guillemot, sea duck, and snow goose.

Collectively, the critical time periods for courtship, breeding, and fledgling maturation or molting in the case of the sea duck occur between the months of April and November. Therefore, it is repeatedly suggested that human disturbances be limited throughout those months. The main disturbances to be concerned about are those caused by oil-drilling development such as exploration, extraction, and transportation tactics.

It has been reported by several sources that many species, especially the tundra swan and snow geese populations, are significantly affected by noise pollution. In fact, tundra swans are so sensitive that they will abandon nests, and snow geese will often not return to areas where noise repeatedly disrupts the environment. Other species such as the sea duck are more vulnerable to seismic activity that is employed for the purpose of exploration. In addition, although oil spills are becoming less common and smaller in volume as technology improves, they continue to pose a major threat to the birds that inhabit the 1002 area every summer.

Tundra Swan

General Information

Twice a year, Tundra Swans migrate 6,000 km between breeding areas in Alaska and The Canadian Arctic and wintering areas in eastern and western North America. Approximately 150 pairs of tundra swans nest on the coastal plain. Tundra swans feed on the following plants: foxtail and other grasses, wild celery, pondweeds, smartweeds, square-stem spike rush , arrowhead, coontail, mermaid weed, muskgrasses, bulrushes, horsetail, wigeon grass, and bur reed. Rice and barley are eaten in stubble fields. Tundra swans also feed on waste corn in both dry and flooded fields and upon harvested potatoes. These swans commonly fly as far as 10 to 15 miles (16-24 km) inland to glean waste corn and soybeans and to browse upon shoots of winter wheat. Animals that prey on tundra swans include: Golden Eagles, jaegers, wolves, foxes, and bears.

Critical Time Periods

Tundra swans start nesting between May and late June, depending on location and weather. During fall migration, tundra swans leave their major breeding grounds in the 1002 area in late September and early October. For their spring migration, tundra swans leave their central California winter grounds in mid-February, and most of the birds have departed within 3 weeks. By early April almost all of them have migrated north to Alaska and Canada.

Sensitivities

Scientists believe that new Tundra swan pairs are less likely to establish themselves on lakes where humans reside. They are extremely sensitive to noise pollution and as a result, inadvertent disturbance can cause adult swans to abandon their nests and cygnets.

Snow Geese

General Information

This species migrates to the 1002 region of ANWR every year for two to four weeks before continuing on a 1300 mile journey to Northern Alberta. Their time spent on the North Slope is critical to their survival since they need to store nutrients for their long migration path. As many as 500,000 species migrate to the region each year. These birds are herbivores, feeding on cotton grass. A major predator is the arctic snow fox.

Critical Time Periods

Lesser snow geese migrate to the 1002 region late August to mid-September

Sensitivities

Studies have been done that display the birds; sensitivity to noise pollution. They are easily disturbed by noise-producing activities, which could present a major problem for oil drilling. Repeated disruptions cause the birds to not return to the same area, which can significantly reduce the amount of food available to them. This affects their survival rate since their flight to their next stop is so intensive and they need to store up on energy.

Sea Ducks

General Information

Sea ducks visit the 1002 region for 2 to 4 weeks every year. While they do not breed here, they use the area for molting purposes. Anywhere from 10,000 to 30,000 birds visit the region each year. Predators include the arctic fox and glaucous gulls.

Critical Time Periods

Sea ducks visit the 1002 region from mid-July to mid-September.

Sensitivities

There has been a decline in the number of sea ducks and other marine birds in the area, which raises concern about the impact that oil drilling will have on them, especially if there is a spill. Sea ducks are especially vulnerable during their stay on the North Slope because the time they spend there is for molting. This leaves them unable to fly for 3-4 weeks. Molting also requires a large amount of protein to grow new feathers. Oil drilling could potentially disrupt the ducks' foraging capabilities, depriving them of much needed nutrients. However, one study showed that the ducks' foraging patterns are not significantly altered by minor disturbances, which perhaps suggests that oil drilling will not have a large impact on them. Another study that was performed showed that seismic activity does disturb ducks. Their results show a decline in population in a certain area where seismic activity starts, although underwater seismic activity had no effect on them.

Buff Breasted Sandpiper

General Information

Although not a common species, buff-breasted sandpipers have been occasionally found in groups of 500-2200 in migration and on their wintering grounds. Their populations suffered tremendously from the settling of the Great Plains of North America and the Pampas of South America.

Critical Time Periods

The Buff-Breasted sandpipers arrive in their Alaskan breeding grounds in mid April and vacate their breeding grounds in mid-July.

Sensitivities

The future of this species is quite threatened. By viewing the population density map below, one can see that the 1002 area is crucial to the survival of this species.

Pigeon Guillemot

General Information

This species resides in rocky coastal areas, with shallow inshore waters as its feeding grounds. Nest cavities are found amongst holes and rock crevices on the West, North, East, and South sides of Great Race Rocks. Some habitat for nesting was created years ago when blasting for the helicopter pad produced rubble that they could tunnel under. Some predators include: Seagulls, Bald eagles and river otters. The Pigeon Guillemot's diet consist of Gunnels, pricklebacks, ronquils, sculpins, flatfish, rockfish, small crustacea, squid, sand lance, smelt, juveniles of cod, herring, pollock, and salmon. Due to their rather low population, great efforts are being taken to keep predators away from the Pigeon Guillemot—primarily foxes, which are their major natural predators.

Critical Time Periods

Pigeon Guillemots begin to return to their breeding grounds in April. In May, most of the birds are present at their colonies and courtship begins. Eggs are generally laid between May and June, while fledging occurs between July and August, taking anywhere from 55 to 100 days.

Sensitivities

While research has not shown this species to have many sensitivities, one very prominent sensitivity is that to oil. Because guillemots feed in shallow, nearshore waters, guillemots and the fish and invertebrates on which they prey are vulnerable to oil pollution. As a result, an estimated 10-15 percent of the spill area population may immediately following the spill, according to information from past spills.

Plant Life

The vegetation of ANWR is characterized as tundra, which literally means barren land. Yet, contradictory to its name, there is much diversity in the types of plants growing in ANWR. The tundra plants are usually less than 1 foot high. Tall plants are restricted to the southern slopes of ANWR. The tundra plants belong to five main groups, namely, 1) lichens, 2) mosses, 3) grasses and grass-like herbs including many sedges and willows, 4) cushion plants and 5) dwarf shrubs. (Patrick D. Baird, 1964) Among them, the first three types are particularly important in providing the herbivores with nutrition and calving ground, nutrient cycle, maintainence of permafrost and a lot more essential functions in the arctic ecosystem. Sedges, willows, mosses and lichens would be discussed in greater details.

Arctic vegetation

Introduction
The type of vegetation in Arctic National Wildlife Refuge (ANWR) is mainly characterized as "tundra", meaning barren land. Contradictory to its literal name, vegetation on the arctic tundra is highly diverse. The types of vegetation found depends on numerous factors such as the terrain, local climate, permafrost and active layer depths, precipitation and water availability and drainage, nutrient availability and cycling. The shrub tundras are dominated by deciduous vascular plants. Slightly warmer soil temperatures, deeper thaw, and more rapid nitrogen mineralization associated with the high water flow rate in water track and river bar localities cause denser canopies and higher total foliar nitrogen.
The differences in canopy structure between the graminoid-dominated wetland tundras and the mixed tussock tundra communities are probably related to drainage characteristics and their effects on nutrient availability. The highly heterogeneous nature of the heath sites is probably determined by their different degrees of exposure on ridge and hill tops. Microtopography affects the growth and structure of heath, with sheltered hollows causing denser vegetation and ridge tops causing sparse canopies. (Shaver et al., 1996) . The arctic coastal tundra consists of thaw lakes and wetlands near the Beaufort

Sea coast and along river deltas. The foothills tundra, a transition between this and the Brooks Range, is dominated by sedge tussock (Eriophorum vaginatum), which provides the lush, new growth needed to feed caribou calves and energize staging snow geese. Riparian areas have willow shrubs that are important nesting habitat for migratory birds. (World Wide Fund for Nature, 2000)

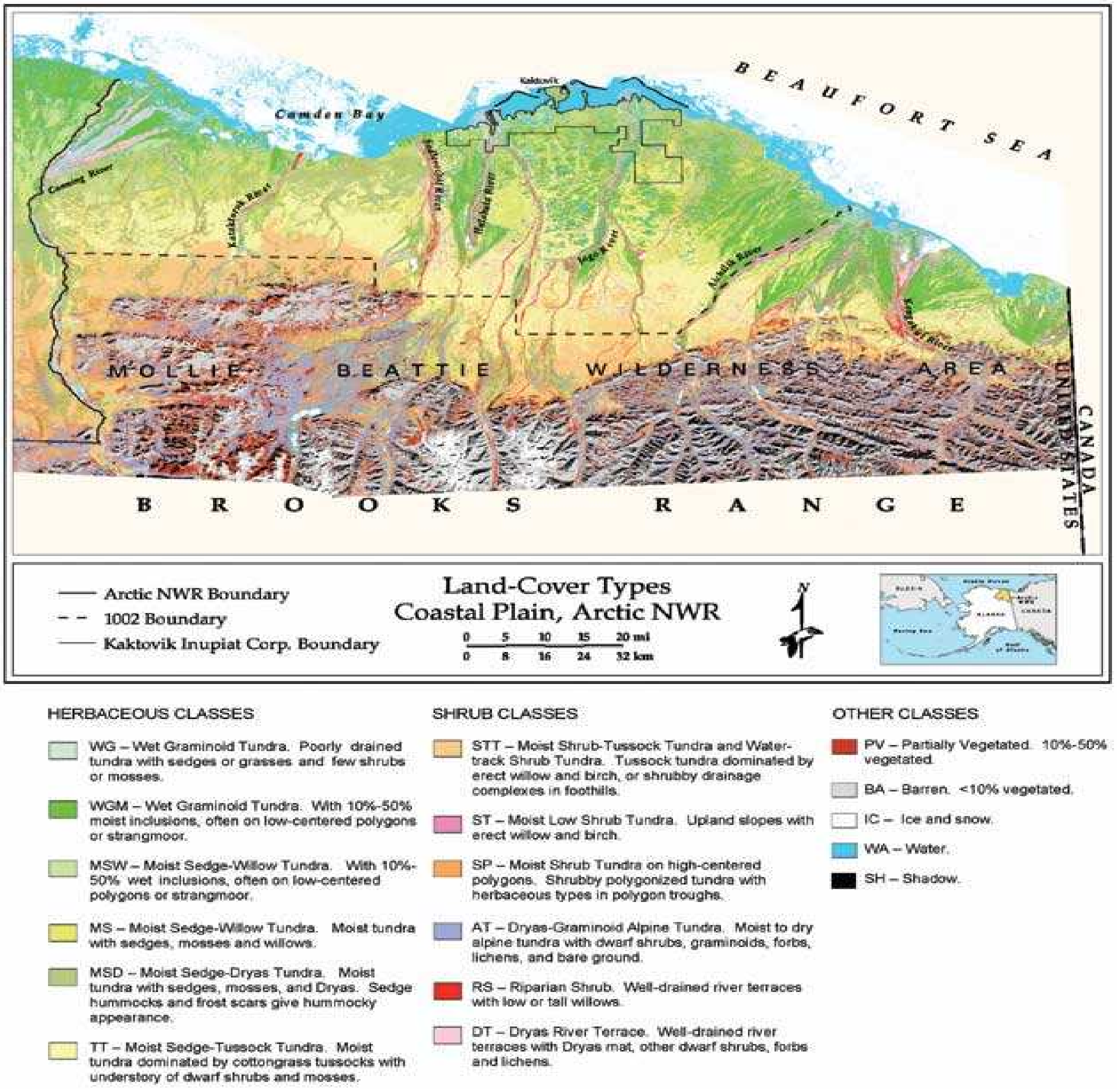
The tundra plants are usually less than 1 foot high. Tall plants are restricted to the southern slopes of ANWR. The tundra plants belong to five main groups:

1. Lichens, either on rocks or in mats on the ground
2. Bryophytes (commonly known as mosses)
3. Grasses and grass-like herbs, including mainly sedges and willows
4. Cushion plants
5. Dwarf shrubs

(Patrick D. Baird, 1964; Janet C. Jorgenson, Peter C. Joria, and David C. Douglas, 2002)
In ANWR, the following four types of plants are particularly important:

1. Sedges, especially tussock cottongrass
2. Willows, especially diamond-leaf willows
3. Mosses, especially Sphagnum spp.
4. Lichens, of various types

The first two is highly nutritious for herbivores to feed on as a food source, particularly during the growing seasons, while the latter two help maintain the ecosystems in other ways and provide food during winter.



Map showing vegetation pattern of ANWR
(Map: http://www.absc.usgs.gov/1002/section2.htm)Reference:

Decomposers

Decomposers are basically microorganisms that feed on dead organic matters. They range from bacteria to fungi. They secrete enzymes to break down large organic matter such as starch, protein, fats and other materials that are present in living organisms. Because of their decomposition function, they are very important in the arctic ecosystem as they play a vital role in nutrient cycles.

The cycling of materials such as carbon, water, and other nutrients is mainly dependent upon soil-dwelling decomposer organisms such as bacteria fungi, earthworms, and insects. Bacteria and fungi are the most abundant of the microbial decomposers, numbering in the billions in only one handful of soil!

As essential components of the environment, fungal and bacterial microbes break down dead and discarded organic materials, supplying a continuous source of nutrients for the plants in surrounding soil. In general, decomposers break down the proteins, starches, and other complex organic molecules that were all once the components of living organisms, and “as products of their own metabolism, [they] convert elements such as nitrogen, phosphorous, calcium, and sulfur into forms that can be utilized by plants” (Dirty, 2). According to several researchers at the University of Jyväskylä, "Reduction in the species diversity of the lowest levels (decomposer fungi) of the food web [become] particularly well manifested as reduced decomposition rate and stagnated nutrient dynamics." They also emphasized that certain variations of microorganisms can play a critical role in controlling nitrogen cycles and plant growth in general.

In addition, it is true that decomposer species tend to be rather resistent to changes in the availablitiy of organic material or changes to the environment in general, but they are still affected by several key factors. For instance, increases in temperature will cause more rapid decomposition reactions--just as would occur for most chemical reactions. However, too high of an increase in temperature affects the microbes adversely. Moisture is also usually favorable unless there is so much moisture that the living environment is waterlogged. When waterlogging occurs, some microbes will die while others thrive on the excess moisture. On the other hand, light tends to be bad for most decomposer microbes.

Concerning the issue of oil drilling on the North Slope of ANWR, one would expect an increase in the amount of organic as well as inorganic waste material in the local environment. This is important, because although fungi and microorganisms thrive off of organic materials such as animal flesh, fecies, dead plant matter, nut shells, etc., it is much harder and time consuming for them to decompose human-made materials that are either high in cellulose--i.e. cotton and paper-cardboard--or metallic or plastic. In fact, metals and plastics are almost impossible to decompose by the microorganisms and fungi--they break down primarily, and over a long period of time, due to weathering processes. Currently advances are being made in the development of biodegradable plastics, but there remains the majority of non-biodegradable plastics. Furthermore, if the diversity of decomposer species decreases in ANWR due to changes in their environment--whether the changes are related to climate, the introduction of oil drilling, or increases/decreases in populations of consumers--it can be assumed that all species that depend upon the decomposers are either directly or indirectly affected by such a flux.

Species:

Although it is true that "no one has yet detailed all the species of fungi that live in Alaska" and "several thousand species of fungi exist, but scientists have only described about 50,000," much can be said about the characteristics and effectiveness of these incredible decomposers. (http://www.gi.alaska.edu/ScienceForum/ASF15/1562.html)

According to the book Ecology of Arctic Environments, research has shown that frost free days and varying levels of nitrogen in soil are not greatly important to the survival of fungi, while temperature, moisture and pH are. In addition, it appears that the cold of the arctic may "have a selective effect" on certain species such as Chrysosporium pannorum. As for arctic fungal species in general, several studies have illustrated that "fungal h yphal length increased with increasing soil moisture and temperature, and decreasing soil pH" (Woodin and Marquiss).

Unfortunately for our purposes, the fungal species lists and biomass values that are available are almost all composed from the research efforts of the Tundra Biome group of the IBP, and are therefore from the long ago period of 1964-1974. Species known to have been studied by the Tundra Biome group include Eriophorum and Carex (Woodin and Marquiss).

General Characteristics:

Suffice to say, "fungi, the subjects in this kingdom, live in the woods, in refrigerators, on rocks, and between our toes. Without them, the natural world would cease to function."

Fungi are part of a very interesting kingdom. In fact, it is so diverse and complex that they are the only species that make up the kingdom. To function on a regular basis, fungi digest their food through the use of extracellular fluids. In other words, digestion occurs outside of their bodies. The extracellular fluids that they excrete are acids and enzymes that act to break down organic material. They then absorb the simple molecules of food through their cell walls, because they do not have stomachs.

Furthermore, many fungal species exist in symbiotic relationships with vegetation such as trees. An example of such a relationship occurs when fungi beneath the soil cling on to tree roots, resulting in roots that are coated with hairy fungi called mycorrhizae. The fungi help trees and other plants absorb minerals (http://www.gi.alaska.edu/ScienceForum/ASF15/1562.html).

Furthermore, "decomposer microorganisms require a balance of carbon and nitrogen that requires a far greater turnover of nitrogen accompanying carbon dioxide production…in order to simultaneously meet energetic and nutritional needs" (Reynolds et. al, 311). Plants even compete both with each other and with soil microbiota for the nitrogen and nutrients released through decomposition. Therefore, when the availability of nitrogen is lower, it is harder for a variety of plants to survive.

Investigations on decomposition in the arctic have been conducted primarily by Flanagan and Scarborough as part of the Tundra Biome project that occurred from 1964-74. They stated that the best soil pH for cellulose decomposition by about 60% of Alaskan strains was between 4.5 and 5 (acidic), while a slightly more basic pH of 6 was best for the decomposition of pectin and starches (Woodin and Marquiss).

It is observed that the "fungal species composition in arctic environments is very similar to those in temperate latitudes, although the isolates are often adapted to low temperatures" (Woodin and Marquiss). Nevertheless, in the extreme soils that are more characteristic of the North Slope (aka the 1002 region—that which is in debate for oil drilling), fungal biomass is clearly seasonal and may overall be lower than that which is found in temperate ecosystems.

At the University of Alaska Fairbanks, the Institute of Arctic Biology scientists are attempting to determine the "characteristics of tundra and forest fungi that allow them to live in cold soils and to release nitrogen and phosphorus as they decompose organic remains." The resistance of fungi to oil spills or other environmental disturbances must be investigated and known, for "if the stability of the fungi is undermined, an entire forest or tundra grazing land can be destroyed.

Although the relationships between nutrient mineralization, microbial immobilization, and plant uptake still need to be better documented and understood, enough is known about Alaska's tundra to understand conditions that affect the resident decomposer species (Reynolds, et. al).
Basically, low temperatures, the existence of permafrost, low nutrient input and frequent waterlogged conditions result in a reduced rate of organic matter turnover and cycling of organically bound nutrients. In addition, the accumulation of dead organic matter enhances these conditions which inhibit decomposition. Meanwhile, soil temperature and water regimes also affect anaerobic respiration by decomposers in the tundra soil. Normally, warmer temperatures will increase respiration rates and increased levels of moisture will as well, but if an environment is overly saturated, decomposer activity is inhibited. In such saturated sites, there are larger accumulations of organic matter due to the limit on decay and peat tends to form. For example, the Imnavait Creek watershed in northern AK normally has a layer of organic matter overlying mineral soil that ranges from 10-40 cm in thickness, due to its rather low rate of decay (Reynolds et. al).

Ice microbial communities, although for the most part poorly understood, are challenged physiologically and ecologically by meltwater fluxes. Basically, in the summer low-salinity meltwater promotes the flushing of a substantial fraction of the sea-ice microbial habitat. Due to steadily increasing temperatures in the arctic, such freshwater immersion may be increasing in duration and extent as precipitation and snow melt amounts increase (http://siempre.arcus.org/4DACTION/wi_pos_displayAbstract/6/440).

A pleasant reflection from a woman who once visited the arctic:

"I was in for a surprise when we looked at the bottom of the ice core sample. I grew up in Michigan and spent my winters boring fishing holes into Lake Huron, so I was familiar with freshwater ice. But unlike that ice, the bottom surface of sea ice is not smooth. It has a very rough surface and is distinctly greenish-brown in color. The color is caused by a large increase in biological material --mostly algae such as diatoms .

The color also comes from dissolved organic material that supports the growth of bacteria. There is a surprisingly high diversity of viruses and fungi as well. Crustaceans feed on the several hundred different species of algae that live in this bottom-most layer of ice, and fish feed on the crustaceans. It's a complex food web. Yet standing here on the icy surface, you'd never know this ecosystem was there. You have to penetrate down through the ice to have any chance of discovering it (http://www.astrobio.net/news/print.php?sid=467)."

Plant growth can be limited by a lack of organic compounds in the soil, an effect that occurs because decomposing matter takes longer as it becomes integrated into the soil. Due to the even slower function of decomposition in cool climates, soil is slow to recover from any disturbances caused by the force of erosion, animals, or humans.

Even so, the freezing and thawing that takes place over the course of a year in the arctic actually speeds the access for bacteria and fungi to the insides of cells of dead plants and animals. This can happen because when a cell freezes, the water in its tissue expands, therefore breaking cell walls and making it possible for materials to diffuse in and out of the cells once the tissue thaws. Despite this activity, the extreme cold of the arctic has the net effect of slowing decomposition (http://www.blm.gov/education/00_resources/articles/alaskas_cold_desert/classroom.html).

Ocean currents and the proximity to land are both factors upon which nutrient distribution in water depends. The weathering of rocks on land causes many of these nutrients to be carried into the ocean by rivers, which is why many of the most nutrient rich oceanic areas are near river mouths. In addition, the decay of plant and animal material by bacterial processes recycles the nutrients. Therefore, the areas on the Coastal Plain at 1002 where the rivers empty into the ocean are highly concentrated with nutrients and in turn attractive habitat for birds and other wildlife to find nutrition (oceanexplorer.noaa.gov/explorations/ 02arctic/welcome.html).

Basic Population Dynamics:

It has been found that populations of soil bacteria in tundra areas are very close to the same as those found in other regions “and no types unique to tundra regions have been recognized” (Woodin and Marquiss). However, estimates of bacterial biomass are greatly influenced by the unreliability of plate and direct microscopic counts as well as the difficulty in figuring out “whether the cells are alive, dead, or in a non-culturable but viable state” (Woodin and Marquiss). Efforts to make direct counts of bacterial biomass have demonstrated that biomass increases with decreasing latitude, as is evidenced by the counts made from oven-dried soil which range from $2.26\ \mu g\ g^{-1}$ at Stordalen to 8600 in a horizon at Moor House (Woodin and Marquiss).

According to information compiled by Reynolds etc. al, “current levels of soil moisture appear close to optimum for decomposition…any net changes in soil moisture may decrease carbon mineralization.” They also reported on recent simulations performed under various climate change scenarios. The simulations suggest that there is a “large potential variability compared to current carbon and nitrogen dynamics, depending on the rates and directions of changes in soil moisture and temperature regimes.”

Drilling

Exploration Technology

Seismic Exploration

Background
Seismic exploration uses vibrations such as sound waves and shock waves in order to map the different layers of the ground, thus enabling the operator to predict the earth's density at varying depths. It is able to map the subsurface and to show in a 2-D, 3-D or even 4-D maps the explored region thus suggesting the locations of the oil or gas "traps" for drilling purposes.
Seismic surveying uses tools such explosives or vibroseis trucks in order to explore on land, or a tool called the airgun in order to explore offshore (ocean floor).
Here is the explanation of seismic surveying by Utah BLM Stone Cabin:
"Seismic survey methodologies are tools for analysis of geologic formations and features in the subsurface. The process consists of using a source of energy that is directed into the subsurface and then recorded back at the surface (with geophones) as the energy waves travel through the subsurface and reflect back to the surface. Various types of rock reflect the energy waves differently, and these differences are measured. Data helps show the tops and bottoms of formations, thickness, and structural configurations. It cannot

identify pools of oil and gas, but rather, conditions favorable for the possible accumulation of oil and gas."
This can be found at the link:
http://www.ut.blm.gov/stonecabin/Q&As.htm
Geophone by Gisco (http://www.giscogeo.com/)

Explosives
Seismic geophones are able to collect their data from many sources that generate shock waves. Explosives method is one of those sources. By drilling small holes into the ground, approx. 12 meters deep, and packing them with 10 pounds of capped explosives (directed towards the center of earth), followed by detonation of those explosives, the geophones will be able to get sufficient data to map the are underneath the receivers. The grid lines of the explosives vary because of the different ground composure. Computer based software is often used to calculate the distance needed between the location of such explosive holes. Based on the study assembled by USGS, the grid of the explosives used in the seismic surveying that was done in ANWR 1002, was about 300 feet between the charges. Geophones were positioned in groups of 24 geophones per group while the interval between the groups was about 100-160 feet. In overall there were 120 groups in use. Due to the breaking of the ice immediately after detonation of the charges, the geologists encountered many problems, such as picking up wrong vibration data (vibration caused by the breaking and not by the blast) such secondary data affected the precision of the survey.

"Thumper" trucks, Vibroseis
30,000 pounds trucks generate vibrations underneath the ground by elevating themselves above the ground on a short pole, thus concentrating their entire weight on a platter and "shaking" for several second per location, thus sending vibrations through the ground. The rest of the process is very similar to the explosive process because all that is left is the data gathering phase. This process is the most precise process as it uses controlled vibrations that are spread over period of time, as oppose to the explosion vibration that is just a giant burst of energy. Those trucks are able to operate even inside major cities because the vibration they are causing is negligible due to the spread of vibration over a period of time.

Airgun
Airgun is an excellent example of an offshore method. This exploration technique is used with assistance from a ship that actually carries all the equipment necessary to both send signal and to analyze. Such ship will carry an airgun and many receivers at greater distance that actually read the sound data as it is reflected from different rock formations and layers beneath the ocean floor. Then, just as the land surveys, the data is being processed by a computer which is later on able to generate a detailed map of several layers underneath the sea bottom.

Data Processing
The data is being received by geophones, which are relatively small devices placed on the ground. Those devices are synchronized with computer and placed on the ground using DGPS equipment (more precise than GPS, 2 meters to 30cm precision). This way the computer that analyzes the data has all the variables, the time of the vibrations, the relative distances at which the reflections are measured, and the strength (wavelength) of the vibrations. Different rocks and layers give different reflections of vibration, different changes in frequencies in the wavelength of the vibration. Using this data, gathered from the sensors, the main computer unit is able to constructed a detailed map, thus enabling it's user to analyze the map for possible oil location. It is worth mentioning that the computer is in most cases a dedicated super computer and not just a regular PC/MAC. The computer is able to generate a 3-D map of the subsurface, enabling future analysis of the region by experts and recommending a possible drill site. Another capability is a generation of 4-D map, which is a relatively new concept. Basically 4-D is a 3-D map repeated over time period. This way you can also see any changes in the ground versus time. For example shift of layers or flow of material in reservoirs.

The truck on the left is the vibroseis truck sending vibrations as waves into the ground which are reflected of the different layer, recorder by geophones and transmitted to the data recording truck

Non-Seismic Exploration Techniques:

Electrical Resistivity:
Overview: This process involves placing probes in the ground and passing a current between them. By measuring the resistance of this current you are able to tell within a degree of certainty whether there is oil or not.

www.digistar.mb.ca/minsci/ finding/resist1.htm
"Electrical and electromagnetic data are analyzed primarily to yield the electrical resistivity of the rock formation where currents have been injected or induced to flow. The resistivity is in turn a strong function of the porosity and pore fluid saturation. (1)"

Potential Problems: The steel casing of the pipes underground can act as a barrier to the electrical signals.
"Steel casing severely attenuates electromagnetic signals transmitted or received from within the pipe. The casing typically acts as a low-pass filter, attenuating signal above 10 Hz and virtually eliminating signals above a few hundred Hz. …This means that field measurements are more difficult in steel casing, and field data predominantly reflects casing effects. (1)"
Solutions: By taking into account the effects that the pipe has on the signal, you can separate it when you interpret the data and just get the information you want.
"Current research suggests, however, that the shielding effect of the steel pipe is a fairly

simple function of the thickness, electrical conductivity, and magnetic permeability of the steel pipe segment surrounding the sensor. Although EM fields are severely attenuated by the steel pipe, the response may be calculated with fairly simple numerical models and separated from the formation effect using straightforward techniques. …Thus, if the properties are obtained, the response due to the casing may be easily separated from the total field, leaving the formation response as a residual. (1)"

Experimental Methods

Earth's field NMR:

By using the earth's magnetic field, you can disrupt water molecules. By measuring this disruption you can have a good idea of whether there is water in an area. This technique is used for finding groundwater but it might be able to be used to find oil as well.
"This technique involves locally perturbing the direction and amplitude of the earth's ambient magnetic field to affect the dipole moment of hydrogen-based molecules (i.e. water or oil) within the pore structures. After the perturbing field is shut off, a decay signal is generated in regions containing mobile hydrogen atoms. These data can be used to estimate the porosity, saturation, and possibly even permeability of these volumes. …Recently, a project has been initiated through the DeepLook consortium to study the feasibility of extending this technology to oil and gas exploration. (1)"

Electrical Vs. Seismic:

Electric is better at telling if there is oil and Seismic is better at telling if there is gas. Seismic is also better at characterizing the structure of the reservoir.
"Although electrical data are sensitive to variations in storage and saturation of reservoir liquids, seismic techniques are more sensitive to the presence of the reservoir gases. In addition, the higher resolution offered by seismic techniques is superior in mapping reservoir structure. (1)"

Magnetic

Overview: By measuring the magnetic field, you can tell where there is likely to be oil because the rocks that may contain oil have very low magnetic readings. The magnetic field can be measured with an instrument called a magnetometer which can be flown over an area or used on the ground.
"Magnetic surveys are usually made with magnetometers borne by aircraft flying in parallel lines spaced two to four kilometers apart at an elevation of about 500 meters when exploring for petroleum deposits. …Ground surveys are conducted to follow up magnetic anomaly discoveries made from the air. Such surveys may involve stations spaced only 50 meters apart. …Magnetic effects result primarily from the magnetization induced in susceptible rocks by the Earth's magnetic field. Most sedimentary rocks have very low susceptibility and thus are nearly transparent to magnetism. Accordingly, in petroleum exploration magnetics are used negatively: magnetic anomalies indicate the absence of explorable sedimentary rocks. (2)"

Methods:
Proton-precession magnetometer: One type of magnetometer which utilizes the disruption of protons in oil to measure magnetism. .
www.eri.u-tokyo.ac.jp/KOHO/ Yoran2001ep/08_05.html
"One such method involves the proton-precession magnetometer, which makes use of the magnetic and gyroscopic properties of protons in a fluid such as gasoline. In this method, the magnetic moments of protons are first aligned by a strong magnetic field produced by an external coil. The magnetic field is then turned off abruptly, and the protons try to align themselves with the Earth's field. However, since the protons are spinning as well as magnetized, they precess around the Earth's field with a frequency dependent on the magnitude of the latter. The external coil senses a weak voltage induced by this gyration. The period of gyration is determined electronically with sufficient accuracy to yield a sensitivity between 0.1 and 1.0 nanotesla. (3)"

Schmidt vertical-field balance: Another type of magnetometer that measures the relative magnetic field by observing the torque produced by the earth's magnetic field on the instrument. Using this instrument involves setting up observation stations along the region of interest approximately a half mile apart.

(www.xtrsystems.com/ magnetometer/coil)
"The Schmidt vertical-field balance, a relative magnetometer used in geophysical exploration, uses a horizontally balanced bar magnet equipped with mirror and knife edges. (4) "Field procedure consisted of observation stations located at .5 mile intervals for reconnaissance surveys and .025 mile intervals for detail surveys. (5)"

Evaluation: The field balance is a more accurate way of exploring for oil when the region of interest is shallow.
"Field experiments showed that aerial magnetometers, proton precession magnetometers, and gravity surveys were not sufficiently accurate to map the small topographic lows of the Precambrian granite. Our conclusion was that only the field balance, …could acquire the necessary data. (5)"

Gravitational
Overview: This procedure involves taking reading about a kilometer apart throughout the region with a device called a gravimeter. The gravimeter measures the gravitational field and this reading correlates with the density of the region. By studying the differences in the density, you can predict which areas of the region might contain oil
www.seismo.unr.edu/ftp/pub/ louie/class/492/album02/
"Gravity differences occur because of local density differences. Anomalies of exploration interest are often about 0.2 mgal. …Gravity surveys on land often involve meter readings every kilometer along traverse loops a few kilometers across. …In most cases, the density of sedimentary rocks increases with depth because the increased pressure results

in a loss of porosity. Uplifts usually bring denser rocks nearer the surface and thereby create positive gravity anomalies. Faults that displace rocks of different densities also can cause gravity anomalies. Salt domes generally produce negative anomalies because salt is less dense than the surrounding rocks. Such folds, faults, and salt domes trap oil, and so the detection of gravity anomalies associated with them is crucial in petroleum exploration. (2)"

Conventional Gravimeter Vs. Gravity Gradiometry: A gravity gradiometer is another type of gravimeter that can give more information about the gravitational field of a region. This information can give more accuracy in oil exploration but interpretation of it is underdeveloped and is usually done using techniques for interpreting conventional gravimeter data.
www.microgsolutions.com/ gradiometer.press.htm
"The conventional gravimeter measures a single component (the vertical component) of the gravity field vector. In contrast, a gravity gradiometer can measure up to five of the nine terms in the gravity field's gradient tensor which completely describes the anomalous gravity field gradient. …Note how the two gradiometer measurements better emphasize the structural highs and lows as well as the bounding fault zones. … interpretation of gravity gradiometry data is presently immature in practice and application. …However, many existing gravity and magnetic interpretation algorithms are easily and naturally adapted to the interpretation of gravity gradiometer data. (6)"

Conclusion: Each of these methods is unique and would provide valuable information in the exploration stage. Based on my research, it is my recommendation that we utilize each of these techniques, in addition to seismic technology, in order to get a comprehensive view of the region. I believe that it is crucial to have as much information as we can from exploration so that we can reduce the impact of drilling needlessly.

Production Technology

Vertical Drilling
The oldest method of drilling is to drill a vertical well. In this method, a wellbore is drilled with as little deviance as possible directly towards the reservoir; once it penetrates and goes through the reservoir, the well is stopped and the drill string removed. At this point cement is poured down the well to prevent hydrocarbons from flowing down the well once it is perforated. Then the well is perforated, and the pressure in the formation forces the oil out of the rock and up the pipe.
Directional Drilling
Directional drilling is a relatively new technology which allows a well to be drilled along a predetermined path which is not vertical. A directional well has the added benefits of

being able to thread through a horizontal strata, in order to obtain the most pipe-to-formation surface area. Directional drilling is useful for a number of reasons, including

•sidetracking •offshore development drilling
•drilling to avoid geological problems •horizontal drilling
•controlling vertical holes •increasing oil pressure due to penetration
•drilling beneath inacessible locations
•drilling to reach oil in reservoirs which would be unreachable by vertical wells.

Directional drilling must be approached carefully. It is not as risky as it used to be due to special tools to help the well deviate in a controlled manner and new technology to keep track of the directional of the well once it has deviated. Often the target of the well is very precise and must not be missed. There is a possibility of drilling many different wells from the same well bore, which dramatically decreases pad size and increases possible production from the well.
Horizontal drilling has the added advantage of being able to thread back and forth through a horizontal reservoir to increase the formation penetration. The horizontal technique combined with multilateral wells allow several formations to be penetrated horizontally at once.
Recommendation: Directional Drilling with other necessary components added as necessary.

Rigs
Drill rigs vary dramatically depending on the depth and the type of formation they are drilling through. Since this information is not offered in the absolute for the ANWR region, it is only possible to speculate on the best rigs for the job. Companies being looked at to supply possible rigs include Anadarko and Schlumberger.

Exploration Drilling
After seismic exploration has taken place, one must go in and drill to to find the the true dimensions of the well. Directional drilling with coring is the best way to do this, making a minimum of holes and still determining the dimensions of the well. This can be drilled from a fairly mobile, lightweight rig. We are still researching exploration drilling techniques.

Rig Components
Drill Bits break down into categories:
Roller cone bits have one, two or three cones that have teeth sticking out of them. The cones roll across the bottom of the hole and the teeth press against the formation with enough pressure to exceed the compressive strength of the rock. They're made for rougher drilling conditions and less expensive; they aren't ideal for small holes, but they are very sensitive to the porosity of the rock they are drilling through (drilling faster or

slower depending on the pore pressure) giving the drilling crew a good idea of changes in pressure in the wellbore. Roller cone bits with steel teeth are called mill tooth bits; they withstand high drilling stresses while tungsten carbide bits can drill for long distances without wearing out. Tungsten bits are more expensive; tungsten carbide insert bits have teeth coated with diamond, which give them an even longer life.
Fixed cutter bits have no moving parts, and therefore only the cutting surfaces become dull. Diamond fixed cutter drill bits produce small rock cuttings called rock flour; they drill through the hardest formations, though slowly, and are also extremely expensive. These bits are only used in formations which have high compressive strength or are very abrasive and would destroy other bits before they made much progress. PDC bits drill with a diamond disk mounted on a tungsten carbide stud; they have the capability to drill very fast (100 feet an hour) and are very costly. They can be built with either steel or molded tungsten carbide bodies (matrix body). These bits are made in many different shapes and can be made to drill directionally; the shape also affects how many cutters can be mounted on the bit. Fishtail bits are of very old design and only suitable for drilling in very soft formations.The drill bits will need to be replaced as they become dull. The drill will be equipped with a jet to direct the flow of drilling fluid to clean cuttings from the bottom of the hole and allow them to rise to the top of the well bore. There is an optimal speed for the bit, which allows it to clear away the most rock and still maintain a high RPM).
There are many different types of drill bits to choose from and since the exact type of strata to be drilled through in ANWR is unknown, it is almost impossible to select drill bits. Instead, drill bits have been listed to accommodate as many different types of strata as possible. Roller cone bits would be good for exploration drilling; because they are so attentive to the porosity of the hole, it is a good indicator to the drilling crew if there is danger of a blowout. For longer drilling operations in harder formations, PDC bits appear to clearly be the best choice.

Drilling Power
The torque needed to drill the bit may be given by a top drive motor, suspended by the traveling block above the drill pipe in the derrick; it turns the drill string. This motor is electrical. New technology includes instead downhole equipment, where the torque provided to turn the bit is initiated at the bottom of the hole. The drill bit can be driven by a mud motor, which rotates the bit through the pressure of the drilling mud. This has obvious benefits, like not needing an additional outside power source. The drill collar is placed behind the drill bit in order to give it enough weight to be pressed against the formation while drilling. Drilling fluid is forced down the drill string and is expelled out the jets, lubricating and cooling the drill bit while at the same time carrying the rock cuttings away from the bit, exposing fresh formation to be drilled. The drilling mud performs many crucial functions and also has substantial environmental impact.

Drilling Mud
The drilling mud is essential to safe, efficient and economic oil well drilling. Drilling

mud is depended upon for:
•Control formation pore pressures to assure proper well control
Minimize drilling damage to the reservoir
•Stabilize the wellbore so that the hole diameter remains equal to bit diameter, or at least minimizes hole enlargement
•Remove cuttings from under the bit while drilling
•Carry drilled cuttings to the surface while circulating
•Suspend the cuttings to prevent them falling back down the hole when pumping stops
•Release the drilled solids at the surface so that clean mud can be returned downhole
•Keep bit cool
•Provide necessary lubrication to the bit and drill string
• Allow circulation and pipe movement without causing formations to fracture
•Absorb contaminants from downhole formations and handle the difference between surface and downhole temperatures, all without causing serious degradation of mud properties.

(Drilling Tech, 146)
There are approximately six types of mud: dispersed mud, non-dispersed mud, solids free brines, oil mud and invert oil emulsion mud, air mud, and aerated and foamed mud. Dispersed mud means that the clay (cuttings from the well) is dispersed throughout the fluid. This is achieved by adding alkalis to water which increase its polarity; the more polar the water, the more reactive clays will disperse throughout the mud. Montmorillonite may be added to the mud to give it useful properties; this is commercially known as bentonite. The addition of this causes the mud to become viscous, and may help maintain hole stability. Non-dispersed muds rely on the opposite of this effect by using little water and attracting many clay particles to the same electrical charge, enabling the polymer to wrap itself around the clay cuttings, essentially dissolving the cuttings with the mud as the solvent. These are described as encapsulating polymer muds. It is now possible to tailor synthetic muds to specific drilling situations, depending on variables such as: increasing the viscosity of the fluid, increasing the gellation properties, decreasing fluid loss into the formation, and acting as a surfactant, to allow oil and water to mix together in an emulsion. Solid free brines are used when working within the reservoir to minimize damage to the formation. They can be formulated with densities of up to 1.07psi/foot. The brine is unlikely to damage the formation because it won't plug the reservoir with irremovable solids or by causing reactions with formation fluids or solids. This makes solids-free brines useful during completion or workover operations.Oil mud and oil emulsion mud, water is present less then 10% by volume; the continuous phase is the oil. These are mostly no longer used as some of them are toxic, carcinogenic, and flammable, which are undesirable for safety, environmental and health reasons. It is possible to use compressed air instead of mud, but requires specific conditions, namely a formation which can remain stable without hydrostatic mud pressure to support it and there can be no danger of a fluid influx into the well. Aerated and foamed mud is essentially drilling mud injected with air, which in turn

lightens the fluid column. This mud is restricted to about 2800 feet as the pressure below these depths cannot be sustained by the mud density. Its lifting capacity is greater than that of regular drilling mud, but will not survive immersions in oil or salt water.

The basic physical properties of mud which should be monitored by the drilling crew are densities, fluid loss, and sand content. As of yet it is hard to make an estimate of how much mud will be needed in order to maintain the wells, because there is still a vary vague idea of how many wells need to be drilled. However, the mud can be reused many times and we are currently working on a way to dispose of it efficiently and safely.

Drilling process

Once an area has been picked and appropriately cleared, the well is spudded by driving a conductor pipe into the ground with a pile driver. This pipe must then be cleaned of rubble using a small drill head which breaks up the rubble and forces it to the surface. The initial size may vary, but the pilot hole may be approximately 12-1/4" in diameter; this may get bigger. Our team is currently researching how to drill to great depths using the smallest holes possible. This pilot hole will later be re-drilled with a larger bit. Slowly a drill bit of approximately 24" inches in diameter (again, we are still researching this and believe it is possible to achieve much smaller hole diameters) will be forced into the ground by the pressure of the drill collars, which weigh approximately 6,000 lbs each. Mud is pumped down the drillstring to clear the the cuttings as the bit begins to cut into the rock; it needs to be moving at an annular velocity of approximately 100 feet per minute to efficiently clean the well pipe (minimum 50 fpm). The amount of mud needed may be calculated by initially subtracting (D2-d2) and multiplying by 0.0408 where D equals the diameter of the hole and d equals the diameter of the drill pipe yielding the gallons per foot. Multiply this quantity by the minimum annular velocity, 50 fpm, and it yields the number of gallons of mud needed per minute. It is as yet undecided how big the hole needs to be and how many holes need to be drilled, so only rough estimates may be made. The mud may be reused. The drainpipe, held up by the derrick or mast, lowers the bit into the ground. When enough drill collars have been applied to give the bit the weight it needs, a crossover pipe is added to the end and then the drill string is solely added to the drainpipe. During this initial phase there may be much mud loss. When the drill reaches the required depth, the cuttings are cleaned out and the the first casing is installed and cemented into the well bore. It is important to cement the pipes in formations which are strong enough to withstand the pressures of drilling. The process is again repeated until the bit reaches the desired depth. There is instrumentation for determining how much the well deviated from its path and it is still being looked into. If a directional well is being drilled, a whipstock or a jet will be used to create the deviation in the desired direction.

Jetting is when a particularly pressurized stream of mud is shot out in the direction the bit should go, essentially eroding the rock in the needed direction. However, this only works in soft formations. The whipstock is tool which is attached to the end of the drillstring and fed into the wellbore head of the drill bit. Its wide, flat edge prevents the bit from following the path it normally would have taken and instead forces the bit to deviate to

the side.
Another essential part of equipment for the drilling process is the blow out preventer, which monitors the downhole pressures and uses a system of valves to close access to the hole incase a pocket of natural gas or highly pressurized fluid is hit. It is important to pick a blow out preventer which will be able to handle the pressures which may be encountered along the drilling path. Once the hole has been drilled, perhaps with several deviated wells traveling horizontally through reservoirs, it becomes necessary to complete the well. First, tubing is run down the well so that the hydrocarbons are not flowing directly up the casing. We will used coiled tubing in the well completion, and we are looking into using it more instrumentally in drilling as well. Coiled tubing is faster and less expensive because unlike regular tubing, it can be fed into the hole faster and does not need to be connected through joints, which takes time to complete. Once each ending of the wellbore is left open or blocked off with cement. When it is left open, it is called and open-ended perforation and the pressure in the formation must be such that the oil will rise in the hole and not sink into the formation below it. Sometimes the pressure is not enough and in order to prevent the loss of hydrocarbons, the finished well will be sealed with cement. When the company is ready to start producing, it will send a few charges down the well, and detonate them, perforating the tubing and allowing the hydrocarbons to flow into the tube.
Once the drill has been perforated and starts producing, a Christmas tree is installed on top. This device allows the operator to control the amount of production or shut down the well entirely if needful, or to direct the flow of the oil once it reaches the surface. Usually, once the Christmas tree is installed the well is complete.

Enhanced Recovery

The initial drilling process will only allow as much oil out of the well as the pressure forces out. The easiest way to stimulate a flagging pressure is by means of pumps to keep the tubing pressure less than the formation pressure. However, soon this no longer becomes feasible and at this point only 5-10% of the oil may have been recovered. Therefore secondary methods have been developed to increase the oil production from reservoirs; these usually involve flooding the reservoir with water and using the water to create pressure, driving the oil before it and up the pipe. This water flooding method may increase oil production by approximately 45% of the original oil concentration. In order to make the well extract the greatest amount of oil, tertiary (enhanced recovery methods) may be used. If the viscosity of the crude oil could be reduced, it would not need high pressures to push it up the drill pipe; therefore by adding solvents or by forcing steam into the well, the now “thinned” oil will flow up the pipe. This method may remove approximately 60% of the reservoir’s initial concentration. Technology is being developed which would utilize microbial recovery systems, limiting the amount of chemicals used.

Transportation Technology

Transportation by land, sea, and air:
-water transportation: by boat not feasible in the northern Arctic because Arctic Ocean freezes
-land transportation: by rolligon, hovercraft, snow-mobiles, roads
-air transportation: by helicopter, plane

-rolligons: out of proportion big tires to distribute the weight over a larger area, decreases pressure on ground to around 3psi; max payload 30 tons; max speed around 20mph

-hovercraft: use fans to push air under the vehicle, then uses a skirt to trap the air under and prevent it from dissipating, therefore pushes the vehicle up; only contact with ground due to skirt contact, which can tear up vegetation; minimal ground contact decreases friction and increases efficiency; documented hovercrafts passing over bird eggs and small rodents without inducing physical injury; payload of up to 160 tons, maybe more; can be disassembled for travel and reassembled for use; noise pollution inevitable; designed so that in case of massive skirt failure, air still leaks out relatively slowly and therefore provides a soft landing (just now a LOT of pressure); can be very big vehicles: about the area of entire rooms/buildings for equipment transportation; also can be very small vehicles: personal/passenger hovercraft; amphibious, can be used on land, liquid water, mud pits, melting snow; however only suited for flat terrain…can't push itself up steep slopes

-snow-mobiles: as in conventional snow mobiles, not special equipment like rolligons/hovercraft; requires lots of snow to be environmentally friendly, but many can be used on roads without damage to the vehicle; 2 types: tired and traction-ed vehicles; consumes diesel

-roads:
-gravel: more vegetation around edges of gravel roads, attracts animals; roadkill????; require acquire gravel from riverbeds/outside sources; stays through the seasons, can but doesn't get cleaned up; in non-winter seasons, directly laid on tundra
-ice: require about 1.5 million gallons of water pre mile of 40 ft wide 6 in thick ice road; lots of water, where to get it? melts with the warming of seasons, non-permanent, needs to be rebuilt every year; also ice airstrips and ice pads

-diesel fuel: new ultra low sulfur fuel to decrease the amount of particles given off, therefore decrease pollution….already being adopted by state of Alaska

-airplanes: focus on military aircraft C-130's: can travel in hurricanes/carry 20 tons, minimum range of 2,350 miles, average cost (in 1999) $44.1 million; very large and very stable, equipped with ski's to land on snow and ice, equipped with tires to land on runways; previously deployed to the Antarctic; more stable and more efficient to fly than helicopters

-helicopters: Sikorsky Skycrane (~10 ton load), Chinhook CH-47F (~13 tons), and the Skyhook Super Stallion(~16 ton load); compared to planes: flies lower, makes more noise???, less efficient; may land directly on frozen tundra; if helipad needed, size of helipad would be considerably smaller than size of landing strip for airplanes

Pipeline Technology

The proposed pipeline will be modeled after the Trans-Alaskan Pipeline System (TAPS) which features the following technologies:
- sideways maneuverability: horizontal shifting along pylons and zigzag formation; together, these will allow for thermal expansion from the transport of heated fluids and motion during seismic activity; these features help ensure the structural integrity of the pipeline
-internal heating and insulation: to keep the oil within the pipelines liquid in an arctic environment while minimizing thermal radiation to the environment at large
-leak control system: series of valves, automated control, for shutoff in case of detected leaks; these valves limit the maximum volume of oil that can be spilled; there are also manned routine maintenance trips along pipeline
-pigs: automated vehicals which travel up and down the inside of the pipe which are used to 1) clean the inside of the pipeline by scraping, 2) sense/detect pipeline cracks/ deformations; small enough to fit in pipe but big enough to maintain one-way orientation (i.e. won't turn around/rotate inside the pipe)
-vertical loops: used at the Alpine field, artificial high points in pipeline system which create a vacuum/siphon at top of a "loop" (really, just vertical zigzags) in case of leak; replaces the need for most valves, which themselves leak
-coating: protective coating along pipeline to guard against corrosion; different coatings for above and below ground pipes; often pipes manufactured pre-coated
-sacrificial anodes: when pipes underground, sacrificial anodes in place to corrode it instead of pipe

-elevated pipe to allow animals to cross; TAPS buried almost ½ of the pipes because to not disturb animals
-if buried, pipes should be buried in stable permafrost; in the past, this has been done by traditional burying, with no refrigeration systems; refrigeration systems only used when pipelines buried in unstable permafrost; either way, the permafrost melts, but having a refrigeration system is better than not having one
-geographical obstacles, like rivers, can be crossed by either 1) constructing a bridge, or

2) digging under it with directional drilling

Environmental Restoration Technology

Accident Cleanup:

The Coastal Plain area of the Arctic National Wildlife Refuge is covered mainly by wet tundra. The high water content of this type of tundra provides some protection to the roots of the plants from crude oil spills, which tend to float in the water. Water can also slow the movement of non-water soluble substances into the soil pore spaces, and while the leaves of the plants might be killed by the spill, the roots may survive and grow during the next spring. Wet tundra is also very sensible to physical damage, but it can also recover more quickly from it than drier types of tundra do.

When treating a spill in wet tundra, the possibility of contamination of water sources should be taken into consideration, since the water in the soil might move the spilled substance. If the drainage transect the spill site, dividing the water flow may be required to treat the site. Frozen wet tundra facilitates the recovery of a spill because it prevents the substance from penetrating the ground.

The possible damages caused when responding to a spill need to be weighed against the benefits of removing additional crude oil. It has been proven that a spill of 250 barrels per acre, or 10 mm in height, recovers completely without treatment in 24 years. However, larger spills don't show the same rate of recovery.

The initial response to any spill should be to stop the spread of the substance across the tundra, to prevent wildlife injury, and to recover as much free material as possible to minimize soil penetration.

Crude oil spills:

Winter: The months when the coastal plain is covered by snow are the ones when it is easier to recover from an oil spill. The crude oil will be absorbed by the snow, making it easy to remove using hand tools or heavy equipment in rolligon tires, depending on the extent of the spill. If the crude is doesn't land directly on snow, this method can still be used by applying snow to the substance and recovering the mixture by the same method. The saturated snow should be recovered in plastic bags or disposal drums and transported to offsite facilities for treatment and/or disposal.

If the ground is frozen and the crude oil has reached the soil, it is necessary to scrape the top 1 to 3 inches of surface contamination to remove contaminated material while preserving some of the roots and stem bases of plants to allow for re-sprouting. It is first necessary to clear the area of snow using a front-end loader to expose the tundra. Then the top 1 to 3 inches of vegetation are removed and transported to waste disposal facilities.

Spring, Summer & Fall: The first measure that should be taken during a crude oil spill during the warmer months is to contain and stabilize the contaminated area using large-diameter water-filler hoses. Sand bags can also be used but may contaminate an area during storage since they can't be properly cleaned and may not be reused multiple times. Once the area is surrounded by the land barrier, fresh warm water should be used to flood the spill site. This will reduce the infiltration of oil into the root zone and the amount of oil in contact with vegetation. The floating oil can be recovered by using skimmers such as a portable rope-mop or vacuums. After the majority of the spilled substance has been removed, the surface can be flushed with commercially available surfactants to increase the ability of water to dissolve non-miscible products and reduce the adhesion of crude oil to vegetation. Using warm water at low pressure, flush towards a lined depression or trench and shored with a land barrier. The ground may be agitated while flushing using the water flow or a squeegee. The flush water should be recovered from the depression with a pump and disposed of.

Saline water spills: Saline water comes to the surface during oil production and its frequently used for enhanced recovery. Fire-fighting chemicals also contain large quantities of salt and represent the same threat to the environment.

Salt increases the osmotic potential of soil water, making it impossible for plants to absorb it. It spreads rapidly in wet tundra, covering a larger region each season and reducing plant coverage by as much as 80%. In mixed spills of crude oil and saline water, the clean up should start with the salt water since it spreads more easily and it is not biodegradable.

The immediate measures taken during a saline water spill should be to contain it using land barriers like large-diameter water-filled hoses or sandbags, and vacuuming as much salt water as possible. Then it is necessary to repeatedly flood and vacuum the spill site to dilute the salt and minimize the effects it will have on the soil. If all measures fail and the salinity of the soil is extreme, gypsum can be added to counteract the effects of the salt and salt-resistant plants can be planted to populate the area.

Mud spills: Mud spills occur from dripping mud reserve tanks and from well blowouts. During the winter months, the mud will freeze in contact with the snow and can be recovered by scrapping down to 1 or 2 inches from the soil and vacuuming the rest of the frozen substance. During the warm months, the mud spills can be treated like saline water spills and recovered by flooding and vacuuming.

Significance of bigelow sedges in revegetation program

Sedges are also found to be important in the arctic Alaskan vegetation. A type of sedge is called Bigelow Sedge (Carex bigelowii), which is though not considerably consumed by herbivores, but is important to the area in terms of revegetation. When oil exploration occurs, this sedge is found to colonize the land quickly after the destruction. This is partly due to their strong resistance to weather and low requirement of nutrients (so itself is not highly nutritious) It helps "rebuild" the ecosystem after devastation or human impact. Observations have shown that they can quickly recolonize the damaged areas of oil spills or sulphur pollution within 2 months, which is very rapid in terms of ecological scale. They then become the primary food source and later on allow successions of other plants to take place. The ecosystems can then be siginificantly resumed. So it is suggested that it may be used as a tool to recover the damage to ecosystems after oil explorations. (Bliss, L. C.; Wein, R. W., 1972)

Further information about its physiology, distribution, values and uses can be found at the following website:

http://www.1upinfo.com/wildlife-plants-animals/plants/graminoid/carbig/all.html

Drilling Plan

Non Seismic Exploration

Some non-seismic data is already available for ANWR, but it is impossible to know whether scientists will find that they need more data when the time comes to actually undertake the exploration process. If more is necessary, then it will be collected as the petroleum geologists and environmental experts deem appropriate. Non-seismic data is essential to the exploration process because it provides a unique viewpoint that supplements seismic data. The type of non-seismic exploration techniques that would be most valuable in ANWR would be those involving potential field methods, i.e. Magnetic and Gravitational. Magnetic field methods can be done with an aerial pass of a magnetometer or on the ground using a type of magnetometer called a vertical field balance. These readings tell experts whether there is likely to be oil because there is a correlation between low magnetic readings and rocks that contain oil. Gravitational methods can also be done aerially with a gravimeter or on the ground using a more precise instrument called a gravity gradiometer. The data from gravitational methods is valuable because differences in the gravitational field indicate a difference in the density of the ground which correlates to rocks that contain oil. Both of these methods are relatively low impact because they only involve either not touching the ground at all, or by setting up stations approximately 100 yards apart using low-impact transportation.

Thus the impact of non-seismic techniques is significantly lower than the impact that would be caused by drilling unnecessary wells.

Seismic Exploration:

Based on the USGS report, the ANWR region was seismically explored in 1984-1985. Data, acquired using seismic surveying, totaling 1,451 miles is available. Furthermore, this data has already been processed and is a substantial part of the USGS report on the ANWR region. Based on those evaluations alone, it is possible that no further seismic or non-seismic surveying will be necessary in order to proceed with exploratory wells drillings. However, it is also possible that in order to suggest a more specific location of drilling further seismic exploration will be required. There are several advantages in doing at least some part of seismic exploration because of the progressed technology in the field of both data inquisition and data processing. Thus several of the seismic exploration methods should be considered.

First, the Explosives method: This method possesses much potential. Very little equipment is needed in order to drill the holes and to pack them with explosives. Although many safety measures have to be taken, it is quite possible to achieve low impact on the surface using this method. The intrusion factor of the personnel to the area of exploration is minimal. However, due to the close packed grid using this equipment it is needed to further asses the possible damage that can be caused underground.The second possibility is the use of Vibroseis trucks, which will be adapted to the Alaskan area. One of the methods is to replace the wheels of such trucks with tracks or thick tires, thus maximizing the spread of the weight and minimizing the pressure per point on the permafrost. Another factor is the precision of this method. Vibroseis trucks are much more precise than explosives because they deliver controlled vibration to the ground. It is even possible to send different type of waves, such as P waves (vertical) or S waves (horizontal). This way the data that will be further analyzed may yield a more precise evaluation. The trucks will be stopping for a short period of time to send the vibration and then evacuate the area, such that there is no long term damage. However, further assessment of the damage done by such tracks to the permafrost needed, as well as the assessment of the way the trucks will get into the reservoir

Depending on the quantity and quality of existing seismic data, one or both of these methods may be used in such a way that they complement eachother in order to have the least environmental impact. If a small area needs to be assessed, the explosions provide the least amount of impact. However, if the existing data is insufficient it might be necessary to use the trucks. The impact of these trucks will be significantly lowered by using large inflatable rolligon tires to lessen the applied pressure and adequate snow cover will be assured before their deployment.

Production and Drilling

Estimating Number of Wells

Once all of the exploration data has been gathered, the drilling locations will be selected. The goal is to minimize the number of drilling sites required and the environmental impact of each while hitting as much of the oil in the undeformed region as possible. The maximum reach of a single oil well is between three and four miles, depending on the depth of the wellbore, the depth of the kickoff point and the amount of deviation from vertical. This opens somewhere between thirty and fifty square miles. Given that the proposed drilling region is approximately 470 square miles, this require ten to fifteen production sites if the oil were evenly distributed. Since it is unlikely that the oil is evenly distributed, there will most likely be no more than around 15 drilling sites and probably no less than five.

Choosing the Drill Site

Foremost in choosing these sites is the avoidance of especially sensitive environmental areas. Drilling sites will be kept a distance to be determined by field study away from major water ways and away from the more sensitive coast in order to prevent possible significant platform spills from devastating the aquatic ecosystem. Smaller creeks and streams will not be built upon but will have activity much closer to them if it is necessary to reduce the total number of drilling sites. The site will also need to be tested for tundra integrity to ensure that the soil in the area can support the drilling platform and equipment.

Transportation of Materials

Once the winter begins, construction will start at the first sites. For the drilling companies, the winter season should be as long as possible in order to conduct the most efficient drilling and production strategy. However, primary interest concerns the well being of the 1002 ecosystem, and towards that end the drilling season will be evaluated each year to assess the drilling time which would have the least environmental impact. The three main priorities include a) a significant drop in the wildlife population as the migratory species leave, b) to have the active layer of the permafrost refreeze, and c) to have adequate snow cover to protect the tundra from moderate weight.

Sites closest to the western border of ANWR will be built first and then radiate east over the years. Since the pipeline network will use the production sites as both pumping stations and nodes, it is important to expand in this manner. The first site, assuming that oil is found, will connect to the single output line.

In order to minimize long term impact on the tundra ecosystem and to minimize the transportation burden of traditional gravel pads and the water requirements of their modern ice equivalents, the drilling and production equipment will be located on elevated platforms. Such fast assembly platforms have already been prototyped in the North Slope area and in 1002 will operate like offshore platforms in the midst of a fragile tundra sea. Such platforms would be prefabricated in modular sections and taken to the airbase outside of ANWR. In order to assemble the platforms on site, several pieces of construction equipment will be required including an auger, a crane and a forklift, as well as temporary housing until the modular sections for housing can be assembled.

These platform modules will be transported to the sites in one of two ways. The most straightforward would be by heavy-lift helicopter. Capable of loads between 7000 kg and 9000 kg, heavy-lift helicopters can carry in the modular sections or least significant pieces of them. Ground crews would arrive on site via smaller helicopter and see to the lowering of the platform modules into nearly the perfect position. The obstacle to this method of cargo transport is the arctic weather with frequently low visibility and the potential for high winds. This decision revolves around weather and flight data which is not yet fully collected or analyzed.

The alternate option, still by air, would be to use C-130 Hercules or equivalently rugged cargo planes to haul in the platform modules. This would require partial disassembly of the module sections or a more linear design capable of fitting in the fuselage. Such aircraft are capable of punching through weather more severe than likely to be found in the arctic and have a greater fuel range and weight capacity. The disadvantage is that while they can land directly on the snow covered tundra, in order to protect the underlying vegetation they might require an airstrip. It is possible that the frozen ground and the average snow cover will be sufficient to withstand the impact of landing. This could be aided by the use of larger rolligon tires. In this case no airstrip will be built and aircraft will be used instead of helicopters.

If an airstrip does need to be constructed, the standard material - gravel - is not really feasible as it a) has a high environmental impact but more importantly b) needs to be brought in by truck, requiring roads, etc. The next most common option - ice - is possible, but at an estimated one million liters per airstrip, acquiring the necessary water locally will be very difficult and transporting it seems even more preposterous. It might be possible to use some sort of synthetic material which could be applied to the ground in layers to help cushion the impact of landing aircraft. The decision of which plan to implement is contingent on future studies.

Platform Construction

The platforms, which are are supported on posts which are screwed into the ground, will need to have pilot holes drilled by a small auger; cranes and forklifts are also required to put the platform in place. This equipment may rest on a small ice pad in order to minimize damage to the tundra. All construction activities will take place in the winter.

Once the platform modules arrived at the sites, the construction crews would start assembling them. Portable hydraulic jacks will lift the pieces onto sleds which snowcats can haul into the desired place. This equipment will all be brought in with the platform modules, each built to obtain the largest surface area which could reasonably be airlifted in. A drilling platform should be approximately half an acre, with an appropriate number of pylons for support. Assembly of the entire platform should take about one month. The support pylons are designed to be screwed into the ground to provide maximum support and easy assembly. Holes to get the pylons started will be bored with the backpack drills similar to those used by the seismic teams earlier. Snowcats will move equipment around the site while mobile cat mounted cranes will help with the initial construction. Once the pylons are in place, winch towers will be bolted on to hoist the platform pieces themselves into place to be bolted on. The whole assembly should erect itself accordingly with bolting and bracing so the final platform can be dissembled just as easily.

In order to prevent the permafrost from thawing due to the thermal conductivity of the platform legs, the pylons themselves will contain some type of circulating coolant, perhaps anhydrous ammonia and the radiator system employed on the Trans-Alaskan Pipeline. The first platform to be built will hold the dwelling modules for the platform workers. Supply storage will also be on this platform. The habitation platform will connect to the rising production platform by a suspended metal link bridge.

Once the production platform is in place, the drilling equipment can be bolted on. The rig must be pieced together on the platform in a space-efficient way in order to make the smallest drill pad possible. The derrick will be bolted directly to supporting pylons to give it maximum stability. Other equipment will be attached to pylons directly or to the crossbars, however the engineering specifics dictate. The diesel engines should be placed in an out of way place along with the generators, possibly insulated to cut down on noise pollution. The mud tanks should also be placed out of the way, but in such a way that the feeder pipes can be run to and from the drill string. The full list of equipment can be found here. Ideally assembly will finish only partly through the winterseason. If it takes the whole season, operations will shut down and only a small watch staff will remain at the platform. If there is significant time left in the winter, drilling will begin.

Drilling

The well must be spudded by driving a conductor pipe of approximately 12" diameter into the ground with a pile driver. The pipe will then be cleaned of rubble using a small drill head which breaks up the rubble and forces it to the surface. Once the pilot hole has been started, the drill bit of approximately 24" diameter will be lowered. Before any drilling commences, a blowout preventer must be installed in the event that the drill bit runs into a natural gas reservoir in the shallow strata.

The initial drill bit is lowered into the hole and depends on a top drive motor to drill the initial strata. Once some depth has been achieved, the drill string is raised and the down hole motor is attached directly behind the drill bit. At this point, the mud pump is connected to the drill string via a rotary hose, and the mud pump will pressurize the drilling fluid. The drilling fluid flows into the mud motor and then strikes a spiral shaft which then goes into tubular housing in such a way as to cause it to turn. As the drill goes further into the ground, drill collars are added to the drill string in order to give the drill bit the right amount of pressure drilling into the formation. The pressure needs to be just right in order to ensure the bit is contacting and drilling the formation efficiently. Each drill collar weighs approximately 6,000 pounds; it is not uncommon to have 6 drill collars to apply pressure to the drill bit. The drill bit can then be raised or lowered in order to modify the pressure put on the drill bit in order to achieve maximum drilling efficiency at all times. The drilling fluid will constantly be moving down the drill string and then up the sides of the hole, cooling and cleaning the bit and lifting the cuttings to the surface where they can be collected.

A smaller, second well will need to be drilled well away from the reservoir to be used for reinjection of well wastes. It could be drilled from a small, portable drill rig on an ice pad and take a matter of days. This is the most cost efficient and safest way to dispose of well wastes which cannot be cleaned effectively.

Once a stable formation has been reached, drilling momentarily ceases as the first casing may be cemented. Casing pipe of slightly smaller diameter than the hole is lowered into the drill site in 30 foot sections. Once the first casing section is in, cement is poured in-between the casing and the outside diameter of the drill hole, cementing the casing to the hole. It is important that the formation that the first casing is cemented into is strong enough to hold the casing, especially in the case of a blowout; if the formation is not strong enough to hold the cemented casing and a high pressure pocket is hit, the casing may shoot straight out of the hole.

Once the first casing has been cemented, drilling resumes and continues with the drill mud rotating the bit. Special mud logging equipment, attached behind the mud motor, can analyze the mud as it moves past on its way out of the hole and send that information back to the drill bit operator; it can give important notice about formation composition and pressures. Soon the cementing and casing process is repeated. After several lengths of casing has been installed, the next casing lowered will be of a slightly smaller diameter. This decreases the amount of friction exerted on the drill string. Eventually, the well bore will only be 5" in diameter, cutting down on expense and waste products.

Drilling fluids will rise out of the wellbore, carrying with it the cuttings from the formation. These will need to be cleaned out of the mud before it can be reused; this is done by a collection of mud purification and storage devices. The mud is sent through the shale shaker, which removes the larger cuttings; it is then strained through the desilter, degasser anddesander which remove the finer particles which would dramatically contribute to the deterioration of the well bit if they were recirculated in the mud. The cleaned mud is then drawn back to the mud pump, pressurized, and sent down the drill string, repeating the process.

A large diameter hole may be drilled vertically in order to penetrate all oil reservoirs vertically below the rig. That hole will then be closed by pour some cement down the hole and closing off the bottom of the hole, after the drill bit has been raised. Once the initial hole as been completed, the drill bit can be lowered again with a whipstock. This special tool fits around the drill head and forces it to deviate; how it is positioned determines the amount of deviation. In this way, the well may be explored directionally to exploit reservoirs not directly below the drill pad; the drill path may also flow horizontally through a reservoir, increasing the surface area of the pipe to the formation and allowing for faster oil production. Once that well has been fully drilled, it too will be sealed off with cement and the process will be repeated until all possible reservoirs have been tapped and exploited in an efficient manner.

Completion

Once all well bores have been drilled, coiled tubing is run into each well bore. This tubing, fairly thin, protects the casing from corrosion and is much easier to repair in the case of an accident. After each bore has been lined with coiled tubing, small explosive guns are lowered into each wellbore. These guns shoot metal slugs in all directions, perforating the tubing and shooting into the formation, perhaps even fracturing the formation. Once each charge has been set off, all wells are then opened into the main pipe and formation pressures will force the oil up the pipe. In this final stage of production, a Christmas tree (a series of valves and gauges) is installed over the producing hole which regulates the pressure of the formations and triggers safety measures if the pressure should rise outside controllable areas. The flow of the oil out of the reservoir may be controlled by the Christmas tree. A subsurface safety valve will also be installed, which remains open as long as fluid flow is normal; if the valve senses a discrepancy in the flow, it will immediately shut down. Ideally, the entire bore will be online before the end of winter. Likely it will not as there are so many sub-wells to drill in which case drilling will resume in the next winter and the platform will go into summertime hibernation. But as soon as a significant oil reserve is discovered, pipeline construction will begin. The pipeline will be constructed in sections, proceeding to each drill site after oil has been found but ideally before production has begun. Oil flow cannot begin until the pipeline is complete.

Enhanced Oil Recovery

The initial drilling process will only allow as much oil out of the well as the pressure forces out. The easiest way to stimulate a flagging pressure is by means of pumps to keep the tubing pressure less than the formation pressure. However, soon this no longer becomes feasible and at this point only 5-10% of the oil may have been recovered. Therefore secondary methods have been developed to increase the oil production from reservoirs; these usually involve flooding the reservoir with water and using the water to create pressure, driving the oil before it and up the pipe. This water flooding method may increase oil production by approximately 45% of the original oil concentration. In order to make the well extract the greatest amount of oil, tertiary (enhanced recovery methods) may be used. If the viscosity of the crude oil could be reduced, it would not need high pressures to push it up the drill pipe; therefore by adding solvents or by forcing steam into the well, the now "thinned" oil will flow up the pipe. This method may remove approximately 60% of the reservoir's initial concentration.

Pipeline

The pipeline will be routed so that one line comes into 1002 and then it branches progressively into the region to hit all of the platforms using each successive platform as a potential split. The platforms themselves will house the pumping equipment to keep the oil flowing as well as storage tanks to regulate flow. All of this will be housed on a third platform connected to the production one by another bridge. A facility to launch and retrieve "pigs" (bullet-shaped sensing devices which travels the length of the line) into the pipeline will also be erected on the platform.

The pipeline itself will be designed in a manner similar to the Trans-Alaskan Pipeline <http://www.alyeska-pipe.com/Pipelinefacts/PipelineEngineering.html> with a few small changes and one major one - the erection of a small cog rail line directly parallel to the pipeline. The pipeline and rails will be suspended from triplets of vertical pylons spaced at 20 meter intervals with two meters between them each. Between one pairing will run the crossbar supports for the pipeline while the other will have the supports for the tracks. The pipeline will be built much like TAPS with the ability to rock on the crossbars and with bumpers to soften its motion. This will also give it the ability to deal with thermal expansion. The rail lines will be cog tracks as are used in many parts of the world with high snowfall and will make it very difficult for vehicles to derail. The whole gap for the rail line is only about two meters but the structure will be designed for moving inspection and maintenance crews along the pipeline, allowing foremergency access to valves and leaks, and for regular activities like platform crew changes and supply delivery. Replacement parts for the production platforms will also be brought in this way. The trams themselves will be powered by replaceable batteries which can be changed and recharged at every platform.

Additionally, the actual construction of the pipeline will take advantage of the rail line to minimize surface impact. The rail line will be built first in pieces so that each new piece can be moved along the line to the growing end. The support pylons will be installed much like those of the platforms and the rails will be hoisted into position from those pylons. The final structure will be bolted and welded as it is much harder to inspect and maintain every bolt on the pipeline than it is for the platform. As the rail line goes in, the third pylons will be screwed into the ground and the pipeline itself will be raised into place in 10 meter sections from rail mounted cranes and pylon mounted hoists. As many of the parts as possible for the construction will be prefabricated to ensure the highest level of factory based quality control and to ease and speed assembly. When the winter ends, construction will be halted as is the norm.

In addition to transporting oil and moderate freight, the line will also carry fiber-optic cable for communicating between platforms and outside of ANWR as an alternate to satellite. Also, the pipeline will be built with a catch basin running the length under it to catch any small spills. This basin will also hold all of the sensing equipment so that should a leak occur, workers all over the region will know and be able to respond via cog rail or helicopter if weather permits.

Once the pipeline is connected to a platform, it is able to go online - assuming the drilling is complete. The production equipment (oil/water/gas/sand separators, further dehydration, water treatment, etc) will have also been set up in this time. A secondary derrick will have also drilled a single bore for reinjection of waste water, unburned gas, and rock fragments. Gas generators will also be set up to transfer electrical production from import diesel to produced natural gas. If it is not dangerous to do so, electrical lines will also be run with the pipeline (on the far side of the track) to allow drilling platforms to run off of the gas electricity of producing platforms and to provide greater electrical reliability.

Facilities Outside of ANWR:

In addition to pipeline pumping stations, the water requirments of the drilling project will require the construction of a sizeable desalinaztion plant on the coast outside of ANWR, preferably in the already disturbed region of Prudhoe bay. Powered by local natural gas sources, the plant will generate the pure water necessary for manufacturing drilling muds and for making ice airstrips should they be necessary for landing cargo planes. The water will be distributed to the platforms via a smaller pipe coupled to the oil pipeline and cog rail system.

Routine Maintenence:

In addition to the many sensors that will be monitoring the pipeline for any discrepencies in its integrity, there will be routin visual checks of the pipeline by platform crews sent out on the rail system. They will check individual sensor calibration at valve points and assess pipeline integrity. On the platforms, on-duty mechanics will be monitoring valve and formation pressures at all times in case of a sudden change in formation pressure. This is an added measure in conjunction with the Christmas tree and subsurface valves.

Accident Clean Up:

Current methods for how to clean-up oil spills in arctic environments vary depending on the season. During the winter months when there is snow cover on the tundra, any crude oil spilled can be absorbed by the snow, allowing for fairly easy removal using hand tools or heavy equipment on rolligon tires. The saturated snow could then be recovered in plastic bags or disposal drums and transported to offsite facilities for treatment for disposal. If the crude oil has reached the soil, contamination will penetrate into the ground 1 to 3 inches. As much of the contaminated material as possible should be removed, but the roots and stem bases of plants should be preserved to allow for re-sprouting.

For a crude oil spill in the warmer months large-diameter water-filler hoses could be used to contain and stabilize the contaminated area. Sand bags would be needed to surround the spill so that fresh warm water could be used to flood the spill site and thereby reduce the infiltration of oil into the root zone and the amount of oil in contact with vegetation. The floating oil would then be recovered by using skimmers such as a portable rope-mop or vacuums.

Coupling these two seasonal methods with bioremediation efforts (microorganisms and fertilizers) could potentially decrease original hydrocarbon content of contaminated waters and sediments by up to 70% – 90% of the original spill. It is difficult to completely remove the pollutant even with bioremediation efforts because there is often a buildup of inhibiting metabolites as well as recalcitrant "leftover" compounds. Nevertheless, the damage remaining after clean-up would be minimal if all these clean-up efforts are taken.

Environmental Restoration:
Once the period of production has ended the production equipment, drilling platforms, and pipelines will be deconstructed and transported out of ANWR for reuse or disposal. The tundra underneath will be restored with whatever is believed to be the most effective treatment at the time. Since this will likely occur 90 years down the road, it is difficult if not impossible to determine the exact technologies which will be employed. Replanting or tundra vegetation and application of fertilizers are likely to be the primary ideas.

Cost Benefit

Introduction

"Benefit-cost analysis can indeed be a useful tool in helping society allocating its resources between environmental protection and other activities as well as among various environmental goals. But it is only one such tool, and its limitations must be acknowledged." George C. Eads, Charles River Associates, Washington, D.C.

Assigned with the task of solving the 'Complex Problem' regarding the development of the Arctic National Wildlife Refuge, Mission 2007 was required to "evaluate whether or not the hydrocarbon resources that might be extracted from beneath ANWR are worth the environmental damage that might result from the process." Faced with quantifying and comparing "hydrocarbon resources" and "environmental damage," Mission decided to break down the issue into its simplest components. What follows is our attempt at simplifying this problem into a form that can be readily approached by anyone interested in this topic.

By simplifying this issue we realize that we lose certain facets of the problem, which are important, but which, given the time constraints and resource limitations, we could not address. Nevertheless, this study represents what we consider to be a reasonable analysis of the issue surrounding drilling in ANWR and a road map of the future research required.

The model we have created separates the potential costs and benefits should drilling occur. While it would be relatively straightforward to perform the cost-benefit analysis from strictly the oil corporation's perspective, we would thereby be disregarding the external costs and benefits of drilling upon society. Hence, we have performed this analysis from the perspective of American society, which we feel gives the most holistic and appropriate view of the problem. The benefit, then, is the national economic benefit offered by exploiting the hydrocarbon resources in ANWR and fundamentally this comes down to the projected increase in GDP stemming from the entry of such hydrocarbons into the economy.

In the interest of a quantitative comparison, we have translated all costs and benefits into numerical financial figures, namely dollars, which, while not the ideal unit, is readily accepted in the world of economics and the most straightforward unit to use. The costs then, have been derived under the theory that natural places otherwise untapped for their economic resources possess a certain "existence value" and act as natural capital which yield an annual, measurable benefit to society. Development of ANWR will decrease that annual yield and it is through this mechanism that we plan to measure the quantitative cost of the environmental damage to society.

Benefits

Method:

Deriving the economic benefit of oil extraction is relatively straightforward in the simplest case: take the expected recovery of oil, multiply it by the market price of oil, and then multiply that revenue value by the Keynesian Multiplier to find the total economic benefit to society. This value represents the benefit not to the oil companies - which may or may not profit by implementing the proposed drilling strategy - but to society as a whole in the form of an increase in the Gross Domestic Product (GDP), which stimulates economic growth.

Expected Recovery:

ANWR has been designated as federally-protected land that cannot be developed for any reason. Only the 1002 portion of ANWR could potentially be open by the Federal Government to development. As a consequence of these restrictions on exploration and drilling, insufficient data exists on the amount of oil in ANWR. However, from a government-approved seismic study conducted in the mid-1980s, we have a crude estimate of the extractable oil within the undeformed area of the 1002 region of ANWR.

USGS data and analysis from that study concluded that the amount of oil in the undeformed region had a 95% chance being at least 3.771 billion barrels and a 5% chance of there being more than 10.974 billion barrels, with a calculated mean of 6.993 billion barrels (source 1). More information on these values and their derivation can be found in the geology section of this report.

Value of the Oil:

To determine the world oil price under which oil from ANWR would be sold, the years in which the oil is actually on the market need to be considered. Assuming that drilling is initiated in 2010, the oil from ANWR would be on the world market between 2020 and 2070, reaching a production peak at around 2030. Those years, however, seem to be difficult years for which to determine the oil price since they occur after most modern predictions of the world oil production peak. The level of peak production estimated by experts ranges from 68 to 90 million barrels per day and is predicted to occur within the next decade (source 2). On the other side of the market, there is a projected rise in demand for oil of 1.6 percent per year over the next thirty years (source 3). With current demand at about 75 million barrels per day, this increase in demand would set the demand in 2030 to 120 million barrels per day. The change in the intersection of the demand and supply curves over the fifty year producing period of ANWR (and the ten to twenty year time lag) represents the price at which ANWR oil would be sold as it becomes available.

As a resource in shrinking supply, the value of the extracted oil seems likely to increase in the future leaving many to argue that development in ANWR ought to be delayed a few more decades or longer to maximize the total gain. What these arguments fail to consider, however, is that the existing infrastructure in Prudhoe Bay is critical to the development of 1002. Should development in 1002 be significantly delayed, other North Slope production will finish, forcing the closure of the pipeline and the removal of support facilities and infrastructure and a flight of the critical development skills and associated human capital. The environmental cost of restarting North Slope development, the repair or replacement of TAPS, and the reconstruction of the support infrastructure will greatly increase the environmental cost of the development of 1002 and might overwhelm the increased benefit brought on by distant oil prices. Furthermore, the advances in renewable energy sources, fuel cell vehicles, green plastics, and other oil-use mitigation technologies could have the opposite effect in the future and considerably lower the demand for oil. Our model therefore focuses on the present or near term exploitation of hydrocarbons in the undeformed region. Therefore we assume that the price of oil will follow a simple linear-growth pattern over the given time period which may seem an unreasonable assumption, but it does provide a baseline value for the total revenue that could be potentially generated.

There is also the issue of oil production from ANWR affecting the world oil price. Research has shown that the world oil price tends to increase along a roughly straight line, with variations being caused primarily by decisions made by OPEC (Organization of the Petroleum Exporting Countries). The oil in ANWR is orders of magnitude smaller than the global supply of oil, and therefore the world oil price is independent of any sort of activity in ANWR. The only threat to the linear growth model is a major policy shift by OPEC or an international conflict that would spur such a shift. In these regards, this model falters because it assumes an era of relatively small conflicts (this era which does not need to begin until about 2020, which provides for enough time for the oil prices to return to the linear-growth model). Furthermore, peaks in the world oil price are precipitated by steeper growth, and this is not being seen today, so the assumption that there will not be a large peak in the oil price is reasonable.

Ignoring shifts in the equilibrium price, a simple procedure of extending oil prices along their linear pattern give the average value of the price of oil from 2025 to 2045, the major years of production, as \$34.8 per bbl, with an uncertainty of \$2.60 (sources 4, 5, 6). We are predicting that even with the development of alternative sources of energy that the dwindling oil supply and increasingly unstable situation overseas will maintain this price for oil. The real value will depend on technology, discovery, and politics, but it will most likely be greater and apt to increase from that value over the projected time of production. Using the baseline price above, the value of the oil extracted from the undeformed region therefore has a 95% probability of being \$131 ± \$9.8 billion and a 5% probability of being \$382 ± \$29 billion, with a mean value of \$243 ± \$18 billion.

Multiplier:

When the oil enters the American economy, the value above is injected into the economy as the profits are reinvested and wages are given to households which in turn spend part of their increased income on consumer goods, which is re-spent in the same manner by the subsequent recipients. This process continues until the entire injection has 'leaked' out of the economy by way of savings. This is called the Keynesian Multiplier and we have accounted for this augmentation by calculating the multiplier for this situation.

According to one source, the multiplier (in the United States) is estimated at a value around 2.0 (source 7). According to another source, a study of the Alaska dividend where the state distributes the economic rewards of its ownership of land and mineral resources to citizens, households increase their spending in anticipation of this annual income receipt. They space their expenditures from the anticipated dividend fairly evenly over the year (Hsieh 2000). The main finding with respect to the marginal propensity to consume out of tax refunds is that, across all households, almost two-thirds of every extra dollar of refund is spent within a quarter (Souleles 1999, 955). The multiplier is equal to 1/MPS or 1/(1-MPC) where MPS = marginal propensity to save and MPC = marginal propensity to consume. MPC and MPS summed should be one.

If households spend two-thirds of every dollar of income, their MPC = 2/3. Hence, the value of the Multiplier is 1/(0.33) = 3. Another source we used, said the multiplier usually fluctuates between 1.6667 and 3. This averages out to 2.3333. From these three values, the average value of the Multiplier is 2.444.

This multiplier might be disproportionately tilted towards the Alaskans. However, since the oil revenues fund the Alaskan government and the social services it provides, the benefits of drilling are also disproportionately felt by Alaskans.

When the total projected revenue from the oil is amplified by the multiplier, a mean total of 594 billion dollars ± 7.4% is obtained. This represents the total benefit to society should drilling occur.

Some would argue that if the multiplier is to be used to augment the value of the extracted hydrocarbons, then it must also be used in regard to the environmental costs below. However, the trickle down effects accounted for by the multiplier do not apply to the environmental costs. The economic benefit of the oil revenue enters the economy in a few places, mainly in the form of wages and other liquid assets, and expands by the multiplier into total social benefit. Conversely, the environmental costs represent the social impact directly and therefore further expansion would be redundant and logically incoherent.

Costs:

Method:

Calculating the social cost of environmental damage is a considerably harder and less tangible task than determining the economic benefit of development. While numbers can be assigned to many representative quantities, much of ANWR's worth to many is fundamentally priceless and borders on the sacred. We recognize the inadequacy of quantitative methods in accounting for such intangibles as the social worth of "wilderness" but we will nevertheless attempt to assign a representative number.

ANWR in its current state is a great national environmental resource and drilling in the region, despite precautions, will inevitably decrease the value of that resource. To attempt to quantify this, we will assume ANWR has an "existence value," a method of quantifying the environmental worth of natural places coined by John Krutilla of Resources for the Future in 1967. More recent ideas attempt to treat environmental assets as being "natural capital" which, like all capital holdings - industrial, human, financial, etc, are prized for their annual benefit. We have used these theories to declare that ANWR's existence bestows on American society a benefit each year, much the way in which capital assets can be valued by their annual yield. The punch line is that that annual benefit for ANWR will decrease in value if oil is extracted and we can attempt to quantify that loss in value integrated over time.

As soon as we commence human activity in 1002, ANWR (or at least the undeformed region) will loss its social value as being "pristine" wilderness. This loss in annual value will last for throughout the construction, production, and reconstruction phases and only begin to return as once the ecology of the undeformed region has been fully repaired and the memory of human disruption attenuates with time.

Once construction begins, the undeformed region will lose further value as the physical environment itself is destroyed. As long as the human footprint remains, the annual value of ANWR's existence will have decreased by a fixed value based on the state of the land. Since this damage represents a drop in environmental value, its worth should be equal to the annual cost of returning the environment to its untouched state. This is the restoration cost.

In addition to somehow accounting for the loss of the pristine and the planned physical damage, there must also be a way to account for unplanned damage, namely in the form of oil spills which likely are the most environmentally damaging aspect of the proposed oil development strategy.

Like the cost of environmental damage, the annual cost of oil spill damage can be found by determining the annual cost of oil spill clean up and restoration - the cost required to undo, insofar as it is possible, the loss in existence value brought about by an oil spill.

Once the value of these cost can be determined, we can make a graph of the annual benefit derived from the existence of ANWR versus time. Along the x axis we have the phases of damage - construction, production, restoration, and the time which ANWR requires to regain its initial wilderness value. The function of the annual benefit starts at the initial existence value of ANWR (which thankfully does not need to be calculated) and immediately drops by a value A equal to the "wilderness" value as soon as the ground has been broken. Through the construction periods the function will decay by a further value B (calculated via the restoration cost) and then at some point - let us say the start of production - by a further value C (the cost of oil spill damage). Once the production period has ceased, the value should, after a short fall due to the deconstruction activities, steadily rise to the initial value minus A. At this point the ecosystem is functionally equivalent to its pre-construction state though certain aspects of it will naturally be different. What remains is for ANWR to recover its complete value (by regaining A) and this we are proposing it will regain with the lengthy passage of time.

The construction period is predicted to last 20 years, with the first wells coming on line after the first ten. This phase includes what exploration needs to be done, the construction of the platforms, and the building of the pipelines.

The production phase is slightly more difficult to estimate. Mission has decided that the best way to estimate the length of time between the first drop of oil flowing through the ANWR pipeline and the last would be to look at the production rates of Prudhoe Bay and compare. Supposing this was a feasibly comparison, ANWR would take slightly longer than Prudhoe Bay because there will be many less wells producing in ANWR than in Prudhoe Bay. However, pressure should be increased due to the amount of wells flowing into the single wellbore at the surface. Looking at Prudhoe Bay as a rough estimate on a lower range, first oil flowed from the bay in 1977. Eleven years later, Prudhoe hit peak production at 2.02 million barrels a day. Since then, it has decreased approximately 6% over the past ten years. Production will continue decrease at a rate of approximately 3-4% per year; currently Prudhoe Bay is producing 85,000 barrels per day. Since the lowest possible capacity of TAPS, with current modifications, is 28,000 barrels per day. If the 1002 area produces at a comparable rate to Prudhoe Bay, this means it will produce for approximately 30 years after peak production. Therefore total current production will last approximately 41-50 years, allowing for the ten years to reach peak production and a longer producing time due to less wells. Ten years into the construction phase production will commence and peek production, by this model, will be reached right when the construction phases is complete and all the wells are online. The production phase after that point will then last, on the high side, around forty years.

(sources: http//www.alyeska-pipe.com/Inthenews/Monthlynews/2003News.html; http//www.qv3.com/policypete/domesticoil.htm).

Analysis of the literature in the environmental restoration area determined that the restoration period will last 30 years.

To find the total value of the environmental damage, then, it is necessary to integrate the existence value of ANWR through the interval of disturbance and from that value subtract the initial value of ANWR multiplied by the same value, that is to integrate the loss in annual value over time.

Wilderness factor:

This is the least tangible aspect of this analysis and up front it is worth saying that a superior method ought to be found to derive this value before any decision regarding ANWR should be made. The value of an undisturbed 1002 region simply cannot be quantified by direct methods. What is agreed on is that any type of disruptive exploration or construction will greatly diminish the wilderness character that the area currently has from the point of view of American society. How much that character is valued by society is the question at hand.

Based on the methods presented by Gordon and Meade (1994), we decided to calculate the wilderness factor of ANWR by assuming that joining an environmental organization constitutes a will to preserve the environment and keep regions like 1002 pristine. We are then conjecturing that the amount of money that these organizations get annually from their members is what our society would be willing to pay to preserve ANWR. This is the value we concluded represented the wilderness factor.

The whole idea of looking at environmental groups is not to assess people's value of ANWR, but rather to see how much money they are willing to spend to protect "wilderness" in general. Since ANWR represents what we feel to be the epitome of the wilderness case, money devoted to such a cause would likely defend ANWR as a first priority. The way in which several environmental groups have been liquidating other conservation assets in order to fund their ANWR campaigns is evidence of this.

This is clearly an indirect method which both undervalues the region by not considering other sources and means of wilderness protection - most especially the value of the human capital donated by those who dedicate their lives to protecting the environment - and overvalues the undeformed region of ANWR by assuming that all conservation funding is targeted that that one region. What this number approximates is the American people's individual annual monetary contributions towards conservation and given the fractional size of the undeformed region compared to all of America's sensitive environmental lands, we believe that this value, despite its severe limitations, will if anything overestimate the wilderness value of the undeformed region.

We took the Natural Resources Council of America, formed by 28 million members to be representative of the majority of the population that is a member of an environmental group. If all members of the NRCA are members of only one of their organizations, then 10% of the American population is part of an environmental group. If all members of the NRCA are members of two organizations at the time, since they would be counted twice by the Council, are the 5% of the American population.

The population of the United States is of 290,342,554 (2002). 10% of the population is then 29,034,255 people and 5% is 14,517,128 people.

To calculate the average membership fee of an environmental organization, the cost of the memberships of five widely recognized groups (Audubon Society, Sierra Club, National Wildlife Federation, The Wilderness Society, WWF) were averaged. The resulting value is of $26.8 for an annual membership to an environmental organization.

To obtain the wilderness factor of ANWR, we multiplied the number of people calculated to be part of an environmental organization by the fee they would pay annually. The resulting values are $778,118,034 when 10% of the population is member of an environmental organization and $389,059,017 when 5% of the population is. We will therefore select the larger figure, $780 million as the amount per year that the ANWR as wilderness is worth to American society.

Restoration Costs:

The restoration cost is the cost that will be encountered to dismantle the exploration, production, and transportation equipment and to erase as much of the footprint due to the drilling as possible. The restoration includes taking down roads, removing pipelines, deconstructing processing plants and all other Drilling Infrastructure, and the restoration of Tundra. For the North Slope, the restoration cost ranges between $2.7 Billon to $6 Billion. Assuming that the damage on the North Slope is no less per unit are than the damage proposed for the undeformed region, we can take ratios of the footprint areas and therefore calculate the likely restoration cost of the undeformed region.

The area of the footprint on the North Slope ranges between 10,000 acres and 15,000 acres. To account for the unanticipated, we want to maximize the cost of restoring the environment, and so we want to take the minimum area of the North Slope footprint, as that will give us a greater cost per square kilometer. Therefore, we assume that the footprint for the North Slope is 10,000 acres. To convert acres into square kilometers, we must divide the acres by 247. Hence, the footprint for the North Slope is 40.49 square kilometers. To get the maximum cost per square kilometer, we take the cost as $6 billion. Thus, the restoration cost per square kilometer is $148.2 million. This cost will occur over at least a 10 year period. Hence, the restoration cost per square kilometer per year is about $15 million.

We now consider the footprint on the undeformed region. We assume that we build 500 kilometers of pipes (the theoretical maximum given the size of the region and number of sites) which will leave a footprint 10 meters wide along the width of the pipe. This width accounts for local proximity impacts as well as construction damage as the physical pipeline is roughly half that width. This gives a footprint of 5 square kilometers. We also assume that we will build 20 platforms, which have an area of about 2000 square meters each. This implies that the area of the platform is 0.002 square kilometers. Another assumption we make is that the footprint of the platform is going to be at most 2.5 times the area of the platform to again account for proximity effects and construction damage. Hence the footprint of the platforms is 0.005 square kilometers. Therefore, the total footprint on the undeformed region is 5.005 square kilometers. Hence, the restoration cost for the undeformed region per year is about $75 million.

At first glance, this might not make sense, because this implies that the longer the corporation takes to restore the environment, the greater are their costs. But let us assume that the 'value' of ANWR decreases by about $75 million a year for every year that the corporation is in ANWR. Therefore, for every year that the oil corporation is in ANWR, society 'loses' $75 million. Hence, it would be in the best interests of society to finish drilling, and restoration as soon as possible.

Theoretically, there should be an Enforcement Cost because the Restoration will have to take place within a certain time limit. However, due to limited time, and a lack of other resources, we could not find the regulations imposed by the Government on Oil Corporations. This is a matter for further study, as it would affect the total Restoration Cost.

Accidental Oil Spill Cost

In addition to the anticipated damage oil extraction will inflict on the environment, there are potential unexpected costs from accidental oil spills. As outlined in the proposed drilling method, sensors to detect changes in volume and pressure, catches to contain smaller leaks, and valves to minimize the amount of larger spills will be used throughout the pipeline network. Despite these precautions, spills will most assuredly occur and the cost of clean-up and remaining damage will be a burden borne by society.

There is a solid body of data on the severity and frequency of oil spills from the Trans Alaskan Pipeline (TAPS) which can be used to extrapolate the potential oil spills from the infrastructure created for ANWR drilling. TAPS is a considerably longer network, uses older technology, and travels through more seismically active land. The values from TAPS thus can be used as a maximum for the damage that oil spills could inflict on ANWR.

To quantify the most probable maximum annual spill volume in ANWR, the frequency of each possible spill event is multiplied by the maximum spill volume of each event and the individual spill events summed. From this methodology, the maximum probable annual spill volume is 12.3 million liters (see chart). For a sense of scale, if this spilled oil was concentrated in one place to a depth of 10mm, it would cover 1.23 square kilometers, or 1/10 of 1% of the undeformed region.

The cost of cleaning up these potential spills using current methods (admittedly not the same degree of oil removal as with all the above mentioned methods), can be calculated using information from a study presented at the Artic and Marine Oil Spill Program Technical Seminar, which averages the cost of cleaning-up all spills in the U.S. per tonne of oil. For crude oil spills, the average cost according to this study is $13.05/liter.

Litigation Costs: If drilling is approved, it has been argued that there could be several potential court cases brought up by environmentalists and other social groups. Since 1995, most environment litigation cases brought up have not been about dams, nuclear power or pesticides, but about rare and endangered species. We estimate that there will be anywhere from 1 to 10 litigation cases (about half the number of environmental groups because we suspect that most of the cases will be class action lawsuits). The time and effort spent on these cases by the judicial system could have been spent on other matters, and hence this is a cost to society. While it is possible to assign a value to this damage, such is beyond the scope of this project and is a matter for future investigation. Most likely the total damage would be comparatively insignificant, but a more complete analysis should examine this figure.

Results

According to this model, the total societal benefit from the extracted hydrocarbon resources in the undeformed region of 1002 has a mean value of $594 billion ± 7.4%. This value takes into consideration the possible variations in extractable oil and then assumes a relatively uniform oil demand and supply over the interval or production and a multiplier of roughly 2.44. The cost of the environmental damage, treating the affected region as natural capital whose annual yield will be decreased by the extraction process over the interval of human involvement and taking the higher end of estimates at all juncture in the hope of compensating for what has not been considered, has been calculated to be $123 billion with an unknown and uncalculated error.

From these data two conclusions may be drawn. The first would be that based solely on this model, it would be in the long term interests of American society to implement the proposed drilling plan as the societal economic benefits appear to outweigh the societal environmental costs by more than a factor of 5:1. The second, and far more important conclusion, is that a great deal of research remains to be done about this problem, especially in the area of gauging the value the American people place on the environment and methods for quantifying that value and therefore the cost of environmental degradation. Only with this research will such a significant decision as oil development in the 1002 region be able to be made.

Implications

Environment

The Arctic National Wildlife Refuge is a diverse but fragile ecosystem. The 1002 region in particular, a coastal strip caught between the Brooks Range Mountains and the Beaufort Sea, is an intricate network of species and their surroundings that stand to be severely damaged by human activities. It is essential to establish a baseline of the ANWR ecosystem in order to create an assessment of the effects of oil drilling on its well-being and to take the proper precautions to preserve it.

In order to create a comprehensive model of the ecosystem, we have to set up the important parameters and components that define an ecosystem. Based on ecological models from multiple references, we have determined the main constituents of an ecosystem to include the following: geography structure and relief, climate, soils, hydrology, producers and consumers, decomposition and soil processes, energy and nutrient cycling, and interaction between terrestrial and aquatic communities (if relevant to the area of study). By developing a descriptive and quantitative model for each constituent we can compile the information for the structure and function of the ANWR ecosystem

Surface Operations

Surface Operations

Impact Report: Surface Operations

Of all the aspects of surface operations (pad construction, camp construction, personnel, dining, lodging, maintenance shops, water plants, waste water plants) the largest impact will be caused by the physical existence of the drilling pad. However, all activity has impact, just varying in terms of duration and geographic scope. The impacts of this are listed below, along with a rating of significance. The rating of significance is based on the intensity (magnitude, geographic scope, and frequency/duration) and the probability of occurrence, with the scale being high, moderate, or low. Probability of biological impacts is extremely difficult to predict. Thus, the probability should be evaluated in the context of professional judgment and past occurrences of impacts. In ANWR this is complicated because there has been no prior development to reference to.

ELEVATED PLATFORM

- Support: Steel poles

o Direct impact on permafrost.

Depending on metal used and extent of insulation from high temperature drilling equipment, thawing may occur.

o Attraction for curious, nesting, or hiding animals.

:: Significance:

o Intensity

Magnitude: (LOW) Animals might be scared away from the poles, but since the poles would not block migration, feeding or breeding it is unlikely that it would directly change the size or geographic range of an animal or plant population. The permafrost melting could be minimized with the correct insulation and/or materials.

Geographic Scope: (LOW) The effect would be site specific at a few locations.

Frequency: (HIGH) The poles would be permanently in place

Duration: (LOW) The poles will be removed after the extraction of oil is complete, and therefore will have a finite life of impact

- Operating Surface: Aluminum sheets

o Damage to tundra vegetation by oil leaks

o Damage to tundra vegetation by shading

Could be reduced by having slots or small holes in the pad, allowing some light to get through

:: Significance:

o Intensity

Magnitude: (LOW) This depends on the amount of oil leaked. But since the tundra beneath the platform is already (at least nearly) dead it seems that the effects from oil spills would be a minimal addition to any unavoidable vegetation damage. Animals might come in contact with some leaking oil, but very minimal amounts, and not likely enough to alter an entire population.

Geographic Scope: (LOW) The effect would be site specific at a few locations.

Frequency: (HIGH) The platform would be permanently in place

Duration: (LOW) The pad will be removed after the extraction of oil is complete, and therefore will have a finite life of impact

CONSTRUCTION

- Transportation of the pieces: Helicopter

o Flight will create noise that may be detectable to animals on the ground surface, and occasionally wintering birds

Increased flight elevation will significantly diminish the severity

o No landing pad will be needed as the pieces are to be lowered into place.

Will be increased by holes in pad

:: Significance:

o Intensity

Magnitude: (MODERATE) The impact from the period of construction and removal is understood to be very harsh on both tundra and animals. However, it would not be enough to directly change the size or geographic range of an animal or plant population.

Geographic Scope: (LOW) If the parts are flown in by helicopter, the impact will be site specific at a few locations. If land transport is used then a larger impact might occur.

Frequency: (HIGH) Personnel or equipment would most likely be at the site throughout the construction period

Duration: (LOW) Construction will be very small in terms of the life of the pad, and therefore will have a finite time of impact. The use of the aluminum platform allows for an even smaller construction period, than gravel pads, because gravel pads must wait for the completion of ice roads.

REQUIREMENTS OF PERSONNEL

- Sewage Disposal

o Transport of solids will have noise effects and need for further development of helicopter/plane landing and pumping facilities

This will also be a constant need for gasoline (defeating the purpose of drilling)

o Disposal in or on the tundra will impact the chemical composition of the tundra, and could be especially harmful if water sources are affected.

Possibilities for reuse/recycling should be considered

- Fresh Water

o Fresh water for human use is scarce on the North Slope. Any large needs would deplete fresh water sources for animals, thus possibly beginning a chain of impact through the ecosystem

o Wetland ecosystems would be disturbed by the collection or piping of water from them

Possibilities for desalinization should be considered

- Food

o Transportation of food would cause impacts. See below.

o Storage of food might attract animals.

o Disposal of trash. Might attract animals. Must be flown out eventually (See below).

Note: Possibility in all this for introduction of an invasive species of plant or animal.

- Transportation: People and supplies

o Noise effects from air travel

o Tundra and animals impacted from landing pad/equipment

> Ideally a helicopter landing-pad would be on the housing platform adjacent to the drilling platform, to minimize direct tundra impact.

1. Non-seismic exploration

Due to the fact that magnetic and gravitation exploration do not give off magnetic waves, the only effects produced by this method are caused by the service operations associated with the method.

The effects are:

Due to the airplanes used, there will be noise pollution. In addition to that, the nitrous oxides and carbon monoxide produced will reduce the air quality. Mild, wide-spread, short-term.

Any surface operations necessary will be conducted by attaching the magnetic exploration equipment to seismic exploration trucks thus requiring no extra vehicles of transport.

2. Seismic Exploration

A very useful tool that we relied on when conducting our evaluation is the Seismic exploration that was conducted along the coastal plain of the Arctic Refuge during the winters of 1984 and 1985.

Also note that 3-Dimensional subsurface image creation requires a much denser grid than that required for 2-D. The 1984-85 trails were usually four miles apart, whereas the 3-D seismic trails that are currently impacting areas where they are in use are about half a mile (or less) apart. This means that the tracked vehicles will basically blanket the area. 3-D crews are twice the size of 2-D crews, so more than twice the tracked vehicles are out on the tundra (more equipment and more bulldozers to transport the camps). Furthermore, the turns that the heavy equipment need to make are much tighter in 3-D seismic than they are in 2-D seismic, so the damage made to vegetation and the tundra in general is greater.

Strong winds usually blow the snow into depressions, leaving the higher areas with thinner snow cover and making them much more susceptible to impacts from vehicle tracks. After the 1984-85 seismic exploration 1400 miles of trails that have been made by drill, vibrator and recording vehicles impacted the tundra. In addition to the trails left by the exploration equipment, trails were also created by D-7 Caterpillar tractors that pulled ski-mounted trailer-trains between work camps. In 1999, 15 years after the exploration conducted a significant amount of the trails persisted. Some of them became troughs that are visible from the air (all vegetation removed). In other trails, the amount and type of vegetation present changed. This implies that the entire food-web dependant on this vegetation is affected and altered. Animals can be displaced out of their original habitats if their source of food is no longer available. In other areas, permafrost melted and the trails remained wetter than they previously were. Severe, localized, long-term.

Even though the caribou and birds are usually absent from the 1002 Area during the winter months, there are several species that are adapted to the harsh conditions and that remain in the area during the winter. These species are likely to be affected by the seismic exploration activities. They include primarily muskoxen and polar bears, but there are also other species including wolverine, arctic fox and arctic grayling. In addition, the sensitive arctic tundra vegetation is affected. Moderate, localized, short-term.

3. Transportation:

a. Rolligons:
Exerts pressure of about 3psi that is relatively less than an ordinary vehicle. They would, however, still leave a small footprint on the ground. Mild, localized, short term.
Atmospheric pollution caused by the use of diesel fuel (see airplanes).

b. Helicopter:
Noise pollution caused by the propellers of the helicopter will affect bird migration, polar bears, and other animals. Mild, localized, short-term.
Hazard of encountering birds in the air which would increase bird mortality and decrease the efficiency of the helicopter. Mild, localized, short-term.

At times air travel will not be possible due to extreme weather conditions which can persist for days. As a result, local storage needs would increase and more pad area would be required. (see environmental impact of surface operations). Mild, localized, short-term.
Degradation of air quality: see airplanes.

c. C-130 Hercules

Landing on snow cover may put pressure on the surface. Moderate, localized, short-term.
May affect air quality. Moderate, wide-spread, short-term.
If an ice strip was used, this would put a strain on water resources since one million liters are required per air strip. Severe, localized, long-term.
The option of using synthetic materials could be a problem if they are not biodegradable or if they are toxic. Severe, localized, long-term.

4. Drilling

Permafrost destroyed when drill bits driven into the ground. The area around the drill hole thaws. Severe, localized, long-term.

The flooding technique of recovering oil from the wells will have two effects:
- It will use up excess H20 Mild, localized, short-term.
- Chemicals will circulate into the ground material. Moderate, localized, long-term.

Benefits of drilling plan:

- Directional drilling and coiled tubing are the best choice: they will provide a minimal impact on the environment. Directional drilling allows for the installation of infrastructure beneath these areas without affecting the delicate ecosystem; animal habitats and sensitive areas can be avoided as a result.
- Coiled tubing reduced the amount of waste produced and results in a smaller footprint. Because the joint connection operations of a convenient drill string are not required, noise levels are reduced as well.

5. Pipeline

Permafrost thaws around pole-support structure. Mild, localized, short-term.
Vegetation does not grow underneath sunlight due to lack of sunlight. Mild, localized, long-term.
Potential fragmentation of habitats. Ex. Caribou might not want to cross underneath pipeline, and although they are not highly active around this area, their migratory route still runs through there. Moderate, wide-spread, long-term.

Impacts of Oil Exploration and Drilling on Permafrost

Examining the soil and water cycles of the 1002 region, one cannot ignore the presence of permafrost, or permanently frozen soil,¨ which underlies 80% of Alaska and remains a central issue in the debate about oil drilling. Permafrost has been defined as frozen ground in which a naturally occurring temperature below 0æ C (32æ F) has existed for two or more years (A). On the North Slope, permafrost ranges in thickness from about

700 to as much as 2,240 feet thick, and may be as cold as -8° to -10° C.
Permafrost can be either thaw-stable or non thaw-stable, depending on the type and percentage water of the soil it is made of. Permafrosts in more fine-grained soils like loess (silty) tend to thaw, sink, and create thermokarsts more often. Permafrost thaws from heat input, such as global warming or human activity, as well as the clearing of vegetation which insulates the ground.
Permafrost is affected by road dust generated by traffic on unpaved roads; snow melt due to dust deposition can lead to flooding, ponding, and hydrological changes in oil. Continuing oil and gas exploration, development, and production, construction of a natural gas pipeline, the operation and maintenance of facilities, and other activities requiring road travel would add cumulatively to the volume of road dust generated on unpaved roads (A). Regions of ice which have been wind-dusted are likely to undergo localized melting earlier than the neighboring non-dusted ice (A).

There are three approaches to dealing with the permafrost problem in the construction practice. The first and most obvious is to avoid it entirely. The second is to destroy it by stripping the insulating vegetative cover and allowing it to melt over a period of years. This has the obvious drawback of requiring a considerable period of time to elapse before construction can begin, and even then, it is a good idea to excavate the thawed ground and replace it with coarse material.
The third approach, and one which is becoming more widespread, is to preserve it. This can be accomplished by building on piles to allow cold air to circulate beneath heated structures, by building up the construction site with gravel fill which insulates and protects the permafrost below, or by refrigeration to maintain low ground temperatures. This is done by utilizing thermal piles or freeze tubes, such as those used by the trans-Alaska pipeline. These devices are filled with a non-freezing liquid and act like coffee percolators. They are cooled during the winter months and draw heat from the ground to retard thawing during warm weather (A).

In nearshore areas, ice-bonded permafrost is probably present and must be considered in the design of an offshore pipeline. But nearshore ice-wedge permafrost under shallow water, particularly along a rapidly receding coastline, is even more critical for design. Oil pipelines placed in areas of ice-bonded or ice-wedge permafrost must be heavily insulated to limit thawing of permafrost. The best location for an offshore platform is at water depths of 6.5-65 feet, to minimize ice gouging. Beyond the 6.5 foot water depth the top of the ice-bonded permafrost generally is below the surface of the seabed. Inshore of the 18-foot bottom-depth contour, ice gouging is typically less than 1.6 feet (Y). Relation of oil drilling, permafrost and vegetation Permafrost layer restricts the drainage of water through the soil, making it moist in the short summer growing season. It is easily broken by road construction or the seismic explosions used in oil exploration, changing the water drainage patterns of the soil and thus retention of moisture. Melting permafrost has also led to widespread damage of buildings, costly road repairs, and increased maintenance for pipelines and other infrastructure impacts that will continue to grow in magnitude. Permafrost also stores large amount of ancient carbon and methane; thawing is likely to release some of this stored carbon and methane back into the atmosphere, amplifying the risk of further climate change. The boreal forest will advance northward into present coastal plain tundra, and mixed forest into present boreal forest. Forest fires and insect outbreaks, both of which have increased sharply in recent years, will further increase. If the permafrost thaws, the vegetation will in the long term dries out, altering plant communities and use by wildlife.

t has been observed that in areas where the permafrost thaws, there is a sudden rapid growth of plants, which attract more animals to feed on. However, this is only momentary. Once the permafrost thaws, temporarily there is much water for plants to grow well for like a month or two, but then the water is continuously used up and drained away as there is no layer to prevention drainage now; yet the permafrost, once destroyed, take years to resume. Therefore, a few months after destruction, water will finally be deficient and no plants can grow well even during summer when water has already been used up, drained away but no permafrost exists to trap them for the growing season. This detrimental effect on vegetation is permanent, while the vast growth of plants is just transient.

Impacts of Seismic Exploration:

Seismic exploration involves a large number of vehicles driving across the tundra in a grid or network. The snow covering the vegetation in teh 1002 area is often shallow and therefore it doesn't provide great protection to the vegetation and soil underneath. The impact from the seismic grid will depend on the following:

a. Type of vegetation. Trails in shrub-dominated tundra have the slowest rate of recovery, whereas trails in sedge-dominated tundra recover well.

b. Texture and ice content of the soil.

c. The shape of the surface.

d. the depth of the snow; snow depths of at least 25 cm are required to minimize disturbance.

e. Type of vehicle. Surprisingly enough, camp move trails persist much longer and produce a more scarring effedct than seismic trails, due the great pressure exerted by camp move trails.

Studies conducted by the US Fish and Wildlife Service (USFWS) after the 1984-85 exploration showed the following effects:

a. The depth to permafrost was greater on disturbed sites than nearby controls.

b.Increased thaw depths.

c. Increased trail subsidence.

d.Shifts to wetter conditions.

e.Formation of distinct ruts.

f. Invasion of grasses

g. Decreases in shrub cover.

h. Longterm disruption of the soil thermal regime.

Biodiversity

Terrestrial

Polar Bears

ANWR is an important place not only because of the wide variety of species that it shelters but also because this "coastal tundra is America's only land denning habitat for polar bears" (2). "According to studies of radio-collared polar bears of the Beaufort Sea population between 1981 and 2000, 53 dens were located on the mainland coast of Alaska and Canada. Of these 53 dens, 22 (42%) were within the Arctic Refuge's 1002 Area" (4)† Over the past two decades the polar bear population has been steadily increasing, growing at more than 3% per year from 1967 to 1998, to reach an estimated number that could be as high as 2500 animals in 2001 (3). This rapid population growth of this species has "spanned the entire history of petroleum development in arctic Alaska" (3) as the polar bear population is thriving and thus will not likely be decimated even if drilling is to negatively affect the bears. In fact in a study (Amstrup and Durner) conducted in 1995, 85% of documented deaths of adult female polar bears were a result of hunting and not of environmental changes or natural factors. Although polar bear population is nearing "historic heights" caution must be taken as "possible changes in human activities, including hunting and habitat alterations could precipitate further declines" (3). This point will be clarified in the next section that discusses bears in general (of which polar bears are a part).

Yet, according to WWF report on ANWR, polar bears are especially sensitive to disturbance during denning. The Agreement on the Conservation of Polar Bears committed the arctic nations to "protect the ecosystems of which polar bears are a part, with special attention to habitat components such as denning and feeding sites and migration patterns." Females may abandon their dens if disturbed, and early den abandonment may be fatal to cubs unable to fend for themselves. In 1985, a female polar bear abandoned her maternity den in the Arctic Refuge coastal plain after seismic exploration vehicles tracked within 700 feet of it ¡V even though regulations at the time required a 0.8-kilometer buffer from known dens. This occurred despite the most extensive monitoring program ever in place for seismic exploration on the North Slope. Most maternity den sites are never known, and therefore cannot be avoided. Their natural curiosity and keen sense of smell often places polar bears in harm¡œs way ¡V they can be attracted to drill rigs, garbage dumps, and contaminants.
Polar bears are especially sensitive to oil spills because they search for food in the open leads or broken ice where oil accumulates. Laboratory experiments showed that oil ingested during grooming caused liver and kidney damage.† One bear died 26 years after oiling and another was euthanized.† However, as far as is known, neither ringed seals or polar bears have been affected by oil spilled as a result of North Slope industrial activities.† Yet, drilling in 1002 may have a greater effect on polar bears as 1002 is a much more important habitat for polar bears as discussed above.

Interactions between polar bears and humans are often lethal. A young bear was shot in Prudhoe Bay by an oil industry employee during the winter of 1968-69, and in 1990 a bear was killed when it approached an offshore rig in Camden Bay, off the Refuge. (WWF's paper titled "Protection of the Artic National Wildlife Refuge: Key to Managing one of the World's Most Biologically Valuable Ecoregions, the Arctic Coastal Tundra")

Parameter:
Polar Bears: "A female polar bear abandoned her maternity den in the Arctic Refuge coastal plain after seismic exploration vehicles tracked within 700 ft of it even though regulations at the time required a 0.8 kilometer (0.5 mile) buffer from known dens. "(WWF "Protection of the Arctic National Wildlife Refuge: Key to Managing one of the world's most biologically valuable ecoregions, the arctic coastal tundra") Therefore exploration and production activity should be kept at least 0.8 km away from all known areas of polar bear dens.

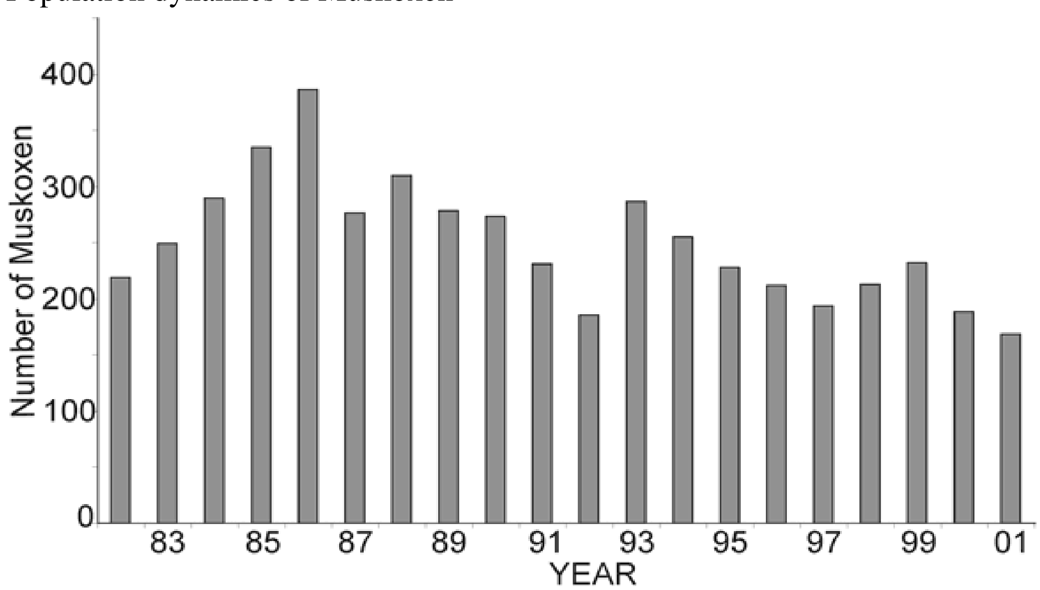
As previously mentioned, seismic exploration involves the movement of vehicles in grid patterns all across the tundra. Maternal polar bears with their newborn cubs can be chased out of their winter dens by the noise and vibrations and all of the human activities that come along with the exploration activities (particularly the explosives).

Anticipated negative effects include:

a. Human-bear encounters that can be fatal to either party on many occasions.
b. Increased mortality of cubs due to harsh winter conditions that they're not prepared for.

Muskoxen

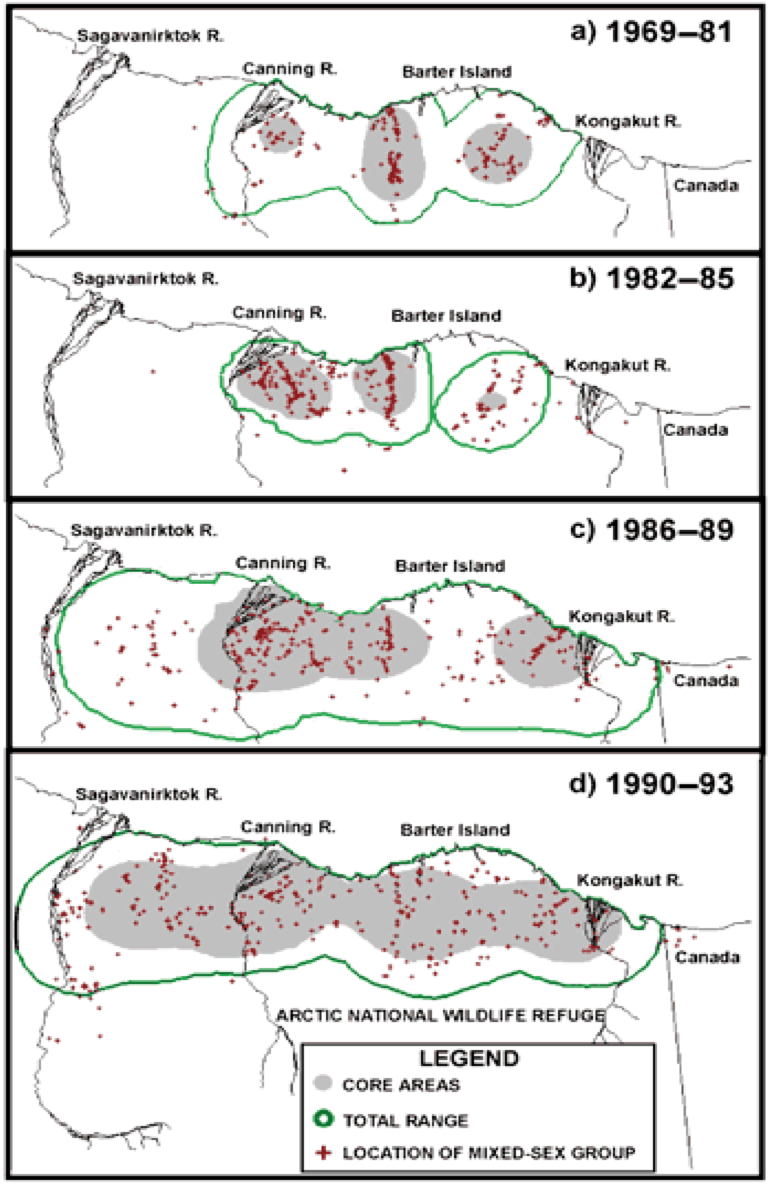
Muskoxen (Ovibos moschatus) were driven to extinction before the 20th century. They were reintroduced in 1969 and their numbers reached a peak at almost 400 individuals in 1986. Since then, the muskoxen population has declined to around 200 individuals. Reasons for this population decline include emigration, increased predation by grizzly bears, and severe winters. Also, hunting by humans has increased since their reintroduction. (Patricia E. Reynolds, Kenneth J. Wilson, and David R. Klein, 2002)
Population dynamics of Muskoxen



Graph: http://www.absc.usgs.gov/1002/images/Fig07-01.gif.

Muskoxen conserve energy by limiting their movement; they tend to stick to a core area about 50 km2 in the winter and 200 km2 during the calving and summer seasons. Calving occurs from March to June, so it is especially important for mothers to build up enough reserves during the summer to last the winter and to feed the newborn. Thus, a prolonged winter would have significant negative impacts on calf survival.
Muskoxen depend on riparian cover along river corridors, floodplains, and foothills year-round. During the winter, it seeks out areas of soft shallow snow. Its winter diet consists mainly of low-quality forage such as sedges, grasses, mosses, and forbs. In the spring, it feeds on high quality flowering sedges. Muskoxen tend to be very loyal to a particular spot, returning there year after year. (Patricia E. Reynolds, Kenneth J. Wilson, and David R. Klein, 2002)

Muskoxen herd
(Photo: http://www.saskschools.ca/%7Egregory/arctic/Amuskox.html)
Any human activity should stay away from the muskoxen habitats, including adjacent uplands. The areas that muskoxen frequent are places often used for gravel and water extraction for roads and/or platforms. Muskoxen congregate into larger groups in the winter, and large groups of animals are more likely to be disturbed by human activity because they tend to have more sensitive individuals.
Muskoxen groups that have moved west tolerate the Trans-Alaskan pipeline and the Dalton highway, but it is due to the wider area of habitable land available to the animals. Muskoxen remaining in the 1002 coastal plain are in a more geographically constricted habitat, with the Beaufort Sea to the north and the Brooks Range to the south. Eastern muskoxen populations are likely to suffer if human activities displace their territories and there are few alternative habitats available. (Patricia E. Reynolds, Kenneth J. Wilson, and David R. Klein, 2002)



Range expansion of muskoxen in mixed-sex groups in and near the Arctic National Wildlife Refuge, Alaska, 1969-1993. Total ranges were defined by 95% adaptive kernel contours. Core areas were defined by 70% adaptive kernel contours.
(Map: http://www.absc.usgs.gov/1002/section7part1.htm)

As muskoxen populations in the far west have coexisted peacefully with the Trans-Alaskan pipeline, a similar pipeline through the 1002 region should have little impact as well-- if it is built with the same environmental precautions. For example, the Trans-Alaskan pipeline has 579 animal crossings over its 800 mile span.
Helicopters and low-flying aircraft have been noted to cause some herds to stampede and

abandon their calves. Some herds have been agitated by 3-D seismic exploration as far as three kilometers away; other herds seem unperturbed as close as 300 m. Generally, noise produced by traffic, etc will have a negative effect on the animals. (Patricia E. Reynolds, Kenneth J. Wilson, and David R. Klein, 2002)
Little data are available on the interaction between muskoxen and human settlement associated with oil development. This is because drilling platforms have been built in regions rarely visited by muskoxen. However, the nature of the muskoxen's normal food source is such that its scavenging among human waste is unlikely. The major concern is the gravel used for the platforms, which would have to be extracted from muskoxen habitats.The specific impacts of seismic exploration on muskoxen:
The population of muskoxen in the 1002 area is approximated to be about 250 muskoxen living all year long. The survival of muskoxen is influenced by environmental conditions such as the depth of snow, which is in turn greatly influenced by seismic exploration activities. In general, the following effects are feared if exploration is to be conducted in the 1002 area:

a. Displacement of muskoxen from their winter habitat.
b. Due to this displacement, there will be greater energy needs.
Muskoxen need to reduce their activity and movement during the winter in order to preserve their energy and survive.
c. Decreased body fat in females. This body fat must be maintained during the winter if they are going to rear a calf.
d. Greater chances of predation.
e. As a consequence of the above, there will be decreased calf production and less survival of the animals. Impacts of Oil Exploration and Drilling on Lemmings and Voles
Lemmings and Voles tend to be more abundant and have less survival issues than muskoxen. In the winter they live in large underground burrows that may be as close as two inches from the permafrost. They subsist on willow twigs, sedges, and stored tubers during the long winter season. Burrows of voles are often raided by native peoples, who pilfer the stored tubers for their own use. (John Whitaker Jr., 1996)
Because of their numbers lemmings and voles are not likely to be wiped out by human activity in the region. However, they are an important source of food for higher lever consumers, including polar bears, wolves, and foxes. Lemming cycles, for example, are closely tied to the population cycles of various predators. A sharp drop in their numbers could potentially cause a population decrease in many other, higher-level consumers. (John Whitaker Jr., 1996)

Other Bears

Land mammals that are "most likely to interact with or be affected by the proposed operations (drilling) are river otters, black bears, and brown bears" (4).† Brown bears use the coastal areas from April to November, relying especially on coastal meadows, beaches, and shorelines for food (4).† As they feed on salmon, and other fish, uncontaminated water sources are essential to their survival, especially during summer and early fall when brown bears "congregate along coastal streams" (4).† Therefore chemical runoff of drilling released in streams would affect the bear population. Also, if ice roads are to be built, and these deplete, the water supply would decrease the fish population in rivers, the bears would be additionally affected.†

In the case of Prudhoe Bay, it has been observed that bears are attracted to the pipelines and oil developments by sheer curiosity, food odors, or trash (4, pg. 118). These bears become food conditioned and return to these places. If this happens often enough, and this event threatens human security, these bears have to be shot. In fact in a study of Prudhoe Bay oilfields (Shideler and Hechtel 2000) , it was found that "mortality rates of all adults and subadults that fed on anthropogenic [of human origin] foods was significantly higher than for bears that fed on natural foods" (4, pg. 118).† This finding could be related to the toxicity of human wastes or to the fact that these bears had to be killed by humans, as was before mentioned, because food conditioning occurred. Additionally, it is possible that in the future, "increased access opportunities (roads and airstrips) and changes in village lifestyles or economies could result in more bears being

killed for sport and subsistence" (4) especially as these animals are attracted to human settlements.
Another area of concern is the "construction of industrial facilities [that would] result in alteration or destruction of grizzly bear habitat" (4). This especially concerns disturbances created by roads or drilling that can affect the denning habitat of bears, and change food availability. This is especially dangerous if oil development is to spread into the foothills, as these provide the major habitats of bears. (4)

It also must be taken into account that bears are the predators that top the food chain, implying that any change in their dynamics would also affect that of other organisms residing in the lower branches of the food chain.† For example, if bear population is to increase because of increase access to food coming from human wastes, or if it is to decrease as hunting prevails, this will affect other species.† The major species affected by this change in bear population would be the caribou, the main food source of brown, and black bears.†† Increased numbers of bears would decrease the number of caribou present, and likewise, a decreased number of these predators would probably allow for an increase in the number of these herbivores.

Migratory Species

Throughout the year, hundreds of species migrate to the 1002 region of the Arctic National Wildlife Refuge. These include birds, mammals and fish which migrate to this region for a multitude of purposes generally between the months of May and October. This region has proven to be a center of biological activity throughout these months due many factors including nutritional benefits, increased safety from predators and a more favorable climate. Thus, a method to extract oil should carefully take into consideration these species and the impact on their habitat and livelihood in order to preserve the current ecosystem. Because the area has been left untouched for centuries, the impact of oil drilling could be severe if the migratory species are not taken into consideration.

For many species, the 1002 region is not a critical stopover along their migratory paths. For example, over 135 bird species visit the area each year, but only a small percentage stay significant periods of time, while even fewer use the area for breeding purposes. For land species, this also holds true. For example, the moose population would be minimally impacted by oil drilling because its calving grounds is in the Old Crow Flats in Canada and their stay in the 1002 region is brief. However, for the few species that do spend a significant amount of time in the region, the environmental impact of oil drilling can be devastating. Disturbances such as roads and noise pollution could potentially affect the survival rates of species which breed and calve in the area, as well as species which depend on the region for nutrition. For instance, the preservation of the 1002 region is essential to the survival of the porcupine caribou herd, which calve there. This is an extremely critical time period for the calves because of their vulnerability to predators and great nutritional need. Therefore it is necessary to identify critical time periods during the year in which the most damage would occur so that oil drilling could be planned accordingly. Also, the impacts of permanent structures and disturbances caused by oil extraction should be properly assessed and evaluated. In order to comprehensively consider the consequences of oil production, this report will present an analysis of major species, the potential impact of drilling, and propose methods of minimizing this impact.

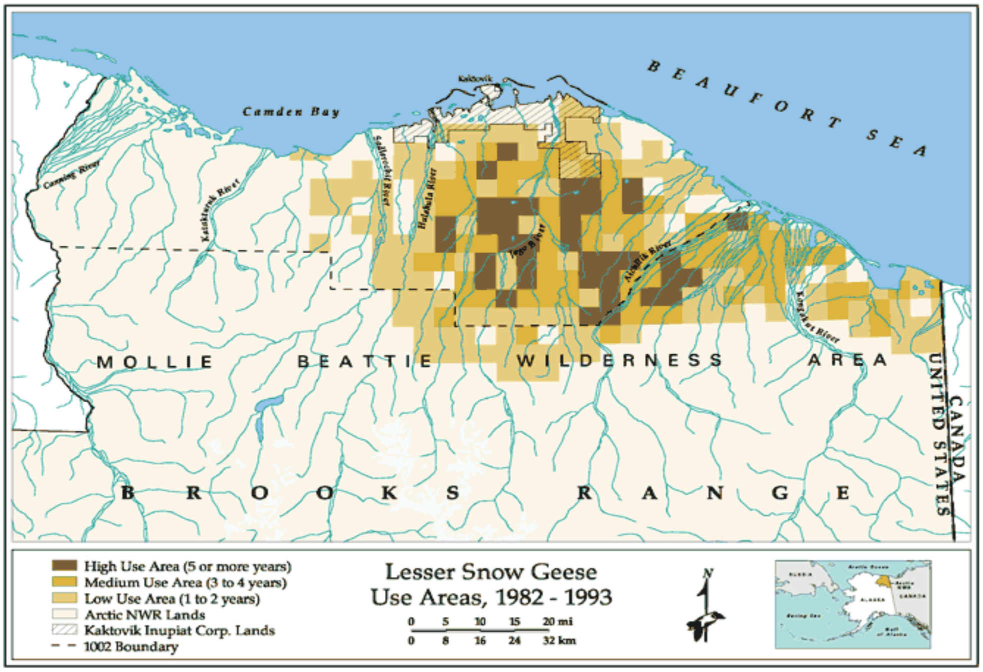
Avian

Snow Geese

This species migrate to the 1002 region of ANWR every year for two to four weeks before continuing on a 1300 mile journey to Northern Alberta. Their time spent on the north slope is critical to their survival since they need to store nutrients for their long migration path. As many as 500,000 species migrate to the region each year (Hupp et al, 2002). These birds are herbivores, feeding on cotton grass. A major predator is the arctic snow fox. The North Slope supports over 60% of the Pacific population (National Research Council, 2003).

(Photo: www.saskschools.ca/~gregory/arctic/Abirds.html)

Critical Time Periods
Lesser snow geese migrate to the 1002 region late August to mid-September



(Hupp et al, 2002) Density Distribution of Lesser Snow Geese
(Map: Jerry W. Hupp, Donna G. Robertson, and Alan W. Brackney, Artic Refuge Coastal Plain Terrestrial Wildlife Research Summaries, http://www.absc.usgs.gov/1002/section9.htm)

Other birds

Sea Duck

Sea ducks visit the 1002 region for 2 to 4 weeks every year. While they do not breed here, they use the area for molting purposes. Anywhere from 10,000 to 30,000 birds visit the region each year. Predators include the arctic fox and glaucous gulls.

Critical Time Periods
Sea ducks visit the 1002 region from mid-July to mid-September.

Sensitivities
There has been a decline in the number of sea ducks and other marine birds in the area, which raises concern about the impact that oil drilling will have on them, especially if there is a spill. Sea ducks are especially vulnerable during their stay on the North Slope

because the time they spend there is for molting. This leaves them unable to fly for 3-4 weeks. Molting also requires a large amount of protein to grow new feathers. Oil drilling could potentially disrupt the ducks' foraging capabilities, depriving them of much needed nutrients. However, one study showed that the ducks' foraging patterns are not significantly altered by minor disturbances, which perhaps suggests that oil drilling will not have a large impact on them. Another study that was performed showed that seismic activity does disturb ducks. Their results show a decline in population in a certain area where seismic activity starts, although underwater seismic activity had no effect on them.

Buff Breasted Sandpiper

General Information

Buff-breasted Sandpipers migrate to their wintering grounds in groups from 500-2200; their populations suffered from development of agriculture in the Great Plains of North America and the Pampas of South America. The Sandpiper's key wintering sites must be protected.

Critical Time Periods
The Buff-Breasted sandpipers arrive in their Alaskan breeding grounds in mid-April and vacate their breeding grounds in mid-July.

Sensitivities
The Buff-breasted Sandpiper mates in leks, or an area of ground approximately 8 acres in size, each containing about 10 males. Therefore the ground taken up by a mating Buff-breasted Sandpiper flock is fairly extensive. Human development of winter habitats infringes on land, disrupts the mating pattern and also attracts predators to the area.

Tundra Swan

General Information
Twice a year, Tundra Swans migrate 6,000 km between breeding areas in Alaska and The Canadian Arctic and wintering areas in eastern and western North America. Approximately 150 pairs of tundra swans nest on the coastal plain. Tundra swans feed on the following plants: foxtail and other grasses, wild celery, pondweeds, smartweeds, square-stem spike rush , arrowhead, coontail, mermaid weed, muskgrasses, bulrushes, horsetail, wigeon grass, and bur reed. Rice and barley are eaten in stubble fields. Tundra swans also feed on waste corn in both dry and flooded fields and upon harvested potatoes. These swans commonly fly as far as 10 to 15 miles (16-24 km) inland to glean waste corn and soybeans and to browse upon shoots of winter wheat. Animals that prey on tundra swans include: Golden Eagles, jaegers, wolves, foxes, and bears.

Critical Time Periods
Tundra swans start nesting between May and late June, depending on location and weather. During fall migration, tundra swans leave their major breeding grounds in the 1002 area in late September and early October. For their spring migration, tundra swans leave their central California winter grounds in mid-February, and most of the birds have departed within 3 weeks. By early April almost all of them have migrated north to Alaska and Canada.

Sensitivities
Scientists believe that new Tundra swan pairs are less likely to establish themselves on lakes where humans reside. They are extremely sensitive to noise pollution and as a result, inadvertent disturbance can cause adult swans to abandon their nests and cygnets.

Plants

"Due to the extreme cold, short growing season and nutrient-poor soils, Arctic vegetation is extremely fragile. Plant communities scarred by bulldozer tracks, oil spills and other human activities can take decades to recover."
Source: http://oz.plymouth.edu/~lts/conservation/Ecosystems/northslope.html

1. Sedges and willows for nutrition

There are two major types of plants that are very important in providing the herbivores (caribou, muskoxen, etc) with high quality and nutritious food: tussock cottongrass (Eriophorum vaginatum) and diamond-leaf willow (Salix planifolia ssp. pulchra). Surveys by US Geological Survey have shown that disturbed areas by petroleum development in other parts of Alaska exhibit significant decreasing quantity and quality of these two plants. In disturbed areas, they have lower biomass, lower nutritional values and higher fiber and lignin concentrations which decrease digestibility. This in turn significantly adversely affects reproduction and calving success of caribou that highly depend on them.(Janet C. Jorgenson, Mark S. Udevitz, and Nancy A. Felix, 2002)

2. Sedges and willows for inhabitation

Willows in riparian areas are important nesting habitat for migratory birds. Willows will be reduced in amount by heavy tracked vehicles for seismic studies. They will also be affected in the long term by thawing of permafrost, which would be discussed in greater details in the latter part of this essay. Loss of nesting places means unsuccessful calving for birds and higher chances of predation. Successful rehabilitation techniques are yet to be developed for these areas.

(World Wide Fund for Nature, 2000)

Flame orange dwarf birch and golden willow
Photo: Subhankar Banerjee

3. Mosses and lichens for nutrition
While sedges and willows are important food source for herbivores during summer, the growing and calving seasons, mosses and lichens are more important for local herbivores during the bitter winter as they can still grow well during the winter, though they have lower nutritional values. Construction of drilling site, roads and tracked vehicles all directly destroys the delicate mosses and lichens, lowering the energy source for the herbivores such as muskoxen.
(Sarah J. Woodin & Mick Marquiss, 1997)4. Mosses and lichens for carbon and nutrient cyclingMosses and lichens have a major influence on nutrient cycling in tundra and other northern ecosystems through their role in nitrogen fixation, and the ability of mosses to accumulate and retain elements from precipitation. They restrict the draining away of nutrients and help trap them during the summer and avail the nutrient for the herbivores during the winter. Slow decomposition of mosses allows the mosses to contribute significantly to the Arctic carbon sink. By photosynthesis, they "fix" carbon from the atmosphere to organic compounds and by slow decomposition they help trap the carbon instead quickly releasing them back to the atmosphere. This helps soothing global warming. Destruction means that all these functions cannot carry on.
(Sarah J. Woodin & Mick Marquiss, 1997)5. Mosses and lichens for maintaining the permafrost. Mosses and their under-composed remains are particularly efficient in thermal insulation when dry, thus restricting heat penetration into arctic soils in summer. Thermocarst resulting from destruction of the vegetation by the summer use of tracked vehicles during early stages of arctic oil exploration demonstrated the importance of the moss layer in maintaining permafrost. This caused extensive thawing of permafrost. The importance of permafrost on arctic ecology will be discussed in the next paragraphs.

(Sarah J. Woodin & Mick Marquiss, 1997)

Summary
"The effects of winter seismic trails on tundra vegetation were studied on the Coastal Plain of the Arctic National Wildlife Refuge. Plant cover was lower on most disturbed plots than on their adjacent controls, with decreases as high as 87% the first summer following disturbance. The species most sensitive to disturbance were evergreen shrubs, followed by willows, tussock sedges, and lichens. Willow height in riparian shrubland plots was significantly reduced by 5 to 11 cm (from an average of 16 cm, $p < 0.05$). Little recovery of plants occurred in the second or third summers after disturbance; only four plots in river floodplain habitats (Dryas terrace and riparian shrubland) showed improvements in cover of a few species."
(Felix NA, Raynolds MK, 1989)

Significance of bryophytes and lichens in arctic coastal plain

<u>Nutrient cycling</u>
The soil under bryophyte and lichen mats tends to be cold and moist. Lichens and mosses affect nutrient cycling of the ecosystem by intercepting aerial deposition and leaching from dripping aboveground vascular plant parts(Cowles, 1984; Rosswall and Granhall, 1980). Lichens with cyanobacterial symbionts and bryophytes with cyanobacterial associations provide the main input of nitrogen into the ecosystem(Alexander et al., 1978; Baselier et al., 1978,; Kallio, 1975)
Arctic ecosystems receive a higher proportion of nutrients input from precipitation and nitrogen fixation than do temperate systems, because chemical weathering is inhibited by low temperature and permafrost. Mosses and lichens have a major influence on nutrient cycling in tundra and other northern ecosystems through their role in nitrogen fixation, and the ability of mccosses to aumulate and retain elements from precipitation. Retention of precipitation by bryophytes is also likely to redice losses by leaching of nutrients already existing in the soil. The general role of mosses and lichens in nitrogen fixation bases on that the cyanobacteria growing on their stems and roots help transfer the nitrogen nutrients to the mosses and lichens themselves and also to the other plants, enriching the nitrogen content of the whole vegetation. (Sarah J. Woodin & Mick Marquiss, 1997)

Bryophytes act as efficient filters of nutrients arriving in precipitation, throughfall or litter and from the soil by absorbing them directly into their tissues, or retaining them externally in solution in capillary spaces. The annual growth increment of the moss layer at an Alaskan taiga site was found to contain nutrients in excess of inputs from throughfall. The mosses, and also the lichens, help increase the nirtogen concentration in the soil. Their absorption from the soil retains large amount of phosphorous and potassium in their cytoplasm. Mosses alone account for 75% of the annual accumulation of phosphorous in an Alaskan black spruce (Picea mariana) forest. Other nutrients such

as calcium and magnesium are also intensively retained in the tissues of mosses and lichens. (Sarah J. Woodin & Mick Marquiss, 1997)
Nutrient immobilization in slowly decomposing bryophyte phytomass may thus have a major influence in restricting recycling, and therefore in controlling ecosystem development and productivity. In mires, absorption of nitrogen and other elements by Sphagnum reduces availability to other plants. Bryophytes therefore may increase the pools of nutrients in the Alaskan ecosystems, but reduce availability to other organisms. (Sarah J. Woodin & Mick Marquiss, 1997)

Arctic tundra domonated by mosses and lichens
Photo: http://www.r7.fws.gov/nwr/arctic/issues1.html

<u>Maintenance of permafrost</u>
Mosses and lichens are important in the structure and function of the ecosystems because of their effects as insulators and filters. Their insulating properties is partly from increased reflectance and partly from the numerous air pore space when dry. They as an effective mulch, retaining moisture in the upper layers of the soil. Mosses and their undercomposed remains are particularly efficient in thermal insulation when dry, thus restricting heat penetration into arctic soils in summer. When wet and frozen in winter, their effect in reducing heat flux away from the soil is reduced. The net effect of mosses in decreasing soil temperatures in summer is generally greater than the converse effect in winter, and over much of the Arctic the distribution of permafrost is positively correlated with that of mire vegetation underlain by mosses. Thermocarst resulting from destruction of the vegetation by the summer use of tracked vehicles during early stages of arctic oil exploration demonstrated the importance of the moss layer in maintaining permafrost, which is an important habitat for many other species naturally occuring in Alaska as well as ANWR. Destruction of such vegetation can lead to extensive melting of permafrost, both directly and by accelerating the decomposition of organic matter. (Sarah J. Woodin & Mick Marquiss, 1997)
Apart from maintaining the natural permafrost habitat, mosses, and also lichens, provide

microenvironments of vital importance for invertebrates, and in some communities for the establishment of vascular plants although the relationships may be complex. Lichens release compounds capable of supressing the growth of associated vascular plants and bryophytes. Sphagnum spp. control the environment of mires by lowering pH, by releasing H+ ions in exchange for other cations, and creating waterlogged, anaerobic conditions to which only a characteristic range of other organisms is adapted. (Sarah J. Woodin & Mick Marquiss, 1997)

Decomposers

Likely effects from oil drilling

At this time, more detailed soil profile descriptions and soil climate data are needed for more accurate characterizations of patterns and net change in decomposition. However, the big picture implies that "environmental changes may have little impact on plant productivity unless average nutrient availability also changes" (Reynolds etc. al). This statement emphasizes the importance of decomposer species in any given ecosystem. Since they control the nutrient availability to an environment, they control not only plant productivity, but the competition that consequently occurs between plants for the nutrients, which affects evolution (according to survival of the fittest), and in turn the nutrition of herbivores and the carnivores that feed on the herbivores, etc. In essence, the entire food web of an ecosystem depends upon the availability of nutrition.
That said, the impact of road dust to decomposer species is as follows:
The influence of road dust results in higher soil pH levels (moving along the scale from acidic to basic), lower soil moisture, and greater thaw depth; although there are yet to be experimental studies of the impact on decomposer species specifically, the combination of the previously mentioned conditions when applied to simulations and past studies have shown that "soil enzyme activities in surface organic materials were found to be affected by dust loading: Activity increased rapidly with increased distance from the road" (Reynolds etc. al).

Even so, the biggest effects to decomposer species are likely to be those caused by changes in soil moisture. Reynolds etc. al found that "areas with moist tundra where water in channeled (water tracks) have higher vascular productivity and nitrogen availability than areas that do not." Basically, decomposition rates are higher and nutrient uptake is easier. Yet, without moving water—i.e. under more stagnant conditions—wet soils relate to low nitrogen availability due to the anaerobic, decomposition inhibiting circumstances (Reynolds etc. al).
One of the problems that arise in evaluating the effects of disturbance in the Arctic is that there is a major lack of information describing the dynamic response of ecosystems to

altered hydrological regimes and accompanying change in water quality. Therefore, it is my opinion that before conclusions concerning the impact of specific development strategies can be drawn, more experiments need to be performed.
Furthermore, in reference to decomposer species only, most of the impacts that I have discussed tend to operate on a more local scale. They would likely not affect an ecosystem as a whole unless there were many such local areas subjected to those impacts.

Political Implications

Political ramifications of a decision to drill in ANWR are hard to quantify and vary by scale. These scales include state, national, and international levels. The local/state level would benefit from drilling. The Alaskan government would be economically stable for approximately 30 years, dependant on the amount of oil and time of production. This stability will lead to the support of government sponsored organizations such as education, public safety, and some health care. These services are invaluable to the people of Alaska. On the national level there would be no major gains or losses on the political front. Drilling in ANWR is sure to be an issue in Election 2004, but a candidate¹s stance on the issue will not, alone, cause him or her to loose the election. Finally on the international level there would be a cost to drilling in ANWR. This cost would be in the form of a poor environmental record with the rest of the world. The world oil market and the politics which surround it would be minimally impacted by a decision to drill. The political ramifications of drilling would be a benefit to the Alaskan people and a cost to the United States within the world¹s view of environmental policy.

Historical Background

1959 Alaska became a state.

1960 The northeast corner of Alaska named a Wildlife Range by the Federal Government.

1960s Alaskan Natives filed land claims with the Federal Government.

1966 The Federal government froze all federal lands in Alaska. The state, natives, and other organizations were unable to claim over 96% of the land in Alaska. This freeze allowed the Federal Government to settle the outstanding Native Claims before Alaska and private interest groups could claim the land that Natives wanted.

1968 Oil was discovered in Prudhoe Bay, Alaska. Drilling was prohibited because of the land freeze, so pressure was put on the Federal Government to settle the Native Claims.

1971 Alaska Native Claims Settlement Act was passed by US Congress. This Act ended the land freeze in Alaska because it settled the Native Claims. Native Corporations were formed to govern the lands in the best interests of the company shareholders.

1980 Alaska Native Interest Land Claims Act (ANILCA) was passed by US Congress. ANILCA created present day ANWR and designated 13 million of the 19 million acres in ANWR as wilderness. Section 1002 excluded the Coastal Plain from wilderness status, leaving it available for further study and possible resource development. Section 1003 stated that Congress had to approve any development within the 1002 area.

1980s Following the passage of ANILCA, the opening of the Coastal Plain to drilling was under heavy debate in Congress. The oil crisis during the 1970s led to the desire of policymakers to secure a domestic oil supply in case of a similar occurrence.

1989 The Exxon Valdez oil spill occurred. The Congressional Republicans' hopes of opening ANWR met renewed resistance from the Democratic Party, which was against the idea of drilling in the first place.

1992-2000 President Clinton's vow to veto any measure that allowed for drilling ended any debate by Congress about opening ANWR.

2000 President Bush declared that he would pass a measure for opening ANWR. The debate for opening ANWR was renewed.

State Ramifications

An investigation of the political groups associated with the State of Alaska found that the political ramifications of a decision for drilling would be good in the short and long term. The main benefit of opening ANWR for drilling is the economic stability that it would bring to the state as a whole. Oil is the main source of income and stability for the Alaskan government and Alaska would be economically sound for 20-30 years after the opening of ANWR, because of the oil royalties. This would allow for the State to address important issues such as education and healthcare instead of combating the unemployment and the slowed economy which will eventually be the result of keeping ANWR closed.

Native Alaskans are hoping to gain more political influence, something they have been losing since Alaska became a state. The majority of their influence comes because of their corporations. These corporations would benefit from oil drilling because of the royalties they are entitled to by the Alaska Native Claims Settlement Act. The larger these corporations grow the more economic influence they have on state politics. The hopes of Natives that their economic influence will translate to social influence can only be bolstered by the economic gains of oil drilling.

The State of Alaska has three representatives in U.S. Congress: Congressman Don Young, Senator Ted Stevens, and Senator Lisa Murkowski. Both Senators Stevens and Murkowski are already leaders for the Republicans in the Senate. The opening of ANWR for drilling won't affect their political careers. Looking at the picture of Alaska's role in the federal government, Alaska will more than likely maintain its current role when ANWR is opened. Alaska is already a major oil producing state for the US and this would not change. One way Alaska could gain more power in Congress is through an increase in representation, which only comes with population increase. Oil drilling in ANWR will not increase the amount of people that emigrate to Alaska, and so Alaska's congressional standing won't change.

Native Corporations and the State of Alaska will benefit from production of ANWR's oil resources. Alaska, on the national level, won't gain or lose any standing with a pro-drilling decision. The combination of these factors and no major political drawbacks indicate that the state political ramifications of oil production are better than those associated with the protection of ANWR.

National Ramifications

Opening ANWR has implications for the upcoming presidential election. Bush will be running for re-election and will be able to say that he accomplished his goals for energy. His main energy platform of the 2000 election was the opening of ANWR and with the Mission 2007 Proposal this goal would be achieved. The Republican Party could promote the number of jobs the decision created and the positive effect it potential could have on the economy. Democratic presidential hopefuls would be able to paint Bush as anti-environmental for opening ANWR to drilling. Also some Democrats claim that drilling in ANWR would only be the beginning of GOP plans to roll back environmental protection policies. Since there are so many democratic nominees at this point in the race there are sure to be varying positions on the decision to drill. This variation in position will give voters the opportunity to choose a candidate who reflects their views.

Environmental and energy platforms in Election 2004 won't be the deciding factors in whether a voter votes for Bush or for the Democratic nominee or for a third party candidate. Thus, since drilling in ANWR would minimally affect the election of the President and other government officials, in the long run the national political ramifications would be minimal.

International Ramifications

Oil is bought and sold across country lines like any other commodity. However, since 1973, the practical workings of the oil market have been antithetical to the nature of pure competition. The Organization of Petroleum Exporting Countries (OPEC) has used its power as a cartel to control the market price of oil.

Prior to OPEC's actions in 1973, the price of oil was stabilized at approximately $3 a barrel. OPEC took advantage of the nearly perfectly inelastic demand for oil, and cut its supply; thus, the price for oil rocketed from $3, to $5, to $12, up to today's range of $22 to $28. OPEC will cut or raise production so that the price doesn't deviate from this range. While this sounds like a perfect system for the countries in OPEC, it assumes that OPEC has unlimited production capability and that they can cut off all world oil production.

OPEC itself satisfies neither of those two assumptions. However, they are close. The eleven member nations of OPEC -- Algeria, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates, and Venezuela -- control approximately 35% of world oil production. In many cases, this number would be enough to minimize their impact on the world oil market. However, OPEC controls over 80% of surplus capacity in the world; no other countries can raise production enough to balance out OPEC's influence. Also, OPEC's control of 78% of proven oil reserves gives it a long term capability to control the oil market.

The influence of American drilling in ANWR therefore must be understood within the context of the current oil market. While production in the 1002 region could yield approximately 10 billion barrels of oil, its impact on the world oil market will be minimal. Variations in proven oil reserves can make a difference to one country's power in the market under a more traditional oligopoly, but since the OPEC cartel can simply cut production by an equivalent amount, the price of oil would remain in the current range.

There is a point, however, past which OPEC cannot cut its production, because member nations will simply ignore quotas. However, as world oil demand increases, and with OPEC still controlling a significant majority of the world's excess capacity, the production minimum will disappear within the next decade. And, coincidentally, it will take that decade before significant quantities of oil can be extracted from ANWR. At that point, the world demand will be high enough that OPEC can cut its production by whatever comes out of ANWR and still maintain reasonable quotas for its member states.

For a case study, consider the influence of war in Iraq on the world oil community. Iraq's prewar production level of 1.5 million barrels per day is, within a factor of two, the rate of production in ANWR. The impact of war in Iraq due to the cessation of production of 1.5 million barrels per day was next to nothing. Yes, there was a temporary spike in the price of oil, most of which can be attributed to fears of the war spreading to other oil producing countries; however, the spike was temporary. By compensating in their own export quotas, OPEC was able to maintain the price bracket on oil. Yes, drilling in ANWR is substantially different from war in Iraq; however, the analogy to the oil market impact does hold.

The impact of American oil drilling in the wildlife refuge will be more than the simple number of barrels of oil. The US will send a message that it is willing to do anything to preserve its oil-driven economy. As drilling in ANWR will lead to a slight decrease in OPEC and the Middle-East oil production, the situation for purchasing oil on the European continent could be negatively impacted. This impact coupled with the strong environmentalism present in European countries will lead to tense relationships between the United States and Europe.

The US already has a poor reputation for environmental policy with European countries. This reputation stems from the policies of the United States on international environmental treaties such as the Kyoto Protocol. Many developed nations are disappointed by the fact the US refuses to sign the Protocol and work toward lower greenhouse gas emissions. Opening ANWR for drilling would show environmentalists that the US has less interest in pursuing sustainable resources, and more interest in a cheap source of oil.

In short, drilling in ANWR will have a negligible impact on the economics of the world oil market. In turn, that means that its political impact will be negligible, because the United States will be in no stronger a negotiating position with OPEC. The member nations of OPEC won't have any harder of a job to control the world's oil production. Europe will still have negative feelings towards the United States for its environmental policies and for its continued reliance on oil as its main energy source.

Societal Implications

When evaluating the impact a large decision such as whether or not to drill in the Arctic

National Wildlife Refuge (ANWR) will have on a region, the sociological implications of the action must be taken into consideration. Since the current situation is already known and would not change drastically if drilling did not occur, research focused on what would happen if drilling was allowed. Though the results of drilling may be more pronounced and long-term for the environment, any detrimental or beneficial effects that such operations have on the people of Alaska will be immediately vocalized and brought to the attention of the global community.

Though people throughout the world will be affected by drilling, the people of Alaska are nearest to the heart of the issue and will therefore bear the major effects of oil drilling. Most of the citizens of this state can be grouped into four general categories, based on their beliefs, culture, or current occupation. Though the groups may vary in size and political clout, all have a stake in the future of Alaska. Therefore, the opinions of all four groups must be weighed before a decision can be reached on this issue.

The people who have lived in Alaska the longest are the native tribes. In the ANWR area of Alaska, there are two main tribes - the Gwich'in and Inupiat. The larger Gwich'in tribe subsists mainly on land animals, especially the caribou, and would be adversely impacted by the effects oil drilling would have on these species. In contrast, the Inupiat support drilling because the money it would bring in to the area would allow them to modernize many aspects of their life. Since their diet is primarily one of sea animals, their food source would not be seriously affected by onshore drilling.

Research done on the impact of oil drilling on the rest of Alaska's citizens suggests that such activities may be beneficial in the short-term but detrimental in the long run. Certainly, jobs would be created, but these would be temporary and would expire as quickly as the oil disappeared. Congressional power of the state would rise with increasing oil production, but most estimates conclude that no oil would appear on the market for at least ten years. The eventual influx of new wealth appeals to many of Alaska's citizens, and that is why the majority of the people of Alaska support drilling.

Those who play roles in the corporations and government of Alaska will also be impacted by oil drilling in the 1002 region. There are two different types of corporations, and each has a different view on drilling. The corporations owned by the natives must keep an eye out for the health of the people and the local environment, so they support looking for other places to drill. On the other hand, outside corporations, including the large oil companies, are seeking to drill in ANWR to increase their profits while creating short-term jobs for the local communities.

Finally, Alaskan environmental groups, who of course oppose all drilling, will be affected by drilling. If such activities are allowed, most groups have vowed to issue time and money consuming litigation which will slow the actual start of drilling. This litigation will either increase or decrease the power of these green groups, depending on how it is depicted by the media. Either way, these groups will try their hardest to oust any drilling from the region if it becomes a reality.

In evaluating the total impact of this decision on the people, it was found that there would be several negatives and positives. These effects will be factored into the cost-benefit analysis to determine the overall impact of drilling on Alaska. While no amount of research can correctly ascertain the true impact of future drilling, one can be assured that the sociological implications will be great.

Alaskan Environmentalists

Overview/Background

To a certain extent, many Alaskans, are "environmentalists." This largest subset of the general population includes men and women of every ethnicity and religion who recycle, teach their children not to litter, and help protect the environment in small ways. A smaller portion takes a more active role in environmental protection. Most of these individuals participate in environmental activities while showing respect for the law. Only a small number of environmentalists go to the extreme of breaking the law to "fight" for what they believe, yet this small sample has given a bad reputation to the entire environmentalist movement (Whitehurst, Jr., 2002). The news media's coverage of the outrageous and dangerous activities of the most demonstrative activists has formed an incorrect stereotype of a tree-hugging, dirt-loving green freak as the prime example of an environmentalist.

In recent years, the environmental movement has become slightly more radical. Clinton's election in 1992 led to a decrease in private funding for most groups because the Democratic president was expected to adopt a more liberal environmental policy. To deal with this financial crisis, green groups became dependent on foundation grants from organizations supporting a harder, more extreme environmental line. This in turn meant the environmental groups adopted the donating group's more extreme stance. The Bush administration will therefore have to deal with more aggressive environmental interest groups than did his predecessor's (Thoreau Institute, 2001).

Specifics

General estimates based on informational interviews conclude that roughly three to five percent of Alaskans are registered environmentalists. Surveys suggest that somewhere between twenty and thirty percent of Alaskans support the environment, but the majority of opposition to drilling in the Arctic National Wildlife Refuge (ANWR) comes from outside the state (Defenders of Wildlife, 2003). It has been found that more than half of Americans do not want drilling in ANWR, which means that Alaskans are actually more supportive of drilling than the rest of the nation. This drilling issue has become a focal point for several vocal green organizations, but the majority are not specifically Alaskan in composition. One group web site commented that "opposition to ANWR oil exploration is one of those rare issues where you can find consensus among all or most environmental groups" (Michaels, 2001).

Focusing in on the groups that are based in Alaska, several general trends can be discerned. These groups are closely intertwined and cooperative in nature; they coordinate local, state, and national events to raise awareness about the issue; they are not solely concerned with the issue of drilling in ANWR; and they are typically privately funded (Scanalon, 2003). Political and corporate campaigns are being waged simultaneously, and groups are urging their members and other concerned citizens to write their representatives in Congress and the heads of the oil companies (SaveTheArctic.com, 2003). Very few of these groups currently have a plan for what course they would pursue if drilling was allowed in ANWR, but several have said that some sort of litigation would be forthcoming. Since an Environmental Impact Statement must be written in a process which requires public input before any drilling can start, these groups would definitely use that time to input their opinions on the issue and slow the start of drilling.

The reality is that these groups are not planning a backup because they believe there is "a lot of momentum behind the movement to keep the oil companies out of the area." Since this issue seems to be more about politics than the actual oil that can be taken from the site, some Alaskan environmental groups have stated that they would not accept a compromise on this issue. Opening even a small portion would make the whole area vulnerable, since drilling in only one part would not be economical (Scanalon, 2003).

Another consideration to take into account is the moral support that the environmental groups have recently acquired. Catholic, Protestant, Jewish, and Evangelical Christian leaders formed the National Religious Partners for the Environment, and recent advertisements cosponsored by the National Council of Churches and the Sierra Club say that "caring for creation" is incompatible with Bush's oil drilling proposal (N/A, 2003).

A final consideration is an economic one based on the way green groups view the public lands they are trying to protect. Examples can be found where environmental groups allowed oil drilling in lands they owned to raise money to support efforts to protect other lands that were considered "more valuable." By opposing drilling in ANWR, environmental groups can capitalize on contributions while losing nothing (Lee, 2002).

Conclusion

Environmentalists will not support any amount of drilling in ANWR. The heart of their argument is that "you can't have development and wilderness it's either one or the other. No matter how well done, oil development will industrialize a unique, wild area that is the biological heart of the refuge" (SaveTheArctic.com, 2003). Groups have helped build awareness and resistance to oil drilling in the refuge. If drilling is allowed, costly litigation will be pursued and the issue will not be dropped for a long period of time. This litigation will be similar to that filed after drilling was allowed in Prudhoe Bay or after the Trans-Alaska Pipeline was built, but it will be larger and more intense in scope since more groups are focused on this current issue. To limit the litigation the environmental groups will pursue, the method of drilling that least impacts the environment must be chosen. Drilling itself may actively strengthen the support of the environmental groups, though a perceived improper response to drilling may conversely injure the environmental movement in Alaska.

The lack of compromise that is inherently present in these groups' beliefs makes it easy to see what they want but almost impossible to fit them into an encompassing solution that results in the drilling of ANWR, even drilling that is "environmentally-friendly." Still, the effect these groups will have on the time it takes to actually start drilling, the political and economic cost of their litigation, and their ability to dissipate information about the negative environmental impacts of drilling to the public must not be ignored.

Alaskan Citizens

Alaskans feel that they should have more of a say in what happens to their land than U.S. citizens who live in the states. According to Common Wealth North, a non-profit organization that discusses Alaskan state issues, oil drilling would be beneficial for Alaska for several reasons. First of all, there will be higher income for the state treasury, and this money will create more jobs, and more people will go to Alaska. The population influx will create more power for the state of Alaska because of increased representation in Congress due. It is projected by Common Wealth North that there will be economic benefits from construction activity as well as long term project benefits from construction activity and in-state ownerships of a project.

We must also consider what will happen when the oil runs out. There is a trust fund that is similar to Social Security called the Permanent Fund that holds all the revenue that Alaska makes through oil drilling, and a portion of this money is given to Alaskan citizens every year. As of June 2003, the Permanent Fund was valued at $24.2 billion. It was the voters' decision to create this fund and its purpose is to conserve the revenue from oil drilling to make oil drilling revenues last (Alaska Permanent Fund Corporation, www.aptc.org).

An article written by Don Shackelford in the Anchorage Press reflects upon the book Crude Dreams by Jack Roderick. Shackelford notes that, instead of America being dependent on foreign oil, Alaska's economy will be dependent on oil. Alaska could be analogous to third world countries whose economy is saved by oil which almost always leads to social disruption. He thinks that oil drilling is a love-hate relationship for all Alaskan citizens because of the inherent destruction and exploitation contrasted with the revenue received from oil drilling.

According to Tom Moran's article in the Fairbanks Daily News-Miner, *"Increasing Revenue", s*ome people argue that drilling ANWR will be the only way to pay for the deficit that Alaska has now. However, if there was drilling, it would not produce revenues until after all the reserve money is gone (estimated to be Jan 2007). However, according to Andrea Doll from JuneauEmpire, a barrel of oil would not be seen until 2010, and drilling is a risk because it is not known whether or not revenues from oil drilling will cover the debts that Alaska has.

According to Alaskan Ben Crosby, one of our mentors for Mission 2007, citizens are very active voters, especially concerning local government. For the most part, according to trends, most Alaskan citizens do not have a tendency to save any of Permanent Fund dividends. Permanent Fund Dividends are given out to all citizens of any age, including infants. In our interview, he gave a very relevant example; he introduced a similar situation to oil drilling where an Alaskan town was developed for non-renewable resources. The area was near Kotzebue, and the development was a zinc mine called Red Dog Mine. In this situation, there was a lot of "fast cash" to which citizens flocked. Jobs were created to maintain the services needed to keep up this project of taking zinc out of the mine. This is analogous to drilling in ANWR because oil is a nonrenewable resource and will create jobs for Alaskans as did Red Dog Mine. In the case of Red Dog Mine, fathers and mothers would go to this mine and work there for large amounts of cash that they were not used to. This created a multitude of problems including family breakdown due to parental absence. In addition, lack of income once the renewable resource was gone was a major issue. Due to the culture, most Alaskans do not have a tendency to save for the future, and, when the zinc from the mine was gone, so were the jobs and source of money for these families that were dependent on it.

Although it is true that drilling for oil in ANWR will create jobs and might help pay off the deficit of Alaska State, questions arise as to how fast this money will come in and how long the jobs will last. From past examples such as the Red Dog Mine, the results are not very favorable. Such projects have resulted in quick wealth, and, when the jobs were eliminated because there was no more zinc, the wealth was eliminated as well. Meanwhile, development weakened family units due to absence of parents who worked far from home.

There is a Permanent Fund, and this will help distribute and lengthen the wealth from oil. However, there have been votes as to whether or not Permanent Fund should just be given out in larger chunks, and the votes have come closely in favor. This suggests that the mentality of most Alaskan citizens is not to save.

From estimates, a barrel of oil would not be seen until ten years later if drilling began today. There will be increased power in Congress for Alaska due to increased representation; however, instead of the US being dependent on foreign oil as most proponents for drilling argue, the power of Alaska State will be dependent on something as unreliable as oil drilling.

Native Alaskans

Importance of the Environment

The subsistence strategy of both the Inupiat and Gwich'in depends on the environment. The Inupiat of Kaktovik rely primarily on the sea for their diet, whereas the Gwich'in diet is based primarily upon the Porcupine Caribou and other land species.

Oil Drilling

The majority of Kaktovik Inupiat support drilling. They believe drilling, the revenues associated with it, and the influx of people will improve schools and health care, and create jobs.

The Gwich'in are strongly opposed to drilling in ANWR. "'In 1988, our people became aware of oil companies trying to gain access to the coastal plain of the Arctic National Wildlife Refuge. Oil development there would harm the caribou and threaten our future. So we gathered for the first time in over a hundred years in Arctic Village. The Gwich'in Nation was reborn. Everyone spoke resolutely about how important the caribou are to our culture. At the end of the gathering, we spoke with one voice, one mind and one heart with a renewed commitment to protect our way of life for future generations. We came up with the Gwich'in Nintsyaa-a unified standing resolution calling for permanent protection of the Porcupine Caribou Herd birthplace. The Gwich'in Steering Committee was created." (Faith Gemmil)

Economy and Employment

The Inupiats of Kaktovik need an outside source of employment to bolster their economy and provide them with the funds to improve their living conditions and support technology-enhanced subsistence. Kaktovik does not currently have sanitation facilities, and the unemployment rate is 15.8% (about 10% above the national average), but 27.4% of the eligible workforce is not seeking employment. More drilling in Alaska would result in higher yields from the Alaska Permanent Fund Dividend Program, giving the Inupiats and all Alaskans more purchasing power. The Inupiat native corporation, Arctic Slope Regional Corporation, would increase in value and thereby increase the value of the Inupiat shareholders' stocks if their corporation were to become involved in the drilling process. These jobs, however, would not be permanent, and the economy of Kaktovik would not be stable in the long run.

The Gwich'in also suffer from a high unemployment rate (16.7% in Arctic Village, 36.2% in Venetie, 18.0% in Fort Yukon, and 0% in Chalkyitsik). The percent of natives not seeking employment is also higher in Kaktovik villages (26.3% in Arctic Village, 52.1% in Venetie, 35.6% in Fort Yukon, and 63.8% in Chalkyitsik). More jobs would be available if drilling were to begin in ANWR, but it is uncertain if the Gwich'in would take these jobs. More drilling in Alaska would result in higher yields from the Alaska Permanent Fund Dividend Program, giving the Inupiats more purchasing power. If Doyon Drilling, the Gwich'in regional drilling corporation, became involved in the drilling process, then Gwich'in shareholders' stocks would increase.

Rights of the People

The International Porcupine Caribou Commission [IPCC] (comprised of Venetie, Fort Yukon, and [Inupiat] Kaktovik in Alaska; and Old Crow in the Yukon Territory.) formed to address the rights of Alaskan natives. The IPCC's major joint statement is, "In no case may a people be deprived of its own means of subsistence." A large scale impact to the Porcupine Caribou herd from drilling in ANWR is a threat to the Gwich'in means of subsistence.

Summary of the Inupiat of Kaktovik Perspective

The Inupiat primarily subsist on marine mammals and fish and use land mammals and fowl to supplement their subsistence. While the Inupiat are concerned with the caribou, adverse effects on the Porcupine Caribou herd from drilling would not destroy their subsistence strategy. Instead, the Inupiat Eskimos of Kaktovik are in need of jobs due to the high cost of living and higher than average unemployment rates. Drilling would be the mechanism to revitalize their economy by providing jobs, revenues for sanitation services, increasing their yearly dividends through the Alaska Permanent Fund Dividend Program, and increasing the value of their shares in Arctic Slope Regional Corporation if the corporation is involved in the drilling process. The majority of Kaktovik Inupiats embrace drilling in the 1002 area as long as the drilling is onshore (Drilling offshore would adversely affect their subsistence strategy because the noise from rigs and seismic exploration is proven to deter bowhead whales within a 20 mile radius.).

Summary of the Gwich'in Perspective

The Athabascan Gwich'in (Caribou People) do not as a whole support drilling in the 1002 area as shown through the Gwich'in Steering Committee. They feel that enough research exists to substantiate the claim that oil drilling displaces calving caribou, and if the caribou (their main source of subsistence) are displaced from their prime feeding ground, the herd will dwindle and subsequently the Gwich'in population's food source will decrease. According to the resolution formed by the International Porcupine Caribou Commission, "In no case may a people be deprived of its own means of subsistence." The Gwich'in could benefit from oil drilling through seasonal work, increased dividends from the Alaska Permanent Fund Dividend Program, and if their drilling corporation, Doyon Drilling, Inc., drilled in ANWR, Gwich'in stocks in Doyon would increase from oil revenues. However, the Gwich'in do not value these economic incentives for drilling as much as they value keeping their subsistence strategy and culture intact.

Alaskan Corporations

The Alaska Native Claim Settlement Act divided land in Alaska among several Alaskan corporations, private property, governmental, and national parks. These lands fall on top of each other. This means that the Arctic National Wildlife Refuge and the 1002 area are national parks, yet there are spots of land that are territories of native corporations. These spots of land include primarily the villages of native Alaskans. Such areas are creating the greatest controversy because they are corporately owned, so the corporations feel that they should be able to do whatever they please with this area. The locations are also in a federally protected area, so certain limitations are in place. On the North Slope, the Arctic Slope Regional Corporation (ASRC) is in control of the land. This land includes the 1002 region, which is approximately half of ANWR. The Doyon company is in charge of the largest area of land in Alaska and is in charge of the rest of ANWR. The actions of each company directly affects the other company, because they are so close to each other and share the same types of resources.

Corporations want to drill for oil, because it will lead to profit; however, native corporations, which are owned by the natives that live in the area, are concerned about the condition of the environment and the health of their people. The ASRC has several underlying diversified companies including: ASRC Energy Services and Petro Star which are primarily concentrated on oil drilling, Alaska Growth Capital which is a banking system, and Top of the World Hotel which is a tourist enterprise that depends on a pristine wilderness. Doyon has corporations that are just as varied such as the following: Doyon Tourism, Doyon Drilling, Lands and Natural Resources, and The Doyon Foundation which has an emphasis on the well-being of Native Alaskans. If the native corporations were solely concerned with obtaining oil, one would think they would be completely pro oil exploration in the 1002 area, but the corporations also know that there are other sites in Alaska with oil. For example, the ASRC stated in their 2002 annual report, "ASRC will continue to advocate for development of our resources in the coastal plain of the Arctic National Wildlife Refuge (ANWR), but ANWR is not the only egg in the basket. With opposition in Congress still a barrier to ANWR, oil industry attention is now focusing on the National Petroleum Reserve Alaska (NPR-A). The Company strongly supports exploration and development in the NPR-A because of the jobs and other economic boost it would give to our region" (pg. 4).

In addition, Deborah Williams, part of the Alaska Conservatory, pointed out that the Alaskan government does not acquire taxes from its people or companies and that there is no tourism fee. Several cruises use Alaska as their main destination every season. As stated earlier, the corporations are involved with tourism, and those branches of the corporation could expand and profit form an inflated tourism program. The Alaskan government likes the prospect of drilling because it obtains royalty revenue from the drilling corporations, but revenue can also be obtained from other means such as tourism.

Drilling affects families possibly quite detrimentally. Workers will live at the drilling site for long shifts because of the length of the commute to get to the drilling site. Traditionally, shifts last around two to four weeks. It is not the optimal setting to raise a child in a home that has one or more of its caretakers gone for this amount of time.

Conclusion

The fragile nature of tundra habitats and the uniqueness of the ANWR wilderness makes the principal consideration when developing an extraction strategy the mitigation of environmental disruption. Looking at past construction in the Alaskan North Slope, it becomes clear which methods damage the underlying ecology and which are relatively benign. Some newer technologies, such as elevated platforms, have been employed quite successfully while other more damaging methods, such as gravel roads, have gained increasing criticism. The resulting plan for exploration, development, production, and restoration is as close to ³environmentally correct² as specified by the assignment as we believe can be accomplished while still extracting a significant amount of oil from ANWR.

Because of the need to traverse almost all of the affected region, exploration methods have been an area of special concern. Modern oil development virtually requires seismic exploration to maximize recovery potential while minimizing the number of necessary platforms and wells. Should the studies of 1984-85 prove to be insufficient to locate oil reservoirs, further seismic exploration can be conducted with vibrosies trucks modified with rolligon tires and restricted to seasons and places with sufficient snowfall to protect the tundra. The traditional work camps that follow the equipment will be abandoned and the seismic crews greatly reduced in size. Should this method succeed as planned, the impact from exploration will be minimal.

Once exploration has finished, we advocate the selection of drilling sites with close environmental guidelines and then the construction of such sites on elevated platforms. Operating like their offshore brethren, such platforms should have minimal impact on the local vicinity and be considerably easier to remove than the gravel alternative. A network of elevated pipelines will be erected between these platforms and joined to the pipeline will be small cog railway for maintenance and emergency repairs. All platform materials will be transported to the respective sites by air and the pipelines will be erected by shuttling equipment along the cog rail. The bottom line of the plan is to have structures which can be easily removed and no roads whatsoever within ANWR.

Despite the minimization of impact in the above plan, we also strongly advocate a serious and intensive restoration effort following the end of oil production. All structures should be disassembled and removed. The tundra should be revegetated and the habitat otherwise restored as much as possible to match the state of the surrounding ecosystem. Only then will the extraction project be complete.

But no matter how much care can be taken to minimize the impact of resource extraction, drilling in ANWR will have a negative environmental impact and so it becomes necessary to evaluate whether it is worth engaging in even the best possible method of extraction. A cost-benefit analysis was performed from the prospective of American society to determine if the economic benefits of the oil likely to be extracted from the undeformed region outweighed the social cost of the environmental damage likely to result from the process. The economic benefit was found by multiplying the expected recovery by the probable market price and then by a multiplier to find the total economic benefit with the result being $594 billion +/- 7.4%. The social cost was found by considering ANWR to function as untapped natural capital whose sole worth was its existence value and then integrating the decline and recovery of that value[1]s annual yield over the interval of disturbance. The result obtained, $123 billion, was significantly less than the calculated social benefit of oil extraction.

The data from the cost benefit analysis, therefore, indicates that insofar as this model can measure, it is in the interest of American society to open the undeformed region of 1002 in ANWR to hydrocarbon extraction as specified in the strategy summarized above. This does not by any means constitute advocacy for reversing the recent decision of Congress, nor for opening all of the costal plain to development by all possible methods. We strongly advocate that the deformed region of the 1002 area not only remain closed, but be declared wilderness in exchange for the opening of the undeformed area. Furthermore, the strategy outline above was developed to have the least possible environmental impact and we advocate that any future decision to drill in ANWR take this as the central design principal. The profitability of oil extraction was not and should not be an issue of concern if it would reverse the social cost-benefit analysis. Whether or not any single oil corporation or consortium thereof would ever drill in ANWR with the plan outlined above is a matter for the industry to decide for itself. The above analysis merely concludes that it is in society[1]s interest for such drilling to occur as the benefits from the extracted hydrocarbons would most likely outweigh the social harm their extraction would cost in the form of environmental damage.There is, however, a great deal of further study which must be done before any major decision can be reached. As stated in the cost-benefit analysis, a significant amount of research remains to be done in quantifying environmental damage, especially deeply intangible elements such as the social value of [3]wilderness.[2] Other social factors, such as the disproportionate impact of a decision to drill on Alaskan citizens and especially Alaskan natives, need to be considered. Thorough environmental and geological field tests on the impact of development on the ANWR ecosystem and the exact nature of the buried hydrocarbons would also be essential to making this decision as the data from which we have worked is in many cases outdated and/or incomplete. Many of the technologies suggested in this report also require further feasibility and impact studies - low impact seismic exploration, onshore platforms, and especially the proposed cog rail accompanying the pipeline. In short, much study remains.

What has been presented here is a start and hopefully a road map for devising the ideal drilling plan to employ in ANWR and then the methodology for evaluating the social worthwhile of such a plan. It is our hope that what we have articulated here will be of use as an intellectual stepping stone to an ultimately beneficial decision. It is also our hope that this work will not be taken out of context or employed without its many caveats and that in any event a great deal more research and thought will be dedicated without bias to this challenge. ANWR has significant economic potential to offer us, but it is also an irreplaceable national treasure. It is our hope above all that care, discretion, and sound impartial science will be used to determine the future of ANWR - and of our environment as a whole.

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