BEAUFORT SEA OIL AND GAS DEVELOPMENT/ NORTHSTAR PROJECT

FINAL ENVIRONMENTAL IMPACT STATEMENT

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LIST OF ACRONYMS AND ABBREVIATIONS

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AAC	Alaska Administrative Code
ACMP	Alaska Coastal Management Program
ACS	Alaska Clean Seas
A.D.	Anno Domini
ADEC	Alaska Department of Environmental Conservation
ADL	Alaska Division of Lands
ADNR	Alaska Department of Natural Resources
AEWC	Alaska Eskimo Whaling Commission
ANCSA	Alaska Native Claims Settlement Act
ANWR	Arctic National Wildlife Refuge
ARCO	Atlantic Richfield Company (or ARCO Alaska, Inc., a subsidiary)
ARRC	Alaska Railroad Corporation
AS	Alaska Statute
BACT	Best Available Control Technology
barrels/day	barrels per day
BLM	Bureau of Land Management (USDOI)
B.P.	Before Present
BPXA	BP Exploration (Alaska) Inc.
Btu/hr	British thermal units per hour
°C	degrees Celsius
CAA	Clean Air Act
CAH	Central Arctic Herd (Caribou)
CCP	Central Compressor Plant
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
cfs	cubic feet per second
CIDS	Concrete Island Drilling Structure
cm	centimeter(s)
CMP	Coastal Management Plan
CO	carbon monoxide
COFR	Certificate of Financial Responsibility
Corps	U.S. Army Engineer District, Alaska
CRI	Caisson Retained Island
dB	decibel(s)
dBA	A-weighted sound level
DEIS	Draft Environmental Impact Statement
DEW	Distant Early Warning (Line)
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
°F	degrees Fahrenheit

FEIS	Final Environmental Impact Statement
FR	Federal Register
ft	foot, feet
ft^3	cubic feet
ft/yr	feet per year
GCM	Global Climate Model
gpd	gallons per day
Hz	Hertz
INTEC	INTEC Engineering, Inc.
IWC	International Whaling Commission
kHz	kilohertz
km	kilometer(s)
km/hour	kilometers per hour
km^2	square kilometer(s)
liters/day	liters per day
LMRs	land management regulations
m	meter(s)
m^3	cubic meter(s)
m/yr	meters per year
m^3/s	cubic meter(s) per second
mg/L	milligrams per liter
MLLW	mean lower low water
mm	millimeter(s)
MMS	Minerals Management Service (USDOI)
mph	miles per hour
NAAQS	National Ambient Air Quality Standards
NEPA	National Environmental Policy Act
NHPA	National Historic Preservation Act
NMFS	National Marine Fisheries Service (USDOC)
NO_2	nitrogen dioxide
NOAA	National Oceanic and Atmospheric Administration (USDOC)
NPDES	National Pollutant Discharge Elimination System
NPRA	National Petroleum Reserve - Alaska (formerly Naval Petroleum Reserve Number 4)
NSB	North Slope Borough
NTU	nephelometric turbidity units
NWI	National Wetlands Inventory
OCS	Outer Continental Shelf
ODCE	Ocean Discharge Criteria Evaluation
ODPCP	Oil Discharge prevention and Contingency Plan
%	percent
pH	potential of Hydrogen (measures the acidity or alkalinity of a substance)
PM1	Point McIntyre No. 1
PM_{10}	particulate matter less than 10 microns in diameter

PM2	Point McIntyre No. 2
PPA	Pressure Point Analysis
ppm	parts per million
ppt	parts per thousand
Put 23	Put 23 Oxbow
PSD	Prevention of Significant Deterioration
ROD	Record of Decision
s	second
SCADA	Supervisory Control and Data Acquisition
sec	second
SHPO	State Historic Preservation Officer (or Office)
SO_2	sulfur dioxide
SPCC	Spill Prevention Containment, and Countermeasure (Plan)
SPL	sound pressure level
SPO	State Pipeline Office
SSDC	Single Steel Drilling Caisson
STP	seawater treatment plant
TAPS	Trans Alaska Pipeline System
TOC	total organic carbon
tpy	tons per year
µg-at/L	microgram atoms per liter
UIC	Underground Injection Control (Permit)
µPa	microPascal
USDOC	U.S. Department of Commerce
USDOI	U.S. Department of the Interior
USFWS	U.S. Fish and Wildlife Service (USDOI)
VOCs	volatile organic compounds
VSMs	vertical support members
yd^3	cubic yard(s)

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CHAPTER 5.0

AFFECTED PHYSICAL ENVIRONMENT AND IMPACTS

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CHAPTER 5.0 AFFECTED PHYSICAL ENVIRONMENT AND IMPACTS

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5.0 AFFECTED PHYSICAL ENVIRONMENT AND IMPACTS

5.1 INTRODUCTION

Chapter 5 presents the environmental setting and potential impacts of each alternative on the physical environment. Aspects of the physical environment addressed in this chapter include geology, hydrology, water quality, meteorology, air quality, oceanography, and sea ice. Information in this chapter also supports National Environmental Policy Act (NEPA) decision-making for water discharge National Pollutant Discharge Elimination System (NPDES) and ocean dumping (Section 103) permits.

The information presented in Chapter 5 describes the physical environment in the vicinity of the Northstar Unit and demonstrates how aspects of the physical environment drive selection of alternatives as presented in Chapter 4. Impacts of these alternatives on physical environmental resources are also discussed. The criteria used to determine if an impact on the physical environment is potentially significant were determined based on the NEPA definition of significance, which requires consideration of context (as it affects the affected region, the affected discipline, and the locality) and intensity or severity of the impact. The range of severity/intensity includes none (no impact), negligible, minor, and significant as defined in Section 1.8. The analysis of intensity considered the magnitude of the impact, the geographic extent, duration and frequency, and the likelihood of an impact occurring. Professional expertise and judgement, based on available engineering and scientific data, were used to determine if an impact was significant and, therefore, would require avoidance or minimization to reduce the impact. The text highlights design or operational features of each alternative that are principally responsible for identified impacts, or which substantially reduce impacts that might otherwise occur.

Chapter 5 addresses the following issues related to the project's potential impacts on the physical environment. Issues related to impacts of the physical environment on the project are also addressed.

Issues/Concerns	Section
· Would gravel mining operations at the Kuparuk River affect the channel morphology of the river?	5.3.2
· Would freshwater withdrawals for ice road construction affect lake levels or water quality?	5.3.2
· How would island reconstruction affect sediment quality?	5.3.2
· Would onshore pipeline construction disturb soils, lakes, or rivers?	5.3.2
· Would offshore pipeline construction affect sediment quality?	5.3.2
· Would the stratigraphy underlying Seal Island be conducive to the use of waste injection wells?	5.3.2
· Would subsurface gas affect drilling operations?	5.3.2
· Would island discharges affect sediment quality?	5.3.2
· Would permafrost thaw settlement affect the integrity of the island, offshore pipeline, or shore approach?	5.3.2
· What effect would oil removal have on geologic formations?	5.3.2

Issues/Concerns	Section
· Could pipeline vibration affect pipeline stability?	5.3.2
· What effect would the pipeline have on onshore permafrost?	5.3.2
· Would physical hydrologic processes have a detrimental effect on the onshore pipeline?	5.3.2
· Would coastal erosion affect pipeline integrity?	5.3.2
· Would shoreline disturbances alter coastal erosion patterns?	5.3.2
· Would extension of barrier islands by natural processes affect offshore pipeline integrity?	5.3.2
· Would marine sediment erosion affect the pipeline?	5.3.2
· How would an oil spill affect soils, onshore water bodies, or seafloor sediment?	5.3.2
· Would pipeline inspections/repairs affect soils onshore or sediment quality offshore?	5.3.2
· What would be the sources of air emissions during construction, drilling, and operation activities, and what would be the project impacts upon project area air quality?	5.4.2
· What would be the effects of island reconstruction activities on the bathymetry and marine water quality in the vicinity of the island?	5.5.2
· What would be the effects of pipeline construction on marine water quality and bathymetry?	5.5.2
· Would currents in the project area be altered by the reconstructed Seal Island?	5.5.2
· Would drilling and processing facilities on the island or facilities onshore be susceptible to damage resulting from an abnormally high tide or storm surge?	5.5.2
· How would the breach in the West Dock causeway affect the integrity of the subsea pipeline?	5.5.2
· What would be the effects of operational activities on long-term marine water quality?	5.5.2
· How would an oil spill affect the water quality in the project area?	5.5.2
· Would gravel mining and hauling activities affect the sea ice?	5.6.2
· Could the use of heavy trucks and equipment on ice roads affect the integrity of the floating fast ice enough to delay the project?	5.6.2
· Could winter storms affect the ice road?	5.6.2
· How would installation of the pipeline affect the sea ice?	5.6.2
· Could horizontal sea ice movements during trench excavation affect pipeline installation?	5.6.2
· What extreme ice override events could occur and how would they affect project facilities?	5.6.2
· How would normal ice movement affect the facilities on the island and on the mainland?	5.6.2
· How would the submarine portion of the pipeline be protected against damage from ice gouging?	5.6.2
· Could strudel scour expose the buried submarine pipeline?	5.6.2
· Could damage to the pipeline by an ice gouge or by strudel scour be detected?	5.6.2
· How would an oil spill affect sea ice in the project area?	5.6.2
· How would the pipeline be accessed for repairs?	5.6.2

5.2 TRADITIONAL KNOWLEDGE

Traditional Knowledge is included in this Environmental Impact Statement (EIS) in acknowledgment of the vast, valuable body of information about the Arctic that the Inupiat people have accumulated over many generations. This knowledge contributes, along with western science, to a more complete understanding of the Arctic ecosystem. Although Traditional Knowledge has been accumulating for a much longer time than western science, it has been maintained orally and been recorded sporadically. While such transcriptions have occurred coincident to various research efforts, they rarely have been focused directly on the topics of this EIS. Therefore, in this effort to collect references to Traditional Knowledge on specific topics such as weather, marine conditions, and sea ice, the results are fragmentary and in no way represent the complete body of Traditional Knowledge on these topics.

Traditional Knowledge on the physical environment was obtained from testimony by village elders, whaling captains, and other individuals from the villages of Barrow, Nuiqsut, and Kaktovik at the majority of hearings on North Slope oil and gas development held since 1979. Information also was obtained through personal interviews with interested individuals near the project area. Reviews of engineering studies and environmental reports associated with previous and ongoing oil and gas exploration and development activities provided a source of additional Traditional Knowledge. Published and unpublished scientific reports and data; and environmental reports and studies conducted by universities, the oil industry, federal and state agencies, and the North Slope Borough also were used as sources for Traditional Knowledge.

Inupiat names are spelled according to the transcripts of the hearings, and some statements have been paraphrased to make the information readily understandable.

5.2.1 Geology and Hydrology

Relatively little Traditional Knowledge has been recorded on geology and hydrology issues. Pertinent information that is available focuses on Inupiat experience with erosion and rivers.

5.2.1.1 Geology

In community meetings held in Barrow, a whaling captain made the point that over the years, all the barrier islands from Point Barrow to Dease Inlet along Elson Lagoon, located about 130 miles (209 kilometers [km]) west of the project area, have reduced in size because of the ice (Pers. Comm., Barrow Whaling Captains Meeting, August 27 and 28, 1996:1). Kenneth Toovak, also of Barrow, reported in past testimony for the Diapir Field EIS that, *"Erosion from wind, waves, and storms can be very severe...and should be considered in all decision-making steps."* (USDOI, MMS, 1983:71).

5.2.1.2 Hydrology

Observations of water levels in rivers rising during storms have been made by both Barrow and Nuiqsut residents. A whaling captain in Barrow reported that the biggest storms occur in September, causing water levels in the rivers to rise. Archie Ahkiviana, a Nuiqsut whaling captain, reported that rising marine water levels during a storm surge can force water over the top of sea ice and flood the river drainage in their area to a distance of 18 miles (29 km) (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:8).

5.2.2 Meteorology and Air Quality

Traditional Knowledge on weather and air quality encompasses wind direction, short-term and long-term changes in climate, storms and precipitation, and arctic haze. In discussions on weather, Inupiat residents usually stress the interaction among various physical phenomena; for example, the cause and effect relationship among winds, currents, and ice movement.

5.2.2.1 Weather

Inupiat residents have relayed knowledge on weather in various accounts. Nuiqsut whaling captains explained that Seal Island is most vulnerable to a southwest wind, compared to the milder effects of a northeast wind (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:3). A Barrow whaling captain reported that in fall and winter the prevailing wind is northeast, with occasional strong west winds. Nuiqsut elder Sarah Kunaknana grew up in the project area and reported that storms can come from different directions, but usually are from the north, and observed that the area inside the barrier islands is not affected heavily by storms (Pers. Comm., Nuiqsut Community Meeting, August 14, 1996:2).

Warren Matumeak, a Barrow resident, reported that during the last part of September or October the weather begins to change; typically snow is falling, and fog and ice form during this period (USDOI, MMS, 1990:41). Nuiqsut hunters pointed out that snow drifting around Seal Island will begin in October, explaining that October through December are the critical months for snow drifts. A Nuiqsut resident indicated that in recent years there have been climate changes resulting in warmer temperatures. Residents recently observed blue jays for the first time in these northern areas (Pers. Comm., Nuiqsut Community Meeting, August 14, 1996:4).

Inupiat residents have relayed numerous accounts of their experience with extreme wind and storm events. Thomas Napageak, a Nuiqsut whaling captain, described an incident where a boat was swamped after abandoning a whale because, *"The wind got so fierce, south, southwest wind..[at] night."* (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:13). Sarah Kunaknana indicated that a warm breeze and warming temperatures in the summer are indicators of an impending major storm (Pers. Comm., Nuiqsut Community Meeting, August 14, 1996:2). In recent public meetings, Barrow whaling captains John Nusunginya and James Ahsoak described how the weather changes constantly and is very unpredictable, and that the biggest storms occur in September (Pers. Comm., Barrow Whaling Captains Meetings, August 27 and 28, 1996:3). Jonas Ningeok, a Kaktovik resident, described the sudden and extreme storms that occur in the Alaskan Beaufort Sea: *"...from experience, I know no matter how beautiful the day may look, in a moment's time, we can have a snow storm...that you can't even see [the] distance...to the end of the table.... It doesn't happen every year, but when it does happen, there's no* *telling [when].... As we were growing up, there have been several times when my...father [would] look up at the clouds, the sky, and tell us to get everything...all the firewood.... We'd get everything ready, and without any notice at all, it would seem like that all this storm would come upon us..."* (USDOI, MMS, 1990:20-21).

Thomas Napageak explained how whaling camps are located partly based on wind protection considerations: "*[camps] ...used to be at Narwhal [Island], but we abandoned that due to the fact that...you got no protection from fierce winds or winds from any direction. You are out in the open. But at Cross [Island], you are in a cove where you have shelter from both the south and northeast wind and north wind. Even if its offshore wind, you can get into one of the smaller coves and have protection...we find the protection that we want at Cross Island, regardless of the weather conditions."* (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:27).

5.2.2.2 Air Pollution

Very little Traditional Knowledge on air quality issues was found in a review of testimony by local residents. At a public hearing on Lease Sale 144, Frank Long, Jr., a Nuiqsut whaling captain, observed: *"...there is air pollution by the [oil] industry that forms and shifts every which way the wind turns. It's a yellow smog that you can see this time of year [November] till spring."* (USDOI, MMS, 1995:23). Joseph Akpik, another Nuiqsut resident, stated: *"There's a hydrocarbon fallout that is going on.... I've seen it; it's just like smog out there. The cold weather sets in from the air, and it keeps that hydrocarbon fumes coming out, and it falls out to the tundra and the waterways..."* (USDOI, MMS, 1995:31-32).

5.2.3 Physical Oceanography and Marine Water Quality

From the point of view of local residents, several factors determine the behavior of the physical marine environment, including the season of the year. Local residents understand that different aspects of the marine environment are tied together and work in combination to create dangerous conditions. Much of Inupiat knowledge regarding the offshore environment has been derived from their experiences during the fall whaling season, which can extend from the last week in August through early November (T. Napageak and F. Long, Jr. - Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:16). Late summer and fall is considered a dangerous time in the project area offshore of Nuiqsut and near Cross Island, with the occurrence of storms, storm surge flooding, and the formation and movement of ice. Unpredictable conditions during this period, particularly with respect to moving young ice, result in elders warning hunters not to go out because of the risk involved (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:1).

5.2.3.1 Water Levels

In a Northstar public meeting, Thomas Napageak relayed knowledge of the interaction between wind and water levels: *"...you don't get...high tides [storm surges] on a northeast wind.... But when we've got the southwesterly wind, that's when the tide [water level] comes up."* (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:7). Nuiqsut residents spoke of big storm surges occurring at Cross Island, accompanied by two-story high waves, high winds, and flooding across the center of the island. They gave an account of a storm that occurred during the second week of September one year, when sand bags were used to control water at Cross Island, and they had to pull out and run to higher ground (Pers. Comm., Nuiqsut Community Meeting, August 14, 1996:2).

Frank Long, Jr. described how a rising tide or storm surge can force water over the top of sea ice and flood river drainages, *"If there's enough water that comes in, it'll bring the ice up, plus water will be flowing...up over the edge."* (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:8). An example of a negative storm surge was also observed by Nuiqsut whaling captains who reported that, in 1977, the water drained out of a bay near Oliktok Point and then came back in (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:3).

5.2.3.2 Currents

Nuiqsut residents indicated that currents are very strong in early fall and move from west to east (Pers. Comm., Nuiqsut Community Meeting, August 14, 1996:2). They also indicated that currents resulting from a northeast wind are not as strong or dangerous as currents resulting from a southwest wind. Thomas Napageak reported: *"From...northeast, wind and current is not [as]...fierce.... South southwest wind, that's the wind that...Seal Island is going to be in danger [of]...the current is very strong, and...they both work together, the current and the wind."* (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:6-7).

Inupiat residents have relayed observations of the currents changing with distance from shore and location along the coast. Frank Long, Jr. indicated, *"The further you go [out from shore], the stronger it gets."* (USDOI, MMS, 1995:24). Nuiqsut whaling captains spoke of a strong current they have encountered during the fall whaling season offshore of Cross Island, sometimes at a distance of about 40 miles (64 km). Thomas Napageak reported: *"...from Cross Island, it moves in and out. You can get to it...sometimes in half an hour, sometimes hour and a half, by outboard.... This movement...ties in with Point Barrow current."* (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:13). According to Frank Long, Jr., the location of this current, *"...move[s] every year...just like everything else, it sways."* (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:13). *"We had to go 40 miles or so out there to get to those whales who were migrating.... And that's when we run into super heavy fast current that don't need no wind force to help it. It helps itself, break its waves."* (T. Napageak and F. Long, Jr., Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:16). Nuiqsut residents spoke of Seal Island lying just far enough toward the shore to avoid the zone of major current movement, and that Northstar Island is in a much more dangerous place (Pers. Comm., Nuiqsut Community Meeting, August 14, 1996:2). During testimony given at public hearings for the Diapir Field lease sale (Chukchi Sea), Barrow resident Arnold Brower, Jr. stated, *"...the area from Midway Island [near Barrow] to Flaxman Island...has even stronger currents in comparison to the proposed area of the lease sale."* (USDOI, 1982:43).

A Barrow whaling captain explained that when the wind hits the top of the ocean and forces the current down and causes it to change, it swirls and creates underwater storms. Combined with the presence of broken ice, these swirling conditions can be extremely dangerous (Pers. Comm., Barrow Whaling Captains Meetings, August 27 and 28, 1996:1). A Nuiqsut whaling captain remarked that there is free water always moving underneath the ice, especially with a southwest wind (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:2). Ben Nunqasuk expressed concern about the strength of the currents through an interpreter: *"He doesn't want drilling because he knows the sea is rough and the current is strong, it can do anything without even the help of the wind. The current is so strong that it can damage anything."* (USDOI, MMS, 1982:46). In addition, under solid ice cover, Inupiat residents also have relayed observations of under-ice currents and currents changing with depth. Nuiqsut residents spoke of constantly changing currents, different in magnitude on the surface and bottom (Pers. Comm., Nuiqsut Community Meeting, August 14, 1996:4).

5.2.4 Sea Ice

Through Traditional Knowledge, Inupiat residents often describe the power of sea ice and its movements along the Alaskan Beaufort Sea coast. As with physical oceanography, the interaction between storms, currents, wind, and ice affects the behavior of ice. Similarly, the interaction of polar pack ice and "young" ice that forms annually affects ice movement and behavior.

5.2.4.1 Ice Formation and Zonation

Inupiat knowledge of sea ice zones distinguishes between a floating landfast zone, a shear zone, and the Arctic (or polar) ice pack. Thomas Napageak indicated local knowledge of ice zones near Cross and Seal Islands: *"...the floating ice is usually located about three-quarters of a mile from the sand spit [at Cross Island],...where it's deep, it hits bottom there, that's how far [towards shore] the Arctic ice pack gets to be. But over at Seal Island, it's much further out.... But anything in between is something that has, is formed yearly. And it crushes by this Arctic ice pack."* (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:6). Nuiqsut whaling captains indicated that Seal Island is in a more stable nearshore zone with respect to ice and current conditions than Northstar Island, where currents and movement of the polar pack are much stronger. They report that the polar ice pack does not reach Seal Island because it is too heavy and becomes grounded before it gets there (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:2).

Rex Okakok of Barrow stated: *"Sea ice, and icebergs, constitute potentially the most serious natural hazards in the Arctic ... The effect of the sea ice is both variable and patchy in its role as discontinuous boundary with consequences for the surface fluxes of momentum, mass, and energy, and for the resultant circulation and mixing."* (USDOI, MMS, 1987:34).

Frank Long, Jr. relayed his observations of the polar ice pack: *"... ice...not only form[s] on shore; it's* *already out there. It's out there year round, 365 days a year."* (USDOI, MMS, 1995:24). Thomas Napageak stated: *"The polar ice pack is visible most of the years. I would say that within all the time I've been whaling out there [23 years], there were three seasons that the polar ice pack was too far out for me to even see."* (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:11).

One Nuiqsut resident mentioned that there have been changes in ice formation patterns in recent years, indicating that the ice is not forming the way it used to and that animals (probably seals) are going farther out and following the ice to find food (Pers. Comm., Nuiqsut Community Meeting, August 14, 1996:4).

5.2.4.2 Ice Season

Inupiat residents provided comments on the occurrence of sea ice during different seasons of the year. Joseph Nukapigak stated, *"...In the Arctic, nine months out of the year...we have sea ice."* (USDOI, MMS, 1995:15-16). Thomas Napageak remarked: *"...The critical months [for ice formation] are October, November, and December. After the first of the year, the ice is solid enough that you'll start moving further north from the shore-fast ice."* (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:7). Elijah Kakinya, an Anaktuvik elder, stated: *"In summer months, when there is a westerly wind, you can see [polar pack] ice from shore. But when the wind is blowing from northeasterly, the ice always goes out...you can't see any ice from shore when the wind is blowing from the northeast..."* (NSB, 1980:152).

5.2.4.3 Ice Movement

Inupiat residents consider October through December to be the most critical months of the year for ice movement hazards offshore of Nuiqsut and near Cross Island, due to storm conditions and the formation and movement of ice (Pers. Comm., Nuiqsut Community Meeting, August 14, 1996:1-3). Nuiqsut whaling captains explained that Seal Island is most vulnerable to ice movement in a southwest wind, compared to the milder effects of a northeast wind. Extremely hazardous conditions result from a combination of storm, current, tide and ice factors, particularly with a southwest wind. Momentum generated by moving polar ice under these conditions pushes and accelerates young ice that is 1 to 2 feet (ft) (0.3 to 0.6 meters [m]) thick (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:1). Samuel Kunaknana, a Nuiqsut elder, stated: *"It's always a real hazard, especially when the wind is from the west during the wintertime. But at this time of year [April]...when the ice is more solid,...it would seem it was less hazardous than during early winter."* (USDOI, MMS, 1990:29). Michael Jeffrey of Barrow explained that when wind combines with strong currents, these elements can move the entire ice sheet *"...and there's nothing that's going to stop it."* (USDOI, MMS, 1982:32-33).

Inupiat residents note that changes in wind direction are responsible for shifting the ice pack, and that anytime the wind shifts, the ice pack follows. Frank Long, Jr. stated, *"...Every time the wind shifts, the [polar] ice pack will start to shift around, when the wind changes back, then it goes back again."* (Pers.

Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:10). Otis Ahkivgak reported: *"The wind controls the ice movements. When there is no wind, there is no ice movement, but whenever the winds are strong, the ice starts moving. It always happens like that as far as I know."* (NSB, 1980:100).

Inupiat residents observe that the polar ice pack provides the force that moves young ice. This young, forming ice is of primary concern to whalers with respect to ice movement hazards. Thomas Napageak stated: *"...about 50 years I have been in the Arctic area...using the subsistence resources of the sea. I've never seen the polar ice pack tearing up.... The most dangerous of the...ice conditions...[concerns] the ice that is formed...from the mainland out to the Arctic ice pack; the polar ice pack is the force that tears up this ice..."* (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:3). He also observed on ice movement: *"...for the wind to push the arctic ice pack towards shore; ...there's no current--it's the wind that's doing it. It'll stop when it gets into shallow water. There's hardly any force on it."* (Pers. Comm., Nuiqsut Whaling Captains Meetings, August 13, 1996:12).

Nuiqsut whaling captains speak of the power of the ice and ocean when combined with currents, wind, and storm conditions. They indicate it is often unpredictable and moves fast. Polar pack ice can gain speeds of 3 to 6 knots (6 to 11 km/hour) when it moves, which pushes the young ice and smaller floes, causing it to "swing around" at speeds of up to 8 to 12 knots (15 to 22 km/hour) (A. Ahkiviana - Pers. Comm., Nuiqsut Whaling Captains Meetings, August 13, 1996:3; F. Long, Jr. - Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:9).

Residents have relayed many incidents of people killed on the ice during movement events (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:1). The swiftness of the event is illustrated by Thomas Napageak's example: *"Back in the...1940s,...a family of four traveling in...December...[in] this ice that has formed itself this side of the arctic/polar ice pack. The wind hit as they were traveling by dog team.... It was stormy, blowing, and it was south wind, like the wind...when the tide [storm surge] comes up. That polar ice pack moves swiftly. That's when right in their path, it cracked opened up and closed again. ...The ice being pushed by this polar ice pack...went up.... The two kids...got under and [it] flatten out again. In the meantime, part of it cracked open. The wife fell down and [it] closed on her, caught her. Her husband grab his knife and tried to chop the ice out, but she went down anyway."* (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:4). Nolan Solomon, a Kaktovik whaler, described being stranded on the ice when it began to move and all the boats were crushed (USDOI, 1990:29-30).

Wildlife is affected by ice movement also. Samuel Kunaknana stated: *"The animals, like people, travel to stay alive. The people in turn follow the animals, because this is what they live on. The polar bears live on the ice, but a female does not have her young on the ice, knowing how the ice moves. ...They know that the ice never stops moving and [is] threatening to live on."* (USDOI, MMS, 1979:5).

Landfast Ice Movement: Inupiat residents have relayed incidents of apparently stable landfast ice breaking off from the mainland and floating away. Thomas Napageak indicated that this phenomenon could happen anywhere and gave an account of an incident in the late 1980s, when, during the month of November, barges tied together were ripped from their concrete moorings at West Dock and taken to Barter Island (to the east) by the movement of the ice (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:5). *"A lot of good stories about the ice breaking up on people, and while trying to get help by foot, [they] froze to death. ...In Barrow...area, there have been people that have been floated out, but they've always come back."* (T. Napageak - Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:6). He reported: *"[In the] Pole Island area,...a family was moving from...either Brownville or Flaxman on their way to Tiragroak to meet with families there for Christmas week holidays. That's when it happened....the ice went out, broke off the edge and just float the people out...they were out there drifting around for about a week. Evidently, when it freezes over again or the lead closes, they managed to get back to their homes."* (T. Napageak - Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:4).

The effects of the vertical movement of landfast ice due to tides or storm surges have been noted by local residents. Frank Long, Jr. stated, *"If there's enough water that comes in, it'll bring the ice up, plus water will be flowing over up over the edge..."* (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:8). According to Thomas Napageak, *"...When the tide comes, these chunks of ice that are...frozen [in place], the ice breaks around them, and...that's where the water comes out."* (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:8).

Pressure Ridges/Shear Ice Zone: Inupiat residents report that ice movement is much more dangerous in the deeper, faster moving waters offshore of Cross and Northstar Islands, than inshore of Seal Island and the barrier islands (Pers. Comm., Nuiqsut Community Meeting, August 14, 1996:2), due to active ridge formation in the shear ice zone. Ice coming from the north forming pressure ridges is not considered as dangerous as ice which moves from side to side, particularly from southwest to east, like the ice that moved the barges in the example given above (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:2).

Henry Nashaknik, a Barrow elder, stated, *"...These big pressure ridges which have been grounded on the ocean bed, when these become grounded in shallow water, they call them kisitchat."* (NSB, 1981:414). In testimony gathered during the Diapir EIS, Joash Tukle of Nuiqsut warned that pressure ridges form up to 20 ft (6 m) high in some areas (USDOI, MMS, 1982:5). The correlation between ridge formation and wind has been observed by Otis Ahkivgak, a Barrow elder, *"The ice beyond the islands is unpredictable; even though it's frozen thick, it forms large pressure ridges when it's windy in any direction."* (NSB, 1980:100). Thomas Napageak noted that the pressure ridges are higher following winters when the polar ice pack is further out to sea (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:11).

Leads: The formation of open leads in sea ice is important to the Inupiat with respect to ice movement and open water hazards, as well as ease of travel over the ice. Leads are unpredictable and appear in different places every year. They also open and shut quickly, which is the primary reason why there is no spring whaling season in Nuiqsut (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:2). Bernice Pausanna of Nuiqsut stated: *"When you're out on the ice, everything happens real fast, and anything can happen in less than two, three minutes. When you're out on the ice, when the wind changes, opens a crack, then you have an open lead all of a sudden. Then you have to pack everything and go to safe ice. It happens real fast, even closing."* (USDOI, MMS, 1995:41).

Wind causing leads to open also was noted by Elijah Kakinya in the following account: *"...westerly wind usually opened the lead. There's a break before it gets real frozen in. When the wind shifts over to a northeasterly wind, it moves on the shore ice. The ice usually crumbled up and formed some pressure ridges way out on the edge of the lead."* (NSB, 1980:152).

During the fall whaling season, hunters often look for leads as a travel pathway. Henry Nashaknik stated: *"I know people from Napaqsralik [Cross Island, who]...hunted on open leads. When the wind is from the west, the leads would open."* (NSB, 1980:152). Frank Long, Jr. observed, *"...During the fall when we're out on ice, heavy ice conditions, there are...leads that open up."* (USDOI, MMS, 1995:24). Leonard Tukle, a Nuiqsut whaling captain, recalled: *"I remember one time when there was heavy ice all the way along the coast, we had to come...pretty close to the rig [near Seal Island]...for driving out for open water. The only open lead that we had was around that rig at one time. I think this was in '91 or '92."* (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:17).

Open Water Floe Movement: Inupiat residents noted the following with respect to the occurrence and movement of ice floes during the open water season. According to Walter Akpik, Sr., of Barrow: *"The ice moves out on the ocean side of the islands and the mainland; goes out towards the ocean during the spring breakup in between the islands. The ice from the ocean [polar ice pack] hardly ever gets inside the bays. Sometimes there might be a piece in there now and then. The bays are clear of ice by the middle of summer."* (NSB, 1980:106). Elijah Kakinya noted: *"In some years when the ice goes out in spring, it isn't visible in summer. Some years the ice goes out and comes back and is visible, and hangs around all summer months."* (NSB, 1980:152). Harry Akootchook of Kaktovik indicated that the ocean currents are strong in that area, with big icebergs (USDOI, MMS, 1982:5).

Inupiat residents speak of the movement of ice floes as being controlled primarily by wind direction. Elijah Kakinya stated: *"In summer months, when there is a westerly wind, you can see ice from shore. But when the wind is blowing from northeasterly, the ice always goes out...you can't see any ice from shore."* (NSB, 1980:152). Henry Nashaknik, who has hunted for several decades in the vicinity of Cross and McClure Islands and the Colville and Sagavanirktok Rivers, provided similar observations: *"...when the wind is constantly from the east in the summer months, all the ice goes out seaward of these barrier islands. The coastal ice [also] goes out when the wind is from the west, but even when the wind is strong and constant from the west, the ice seaward of the barrier islands is still visible. Only when the wind changes from west to east does it [ice floes] finally go out completely."* (NSB, 1980:152). Bruce Nukapigak, a Kaktovik elder, observed: *"The pieces of polar ice come in through the bay between Return Islands and Midway Islands; this is...when the strong winds are from the west. When there is little wind, the currents really play with ice along there."* (NSB, 1980:174).

The movement of ice floes through barrier island channels due to tides or storm surges was noted by Bruce Nukapigak: *"...In summer months and at Pinu, Bodfish and Cottle Islands, the pieces of ice move in and out through the channels with the tides. The polar ice gets pushed in from the ocean just west of Napaqsralik [Cross Island] to Beechey Point. There is no strong current on the ocean side of the islands,...but the ice in places with "singaq" [channels] are controlled by the tidal currents."* (NSB, 1980:174).

5.2.4.4 Ice Pile-Up and Ride-Up

The force and speed at which ice moves during the fall season, potentially causing override situations, is of great concern among the Inupiat people. Whaling captains observe that the polar ice pack "crunches up" young (first-year) ice that is 1 to 2 ft (0.3 to 0.6 m) thick with great speed and force (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:3). This hazardous condition typically results from a combination of storm, current, tide, and ice conditions, particularly under a southwest wind, according to Thomas Napageak (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:3). Otis Ahkivgak, a Barrow elder, spoke about the wind being the main controlling force behind major ice override events (NSB, 1981:100). Kaktovik residents indicated that these powerful ice movements can occur even without the contributing factor of wind, because the currents in that area are extremely strong and swift (H. Rexford in USDOI, 1979:49; J. Ningeok in USDOI, MMS, 1990:19-20).

Numerous reports of extreme pile-up and ride-up events have been documented through testimony and transcripts. Phillip Tikluk, Sr. of Kaktovik described the ice piling up on a 30- to 40-ft (9 to 12 m) cliff by Kaktovik one June, depositing 5 to 6 ft (1.5 to 2 m) of ice on top of the cliff (USDOI, MMS, 1979:4). A similar event was reported by Archie Brower at Bullen Point in the vicinity of Flaxman Island, located approximately 40 miles (64 km) east of the project area: *"I saw how a garage that was about 30 ft (9 m) above the water line on the coast had been destroyed by ice.... Ice had piled up...from both the east and the west."* (USDOI, MMS, 1979:4). In a description of possibly the same incident at Bullen Point, Thomas Napageak and Archie Ahkiviana both indicated that the garage was located inland approximately 50 to 100 ft (15 to 30 m), and that the force of the ice bent a steel H-beam in the garage, popping 1-inch (2.5 centimeter [cm]) bolts out of the cement (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:9). A Nuiqsut elder described an incident that happened in the 1940s on one of the offshore islands in the area (possibly Cross Island), where a family was camping and ice moved onto their tents as they slept, killing them (Pers. Comm., Nuiqsut Community Meeting, August 14, 1996:2). Hugo Engel of Barrow reported that he witnessed huge, massive pieces of ice taking down utility poles during an extreme override event (USDOI, 1982:86). Warren Matumeak, also of Barrow, indicated that he had seen ice override a 20-ft (6 m) bluff at the far end of town (USDOI, MMS, 1982:92). Charles Edwardsen of Barrow recalled a situation where ice destroyed a manmade structure (USDOI, MMS, 1982:22).

Inupiat residents have remarked on the speed at which ice override events can occur, as well as how rapidly ice conditions can change. Archie Brower of Kaktovik reports: *"The ice conditions are very changeable. Unusual storms can come up at any time, and if wind and currents combine in certain ways, the ice destroys structures on or near the ice pack."* (USDOI, MMS, 1979:4). Several Kaktovik hunters described these ice events as occurring very rapidly, allowing little time for response (J. Ningeok in USDOI, MMS, 1990:19-20; H. Rexford in USDOI, MMS, 1979:49; P. Tikluk in USDOI, MMS, 1979:49).

Information regarding ice override at barrier islands and along shorelines inshore of barrier islands are found in several sources of Traditional Knowledge. Bruce Nukapigak, an 18-year resident of the Siklaqtitaq (Point McIntyre) and Beechey Point areas, indicated: *"The ice piles up along the coast outside* *of the barrier islands [at Beechey Point]...[and that he's] never seen big piles like you get at Utqiagvik [Barrow]."* (NSB, 1980:174). Walter Akpik, Sr. stated: *"I have seen the ice pile up on the side of the barrier islands, but never covering them completely. During our first winter at McClure Island, the ice was moving and piling up so high, that some ice broke off the top and almost hit our house. This island is not very wide and our house was in the middle of the island, and that piling ice just barely missed reaching it."* (NSB, 1980:106). Elijah Kakinya, a resident of Flaxman Island, reported: *"...on the lagoon side...after the ice formed and froze, it never moved or made any disturbance...in fall, the ice usually crumbled up and built ridges along barrier islands...I never noticed any ice slide over the barrier islands...when the ice crumbled up along the ocean side of the barrier islands, the highest points...were approximately 12 to 15 feet high."* (NSB, 1980:152). Archie Brower reported that during years in which the ice is thin in the winter, it can, *"...override even high coastal bluffs in areas that are inside the barrier islands"* (USDOI, MMS, 1979:4). In addition, the ice at times has pushed from the ocean side of the Kaktovik airport road to the lagoon side, blocking the road (A. Brower in USDOI, MMS, 1979:47-48).

The many years of observation by Inupiat residents include occasional extreme events. Isaac Akootchook of Kaktovik gave an example of the necessity for considering many years of data to predict extreme events, when he described ice that piled up as much as 40 ft (12 m) high at the shore in this area, adding, *"... but for many years - maybe 50 years now - we haven't seen [it that high]."* (USDOI, MMS, 1982:3). Nuiqsut whaling captains questioned the scientific concept of a 100-year event, particularly as a severe event that only happens once every 100 years. They indicate that it could happen more frequently and during any year and that they never know when (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:3). However, Nuiqsut residents generally were less concerned about dangerous ice conditions near Seal Island, which is in a more stable nearshore zone, compared to greater hazards near Northstar Island, which is near the shear ice zone (Pers. Comm., Nuiqsut Community Meeting, August 14, 1996:2).

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5.3 GEOLOGY AND HYDROLOGY

5.3.1 Affected Environment

Active geologic and hydrologic processes contribute to the development and continual modification of both the onshore and offshore physical environments. These factors, in combination with climatic and oceanographic conditions, have resulted in unique physical characteristics, including a partially relict (having survived from an earlier era) shoreline, onshore and subsea permafrost, and permafrost-related thaw features. “Hydrologic environment” in this section refers to onshore surface water and groundwater. Marine waters are discussed in Section 5.5.

5.3.1.1 Physiography and Landforms

The onshore portion of the project area is located on the Arctic Coastal Plain. The coastal plain is within the zone of continuous permafrost and has flat to rolling terrain with many shallow ponds and lakes (Figure 5.3-1). The coastline consists of beach bluffs, bays, spits, and bars. Deltas form along the coastline at the mouths of large rivers, such as the Kuparuk, Colville, and Sagavanirktok.

The ground surface over most of the flat thaw-lake plain varies by less than 6 ft (1.8 m), except at pingos, which may reach 60 ft (18 m), and along banks of the larger streams (Walker and Acevedo, 1987:3). Low-centered and high centered ice wedge polygons, geometric topographic features caused by ice formation in soil and subsoil, cover most of the project area and all four of the onshore pipeline routes considered in this

Figure 5.3-1 (page 1 of 2)

Figure 5.3-1 (page 2 of 2)

EIS. The gravel source for the reconstruction of Seal Island is located within the floodplain near the mouth of the Kuparuk River.

The coastline within the project area contains numerous spits and barrier islands formed by longshore currents. The shallow nearshore area is semi-enclosed to the north by these low barrier islands (Figure 5.3-1). The barrier islands are composed mostly of sand and gravel; however, some parts are submerged remnants of a once more extensive coastal plain. The bluff at the Point Storkersen landfall (Alternatives 2 and 3) ranges in height from 3 to 4 ft (0.9 to 1.2 m) (CFC, 1996:4). The landfall for Alternative 4 is located in an intertidal area with a shallow sloping shoreline. Alternative 5 intercepts the manmade West Dock gravel causeway. Several other offshore features have been built in the project vicinity including Seal Island, Northstar Island, and the Endicott causeway and islands.

5.3.1.2 Regional Geology

Structurally, the project area is dominated by the effects of Jurassic and Early Cretaceous rifting (Plafker and Berg, 1994:17). The period of rifting (pulling apart) resulted in the formation of the Canada Basin, an ocean basin which lies northeast of the central Alaskan Beaufort Sea shelf. A generalized stratigraphic column (diagram showing subsurface rocks) for the project area is presented on Figure 5.3-2. Metamorphic rocks (of Silurian and Ordovician age) form the deep basement complex in northern Alaska. These rocks are overlain by a series of sedimentary rock units which range in age from Devonian to Quaternary.

The Northstar reservoir is located along the north side of the Barrow Arch within the Triassic age Ivishak formation, which is part of the Ellesmerian sequence (BPXA, 1996b:3-1; BPXA, 1997:Table 3.6-1). The oil reservoir is at a depth of approximately 10,839 to 11,100 ft (3,304 to 3,383 m), and generally is situated beneath the manmade Northstar and Seal Islands (Figures 4-2, 4-3, and 4-4). The Northstar oil deposit exists because impermeable rocks overlying the Ivishak formation are folded downward and form a trap (Figure 4-3).

Two proposed waste injection zones (for disposal of produced water, drilling wastes, surface runoff, and domestic and/or sanitary wastes generated from the project) are depicted on Figure 5.3-3. Details of the waste injection process and receiving formations are presented in Appendix A. The zones lie at approximate depths of 4,000 and 4,700 ft (1,219 and 1,433 m) within sandstones of the upper Cretaceous-age Prince Creek/Ugnu formation (BPXA, 1997:Table 3.6-1). Waste injection zones are located beneath a low permeability confining zone within the Tertiary-age Sagavanirktok formation, and above a low permeability shale barrier within the upper Cretaceous-age Seabee formation. The upper and lower barriers isolate both waste injection zones from the formations above and below, including the oil producing unit. These injection zones and upper and lower confining layers are the same units successfully utilized for waste disposal at the Prudhoe Bay and Duck Island units (BPXA, 1997:Appendix A). Appendices J and N contain the draft and final Underground Injection Control permits, respectively.

Seismicity within the North Slope region is relatively low. Seventy-three earthquakes were recorded along the Arctic Coast from Point Barrow to the Canadian Border between 1937 and 1992. The magnitude of the earthquakes ranged from less than 1.0 to 5.3 on the Richter Scale, and most were centered in the Camden Bay region, located approximately 80 miles (129 km) east of the project area. There are no records of any damage to facilities at Prudhoe Bay resulting from these events.

Shallow faults are known to occur along the Alaskan Beaufort Sea shelf outside the project area. These faults have been reported northwest of Milne Point associated with the Barrow Arch and offshore of Camden Bay (Craig et al., 1985:152). Although it is possible that additional high resolution seismic surveys could show more shallow faults within the project area, there are no major faults on the Northstar reservoir formation at the depth of the waste injection zones (BPXA, 1997:3-2).

The presence of shallow gas has been observed on high resolution seismic data collected from Stefansson Sound within the project area (Craig et al., 1985:161-163). Shallow gas has been mapped near Endeavor Island and offshore of Midway and Cross Islands (Craig et al., 1985:Figure 47). However, the four exploration wells drilled at Seal Island did not encounter shallow gas deposits.

Subsurface gas can also occur in marine environments in the form of gas hydrates (solids composed of ice and gas). Gas hydrates tend to cement the sediment, creating a zone of reduced permeability at their base that may act as a trap for free gas (Grantz et al., 1982:29). Gas hydrates typically occur near the seafloor under low temperature and high pressure conditions of the Beaufort Sea in water depths exceeding approximately 1,000 ft (305 m) (Grantz et al., 1982:29). Gas hydrates are also known to occur at shallow depths onshore in the Prudhoe Bay area where permafrost conditions exist (Kvenvolden and McMenamin, 1980:1-3). Based on geophysical data collected across the Beaufort Sea shelf, gas hydrates are estimated to occur in the Northstar Unit at depths ranging from approximately 2,953 to 4,921 ft (900 to 1,500 m) (Collett - Pers. Comm., 1997:2).

5.3.1.3 Permafrost

Permafrost is defined as ground that remains at a temperature below 32 degrees Fahrenheit (°F) (0 degrees Celsius [°C]) over a period of many years. Permafrost is present throughout the project area, both onshore and offshore. Permafrost is present along the Arctic Coastal Plain from very near the surface to

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Figure 5.3-2 (page 2 of 2)

Figure 5.3-3 (page 1 of 2)

Figure 5.3-3 (page 2 of 2)

depths ranging from approximately 656 to 2,133 ft (200 to 650 m) (Lachenbruch et.al., 1988:647). The depth of seasonal thaw (active layer) varies with specific soil conditions, but in undisturbed dry areas is generally about 1 to 2 ft (0.3 to 0.6 m) and rarely exceeds 3.5 ft (1 m) in wet soils (Rawlinson, 1983:4-7).

Thaw bulbs are permanently unfrozen soils found in permafrost and are likely to be present within the project area below lakes and river channels and in areas disturbed by human activities (Rawlinson, 1983:4-7). Within these thaw bulb areas, engineered facilities are susceptible to the effects of frost heave and frost jacking.

Permafrost in the offshore environment formed when portions of the Alaskan Beaufort Sea shelf were exposed to the Arctic climate during periods of lower sea levels. It is believed that permafrost formed to depths of 1,000 ft (305 m) beneath the exposed shelf, then partially melted during later periods of higher sea level (Craig et al., 1985:146). The existence of subsea permafrost is dependent on several other factors as well, including seawater temperature and salinity, lithology, and the extent of shorefast ice in winter.

Offshore permafrost in the project area consists of either unbonded or ice-bonded (Figure 5.3-4) frozen ground overlain by an active layer of seasonally thawed sediment. In the offshore environment, unbounded permafrost consists of sediments with temperatures below 32° F (0° C) that exhibit no interstitial pore ice bonding. In these sediments, the salinity of the seawater within the interstitial pores inhibits ice formation due to the depressed freezing points of the highly saline waters. Seafloor sediment is often unbonded due to this salinity effect (Rawlinson, 1983:6). Lithology soil type can also control the distribution of bonding in offshore sediment, as evidenced by grain size and organic content variations in borings drilled by Miller (1996:Appendix A) (Figure 5.3-4). Ice-bonded permafrost occurs when the sediment is held together by interstitial ice so that it is relatively resistant to chipping or breaking. Ice-bonded sediments in the offshore area are mostly relicts of permafrost formed during subaerial exposure when the sea level was lower.

Data gathered from borings drilled in the project area show that the depth to ice-bonded permafrost varies in the offshore environment (Figure 5.3-4). Recent borings drilled in the project area generally encountered ice-bonded sediments between the shoreline and Stump Island at depths ranging from 1 to 33 ft (0.3 to 10 m) (Miller, 1996:Plate 2, Appendix A).

Offshore zones of icebonded permafrost are located in Simpson Lagoon between the coastline and approximately 2,200 ft (671 m) from shore, and between 3,800 ft (1,158 m) from shore and 2,000 ft (610 m) offshore of the barrier islands. Data for the area offshore of West Dock show an abrupt dip in the depth of ice-bonded permafrost close to the present day shoreline (Rawlinson, 1983:7; Craig et al., 1985:148). Between approximately 1,312 and 1,608 ft (400 to 490 m) from shore near West Dock, the depth to ice-bonded sediment increases abruptly from approximately 10 ft (3 m) to approximately 65 ft (20 m), corresponding roughly to the limit of shorefast ice in winter (Osterkamp and Harrison, 1976:16).

The depth to ice-bonded permafrost at Seal Island is approximately 300 ft (91 m) (BPXA, 1996b:Exhibit 3-2). No ice-bonded sediments were encountered in any of nine soil borings drilled within the project area near Northstar Island, although sediment temperatures of less than 32°F (0°C) were reported, indicating the presence of unbonded permafrost (Musial and Nidowicz, 1984:6).

Barrier islands in the project area are underlain by permafrost (Rawlinson, 1983:8). Two site investigation boreholes drilled on Stump Island showed ice-bonded permafrost between the surface and the maximum depth of drilling at 36 ft (11 m). On Reindeer Island, in the northeast portion of the project area, well data indicates the presence of two layers of permafrost at depths of approximately 0 to 62 ft (0 to 19 m) and 299 to 420 ft (91 to 128 m) (Craig et al., 1985:149). The deeper layer of permafrost is believed to be quite old, while the shallower layer is believed to have developed under modern arctic conditions.

Ice lenses may be present within both bonded and unbonded subsea permafrost in the project area. Ice lenses are normally about 1/4-inch (0.6 cm) thick, but occasionally form to 18 inches (46 cm). Ice lenses have been reported in offshore sediment in Stefansson Sound and Mikkelsen Bay at depths of up to 300 ft (91 m) below the seafloor (Miller and Bruggers, 1980:329).

5.3.1.4 Terrestrial Soils

Soils in the project area generally consist of poorly drained silty to clayey loams and peats. Floodplains have gravelly to sandy soils (Rieger et al., 1979: Sheets 2 and 3). Thickness of the vegetative mat varies with soil type, as does the ice content of frozen soils. Thick permafrost underlies these soils, and frost-patterned ground is common. Onshore soils in the southcentral portion of the project area generally include a very wet, 2- to 12-ft (0.6 to 3.7 m) thick, organic mat or silt layer underlain by brown sand with minor silt and gravel, or silty gravel (Dames & Moore, 1989:2; 1991:4; Walker et al., 1980:9). Organic soils in this area are ice-rich, containing approximately 25 to 30 percent (%) visible free ice, while the sandy soils contain less than 5% visible ice.

5.3.1.5 Offshore Sediment

Seafloor deposits within the project area generally consist of muddy sand and sandy mud with minor amounts of gravel (Barnes and Reimnitz, 1974:457 and 458). The deposits primarily include very stiff, silty clay inshore of the barrier islands, and stiff silts offshore of Long, Egg, and Stump Islands at water depths of about 5 to 10 ft (1.5 to 3 m) with scattered gravels and cobbles throughout. The silts are generally highly over-consolidated due primarily to freezing and thawing cycles (Reimnitz et al., 1980:1).

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Geotechnical borings drilled in the project area (Figure 5.3-5) provide information on sub-bottom sediment units (Table 5.3-1). Several borings drilled inshore of the barrier islands encountered 15 to 25 ft (4.6 to 7.6 m) of fine-grained sand and silt, overlying sand and gravel (McClelland-EBA, 1985:5-6; Miller, 1996:Plates 1 and 2). Borings drilled in the area between West Dock and Stump Island encountered a layer of fine-grained sediment to depths of 5 to 23 ft (1.5 to 7 m) below the seafloor, underlain by coarser sediments (McClelland-EBA, 1985:6). Surface sediment encountered between Egg and Stump Islands generally consisted of sand and silt.

Although these geotechnical borings are generally along the proposed offshore pipeline routes, it is important to note that no geotechnical boring program has been completed directly along the complete length of any of the action alternatives (Alternative 2 through 5). In particular, for the shoal zone between Egg and Stump Islands where considerable differential thaw settlement could potentially occur, the two borings taken in this general area are spaced more than 1,000 ft (305 m) apart (PS-1 and McE-16, Figure 5.3-4) and are 700 to 800 ft (213 to 244 m) to the east of the offshore pipeline route for Alternatives 2 and 3. Hence, these borings provide limited site-specific information. This was substantiated by independent review by the U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory (see Appendix P for additional details).

Four categories of sediment have been identified based on borings located offshore of the barrier islands (Miller and Bruggers, 1980:327; Miller, 1996:Plate 2, Appendix A). These include: soft to medium stiff, fine-grained deposits; medium dense to very dense, uniform fine-grained sand; stiff to hard silt and clay deposits; and dense sand and gravel. Boring logs in the area offshore of Stump Island generally indicate a thick sequence of sands and gravels starting at 10 to 35 ft (3 to 10.7 m) below the seafloor, overlain by a younger layer of fine-grained sand and silt. The buried or sub-bottom depth to the top of the sand and gravel unit in the project area generally increases from nearshore to offshore, and from west to east. Borings drilled offshore of the barrier islands in the vicinity of Seal and Northstar Islands indicate similar sediment conditions to those further inshore (Table 5.3-1).

Geotechnical analyses conducted to assess the suitability of seafloor sediment with regard to trenching indicated that sediments in an ice-bonded condition can support high loadings, but silts and unbonded sediments are susceptible to settlement (HLA, 1979:82; WCC, 1981:3-7; Miller, 1995:3-6, Plate 5). The slope stability of shallow sub-bottom sediment was studied during a test trenching operation in March 1996 (INTEC, 1996e:4; 1996g:2-4; 1997c:4). Frozen silts in contact with bottomfast ice in Simpson Lagoon held vertical sidewalls with very little slumping. At another site where the sediments were frozen to partially frozen and there was water beneath the ice sheet, sidewalls slumped after several hours. In approximately 16 ft (4.9 m) water depths offshore of Stump Island, where sediments are composed of 5 ft (1.5 m) of unfrozen silt overlying sand, vertical test trench sidewalls were maintained to the 5 ft (1.5 m) depth, until sand slumping beneath this layer caused the silt walls to slump.

Table 5.3-1 (page 1 of 1)

Figure 5.3-5 (page 1 of 2)

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Sediment chemistry in the project area, including parameters such as total organic carbon (TOC), trace metals, and hydrocarbon content, is affected by sediment transport processes (Section 5.3.1.6). Primary sediment sources in the marine environment, including riverine input of suspended material and erosional transport of mainland shoreline peat and tundra vegetation, contribute large amounts of organic carbon, hydrocarbons, and trace metals to the subsea sediments (Boehm et al., 1990:1-11).

Sediment sampling and analyses in the Alaskan Beaufort Sea region has focused on hydrocarbons and trace metals because of their association with oil and gas activities. Recent sediment quality information comes from site-specific monitoring efforts performed in conjunction with oil and gas development activities, such as those at the Kuparuk, Endicott, and Prudhoe Bay oil fields. Sediment quality data was collected on the trench sediment samples discussed above and along the offshore pipeline route (Montgomery Watson, 1996:10-12; 1997). Sediment quality monitoring stations are shown on Figure 5.3-6 and sediment chemistry results are presented in Table 5.3-2 (WCC, 1996:1-9).

TOC is a parameter sometimes used to quantify sediment mixing (disturbances). A higher TOC value may indicate higher rates of deposition and, therefore, little mixing by benthic invertebrates. Conversely, a lower TOC value indicates greater mixing of sediments. TOC at Alaskan Beaufort Sea monitoring stations from 1984 to 1986 ranged from 3.4 to 18 parts per thousand (ppt) (Boehm et al., 1987:6-20, 6-21). TOC values ranged from 0.7 to 30 ppt at 49 monitoring stations sampled during the 1989 sampling program, 39 of which had been sampled previously in the 1984 to 1986 studies (Boehm et al., 1990:4-35). TOC values for test trench sediment samples ranged from 6.3 to 26.3 ppt for the Simpson Lagoon location, and 4.6 to 40 ppt for the location offshore of Stump Island (Montgomery Watson, 1996:Table 4). Higher TOC values were generally found near river deltas.

Alaskan Beaufort Sea sediment analyses have focused on those metals likely to increase due to the presence of oil and gas development activities. For example, barium and chromium are components of drilling muds, and vanadium is a constituent of the petroleum combustion process. There is considerable variability in trace metal concentrations in Alaskan Beaufort Sea sediment, including seasonal variations (USACE and ERT, 1984:3-39, 3-44). It appears some metals (barium and cadmium) increase with the influx of sediment from local rivers during the open water season each year, and decrease during winter.

Hydrocarbons found in Alaskan Beaufort Sea sediments primarily are naturally-occurring compounds resulting from riverine and other onshore sources rather than from human activities. Hydrocarbon compounds are dominated by waxy plant material (peat) and fossil fuels (coal and oil). Hydrocarbons found in nearshore and offshore sediments show little evidence of anthropogenic (caused by human activity) petroleum inputs (Boehm et al., 1990: 5-69). The results of chemical analysis for fuel products from a 1995 sediment sampling program in the project area are presented in Table 5.3-2 (WCC, 1996:7-9).

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Figure 5.3-6 (page 1 of 2)

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5.3.1.6 Erosion and Sediment Transport

Coastal erosion within the project area results in constant change to the shoreline. Waves, storm surges, and thermal degradation, such as thaw bulbs or melting ice lenses, can result in dramatic erosion and shoreline retreat. In addition, extremely strong currents moving across the inner shelf during these surges deeply erode the shoreline and barrier islands. Erosion rates are highest along coastal points and bluffs composed of fine-grained soil and ice lenses (Grantz et al., 1982:35).

Local coastal erosion rates within the project area were evaluated by reviewing historic aerial photographs for the years 1949 through 1996. Based on measurements averaged along eight different segments of the coastline (Figure 5.3-7), it appears to be retreating at rates ranging between 0.8 and 9.8 feet per year (ft/yr) (0.2 and 3.0 m/yr). The rates of erosion tend to vary substantially depending on the location of barrier islands and manmade structures, local lithology, and shoreline morphology (structure and form). The highest individual measurements of shoreline retreat were located near the west side of the base of West Dock where an erosion rate of 9.8 ft/yr (3 m/yr) was calculated over a 40-year period (Figure 5.3.7). It appears that the presence of West Dock since the early 1980s has affected longshore sediment transport (to the west) such that loss of sediment along the lee (i.e., west side) of the West Dock causeway is not being replenished. The next highest measured coastal erosion rates, which are expected to be representative of current conditions, are between Point Storkersen and near the unnamed point east of the nearby Distant Early Warning Line site. The least erosion occurred right at the site (0.8 ft/yr [0.2 m/yr]), where historic stabilization activities may have kept shoreline retreat in check. Similar erosion rates were calculated by other researchers. Measured retreat rates west of Gwydyr Bay range from 3.6 to 4.1 ft/yr (1.1 to 1.2 m/yr) (Leidersdorf and Gadd, 1996:4). Average shoreline retreat rates of 4.6 ft/year (yr) (1.4 m/yr) for the section of shoreline between Oliktok Point and Prudhoe Bay, and 9.8 ft/yr (3 m/yr) for a 20-mile (32 km) section of coastline east of Prudhoe Bay have been reported (Hopkins and Hartz, 1978:19).

Barrier islands within the project area act as a buffer against weather, ice, and waves with respect to the mainland shoreline. Their presence results in a low-energy environment and more stable onshore conditions. Barrier islands lying within the project area include Stump, Egg, Long, and Cottle Islands, of the Return Islands chain; and Bodfish and Bertoncini Islands of the Jones Islands chain. These islands form an elongated band parallel to the present coastline, approximately 0.5 to 2.5 miles (0.8 to 4 km) from shore (Figure 5.3-1). Barrier islands typically are depositional features; however, parts of the islands in the project area are believed to be sections of the former mainland shoreline which were isolated from the mainland during the last sea level rise (Rawlinson, 1990:19). The shape, location, and orientation of the remnant shoreline sections suggests they may represent the edges of former thaw lakes, connected by recently deposited sediment.

Within the project area, barrier island shape, size, and location is controlled by sediment transport and deposition, and the presence of stationary sections of submerged remnant shoreline. Currents along the coastline result in a net westerly sediment transport. The result is island extension rather than migration.

Barrier islands within the study area have extended toward the west at an average rate of 35 to 40 ft/yr

(10.7 to 12.2 m/yr) from 1955 to 1995. The approximate change in configuration of Stump and Egg Islands over a 40-yr period is shown on Figure 5.3-8. The islands are breached periodically, presumably during storm surge events. In some cases, the breaches appear to be self-healing as a result of a steady supply of sediment carried by longshore currents and deposited along the stationary sections of remnant shoreline.

Sediment erosion and transport between the shoreline and approximately the 66-ft (20 m) water depth generally are caused by wind-generated waves, currents, and sea ice, which gouge the seafloor causing resuspension of bottom sediments. Ice also dampens currents and waves, slowing sediment transport. Winter tends to be an inactive period, while summer is an active period for sedimentary processes (USACE and ERT, 1984:3-32).

Average sedimentation rates in the nearshore portion of the Alaskan Beaufort Sea shelf generally are about 1.6 ft (0.5 m) or more of deposition per year, although subsequent erosion removes some or all of the material deposited (USACE and ERT, 1984:3-37). Sediment is supplied to lagoons from river outflow (Boehm et al., 1990:1-11). The project area is offshore of the Kuparuk and Sagavanirktok River Deltas and is affected by flow from these systems. Erosion of tundra bluffs and beach areas also results in sediments entering the marine environment. The Kuparuk River reportedly discharges about 4.4 times the amount of sediment to the marine environment as that coming from coastal erosion in the project area (USACE and ERT, 1984:3-32). However, dramatic rates of erosion can also result from degradation of coastal permafrost. At Oliktok Point, located about 9 miles (14.5 km) west of the project area, the coast receded 35 ft (10.7 m) during one 2-week period (Hopkins and Hart, 1978:28).

Wave action and longshore currents are important mechanisms for the transport of sediment within the project area. Longshore currents erode and transport large amounts of beach sediment. Studies conducted at Egg Island indicate that an average of 110,000 cubic feet (ft^3) (3,115 cubic meters [m^3]) of beach sands are transported annually by longshore currents (USACE and ERT, 1984:3-32 through 3-34). Wave action and currents are described further in Section 5.5.

Wind-blown material also may contribute to soil and sediment deposition within the project area. Wind action during winter has been observed to create plumes of sand on top of landfast ice downwind of several barrier islands. Observations made at Egg Island indicate that approximately 7,100 ft^3 (201 m^3) of sand were eroded from the island by the wind during a single winter (USACE and ERT, 1984:3-32).

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Figure 5.3-8 (page 1 of 2)

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Ice effects such as gouging, ice push, strudel scour, and entrainment by freezing can act as mechanisms for erosion and transport of marine sediment in the project area. Ice gouging is identified as one of the most important processes of sediment reworking on the Arctic continental shelf, particularly at mid-shelf and inner-shelf water depths (Craig et al., 1985:124). Ice push and ice override events along the coastline can erode and transport large amounts of nearshore and coastal sediment into ridges further inland. This process is most important on the outer barrier islands (Craig et al., 1985:128). Strudel scour causes holes in the seafloor sediment when landfast sea ice is overflowed by river floodwaters, which flow through holes or cracks in the ice creating depressions in the seafloor by erosion. Additional details on the destructive or erosional effects of these processes are presented in Section 5.6.1. Sediment also can be frozen in sea ice and then transported as the ice moves. Large quantities of sediment may be captured in sea ice as it freezes to the seafloor. It has been estimated that an average of approximately 6,400 ft^3 (181 m^3) of sediment may be present in each square mile (2.6 square km [km^2]) of sea ice (USACE and ERT, 1984:3-32 through 3-34).

5.3.1.7 Onshore Hydrology

Onshore hydrologic conditions have a strong influence on both the onshore and offshore physical environments of the North Slope. River discharge is the major source of sediment input to the marine environment. Onshore water quality, river flow, and sediment load affect marine water quality in the nearshore region. River flow during breakup is an important factor in nearshore seabed erosion (strudel scour) (Section 5.6.1.4). Surface water bodies cause thaw bulbs and other permafrost features in the onshore permafrost (Section 5.3.1.3), which in turn affects the distribution of surface vegetation. The arctic hydrologic environment is influenced by severe climate, seasonal frost and associated permafrost, and flat topography. Severe arctic conditions, including below freezing temperatures throughout most of the year and continuous permafrost, cause wide fluctuations in runoff and stream flow.

Surface water flow (sheet flow) outside existing streams typically occurs on the North Slope between early May and mid- to late September (Hinzman, 1989:35-36). The presence of shallow permafrost limits the infiltration of water through the soil, and a perched water table within the active layer develops. Surface water flow is generated when the suprapermafrost (above the permafrost) water table rises above the ground surface. Saturation of the active layer and filling of depressions in the ground surface must occur before surface runoff can begin. Project design features, such as the elevated pipeline (onshore segments) and the use of ice roads, will not create any impediment to surface water flow.

Thaw lakes are a dominant onshore feature in the project area, and are often used as a source of freshwater for ice road construction. They are formed by localized thawing of the upper permafrost by ponded water and range in depth from less than 3 to 20 ft (0.9 to 6.1 m) (USACE and ERT, 1984:3-38). Localized thawing of the upper permafrost can be caused by removal of the organic cover. A thaw lake may develop if the disturbed area collects surface water. The body of water expands by thawing permafrost below the water level and undercutting the surrounding tundra. The position of the lakes generally is perpendicular to the dominant wind direction because the wind increases undercutting of the soil. Continuation of these processes results in the lake shorelines migrating in the direction of prevailing winds (USACE and ERT, 1984:3-38).

Lake water generally has lower total dissolved solids than stream water, but may have a dark color and/or odor, distinctive of a high iron content plus tannic acid from peat. Lakes less than 6 to 10 ft (1.8 to 3 m) deep freeze to the bottom in the winter, while the bottom layer of deeper lakes remains unfrozen throughout the year. Lakes located near the coast may have high salt levels, depending upon the amount of marine water input from storm surges (USACE and ERT, 1984:3-94).

Stream flow in the project area originates from headwater tributaries of the Brooks Range, the Arctic Foothills, precipitation, and from stored water in lakes and wetlands along the Arctic Coastal Plain. Streams and rivers in the project area are frozen for 7 to 8 months of the year (Selkregg, 1975:90). Streams originating in the Brooks Range typically have larger watersheds, such as the Sagavanirktok River, where flow may be derived from a combination of glacier-fed tributaries, surface runoff, groundwater, and springs. Streams originating in the foothills of the Brooks Range or on the Arctic Coastal Plain typically have smaller watersheds where flow is generated primarily by the melting of snow and ice, with little or no input from groundwater sources due to continuous permafrost (USACE, Alaska, 1980:F-1).

The principal drainage basins in the project area from west to east include the Ugnuravik, Sakonowyak, Kuparuk, Putuligayuk, and Sagavanirktok Rivers (Figure 5.3-1). Smaller drainages within the project area include two located near Milne Point, two between Milne Point and the Kuparuk River, Fawn Creek located between the Kuparuk and Putuligayuk Rivers, and an unnamed creek west of the Shaviovik River. Stream flow data for the two drainages (Kuparuk River for the gravel mine sites and Putuligayuk River for pipeline crossings) are presented in Table 5.3-3. A discussion of the watershed, stream flow, and water quality characteristics for the individual rivers follows.

The Kuparuk River originates in the foothills of the Brooks Range and drains an area of 3,130 square miles (8,107 km^2). Flow in this river typically peaks in early June during breakup (Scott, 1978:6-7). Mean monthly flows for the gauged basin area range from approximately 2 cubic ft per second (cfs) (0.06 cubic m per second [m^3/s]) in late winter (February through April) to approximately 11,056 cfs (313 m^3/s) in June (Table 5.3-3). Water quality and sediment discharge data for the Kuparuk River are shown in Tables 5.3-4 and 5.3-5, respectively.

The Putuligayuk River is a low-gradient, meandering river that has bed material consisting of fine gravel and stream banks of cohesive silt and clay with soil development overlying fine gravel (Scott, 1978:7). Stream flow measurements since 1970 indicate that the Putuligayuk River generally peaks rapidly, rising from near zero to peak flow during a one to two week period in early June, and falling continuously to low summer levels

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in about the same amount of time. Mean monthly flows range from 4 cfs (0.1 m^3/s) in May to a maximum of 694 cfs (19.7 m^3/s) in June (Table 5.3-3). Flows rapidly drop in July and reach zero by November. Just downstream of the Spine Road, the river is crossed by a pipeline bridge. Scour has been monitored over the life of the pipeline bridge, and the use of grout bags and rock gabions has minimized losses to the bank from scour during highwater periods. Water quality and sediment discharge data for the Putuligayuk River are shown in Tables 5.3-4 and 5.3-5, respectively.

Extensive flooding is typically associated with rivers and streams on the Arctic Coastal Plain during spring breakup between May and early July, with peak flow conditions in the first week of June. Breakup progresses rapidly, and by early July, 60% to 80% of the total annual discharge of most rivers has occurred. Ice jams and ice that is frozen to the channel bed increase the height of the floodwater during breakup in downstream river areas. The extent of river floodplains in the project area is depicted on Figure 5.3-1. Flooding subsides as the ice is broken up and melts or is carried downstream and out to sea.

Observations of water levels in rivers rising during storms have been made by both Barrow and Nuiqsut residents. A Barrow whaling captain reported that the biggest storms occur in September, causing the water levels in the rivers to rise (Pers. Comm., Barrow Whaling Captains Meeting, August 26 and 27, 1996). A Nuiqsut whaling captain reported how rising marine water levels during a storm surge can force water over the top of sea ice and flood the Colville River drainage to a distance of 18 miles (29 km) (A. Ahkiviana - Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:8).

River sediment output peaks with the highest river flows during June when more than 50% of the annual sediment discharge usually occurs in rivers on the Arctic Coastal Plain (Selkregg, 1975:96). Undercutting of frozen stream banks by thawing and erosion is common in arctic streams, particularly at locations of sustained high flow. The increased strength provided by permafrost in stream banks permits greater undercutting at the base of the thawed layer, which in turn produces larger slump blocks (Scott, 1978:9-11). The stream bank material becomes an important source of sediments transported by rivers.

Groundwater hydrology within the project area is affected by climate and the presence of permafrost (Sloan, 1987:241). Surface water is frozen most of the year, which limits recharge to groundwater. Addition-ally, permafrost acts as a barrier which restricts groundwater flow. Groundwater has been found beneath permafrost (subpermafrost groundwater) under most oil and gas units on the North Slope. Subpermafrost groundwater may extend within bedrock to depths of greater than 2,000 ft (610 m) below the ground surface. Groundwater contained under large streams and deep lakes that do not freeze to the bottom is a potential water supply. Subpermafrost groundwater sources, other than springs, are generally too brackish to be considered for water supply use (Sloan, 1987:241-243).

5.3.2 Environmental Consequences

The following section describes the potential impacts of each project alternative on the onshore and offshore geologic environment and the onshore hydrologic environment, including impacts to soil and sediment quality, lakes, rivers, permafrost, and deep geologic formations. Potential impacts of geologic hazards on project components (such as subsurface gas, permafrost thaw settlement, and erosion) are also discussed as they relate to four project phases (construction, operations, maintenance, and abandonment), and various project components within those phases (e.g., gravel mining and pipeline construction). The discussion of impacts is organized based on project alternatives described in Chapter 4. Discussion of Alternative 1, the No Action Alternative, is presented first. Impacts for Alternatives 2, 3, 4, and 5 are discussed together, as there are only subtle differences in impacts. Impact conclusions are the same, except where noted. Impacts are summarized in Table 5.3-6.

5.3.2.1 Alternative 1 - No Action Alternative

The geological and hydrological setting within the project area would not be affected under the No Action Alternative. The project area is naturally stressed as a result of its Arctic location and will continue to be modified by natural forces in the absence of the project. It is anticipated that coastal erosion within the project area would continue at the current rate of approximately 2.6 ft (0.8 m) per year, or approximately 39 ft (12 m) from its present position over the anticipated 15-year design life of the reservoir. Sediment transport would continue to occur in a net westerly direction along the coast and barrier islands in the project area. Seafloor features such as scour holes and undulations as a result of longshore currents and sediment transport processes within the project area would also continue to occur. Similarly, Seal Island would continue to erode, eventually to below the water surface.

The natural freezing and thawing of the active layer of permafrost would continue onshore with the slow formation of thaw lakes, pingos, and other natural physiographic features. Characteristics of onshore surface water and groundwater are not anticipated to change from the current, natural setting. Overall, no impact to the geological and hydrological environments are predicted other than those associated with natural processes.

5.3.2.2 Alternatives 2, 3, 4, and 5

Construction Impacts: Gravel mining activities for Alternatives 2, 3, 4, and 5 would be conducted during a single winter. Slope stability during gravel excavation would be maintained through the use of benching and appropriate slope angles, and gravel would be hauled on ice roads constructed over both the onshore and offshore

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areas. To minimize impacts to the morphology of the Kuparuk River channel, the gravel mine has been located in a gravel deposit which is adjacent to the main river channel. After mining is completed, a 6-ft (1.8 m) deep breach will be dug on the seaward side of the pit connecting the mine site to the main channel of the river, which during spring breakup and overflow will replenish water and sediments to the mine pit through natural processes. The mine is expected to become usable fish and bird habitat once it contains water. Consequently, impacts from gravel mining on onshore geology and hydrology are anticipated to be minor.

Freshwater is required for the construction of ice roads used for hauling gravel to Seal Island for reconstruction. The volume of freshwater required for such construction varies among alternatives due to differing road lengths. Estimated total volumes of freshwater required for Alternatives 2, 3, 4, and 5 are 311, 325, 356, and 350 thousand barrels, respectively. The average of these total volumes is estimated at 335 thousand barrels, which is within 7% of each alternative estimate; therefore, freshwater requirements do not differ much among alternatives.

The required freshwater would be taken from one or more lakes permitted as freshwater sources. One likely lake is at the Kuparuk Deadarm mine site. This lake is already permitted (Permit No. ADL 75979) for removal of up to 2.38 million barrels of water per year, and is replenished each year during breakup. The volume of freshwater required for ice roads is approximately 15% of the annual amount permitted for removal from this lake. In addition, several other permitted sources are available in the project area and may be used to minimize haul distances to desired locations. To limit lake drawdown to 6 inches (15.2 cm), a lake surface of 80 to 90 acres (32.4 to 36.4 hectares) is required. Withdrawals from multiple sources would result in a drop in lake levels on the order of a few inches. Consequently, the impact to water levels would be minor.

Impacts on lakes would also include potential alterations in salinity and alkalinity. During freezing, salts are excluded from the ice. Wintertime removal of more saline water underneath the ice could result in less saline, less buffered lake waters following spring breakup (USDOI, BLM and MMS, 1997:IV-C-2). However, based on the relatively small amount of water that would be removed from these permitted lakes, this impact is considered to be minor.

During island reconstruction, sediment beneath expanded portions of the island and the protective berm would be covered with gravel, and sediment outward of the island footprint would be affected to a lesser extent by settling of suspended material. In addition, dewatering during construction would produce a sediment-laden discharge of up to 1,389 gallons/minute (5,258 liters/minute) discontinuously over a period of approximately 2 to 4 weeks. The discharged sediment is considered to be representative of background conditions, and is not expected to change existing sediment quality in the location where it settles. Consequently, the long-term impact on sediment chemical quality from this activity is considered to be negligible.

Sediment deposition during reconstruction activities would impact the seafloor in the immediate vicinity of the island. The total seafloor footprint of the reconstructed island would be approximately 18.1 acres (7.3 hectares). The footprint of the island when initially constructed was 10.7 acres (4.3 hectares)

(Agerton, 1982:Figure 2). The original island has eroded and spread out since construction to an area exceeding the 18.1 acres required for the new island's footprint. Given that reconstruction activities would be limited to this relatively small area, and would occur during a short period (3 months), the overall impact to offshore sediment quality would be minor.

Construction of the onshore pipelines for Alternatives 2, 3, 4, and 5 would require crossing various distances of undisturbed tundra. In particular, 9.6 miles (15.5 km) of undisturbed tundra would be crossed for Alternative 2 between the Spine Road and Point Storkersen. Alternative 3 would cross 6.7 miles (10.8 km) of undisturbed tundra between the Spine Road and the Central Compressor Plant (CCP) and between the West Dock Staging Pad and Point Storkersen. Alternative 4 would cross 3.5 miles (5.6 km) of undisturbed tundra between the Spine Road and the CCP and between the West Dock Staging Pad and the shore crossing. Alternative 5 would cross 3.1 miles (5 km) of undisturbed tundra between Spine Road and the CCP. None of these areas are accessible by road. These segments would be routed to avoid lakes and other water bodies as much as possible.

Since construction activities are planned for winter, soils would be disturbed only indirectly by construction traffic over ice roads and in the small footprints of the vertical support members (VSM). VSMs would be installed every 55 ft (17 m), for an approximate 1,387, 1,501, 1,166, and 1,150 VSMs for Alternatives 2, 3, 4, and 5, respectively. Approximately 6 ft^3 (0.17 m^3) of soil would be disturbed for every VSM installed. This results in a range of 255 to 334 cubic yards (yd^3) (195 to 255 m^3) of soil disturbed for Alternatives 2, 3, 4, and 5. The cuttings would be transported to the Put 23 mine site or to the newly opened Kuparuk River mine site for disposal. Impacts to soils near the VSMs depend on whether the vegetative cover is disturbed. In particular, if vegetation were removed and not replaced, thawing and exposure of the soil to erosion forces may occur (Walker et al., 1987:37-39). To prevent this, the only vegetation removed is that directly under the VSM. The slurry in which VSMs are set eliminates soil moving to fill voids between the VSM and its excavated hole. VSMs are set during winter to ensure freezing of the structure in the soil prior to summer. The resulting frozen slurry provides a solid foundation for the VSM. The overall impact to soils from construction of the onshore pipeline segments for Alternatives 2, 3, 4, and 5 is anticipated to be minor because operations would be conducted on frozen, snow-covered tundra. VSMs may also be installed on the gravel causeway for Alternative 5. No impacts to local hydrology are anticipated from either the installation or presence of these VSMs.

At the shoreline approaches for Alternatives 2, 3, and 4, soils would be excavated from an 8 ft (2.4 m) wide trench to bury the pipelines. The trench itself would be backfilled with gravel to prevent unacceptable pipeline subsidence. Native soils would then be backfilled on top of this gravel to provide a stable soil bed for revegetation. The pipeline would be buried deep enough to prevent erosion damage. The length of this onshore segment of the trench is sufficient to protect the pipeline from shore erosion over the expected life of the project because the underground structure where the pipeline transitions from the trench to the aboveground VSMs is 110 ft (33.5 m) inland of the shoreline. A gravel pad would be built at the ground surface around the pipeline transition from buried to aboveground pipeline segments. The pad footprint would be 70- by 135-ft (21.3 by 41 m) and would have a minor impact to onshore soils.

Approximately 3 to 45 ft (0.9 to 13.7 m), depending on alternative, of erosion is expected to occur during the 15-year life of the project. During the life of the project, some of this revegetated area may be subsequently removed by natural shoreline erosion. However, in the event of larger than expected erosion, some stabilizing remedial action, such as shoreline protection or nourishment (i.e., the replacement of eroded material), may be required (see Appendix P for additional data from the U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory).

Unlike the shoreline approaches for Alternatives 2 through 4, the subsea pipeline for Alternative 5 transitions to shore through a manmade gravel causeway (West Dock) as opposed to a natural beach line. Although the West Dock causeway is subject to erosion, it is regularly maintained. Hence, the shoreline approach and transition for Alternative 5 is not subject to the erosion uncertainties of Alternatives 2 , 3, and 4.

To simplify construction, onshore pipelines would be routed to avoid lakes and other water features as much as possible. The Putuligayuk River crossing would be an aboveground crossing spanning the river, with two VSM supports in the center of the span. In addition, the VSMs and their foundations would be designed to withstand the effects of river ice and floods. Other VSMs would be placed well back from the river bank to avoid shore erosion. No flow impedance is expected as a result of VSM placement either at the Putuligayuk River or across the tundra. Consequently, impacts to the onshore hydrologic environment from pipeline construction are considered to be negligible.

Installation of offshore pipeline segments for Alternatives 2, 3, 4, and 5 would occur in the winter season during which under-ice water generally is calm and sediment is less likely to be entrained. Construction activities would include excavation of a trench along the 6-mile (9.5 km) long Alternative 2 and 3 routes and the 9- and 8.9-mile (14.5 and 14.3 km) long Alternative 4 and 5 routes (Figure 5.3-5). The total volume of trench material excavated would be 264,000 yd^3 (201,828 m^3) for Alternatives 2 and 3, 380,600 yd^3 (290,969 m^3) for Alternative 4, and 377,700 yd^3 (288,752 m^3) for Alternative 5. Sediment excavated during construction of the offshore pipeline route would either be backfilled into the trench over the pipeline or disposed as excess spoil. It is expected for Alternatives 2, 3, 4, and 5 that a range of approximately 2,500 to 5,000 yd^3 (1,911 to 3,822 m^3) of excess trench spoils would be generated in the lagoon area between the coastline and the barrier islands. It is possible that up to an additional 65,000 yd^3 (49,693 m^3) of excess spoils from the lagoon area may be generated, in the event of abandonment of pipe-laying operations due to weather or ice conditions.

Excess spoils from construction of Alternatives 2, 3, 4, and 5 would be spread onto landfast ice in an area approximately 1,200 by 2,700 ft (366 by 822 m) immediately outside of the barrier islands on floating-fast ice and allowed to disperse into the water column at breakup. Initially, the settlement of excess spoils is expected to create a pile on the seafloor less than 1 to 2 ft (0.3 to 0.6 m) high. An additional area along the west side of the trench offshore of the barrier islands, about 200 by 16,600 ft (61 by 5,060 m), may also receive trench spoils from trenching activities along this deep water segment. These spoils would be less than 3 ft (0.9 m) high. Because of the dynamic nature of the Alaskan Beaufort Sea environment, the spoils disposal pile(s) are expected to erode to baseline conditions within a few years, and leave no permanent alteration of the seafloor topography. Consequently, the disposal of spoils piles on existing sediment would be minor.

The disturbance of seafloor sediments from trenching and backfilling would result in a turbid suspended sediment plume in the water column during the 3-month long activity. Settling of suspended sediment would occur along the margins of the trench, primarily in the down current direction (west). Winter season construction of the pipeline will minimize the size of the plume, as under-ice water currents are generally very low (less than 2 inches/second [less than 5 cm/second]) (Section 5.5.1.3). A maximum probable distance of under ice sediment plume transport of 830 ft (253 m) has been calculated (Montgomery Watson, 1996:7). The physical impact of plume settlement on seafloor sediment is expected to be minor due to winter construction.

Sediments which would be redeposited into the trench during dredge activities or disposed of as excess spoils are similar to undisturbed sediments and would not be expected to change existing sediment chemical quality (Section 5.3.1.5). Consequently, the long-term impact on offshore sediment chemical quality resulting from trenching activities is considered to be negligible.

For Alternative 5, the West Dock causeway area between Dock 2 and the mainland would be widened through gravel hauling and placement techniques to accommodate additional pipelines. An additional seafloor area, on the order of 5.5 acres (2.2 hectares), would be covered by gravel placement or settlement of suspended sediment. Consequently, the impact to sediment would be limited in area and is considered to be minor.

Operation Impacts: A Class I industrial waste disposal well would be used to dispose of drilling muds, cuttings, produced water, and other island wastes into confined formations lying above the reservoir rocks (Section 5.3.1.2). Disposal of waste materials in injection wells is a concern of residents, as reflected in statements made by a Barrow whaling captain, who indicated a desire for strict monitoring of materials reinjection (Pers. Comm., Barrow Whaling Captains Meetings, August 27 and 28, 1996:3).

Waste injection well design incorporates an understanding of confining zone stratigraphy to avoid potential cross-contamination of non-target formations. Waste injection zones are isolated from other formations by low permeability barriers or confining zones (Section 5.3.1.2). The proposed injection, arresting, and confining zones beneath the Northstar Unit (Figure 5.3-3) are within the same formations as those successfully utilized for waste disposal and confinement at the onshore Prudhoe Bay and Endicott units. Groundwater zones above the confining layer and below the permafrost are not considered to be potential drinking water sources due to their salinity (Sloan, 1987:241-243). During the drilling process, casing strings would be positioned and cemented to seal the non-target formations from potential impacts by Northstar reservoir fluids or waste injection fluids. Risks of fluid migration through the wellbore are expected to be slight because of the use of proven, reliable cementing practices consistent with all applicable regulatory requirements.

The maximum total volume of wastes to be injected, including drilling mud, cuttings, produced water, and domestic wastes, is estimated at 120 million barrels during the life of the project. Induced fracturing of injection zones is necessary for placement of these wastes. If the total volume were placed only into the lower injection zone (Figure 5.3-3), the estimated lateral area of influence would extend approximately

1,600 ft (489 m) from the wellbore. It is estimated that vertical fracture growth would be on the order of 250 ft (76 m), and not more than 500 ft (152 m). Even if induced vertical fractures extended past the maximum estimate, there would still be approximately 800 ft (244 m) of vertical section before reaching the top of the upper confining zone (Figure 5.3-3). Furthermore, permafrost is located between the uppermost confining layer and the seafloor, providing an additional barrier to the upward migration of wastes. To further reduce the risk of vertical migration of wastes through induced fractures, the upper injection zone would be used only if necessary, following initial use of the lower injection zone, and then would be used for low solids content wastes (such as domestic wastes) that do not propagate fractures as well as high solids wastes (such as drill cuttings). Consequently, overall impacts to the subsurface geologic environment and shallow sediment quality from injection of wastes are expected to be minor and confined to the injection zone.

Shallow gas accumulations have not been encountered during exploration drilling at Seal or Northstar Islands. In addition, to date there have been no indications of shallow gas accumulations or well control incidents in wells drilled on the North Slope. However, since scattered areas of shallow gas have been mapped on the inner continental shelf, it is considered to have a low risk of occurrence during drilling. Gas hydrates are estimated to occur beneath the Northstar Unit at depths ranging from approximately 2,953 to 4,921 ft (900 to 1,500 m) (Collett - Pers. Comm., 1997:2). Although pressurized gas and gas hydrates could pose a hazard to drilling activities, the use of standard well protection procedures, such as drilling muds, diverters, and blowout preventors, and closely monitored drilling rates that are currently in practice on the North Slope, would control the effect of gas accumulations or hydrates, if encountered. Consequently, the impact level is considered minor.

NPDES permitted discharges to the marine environment would occur during routine island operations and include system flushwater, brine from a desalination system, treated domestic/sanitary wastewater, and fire suppression test water. These discharges are further described in Chapter 4 and Appendix O. All but the fire system test water would be discharged via an outfall through the island's seawalls to the receiving seawater. This outfall requires a mixing zone to ensure compliance with the water quality standards of the State of Alaska. Discharges from this outfall may contact a small area of the island toe. Because of the small size of this mixing zone (16.4 ft [5 m] radius), the impact to sediments by these particular discharges is considered to be negligible. The fire system test involves discharging ambient seawater once a year for 30 minutes through the island's fire fighting system. This test will discharge onto the Beaufort Sea's surface; hence, no impact to sediments is expected.

Surface runoff on the island surface would be the product of snowmelt, rain, waves, and storms. Designs for Alternatives 2 through 5 include drainage control via two catchment basins. Contents of the catchment basins would be injected into the Class I industrial waste disposal well or transported to an approved onshore facility for disposal. As a result, no impacts to sediment quality from surface runoff is expected.

Ice-bonded permafrost is expected to occur beginning at a depth of approximately 300 ft (90 m) below the seafloor at the Seal Island location (BPXA, 1996b:Exhibit 3-2). In addition, a freeze front will progress down through the island following reconstruction. Local thaw settlements may result around the production wellbores and in areas of newly placed gravel as the island freezes and thaws. Thaw settlements up to 2 ft (0.6 m) have been observed in new gravel islands that are constructed in the winter (Tart, 1983:1236). Most of the settlement is expected during the first summer following construction, and subsequent settlement is expected to be relatively small. Design concerns from thaw subsidence at the island include settlement of surface facilities and the ground surface around production casings (Mitchell et al., 1983:855). These impacts are expected to be minor due to maintenance activities, including gravel replacement and annual regrading of the island's surface.

Thaw settlement analyses showed that areas of bonded subsea permafrost would develop a maximum thaw bulb of 35 ft (11 m) below the buried pipelines and 60 ft (18 m) on either side of the pipelines over a 20-year period (INTEC, 1998a:Appendix A). Thaw settlements of up to 2 ft (0.6 m) were predicted. These data (Miller, 1996:Plate.8; McClelland-EBA, 1985:Plate 26; INTEC, 1996a:Appendix A-Fig.26) are expected to be representative of the nearshore portions for Alternatives 2, 3, and 4. The maximum predicted settlement was used in calculations to design pipeline wall thicknesses and diameters capable of withstanding maximum strain (INTEC, 1997a:4). Thus, the impact of nearshore thaw settlement on pipeline stability is considered to be minor.

A local Nuiqsut elder expressed concern about the potential effects of permafrost on the pipeline shore approach (Pers. Comm., Nuiqsut Community Meetings, August 14, 1996:3-4). An evaluation of permafrost behavior in the area of the shore approach was conducted for Alternative 2 (and, therefore, Alternative 3) by INTEC Engineering, Inc. (INTEC, 1996a) based on onshore geotechnical data (Miller, 1996:Appendices A and B). Non-insulated pipes were predicted to develop a maximum thaw bulb that would extend to a depth of approximately 11 ft (3 m) below the pipe and to 7 ft (2 m) on either side of the pipe over a 5-year period. After 5 years of operation, thawing around the pipeline's shore approach was predicted to stabilize. Thaw settlements up to 2 ft (0.6 m) were predicted for soils under the nearshore section of pipeline in Simpson Lagoon (INTEC, 1996a:13). These data are also expected to be representative of the shore approach for Alternative 4 because of the similarity in coastal soil types between Point Storkersen and West Dock (Miller, 1996:Plates A41-A44 and A59-A60; Osterkamp and Harrison, 1976:Appendix A-Nos. 5 and 14). These data were used to design wall thickness and material requirements for the pipeline, and depth of the gravel-backfilled trench in the shoreline approach. Results of the analysis showed that a trench depth of 7 ft (2.1 m) would adequately protect the pipeline at the shoreline. Removal of the native soil and use of select backfill would also mitigate thaw bulb difficulties associated with the shoreline approach. Thus, pipeline design is expected to reduce the impact of permafrost thaw settlement at shoreline to a minor level.

Production of hydrocarbon fluids from the Northstar reservoir would result in removal of a substantial volume of oil resources that are not renewable on a human time scale. Effects on non-target, geologic formations or reservoirs as a result of drilling and oil production would be prevented through design features, such as the use of casing to seal off formations above the producing reservoir. The depletion of oil would have a negligible impact on the geologic environment.

The withdrawal of oil from geologic formations has caused measureable ground subsidence in a few oil fields around the world (for example, North Sea and Long Beach, California). Ground subsidence has not been experienced in the history of oil development on the North Slope. Reservoir pressures are expected to be maintained in the Northstar Unit through fluid or gas injection. For these reasons, and because the Northstar reservoir is relatively deep, the probability that subsidence would occur is considered to be very low. Consequently, the impact level is considered to be negligible.

Nuiqsut residents expressed concern at a community meeting that the pipeline could vibrate during operation, work its way out of the sediment, and float to the surface (Pers. Comm., Nuiqsut Community Meeting, August 14, 1997). However, the pipeline’s specific gravity and method of installation with overlying sediments of sufficient density would prevent the pipeline from vibrating itself out of its trench (INTEC, 1997c:9-12). Consequently, the impact level is considered to be negligible.

The design of the onshore pipeline for Alternatives 2, 3, 4, and 5 would include features and construction methods used successfully in the Arctic for many years. VSMs would be designed to have minimal thermal effect on permafrost. Seasonal freeze-thaw cycles can create frost heave forces on the pile system (INTEC, 1996f:Appendix A). Heave calculations and soil type considerations would be incorporated into the design of minimum pile depths for the VSMs. The use of accepted VSM design criteria would result in negligible to minor impacts to permafrost.

To simplify construction and minimize effects to hydrological resources, onshore pipeline routes would avoid surface water features, such as ponds, lakes, and streams. The aboveground pipeline route river crossing planned at the Putuligayuk River is designed to protect the pipeline and minimize impact to the river. Flow in the Putuligayuk River peaks rapidly during breakup in early June, and falls gradually throughout the summer. Erosion would be possible during breakup when water levels are high and ice is present. The pipeline would be supported by VSMs over the length of the crossing. No disturbances of the river bank are anticipated as VSMs would be placed within the channel just downstream from the existing pipeline bridge. Naturally-occurring scour and bank erosion along the river would not be expected to affect the integrity of the VSMs in the river. VSMs would be installed at depths to resist ice impact at breakup. Hence, physical hydrologic processes should have no detrimental effects on the onshore pipeline.

An average coastal erosion rate of 2.6 ft/yr (0.8 m/yr) has been measured at the Alternatives 2 and 3 landfalls (Figure 5.3-7). For Alternative 4, average coastal erosion rates ranging from 1.3 to 9.8 ft/yr (0.4 to 3.0 m/yr) have been measured between Point McIntyre and the base of West Dock (Figure 5.3-7). A rate of 3 ft/yr (0.9 m/yr) was used in the preliminary design of the coastal set-back for the shore approach facilities (INTEC, 1997b:5). The pipeline is buried deep enough that erosion will not uncover it. In the event of a rare storm resulting in substantial erosion (e.g., a 30 ft [9.1 m] erosion event), the gravel material above the pipeline is sufficient to protect the pipeline from exposure or movement. The design setback distance from the pipeline shore crossing to the aboveground pipeline transition is approximately 110 ft (33.5 m). With an expected shore erosion rate of 3 ft/yr (0.9 m/yr) or less over the project's life of 15 years, this setback is sufficient to protect the pipeline. However, in the event of unexpectedly high rates of erosion due to a severe storm, the pipeline shoreline crossing would be monitored and inspected to determine the extent of erosion. Following such an event, some stablizing remedial action may be required, such as shoreline protection and nourishment (i.e., the replacement of eroded material). The coastal set-back distance, the buried pipeline depth, and gravel backfill are expected to reduce the impact of coastal erosion to a minor level.

Because the gravel causeway (West Dock) on which Alternative 5's subsea pipeline transitions to shore is regularly replenished with gravel lost to erosion, coastal erosion is not expected to affect pipeline integrity for Alternative 5.

Erosion of the coastline at the Alternative 2, 3, 4, and 5 shore approach could occur through both thermal degradation and longshore drift processes (Section 5.3.1.6), causing select gravel backfill used in the shore approach to be exposed. Based on the historic rate of erosion at the Alternative 2 and 3 landfall, it is expected that approximately 40 ft (12 m) of coastline could be lost over the life of the project, potentially exposing the gravel backfill. A coastline retreat ranging anywhere from 20 to 150 ft (6 to 46 m) for Alternative 4 could occur over the life of the project, potentially exposing the gravel backfill. It is possible that the exposed gravel could alter natural sediment transport processes along the coastline. Because the gravel would be coarser than the beach or lagoon sediments, it is not expected to be transported far along the shoreline (less than a few hundred feet). The exposed gravel would resist erosion better than the surrounding sediments, potentially resulting in a small promontory. However, the area is relatively protected from longshore drift sediment transport by the barrier islands and West Dock, and the impact of this potential promontory on accelerating erosion or sediment buildup is expected to be minor.

Stump Island is known to be extending toward the west. Based on the rate of extension measured from aerial photographs since 1955 (Figure 5.3-8), the island is expected to extend to the west approximately 0.1 mile (0.16 km) over the life of the project. It is very unlikely that the island would reach the Alternative 2 and 3 pipeline route (0.2 miles [0.3 km] further west) during the life of the project. No impacts to Alternative 4 and 5 pipeline routes, on the north and east sides of Stump Island, are expected to occur due to island extension. If it were to reach the pipeline, it would result in the beneficial effect of an increase in sediment thickness covering the pipeline. The impact of barrier island migration to the pipeline is considered to be negligible.

Storm surges also could have an impact on Alternatives 2, 3, 4, and 5 pipeline routes in the vicinity of the barrier islands. The nearshore pipeline segments of Alternatives 4 and 5 paralleling the north side of Stump Island would be more susceptible to high energy marine forces than either the lagoon or offshore segments. The Alternative 5 offshore pipeline route could also experience sediment erosion effects from currents passing through the West Dock Breach located about 500 ft (150 m) offshore of the Dock 2 approach. The breach is approximately 650 ft (200 m) wide and was designed to maintain a minimum water depth of 6 ft (2 m) below mean lower low water (MLLW). Breach supports were designed to withstand scour depths of up to 40 ft (12 m). Three years of bathymetric surveys in the area indicate that maximum water depths resulting from scour have ranged from approximately -8.5 to -9.5 ft (-2.6 to -2.9 m) MLLW in an area within approximately 150 ft (46 m) on either side of the breach (ARCO, 1997:Sheet 1; CFC, 1995:Sheet 1; CFC, 1996:Sheet 1). These data suggest that scour depths exceeding about 4 ft (1.2 m) below the seafloor, or -10 ft (-3.3 m) MLLW, would be the maximum depth of erosion in this area. Scour depths of this nature are considered to be of minor impact to pipeline integrity.

Marine water escaping the lagoonal area following a storm surge could cause channeling or breaches to occur where none currently exist. Sediment covering the pipeline could erode during such an event. The depth of pipeline installation in the vicinity of the barrier islands (6 ft [1.8 m]) is equivalent to the deepest existing channel between islands in the area, minimizing the risk to pipeline integrity in the event of storm surge and sediment erosion (INTEC, 1996b:8). Consequently, the impact to pipeline integrity is considered to be minor.

It is anticipated that an oil spill would have some effect on geological resources and onshore hydrological features. Impacts to soils, onshore water bodies, and seafloor sediments are discussed in Chapter 8.

Maintenance Impacts: Inspection of onshore pipelines and VSMs would be conducted along existing roads or, for locations remote from a road, via helicopter. Disturbance to onshore soils in the event of a major pipeline or shore approach repair would occur over a short duration (e.g., a single several month-long season) and would be limited to localized areas adjacent to the repair (e.g., several acres). Major repairs would occur in the winter, except for emergencies. Winter repairs would be accessed via ice roads built specifically for that purpose, and are expected to have a negligible impact on soils. Impacts to soils during a summer repair would be greater than that for a winter repair, but would be expected to result in a minor impact on soil due to special equipment that would be used to access the damaged section. Access for a summer repair would be via helicopter or all-terrain vehicles, which may result in compaction, but not removal, of vegetation. Consequently, overall impacts to soils from routine maintenance and repair activities along the onshore segment of the pipeline would be negligible to minor.

Regular pipeline inspections and pigging would be conducted to detect possible damage to the buried offshore pipeline segment due to thaw settlement or heave. Inspections would include monitoring pipeline geometry and visual or marine survey inspections and would be conducted at start-up, then annually for the first 5 years, and every 2 years thereafter (INTEC, 1996c:5-6; HLA, 1997:2). Offshore pipeline repair becomes more complex with increasing water depth. If repairs to the offshore pipeline are required, sediment would be disturbed locally. Typical offshore repair scenarios range from 25 to 50 days and require sediment excavations ranging from 900 to 16,000 yd^3 (688 to 12,233 m^3) (INTEC, 1996c:Table A.2). In summer, operations would be carried out from a barge or barges. In winter, repair activities would be carried out from the surface of the ice utilizing techniques and equipment similar to those employed during the construction phase. Spoils would be temporarily stored on ice or a barge, and would be backfilled into the trench. These disturbances would be over a short duration (within a single season) and would have minor impact to offshore sediment.

Pipeline and VSM integrity and river bank and channel integrity would be monitored at the Putuligayuk River crossing. Should natural scour or erosion processes threaten the structure of the bank or the pipeline, repairs would be affected. Typically, bank erosion has been repaired with grout bags, which protect the bank from ice and/or water scour (INTEC, 1996d:B-7). Impacts from repairs of this nature are minor.

The gravel island is expected to subside during the first few years following construction due to thawing of permafrost and compaction of underlying sediment. In addition, the island slopes may be damaged by ice or oceanographic processes each year, potentially causing sedimentation impacts to the seafloor. Planned yearly maintenance, as well as the use of filter fabric and concrete armoring in the slope design, would minimize sedimentation impacts to the seafloor. Annual maintenance and repair of the island would include regrading the island work surface following spring breakup, grading prior to freezeup, and replenishment by backpassing or dumping of the gravel berm as necessary. Impacts to seafloor sediment from maintenance activities would be negligible to minor.

Abandonment Impacts: Abandonment impacts would depend upon the abandonment plan adopted, and will be fully addressed in the assessment of the environmental effects of the abandonment alternatives. For an abandonment scenario involving onshore pipeline removal, impacts would likely be minor if abandonment were performed during winter. Removal of the offshore pipeline would be conducted in a similar manner to the installation, and would involve winter trenching through sea ice. The trench would be backfilled with spoils following pipeline removal. The impact on sediment would be similar to the impact of offshore pipeline construction discussed previously, that is, negligible to minor.

In place abandonment of the onshore and offshore pipelines would have no immediate physical impact to soils or seafloor sediment and have less impact than the physical removal of the pipeline. However, damage to the onshore pipeline could occur over time, and erosion of sediment could result in the offshore pipeline being uncovered. Since all oil would be removed from the pipeline as part of this abandonment scenario, impacts to soils and sediment from post-abandonment damage would be negligible to minor.

In the case of island abandonment, the island would be allowed to erode by natural processes, resulting in the introduction of gravel into the marine environment. The impact on sediment would be negligible to minor. Preservation of the island would have no impact on sediment.

5.3.3 Summary

No unavoidable adverse effects, or impacts, were identified for onshore and offshore geological and onshore hydrological resources as a result of implementing the project. This includes any direct and indirect impacts due to construction activities, operational characteristics (with the exception of an oil spill), maintenance procedures and abandonment options.

The primary issues or concerns, related to resources within the physical environment were the potential for direct and long-term impacts to soils, permafrost, and sediment quality, and from accelerated coastal erosion and hazards to project facilities from natural phenomenon. Overall, negligible to minor impacts are anticipated for these resources.

Resources committed to the project would be material and nonmaterial. The project would require an irreversible commitment of geologic resources, i.e., oil and gas reserves. Ground disturbance associated with installation of the subsea pipeline, the onshore VSMs, and gravel mining for reconstruction of the island and associated onshore facilities are also irreversible, as are the direct effect to soils and permafrost during the life of the project.

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- Ahkiviana, Archie

5.4 METEOROLOGY AND AIR QUALITY

5.4.1 Affected Environment

This section discusses aspects of the affected environment related to meteorology and air quality. Meteorological information for the project area is presented in Section 5.4.1.1. Air quality legislation and standards regulated by state and federal law are presented in Section 5.4.1.2. Section 5.4.1.3 describes the existing air quality of the project area.

5.4.1.1 Meteorology

Meteorological data (temperature, wind direction, wind speed, and precipitation) are collected hourly at the Deadhorse Airport located adjacent to the Prudhoe Bay Industrial Complex and at Barrow, 200 miles (322 km) west of the project area. Hourly data were also previously collected at the Barter Island weather station located 120 miles (193 km) to the east. Monthly averages at these stations are summarized in Table 5.4-1.

Climate: The project area is located in the Alaskan Arctic coastal (polar) climatic region and is characterized by persistent wind, low temperatures, and low precipitation. The summer season is short as a result of the high latitude (with continuous daylight) and winter is long (with 2 months of near continuous darkness). Snow covers the ground approximately 8 months of the year.

The National Weather Service operates a weather station in Barrow (Station 50-0546) and did operate another at Barter Island (Station 50-0558). Deadhorse Airport records maximum and minimum daily temperatures, and collects temperature, wind speed, and wind direction data hourly for the North Slope oil fields.

Temperature: Daily and seasonal temperatures are moderated by the maritime effect of the Arctic Ocean. The average annual temperature is 11°F (-12°C); however, temperatures range from -59°F (-51°C), with additional cold from windchill, to an average high of 70°F (21°C) (Gamara and Nunes, 1976:2). Equivalent windchill temperatures of -100°F (-73°C) have been recorded (Gamara and Nunes, 1976:3). Below freezing temperatures are experienced more than 80% of the year and have been recorded during every calendar month.

Elders have said that, in summer, a warm breeze and warming temperatures are indicators of an impending major storm (S. Kunaknana - Pers. Comm., Nuiqsut Community Meeting, August 14, 1996:2). It was also stated that climate changes have resulted in warmer temperatures in recent years (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:4).

Wind: Lack of natural wind barriers in the Alaskan Arctic coastal zone results in unrestricted winds at an annual average of 13.3 miles per hour (21.3 km per hour). Whaling camp locations are partly chosen for wind protection. Whaling activities at other islands have been abandoned in favor of Cross Island, where more protection is available (T. Napageak - Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:27).

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East northeasterly winds prevail during summer months, and west southwesterly winds prevail between January and April (GRI, 1992:7; USDOI, NOAA and Ruffner, 1985:28). Gusting winds are highest and most frequent between September and November. Storms generally move into the area from the west. Nuiqsut whaling captains explained that Seal Island is most vulnerable in a southwest wind, compared to milder effects of a northeast wind (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:3). Southwest winds have interfered with whaling, forcing hunters to abandon whales (T. Napageak - Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:13). A Barrow whaling captain reported that the prevailing wind is northeast in fall and winter, with occasional strong west winds.

Precipitation: Drizzling rain accounts for most of the precipitation along the Alaskan Beaufort Sea. Relative humidity in summer along the coast ranges from 80% to 95%. The relative humidity in winter drops to about 60%, resulting in very light density, granular snowfall. The light, granular snow and persistent wind may create inaccurate snowfall measurements due to drifting and blowing snow (USDOI, FWS, 1987:10). Average annual precipitation ranges from 4.8 inches (12.2 centimeters [cm]) at Barrow to 6.5 inches (17 cm) at Barter Island and occurs mostly as rain in summer. Annual average precipitation recorded at Prudhoe Bay from 1983 to 1993 indicate 7 inches (17.8 cm) of rain/snow fall. Records kept by the National Weather Service indicate a maximum 24-hour rainfall event of 1.32 inches (3.35 cm) over a 72-year recording period (Pollard - Pers. Comm., 1998:1). Data for Oliktok Point and Barter Island indicate 24-hour maximum events of 3.00 and 2.25 inches (7.62 and 5.72 cm), respectively (Brower et al., 1977:22). October has the highest average snowfall and June the lowest, but records show that snow has fallen in every calendar month. Blizzards and whiteouts occur frequently in winter due to the combination of light granular snow and periods of high winds.

Snowfall generally begins during the last part of September or early October and fog and ice form during this period (W. Matumiak in USDOI, MMS, 1990a:41). Nuiqsut hunters indicate that snow drifting around Seal Island begins in October, explaining that October through December are the critical months for snow drifts (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996).

Inupiat residents have relayed numerous accounts of their experience with extreme storms. Weather is described as constantly changing and unpredictable, with the largest storms occurring in September. With little warning, sudden and extreme storms can occur in the Alaskan Beaufort Sea (J. Ningeak in USDOI, MMS, 1990b:20-21). Storms can come from different directions, but usually are from the north, and the area inside the barrier islands is not heavily impacted by storms (S. Kunaknana - Pers. Comm., Nuiqsut Community Meeting, August 14, 1996:2).

5.4.1.2 Air Quality Legislation and Standards

Air quality is influenced by the interaction of air pollution with climatic conditions. Poor air quality can result in harmful effects to human health, animals, and vegetation, and can damage buildings and other objects. The Clean Air Act (CAA) was passed by Congress in 1963 to establish air quality standards. The CAA of 1970 and CAA Amendments of 1990 are the principal air quality laws in the United States. The State of Alaska Air Quality regulations are published in the Alaska Administrative Code (AAC), Chapter 50 of Title 18 (18 AAC 50), effective January 18, 1997. Pertinent sections of this legislation and regulations are summarized below.

U.S. Environmental Protection Agency (EPA) Regulations: EPA regulations regarding air quality that are applicable to this project are discussed below.

National Ambient Air Quality Standards (NAAQS): Primary and secondary NAAQS were established for six criteria pollutants: carbon monoxide (CO), sulfur dioxide (SO_2), particulate matter (PM), oxides of nitrogen (NO_x), ozone (O_3), and lead (Table 5.4-2). Primary standards are designed to protect human health, and secondary standards protect crops, vegetation, forests, and animals. Criteria pollutants are mainly waste products from burning fossil fuels.

In July 1997, the EPA promulgated new ambient air quality standards for ozone (8-hour averaging period) and particulate matter with an aerodynamic diameter of less than 2.5 microns (24-hour and annual average). These standards are being phased into existence, and they are not quantitatively addressed in this document.

Prevention of Significant Deterioration (PSD): The EPA has promulgated regulations to prevent further significant deterioration of the air quality in areas where the ambient air quality is better than the NAAQS.

The PSD Regulations (40 FR 52.21) define a "major stationary source" as any source type belonging to a list of 28 source categories that emits or has the potential to emit 100 tons per year (tpy) or more of any pollutant regulated under the CAA, or any other source type that emits or has the potential to emit pollutants in amounts equal to or greater than 250 tpy [40 CFR 52.21(b)(1)(I)]. The potential to emit is based on the maximum design capacity of a source, subject to federally enforceable permit limitations (e.g., limits on annual hours of operation) and takes into account pollution control efficiency [40 CFR 51.166(b)(4)].

Oil and gas development/production activities associated with the Northstar project are not included in the 28 listed source category types; thus, the 250 tpy threshold criterion for PSD sources is applicable. If the emission level of any one pollutant exceeds 250 tpy, it creates a major source, then a PSD review is applicable to other pollutants emitted in amounts as defined in 40 CFR 52.21 (b)(23)(I) (Table 5.4-3).

The proposed emission rates for the Northstar unit development/production show that the facility will be a major stationary source and, therefore, PSD review must be conducted for each pollutant with potential emissions equal to or greater than their respective PSD significant emission levels. The proposed project emissions trigger a PSD review for NO_X, CO, O_3 (precursor to volatile organic compounds), SO_2, and PM_{10}.

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The following classifications are defined by the EPA:

- Class I: Near pristine air; no significant new pollution source would be allowed. These areas are generally national parks, wilderness areas, and monuments.

- Class II: Moderate deterioration of air would be allowed within the limits of PSD increments. Most of the U.S. falls into this classification.

- Class III: Deterioration of air would be allowed up to the NAAQS limit.

The project area is designated PSD Class II. The nearest Class I area, Denali National Park, is 400 miles (644 km) to the south. PSD Class I and Class II increments are shown in Table 5.4-4. Only the Class II increments are applicable to the project area. Ambient, or surrounding, air quality is regulated by the Alaska Department of Environmental Conservation (ADEC) and the EPA. ADEC has PSD authority and implements monitoring and enforcement of regulations established under the federal programs described above.

Major provisions of the PSD review would include the following analyses:

Analysis of Best Available Control Technology (BACT).
Source Impact Analysis for demonstration of compliance with NAAQS.
Source Impact Analysis for demonstration of compliance with PSD Class II Increments.

New Source Performance Standards: The Federal New Source Performance Standards are applicable to specific categories of sources and apply to new sources of air pollution as well as to modified or reconstructed existing sources (40 CFR 60, Standards of Performance for New Stationary Sources). The standards apply to facilities with stationary combustion sources. An affected source means "any apparatus of the type for which a standard is promulgated ... and the construction or modification of which was commenced before the date of proposal of that standard...". The following subparts apply to development/production of the Northstar Unit.

- Subpart Kb, *"Standards of Performance for Volatile Organic Liquid Storage Vessels (Including Petroleum Liquid Storage Vessels) for Which Construction, Reconstruction, or Modification Commenced after July 23, 1984."* This standard applies to the diesel storage tank to be located at the Northstar facility. This tank exceeds the threshold size of 10,560 gallons (39,970 liters). Because of the low vapor pressure of diesel, however, the only requirement that must be satisfied for this tank will be to maintain records of the size and capacity of the tank.

- Subpart GG, *"Standards of Performance for Stationary Gas Turbines."* This standard is applicable to all stationary gas turbines with a heat input at peak load equal to or greater than 10.7×10^9 joules per hour (10.1 million British thermal units per hour [Btu/hr]) based on the lower heating value of the fuel fired. The equipment inventory for development/production of the Northstar Unit indicates there are

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turbines which have heat capacities greater than 10.1 million Btu/hr. These turbines must meet the requirements of Subpart GG.

· Subpart Dc, *"Standards of Performance for Small Industrial-Commercial-Institutional Steam Generating Units."* This standard is applicable to steam generating units with a heat input of greater than 10 million Btu/hr, but less than 100 million Btu/hr. The waste heat recovery unit for the Northstar Unit falls within this heat input range. This unit must meet the requirements of Subpart Dc.

National Emission Standards for Hazardous Air Pollutants: Section 112 of the CAA, as amended, required the EPA to publish a list of hazardous air pollutants for which National Emission Standards for Hazardous Air Pollutants would be developed. These standards were promulgated for specific industries and pollutants according to 40 CFR 61 (i.e., asbestos, beryllium, mercury, radon, radionuclides, vinyl chloride, benzene, and inorganic arsenic). Although these standards are promulgated on a source-specific basis, none of them apply to Northstar Unit development/production activities.

State of Alaska Air Quality Regulations: These regulations apply to any person who allows or causes air contaminants to be emitted into ambient air. The Alaska ambient air quality standards are identical to the NAAQS (Table 5.4-2), but also include a reduced sulfur compound standard and an ammonia standard. For reduced sulfur compounds, expressed as SO_2, a 30-minute average of 50 micrograms per cubic meter may not be exceeded more than once a year; and for ammonia, 2.1 milligrams per cubic meter, averaged over a consecutive 8-hour period, may not be exceeded more than once per year.

State of Alaska regulations applicable to development/production of the Northstar Unit are presented in Appendix D.

Permit Requirements: Based on the above state and federal requirements, the project will require a State of Alaska PSD permit for construction, drilling, and operation. A separate Title V operating permit will be issued after issuance of the PSD permit.

5.4.1.3 Existing Ambient Air Quality

Existing air quality for the onshore project area has concentrations of criteria air pollutants generally far less than the NAAQS and state standards (USDOI, MMS, 1996:IIIA-14). Onshore emission sources in the region include small diesel-electric generators at the villages of Barrow, Nuiqsut, and Kaktovik and major industrial sources at the Prudhoe Bay, Kuparuk, Endicott, Milne Point, and Lisburne oil production facilities.

Various monitoring programs conducted show that compliance with ambient air quality standards generally is maintained in the region, even at sites expected to have the highest concentrations of pollutants. Four sites were selected for air monitoring conducted in 1986 and 1987. Two sites were to be representative of maximum pollutant concentrations in the industrial area (Prudhoe Bay facilities), and two sites were to be representative of general air quality (isolated from industrial sources) in the area (Kuparuk facilities). An additional monitoring site was selected for the Prudhoe Bay area at Gathering

Center 1. All ambient air quality criteria pollutants except lead were monitored at these sites. Data collected from these sites from 1990 through 1996 are summarized in Table 5.4-5. All values measured at these sites meet the current (1997) state and federal ambient air quality standards, except one exceedance of the PM_{10} 24-hour standard. The PM_{10} 24-hour standard is not to be exceeded more than once per year.

Current allowable emission rates of onshore operating sources are summarized on Table 5.4-6. Actual emissions, as reported to the ADEC for 1994/1995 for all facilities in the western (BP Exploration (Alaska) Inc.-operated) and eastern (ARCO Alaska, Inc. [ARCO]-operated) operating areas, are summarized in Table 5.4-7.

Arctic haze, a phenomenon that affects air quality, occurs in winter and spring. Weather reconnaissance crews first reported Arctic haze in the 1950s, well before any development in the Arctic. Visibility was reportedly reduced from more than 50 miles (81 km) to less than 5 miles (8 km). Atmospheric chemists have collected data at Barrow and Narwhal Island, as well as other sites that experience Arctic haze in Scandinavia, Norway, and Greenland. The data show high concentrations of sulfate and vanadium at Barrow. Vanadium is a pollutant resulting from the burning of heavy industrial oils, commonly used as fuel. Chemists believe the haze is a result of long-range transport of pollution from industrialized Europe (Kerr, 1979:290-293).

North Slope residents have commented on Arctic haze in the past, including the public hearing on Lease Sale 144 and during scoping meetings and public hearings for this EIS (Section 7.8.1.2). They describe this haze as a smog and yellow smog that is visible during cold weather (F. Long, Jr. and J. Akpik, USDOI, MMS, 1995:23 and 32, respectively).

Offshore air quality within the Northstar Unit is expected to be near global background levels due to its location. The Northstar Unit is isolated from major pollutant emission sources other than the existing onshore production facilities described previously.

5.4.2 Environmental Consequences

The following section describes potential impacts of each project alternative on air quality. The discussion of impacts is organized according to project alternatives described in Section 4.4. Discussion of Alternative 1 - No Action Alternative is presented first, followed by the remaining alternatives. Alternatives 2, 3, 4, and 5 are very similar with respect to air quality and are therefore discussed together. Impacts are summarized in Table 5.4-8.

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5.4.2.1 Alternative 1 - No Action Alternative

Implementation of the No Action Alternative would not cause any changes to the existing meteorological conditions or ambient air quality. With the No Action Alternative, existing operations associated with onshore oil and gas activities would continue, decreasing with the decline in oil production. Air quality effects as a result of emissions from current operations would likely improve over the long term. However, the degree to which air quality may improve is uncertain.

5.4.2.2 Alternatives 2, 3, 4, and 5

Construction Impacts: Construction-related activities include utilization of various heavy duty diesel-fired equipment (both mobile and stationary source) for onshore and offshore portions of the project. Activities include ice road construction, operation of a gravel mine, operation of a concrete block plant and a screening plant, reconstruction of Seal Island, construction of onshore and offshore pipelines, and on-island construction.

Various ice roads for trucks hauling gravel to rebuild Seal Island would be constructed between the mine site and Seal Island for trucks traveling between the West Dock causeway and the gravel mine site, and for the onshore pipeline route. Emissions from equipment used for ice road construction would be mostly mobile source, temporary and localized, and the impact on air quality would be minor. These activities would not require an air permit or dispersion modeling.

A new gravel mine near the mouth of the Kuparuk River would be used as a gravel source for reconstruction of Seal Island. Potential for dust emissions from gravel mining is low because much of the blasted extracted gravel will be partially frozen or ice-bound, limiting liberation of dust particles from soils. Fuel consumed by mobile equipment (front-end loaders, dump trucks, and graders) would contribute to localized pollution. Air quality impacts from gravel mining activities would be minor (as determined in part by dispersion modeling). These gravel mine activities have been evaluated and are below major source threshold limits; therefore, no air permit or additional dispersion modeling is required (RILLC, 1996:ES-1).

The operation of a concrete block plant and a screening plant would involve mobile and stationary sources of criteria pollutants. The impacts from these plants would be temporary and localized, and the impact on air quality would be minor. These activities would not require an air permit or dispersion modeling.

Mobile sources such as a ditch witch (backhoe with a cutting blade), a backhoe, and front-end loaders would be used for reconstruction of Seal Island to dump and level gravel. The potential for dust emissions is low; however, increased emissions would occur from heavy equipment operation. Island construction activities would be temporary and localized, and the impact on air quality would be minor. These activities would not require an air permit or dispersion modeling.

Construction of onshore and offshore pipelines would involve mobile and stationary sources of air pollutants. Heavy duty diesel-fired equipment would emit criteria pollutants. Onshore pipeline installation would require a small drilling unit to drill piling holes for VSMs. Onshore pipeline construction for Alternatives 2, 3, 4, and 5 would also require the following bus/truck trips: 900/820, 1,125/1,025, 837/762, and 957/7,691, respectively. Offshore pipeline construction for Alternatives 2 and 3 would require 650 bus and 254 truck trips. For Alternatives 4 and 5, the number of bus/truck trips required would be 985/384 and 969/379, respectively. These impacts would be temporary and localized, and the impact on air quality would be minor (as determined in part by dispersion modeling). These activities would not require an air permit.

On-island construction activities would involve civil activities, non-civil activities, and the ongoing use of a reserve pool of construction equipment. The civil activities include foundation installation, slope armor installation, and pipeline tie ins; all other activities are non-civil, and include electrical, piping, mechanical, and other construction activities. Reserve pool equipment activities would primarily include the use of diesel-fired internal combustion engines and heaters. The annual air emissions of criteria pollutants for these activities are presented in Table 5.4-9. A PSD permit application, submitted to ADEC in February 1998, addresses the impacts of these on-island construction activities. There is minimal overlap between these construction activities and drilling/production operation activities. Air quality dispersion modeling impacts for these activities are presented in Table 5.4-10. These results show compliance with the NAAQS, and impacts are minor. Major sources of nitrogen dioxide (NO_2) emissions (Table 5.4-6) were included as background in this modeling analysis. Lisburne and the Deadhorse Power Plant air emission rates were included in the analysis because of their size and proximity. Milne Point, Badami, and Pump Station No. 1 were not included in the analysis, primarily due to size of emissions and distance from the Northstar project. The allowable emission rates are permitted emission rates (rather than actual emission rates). Thus, the modeling analysis should be conservative. Short-term and long-term emission rates resulting from air dispersion modeling analyses are provided in Table 5.4-6. Emissions of PM_{10}, CO, and SO_2 from background sources would not affect the model results and they were not included in the analysis.

Drilling and Operation Impacts: Drilling and operation activities would be subject to federal air quality permitting regulations, including New Source Performance Standards and National Emissions Standards for Hazardous Air Pollutants. In February 1998, a PSD permit application was submitted to ADEC to address drilling and operations impacts (this application was amended in August 1998). Drilling and operations equipment would have to meet BACT requirements for low emission combustion technology, fuel injection timing retardation, and catalytic oxidation. Methodology used to identify BACT is the five step “top-down” methodology recommended by the EPA. In addition, operation activities would be in accordance with the manufacturer design, which also constitutes compliance with BACT.

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Proposed BACT controls have been described in the PSD air quality permit application for drilling and operation activities. These controls apply to all pollutants and source types and are based on technical feasibility and economic, environmental, and energy impacts. The proposed BACT controls for drilling and operation activities are summarized in Table 5.4-11.

The proposed annual air emissions inventory for the long-term drilling and operation activities are shown in Table 5.4-12. This inventory assumes electric power would be supplied to the drilling rig from the Mars gas turbines. Drilling rig equipment, including heaters and boilers, are also shown in Table 5.4-12. The portable equipment includes a crane, light plants, snowblowers, a welding unit, and portable heaters and engines.

The ambient air quality impacts of drilling and operation activities compared to the NAAQS are shown in Table 5.4-13. Major sources of NO_2 emissions (Table 5.4-6) were included in the modeling as background. The emissions of PM_{10}, CO, and SO_2 from background sources would not affect the model results, thus they were not included in this analysis. Impacts for all pollutants are higher than those predicted for the drilling rig when firing natural gas, so this case has not been presented. These impacts also consider 720 hours per year (and 24 hours/day) of flaring activities from the gas flare. Essentially, this drilling/operation impact analysis presents a worst-case scenario for long-term project operations. Impacts for all pollutants are well below the NAAQS; therefore, air quality impacts from drilling and operation activities are minor.

The ambient air quality impacts of the drilling and operation activities compared to the PSD Class II increments for SO_2, PM_{10}, and NO_2 are below the applicable PSD Class II increments (Table 5.4-14). These impacts reflect BP Exploration (Alaska) Inc.'s proposed project and other increment-consuming services in the project area. These impacts also consider 720 hours per year (and 24 hours/day) of flaring activities from the gas flare. These impacts are expected to be minor. The ambient air quality impacts of the drilling and operation activities to the Arctic National Wildlife Refuge, Kaktovik, and Nuiqsut areas are well below the PSD Class II increments (Table 5.4-15). Impacts of drilling and operation activities are expected to be minor to these areas.

There will be some offshore flaring activities during the operation phase. The oil production facilities will occasionally experience emergency upset conditions that result in flaring of produced gas. These conditions result in emissions that are unplanned and are not subject to permitting requirements. It is expected that flaring occurrences will not exceed 30 days per year. This flare would be engineered to minimize incomplete combustion of gases, thus minimizing “speckling” of snow in the immediate vicinity of the flare. Impacts are expected to be minor.

A visibility impacts analysis was conducted for the Arctic National Wildlife Refuge area, and the results indicated that none of the Class I area criteria were exceeded. During drilling and operation activities, there will be air emission sources at onshore process facilities. These sources include:

- Shore Crossing - a thermoelectric generator (internal combustion engine).

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Table 5.4-12 (page 1 of 1)

Table 5.4-13 (page 1 of 1)

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- CCP Tie-in Location - gas pipeline booster compressor (gas turbine) and a generator (internal combustion engine).

- Pump Station No. 1 - an indirect-fired crude oil heater and a space heater.

An air emission inventory for these three locations is shown in Table 5.4-16. It is currently estimated that the emissions from these sources would not trigger the need for an air quality permit to construct from ADEC. The CCP tie-in and Pump Station No. 1 would require an operations permit. Dispersion modeling of all these locations shows impacts would be minor.

The Northstar Unit process design would incorporate measures to reduce the emissions of greenhouse gases, specifically carbon-dioxide. Measures considered include selection of efficient turbine drivers, minimizing flaring during operational upsets, waste heat recovery techniques, and fuel gas pretreatment to reduce carbon-dioxide content.

Impacts as a result of oil spills and associated clean-up activities are anticipated and are discussed in Chapter 8.

Maintenance Impacts: Maintenance activities associated with operation of the production island and pipeline would take place year-round over the expected 15-year life of the project.

Maintenance and repairs of the island slope protection system would include replacement of concrete mat blocks. Operation of a concrete block plant at a gravel source location (likely to be the Putuligayuk River site) would be necessary if no surplus blocks were available from initial construction. The concrete block plant would operate only if necessary to manufacture new or additional island slope protection blocks. The operation of the concrete plant would result in a temporary, localized, and minor impact to air quality. Island surface maintenance and repairs also would be carried out seasonally. Activity at the island would involve the use of a crane working from the island surface and a work crew. Emissions from these onshore and offshore activities would have a negligible impact to air quality. Maintenance and repair of the gravel berm surrounding the island would result in temporary negligible impacts to air quality from fugitive dust associated with gravel mining, hauling, and placement, as well as vehicle emissions.

Pipeline inspections would include helicopter overflights and regular pigging operations between Seal Island and onshore facilities. Approximately 60 bus and 84 helicopter trips would be required for onshore pipeline maintenance over the 15-year life of the project. These activities would result in negligible impacts to air quality. Maintenance of the offshore pipeline could include excavation of the pipeline trench to make repairs. Trenching and repair of the pipeline would require use of heavy equipment, welding machines, light plants, and air compressors. Trucks and/or supply barges would be used for delivery of repair supplies and/or work crews. Air quality impacts associated with offshore pipeline repairs would be temporary, localized, and negligible.

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Abandonment Impacts: Abandonment impacts would depend upon the abandonment plan adopted, and will be fully addressed in the assessment of the environmental effects of the abandonment alternatives. For an abandonment scenario involving complete removal of all facilities and infrastructure, impacts would be expected to be similar to those generated during construction, and the overall impact to air quality as a result of abandonment would be expected to be negligible.

5.4.3 Summary of Environmental Consequences

No significant unavoidable adverse impacts to air quality from the project were identified. Short-term impacts include localized emissions from construction activities and are negligible to minor. Long-term impacts include emissions from facility operations and vehicles delivering supplies to the offshore site. These impacts to air quality are negligible to minor and will occur as a result of routine facility operation.

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5.5 PHYSICAL OCEANOGRAPHY AND MARINE WATER QUALITY

5.5.1 Affected Environment

Oceanographic topics which affect the project include: the bathymetry of the project area, the effect of the region's weather on the surface of the sea, and local and regional currents which influence water movement beneath the surface of the sea. Marine water quality deals with the physical and chemical characteristics of seawater which may be affected by the project. Physical parameters include temperature, turbidity, suspended sediments, and density. Salinity, dissolved oxygen, nutrients, pH, trace metals, and naturally-occurring hydrocarbons are characterized by chemical parameters which may be used to assess project impacts to the nearshore environment.

An understanding of the oceanographic processes and baseline water quality in the project area allows for meaningful comparisons between project alternatives. Information presented in this section also is used to support the draft and preliminary final NPDES Permit (Appendices F and O) and its associated Fact Sheet (Appendix G), the Ocean Discharge Criteria Evaluation (Appendix H) and Section 103 Evaluation (Appendix I) documents for this project. These four documents address the release of water discharges and trenching spoils back into the Alaskan Beaufort Sea.

5.5.1.1 Bathymetry

Between the mainland and Stump Island, water depths are 0-5 ft (0-1.5 m). Between Stump Island and Seal Island, water depths are 0-40 ft (0-12 m). The appearance of the seafloor in the project area is a result of tides, currents, and other oceanographic processes. Sea ice processes such as gouging and strudel scour, also affect the appearance of the seafloor. (Leidersdorf and Gadd, 1996). North of Seal Island, the seafloor gently slopes downward in an offshore direction (Selkregg, 1975:41) toward the edge of the Alaskan Beaufort Sea continental shelf, approximately 60 miles (97 km) north of the project area. Beyond 60 miles (92 km), the seafloor drops off steeply into the Canada Basin of the Arctic Ocean.

The breach in the West Dock causeway (Figure 5.5-1) was constructed in 1994 to improve nearshore seawater circulation. The breach is 650 ft (198 m) long and spanned by a bridge. It was anticipated that the breach would alter bathymetry in the immediate vicinity of the causeway by constricting current flow and increasing current velocity. As a result, design specifications stipulated bridge support piles of sufficient length to withstand effects of seafloor scour to a depth of -40 ft (-12 m) MLLW.

5.5.1.2 Weather and Water Levels

Water level variations caused by wind generated waves, storm surges and, to a lesser extent, tides are important factors influencing nearshore oceanographic conditions in the project area.

Storm surges are changes in water level resulting from weather disturbances. They are most likely to occur from August through October, during the open water season, which also coincides with highest mean monthly wind speeds (Joy et al., 1979:4). The height of a storm surge is affected by atmospheric pressure; wind speed, direction, and duration; Coriolis effect; rainfall; and direction and speed of storm movement. Fetch, the length of open water surface across which the wind can blow, is a factor which determines wave height and the potential intensity of a storm surge. In some years, the pack ice is well north of the coast, resulting in a long fetch for westerly to northwesterly winds and the potential for high storm surges in the project area. Surge height is enhanced by a shallow, gently sloping seafloor similar to the seafloor at the project area.

Storm surges cause much larger variations in sea level than do astronomical tides (Gantz et al., 1982:35), whereas the tidal range in the project area is less than 12 inches (31 cm) (Figure 5.5-2) (WCC, 1997:2-1). Positive storm surges of 3 ft (0.9 m) above sea level are common along the Alaskan Beaufort Sea coast. Occasionally, larger storm surges of 3.3 to 6.5 ft (1 to 2 m) above sea level can occur (WCC, 1997:2-1). Nuiqsut whaling captains have observed that these large storm surges occur with southwesterly winds, not during northeast winds. (T. Napageak - Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:7). In the project area, barrier islands, artificial islands, and coastal facilities up to 0.6 miles (1 km) inland may be flooded during exceptional storms caused by westerly winds (Grantz et al., 1982:35). A Nuiqsut whaling captain described how storm surges overtop sea ice and come ashore up river drainages (F. Long, Jr. - Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:8).

Rise or fall in water level from a storm surge is greatest along coastal areas where water depths become more shallow. In deeper offshore portions of the project area, such as at Seal Island, it is expected that the effect of storm surges would be much less. Positive storm surge estimates for Seal Island under westerly wind conditions indicate a maximum 1.1-ft (0.34 m) above sea level surge annually and a maximum 4.1-ft (1.2 m) above sea level surge based on a 100-year return period (OCTI, 1996, as cited in INTEC 1996:3-39).

In addition to storm surges, waves are an important oceanographic component which may affect project facilities. Wave height and period (frequency) are determined by wind velocity, duration, fetch, and water depth. Wave heights increase the longer the wind blows. In the project area, wind events usually last 2 to 3 days during the open water period. Based on studies performed on the shore at Point Storkersen, the largest waves had heights of 5 ft (1.5 m) and a period of approximately 6 seconds. The 100-year, westerly storm-

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Figure 5.5-2 (page 1 of 2)

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generated wave at Point Storkersen is predicted to be 4.4 ft (1.3 m) in height with a period of 4.8 seconds. Predicted wave heights and frequencies are listed in Table 5.5-1 for the shore at Point Storkersen (INTEC, 1996:3-39; Britch et al., 1983:219). Offshore of the barrier islands in the vicinity of Seal Island, waves are larger, due mainly to water depths and longer fetches, relative to the shallow, protected lagoon areas. Extreme wave predictions for Seal Island from the Beaufort Sea Hindcast model (based on 25 years of weather data) data are presented in Table 5.5-2.

5.5.1.3 Currents and Circulation

Nearshore currents along the coast in the project area are primarily wind driven during the open water season (Wilson, 1974:55-57). Currents usually orient along bathymetric contours that parallel the coast in an east-west direction (Wilson, 1974:55-57; Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:11). Typical westward and eastward current patterns in the project area are illustrated on Figure 5.5-3.

Current speeds change with wind speed, with a few hours lag time (SAIC, 1993:33). Studies of water movements in the coastal waters near Seal Island have shown current speeds ranging from near zero to 27 inches/second (s) (69 cm/s) during the later open water season. Mean open water current speeds were found to be 2 to 5.5 inches/s (5 to 14 cm/s), depending on water column stratification (WCC, 1996:20).

Nuiqsut whaling captains indicated that currents are very strong in early fall and that currents with a southwest wind are most dangerous (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:2). One whaling captain specifically noted that Seal Island would most likely be affected by the combination of southwest winds and strong currents (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:6-7). Nuiqsut residents also spoke of the difference between currents on the surface and bottom, and stated that the location of currents are unpredictable (Pers. Comm., Nuiqsut Community Meeting August 14, 1996:4).

Surface currents are directed to the right of the wind direction as a result of the Coriolis effect, resulting in a net onshore transport of surface waters in the project area for west or southwest winds. The onshore transport of surface waters is balanced by a return flow of water at depth, resulting in downwelling and mixing along the coast. West winds result in an eastward current of warm, brackish water from the Colville River through Simpson Lagoon/Gwydyr Bay and along the offshore side of the barrier island lagoon system in the project area (Figure 5.5-3). A Barrow whaling captain stated that when the wind hits the top of the ocean and forces the current down and causes it to change, it swirls and creates underwater turbulence (Pers. Comm., Barrow Whaling Captains Meeting, August 28, 1996:1). Combined with the presence of ice, these swirling conditions can be extremely dangerous.

Tables 5.5-1 and 5.5-2 (page 1 of 1)

Figure 5.5-3 (page 1)

Figure 5.5-3 (page 2)

The effectiveness of mixing within the water column is influenced by the physical nature of the seawater. Vertical mixing of the water column is slowed by density stratification of the water column. Easterly winds have been found to induce a high degree of vertical stratification and stability in the nearshore region, slowing the vertical mixing processes. A two-layer structure with lower salinity water due to freshwater from rivers, overlying more marine water is normal during easterly winds. The large density difference between these two layers inhibits mixing. Wind induced surface mixing has little effect on the lower water column during these conditions. Since mixing is limited to the upper layer, surface currents are much greater.

Under west winds, warm, low salinity water collects against the coast, with salinity decreasing and temperature increasing nearer to the shore (Savoie and Wilson, 1986:2-21). Downwelling along the coast tends to reduce vertical stratification of the water column, causing greater vertical mixing. Under sustained west winds (2 to 3 days), the salinity of the eastward longshore flow remains constant, only slowly increasing as winds persist and river flow slows (as snow melt and rainfall decreases). This uniformity was observed in 1983 under west winds from mid-August through mid-September.

Farther offshore within the project area, currents are probably influenced by the eastward flowing "Beaufort Sea Undercurrent," which has been shown to be an important summer feature on the continental shelf seaward of the 160-ft (49 m) isobath extending out to the continental shelf break (Aagaard, 1984:47-72). Nuiqsut residents report that currents change with distance from shore (F. Long, Jr. in USDOI, MMS, 1995:24). One Nuiqsut whaling captain spoke of a strong current he encountered during the fall whaling season offshore of Cross Island, at a distance of about 40 miles (64 km) (T. Napageak - Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:13). The location of this current changes every year (F. Long, Jr. - Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:13). Whaling captains observe that whales swim in this strong current, and that the current is strong enough at times to move against the wind (T. Napageak and F. Long, Jr. - Pers. Comm., Nuiqsut Whaling Captains meeting, August 13, 1996:16). Nuiqsut residents spoke of Seal Island lying close enough to the shore to avoid the zone of major current movement, and that Northstar Island is in a much more dangerous location (Pers. Comm., Nuiqsut Community Meeting, August 14, 1996:2).

Under-ice currents in the nearshore project area are driven mainly by water level fluctuations caused by tides and storm surges. A Nuiqsut whaling captain stated that free water is always moving under the ice, especially with a southwest wind (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:2). Nuiqsut residents involved in spill response drills stated that measurements taken under the ice indicated that current direction could change over relatively short distances (Pers. Comm., Nuiqsut Community Meeting, August 14, 1996:9). Limited measurements taken below the ice during the spring of 1976 showed currents on the inner shelf to be slow, never exceeding 3.6 inches/s (9 cm/s), and generally less than 2.4 inches/s (6 cm/s) (Aagaard, 1984:47 to 72). Based on meteorological records and the limited amount of current data, it was concluded that under-ice currents were driven by coastal storm surges and regional circulation patterns.

Very small under-ice currents, generally less than 2 inches/s (5 cm/s), were measured offshore of the West Dock causeway as part of Arco Alaska, Inc.'s NPDES monitoring program in spring 1994 (KLI, 1995:6-5 to 6-8). The predominant direction of flow was westerly, but fluctuated with the tides. Under-ice currents recently monitored offshore of Stump Island, as part of a Northstar project winter test trench investigation, indicated no currents exceeding the 0.84 inches/s (2 cm/s) resolution of the current meter used (Montgomery Watson, 1996:7). However, average under-ice currents of 0.7 inches/s (1.8 cm/s) and maximum under-ice currents of 3.6 inches/s (9 cm/s) have also been reported (WCC, 1997:2-2).

5.5.1.4 Marine Water Quality

Marine water quality in the project area is measured using a number of physical and chemical parameters. The following sections describe these parameters.

Physical Parameters: The temperature of the seawater in the project area is an important component in the oceanographic system. A change in seawater temperature by only a few degrees could result in alteration of the seasonal freeze/thaw cycle within the project area. An essential part of the ecosystem in the project area, ice formation and break up, could be affected if this seasonal freeze/thaw cycle is altered. Density, or mass per unit of volume, affects vertical movement, stratification, and mixing within a given column of seawater. This density is related to both temperature and salinity.

Water column conditions are discussed for the open water period (spring breakup in early June until freezeup in late September to mid-October) and the winter period (October through May). The open water period is subdivided, for descriptive purposes, into three distinct seasons: early, middle, and late.

<u>Early Open Water Season</u>: The early open water season is a time of transition from the ice-covered winter conditions. Runoff from rivers begins in late May or early June with peak flow usually occurring in the first week of June. Wind-driven mixing is at a minimum during the early season as a result of partial ice cover and low wind speeds and wave heights. Seawater is typically stratified during this period with cold marine water in the lower part of the water column and relatively warm estuarine water in the top part. The pycnocline is the junction between these colder and warmer layers, and it typically occurs at 10 to 20 ft (3 to 6 m) of water depth in the project area (WCC, 1997:2-4).

The transition from early to mid-season occurs in late July or early August and is very dramatic. The transition is usually caused by strong east winds that produce a regional upwelling of marine water along the coast. These winds also cause the ice edge to move farther from shore, increasing the wind fetch and mixing due to waves. Easterly winds cause a general inflow of marine water through channels and inlets as a result of the geometry of Simpson Lagoon. This inflow, coupled with surface water division along the coast, causes marine water to enter the lagoon system through deeper channels. The net effect of the first coastal upwelling event each year is to spread surface waters horizontally, allowing greater mixing of shallow waters and passage of marine waters into the lagoon systems. Colder temperatures and higher salinities in the nearshore zone result.

<u>Middle Open Water Season (Mid-season)</u>: This season is characterized by disintegration of water column stratification. However, as river discharges decline, coastal conditions approach those of deeper marine waters. Alternating easterly and westerly winds may occur in mid-season and have varying effects on vertical mixing temperature and salinity. As described in Section 5.5.1.3, east winds cause upwelling in

the nearshore water column, whereas westerly winds typically result in regional downwelling. Frequent wind reversals increase mixing between coastal and offshore waters, while fewer changes in wind direction (and strength) allow fresher pockets of water to last into late August, with no clear change between middle and late season.

Late Open Water Season: From mid-summer until freezeup, coastal waters become steadily colder and saltier until they are virtually identical to marine waters. Water conditions during the late open water period (early September through October) are relatively constant throughout the region. Temperatures are near freezing throughout the nearshore area. Freezeup of the lagoons usually starts in late September or early October, with shallow offshore areas freezing approximately a month later.

Winter Season: Marine water quality was recently analyzed from samples collected beneath the ice at two locations: in Gwydyr Bay between Point McIntyre and Stump Island, and offshore of Stump Island in 16 ft (5 m) of water (Montgomery Watson, 1996:Table 2). Samples of free water at the Gwydyr Bay location had calculated seawater densities which ranged from 2,990 to 3,226 pounds/yd^3 (1,037 to 1,119 kilograms/m^3) at a water temperature of 25.5°F (-3.6°C). Samples from the offshore location had calculated seawater densities ranging from 2,955 to 3,033 pounds/yd^3 (1,025 to 1,052 kilograms/m^3) at 28.4°F (-2.0°C), indicating that the nearshore waters are generally more dense (saline) than the offshore waters.

Chemical Parameters: Most organisms are dependent upon oxygen in one form or another to maintain metabolic processes. Hence, dissolved oxygen is an important parameter to understand with regard to the health of the marine system. Nutrients, such as nitrogen and phosphate, are also important. pH is a measure of hydrogen ion concentration in seawater and an indicator of the waters' relative acidity or alkalinity. Turbidity is an optical property which describes the interaction between light and suspended particles in seawater. It is frequently used in a qualitative sense to describe the cloudiness caused by sediment suspended in the water.

Dissolved Oxygen: Due to vigorous mixing in the offshore areas by wind and wave action during the open water period, dissolved oxygen concentrations in marine waters along the Alaskan Beaufort Sea coast and in the vicinity of the project area are generally at or near saturation. Dissolved oxygen concentrations for warm, brackish surface waters are similar to values for cold, high-salinity marine waters, although slightly higher dissolved oxygen concentrations are found near the bottom (KLI, 1987:3-8 and 3-9). Typical values for the open water period range from 11 to 13 milligrams per liter (mg/L). Under-ice values around West Dock were found to be high in February through May with concentrations ranging from 9 to 12 mg/L. Dissolved oxygen concentrations under the ice off Oliktok Point during April 1987 ranged from 11.8 to 13.1 mg/L.

Nutrients: Nutrients are compounds of nitrogen and phosphorus that are essential for growth of marine organisms. Nutrient concentrations in surface waters along the Alaskan Beaufort Sea shelf in 1971 and 1972 were generally low, variable, and reached an annual peak in the spring (Schell, 1974:226-228). With an increase in the amount of light in the spring, nutrients are used by ice algae that are beginning to grow on the bottom of the ice.

Nitrogen, in the form of dissolved nitrate is a major nutrient, and elemental nitrogen is essential to all life. River discharges in the spring contribute much of the nitrogen to the coastal waters in the project area (Schell, 1974:226-231). The inorganic nitrogen present at the start of summer is rapidly lessened due to ingestion by plankton. Dissolved organic nitrogen in Simpson Lagoon averaged 5.69 microgram-atoms per liter (μg-at/L). Seaward of the barrier islands, dissolved organic nitrogen had a mean value of 4.86 μg-at/L; nitrate and nitrite were nearly undetectable (Schell, 1974:4-18).

Phosphorus is second only to nitrogen as a nutrient element required by plants and microorganisms. Average phosphate concentrations in Simpson Lagoon and Harrison Bay have been reported at 0.6 to 1.2 μg-at/L with little variation in sample readings (Schell, 1974:229). The lowest phosphate levels occurred near melting ice and nearshore, indicating that neither melting ice nor river runoff were sources of phosphate to the coastal waters. The freshwater in the rivers and deltas is primarily phosphate limited, whereas the coastal marine waters are primarily nitrogen limited which is important for biologic activity.

<u>Hydrogen Ion Concentration (pH)</u>: The pH of water reflects its relative acidity or alkalinity. Although measurements of pH along the Alaskan Beaufort Sea coast are relatively sparse, saline ocean water is a natural buffer that results in fairly constant and similar values throughout a region. In Prudhoe Bay, pH values were 6.8 to 7.9 under the ice, and 7.8 to 8.2 during open water. At Oliktok Point, pH values were 7.5 to 7.7 under the ice, and 7.6 to 8.0 during open water (KLI, 1987:3-10). Offshore of West Dock in 1994, pH values were 8.0 to 8.2 under the ice, and 7.9 to 8.1 during open water. Measurements made in Simpson Lagoon/Gwydyr Bay in August 1970 showed a lower pH, ranging from 7.0 to 7.4 with a mean pH of 7.14 (Alexander et al., 1974:289); however, these data appear to be anomalously low for marine waters.

<u>Turbidity</u>: Turbidity values in the nearshore Alaskan Beaufort Sea area are dependent on wind and wave induced turbulence that resuspends bottom sediment and material discharge from the rivers. The highest turbidity values were found during spring breakup and periods of heavy precipitation when river discharge was high, resulting in turbid plumes that were discharged into the nearshore coastal waters (KLI, 1995:3-10). Turbidity values were found to range from 0 to more than 40 Nephelometric Turbidity Units (NTU), with the majority of the measurements less than 5 NTU. Offshore of the West Dock causeway, turbidity ranged from 3 to 11 NTUs during the open water period, and from 0.5 to 3.4 NTUs during winter under ice conditions. In the offshore portion of the project area that is unaffected by river discharges, turbidity values are expected to be low, similar to those measured offshore of West Dock. Within the inshore portion of the project area, especially Simpson Lagoon where the nearshore waters are influenced by the Kuparuk and Colville Rivers, turbidity values are expected to be higher and dependent on river discharge and sediment resuspension as a result of wave action.

Total suspended solids analyses of recently collected samples from beneath ice at a location offshore of Stump Island in 16 ft (5 m) of water depth, yielded results from non-detectable amounts of solids to 885 mg/L (Montgomery Watson, 1996:11). Samples of free water collected beneath the ice in Gwydyr Bay (between Point McIntyre and Stump Island) showed relatively high total suspended solid values ranging from 7,480 to 26,920 mg/L. Water samples from the same lagoon location, but collected at the ice-sediment interface, were lower in total suspended solids than the free water, ranging from 40 to 3,910 mg/L.

Trace Metals: Trace metals are naturally occurring elements which are present at low concentrations. Trace metal concentrations in marine waters along the Alaskan Beaufort Sea coast and in the vicinity of the project area show no indication of pollution in the water, suspended sediments, or surficial sediments. Trace metal concentrations were determined for seawater samples collected near East Dock in Prudhoe Bay during summer 1979, and were found to be generally low (KLI, 1990:Table 4-2; Boehm et al., 1990:4-1 to 4-11).

Hydrocarbons: Hydrocarbon concentrations in the water column have been found to be low (at l part per billion or less), and appear to be biogenic (biologically derived) in origin (Boehm et al., 1990:4-14 to 4-24).

5.5.2 Environmental Consequences

Impacts to oceanography and marine water quality as a result of development/production activities from the Northstar Unit are discussed in terms of the project phases. Technical topics which build upon issues and background information previously discussed are organized by project alternatives. A description of all alternatives is presented in Chapter 4. Alternatives 2 and 3 are identical with respect to the oceanographic environment and marine water quality and are discussed together. Alternatives 4 and 5 are presented separately to adequately address differences in offshore pipeline routing, length, and landfall locations. Potential impacts from implementation of Alternatives 2, 3, 4, and 5 are summarized in Table 5.5-3.

5.5.2.1 Alternative 1 - No Action Alternative

The oceanographic conditions and marine water quality characteristics would not be affected with selection of the No Action Alternative. The project area is naturally stressed as a result of its arctic location and will continue to be modified by natural forces in the absence of the project. Characteristics of bathymetry, currents, and other oceanographic parameters are not anticipated to change from the current, natural setting. Overall, no impact to the oceanographic or marine environments would occur.

5.5.2.2 Alternatives 2, 3, 4, and 5

The offshore portions of Alternatives 2 and 3 are identical and would require approximately 6 miles (9.6 km) of offshore pipeline trench. Therefore, environmental consequences to oceanography and marine water quality for Alternatives 2 and 3 are identical.

Table 5.5-3 (page 1 of 2)

Table 5.5-3 (page 2 of 2)

The submarine pipeline under Alternative 4 is routed south from Seal Island as it is under Alternatives 2 and 3, but turns southeast approximately 3 miles (4.8 km) south of the island. The pipeline skirts to the north of the barrier islands and turns southwest to reach land on the coast at Point McIntyre. Under Alternative 4, the total length of the offshore pipeline would be 9 miles (14.5 km).

The submarine pipeline route under Alternative 5 skirts north of the barrier islands similar to the route under Alternative 4, but lands at Dock 2. Under Alternative 5, approximately 3.8 miles (6 km) of pipeline corridor would be located in water depths of between 0 and 10 ft (0 to 3 m), approximately 3.4 miles (5.3 km) of pipeline corridor would be located in water depths of between 10 and 20 ft (3 and 6 m), and approximately 1.8 miles (2.9 km) of pipeline corridor would be located in water depths of between 20 and 40 ft (6 and 12 m). The total length of the offshore pipeline would be 8.9 miles (14.3 km).

Construction Impacts: The marine environment would be affected by island reconstruction and trenching and burial of offshore pipelines. The production island would be built over the existing Seal Island site, requiring emplacement of between 700,000 and 800,000 yds^3 (535,185 and 611,640 m^3) of additional gravel to the existing island footprint. A submerged protective gravel berm 50 to 100 ft (15 to 31 m) wide would be placed around the north, west, and east sides of the island. Based on the fact that the reconstruction will not create a new structure, but rather elevate and enlarge an existing one, impacts to bathymetry in the immediate vicinity of Seal Island are considered to be negligible as a result of island reconstruction.

Reconstruction of Seal Island would affect water quality in a number of ways. Increases in turbidity and suspended sediment concentrations in the immediate vicinity of the island during gravel dumping activities are anticipated. Density of the water column and winter season stratification might be altered due to the artificial mixing produced by the gravel dumping. However, due to the relatively short, 3-month duration of gravel placement activities, effects to marine water quality are expected to be short-term and negligible.

Summer construction activities such as grading and shaping the island and sub-sea island slopes would result in re-suspension of sediments, causing localized temporary increases in turbidity and suspended sediment concentrations in the water column. These increases in turbidity and suspended sediment would have minor impacts to marine water quality.

In early spring, excavations for installation of marine outfalls and the seawater intake system would be carried out below sea level. Dewatering activities would involve a discontinuous and variable discharge of up to 1,389 gallons (5,258 liters) per minute. The water discharged early in the dewatering process would have an elevated suspended sediment load, and would result in a turbid discharge. However, the discharge would be discontinuous and short-term, (2 to 4 weeks); therefore, impacts would be considered minor.

Pipeline trenching and subsequent backfilling activities would result in suspension of sediment into the water column. The amount of suspended sediment and plume size would depend on sediment grain size and cohesiveness characteristics and under-ice currents. The effects on water quality would vary along the pipeline route. In the inshore area of bottomfast ice (less than 6-ft [1.8 m] water depth), little or no water would be expected between the ice and sediment, and as a result, no impacts to long-term water quality would occur.

In the offshore area where water would be present between the ice and sediment, water quality would be temporarily affected by trenching and backfilling activities. The extent of sediment resuspension would depend on the water depth, sediment grain size and cohesiveness, strength of the currents, and the amount of sediment released during dredging and backfill operations. An offshore test trench was excavated for the project during March 1996, and total suspended solids concentrations were found to range from only approximately 20 to 40 mg/L above background at distances of up to 1,000 ft (305 m) from the excavation (Montgomery Watson, 1996:Tables 1 and 2). Based on data from this test, Montgomery Watson computed a maximum probable distance of 830 ft (253 m) for under ice sediment plume transport. However, due to the relatively short, 4- to 5-month, duration of pipeline trenching activities, impacts to marine water quality are expected to be localized and temporary in nature and, therefore, have a negligible impact to long-term water quality.

Excess spoils generated from trenching and pipeline installation activities would be disposed on the ice at a location immediately outside the barrier islands over floating-fast ice. The expected volume of excess spoils is approximately 5,000 yd^3 (3,823 m^3), with a maximum quantity of up to 65,000 yd^3 (49,696 m^3). This maximum 65,000 yd^3 (49,696 m^3) spoils volume would only occur if pipeline construction was terminated due to hazardous conditions. The excess spoils will be spread and leveled such that their release, temporary suspension in the water column, and deposition on the seafloor during breakup would be uniform. It is anticipated that these excess spoils will be further scattered and distributed by natural ice and current processes during breakup the following year. The release of the excess spoils during breakup is expected to occur over a period of weeks. The volume of excess material is relatively small (5,000 yd^3 [3,823 m^3]), less than two average days of sediment yield from the Kuparuk River during spring breakup and summer flows (USDOI, GS, 1996:Table 1) and its release will occur only once. The impact to marine water quality and bathymetry from the release of the excess spoil material is considered to be negligible. Impact would be considered to be minor even in the event that all excavated trench material (65,000 yd^3 [49,696 m^3]) was disposed as excess spoil. Within the range of potential spoil disposal from expected to worst case, it is anticipated that natural ice dynamics and other oceanographic processes (e.g., currents) would quickly scatter the spoils. A slight but measurable short-term bathymetric mound could develop. Over the course of several years, or less, these processes would continue to erode any mounds until they were indistinguishable from other naturally occurring seafloor features.

Under Alternative 5, nearshore gravel placement would also be required. Gravel placement would occur along the west side of the West Dock causeway between Dock 2 and the West Dock Staging Pad to accommodate the pipeline route. Between 290,000 and 300,000 yd^3 (221,719 to 229,365 m^3) of gravel would be used to widen the existing causeway by approximately 50 ft (15 m). The new gravel would be placed immediately adjacent to the existing causeway and would match the existing causeway in height. Due to the nearshore nature of the area and its typical bottomfast ice, little or no water would be expected between the ice and sediment, and as a result, no impacts to long-term water quality would occur as a result of the causeway expansion.

Operation Impacts: Once reconstructed, Seal Island would alter water current patterns in the immediate vicinity of the island. Prevailing current direction could be altered slightly as flow is diverted around the island. However, because the perimeter footprint which currently defines the island boundaries would not be substantially increased during the reconstruction, increases in current patterns and velocities in the vicinity of Seal Island will be small, localized, and of negligible impact to project area and regional oceanography.

Nuiqsut whaling captains have observed that the combination of current, storm surges, and "young" ice create hazardous conditions where ice override could affect Seal Island facilities (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996). Structural design criteria for Seal Island includes features specifically intended to protect the integrity of the facilities both on the island and onshore in the event of a storm surge. The predicted storm surge values used for design purposes were 6 ft (1.8 m) for onshore and 4 ft (1.2 m) for Seal Island. Design criteria are based on a 100-year return interval. Operation impacts of ice override are discussed in Section 5.6.2.2.

The Alternative 5 pipeline route is within 500 ft (150 m) of the 650-ft (195 m) breach in the causeway which connects West Dock with the mainland. Increased sediment scour at the breach could lessen the integrity of the pipeline's protective embedment. Since its installation, bathymetric surveys have been conducted annually at the breach to monitor the effects of current scour around the piles which support the bridge structure. Surveys indicate that scour in the vicinity of the piles has increased as a result of the structure, and that the presence of the structure has altered the bathymetry in the immediate area. The magnitude of the scour, however, is an order of magnitude less than predicted. Survey data from 1995, 1996, and 1997 indicate that maximum scour depth in the vicinity of the breach has not exceeded 3.3 ft (1 m) in any given year (CFC, 1995: Drawing CFC-346-001; CFC, 1996:Drawing CFC-359-001; ARCO, 1997:Sketch WDBBATH). Based on a comparison of the 1997 bathymetric scour data and design specifications which allow for scour depths up to 40 ft (12 m), a 3.3-ft (1 m) rate of accelerated marine sediment scour annually is considered minor. It is possible that scour impacts to pipeline backfill material would be slightly greater in the vicinity of the West Dock causeway breach. However, impacts to the integrity of the backfill protecting the pipeline as a result of scour will be minor.

Support vessel operations and permitted discharges will affect marine water quality in the project area as a result of operations. Support vessels, barge traffic, and periodic sea lifts would generate propeller wash and turbulence along the south side of Seal Island where the dock face would be located and at West Dock where vessels and barges would be originating. These vessel operations would result in re-suspension of finer sediments in the immediate vicinity of the dock heads at Seal Island and West Dock. The region of elevated suspended solids and turbidity would be mainly confined to the area within the wake of the vessels as they traverse the shallower waters. The limited areal extent of operationally induced re-suspension of fine sediments related to seasonal vessel traffic to and from Seal Island would result in a negligible impact on water quality in the project area.

No drilling muds, borehole cuttings, or produced water are proposed for discharge to the marine environment. The two proposed marine outfalls related to operational activities are: 1) a combined stream composed of system flush water, brine effluent associated with the potable water system, and treated domestic/sanitary wastewater; and 2) seawater discharged through the fire suppression system during annual tests. The source of feed water for these operational outfalls is seawater collected through a seawater intake system. This seawater is utilized by various facility operations.

The continuous flush system is designed to prevent ice formation and biofouling, while the desalination brine is a byproduct of the potable water system that renders freshwater from seawater. The freshwater produced is utilized for both human and operational activities. Domestic/sanitary wastewater, following an activated sludge and ultraviolet treatment, is generally discharged through a class I industrial disposal well but may occasionally be marine discharged; this treated wastewater stream results almost exclusively from human activities related to food preparation, consumption, and bathing, and does not contain any fluids related to the oil production/processing systems. The above streams are commingled prior to marine discharge and Alaska State Water Quality Standards are satisfied within 16.4 ft (5 m) of the discharge point; therefore, negligible impacts to water quality from these discharges are expected.

Annual tests of the fire suppression system would require discharge of 88,200 gallons (333,873 liters) of seawater over a 30-minute test period. Discharge of ambient seawater is considered to be a negligible impact on water quality.

The above discharges are not expected to impact the island's intake water quality, i.e, the discharge ports are so located to ensure discharged waters do not recycle back into the seawater intake. In addition, these discharges do not contain excessive quantities of pollutants that might bioaccumulate in marine organisms and, therefore, cannot result in elevated levels of toxic or carcinogenic pollutants in marine organisms consumed by humans. Additional details are provided in Appendices G and H.

Some effect to marine water quality would be expected should there be an oil spill in the project area. Dissolution and dispersion of hydrocarbons in the water column could temporarily cause exceeded chronic levels of water quality criteria in waters contacted by oil. Impacts of oil to water quality are also discussed in Chapter 8.

Maintenance Impacts: The island surface will be re-graded to design contours on an annual basis following spring breakup. Should additional gravel be needed it will be mined from an onshore source and transported to the island by barge during the summer months. Annual maintenance of the island may include regrading of the island work surface prior to freezeup to ensure spring runoff and snowmelt will be directed toward the catchment basins. Re-grading activities will not affect marine water quality in the immediate vicinity of the island. All re-grading activities will occur above sea level, thus the marine environment will not be impacted.

The linked-concrete slope protection system which protects the slope of the island will be regularly inspected both above and below the waterline. Above waterline repairs will not affect the marine water quality. Repair actions below the waterline will be of short duration. Minor increases in suspended sediments and in turbidity are possible, but not likely with respect to these repairs. Impacts to marine water quality from repair actions below the water line are expected to be negligible.

The sacrificial gravel berm at the toe of the slope is not slope-protected and, therefore, is subject to erosion. It is anticipated that subsurface currents and wind and wave action will scour the gravel berm in such a manner that the loss of gravel on one side of the island will add to the volume of gravel on the other side of the island. The preferred berm replenishment option involves “backpassing” or relocating the berm gravel from areas of deposition to areas of erosional loss (BPXA, 1997:3.2-3). Backpassing would likely involve localized increases in suspended sediment and turbidity. Increases would be short-term, one to two weeks, and the affected area limited to the immediate vicinity of the island. Thus, impacts from berm replenishment are considered minor.

In the event that repairs to the offshore pipeline are required, sediment would be locally disturbed. However, this disturbance could increase total suspended solids and turbidity in the marine water. This increase would occur infrequently over short periods of time, and, therefore these activities would have a minor impact to offshore marine water quality.

Abandonment Impacts: Abandonment impacts would depend upon the abandonment plan that is adopted, and will be fully addressed in the assessment of the environmental effects of the abandonment alternatives. For an abandonment scenario involving complete removal of all facilities and infrastructure, impacts would be expected to be similar to those generated during construction, and the overall impact to marine water quality from abandonment would be expected to be minor.

5.5.3 Summary of Environmental Consequences

Potential impacts summarized in this section were identified through an analysis of the project alternatives. No unavoidable adverse effects or impacts with respect to physical oceanography or marine water quality were identified as a result of implementing the proposed project. This includes any direct and indirect impacts due to construction activities, operational activities (with the exception of a large oil spill), maintenance procedures, and abandonment options. In the event of an oil spill, minor impacts to marine water quality, as measured in the water column, are predicted to occur, particularly near the oil sheen. The degree of impact would be a function of spill size and season. Potential environmental impacts resulting from an oil spill are discussed in detail in Chapter 8.

5.5.4 References

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- Napageak, Thomas

5.6 SEA ICE

5.6.1 Affected Environment

The offshore project area is ice-covered for 9 to 10 months of the year, making sea ice a dominant, decision-driving marine feature within the project area. Even during summer months, onshore winds occasionally bring icebergs and ice floes into the project area from the permanent polar pack ice to the north. Information about sea ice and its potential effects on the project are presented in this section. This information is also used to support the NPDES Permit and associated fact sheet (Appendices F, G, and O), and the Ocean Discharge Criteria Evaluation document (Appendix H), and Section 103 Evaluation (Appendix I) for this project.

5.6.1.1 Ice Formation

Sea ice is formed from the ocean surface downward. Growth of sea ice is controlled by atmospheric conditions such as air temperature and cloud cover; by marine conditions such as the roughness of the sea, currents, water depth, and salinity; and by the amount of snow cover over ice. Multi-year sea ice survives more than two summers. Multi-year sea ice sheets are typically 7 to 13 ft (2 to 4 m) thick.

The Alaskan Beaufort Sea can be divided into three sea ice zones: the landfast ice zone, shear ice zone (stamukhi), and polar pack ice zone. These sea ice zones, which exist as bands parallel to the shoreline, are shown on Figures 5.6-1 and 5.6-2.

Landfast Ice Zone: *Landfast ice* is connected directly to the shoreline. The landfast ice zone follows the mainland coastline and is made up mostly of first-year bottomfast ice and floating-fast ice (Figure 5.6-1). *Bottomfast ice* is frozen to the seafloor to water depths of approximately 6.6 ft (2 m) and usually remains motionless and relatively undeformed during the winter, both inside and outside of the barrier islands (BWA, 1983:6) (Figure 5.6-3). *Floating-fast ice* is floating ice that generally extends outward from bottomfast ice. It typically occurs at water depths of 6 to 65 ft (2 to 20 m) (SOHIO, 1984: 6.4.1.1; USDOI, MMS, 1996:Fig. III.A.4-1), i.e., extending to about 4 to 8 miles (6 to 13 km) seaward of Seal Island. The project lies within the landfast ice zone. The seaward extent of the landfast ice zone (Figure 5.6-2) varies with the time of year, the amount of protection offered by the coastline, water depth, and the strength of forces that seasonal and polar pack ice exert on the landfast ice (Kovacs and Mellor, 1974:117).

Leads are gaps between ice sheets that occur on the seaward edge of the landfast ice zone. Leads separate the landfast ice zone from the shear and pack ice zones, and open and close as the shear ice zone moves in response to winds and/or currents moving the polar pack ice. Leads have open water for variable periods of time before freezing over with thin, new ice. The new ice then fractures and piles into ridges when the lead closes (Weeks, 1976:184).

Shear Zone: The *shear zone* is the boundary between the moving polar pack ice and the fixed landfast ice. Also referred to as the *stamukhi zone*, it is characterized by drifting ice floes and open water leads. The seaward extent of the shear zone can extend to the edge of the continental shelf, approximately 60 miles (97 km) offshore from the project area (Kovacs and Mellor, 1974:116); however, it is difficult to define due to the effect of local seafloor changes, as well as seasonal changes in the polar pack ice zone (SOHIO, 1984:6.4.1.1).

The shear zone is the most dynamic of the three sea ice zones due to influences from the polar pack ice and its response to wind and currents (Kovacs and Mellor, 1974:123). Movement of the polar pack ice is the major cause of open leads and pressure and shear ridges within the shear zone (Kovacs and Mellor, 1974:124). *Pressure* and *shear ridges* are linear accumulations of ice rubble caused by the compression between ice floes and sheets. Ridges are usually straight, often extend tens of miles in length, and may be up to 13 ft (4 m) high. Pressure and shear ridges primarily occur in the shear zone; however, they also are formed within the floating-fast sea ice zone during seasonal freezeup when the ice cover is thin. If pressure from the pack ice is relatively high, broken ice and rubble may be pushed into pressure ridges with ice keels that extend to the seafloor (Kovacs, 1976:3) (Figure 5.6-4) within the floating-fast ice zone in which the project is located. This is an important consideration for submarine pipelines. The most powerful direction of drifting ice within the shear zone in the project area is east to west (Kovacs and Mellor, 1974:114) due to winds and ocean currents.

High winds during storms and ocean currents are the main forces that cause pressure and shear ridge formation. Frequency and magnitude of storms decrease as winter progresses, thus, the potential for extensive ridge formation is less during late winter (Kovacs, 1976:3). The correlation between ridge formation and wind was observed by a Barrow elder, who reported ridge creation even after the ice has reached substantial thickness (O. Ahkivgak in NSB, 1980:100).

Polar Pack Ice Zone: The polar pack ice zone lies beyond the continental shelf and is outside the project area. The polar ice pack influences the sea ice conditions within the project area because it collides with and moves floating ice within the project area. Nuiqsut whaling captains report that the polar ice pack does not reach Seal Island because it is too heavy and becomes grounded before it gets there (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:2). Generally, it is visible from the project area, but occasionally remains so far out that the whaling captains cannot see it (T. Napageak - Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:11).

The polar pack ice zone influences the formation and movement of the shear and landfast ice zones. As described in Section 5.4, easterly winds prevail during summer, tending to keep the polar pack ice far out to sea, while westerly storm winds that dominate the winter season tend to push the polar pack ice towards the coast (GRI, 1992:7; Kovacs and Mellor, 1974:114). Occasional westerly winds during ice-free summer months can bring ice floes or icebergs from the polar pack ice zone to shore or inside of the barrier islands.

An understanding of ice strength is important in the scope of the project because many of the winter season tasks, including gravel hauling, island reconstruction, and pipeline installation will be accomplished using an ice road. In addition, reconstructed Seal Island would be subjected to ice force seasonally throughout the duration of the project. Strength of sea ice varies widely and primarily depends on salinity, temperature, and thickness, all of which are briefly discussed below.

Salinity: Ice strength is related to salinity (salt content). The lower the overall salinity of a sea ice sheet, the higher the effective strength. Salinity of a sea ice sheet usually is higher at the bottom than on the surface (Weeks, 1981:B-5). Salinity of Alaskan Beaufort seawater is typically 30 to 35 ppt, and newly formed first-year sea ice has a salinity of 12 to 15 ppt. As first-year ice thickens and ages, salinity decreases to 4 to 5 ppt by the end of a year's growth (Weeks, 1976:178). This decrease in salinity occurs when pockets of brine, which do not freeze, move downward through thaw branches and channels in the ice sheet by gravity and concentration gradients (Gerwick and Sakhuja, 1985:12). Brine channels and pockets reduce the percentage of ice-to-ice bonding, thus reducing the effective strength of the ice (Weeks, 1976:177)

Figure 5.6-1 (page 1 of 2)

Figure 5.6-1 (page 2 of 2)

Figure 5.6-2 (page 1 of 2)

Figure 5.6-2 (page 2 of 2)

Figure 5.6-3 (page 1 of 2)

Figure 5.6-3 (page 2 of 2)

Figure 5.6-4 (page 1 of 2)

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Temperature: The temperature of a sea ice sheet has a large effect on its mechanical properties. The temperature at a given time and location varies with atmospheric conditions, such as air temperature, wind speed, and snow cover. Cold sea ice exhibits greater effective strength than warm sea ice. However, sea ice is brittle at low temperatures and elastic at warmer temperatures (Gerwick and Sakhuja, 1985:14). Therefore, mid-winter, cold sea ice will be stronger and more brittle than early fall or late spring (freezeup or breakup) sea ice. Conversely, weak sea ice in early fall or late spring is subject to large deformations and ridging.

Thickness Effect: The strength of a sea ice sheet, whether first-year or multi-year, is related directly to its thickness. Overall ice strength increases as thickness increases, because of the larger cross-sectional area that is available to withstand force. Internal stresses and pressure are greater within a thicker ice sheet, producing higher effective strength per unit thickness.

5.6.1.2 Ice Season

The Alaskan Beaufort Sea is never completely free of sea ice. However, 43 years of data in the project area indicate open water conditions exist for 60 to 86 days of the year. Polar pack ice typically is present within approximately 75 miles (121 km) offshore, even in summer. The ice season varies from year-to-year depending on climate and air temperature ranges. The average length of the ice season in the project vicinity is approximately 300 days, based on observations from a number of sources summarized by INTEC (1996a:3-7), and an Inupiat resident commented that sea ice is generally present 9 months of the year (J. Nukapigak in USDOI, MMS, 1995:15-16).

The annual ice cycle within the nearshore area of the Alaskan Beaufort Sea is described in Table 5.6-1. Historical data from 1953 to 1975 shows that breakup can begin in the project area as early as mid-June, with most breakup periods beginning in early July (Cox and Dehn, 1981:806). Additional information regarding the occurrence and movement of ice floes during summer is presented in Section 5.6.1.3. Historically, freezeup has begun as early as mid-September, with the average start of freezeup occurring in mid-October.

5.6.1.3 Ice Sheet Movement

Winds and currents are the main factors affecting the movement of Alaskan Beaufort Sea ice. Storm winds can cause changes in movement and are usually the reason ice sheets come into contact with a structure or another ice sheet. Conversely, the influence of strong currents can cause sea ice to move against the wind.

Inupiat residents consider October through December to be the period when ice movement hazards are most critical offshore of Nuiqsut and near Cross Island. Unpredictable conditions during this period result in elders warning hunters not to go out because of the risk involved (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:1-3).

Table 5.6-1 (page 1 of 1)

The floating-fast ice sheet moves back and forth perpendicular to shore with the daily tides, averaging movements of about 3 inches/day (8 cm/day). Floating-fast ice motion usually is greater seaward of the barrier islands (OSI, 1980d:8). Ice just north of Northstar Island moved a net distance of 9.3 ft (2.8 m) to the west during a 4-month study in 1980. Maximum movement rates observed during the study were 10 inches/hour (25 cm/hour) (OSI, 1980a:5). Horizontal ice movement has been predicted to occur in the project area at a maximum rate of 6.6 ft/day (2 m/day) for water depths less than 40 ft (12 m) (INTEC, 1996a:3-43). The median ice movement rate near Seal Island is less than 1-ft (0.3 m) per day (Agerton, 1982: 2.1). Polar pack ice in the Arctic Ocean is in constant motion due to a current known as the Beaufort Gyre (Vaudrey, 1985b:46). Ice island pieces and icebergs are sighted in the project area occasionally, and may remain adrift in the Beaufort Sea for years. A study of multi-year ice movements conducted in 1984 and 1985 found that ice drift averaged 13.4 nautical miles/week (24.8 km/week) for most of the study year (ARCTEC, 1985:1). Ridges and floes displayed greater, storm-induced movements, averaging 37.6 nautical miles/week (70.2 km/week) during the fall months (September, October, and November).

The vertical movement and inundation by seawater of landfast ice due to tides or storm surges has been noted by whaling captains (F. Long, Jr. and T. Napageak - Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:8). Inupiat who travel over ice sheets watch for formation of open leads which cause ice movement and open water hazards. Leads are unpredictable and appear in different places every year. They also open and shut quickly, which is the main reason there is no spring whaling in Nuiqsut (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:2). Major ice movements may occur within 2 or 3 minutes of a large wind change (B. Pausanna in USDOI, MMS, 1995:41).

Although open water usually extends from the shoreline to Seal Island by mid-July (INTEC, 1996a:3-9), wind, currents, and storm surges can move multi-year ice floes into the project area. Ice floe concentrations are expected to occur on 3 to 18 days of the open water season (INTEC, 1996a:Table 3-7). Larger ice floe invasions covering more than 1/10th of the sea surface during the open water season typically occur once every 4 to 5 years.

Inupiat residents consider the ice to be much more dangerous in the deeper, faster moving waters offshore of Cross and Northstar Islands, than inshore of Seal Island and the barrier islands because of active ridge formation and movement in the shear ice zone (Pers. Comm., Nuiqsut Community Meeting, August 14, 1996:2). Ice coming from the north forming pressure ridges is not considered as dangerous as ice that moves from side to side, particularly from southwest to east (Pers. Comm., Nuiqsut Community Meeting, August 14, 1996:2).

5.6.1.4 Ice Forces on the Local Environment

Sea ice events, such as ice gouging, strudel scour, and ice ride-up, can cause hazardous conditions or damage within the project area.

Ice Gouging: Ice gouging is the most severe environmental hazard that may be encountered by underwater structures in shallow regions of the Alaskan Beaufort Sea (Walker, 1985:9). Ice gouging

(Figure 5.6-4) is caused by the movement of grounded ice keels within pressure ridges, as well as within icebergs and ice islands, moving in response to wind and currents (Walker, 1985:15). Ice gouging in the landfast sea ice zone is most common during breakup and freezeup, when the ice cover is unstable and highly mobile. In the shear zone (Figure 5.6-1) most grounding occurs in the winter from ridge keels, and gouging can occur any time of year from multi-year pressure ridges or ice islands (Walker, 1985:16). Small ice keels typically produce narrow gouges in shallow waters, and large ice keels produce wide gouges in deep water (Walker, 1985:15). In studies conducted in the Alaskan Beaufort Sea between 1972 and 1979, the deepest gouge observed was 8.5 ft (2.6 m) deep below the seafloor in 125-ft (38 m) deep water. Inside protected lagoons, the deepest gouge observed was 2.3 ft (0.7 m) deep (Weeks et al., 1983:26).

Sonar records and diver observations have revealed that much of the Alaskan Beaufort seafloor is marked by ice gouges (Weeks et al., 1983:1). A graphical representation of gouge depth compared to water depth for the project vicinity is presented on Figure 5.6-5. Ice gouging is particularly heavy in the shear zone at the seaward edge of the barrier islands' landfast ice zone (Figures 5.6-1 and 5.6-2) in water depths of 50 to 66 ft (15 to 20 m) (Weeks et al., 1983:3). The maximum water depth where ice gouging has been recorded is 155 ft (47 m) (Walker, 1985:16). Shallow water and barrier islands block the invasion of large, consolidated ice floes, thus reducing gouging in those areas. The highest potential for ice gouge formation in the project area is in the offshore area from Long and Stump Islands to Seal Island (INTEC, 1997a:7).

Ice gouges can be measured using "gouge intensity," which can be defined as an estimate of the amount of visible sediment disruption. Gouge intensity is calculated by multiplying gouge density over an area of seafloor by maximum gouge depth and width (Norton and Weller, 1984:188). Higher gouge intensities suggest a higher potential for sediment disruption from ice gouging. Gouge intensities mapped along the Alaskan Beaufort Sea shelf are shown on Figure 5.6-6. The project area inside the barrier islands, as well as between the barrier islands and Seal Island, is considered to have a low gouge intensity (Norton and Weller, 1984:202), with gouges to maximum depths of approximately 1.6 ft (0.5 m) (Norton and Weller, 1984:201). Gouge intensity offshore of Seal Island is considered medium to very high, with gouges to maximum depths of 6.6 ft (2 m) (Norton and Weller, 1984:201 and 202). Gouge survey data collected during summer 1995 in the project area indicated a maximum gouge depth of 2 ft (0.6 m) in water depths of 32.5 ft (9.9 m) (Leidersdorf and Gadd, 1996:1). Estimates of 100-year event ice gouge depths in the project area indicate potential gouges to approximately 3.5 ft (1.1 m) (INTEC, 1997a:18,19).

Strudel Scour: Strudel scour is the process where water flowing through holes or cracks in the ice erodes the seafloor. During the early stages of breakup (late May to early June), landfast sea ice near the river deltas becomes overflooded with meltwater from rivers and inland drainages. Downward seepage or drainage of this overflooded water through the sea ice sheet, which results in strudel scour, typically occurs in the region between the 6.6- to 16-ft (2 to 4.9 m) water depth contours. Initially, most scours form a short distance beyond the bottomfast ice (Walker, 1985:46; Vaudrey, 1985a:10). Scour holes are formed in the seabed

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below the drain holes in the ice (Figure 5.6-7). Strudel scour typically occurs within 10 miles (16 km) of river mouths along the Alaskan Beaufort Sea coast (Figure 5.6-8).

Surveys conducted in 1985, 1995, and 1996 in the project area detected scours in water depths of 6 to 20 ft (1.8 to 6 m), with maximum horizontal dimensions in the range of 20 to 89 ft (6 to 27 m), and a maximum scour depth of 5.7 ft (1.7 m) (HLA, 1986; Leidersdorf and Gadd, 1996:3). Results indicated the highest probability of strudel scouring is in 15- to 20-ft (4.6 to 6.1 m) water depths, but the largest scours occur in 6- to 10-ft (2 to 3 m) depths (INTEC, 1997c:11,12). Strudel scour (Vaudrey, 1985a:14) can create deeper depressions in the seabed than ice gouging, making scour an important consideration in the design of the submarine pipeline.

The Kuparuk River overflood region is constrained by barrier islands, which effectively contain most flood waters within Simpson Lagoon. Strudel scouring generally does not occur in areas of bottomfast ice such as Simpson Lagoon, but does occur in water depths greater than 6 ft (1.8 m) where waters drain through floating-fast ice (Vaudrey, 1985a:11). The total number of strudel scour features in the Kuparuk River region during 1984 was estimated between 40 and 50 (Vaudrey, 1985a:11-12).

Ice Pile-up and Ride-up: Ride-up refers to the horizontal movement of ice onto the shore, and pile-up refers to the vertical buildup of ice piled at the shore. Sea ice ride-up and pile-up, also referred to as ice override, occurs along the coastlines, mainland shores, and offshore islands in the project area. Ice sheets, driven by storm winds or currents, either ride-up or pile-up the slopes of beaches at the shoreline of the mainland and barrier islands, as well as manmade islands (SOHIO, 1984:6.4.3). Sea ice sheets shift and move whenever ice covers the Alaskan Beaufort Sea, but large movement events typically occur during freezeup or breakup when the sea ice sheet may be thin, deteriorated, or detached from the coastline. Sea ice ride-up can push aside beach and tundra material, potentially resulting in impact damage to coastal structures.

The Inupiat observe that the polar ice pack provides the force that drives first-year ice from 1 to 2 ft (0.3- to 0.6-m) thick over sizeable barriers with great speed and force. Often this condition results from a combination of storm, current, tide, and ice, particularly under a southwest wind (T. Napageak - Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:3). Generally, the wind is the main force that causes major ice override (O. Ahkivgak in NSB, 1981:100). Kaktovik residents indicated that powerful ice movements can occur even without the contributing factor of wind, because currents in their area are extremely strong and swift (H. Rexford in USDOI, MMS, 1979:49; J. Ningeok in USDOI, MMS, 1990:19-20). When there is a strong southwest wind, combined with current direction from west to east, and high tide, ice can move in a west to east direction at relatively high speeds, accompanied by elevated water levels. These conditions are most likely to occur during the months of October through December (T. Napageak - Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996).

When moving sea ice sheets contact steep slopes or bluffs, failure occurs in a buckling or bending mode, causing pile-up events. It is possible for pile-up to occur at a height sufficient to allow sea ice blocks at the top of the pile to fall onto structures along the shore. Additionally, drifting snow or ice pile-up may form a ramp allowing ice to ride-up over vertical bluffs or sheet pile walls (CFC, 1996:2; Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996).

The Inupiat regard ice override as a potential hazard. Nuiqsut whaling captains indicated that ice override, though infrequent, may occur at any time and with little warning (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:3). Nuiqsut residents were, however, generally less concerned about ice override near Seal Island, which is in the more stable landfast ice zone, than those hazards near Northstar Island shoal, which is near the shear ice zone (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:2).

Studies indicate ice ride-up and pile-up is minimal near Point Storkersen due to protection from ice movement from the barrier islands and shallow water in Simpson Lagoon. Additionally, ride-up and pile-up has not been documented on the shoreward side of Stump or Egg Islands, or along the coastline between the Kuparuk River and Point McIntyre (INTEC, 1996a:3-23). However, Nuiqsut whaling captains have observed that southwest winds, combined with current and moving ice, affected barges moored in nearshore areas near Prudhoe Bay, inside the barrier islands (T. Napageak - Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:2).

Ice pile-up data was summarized for offshore islands in the project vicinity for six freezeup seasons (1980-85) (INTEC, 1996a:3-23). Pile-up heights of 10 ft (3 m) on the offshore side of Stump Island and 20 ft (6 m) at Seal Island were reported. Based on the frequency distribution of data for these islands and others in the project vicinity it was predicted that a maximum ice pile-up height of 56 ft (17 m) could occur as a 100-year event at Seal Island (INTEC, 1996a:3-24). Ice pile-up predictions are an important consideration when designing offshore structures such as Seal Island.

5.6.2 Environmental Consequences

Potential impacts of each project alternative (described in Chapter 4) to sea ice and potential hazards to the project which may result from sea ice are discussed below. Alternative 1 is presented first. Alternatives 2 and 3 are identical with respect to sea ice and are presented together. Alternatives 4 and 5 are discussed separately to adequately address differences in pipeline routing, pipeline length, and pipeline landfalls. Issues for alternatives are related to project phases (construction, operation, maintenance and abandonment). Potential impacts of Alternatives 2, 3, 4, and 5 are summarized in Table 5.6-2.

5.6.2.1 Alternative 1 - No Action Alternative

Sea ice would not be affected with the selection of the No Action Alternative. The project area is naturally stressed as a result of its arctic location and will continue to be modified by natural forces in the absence of the Project. No impacts to sea ice result from the adoption of Alternative 1.

Figure 5.6-7 (page 1 of 2)

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Figure 5.6-8 (page 1 of 2)

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Table 5.6-2 (page 1 of 2)

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5.6.2.2 Alternatives 2, 3, 4, and 5

Under Alternatives 2 and 3, approximately 2.4 miles (3.8 km) of pipeline corridor would be located in water depths of 0 to 10 ft (0 and 3 m), approximately 1.7 miles (2.8 km) of pipeline corridor would be located in water depths of 10 to 20 ft (3 and 6.1 m), and approximately 1.8 miles (2.9 km) of pipeline corridor would be located in water depths of 20 to 40 ft (6.1 and 12.2 m). The total length of the offshore pipeline would be 6 miles (9.6 km). The marine portions of Alternatives 2 and 3 are identical. Likewise, the potential impacts of both project alternatives on sea ice conditions, as well as sea ice forces on both alternatives, are comparable.

The submarine pipeline under Alternative 4 is routed south from Seal Island as it is under Alternatives 2 and 3, but it turns southeast approximately 3 miles (4.8 km) south of the island. The pipeline then skirts north of the barrier islands and turns southwest to land on the coast between Point McIntyre and West Dock. Under Alternative 4, approximately 3.9 miles (6.3 km) of pipeline corridor would be located in water depths of 0 to
10 ft (0 to 3 m), approximately 3.3 miles (5.3 km) of pipeline corridor would be located in water depths of 10 to 20 ft (3 to 6.1 m), and approximately 1.8 miles (2.9 km) of pipeline corridor would be located in water depths of 20 to 40 ft (6.1 to 12.2 m). The total length of the offshore pipeline would be 9 miles (14.5 km).

The submarine pipeline route under Alternative 5 skirts north of the barrier islands similar to the route under Alternative 4, but landfall is at Dock 2. Under Alternative 5, approximately 3.8 miles (6.1 km) of pipeline corridor would be located in water depths of 0 to 10 ft (0 to 3 m), approximately 3.3 miles (5.3 km) of pipeline corridor would be located in water depths of 10 to 20 ft (3 to 6.1 m), and approximately 1.8 miles (2.9 km) of pipeline corridor would be located in water depths of 20 to 40 ft (6.1 to 12.2 m). The total length of the offshore pipeline would be 8.9 miles (14.3 km).

Construction Impacts: Offshore construction, including reconstruction of Seal Island and installation of the offshore buried pipeline, would occur during winter. Construction activities during this period would include preparation of ice roads, offshore transport of gravel over an ice road to Seal Island, offshore pipeline installation and initial drilling. Construction activities associated with the island slope protection and infrastructure installation would take place during the open water season.

Gravel would be mined onshore and hauled offshore to a temporary stockpiling area near Egg Island and then transported to Seal Island for reconstruction. Under Alternative 5, gravel will also be placed to widen the West Dock causeway. Ice thickness would be increased for use as an ice road near the mouth of the Kuparuk River and along the route to be used for gravel hauling from the quarry to Seal Island. Ice disturbance as a result of this activity is limited to thickening and vertical ice movement and would be short-term and limited to the immediate vicinity of the ice road and temporary stockpile area at Egg Island. Impact to sea ice as a result of gravel hauling is considered to be negligible.

The length of the ice season and timing of freezeup and breakup could have an impact on ice road hauling activities and result in delays to construction. It is anticipated, however, that impact on the project would be minimized through ice thickness monitoring.

Trucks and heavy equipment can weigh down floating ice and cause vertical movement which is potentially hazardous to personnel and equipment, particularly if much of the weight is concentrated in one area. This could be an issue during on-ice construction activities such as trenching and gravel hauling. Thickening of the ice for road use in construction, and spacing and weight limitations on heavy vehicles, would result in negligible vertical ice movement, no impact to the floating fast ice, and no impact to the project schedule.

Storm surges can lift grounded landfast ice in the lagoon area and cause flooding over the surface of the ice and the ice road. Nuiqsut whaling captains spoke of sea ice breaking around grounded ice floes during a rise in marine water level (F. Long, Jr. and T. Napageak - Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:8). Equipment can still operate with water on the ice surface, and cracks are likely to freeze over and repair. Flooding of the ice surface would cause negligible, short-term impacts to hauling activities, would not affect the ice road's integrity, and would result in no impact to sea ice.

Onshore pipeline and landfall pad construction would have no impact on sea ice. For the Alternative 2 and 3 offshore pipeline segment between Point Storkersen and Seal Island, sea ice would be cut for winter trenching and pipe-laying activities. The width of the ice slot would be 5 ft (1.5 m), and on floating ice it would be up to 12 ft (3.7 m) wide (INTEC, 1996c:9). In addition, ice thickness would be increased for use as a road bed along the offshore pipeline alignment. Disturbances to sea ice would be limited to thickening and vertical movements. Disturbances would be short-term, limited to the immediate vicinity of the pipeline route, and would have a negligible impact on sea ice. Negligible similar impacts would be expected for Alternatives 4 and 5.

The length of the ice season and timing of breakup would have an important effect on the pipeline construction schedule. An early onset of breakup, or complete loss of ice cover during what would normally be considered the ice season, could extend the duration of pipeline installation (INTEC, 1996c:17). Nuiqsut residents have reported on the hazards of open leads in the project area, particularly during the spring (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996). Impacts to the project from ice season length or leads would be negligible and would be minimized through ice thickness monitoring, and contingency planning.

Vertical ice movement during construction activities described previously for gravel hauling activities also could influence pipeline construction. As a result of thickening of the ice for road use in gravel hauling, and spacing and weight limitations on heavy vehicles, the effects of vertical ice movement would be considered a negligible impact.

Large horizontal sea ice movements over a short period of time could move the ice slot with respect to the trench. Large but rare ice movements have been described in the project area. In mid-March 1981, storm winds caused the ice less than a mile west of Seal Island to separate, opening a 120-ft (36.6 m) wide lead in the ice. However, based on field measurements in the project area over the course of four winters, such movements are rare. The median total ice movement rate near Seal Island is less than 1-ft/day (0.3 m/day) (Agerton, 1982: 2.1). Maximum total horizontal ice movement in the project area is 6.6 ft/day (2 m/day) (Section 5.6.1.3). Typically, horizontal ice movement is characterized by a back and forth motion, thus ice movement is expressed as total movement, not total movement in a single direction. A 1979 ice movement study found that a considerable amount of tide-driven oscillatory, or back and forth, movement did occur in the ice sheet and resulted in negligible net displacement of the ice (OSI, 1980a:5; 1980b:Table 2; 1980c:3).

Daily net horizontal movements of less than 3 ft (0.9 m) would not affect pipeline construction activities. Net movements of 3 to 6 ft/day (0.9 and 1.8 m/day) could require repositioning of the pipeline within the alignment, or repositioning of slotting and pipe-laying equipment. Net ice movements in this range also could result in backfill being misplaced over the pipeline trench, which could require remedial backfill dumping at a later date. Daily net ice movements greater than 6 ft (1.8 m) would likely require stopping construction activities until net movement slowed to a manageable rate.

Ice floe invasions could occur during the open water season. The presence of ice floes could cause delays in delivery of modules and other supplies, as well as the installation of the slope protection system. Floes striking the island slopes or marine outfall area before installation is complete could cause localized damage to gravel slopes or outfall piping, potentially causing delays in the construction schedule. These impacts would be negligible and minimized through short-term schedule changes, and minor repairs (if needed) during construction.

Offshore pipeline construction would include acoustic profiling, route surveying, and ice movement surveying conducted continuously during pipeline construction to monitor effects of horizontal ice movement, and allow changes to construction plans within a short time frame (INTEC, 1996c:18,19). In addition, a marine survey of the route would be conducted 1 year following construction and prior to start-up to confirm that the minimum design backfill is present (HLA, 1997:1).

Operation Impacts: The impacts of sea ice for Alternatives 2 and 3 during operations would be primarily related to damage to the island, facilities, or buried pipelines from ice hazards and effects on normal operations due to variations in ice seasons and floe movements.

An extreme override event on Seal Island could result in damage to the drilling rig, wellheads, or other equipment. Ice forces could also cause damage to the slope of the island. Ice pile-up would likely occur at the waterline around the perimeter of Seal Island following freezeup, creating an ice rubble collar around the island by late November. Based on the frequency distribution of data for Stump and Seal Islands and others in the project vicinity it was predicted that a maximum ice pile-up height of 56 ft (17 m) could occur as a 100-year event at Seal Island (INTEC 1996a:3-24). The effects of an extreme ice override event would be reduced through island design and monitoring of sea ice conditions. The design of Seal Island includes a 75-ft (23 m) wide bench and a 21- to 27-ft (6.5 to 8.3 m) high sheet pile wall to protect against ice override (CFC, 1996:5).

However, Nuiqsut whaling captains indicated that, based on observations of ice conditions and override events, the island height would need to be on the order of 30 to 50 ft (9 to 15 m), or equivalent in height to an offshore drilling platform, to withstand ice override hazards that are likely to occur (F. Long, Jr. and T. Napageak - Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:10). In addition, it was suggested that the sheet pile wall have a concave shape to turn back overriding ice.

Based on the project design specifications, Seal Island would be constructed with a work surface elevation of approximately 16 ft (4.9 m) above sea level. As discussed previously, a perimeter sheet pile wall 21 to 27 ft (6.4 to 8.2 m) high and a 75-ft (23 m) wide bench would be constructed to divert ice during override events. Over the expected 15-year life of the production island and facilities, it is possible that ice could at some point overtop the perimeter wall and reach the island work surface. Engineering modeling and design indicate that the island and facilities are designed to withstand predicted ice override events with minor impacts. However, discussions with Nuiqsut whaling captains indicate that the height of the sheet pile may not be adequate for extreme override events (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:10).

Ice pile-up and ride-up at the Point Storkersen landfall are potential hazards to the normal operations of the pipeline. The likelihood of pile-up and ride-up occurring at the shoreline is low. Based on observations and aerial photo analyses, ice ride-up in the landfall area would be unlikely, since the barrier islands and shallow lagoon in this area provide protection against large ice movements (INTEC, 1997b:6). However, observations by whaling captains indicate that a southwest storm event accompanied by high water and floating ice can affect the area inside the barrier islands (Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996). Ice ride-up in the landfall area of Alternative 5 would be unlikely, since the West Dock causeway provides protection against large ice movements. In addition, the proposed 110-ft (33.5 m) setback from the shoreline for the pipeline and facilities would minimize the risk from extreme events. It is unlikely that the ice pile-up would reach 110 ft (33.5 m) from the shoreline, thus the aboveground pipeline and valve station are not expected to be damaged by even an extreme pile-up event (INTEC, 1996a:Attachment: Drawings). Due to the coastal setback, an extreme pile-up would result in a minor impact to project landfall facilities.

Ice loading stresses from ice forces other than those that occur during an override event could affect island operations. Horizontal movement of first-year ice during fall and winter could form a rubble collar around the island; and multi-year ice floes could strike the island during the summer or freezeup season at relatively high speeds. The latter event is less likely to occur, but could have a more severe impact on the island slopes. The risk of ice pressures having an impact on the structural integrity of the island slopes would be minimized through design and annual maintenance. Because interlocking concrete mats would be used to protect the island from normal ice loading stresses, impacts to the island from normal ice movements are considered minor. Due to the proposed 110 ft (33.5 m) setback, it is unlikely that normal ice movements would affect onshore facilities and, therefore, no impact is expected.

Ice thickness would be increased each winter for use as a road between the island and the mainland. As is the case during the construction phase, the construction and use of ice roads would result in a negligible impact to sea ice. Vertical or horizontal ice movement could impact operations activities; however, as previously discussed, impacts would be minimized through design of ice roads, spacing and weight limitations on heavy vehicles, and monitoring of ice conditions, and would be negligible.

Past testimony by Inupiat residents has demonstrated concern about the potential for an oil spill resulting from an ice gouge damaging or breaking a buried pipeline (I. Akootchook in USACE, 1984:16; F. Long, Jr. in USDOI, MMS, 1995:25; Pers. Comm., Nuiqsut Whaling Captains Meeting, August 13, 1996:3). Ice gouging would be a potential hazard to the normal operations of the buried offshore pipeline. Design for the offshore pipeline is based in part on ice keel protection analysis and specifies a minimum burial depth of 7 ft (2.1 m); north of the Barrier Islands, the pipeline will be buried at depths between 8 to 10 ft (2.4 to 3 m); (INTEC, 1997a:6). This depth would be 3.5 times greater than the depth of the deepest ice gouge observed in the vicinity of the proposed route, which was 2 ft (0.6 m). The design burial depth is twice as great as the predicted 100-year event gouge depth of approximately 3.5 ft (1.1 m) for the project area. Based on an analysis of ice gouge data, it was concluded that burial of the pipeline to a depth of 7 ft (2.1 m) would adequately limit pipeline damage from a 3.5-ft (1.1 m) deep gouge (INTEC, 1997a:4).

Project plans also specify that additional wall thickness (over standard) pipe be used in all sections of the submarine pipeline. Extra thick pipe is intended to protect the pipeline from overburden pressure of an ice keel gouging the sediment above the pipeline. Pipeline integrity would be monitored regularly. Studies have shown that the deepest and potentially most damaging gouges have occurred in deep water. Portions of the pipeline routes located in deep water are 1.8 miles (2.9 km) for Alternatives 2, 3, 4, and 5. Consequently, all alternatives are approximately equal in terms of susceptibility to damage from ice keels. Should an ice keel contact the pipeline, it is likely that the combination of burial depth and pipe thickness would prevent more than a minor impact to the pipeline's integrity.

Erosion of the seafloor and exposure of the pipeline from strudel scour is a potential hazard, especially in the 6- to 16-ft (2 to 4.9 m) water depth range (INTEC, 1997c:5, 11, 12). Approximately 4.1 miles (6.6 km) of pipeline is routed through depths of this range under Alternatives 2 and 3, approximately 7.2 miles (11.5 km) under Alternative 4, and approximately 7.1 miles (11.4 km) under Alternative 5. Surveys indicate a higher concentration of strudel holes along linear features such as tidal cracks and ice roads (Vaudrey, 1985a; 1986). Subbottom marine surveys of the pipeline route would be used to detect strudel scour locations which may pose a threat to the integrity of the pipeline. Exposure of the pipeline by strudel scour would not cause the pipeline to fail. Rather it would result in a maintenance situation where a repair, backfilling of the scour, would be carried out to correct the problem. For this reason, impacts to the pipeline as a result of strudel scour are considered to be minor. Strudel scour densities in the project area are shown on Figure 5.6-8.

Regular geometry pigging, which monitors the curvature of the pipeline's longitudinal axis (bending, such as sags or heaves, and ovality [roundness]), would be used to detect pipeline damage from ice gouging and strudel scour. Geometry pigging would be conducted at start-up, annually for the first 5 years, and every 2 years thereafter. Additional geometry pigging runs would be conducted if severe gouges or scours are observed/suspected to have occurred. As part of the pipeline inspection program, subbottom marine surveying would also be conducted to evaluate backfill thickness and the presence of ice gouges. These surveys would be conducted 1 year after construction, and every 5 years thereafter (or as required by permitting/regulatory agencies) (INTEC, 1996b:5; HLA, 1997:1).

An oil spill during the operations phase could result in limited ice melt due to contact with warm oil or weakening due to encapsulation of spilled oil during new ice growth. Weakening of the floating ice sheet due to oil encapsulation could affect the integrity of the ice roads for a short period of time. Melting of the sea ice would be minimal since the heat from the oil being released would quickly be lost in the surrounding marine waters and ice. The impact from weakening of the sea ice is considered short-term and minor since the duration would be limited to one ice season. Sea ice would have a direct effect on oil spill response and cleanup activities. The effects of broken sea ice in a large oil spill scenario is discussed in Chapter 8.

Maintenance Impacts: Maintenance activities associated with operation of the production island and pipeline would take place year-round over the expected 15-year life of the project. While damage to facilities from sea ice forces could make maintenance and repair necessary, the effects of ice on these activities would be limited. The timing of breakup and freezeup, the length of the ice season, and the occurrence of ice floe invasions during the open water season, would have effects on maintenance activities. Maintenance activities would have a negligible impact on sea ice.

Horizontal ice movements are likely to have similar effects on winter pipeline repair operations as those described for pipeline construction, although smaller in scope. Vertical deflection caused by storm surges, or the presence of heavy equipment may impact pipeline repairs or use of the ice road. The risk of such ice movements to the ice road or pipeline repair operations is low. The use of similar monitoring and surveying methods as those used during pipeline construction would be applied to minimize potential problems from ice. Impact from horizontal and vertical ice movement during pipeline maintenance is considered to be negligible.

Inupiat residents are concerned with how the pipeline would be accessed for repairs during the open water season in the presence of ice floes, and during winter through floating ice (Pers. Comm., Nuiqsut Community Meeting, August 14, 1996:2). Repairs would be conducted during summer using a repair barge or shallow draft vessel, and during winter using ice-based equipment in the same manner as that required for construction. Periods during which repairs could not be conducted include early winter when the ice is not strong or thick enough to support equipment, and during breakup when the potential for local ice failure is high and moving ice floes are not compatible with marine operations (INTEC, 1996b:9). If damage to the pipeline were to occur during these seasons that required immediate repair or indicated the potential for an oil spill, the pipeline would be shut down until stable ice or water conditions existed to allow repairs to be conducted safely. For these reasons, impacts from sea ice to pipeline repair activities are considered to be negligible.

Abandonment Impacts: The offshore segment of the pipeline would either be removed or abandoned in place. Removal of the pipeline would presumably be conducted similarly to the installation, and would involve winter trenching through sea ice. This impact to the sea ice would be short in duration and localized with only negligible impacts, and in place abandonment would have no impact to the sea ice.

5.6.3 Summary of Environmental Consequences

Development of the Northstar Unit would impact sea ice temporarily. With the exception of oil spill effects, which are discussed separately in Chapter 8, none of the impacts from sea ice would be significant. No significant unavoidable adverse effects from sea ice would result from construction and operation activities. All identified effects would be short-term, partly due to the limited duration of activities, and partly due to the seasonal presence of sea ice. The project would not require any irreversible or irretrievable commitment of resources with respect to the sea ice. Project components have been designed to anticipate, accommodate, and alleviate potential impacts from sea ice during all phases of the project.

Traditional Knowledge, however, indicates that design specifications may not be adequate to protect project facilities in the event of an extreme ice override at Seal Island. Maximum ice pile-up height of 56 ft (1.7 m) could occur as a 100-year event at Seal Island (INTEC, 1996a:3-24). Were such an event to occur and should the sheet pile protection be overridden by a large quantity of ice, project facilities on the island could be damaged. Likewise, an extreme ice pile-up at Dock Head 2 facilities, which are not protected by a 110-ft (33.5 m) setback, could also be damaged.

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