U.S. Department of the Interior
Bureau of Land Management

Willow Master Development Plan

Supplemental Environmental Impact Statement

DRAFT

Volume 6: Appendices E.1 through E.15

June 2022

Prepared by:
U.S. Department of the Interior Bureau of Land Management

In Cooperation with:
U.S. Army Corps of Engineers
U.S. Environmental Protection Agency
U.S. Fish and Wildlife Service
Native Village of Nuiqsut
Iñupiat Community of the Arctic Slope
City of Nuiqsut
North Slope Borough
State of Alaska

Estimated Total Costs Associated with Developing and Producing this SEIS: $1,318,200

Mission

To sustain the health, diversity, and productivity of the public lands for the future use and enjoyment of present and future generations.

Cover Photo Illustration: North Slope Alaska oil rig during winter drilling.
Photo by: Judy Patrick, courtesy of ConocoPhillips.

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Willow Master Development Plan

Appendix E.1
Iñupiaq and Scientific Names

June 2022

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1.0 IÑUPIAQ AND SCIENTIFIC NAMES

Some readers may better recognize locations, and common plant and animal names by their Iñupiaq or scientific names. The appendix provides Iñupiaq names for places (Table E.1.1), and Iñupiaq and scientific names for plants (Table E.1.2), mammals (Table E.1.3), fish (Table E.1.4), and birds (Table E.1.5). If an Iñupiaq name did not have a known scientific name, it was labeled as unknown (UNK), and vice versa. Figure E.1.1 shows locations of the Iñupiaq place names.

Table E.1.1. Place Names

Iñupiaq Name	Location
Aanayyuk	Site near the mouth of the Miluveach River
Anaqtuuvak	Anaktuvuk Pass
Bering Sea-mi Taġiuq	Bering Sea
Iiguaåruich	Arctic foothills
Kuukpik	Colville River
Kuukpaaåruġmi niuqtuåviq	Kuparuk oil field
Kuukpaaåruġmi qimiqqat	Kuparuk Hills
Kuukpaaåruk Piŋu	Kuparuk Pingo
Kuukpaagruk	Kuparuk River
Kupigruak	East Channel of the Colville River
Kuukpigruaq	Kupigruak Channel
Milugiak	Miluveach River and surrounding area
Napasalu	Channel connecting Niġliq Channel to the Colville River
Niġliġat	'Second Nuiqsut', located on the East Channel of the Colville River, near the mouth of the Colville River
Niåliq Channel	Niġliq Channel - Westernmost channel of the Colville River Delta, where Nuiqsut is located
Nuiqsapiaq	Old village site on Nuekshat Island in the East Channel of the Colville River
Uuliktuq nuvuġak	Oliktok Point
Pisiktaġvik	Site on a large island in the East Channel of the Colville River, between the mouths of the Miluveach and Kachemach rivers; frequently used for caribou hunting
Qakimak	Kachemach River and surrounding area
Taġium Siñaa Beaufort Sea-mi	Beaufort Sea coast
Tasiqpak Narvaq	Teshekpuk Lake

Source: (HDR 2015; NSB 2016a, 2016b; OHA 2016; SRB&A 2014, 2016; USACE 2012)

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Willow Proposed Development Features
Drill Site (Not to Scale)
Alt E Drill Site (Not to Scale)
Ice Road
Pipeline
Gravel Footprint
Other Infrastructure
Existing Road
Existing Pipeline
Existing Infrastructure
Land Designation
National Petroleum Reserve in Alaska
Option 2 Module Transfer Island
Point Lonely
Harrison Bay
Teshekpuk Lake
Option 1 Module Transfer Island
Atigaru Point
Atigruk
Iqalukpik
Kalikpik
Kanigluq
Oliktok Dock
Oooguruk
Mine Site E
Ilaaqtugviit
Nigligat (2nd Nuiqsut)
Helmerick's
Nuna
CD3
Nigliq/Woods
ALPINE
Pisiksagiagvik
Nuiqsapiaq (1st Nuiqsut)
KUPARUK
Aanayyuk
CD2
CD1
Apkugaruk
Qakimak
Nanuq
CD5
Mine Site F
Mine Site C
CPF2
Alt B, C, D BT4
Alt E BT2
Kalikpik River
Colville River
CD4N
Mustang
GMT-1
Nigliviк
Uyagagviit
Putu
Alt B, C, D BT2
Gravel Mine Site
Napasulu
ASRC Mine Site
NUIQSUT
Kayaktuagiak
GMT-2
Fish (Uvlutuuq) Creek
Judy (Kayyaaq) Creek
BT1
Itqiliqpaa
Illaniktuak
Kuugruchiak
Tirragruaq
Kikkaq
Qitik
Puviqsuq
Ocean Point
Ocean Point
Aki
DS2P
BT3
Judy (Iqalliqpik) Creek
Ublutuoch (Tinmiaqsiugvik) River
Kayuqtusilik
Option 3
Alt E BT5
Alt B, C, D BT5
Kastialurak
Inigok Airstrip
Isuurak
Kugluktuk
0
5
10 Miles
No warranty is made by the Bureau of Land Management as to the accuracy, reliability, or completeness of these data for individual or aggregate use with other data. Original data were compiled from various sources. This information may not meet National Map Accuracy Standards. This product was developed through digital means and may be updated without notification.

Figure E.1.1

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Table E.1.2. Plants

Iñupiaq Name	Scientific Name	Common Name
UNK	*Arctophila fulva*	Pendant grass
UNK	*Carex aquatilis*	Water sedge
Niqaaq	*Cladonia rangiferina*	Lichen
UNK	*Draba micropetala*	Alpine draba
UNK	*Draba pauciflora*	Fewflower draba
Paunġaq, Paunġak, Paunġat, Asiaq (Ti), Asiavik (Ti)	*Empetrum nigrum*	Crowberry
Pikniq, Pikniik, Pitniq	*Eriophorum* spp.	Cottongrass
Qimmiurat	*Eriophorum* spp.	Cottongrass stems
UNK	*Eriophorum vaginatum*	Tussock cottongrass
UNK	*Geum* spp.	Mountain avens
UNK	*Hordeum jubatum*	Foxtail barley
UNK	*Koeleria asiatica*	Eurasian junegrass
UNK	*Oxytropis arctica var. barnebyana*	Barneby’s locoweed
UNK	*Pleuropogon sabinei*	False semaphoregrass
UNK	*Poa hartzii* ssp. *Alaskana*	Alaskan bluegrass
UNK	*Poa sublanata*	Cottonball bluegrass
UNK	*Potamogeton subsibiricus*	Yenisei River pondweed
UNK	*Alix pulchra*	Diamond-leaf willow
Uqpik, Ugpiik, Uqpiich, Uqpiit	*Salix* spp.	Willow
UNK	*Symphyotrichum pygmaeum*	Pygmy aster
UNK	*Taraxacum officinale*	Dandelion, common
Qimmiksit, Uġruq	UNK	Moss, sphagnum
Asiaq (Nu), Asiraq, Asiat, Asiavik	*Vaccinium uliginosum*	Blueberry
Kimmigḷaq, Kimmigñaq, Kimmiŋñat, Kimmigñauraq, Kikminnaq	*Vaccinium vitis-idaea*	Lowbush cranberry or lingonberry

Note: spp. (species); UNK (unknown)
Source: MacLean 2014

Table E.1.3. Terrestrial and Marine Mammals

Iñupiaq Name	Scientific Name	Common Name
Tuttuvak	*Alces americanus*	Moose
Tiġiganniaq	*Alopex lagopus*	Arctic fox (white)
Aġviq	*Balaena mysticetus*	Bowhead whale
UNK	*Balaenoptera acutorostrata*	Minke whale
UNK	*Balaenoptera musculus*	Blue whale
UNK	*Balaenoptera physalus*	Fin whale
UNK	*Berardius bairdii*	Baird’s beaked whale
Amaġuq	*Canis lupus*	Wolf
UNK	*Cystophora cristata*	Hooded seal

Iñupiaq Name	Scientific Name	Common Name
Qiḷalugaq, Sisuaq	*Delphinapterus leucas*	Beluga whale
Qiḷaŋmiutaq	*Dicrostonyx groenlandicus*	Collared lemming
UNK	*Enhydra lutris kenyoni*	Northern sea otter
Ugruk	*Erignathus barbatus*	Bearded seal
Aġviġluaq	*Eschrichtius robustus*	Gray whale
UNK	*Eubalaena japonica*	North Pacific right whale
Ugrugruaq	*Eumetopias jubatus*	Steller sea lion
Qavvik	*Gulo gulo*	Wolverine
Qaiġulik	*Histriophoca fasciata*	Ribbon seal
Aviŋŋapiaq	*Lemmus trimucronatus*	Brown lemming
UNK	*Lagenorhynchus obliquidens*	Pacific white-sided dolphin
Ukalliatchiaq	*Lepus americanus*	Snowshoe hare
UNK	*Megaptera novaeangliae*	Humpback whale
UNK	*Mesoplodon stejnegeri*	Steineger's beaked whale
Avinnaq	*Microtus miurus*	Singing vole
Aviŋŋaq, Avinnaq	*Microtus oeconomus*	Root/tundra vole
Qiḷalugaq tuugaalik	*Monodon monoceros*	Narwhal
Itiġiaq	*Mustela erminea*	Ermine
Itiġiaq, Naulayuq	*Mustela nivalis*	Least weasel
Aiviq	*Odobenus rosmarus divergens*	Pacific walrus
UNK	*Ondatra zibethicus*	Muskrat
Aaġlu	*Orcinus orca*	Killer whale
Umiŋmak	*Ovibos moschatus*	Muskox
Natchiq, Qayaġulik	*Phoca hispida, Pusa hispida*	Ringed seal
Qasiġiaq	*Phoca largha pallas*	Spotted seal
Aġvisuaq	*Phocoena phocoena*	Harbor porpoise
UNK	*Phocoenoides dalli*	Dall's porpoise
UNK	*Physeter macrocephalus*	Sperm whale
Tuttu	*Rangifer tarandus*	Caribou
Ugrugnaq	*Sorex tundrensis*	Tundra shrew
Ugrugnaq	*Sorex ugyunak*	Barren ground shrew
Siksrik, Sigrik	*Spermophilus parryii*	Arctic ground squirrel
Akłaq	*Ursus arctos*	Grizzly (brown) bear
Nanuq	*Ursus maritimus*	Polar bear
Kayuqtuq, Qianġaq, Qiġñiqtaq	*Vulpes vulpes*	Red fox
UNK	*Ziphius cavirostris*	Cuvier's beaked whale

Note: UNK (unknown)
Source: MacLean 2014

Table E.1.4. Fish

Iñupiaq Name	Scientific Name	Common Name
Iqalugaq	*Boreogadus saida*	Arctic cod
Milugiaq	*Catostomus catostomus*	Longnose sucker
Qaaktaq	*Coregonus autumnalis*	Arctic cisco
Tiipuq	*Coregonus laurettae*	Bering cisco
Aanaakłiq	*Coregonus nasus*	Broad whitefish
Pikuktuuq	*Coregonus pidschian*	Humpback whitefish
Iqalusaaq	*Coregonus sardinella*	Least cisco
Kanayuq	*Cottus cognatus*	Slimy sculpin
Iłuuqiñiq	*Dallia pectoralis*	Alaska blackfish
Uugaq	*Eleginus gracilis*	Saffron cod
Siulik, Siułik	*Esox lucius*	Northern pike
Kakiḷaġnaq, Kakiḷasak, Kakalisauraq	*Gasterosteus aculeatus*	Threespine stickleback
Nimibiaq	*Lethenteron camtschaticum*	Arctic lamprey
UNK	*Liopsetta glacialis*	Arctic flounder
Tittaaliq	*Lota lota*	Burbot
Paŋmaksraq, Paŋmagrak, Paŋmaġraq	*Mallotus villosus*	Capelin
Kanayuq	*Myoxocephalus quadricornis*	Fourhorn sculpin
Amaqtuuq	*Oncorhynchus gorbuscha*	Pink salmon (humpy)
Iqalugruaq, Qalugruaq	*Oncorhynchus keta*	Chum salmon (dog)
Iqalugruaq	*Oncorhynchus kisutch*	Coho salmon
Iqalugruaq	*Oncorhynchus nerka*	Red salmon (sockeye)
Iqalukpak, Taġyaqpak	*Oncorhynchus tshawytscha*	King salmon (Chinook)
Iłhuaġniq	*Osmerus mordax*	Rainbow smelt
Saviġuunnaq	*Prosopium cylindraceum*	Round whitefish
Kakalisauraq	*Pungitius pungitius*	Ninespine stickleback
Iqalukpik, Paikḷuk, Aŋayuqaksraq, Qalukpik	*Salvelinus alpinus*	Arctic char
Qalukpik	*Salvelinus malma*	Dolly Varden
Iqaluaqpak, Qaluaqpak	*Salvelinus namaycush*	Lake trout
Siiġruaq, Sii	*Stenodu leucichthys*	Sheefish or inconnu
Sulukpaugaq	*Thymallus arcticus*	Arctic grayling
Aqalugruaq	UNK	Salmon

Note: UNK (unknown)
Source: MacLean 2014

Table E.1.5. Birds

Iñupiaq Name	Scientific Name	Common Name
Saqsakiq	*Acanthis flammea* and *A. hornemanni*	Redpoll
Kurugaq	*Anas acuta*	Northern pintail
Kurugaġnaq	*Anas americana*	American wigeon
Qaqlutuuq, Alluutaq	*Anas clypeata*	Northern shoveler
Qaiŋŋiq	*Anas crecca*	Green-winged teal
Kurugaqtaq	*Anas platyrhynchos*	Mallard
Niġlivik, Niġlivialuk	*Anser albifrons*	Greater white-fronted goose
Tatirgaq	*Antigone candensis*	Sandhill crane
Tiŋmiaqpak	*Aquila chrysaetos*	Golden eagle
Tullignaq	*Arenaria interpres*	Ruddy turnstone
Nipailuktaq	*Asio flammeus*	Short-eared owl
Qaqłutuuq	*Aythya affinis*	Lesser scaup
Qaqłukpalik	*Aythya marila*	Greater scaup
UNK	*Aythya valisineria*	Canvasback
UNK	*Bartramia longicauda*	Upland sandpiper
Niġlinġaq	*Branta bernicla*	Brant goose
Iqsraġutilik	*Branta canadensis*	Canada goose
Ukpik	*Bubo scandiacus*	Snowy owl
Qilġiq	*Buteo lagopus*	Rough-legged hawk
Qupałuk, Putukiułuk	*Calcarius lapponicus*	Lapland longspur
Kimmitquilaq	*Calidris alba*	Sanderling
Siigukpaligauraq	*Calidris alpina*	Dunlin
Puviaqtuuyaaq	*Calidris bairdii*	Baird’s sandpiper
Sigukpaligauraq	*Calidris canutus*	Red knot
Siiyukpaligauraq	*Calidris fuscicollis*	White-rumped sandpiper
Siigukpaligauraq	*Calidris himantopus*	Stilt sandpiper
Siigukpaligauraq	*Calidris mauri*	Western sandpiper
Puvviaqtuuq	*Calidris melanotos*	Pectoral sandpiper
Livilivillauraq	*Calidris minutilla*	Least sandpiper
Livilivillakpak	*Calidris pusilla*	Semipalmated sandpiper
UNK	*Catharus minimus*	Gray-cheeked thrush
Iŋaġiq	*Cepphus grylle*	Black guillemot
Kurraquraq	*Charadrius semipalmatus*	Semipalmated plover
Kaŋuq	*Chen caerulescens*	Snow goose
Papiktuuq	*Circus cyaneus*	Northern harrier
Aaqhaaliq	*Clangula hyemalis*	Long-tailed duck
Tulugaq	*Corvus corax*	Common raven

Iñupiaq Name	Scientific Name	Common Name
Qugruk	*Cygnus columbianus*	Tundra swan
Kirgaviatchauraq	*Falco columbarius*	Merlin
Kirgavik	*Falco peregrinus tundrius*	Arctic peregrine falcon
Aatqarruaq	*Falco rusticolus*	Gyrfalcon
UNK	*Gallinago delicata*	Wilson's snipe
Tuullik	*Gavia adamsii*	Yellow-billed loon
Taasiŋiq	*Gavia immer*	Common loon
Malġi	*Gavia pacifica*	Pacific loon
Qaqsrauq	*Gavia stellata*	Red-throated loon
Tiŋmiaqpak	*Haliaeetus leucocephalus*	Bald eagle
Aqargiq, Nasaullik	*Lagopus lagopus*	Willow ptarmigan
Niksaaktuŋiq	*Lagopus mutus*	Rock ptarmigan
Nauyavaaq	*Larus argentatus*	Herring gull
UNK	*Larus glaucescens*	Glaucous-winged gull
Nauyavasrugruk	*Larus hyperboreus*	Glaucous gull
UNK	*Larus thayeri*	Thayer's gull
Sigukpalik	*Limnodromus scolopaceus*	Long-billed dowitcher
Turraaturaq	*Limosa lapponica*	Bar-tailed godwit
UNK	*Luscinia svecica*	Bluethroat
UNK	*Mareca strepera*	Gadwall
Tuungaagrupiaq	*Melanitta americana*	Black scoter
Killalik	*Melanitta fusca*	White-winged scoter
Aviḷuqtuq	*Melanitta perspicillata*	Surf scoter
UNK	*Melospiza lincolnii*	Lincoln's sparrow
Paisugruk, Aqpaqsruayuuq	*Mergus serrator*	Red-breasted merganser
Misiqqaaqauraq, Piiġaq	*Motacilla tschutschensis*	Eastern yellow wagtail
Sigguktuvak	*Numenius phaeopus*	Whimbrel
Ukpisiuyuk	*Passerculus sandwichensis*	Savannah sparrow
Ikłiġvik	*Passerella iliaca*	Fox sparrow
Auksruaq	*Phalaropus fulicarius*	Red phalarope
Auksruaq	*Phalaropus lobatus*	Red-necked phalarope
Suŋaqpaluktuŋiq	*Phylloscopus borealis*	Arctic warbler
Amaułłigaaluq	*Plectrophenax nivalis*	Snow bunting
Tullik	*Pluvialis dominica*	American golden-plover
Tullivak	*Pluvialis squatarola*	Black-bellied plover
Aqpaqsruayuuq	*Podiceps grisegena*	Red-necked grebe
Igniqauqtuq	*Polysticta stelleri*	Steller's eider
UNK	*Rissa tridactyla*	Black-legged kittiwake

Iñupiaq Name	Scientific Name	Common Name
Qavaasuk	*Somateria fischeri*	Spectacled eider
Amauligruaq	*Somateria mollissima*	Common eider
Qiŋalik	*Somateria spectabilis*	King eider
Misapsaq	*Spizella arborea*	American tree sparrow
Isuŋŋaq	*Stercorarius longicaudus*	Long-tailed jaeger
Migiaqsaayuk	*Stercorarius parasiticus*	Parasitic jaeger
Isuŋŋaġluk	*Stercorarius pomerinus*	Pomarine jaeger
Mitqutaiḷaq	*Sterna paradisaea*	Arctic tern
Uviñŋuayuuq	*Tringa flavipes*	Lesser yellowlegs
Satqagiiøaq	*Tryngites subruficollis*	Buff-breasted sandpiper
Iqirgagiaq	*Xema sabina*	Sabine’s gull
Nuŋaktuaġruk	*Zonotrichia leucophrys*	White-crowned sparrow

Note: UNK (unknown)
Source: MacLean 2014

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Willow Master Development Plan

Appendix E.2
Climate and Climate Change
Technical Appendix

June 2022

Appendix E.2A
Climate and Climate Change

Appendix E.2B
Bureau of Land Management Energy Substitution Model (EnergySub)

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Willow Master Development Plan

Appendix E.2A
Climate and Climate Change
Technical Appendix

June 2022

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List of Acronyms

ºC	degrees Celsius
ºF	degrees Fahrenheit
ADEC	Alaska Department of Environmental Conservation
AMAP	Arctic Monitoring and Assessment Programme
BLM	Bureau of Land Management
BOEM	Bureau of Ocean Energy Management
BSFC	brake-specific fuel consumption
CEQ	Council on Environmental Quality
CH_4	methane
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CPAI	ConocoPhillips Alaska, Inc.
EIS	Environmental Impact Statement
EO	Executive Order
EPA	U.S. Environmental Protection Agency
ICAO	International Civil Aviation Organization
IPCC	Intergovernmental Panel on Climate Change
GHG	greenhouse gas
GHGRP	Greenhouse Gas Reporting Program
GLEEM	Greenhouse Gas Life Cycle Energy Emissions Model
GWP	global warming potential
m	meter
MDP	Master Development Plan
MMT	million metric tons
MOVES	Motor Vehicle Emission Simulator
N_2O	nitrous oxide
NSB	North Slope Borough
$PM_{2.5}$	particulate matter less than 2.5 microns in aerodynamic diameter
Project	Willow Master Development Plan Project
RCP	representative concentration pathway
TAPS	Trans-Alaska Pipeline System
UNEP	United Nations Environment Programme
USEIA	U.S. Energy Information Administration
USGCRP	United States Global Change Research Program
W/m^2	watts per square meter
WPF	Willow Processing Facility

Glossary Terms

Active Layer – The top layer of ground subject to annual thawing and freezing in areas underlain by permafrost.

Albedo – A measure of how a surface reflects incoming radiation; a surface with a higher albedo reflects more radiation than a surface with lower albedo.

Anthropogenic – Resulting from the influence of human beings on nature.

Black Carbon – A component of fine particulate matter that is formed from the incomplete combustion of fossil fuels and biomass.

Carbon Dioxide Equivalent (CO_2e) – The amount of greenhouse gases that would have an equivalent global warming potential as carbon dioxide when measured over a specific timescale.

Greenhouse Gas (GHG) – Gaseous compounds, such as carbon dioxide, methane, and nitrous oxide, among others, that block heat from escaping to space and warm the Earth's atmosphere.

Lake Tapping – The sudden drainage of lakes caused by ice melting or dislodging and opening up a drainage channel.

Particulate Matter 2.5 ($PM_{2.5}$) – Particulate matter less than 2.5 microns in aerodynamic diameter in ambient air; this fraction of particulate matter penetrates most deeply into the lungs.

Positive Forcing – When earth receives more incoming energy from sunlight than it radiates to space.

Thermokarst – A land surface with karst-like features and hollows produced by melting ice-rich soil or permafrost.

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1.0 AFFECTED ENVIRONMENT

Climate change is affecting natural systems across the globe with enhanced impacts in the Arctic. The atmosphere and oceans have warmed, ice cover is shrinking, and permafrost is melting in high-latitude and high-elevation regions. The dominant cause of the observed warming since the mid-twentieth century can be attributed to human influences (IPCC 2014, 2021).

1.1 Greenhouse Gases and Climate Change Overview*

Major **greenhouse gases** (GHGs) include carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). GHGs are produced both naturally through volcanoes, forest fires, and biological processes and through **anthropogenic** activities such as the burning of fossil fuels, land use and water management changes, and agricultural processes. Since GHGs absorb infrared radiation emitted from the Earth's surface, they block heat from escaping to space and warm the Earth's atmosphere. GHGs are necessary for keeping the planet at a habitable temperature, and without GHGs, Earth's surface temperature would be around 60 degrees Fahrenheit (ºF) cooler than it is now. Natural biological and geological processes regulate levels of naturally occurring GHGs in the atmosphere; however, anthropogenic emissions haven driven atmospheric concentrations of GHGs to levels unprecedented in at least the last 800,000 years (IPCC 2014, 2021). Concentrations of CO_2, N_2O, and CH_4, have increased by 47%, 156%, and 23%, respectively, since 1750, largely due to economic and population growth (IPCC 2021). Ongoing emissions of GHGs are expected to continue to warm the planet in the future.

Although **black carbon** is not a GHG, it affects climate in a variety of ways. Black carbon is emitted as a combustion byproduct, and the concentration of black carbon can vary spatially, seasonally, and vertically in the atmosphere (AMAP 2015; Creamean, Maahn et al. 2018; Stohl, Klimont et al. 2013; Xu, Martin et al. 2017). Black carbon affects the climate by absorbing and scattering solar radiation (i.e., sunlight). It can also influence clouds by altering the size and number of water droplets and ice crystals in water and ice clouds. Black carbon in cloud droplets decreases cloud **albedo**, which heats and dissipates the clouds. This also alters the temperature structure within and around the cloud, changing cloud distribution.

1.2 Regulatory Framework*

On October 30, 2009, the U.S. Environmental Protection Agency (EPA) published a rule for the mandatory reporting of GHGs from major sources of emissions (40 CFR 98). The rule requires a wide range of sources and source groups to record and report selected GHG emissions under the Greenhouse Gas Reporting Program (GHGRP). As discussed in Section 3.2.1.3, *Trends in U.S. and Alaska Greenhouse Gas Emissions*, the GHGRP tracks emissions from large emitters (facilities emitting over 25,000 metric tons of carbon dioxide equivalent [CO_2e] annually) and reflects 85% to 90% of the total U.S. GHG emissions (EPA 2022). Various oil and gas operations are required to monitor and report GHG emissions under this regulation. However, since the GHGRP only reports emission data reported by large emitters, GHG emissions from smaller facilities are not included. Since emissions are reported to the GHGRP by the facilities, the reporters have the flexibility to choose among several GHG computing methods, as long as the requirements for using the selected methods are met (EPA 2021c). Such flexibility can contribute to uncertainties in data collected by the GHGRP.

In January 2021, two executive orders (EOs) were issued to address the climate crisis:

- EO 13990, Protecting Public Health and the Environment and Restoring Science to Tackle the Climate Crisis included directives to establish an Interagency Working Group on Social Cost of Carbon to develop social costs associated with GHGs for cost-benefit analyses and to rescind the 2019 draft guidance from the Council on Environmental Quality (CEQ) entitled "Draft National Environmental Policy Act Guidance on Consideration of Greenhouse Gas Emissions" (84 FR 30097).
- EO 14008, Tackling the Climate Crisis at Home and Abroad, established climate considerations as an element of U.S. foreign policy and national security, reaffirmed the decision to rejoin the Paris Agreement, committed to environmental justice and new clean infrastructure projects, and

put the U.S. on a path to achieve net-zero emissions by no later than 2050. Specific directives for the Department of the Interior and Bureau of Land Management (BLM) include, but are not limited to, increasing renewable energy production on public lands and waters and performing a comprehensive review of potential climate and other impacts from oil and natural gas development on public lands (BLM 2020).

Pursuant to EO 13990, the CEQ is reviewing, for revision and update, the previously rescinded 2016 CEQ guidance on analyzing GHGs in National Environmental Policy Act documents ("Final Guidance for Federal Departments and Agencies on Consideration of Greenhouse Gas Emissions and the Effects of Climate Change in National Environmental Policy Act Reviews" [2016 GHG Guidance]). Until new guidance is developed, the CEQ has advised federal agencies to consider all available tools and resources for assessing GHGs and climate change effects of their proposed actions, including the 2016 CEQ Guidance. Thus, the analysis here follows the 2016 CEQ Guidance.

Additional discussion of laws and policies relevant to GHGs and climate change is available in the BLM Specialist Report on Annual Greenhouse Gas Emissions and Climate Trends (2020) (herein referred to as the BLM Specialist Report).

The State of Alaska does not have any GHG regulations beyond federal regulations.

1.3 Observed Climate Trends

1.3.1 Arctic*

Global warming impacts observed globally and nationally are amplified in the Arctic. The Arctic has warmed at more than double the global rate over the past 50 years, and minimum temperatures have increased at about three times the global rate (IPCC 2021). The average surface air temperature over the Arctic in 2021 (October 2020 to September 2021) was the seventh warmest on record, and it was the eighth consecutive year that surface air temperatures were at least 1.8ºF (1 degree Celsius [ºC]) above the long-term average (Moon, Druckenmiller et al. 2021). In 2020, the annual surface air temperature was 3.4ºF (1.9ºC) higher than the 1981–2010 average on the land north of 60 degrees North, marking the second-largest annual average surface air temperature anomaly since at least 1900 (Thoman, Richter-Menge et al. 2020).

Spring snow cover extent, observed by satellites, has been decreasing over arctic land since 2005, especially in May and June (Derksen, Brown et al. 2017). The North American Arctic snow cover extent in June has been below the long-term average every year since 2006, and the complete 2020 snow-free period in the Arctic was the second-longest since recording started in 1998 (Moon, Druckenmiller et al. 2021). With decreased snow cover extent and shorter snow cover duration in the Arctic, more of the sun's energy is absorbed by the dark land surface, warming the surface further. This results in a reinforcing feedback effect that further reduces snow cover (Melillo, Richmond et al. 2014).

The extent of sea ice in the Arctic is also decreasing. Since the early 1980s, average annual sea ice extent has decreased by 3.5% to 4.1% per decade and the annual minimum sea ice extent, which occurs in September, has decreased at a rate of 11% to 16% per decade (USGCRP 2018). The 15 lowest September sea ice extents in the satellite record (since 1979) have all occurred in the last 15 years (Moon, Druckenmiller et al. 2021). The extent of very old ice (4 years or older), which is thicker and more resilient to short-term temperature changes, has also decreased, with old ice only comprising 4.4% of ice cover in the Arctic Ocean in March 2020 compared to 33% in 1985 (Perovich, Meier et al. 2020). Similar to decreases in snow cover extent, decreased sea ice extent also has a feedback effect on climate. An increased amount of the sun's energy is absorbed by the open ocean relative to oceans covered by ice, leading to an increased rate of sea ice melting. Reductions in sea ice also make the Arctic more accessible by ships for transportation, oil and gas exploration, and tourism. This can lead to increased GHG emissions as well as other risks such as oil spills and drilling or maritime-related accidents (Melillo, Richmond et al. 2014). Rising air temperatures over land affect the Arctic permafrost layer. Permafrost is material that exists at or below 32ºF (0ºC) for at least 2 years, and the active layer is the layer above the permafrost that thaws seasonally. The northern circumpolar permafrost zone stores 1,700 petagrams (or 1,700 gigatons) of organic carbon, locked in place due to the slow rate of plant material decomposition in the frozen ground (Schuur, Abbott et al. 2013). With rising temperatures and decreasing snow cover, the permafrost extent is predicted to decrease significantly by the year 2100 (Slater and Lawrence 2013). Thawing permafrost releases CO_2 and CH_4 to the atmosphere and delivers organic-rich soils to the bottoms of lakes, resulting in decomposition that releases additional CH_4. Recent studies (Voigt, Marushchak et al. 2017) suggest that thawing permafrost could also lead to the release of significant amounts of N_2O. These emissions can accelerate climate feedback effects (Jones, Irrgang et al. 2020; Markon, Trainor et al. 2012).

A reduction in sea ice has led to increased primary productivity (i.e., the rate at which energy is converted through photosynthetic and chemosynthetic processes into organic substances) in the Arctic Ocean (Moon, Druckenmiller et al. 2021). Warmer temperatures combined with reduced ice cover have led to the greening of the tundra and increases in soil moisture and the amount of snow meltwater available. These changes have led to an increased active layer depth, changes in herbivore activity patterns, and reductions in human usage of the land due to ground being frozen for a shorter period of time (Clement, Bengtson et al. 2013; Epstein, Bhatt et al. 2017). Although the greening of the tundra can store carbon as biomass, the effect of these changes in the Arctic has been a net release of carbon into the atmosphere (Epstein, Bhatt et al. 2017; Richter-Menge, Overland et al. 2017).

Black carbon has a magnified impact on climate in the Arctic due to snow and ice albedo feedback. This feedback occurs when black carbon settles on top of snow or ice and decreases the reflectivity (albedo) of the surface. This allows more heat to be absorbed by the surface, leading to increased melting, which further decreases the albedo. This feedback is prominent in the Arctic because so much of the surface is snow and ice, which have high albedo. The IPCC (2021) reports that there is "high confidence" that snowmelt in the Arctic is enhanced by deposition of black carbon (and other light-absorbing particles) on snow.

1.3.2 North Slope

Similar to the Arctic as a whole, the North Slope has experienced increased average temperatures, decreased sea ice and snow cover extent, an expanded growing season, and thawing permafrost. Temperatures in the North Slope have been warming at a rate 2.6 times faster than the continental U.S. (USGCRP 2018). Permafrost loss in Alaska's North Slope is already widespread and progressive deep thawing of permafrost in the North Slope region may begin in 30 to 40 years (Thoman, Richter-Menge et al. 2020).Over the 35-year record (1982 to 2016), the North Slope has shown substantial increases in tundra greenness (Richter-Menge, Overland et al. 2017). A warming climate, in addition to regulatory changes and methods for measuring frost depth, has contributed to a reduction in the tundra travel season from 200 days in the 1970s to less than 120 days in 2003 (NSB 2014). With continued climate warming and precipitation changes, the tundra travel season is expected to shorten further. Since the mid-1980s, Alaskan permafrost on the Arctic coast has warmed between 6ºF to 8ºF at a depth of 3.3 feet (1 meter [m]). In 2016, all but one permafrost observational site documented record high temperatures at a depth of 65.6 feet (20 m) on the North Slope. Depth temperatures at 65.6 feet (20 m) in this region have been increasing at rates between 0.38ºF and 1.19ºF per decade since 2000. The active layer depth was at a 210-year maximum on the North Slope in 2016 (Richter-Menge, Overland et al. 2017).

1.4 Observed Greenhouse Gas Trends

1.4.1 National*

GHG emissions in the U.S. are tracked by the EPA and documented in the Inventory of U.S. Greenhouse Gases and Sinks. In 2019, 6,558.3 million metric tons (MMT) of CO_2e were emitted in the U.S. (EPA 2021d). The major economic sectors contributing to GHG emissions in the U.S. in 2019 were transportation (28.6%), electricity generation (25.1%), industry (22.9%), and agriculture (10.2%). CO_2

from fossil fuel combustion has accounted for approximately 76% of U.S. GHG emissions since 1990, and the U.S. accounted for approximately 15% of global CO_2 emissions from fossil fuel combustion in 2018 (EPA 2021d). These fossil fuel combustion CO_2 emissions increased by approximately 2.6% between 1990 and 2019 but decreased by approximately 15.6% from 2005 levels.

1.4.2 Alaska*

The EPA documents GHG emissions from Alaska in the Alaska Greenhouse Gas Emissions Inventory. Emissions are calculated using a top-down approach, where emissions factors are applied to statewide activity data from 1990 to 2015. In 2015, approximately 40 MMT CO_2e were emitted in Alaska. This is a decrease of approximately 8% from 1990 levels and a decrease of approximately 23% from the peak emissions observed in 2005 (ADEC 2018).

The industrial sector, including the oil and gas industry, is the major contributor to GHG emissions in Alaska, followed by the transportation, residential and commercial, and electrical generation sectors. The waste, agricultural, and industrial process sectors each contribute less than 1% of GHG emissions in the state (ADEC 2018).

1.5 Projected Climate Trends and Impacts in the Project Area*

The Intergovernmental Panel on Climate Change (IPCC) Special Report Global Warming of 1.5°C (2018b) estimates with high confidence that in order to limit global warming to 1.5°C, global GHG emissions in 2030 would need to be 40% to 50% lower than 2010 emissions. Based on the IPCC (2018b) findings, the United Nations Environment Programme (UNEP) Emissions Gap Report (2021) estimates global GHG emissions in 2030 would need to be 55% lower than projected 2030 emissions to limit global warming to 1.5ºC and 30% lower to limit warming to 2°C. UNEP (2021) estimated that current pledges for 2030 reduce the projected 2030 emissions by only 7.5%. An analysis by Tong, Zhang et al. (2019) indicates that future global CO_2 emissions anticipated from existing and proposed energy infrastructure already exceed the carbon emissions budget needed to limit global warming to 1.5ºC; however, other studies suggest that attaining a 1.5ºC warming limit is possible by replacing existing infrastructure with zero-carbon alternatives at the end of their life spans, enabling us to meet climate goals (Smith, Forster et al. 2019). For U.S. emissions, the U.S. Energy Information Administration (USEIA) estimates trends in future U.S. CO_2 emissions in the Annual Energy Outlook 2021 Report (2021a). U.S. CO_2 emissions are predicted to decrease from 2023 to 2035 as a result of a transition away from coal and a rise in natural gas and renewable energy, but emissions are then projected to trend upward after 2035 due to increasing population and economic growth, with the rate of increase depending on economic conditions.

Climate projections under both higher (representative concentration pathway [RCP] 8.5) and lower (RCP 4.5) GHG emission scenarios shows that the state of Alaska should expect warmer annual temperatures, reduced snow cover and sea ice extents, thinner sea ice, and potential increases in the area burned by wildfire (USGCRP 2018). Under RCP 8.5, the interior and northern areas of the state are projected to warm by 10°F to 16ºF (BLM 2020). In coastal areas of the North Slope, the number of nights below freezing is projected to decrease by more than 45 nights per year (BLM 2020).

Climate projections for Alaska indicate that snow cover duration is expected to drop, with a later date of first snowfall and an earlier snowmelt, and the arctic waters could be virtually ice-free by late summer before 2050 (BLM 2020; Markon, Trainor et al. 2012; Mudryk, Elias Chereque et al. 2020). Models predict permafrost thawing will continue, with some models predicting that near-surface permafrost will likely disappear on 16% to 24% of the landscape of Alaska by the end of the 21st century (BLM 2020; USGCRP 2018). This will impact rural Alaskan communities by likely disrupting sewage systems and community water supplies. The increasing trend in the length of the Alaska growing season is also projected to continue. This change will reduce water storage as well as increase the risk and extent of wildfires and insect outbreaks in the region. Warmer temperatures, wetland drying, and increased summer thunderstorms will likely continue to increase the number of wildfires in Alaska (USGCRP 2018).

Warmer temperatures in the Willow Master Development Plan (MDP) Project (Project) area will lead to a deeper active layer, which would affect the surrounding ecosystem. A deeper active layer would allow improved water drainage and the migration of deeper rooted plant communities farther north. Changes in plant communities would also be driven by the expanded growing season and warmer, drier soils. These vegetation changes would promote soil formation as root development and organic matter in the soil profile increase.

As the active layer deepens, damage from traffic over the surface during non-frozen periods would likely increase due to accelerated erosion and subsidence of permafrost. Permafrost thawing could also lead to **thermokarst** or slumping, resulting in increased nutrient loading and suspended sediment in lakes and rivers. Warmer temperatures may lead to an increase in the frequency of **lake tapping** (sudden drainage) events as degrading ice wedges integrate into drainage channels at lower elevations.

Arctic fish species will be affected by increased water temperatures as air temperatures increase, but this impact is difficult to predict. Arctic bird species will be affected by habitat loss as aquatic and semiaquatic habitats are converted into drier habitats. A reduction in available habitat would likely cause changes in bird distributions, increased competition for resources, and declines in productivity.

Paleontological resources could be adversely affected by climate change, but the impact is difficult to determine. Paleontological sites may more rapidly decompose in a warmer climate, and sites on hillsides, bluff faces, riverbanks, and terraces may be destroyed by mass wasting. Erosion may lead to increased exposure of known paleontological sites. Many known paleontological sites in the Project area have been exposed due to erosion with few negative impacts.

As with paleontological resources, cultural resources on the North Slope could also be impacted by mass wasting, warmer temperatures, and erosion. In addition, as the permafrost thaws and the active layer deepens, cultural resources may be incorporated into the active layer. These sites would then be exposed to cryoturbation (frost mixing) and subject to vertical disturbances that may cause sites at different vertical layers to become mixed. These disturbances can occur in both vertical directions as seasonal frost cracking can cause downward movement, and frost heaving and sorting, ice wedging, and involutions can push artifacts upward.

Climate change may impact the accessibility of mineral material deposits on the North Slope. While the existence and location of these deposits will not be affected, the excavation process may be made easier, due to the thawing permafrost, or more difficult, as developing deposits in areas with thawed permafrost may require water removal or excavation in swampy conditions.

2.0 ANALYSIS METHODS

2.1 Overview*

To evaluate the potential contribution of the Project to global climate change, GHG emissions from the Project were used as a proxy for climate change impacts. The amount of GHG emissions emitted by the Project under various alternatives was calculated. Emission metrics facilitate multicomponent climate policies by allowing emissions of different GHGs and other climate forcing agents to be expressed in a common unit (CO_2e). The global warming potential (GWP) was introduced in the IPCC's first assessment report, where it was also used to illustrate the difficulties in comparing components with differing physical properties using a single metric. Each GHG has a GWP that accounts for the intensity of the GHG's heat trapping effect and its longevity in the atmosphere. GHG emissions are reported in units of CO_2e to account for the varying GWP of pollutants and to allow for more direct comparisons of the global warming impacts of different GHGs.

The 100-year GWP was adopted by the United Nations Framework Convention on Climate Change (IPCC 2014) and its Kyoto Protocol and is now used widely as the default metric. In addition, the EPA uses the 100-year time horizon in its *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2019* (EPA 2021d).

The 100-year GWP is only one of several possible emission metrics and time horizons. The choice of emission metric and time horizon depends on the type of application and policy context; hence, no single metric is optimal for all policy goals. All metrics have shortcomings and choices contain value judgments, such as the climate effect considered and the weighting of effects over time (which explicitly or implicitly discounts impacts over time) and the climate policy goal and the degree to which metrics incorporate economic or only physical considerations. There are significant uncertainties related to metrics, and the magnitudes of the uncertainties differ across the metric type and time horizon. Three such metrics type/time horizon combinations are listed in Table E.2.1 and were used in the GHG analysis. In general, the uncertainty increases for metrics along the cause and effect chain from emission to effects.

All Project GHG emissions were converted to units of CO_2e for ease of comparison using the GWP values shown in Table E.2.1.

Table E.2.1. Global Warming Potential Factors*

Time Horizon	CO_2	CH_4	N_2O	Rationale for Time Horizon
100 years	1	25	298	Used by the U.S. Environmental Protection Agency in its GHG inventories and GHG reporting rule requirements under 40 CFR 98(a) (EPA 2019).
100 years	1	29.8	273	Used by the IPCC in its climate change synthesis report of the sixth assessment report (IPCC 2021). The IPCC used different CH_4 GWPs for sources originating from fossil carbon and non-fossil carbon. The CH_4 fossil values were used here as all Project emissions originate from fossil carbon.
20 years	1	82.5	273	Used by the IPCC in its climate change synthesis report of the sixth assessment report (IPCC 2021). The IPCC used different CH_4 GWPs for sources originating from fossil carbon and non-fossil carbon. The CH_4 fossil values were used here as all Project emissions originate from fossil carbon.

Note: CH_4 (methane); CO_2 (carbon dioxide); GHG (greenhouse gas); IPCC (Intergovernmental Panel on Climate Change); N_2O (nitrous oxide).

2.2 Direct Greenhouse Gas Emissions Calculation Methods*

ConocoPhillips Alaska, Inc. (CPAI) developed a Project emissions inventory (CPAI 2019) of all known emissions sources (e.g., vehicles, aircraft, drill rigs, generators) that would be present during the construction and life of the Project for Alternative B (Proponent's Project). The BLM reviewed the emissions inventories, and the Alternative B inventory was used as the basis for estimating emissions from Alternatives C (Disconnected Infield Roads) and D (Disconnected Access). In support of the Supplemental Environmental Impact Statement (EIS), CPAI developed a Project emissions inventory for Alternative E (SLR 2022a) which was also reviewed by the BLM. GHG emissions were calculated for each alternative as part of these inventories to estimate the Project's direct GHG emissions.

All action alternatives would include construction, drilling, routine operations, well workovers and interventions, and module delivery. Emissions from these activities would come from stationary combustion sources, mobile on-road and nonroad tailpipe combustion sources, fugitive sources, aircraft sources, and marine vessel sources. GHG emissions quantified from these activities include CO_2, CH_4, and N_2O. The GWPs shown in Table E.2.1 were used to calculate total CO_2e. Under Alternatives B, C, and E, the Project would have a 30-year life, while under Alternative D, the Project would have a 31-year life.

For additional information regarding the methods used to estimate direct on-site emissions for each alternative, see Chapter 2 of the Willow MDP Supplemental EIS Air Quality Technical Support Document provided as Appendix E.3B, *Air Quality Technical Support Document*.

Direct emissions of GHGs from business commuting of employees and contractors by air travel were also estimated. It is anticipated that most employees and contractors would commute from Anchorage to the North Slope (i.e., Willow or Alpine airstrips) using ConocoPhillips Global Aviation services or equivalent (SLR 2022). CPAI estimates that there would be one flight every 2 weeks transporting 60 workers (SLR 2022); this flight activity was assumed to occur over the entire Project duration under all action alternatives.

The International Civil Aviation Organization (ICAO) has developed a standard for calculating the amount of CO_2 emissions generated by a passenger on an aircraft (ICAO 2018). ICAO utilizes a distance-based approach with up-to-date aircraft-type data. The inputs needed to calculate the emissions are as follows: emission ratio per metric ton of jet fuel used, total fuel used, passenger to freight weight ratio, number of commercial seats available on the flight, and passenger load factor. The total fuel used is calculated based on ICAO fuel utilization tables, which give the average fuel used for a given aircraft type per average trip distance (ICAO 2018). The distances from Anchorage to the Willow and Alpine airstrips were calculated using the Google Maps straight distance calculator, and then an ICAO correction factor was applied to account for the great-circle distance between airports. ICAO provides CO_2 emission factors for jet fuel but not for N_2O, and CH_4. Thus, CO_2, CH_4 and N_2O emission factors for conventional jet fuel were obtained from the EPA (2021b). The energy density used was the higher heating value of jet fuel from the Greenhouse Gases, Regulated Emissions, and Energy use in Technologies Model database (Argonne National Laboratory 2021). All other characteristic values, including energy density in terms of volume of jet fuel, were taken from EPA (2021b).

2.3 Indirect Greenhouse Gas Emissions Calculation Methods*

The Bureau of Ocean Energy Management's (BOEM's) Greenhouse Gas Life Cycle Energy Emissions Model (GLEEM; Wolvovsky 2021) is used (with updates, as discussed below) to estimate indirect GHG emissions from domestic transportation, refinement, and oil usage. This model was developed to support the Outer Continental Shelf Oil and Gas Leasing Program 2017–2022, and it represents the best available resource for estimating indirect GHG emissions from petroleum products refined and consumed domestically. A description of the model's capabilities and methodology can be found in Wolvovsky (2021). Updates were made to the model inputs for the Willow MDP Supplemental EIS to incorporate additional data, as discussed below. For this Supplemental EIS, GLEEM was used to estimate the downstream GHG emissions associated with consumption of the oil and gas produced from the Project as well as the energy substitutes (ranging from other oil sources to renewable sources). The BLM's EnergySub Model estimates these energy substitutes that could replace production from the Project or, equivalently, be displaced due to the Project (see Appendix E.2B)[1]. Substitution rates from EnergySub were rounded to the nearest whole percentage for use in GLEEM. BOEM's Office of Environmental Programs developed GLEEM to estimate the full lifecycle emissions from both production and consumption of Outer Continental Shelf resources. For this Project, only the downstream portion of the model is used, as the upstream component is derived in combination with an offshore-specific separate model. The use of BOEM's GLEEM in the GHG analysis for the Project is limited to the emissions associated with the processing and consumption of oil and gas resources and not the emissions from actual production of the resources that were calculated separately, as discussed in Section 2.2, *Direct Greenhouse Gas Emissions Calculation Methods*.

The 2021 version of GLEEM was downloaded from BOEM's website[2] on February 22, 2022, for use in this analysis. The following updates were made to GLEEM input data for use in this Supplemental EIS:

- All national mineral activity data (e.g., U.S. crude oil refinery inputs and refinery processing gain, U.S. petroleum product consumption) in GLEEM were updated to use the latest data available from the USEIA's Monthly Energy Review Report (USEIA 2022).
- The national emissions used in GLEEM 2021 for crude oil refining are from the Petroleum Systems source category of EPA (2021d), which excludes all combustion emissions of CO_2 except for flaring. EPA (2021d) includes the CO_2 combustion emissions from crude oil refining in the industrial sector emissions of the Fossil Fuel Combustion category. GLEEM was updated to use the total U.S. refinery GHG emissions reported under the GHGRP (Subpart Y of 40 CFR

[1] Use of the EnergySub model in this SEIS is based on the specific production aspects of the Project and BLM's prior use of the BOEM MarketSim model in the original Willow EIS.
[2] https://www.boem.gov/environment/greenhouse-gas-life-cycle-energy-emissions-model

98) that include stationary fuel combustion emissions as well as process emissions (e.g., flares, process units, vents, blowdowns, fugitive leaks) (EPA 2021a).

- The national mineral activity data used in GLEEM is for the year 2020 from USEIA (2021b), while the national emissions data used in GLEEM is for the year 2019 from the EPA's annual GHG emissions inventory (2021d). All national mineral activity and emissions data used as GLEEM inputs were updated to use a 5-year average of recent years (2015 to 2019) instead of a single year.
- GLEEM was updated to assume that all Project oil produced under the action alternatives (and energy substitutes under the No Action Alternative) are combusted. This results in a conservatively high estimate of combustion emissions as some oil and natural gas are used for non-combustible products (e.g., fertilizers).
- Minor corrections were made to the EPA (2021b) stationary combustion emission factors used to estimate the downstream combustion emissions of propylene, petroleum coke, and industrial coal.

The Project would increase total U.S. crude oil production, which the results from EnergySub indicate would reduce prices for oil and other energy sources and result in changes in both domestic and foreign energy consumption. The changes in domestic and foreign oil consumption because of Project production are estimated using the BLM EnergySub model (Appendix E.2B). The increases in oil consumption domestically and abroad would result in GHG emissions. Emissions from the change in domestic consumption of crude oil and other energy sources (e.g., coal, natural gas) under the No Action Alternative are estimated using GLEEM with updates to model inputs, as described above. Emissions from the change in foreign oil consumption under Alternatives B, C, D, and E are estimated by applying an EPA (2021a) stationary combustion emission factor to the change in foreign oil consumption estimated by EnergySub. Due to the lack of information on the type and amount of petroleum products consumed in foreign markets, the highest emission factor (11.91 kilograms of CO_2 per gallon, 0.47 gram of CH_4 per gallon, and 0.09 gram of N_2O per gallon) reported by the EPA across all petroleum products (EPA 2021b) was used for a conservatively high estimate of emissions.

In addition to the indirect emissions estimated by GLEEM, indirect GHG emissions from the transport of Willow oil via pipeline and barge and deliveries of diesel fuel to the Project via barge, rail, and truck were also estimated as described below.

2.3.1 Transport of Project Oil to Refineries via the Trans-Alaska Pipeline System and ConocoPhillips Alaska, Inc. Polar Tankers*

Sales-quality crude oil processed at the Willow Processing Facility (WPF) would be transported through the Willow Pipeline to a tie-in with the Alpine Pipeline near drill site Colville Delta 4 North. The oil would then travel through the Alpine Pipeline to the Kuparuk Pipeline and then to the Trans-Alaska Pipeline System (TAPS) near Deadhorse, Alaska. From there, the oil would travel through TAPS to the Valdez Marine Terminal located in southern Alaska, where it would be loaded onto CPAI polar tankers to be transported to refineries. To estimate additional indirect GHG emissions from the transport of Project oil via TAPS, emissions of CO_2, CH_4, and N_2O from the four active TAPS pump stations (i.e., TAPS Pump Stations 3, 4, 7 and Alyeska Pipeline Pump Station 01) and the Valdez Marine Terminal were obtained from the EPA's Facility Level Information on GreenHouse gases Tool for the period 2015 to 2019 (EPA 2022). The annual reported GHG emissions from TAPS and the Valdez Marine terminal were then divided by the total annual TAPS throughput (Alyeska Pipeline Service Company 2022) to estimate the emissions intensity (i.e., metric tons of CO_2, N_2O, and CH_4 per barrel of oil) from transport.
The average emissions intensity from 2015 to 2019 was multiplied by the yearly Willow production under each action alternative to obtain an estimate of the annual GHG emissions from the transport of Project oil through TAPS. A similar methodology was used to estimate annual GHG emissions from the transport of Willow oil on CPAI polar tankers from the Valdez Marine Terminal to refineries. Emissions intensities for CPAI polar tankers (e.g., metric tons of CO_2, CH_4, and N_2O per millions of barrels of oil transported) were obtained from CPAI (SLR 2022) and multiplied by the annual Project production under each action alternative to obtain annual emissions estimates.

2.3.2 Transport of Liquid Fuel to the Project via Barge, Rail, and Truck*

Transport of liquid fuel to the Project is expected to occur from Valdez, Alaska, to the Project site through the following transportation modes, with annual round trips per mode provided by CPAI (SLR 2022):

- Barge from Valdez to the Port of Anchorage
- Rail from the Port of Anchorage to Fairbanks
- Truck from Fairbanks to Deadhorse, then to Kuparuk

To estimate the emissions from barge and rail transport of liquid fuels, an EPA (2020) guidance approach was used that estimates emissions from gross ton-miles. Alaska Railroad (2015) reported that "it takes just one gallon of fuel to move a ton of freight the length of the entire Railbelt." The system map for Alaskan Railroad indicated that the entire Railbelt from Seward to Fairbanks is 470 miles long (Alaska Railroad 2020). which translates to 470 ton-miles per gallon of diesel fuel consumed.

TTI (2017) reported a similar freight fuel efficiency for rail and provided barge transport efficiency as well. The TTI values were used to estimate the emissions for barge (inland towing) and rail freight moves. Note that the ton-miles are for freight moves and returning empty (deadhead) is incorporated in the overall efficiency represented here:

- 647 ton-miles per gallon for inland towing
- 477 ton-miles per gallon for railroads
- 145 ton-miles per gallon for trucking

EPA (2020) port and freight emissions inventory guidance provided the engine fuel efficiency (brake-specific fuel consumption [BSFC]). The EPA's (2009) estimated diesel fuel density of 3,200 grams per gallon was used to convert BSFC to gallon units, which translates to 10,217 grams CO_2 per gallon. Emission factors for CH_4 and N_2O were obtained from EPA (2021b). Tier 2 engines were assumed for the barges (SLR 2022b) and Category 2 (displacement of 5 to 30 liters per cylinder) engines were also assumed. The emission factors used for barge transport were 10,217 grams CO_2 per gallon, 6.41 grams CH_4 per gallon, and 0.17 grams N_2O per gallon, respectively.

EPA (2009) provides locomotive engine emission factors directly in gram per gallon units for different railroad authorities to account for the expected fleet age distribution and other factors. The Small Railroads category was conservatively used for the emission factors as a high emissions case because many railroads run older engines and on higher emitting switching duty. The same diesel fuel carbon density was used as for towboats, above (i.e., 10,217 grams CO_2 per gallon), and the EPA (2021b) mobile combustion emission factors for diesel locomotives of 0.8 and 0.26 gram per gallon were used for CH_4 and N_2O, respectively. Multiplying the freight tonnage by the distance moved (one way) provides ton-miles and dividing by the freight transport efficiency estimates the fuel consumed by mode. Then the fuel consumption multiplied by the emission factors in gallon units provides the expected emissions from freight transport.

Estimates from emissions of liquid fuel transport via truck were calculated using the latest version of the EPA's Motor Vehicle Emission Simulator (MOVES), MOVES3 (EPA 2021e). MOVES was run in inventory rate mode for the state of Alaska. Based on information provided by CPAI (SLR 2022), the vehicle type chosen was diesel combination long-haul truck. The model was run for the first project year (2023), the fifth year (2027), and the tenth year (2032), from which emissions levels were assumed to be constant during the remaining Project life. This is a conservative assumption as equipment turnover over time would likely decrease emissions. The model emissions and activity were output on an annual basis by vehicle type, fuel type, road type, and calendar year and aggregated annually across all model years representing the MOVES default national age distribution for diesel combination long-haul trucks. Year 1 (2023) was used as a conservative surrogate for Years 1 to 4, Year 5 (2027) was used as a conservative surrogate for Years 5 to 9, and Year 10 (2032) was used as a surrogate for emissions in Year 10 through the end of the Project. Running, short-term idling, and extended idling emission factors were then calculated using output emissions and their respective activity surrogate; extended idle hours for long-term idling (mandated driver rest), source hours operating for short-term idling (idling of 1 hour or less is expected to happen during travel milestone stops), and mileage for running exhaust for all GHGs. Emissions were then calculated using annual activity provided by CPAI (SLR 2022) alongside calculated emission factors.

3.0 ENVIRONMENTAL CONSEQUENCES

3.1 Effects of the Project on Climate Change

3.1.1 Alternative A: No Action

Under Alternative A, the Project would not occur. Direct and indirect GHG emissions from the Project would not occur and hence not contribute to climate change. Current trends in global, U.S., and Alaska GHG emissions would continue, unaffected by the Project. For ease of comparison to the action alternatives, GHG emissions in the No Action Alternative are assigned a baseline value of zero in this Supplemental EIS, reflecting the status quo and current GHG emissions trends in the absence of the Project.

3.1.2 Alternative B: Proponent's Project

Alternative B direct and indirect CO_2e emissions are quantified and described in the following sections. Black carbon effects on climate are also discussed.

3.1.2.1 Direct Greenhouse Gas Emissions

Direct and indirect emissions of the GHGs CO_2, CH_4, and N_2O will impact the climate. The Project is also expected to produce a small amount of sulfur dioxide, a GHG that has an overall cooling effect; however, the effect of sulfur dioxide emissions would be negligible. Direct emissions for the Project include, but are not limited to, emissions from vehicle traffic, air traffic, power generation, and drill rigs.

GHGs have long lifetimes (i.e., 10 to 100 years) before they are chemically broken down or otherwise removed from the atmosphere through absorption or deposition. Since GHGs are relatively stable, changes in GHG emissions have long-lasting effects on the climate. Alternative B direct GHG emissions estimated over the 30-year Project lifetime are provided in the main body of this Supplemental EIS (Table 3.2.2 in Section 3.2.2.3, *Alternative B: Proponent's Project*). Emissions are given in CO_2e units to account for the GWP of pollutants and were calculated using GWP values for both 100-year and 20-year time horizons (Table E.2.2). Note that the Project activities vary considerably over the life of the Project, and GHG emissions in any given year may be higher or lower than annual average GHG emissions (see Table E.2.2). The annual average emissions for Alternative B shown are for gross GHG emissions and do not account for the market substitution effects discussed in Section 3.2.2.2, *Alternative A: No Action*.

Table E.2.2. Annual Average Gross Greenhouse Gas Emissions for Alternative B (thousand metric tons per year)*

GHG Emissions	CO_2	CH_4	N_2O	CO_2e (100-year AR4 GWP)	CO_2e (100-year AR6 GWP)	CO_2e (20-year AR6 GWP)
Direct	779	0.295	0.002	787	788	804
Indirect	8,651	0.614	0.089	8,693	8,694	8,726
Total[a]	**9,430**	**0.909**	**0.091**	**9,480**	**9,482**	**9,530**

Note: AR4 (fourth assessment report of the Intergovernmental Panel on Climate Change [IPCC]); AR6 (sixth assessment report of the IPCC); CH_4 (methane); CO_2 (carbon dioxide); CO_2e (carbon dioxide equivalent); GHG (greenhouse gas); GWP (global warming potential); N_2O (nitrous oxide). Year 0 only included 1 month of construction activity and thus this year was excluded from the average annual emissions.
[a] Total values may have small differences due to rounding.

3.1.2.2 Indirect and Total Domestic Greenhouse Gas Emissions

Indirect emissions are expected to come from transportation, refinement, and downstream consumption of the oil extracted by the Project. Natural gas extracted from the Project would be reinjected into the well and would not be transported for consumption.

Indirect GHG emissions estimated over the 30-year Project lifetime are shown in Table 3.2.2 in Section 3.2.2, *Environmental Consequences: Effects of the Project on Climate Change*. The Alternative B annual average indirect and total GHG emissions (see Table E.2.2) are calculated by dividing the indirect and total GHG emissions (gross emissions) by the 30-year Project lifetime. As in the case of direct emissions, GHG emissions in any given year may be higher or lower than annual average GHG emissions because Project activities vary considerably over the life of the Project.

*3.1.2.3 Black Carbon Effects on Climate**

Black carbon is a short-lived pollutant with an estimated lifetime of several days to weeks (AMAP 2011, 2015; IPCC 2021; Paris, Stohl et al. 2009). Black carbon emissions have a **positive forcing** effect and warm the climate both in the atmosphere and when deposited on snow or ice (Bond, Doherty et al. 2013; IPCC 2021). The IPCC (2018a) reports that black carbon emissions must fall by at least 35% across all sectors from 2010 levels by 2050 to limit global warming to 1.5°C (2.7°F).

Black carbon is a by-product of incomplete combustion. It is removed from the atmosphere through wet and dry deposition. Concentrations of black carbon vary depending on the season (AMAP 2015), spatial location (Creamean, Maahn et al. 2018), and vertical height in the atmosphere (Creamean, Maahn et al. 2018; Stohl, Klimont et al. 2013; Xu, Martin et al. 2017). On Alaska's North Slope, black carbon can come from international transportation sources (Matsui, Kondo et al. 2011; Stohl 2006; Xu, Martin et al. 2017), biomass burning (Creamean, Maahn et al. 2018; Stohl 2006; Xu, Martin et al. 2017), shipping (Corbett, Lack et al. 2010; Lack and Corbett 2012), oil and gas exploration and production activities (Creamean, Maahn et al. 2018; Stohl, Klimont et al. 2013), and residential combustion (Stohl, Klimont et al. 2013). In particular, black carbon emitted from shipping can be deposited directly onto sea ice, and ice breakers can deposit black carbon onto the ice pack itself (Brewer 2015). Black carbon emitted onto ice and snow can increase melting and exacerbate warming as darker and more absorbent land and water surfaces are exposed as a result. With Project construction, black carbon would be emitted as part of particulate matter less than 2.5 microns in aerodynamic diameter **($PM_{2.5}$)** emissions from diesel-fired equipment, including engines, boilers, heaters, pumping units, and other equipment, such as aircrafts and flares.

Black carbon has a strong impact on Arctic regions due to its ability to change the reflective properties of ice and snow. When black carbon is deposited on ice or snow, it darkens the ground, decreasing the reflectiveness of the surface (the albedo) and warming the surface (+0.13 watts per square meter [W/m^2]) (Bond, Doherty et al. 2013). Since black carbon emitted in the Arctic has a higher probability of being deposited onto snow or ice, this "snow- and ice-albedo feedback effect" is stronger when black carbon is emitted in the Arctic than when it is transported from lower latitudes (Sand, Berntsen et al. 2013). Black carbon that is not deposited can increase warming when it absorbs solar radiation in the lower troposphere and boundary layer, decreasing cloud cover and leading to increased melting, further enhancing the snow- and ice-albedo feedback effect as the surface turns from bright snow and ice into darker water. In fact, black carbon has a strong direct radiative effect, meaning it is effective at warming the climate through the direct absorption of radiation, and is the component of $PM_{2.5}$ that is most effective at absorbing solar energy. For the period 1750 to 2005, Bond, Doherty et al. (2013) estimated the direct radiative effect of black carbon to be +0.71 W/m^2 and the total climate forcing (including cloud, snow, and sea ice effects) to be +1.1 W/m^2. Black carbon can also affect the formation of clouds and change their radiative properties, leading to increased warming (+0.23 W/m^2) (Bond, Doherty et al. 2013). When black carbon mixes with other pollutants in the atmosphere, a coating can form around the black carbon particle, causing it to grow in size. It is predicted that black carbon particles that have reacted with chemical compounds in this way may have an increased warming effect (Kodros, Hanna et al. 2018).

Black carbon can also cool the climate. When black carbon is lofted high into the atmosphere, it can block solar radiation from reaching the surface in a process called surface dimming (Flanner 2013; Sand, Berntsen et al. 2013). Surface dimming also decreases the equatorial-polar temperature gradient, causing less heat to be transported to the Arctic from lower latitudes. Black carbon can also increase reflected incoming solar radiation by increasing high-altitude clouds that reflect solar radiation. Bond, Doherty et al. (2013) also find that black carbon is co-emitted with other pollutants, and these pollutants can reduce the amount of warming caused by black carbon alone (-0.06 W/m^2).

The effect of black carbon, although expected to be positive overall, is highly variable and dependent on the location and timing of the emissions, the mixing state of the atmosphere, and deposition processes. The complex interactions and feedbacks between black carbon and the environment all contribute to the effect of black carbon on the arctic climate.

Black carbon would be emitted by sources and activities under Alternative B. For the Project, black carbon emissions were not explicitly quantified; however, black carbon is a component of $PM_{2.5}$ and black carbon emissions are included in $PM_{2.5}$ emissions that are quantified in the air quality analysis (Chapter 3.3, *Air Quality*).

3.1.3 Alternative C: Disconnected Infield Roads*

Alternative C GHG emissions estimated for the 30-year Project lifetime are provided in Table 3.2.2 in Section 3.2.2.3, *Alternative B: Proponent's Project*. Annual average GHG emissions (Table E.2.3) are calculated by dividing the Project's lifetime GHG emissions by the 30-year Project duration. As in the case of Alternative B, GHG emissions in any given year may be higher or lower than annual average GHG emissions (see Table E.2.3) because Project activities vary considerably over the life of the Project.

Black carbon would be emitted by sources and activities under Alternative C. Although black carbon is not explicitly quantified, it is a component of $PM_{2.5}$, and $PM_{2.5}$ emissions would be approximately 19% greater under Alternative C than Alternative B (see Appendix E.3B, *Air Quality Technical Support Document*). Therefore, it is anticipated that black carbon emissions would also be greater under Alternative C than Alternative B, and the effects of black carbon on the environment would increase under Alternative C relative to Alternative B. The annual average emissions for Alternative C shown in Table E.2.3 are for gross GHG emissions and do not account for the market substitution effects discussed in Section 3.2.2.2, *Alternative A: No Action*.

Table E.2.3. Annual Average Gross Greenhouse Gas Emissions for Alternative C (thousand metric tons per year)*

GHG Emissions	CO_2	CH_4	N_2O	CO_2e (100-year AR4 GWP)	CO_2e (100-year AR6 GWP)	CO_2e (20-year AR6 GWP)
Direct	851	0.298	0.002	859	861	876
Indirect	8,651	0.614	0.089	8,693	8,694	8,726
Total[a]	**9,502**	**0.912**	**0.091**	**9,552**	**9,554**	**9,603**

Note: AR4 (fourth assessment report of the Intergovernmental Panel on Climate Change [IPCC]); AR6 (sixth assessment report of the IPCC); CH_4 (methane); CO_2 (carbon dioxide); CO_2e (carbon dioxide equivalent); GHG (greenhouse gas); GWP (global warming potential; N_2O (nitrous oxide). Year 0 only included 1 month of construction activity, and thus this year was excluded from the average annual emissions.
[a] Total values may have small differences due to rounding.

3.1.4 Alternative D: Disconnected Access

As mentioned in Section 2.2 of this appendix and explained in more detail in Chapter 2.0, *Alternatives*, Alternative D would have a 31-year Project lifetime rather than the 30-year Project lifetime for Alternatives B and C. Alternative D GHG emissions estimated over the 31-year Project lifetime are shown in Table 3.2.2 in Section 3.2.2.3, *Alternative B: Proponent's Project*. Project activities vary considerably over the life of the Project, and GHG emissions in any given year may be higher or lower than the annual average GHG emissions (Table E.2.4).

Black carbon would be emitted by sources and activities under Alternative D. Although black carbon is not explicitly quantified, it is a component of $PM_{2.5}$, and $PM_{2.5}$ emissions would be approximately 8% greater under Alternative D than Alternative B and emissions under Alternative D would be approximately 10% less than Alternative C (see Appendix E.3B, *Air Quality Technical Support Document*). Therefore, it is anticipated that black carbon emissions would be greater under Alternative D than Alternative B but reduced relative to Alternative C. Similarly, the effects of black carbon on the environment described in Section 3.2.1, *Affected Environment*, would increase under Alternative D relative to Alternative B. The annual average emissions shown in Table E.2.4 are for gross GHG emissions under Alternative D and do not account for the market substitution effects discussed in Section 3.2.2.2, *Alternative A: No Action*.

Table E.2.4. Annual Average Greenhouse Gas Emissions for Alternative D (thousand metric tons per year)*

GHG Emissions	CO_2	CH_4	N_2O	CO_2e (100-year AR4 GWP)	CO_2e (100-year AR6 GWP)	CO_2e (20-year AR6 GWP)
Direct	758	0.284	0.002	766	767	782
Indirect	8,372	0.594	0.086	8,413	8,413	8,445
Total[a]	**9,130**	**0.878**	**0.088**	**9,178**	**9,180**	**9,227**

Note: AR4 (fourth assessment report of the Intergovernmental Panel on Climate Change [IPCC]); AR6 (sixth assessment report of the IPCC); CH_4 (methane); CO_2 (carbon dioxide); CO_2e (carbon dioxide equivalent); GHG (greenhouse gas); GWP (global warming potential; N_2O (nitrous oxide).
[a] Total values may have small differences due to rounding.

3.1.5 Alternative E: Three-Pad Alternative*

As explained in detail in Chapter 2.0, *Alternatives*, Alternative E includes a WPF and four drill sites and would have a 30-year Project life.

Project facilities proposed for Alternative E are generally the same as Alternative B, with the exception that Alternative E would not include construction of drill site BT4, and drill site BT2 would be located farther north at the coordinates for BT2 in Alternative B. BT5 would be located east of the location proposed for other action alternatives, which would also reduce the length of the BT5 road and infield pipelines.

Alternative E GHG emissions estimated over the 30-year Project life are shown in Table 3.2.2 in Section 3.2.2.3, *Alternative B: Proponent's Project*. Project activities vary considerably over the life of the Project, and GHG emissions in any given year may be higher or lower than the annual average GHG emissions (Table E.2.5).

Black carbon would be emitted by sources and activities under Alternative E. Although black carbon is not explicitly quantified, it is a component of $PM_{2.5}$ and $PM_{2.5}$ emissions under Alternative E would be approximately comparable to (0.005% higher than) Alternative B while emissions under Alternative E would be approximately 16% less than Alternative C and approximately 6% less than Alternative D (see Appendix E.3B, *Air Quality Technical Support Document*). Therefore, it is anticipated that black carbon emissions under Alternative E would be comparable to Alternative B but less than Alternatives C and D. Similarly, the effects of black carbon on the environment under Alternative E, described in Section 3.2.1, *Affected Environment*, would be comparable to Alternative B. The annual average emissions shown in Table E.2.5 are for gross GHG emissions under Alternative E and do not account for the market substitution effects discussed in Section 3.2.2.2 (*Alternative A: No Action*).

Table E.2.5. Annual Average Greenhouse Gas Emissions for Alternative E (thousand metric tons per year)*

GHG Emissions	CO_2	CH_4	N_2O	CO_2e (100-year AR4 GWP)	CO_2e (100-year AR6 GWP)	CO_2e (20-year AR6 GWP)
Direct	780	0.282	0.002	788	789	804
Indirect	8,439	0.599	0.087	8,480	8,480	8,512
Total[a]	**9,219**	**0.881**	**0.089**	**9,268**	**9,270**	**9,316**

Note: AR4 (fourth assessment report of the Intergovernmental Panel on Climate Change [IPCC]); AR6 (sixth assessment report of the IPCC); CH_4 (methane); CO_2 (carbon dioxide); CO_2e (carbon dioxide equivalent); GHG (greenhouse gas); GWP (global warming potential; N_2O (nitrous oxide). Year 0 only included 1 month of construction activity and thus this year was excluded from the average annual emissions.
[a] Total values may have small differences due to rounding.

3.1.6 Module Delivery Options

Project lifetime and annual average direct GHG emissions from module delivery options alone are shown in Table E.2.6 for Option 1 (Atigaru Point Module Transfer Island), Option 2 (Point Lonely Module Transfer Island) and Option 3 (Colville River Crossing). Note that emissions from Option 3 vary based on the action alternative it is paired with for analysis. Table E.2.6 also provides the differences between Options 1 and 2 from Option 3. Annual average GHG emissions for module delivery options are calculated by dividing the Project lifetime GHG emissions by the expected duration of module delivery emissions, which is 6 years. Direct GHG emissions from Option 2 are more than twice the emissions from Option 1 because vehicles would travel a longer distance to reach Point Lonely. Direct GHG emissions from Option 3 are considerably less than Options 1 and 2 (under all action alternatives) because Option 3 would make use of the existing Oliktok Dock and construct the least amount of new infrastructure to support sealift module delivery. Total GHG emissions for the Project would be the sum of the selected alternative and the selected module delivery option.

Black carbon would be emitted by sources and activities as part of all module delivery options. Although black carbon is not explicitly quantified, it is a component of $PM_{2.5}$, and $PM_{2.5}$ emissions would be greatest under Option 2 and lowest under Option 3 (under all action alternatives). Therefore, it is anticipated that black carbon emissions would also be greatest under Option 2 and lowest under Option 3 (under all action alternatives), and the effects of black carbon on the environment described in Section 3.1.2.3 of this appendix, would be greatest under Option 2 and lowest under Option 3 (under all action alternatives).

Table E.2.6. Direct Greenhouse Gas Emissions Associated with Module Delivery Options (thousand metric tons)

GHG Emissions	Total CO_2e (100-year AR4 GWP)	Annual Average CO_2e (100-year AR4 GWP)	Total CO_2e (100-year AR6 GWP)	Annual Average CO_2e (100-year AR6 GWP)	Total CO_2e (20-year AR6 GWP)	Annual Average CO_2e (20-year AR6 GWP)
Option 1: Atigaru Point MTI	140	23	140	23	141	23
Option 2: Point Lonely MTI	341	57	341	57	342	57
Option 3: Colville River Crossing – Alternatives B, C, and E	40	7	40	7	40	7
Option 3: Colville River Crossing – Alternative D	43	7	43	7	43	7
Option 1 minus Option 3 (Alternatives B, C, and E)	100	17	100	17	101	17
Option 1 minus Option 3 (Alternative D)	97	16	97	16	97	16
Option 2 minus Option 3 (Alternatives B, C, and E)	301	50	301	50	302	50
Option 2 minus Option 3 (Alternative D)	298	50	298	50	298	50

Note: AR4 (fourth assessment report of the Intergovernmental Panel on Climate Change [IPCC]); AR6 (sixth assessment report of the IPCC); CO_2e (carbon dioxide equivalent); GHG (greenhouse gas); GWP (global warming potential); MTI (module transfer island).

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Willow Master Development Plan

Appendix E.2B

Bureau of Land Management Energy Substitution Model (EnergySub)

June 2022

Prepared by Bureau of Land Management

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List of Acronyms

AEO	Annual Energy Outlook
BLM	Bureau of Land Management
BOEM	Bureau of Ocean Energy Management
DOE	Department of Energy
EIA	Energy Information Administration
EMF	Energy Modeling Forum
EnergySub	Energy Substitution Model
IEA	International Energy Agency
LNG	Liquefied Natural Gas
MarketSim	Market Simulation Model
NETL	National Energy Technology Laboratory
NEMS	National Energy Modeling System
OCS	Outer Continental Shelf
UNLV	University of Nevada, Las Vegas

1.0 BACKGROUND

The BLM developed the Energy Substitution Model (EnergySub) to more effectively assess the energy market impacts associated with onshore oil, gas, and coal related management actions, including potential substitution between various energy sources and changes in energy prices and consumption.
The EnergySub model is based on the Bureau of Ocean Energy Management's (BOEM) Market Simulation (MarketSim) Model, which is used to assess potential energy market impacts of leasing and subsequent development of offshore oil and gas resources along the Outer Continental Shelf (OCS).[1] Since MarketSim was not configured to adequately model onshore mineral development scenarios, the BLM made several modifications to BOEM's MarketSim model while retaining its overall structure and functionality. The purpose of this document is to provide a detailed description of the methods and data which underpins the EnergySub model.

2.0 MODEL DESCRIPTION

EnergySub is an excel-based partial equilibrium model which uses a series of supply and demand equations to create a mathematical representation of U.S. energy markets. The model simulates end-use domestic consumption of oil, natural gas, coal and electricity in four sectors (residential, commercial, industrial and transportation); production of primary energy fuel sources; and the transformation of renewable and nonrenewable resources into electricity. The model predominately represents U.S. energy markets but captures foreign energy market interactions through its mathematical representation of a worldwide oil market with foreign sources of supply and demand and its inclusion of domestic imports and exports.

Key inputs to EngerySub include an energy forecast produced by the Energy Information Administration's (EIA) National Energy Modeling System (NEMS) and an onshore oil, gas, or coal production scenario developed by a BLM specialist as part of a Reasonable Foreseeable Development Scenario. EnergySub uses the energy market forecasts from NEMS to establish baseline market equilibriums which simulation model runs can calibrate to. The configuration of EnergySub used to analyze potential market impacts associated with the Willow Project calibrates to the reference case in the Energy Information Administration's (EIA) *Annual Energy Outlook (AEO) 2021* – the most recent AEO available at the time of this modeling.

The user-specified BLM production scenario is then added to or subtracted from the supply side of the market equilibration (depending on whether the scenario is incremental to baseline projections produced by NEMS or a component of them). The model then adjusts prices until all markets converge on a new equilibrium.

3.0 BASELINE SUPPLY AND DEMAND PROJECTIONS

The baseline supply and demand projections in EnergySub are produced by EIA's NEMS model.[2] Unlike MarketSim which calibrates to a special NEMS runs which limits future offshore production to existing OCS leases as of 2020, EnergySub is currently configured to calibrate to the AEO 2021 reference case which includes potential mineral development from all proven and unproven onshore and offshore reserves. In addition to publicly available AEO data accessed from EIA's website, the baseline equilibrium was established using additional more detailed coal datasets obtained directly from EIA analysts.

4.0 MODEL FRAMEWORK

EnergySub's represents the observed conditions prevailing at any moment in the market as observable short-run conditions that are the result of a market equilibrating process and the partial adjustment toward long-run demand and supply conditions. These long-run conditions are not directly observable but can be

[1] See Industrial Economics, Inc. (2017).
[2] EnergySub extrapolates the baseline data after 2050 provided in the NEMS projection forecasts to cover the modeled time period if it extends beyond 2050.

inferred from observed market conditions and the underlying parameters of the model. The result is a model that is characterized by partial adjustment toward a long-run equilibrium in each time period.

To create such a model, it is necessary to provide a set of assumed long-run elasticities. These were developed by reviewing the appropriate economic research, using technology assessments and by making comparisons across existing runs of NEMS to infer elasticities (see below). The supply and demand equations in the sections that follow illustrate how EnergySub applies these supply and demand elasticities.

5.0 OIL MARKET

EnergySub represents a world oil market with sector detail for the domestic market, a single supply equation for foreign production, and a small number of demand equations for foreign consumption. It models foreign oil markets as a simplified single market using a limited number of supply and demand equations in order for EnergySub to equilibrate. The introduction of multiple international markets is beyond the capabilities of this partial equilibrium model.

These equations estimate supply and demand for oil by the residential, commercial, industrial and transportation sectors. Oil use for electricity generation is represented elsewhere in the electricity section of the model. The equations that follow below illustrate how EnergySub estimates U.S. oil demand, foreign oil demand, U.S. oil supply, foreign oil supply, oil imports delivered to the U.S. by tanker, U.S. crude oil exports, and U.S. exports of refined petroleum products.

5.1 U.S. Oil Demand

$$Q_{Doi,t} = A_{oi,t} \cdot P_{o,t}^{\eta_{oi}} \cdot \prod_j P_{j,t}^{\eta_{oji}}$$

For each U.S. end-use sector *i*; and *j* = *g* (gas), *c* (coal), and *e* (electricity) where:

$Q_{Doi,t}$ represents the quantity of oil demanded in sector *i* at time *t*,
$A_{oi,t}$ is a constant calibrated to the AEO market projections,
$P_{o,t}$ is the price of oil at time *t*,
η_{oi} is the long-run price elasticity of oil demand in sector *i*,
$P_{j,t}$ is the price of energy source *j* at time *t*, and
η_{oji} is the long-run elasticity of demand for oil with respect to the price of energy source j in sector *i*

The four U.S. end-use sectors *i* are residential, commercial, industrial, and transportation. To estimate cross-price effects in the industrial and other sectors, EnergySub uses a single weighted average minemouth price of coal (instead of the separate regional coal prices described in Section 7 below).[3]

5.2 Foreign Oil Demand

$$Q_{Dox,t} = A_{ox,t} \cdot P_{o,t}^{\eta_{ox}}$$

Where:

$Q_{Dox,t}$ represents the quantity of foreign oil demand at time *t*,
$A_{ox,t}$ is a constant calibrated to the AEO market projections,

$P_{o,t}$ is the price of oil at time *t*, and
η_{ox} is the long-run price elasticity of foreign oil demand

[3] The model uses the weighted average price of coal, using industrial sector consumption as weights.

Foreign oil demand is strictly a function of the oil price, and no other prices, domestic or foreign. EnergySub specifies three categories of foreign oil demand: (1) foreign demand for U.S. crude oil, (2) foreign demand for U.S. refined products, and (3) foreign demand for foreign oil. The model assumes that these three categories are mutually exclusive.

5.3 U.S. Oil Supply

$$Q_{Sou,t} = B_{ou,t} \cdot P_{o,t}^{\eta_{ou}}$$

For each domestic source *u* = lower 48 onshore non-tight oil, lower 48 onshore tight oil, lower 48 offshore, Alaska onshore, Alaska offshore, biofuels, natural gas plant liquids, other, or rest of world; where:

> $Q_{Sou,t}$ represents the quantity of oil supplied from U.S. source *u* at time *t*,
> $B_{ou,t}$ is a constant calibrated to the AEO market projections,
>
> $P_{o,t}$ is the price of oil at time *t*, and
> η_{ou} is the long-run elasticity of oil supply from source *u*

Consistent with the EIA classification, the term "oil" includes all liquid fuels that are close substitutes for petroleum products (e.g., biofuels).

5.4 Foreign Oil Supply

$$Q_{Soy,t} = B_{oy,t} \cdot P_{o,t}^{\eta_{oy}}$$

Where:

> $Q_{Soy,t}$ represents the quantity of foreign oil supplied at time *t*,
> $B_{oy,t}$ is a constant calibrated to the AEO market projections,
>
> $P_{o,t}$ is the price of oil at time *t*, and
> η_{oy} is the long-run elasticity of foreign oil supply

Foreign oil supply is estimated in EnergySub's equilibrating equations as a separate value that represents tanker imports and pipeline imports combined, consistent with *AEO* reporting.

5.5 Oil Imports Delivered via Pipeline

EnergySub uses the equations outlined above to find changes in oil market consumption, production, and prices under a given development scenario. The model's calculation for imports from Canada is similar to the foreign oil supply formula except with its own parameter and elasticity.

$$Q_{Soc,t} = B_{oc,t} \cdot P_{o,t}^{\eta_{oc}}$$

Where:

> $Q_{Soc,t}$ represents the quantity of Canadian pipeline oil imports supplied at time *t*,
> $B_{oc,t}$ is a constant calibrated to the AEO market projections,
>
> $P_{o,t}$ is the price of oil at time *t*, and
> η_{oc} is the long-run elasticity of Canadian pipeline oil imports

5.6 U.S. Crude Oil Exports

As described above, EnergySub models oil as a global market with supply (i.e., production) and demand (i.e., consumption) specified separately for the U.S. and the rest of the world. To facilitate the estimation of changes in oil exports, EnergySub's demand equations specify the three categories of foreign demand identified above: (1) foreign demand for U.S. crude oil, (2) foreign demand for U.S. refined petroleum products, and (3) foreign demand for foreign oil. The first of these items represents U.S. crude oil exports.

Therefore, to estimate the impact of a given BLM development scenario on U.S. crude oil exports, EnergySub calculates the difference between foreign demand for U.S. crude oil between the development scenario and the AEO baseline projections.

5.7 U.S. Exports of Refined Petroleum Products

EnergySub estimates U.S. exports of refined petroleum products based on the specification of foreign demand for refined petroleum products in the model's equilibrating equations.[4] For a given development scenario, the change in U.S. refined petroleum product exports is equal to the estimated change in foreign demand for U.S. refined petroleum products. This approach is similar to that outlined above for U.S. exports of crude oil, which EnergySub estimates based on the change in foreign demand for U.S. crude oil.

6.0 NATURAL GAS MARKET

EnergySub represents the U.S. natural gas market with exports and imports. This stands in contrast to the oil market, which EnergySub simulates as a global market due to the relatively low cost of transporting oil and the large volume of oil traded on international markets. Natural gas use for electricity generation is represented elsewhere in the electricity section of the model. The equations that follow specify EnergySub's estimation of U.S. natural gas demand, demand for U.S. natural gas exports, and U.S. natural gas supply.

6.1 U.S. Natural Gas Demand

$$Q_{Dgi,t} = A_{gi,t} \cdot P_{g,t}^{\eta_{gi}} \cdot \prod_j P_{j,t}^{\eta_{gji}}$$

For each U.S. end-use sector *i*; and *j* = *o* (oil), *c* (coal), and *e* (electricity) where:

$Q_{Dgi,t}$ represents the quantity of natural gas demanded in sector *i* at time *t*,

$A_{gi,t}$ is a constant calibrated to the AEO market projections,

$P_{g,t}$ is the price of natural gas at time *t*,

η_{gi} is the long-run price elasticity of natural gas demand in sector *i*,

$P_{j,t}$ is the price of energy source *j* at time *t*, and

η_{gji} is the long-run elasticity of demand for natural gas with respect to the price of energy source *j* in sector *i*

The U.S. natural gas demand sectors represented in EnergySub include the residential, commercial, industrial, and transportation sectors. As in the oil market, EnergySub uses a single weighted average minemouth price of coal instead of separate regional coal prices to estimate cross-price effects in the industrial sector.

[4] As noted above, this category of foreign demand represents one of three included in the model. The other two categories are foreign demand for U.S. crude oil and foreign demand for foreign oil.

6.2 Demand for U.S. Natural Gas Exports

$$Q_{Dgx,t} = A_{gx,t} \cdot P_{g,t}^{\eta_{gx}}$$

Where:

$Q_{Dgx,t}$ represents the quantity of U.S. natural gas exports at time *t*,

$A_{gx,t}$ is a constant calibrated to the AEO market projections,

$P_{g,t}$ is the price of natural gas at time *t*, and

η_{gx} is the long-run price elasticity of export demand for U.S. natural gas

U.S. natural gas exports are dependent only upon the domestic price of natural gas and no other prices, domestic or international.

6.3 U.S. Natural Gas Supply

$$Q_{Sgu,t} = B_{gu,t} \cdot P_{g,t}^{\eta_{gu}}$$

For each domestic or imported source *u* = lower 48 conventional, lower 48 unconventional, lower 48 offshore, Alaska onshore, Alaska offshore, other (e.g., synthetic natural gas and coke oven gas), pipeline imports, and LNG imports, where:

$Q_{Sgu,t}$ represents the quantity of natural gas supplied to the U.S. market from domestic or imported source *u* at time *t*,
$B_{gu,t}$ is a constant calibrated to the AEO market projections,

$P_{g,t}$ is the price of natural gas at time *t*, and

η_{gu} is the long-run elasticity of natural gas supply to the U.S. market from source *u*

7.0 COAL MARKET

EnergySub represents the U.S. coal market as 14 separate sub-markets defined according to the region where coal is produced, with exports. The model also includes imports as exogenous to the model. The 14 coal markets in EnergySub correspond to the coal supply regions represented in the Coal Market Module of EIA's NEMS, shown below in Figure 1. These supply regions are modeled separately to account for differences in the sulfur content, thermal value, rank, and production method of different coals. Because coal characteristics often differ by region (e.g, the Southern Powder River Basin region produces *only* low-sulfur, surface mined subbituminous coal), this approach (in most cases) implicitly captures the important differences between domestic sources of coal. With 14 distinct coal markets (one for each supply region), EnergySub estimates 14 equilibrium coal prices for each year.

Coal use for electricity generation is represented elsewhere in the electricity section of the model. The equations that follow present the model's estimation of U.S. coal demand, demand for U.S. coal exports, and U.S. coal supply.

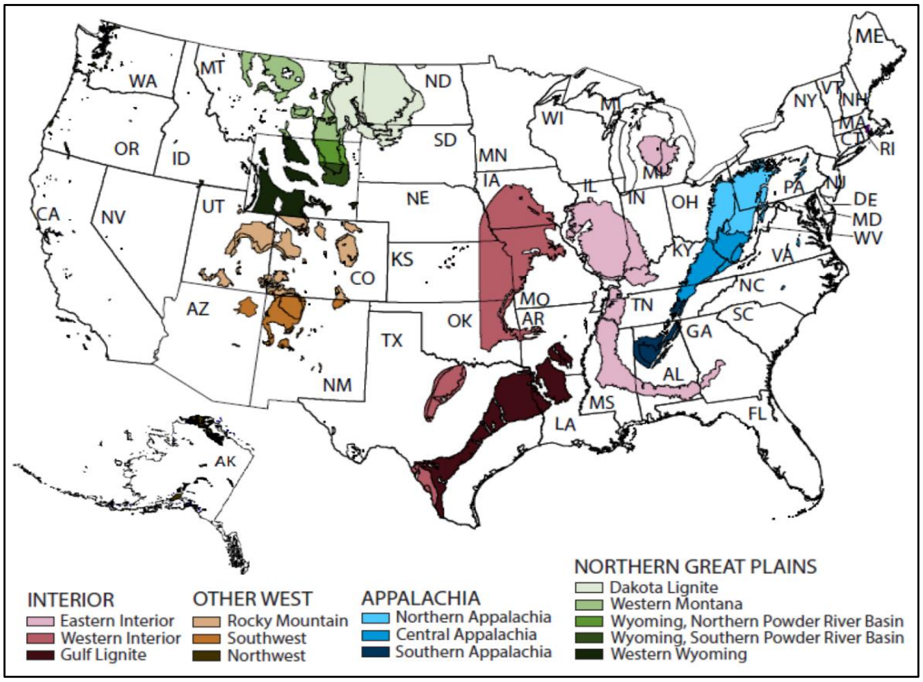

Figure 1. EnergySub Coal Supply Regions

7.1 U.S. Coal Demand

$$Q_{Dcir,t} = A_{cir,t} \cdot P_{cr,t}^{\eta_{ci}} \cdot \prod_{j} P_{j,t}^{\eta_{cji}}$$

For each U.S. end-use sector *i*, for each coal supply region *r*; and $j = g$ (gas), *o* (oil), and *e* (electricity) where:

$Q_{Dcir,t}$ represents the quantity of coal demanded in sector *i* from coal supply region *r* at time *t*,

$A_{cir,t}$ is a constant calibrated to the AEO market projections,

$P_{cr,t}$ is the minemouth price of coal from supply region *r* at time *t*,

η_{ci} is the long-run price elasticity of coal demand in sector *i*,

$P_{j,t}$ is the price of energy source *j* at time *t*, and

η_{cji} is the long-run elasticity of demand for coal with respect to the price of energy source *j* in sector *I*

Other than the electricity sector, whose coal demand is modeled separately, EnergySub's domestic demand sectors for coal include industrial and other.

7.2 Demand for U.S. Coal Exports

$$Q_{Dcrx,t} = A_{crx,t} \cdot P_{cr}^{\eta_{cx}}$$

For each coal supply region, *r*, where:

$Q_{Dcrx,t}$ represents the quantity of U.S. coal exports from coal supply region *r* at time *t*,

$A_{crx,t}$ is a constant calibrated to the AEO market projections,

$P_{cr,t}$ is the minemouth price of coal from supply region *r* at time *t*, and

η_{cx} is the long-run price elasticity of export demand for U.S. coal

Coal exports in EnergySub are only dependent upon the domestic minemouth price of coal from each coal supply region. No other energy prices, domestic or international, affect exports of coal.

7.3 U.S. Coal Supply

$$Q_{Scr,t} = B_{cr,t} \cdot \ {P_{cr,t}}^{\eta_{cr}}$$

For each coal supply region, *r*, where:

$Q_{Scr,t}$ represents the quantity of coal supplied to the U.S. market from coal supply region *r* at time *t*,

$B_{cr,t}$ is a constant calibrated to the AEO market projections,

$P_{cr,t}$ is the minemouth price of coal for coal supply region *r* at time *t*, and

η_{cr} is the long-run elasticity of coal supply to the U.S. market from coal supply region *r*

As noted above, EnergySub treats coal imports as exogenous. For each BLM development scenario, imports are assumed to be the same as under the baseline scenario. The model makes this simplifying assumption because imports are projected to make up a *de minimis* fraction (less than 1 percent) of U.S. coal demand according to the AEO and imports do not align with the 14 coal markets specified in the model.

8.0 ELECTRICITY MARKET

Equations in EnergySub represents the U.S. electricity market and models U.S. exports and imports of electricity as net imports. The electricity sector in EnergySub also provides additional demand for oil, natural gas, and coal. The equations below present EnergySub’s approach for estimating U.S. electricity demand, U.S. electricity supply, and demand for fossil fuels for electricity production.

To depict the use of coal for electricity generation with greater spatial detail, EnergySub divides the electricity supply market into nine regions (the U.S. Census Divisions), shown in Figure 2 below. Each electricity supply region is also modeled to receive coal from the 14 separate coal supply regions described above, resulting in a total of 126 total coal supply-electricity supply region combinations.

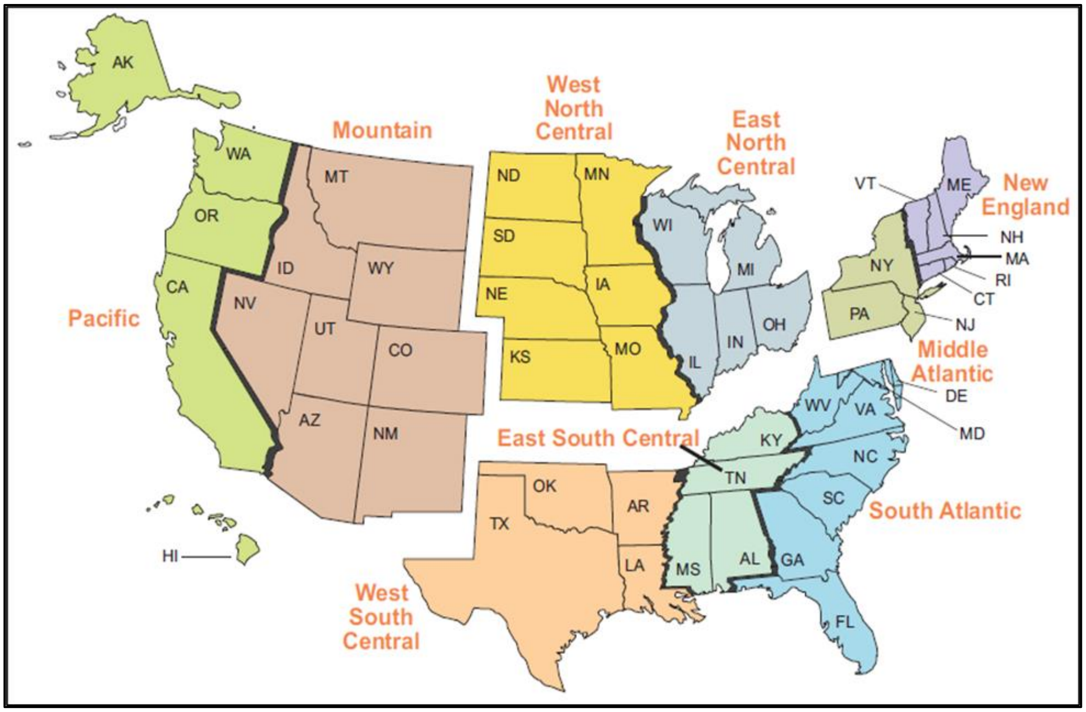

Figure 2. EnergySub Electricity Supply Regions

8.1 U.S. Electricity Demand

$$Q_{Dei,t} = A_{ei,t} \cdot P_{e,t}^{\eta_{ei}} \cdot \prod_j P_{j,t}^{\eta_{eji}} + (1 - \gamma_{Dei}) Q_{Dei,t-1}$$

For each U.S. end-use sector i; and $j = g$ (gas), c (coal), and o (oil), where:

$Q_{Dei,t}$ represents the quantity of electricity demanded in sector i at time t,

$A_{ei,t}$ is a constant calibrated to the AEO market projections,

$P_{e,t}$ is the price of electricity at time t,

η_{ei} is the long-run price elasticity of electricity demand in sector i,

$P_{j,t}$ is the price of energy source j at time t,

η_{eji} is the long-run elasticity of demand for electricity with respect to the price of energy source j in sector i, and

γ_{Dei} is the rate at which demand for electricity in sector i adjusts.

The U.S. demand sectors for electricity in EnergySub include (1) residential, (2) commercial, (3) industrial, (4) transport, and (5) other. As in the oil and gas markets, EnergySub uses a single weighted average minemouth price of coal instead of separate regional coal prices to estimate cross-price effects in the industrial and other sectors.

8.2 U.S. Electricity Supply

EnergySub uses separate approaches for the estimation of electricity derived from gas and oil, coal, and electricity derived from other sources. While the quantity of electricity generated from gas, oil, and coal is dependent on fossil fuel prices, changes in these prices do not directly factor into the generation of electricity from non-fossil energy sources.[5] In addition, EnergySub accounts for the cost of transporting coal from each coal supply region to each electricity supply region by adding the coal transportation cost to the minemouth price of coal, which yields an estimate of the delivered price of coal. To account for this difference in the economics of electricity generation for different types of power producers, EnergySub specifies electricity supply separately for three classes of generation as follows:

$$Q_{Sej,t} = C_{j,t} \cdot (P_{e,t}/P_{j,t})^{\eta_{ej}} + (1 - \gamma_{Sej})Q_{Sej,t-1}$$

For *j* = oil and natural gas, where:

> $Q_{Sej,t}$ represents the quantity of electricity supplied from fossil fuel energy source *j* at time *t*,
>
> $C_{j,tt}$ is a constant calibrated to the AEO market projections,
>
> $P_{e,t}$ is the price of electricity at time *t*,
>
> $P_{j,t}$ is the price of fossil fuel energy source *j* at time *t*,
>
> η_{ej} is the long-run elasticity of electricity supply from fuel *j*, and
>
> γ_{Sej} is the rate at which electric power from fossil energy *j* adjusts.

$$Q_{Secrz,t} = C_{crz,t} \cdot [P_{e,t}/(P_{cr,t}+T_{crz})]^{\eta_{ec}} + (1 - \gamma_{Sec})Q_{Secrz,t-1}$$

For *c* = coal, for each coal supply region *r* and each electricity supply region *z*, where:

> $Q_{Secrz,t}$ represents the quantity of electricity supplied from coal supply region *r* to electricity supply region *z* at time *t*,
>
> $C_{crz,t}$ is a constant calibrated to the AEO market projections,
>
> $P_{e,t}$ is the price of electricity at time *t*,
>
> $P_{cr,t}$ is the minemouth price of coal from supply region *r* at time *t*,
>
> T_{crz} represents the transportation cost of coal from coal supply region *r* to electricity supply region *z*,
>
> η_{ec} is the long-run elasticity of electricity supply from coal, and
>
> γ_{Sec} is the rate at which electric power from coal adjusts.

As noted above, EnergySub accounts for the cost of transporting coal between each of the 14 coal supply regions and each of the nine electricity supply regions. The model therefore includes estimates of the per-ton cost of transporting coal (T_{crz}) for all 126 combinations of coal supply and electricity supply regions.

$$Q_{Sel,t} = C_{l,t} \cdot {P_{e,t}}^{\eta_{el}} + (1 - \gamma_{Sel})Q_{Sel,t-1}$$

For *l* = nuclear, hydro, wind, solar, other electric, net imports, where:

> $Q_{Sel,t}$ represents the quantity of electricity supplied from source *l* at time *t*,
>
> $C_{l,t}$ is a constant calibrated to the AEO market projections,
>
> $P_{e,t}$ is the price of electricity at time *t*,

[5] All else equal, renewable electricity generation in EnergySub will increase as fossil fuel prices rise, but the effect is indirect. For a given level of electricity demand, fossil fuel-based generators will supply less electricity as fossil fuel prices rise, which will shift generation toward renewables.

η_{el} is the long-run elasticity of electricity supply from source *l*, and

γ_{Sel} is the rate at which electric power from source *l* adjusts.

8.3 Demand for Fossil Fuel Energy to Produce Electricity

8.3.1 Oil and Natural Gas

$$Q_{Dje,t} = K_{j,t} \cdot Q_{Sej,t}$$

For *j* = oil and natural gas, where:

$Q_{Dje,t}$ represents the quantity of energy source *j* used to produce electricity at time *t*,

$K_{j,t}$ is a constant calibrated to the AEO market projections, and

$Q_{Sel,t}$ represents the quantity of electricity supplied from source *l* at time *t*

8.3.2 Coal

$$\sum_{z} Q_{Dcerz,t} = K_{cr,t} \cdot \sum_{z} Q_{Secrz,t}$$

For c= coal, where:

$\sum_z Q_{Dcerz,t}$ is the sum of demand for coal from coal supply region *r* for electricity production across all *z* electricity production regions at time *t*,

$K_{cr,t}$ is a constant calibrated to the AEO market projections, and

$\sum_z Q_{Secrz,t}$ is the sum of coal supplied for electricity production from coal supply region *r* across all *z* electricity production regions at time *t*.

9.0 MODEL CALIBRATION

For a given set of elasticities, market quantities, and prices in the baseline projection, EnergySub uses the series of supply and demand equations outlined above to calculate the parameters *A*, *B*, *C*, and *K* in these equations. These parameters, having been calculated on the baseline projection equilibrium state, calibrate the model formulas directly to the market conditions observed in the baseline projection data. EnergySub then uses these parameters as constants in the simulation supply and demand formulas that equilibrate all fuel markets under a given BLM development scenario.

10.0 EQUILIBRIUM

The equilibration calculation of EnergySub selects $P_{o,t}$, $P_{g,t}$, $P_{cr,t}$, and $P_{e,t}$, for each period *t* such that the quantity of oil, natural gas, coal (by coal supply region), and electricity supplied equals the quantity demanded in each period *t*. For coal, not only must the national market be in equilibrium but the quantity of coal supplied by each coal supply region *r* at period *t* must equal the quantity of coal demanded from coal supply region *r* at each period *t*. The model specifies these equilibrium conditions as follows:

World Oil Market

$$Q_{Doe,t} + Q_{Dox,t} + \sum_i Q_{Doi,t} = Q_{Soy,t} + \sum_u Q_{Sou,t}$$

Where:

$Q_{Doe,t}$ is the U.S. demand for oil to produce electricity at time *t*,

$Q_{Dox,t}$ is foreign demand for oil at time *t*,

$\sum_i Q_{Doi,t}$ is the U.S. demand for oil across all other end use sectors *i* at time *t*,

$Q_{Soy,t}$ is the oil supply from foreign sources at time *t*, and

$\sum_u Q_{Sou,t}$ is the domestic oil supply from all domestic sources at time *t*.

U.S. Natural Gas Market (with exports and imports)

$$Q_{Dge,t} + \sum_i Q_{Dgi,t} + Q_{Dgx,t} = \sum_u Q_{Sgu,t}$$

Where:

$Q_{Dge,t}$ is the U.S. demand for natural gas to produce electricity at time *t*,

$\sum_i Q_{Dgi,t}$ is U.S. demand for natural gas across all end use sectors *i* at time *t*,

$Q_{Dgx,t}$ is the demand for U.S. natural gas exports at time *t*, and

$\sum_u Q_{Sgu,t}$ is the supply of natural gas from all *u* domestic sources at time *t*.

U.S. Coal Markets, by Supply Region

$$\sum_z Q_{Dcerz,t} + \sum_i Q_{Dcir,t} + Q_{Dcxr,t} = Q_{Scr,t}$$

Where:

$\sum_z Q_{Dcerz,t}$ is the quantity of coal demanded from coal supply region *r* across all electricity production regions *z* at time *t*,

$\sum_i Q_{Dcir,t}$ is the quantity of coal demanded from each coal supply region *r* across all end-use sectors *i* at time *t*,

$Q_{Dcxr,t}$ is the quantity of coal demanded for exports from each coal supply region *r* at time *t*, and

$Q_{Scr,t}$ is the quantity of coal supplied by each coal supply region *r* at time *t*.

U.S. Electricity Market (with net imports)

$$\sum_i Q_{Dei,t} = \sum_j Q_{Sej,t} + \sum_z \sum_r Q_{Secrz,t} + \sum_l Q_{Sel,t}$$

Where:

$\sum_i Q_{Dei,t}$ is the demand for electricity across all end-use sectors *i* at time *t*,

$\sum_j Q_{Sej,t}$ is the supply of fossil fuel electricity (excluding coal), for all other *j* fossil fuel sources at time *t*,

$\sum_r \sum_z Q_{Secrz,t}$ is the supply of coal-fired electricity across all $r \times z$ electricity production regions at time *t*, and

$\sum_l Q_{Sel,t}$ is the supply of renewable electricity across all *l* renewable sources at time *t*.

To initiate the equilibration process for a given development scenario, EnergySub first adds (or subtracts, depending on whether the user-specified scenario is incremental to the baseline or a component of the baseline) the change in production on BLM-managed lands to the oil, gas, or coal supply terms in the above equilibrating equations. Using Excel's solver function, EnergySub then uses reduced gradient methods to iterate through several combinations of the three national fuel prices and 14 regional coal prices until the model can bring all 17 fuel markets' supply and demand into equilibrium. During this process, all simulated supply and demand values are calculated using the same elasticity and parameter values used to represent the baseline. When zero disparity between supply and demand across all 17 fuel markets is achieved, EnergySub saves the market-clearing prices and proceeds to the next year to perform the same equilibration.

11.0 ELASTICITIES

All elasticities in EnergySub have default values that are obtained from the literature, derived from NEMS supply curves, inferred from NEMS output, or obtained from BOEM's MarketSim Model.[6] The sections below document the derivation of elasticities used in the EnergySub model.

To the extent possible, EnergySub relies upon demand and supply elasticities from peer-reviewed studies in the empirical economics literature. Using peer-reviewed values is central to ensuring that EnergySub's simulation of market responses to changes in energy prices reflect the best information available. As suggested above, in the few cases where peer-reviewed values are not available, elasticity estimates were derived from NEMS outputs or from expert input, consistent with BOEM's MarketSim model.

11.1 Demand Elasticities

To capture the complex interactions between different segments of U.S. energy markets, EnergySub utilizes own-price and cross-price demand elasticities for each energy source included in the model. For each major energy consuming sector (e.g., the residential sector), BLM prioritized using own-price and cross-price demand elasticities from the same empirical study to ensure that each sector's simulated responses were based on price sensitivities derived using the same methods, assumptions, and data. The selection of demand elasticities also considered the quality of the estimates produced by each study. BLM's assessment of quality for individual elasticity estimates considered, among other factors, (1) whether they are statistically significant, (2) methods by which they were derived, and (3) the richness of the data supporting each estimate (e.g., whether they are based on a multi-year panel or reflect energy market data for a single year).

Based on these criteria, EnergySub relies heavily on own-price and cross-price demand elasticities from Serletis *et al.* (2010) for the residential and commercial sectors and Jones (2014) for the industrial sector.

[6] Many of the elasticities used from the BOEM MarketSim model were provided by energy economist Dr. Stephen Brown (2011) of the University of Nevada, Las Vegas (UNLV). See Industrial Economics, Inc. (2017).

Serletis *et al.* (2010) investigate inter-fuel substitution possibilities for energy demand across four fuels (i.e., oil, gas, electricity, and coal) using EIA data for the 1960–2007 period. Based on these data, Serletis *et al.* estimated own-price and cross-price elasticities for the commercial, residential, and industrial sectors, using a flexible translog functional form. Across most sectors, Serletis *et al*. produced statistically significant elasticity values of the expected sign.

Jones (2014) focuses on inter-fuel substitution in the industrial sector, using EIA data for the 1960–2011 period for the same fuels included in Serletis *et al.* (2010) plus biomass. Jones specifies a dynamic linear logit model to estimate own-price and cross-price elasticities, and within this framework, estimates both short-run and long-run elasticities. In addition, to assess the role of biomass in industrial sector inter-fuel substitution, Jones develops two sets of models, one including the four energy sources traditionally included in industrial sector energy models (i.e., natural gas, oil, coal, and electricity) and another that includes these energy sources plus biomass. Jones finds that the addition of biomass reduces both the own-price and cross-price elasticities of demand for the four traditionally modeled fuels. The effect is most significant for those values associated with electricity. In both models, the four traditional energy sources are found to be substitutes with each other with the exception of electricity and oil; the cross-price elasticities for these energy sources are not statistically significant.

Table 1 presents the default own-price and cross-price demand elasticities used in EnergySub for the residential, commercial, industrial, and transport sectors. The table also shows the default elasticity values for miscellaneous demand sectors included in EnergySub (e.g., natural gas demand in U.S. export markets). As indicated in the table, EnergySub uses results from Serletis *et al*. (2010) as defaults for the commercial and residential sectors, except for the elasticity of demand for natural gas with respect to the price of oil and the elasticity of demand for oil with respect to the price of natural gas. The estimates for these cross-price elasticities in Serletis *et al.* were of the unexpected sign (negative) and were not statistically significant. Therefore, in lieu of Serletis *et al.*, EnergySub uses results from Newell and Pizer (2008) for these values, for both the commercial and residential sectors. Newell and Pizer (2008) estimate these cross-price relationships for the commercial sector only. While EnergySub would ideally use default values specific to the residential sector, alternative values for these cross-price elasticities were not readily available for the residential sector. Given the similarities between the commercial and residential sectors, EnergySub uses these two cross-price demand elasticities from Newell and Pizer (2008) as a reasonable approximation of the corresponding residential sector values.

Table 1. EnergySub Default Demand Elasticities

	Elasticity With Respect to Change in Oil Price	Elasticity With Respect to Change in Gas Price	Elasticity With Respect to Change in Electricity Price	Elasticity With Respect to Change in Coal Price
***Commercial Sector*[1]**				
Oil	-0.939	0.2	1.08	-
Natural Gas	0.07	-0.296	0.419	-
Electric	0.092	0.041	-0.134	-
Coal	-	-	-	-
***Residential Sector*[1]**				
Oil	-1.002	0.2	1.151	-
Natural Gas	0.07	-0.313	0.507	-
Electric	0.214	0.072	-0.287	-
Coal	-	-	-	-
***Industrial Sector*[2]**				
Oil	-0.264	0.249	0.01	0.090
Natural Gas	0.172	-0.468	0.178	0.050
Electric	0.009	0.118	-0.125	0.061
Coal	0.440	0.351	0.652	-1.468
Miscellaneous Demand Categories				
Oil – Transport Sector[3]	-0.300	-	-	-
Oil – Rest of World Demand for US Crude[4]	-0.15	-	-	-
Oil – Rest of World Demand for US Refined Products[4]	-0.15			
Oil – Rest of World Demand for non-US oil[4]	-0.15			
Natural Gas – Transport[5]	-	-1.00	-	-
Natural Gas – US Export Markets[6]	-	-0.89	-	-
Electricity – Transport[5]	-	-	-1.00	-
Electricity – "Other"[7]	-	-	-0.18	-
Coal – Other[8]	-	-	-	-1.468
Coal – US Export Markets[5]	-	-	-	-1.00

Notes:

1. Commercial and residential sector values are from Serletis *et al.* (2010), except for the cross-price elasticity for gas in response to oil prices and the cross-price elasticity of oil in response to gas prices. For these latter two values, EnergySub uses demand elasticities from Newell and Pizer (2008). Also, Deryugina et al. (2020) estimate a range of residential elasticity values for electricity consistent with the value in Serletis et al. (2010).
2. For the industrial sector, EnergySub uses demand elasticities from Jones (2014), except for the cross-price elasticity of electricity in response to oil prices and the cross-price elasticity of oil in response to electricity prices. For these values, EnergySub uses demand elasticities from Serletis *et al*. (2010).
3. Dahl (2012)
4. Huntington *et al*. (2019)
5. Assumed to be -1.00.
6. Dahl (2010)
7. Assumed to be average of own-price elasticity values for industrial, commercial, and residential sectors
8. Industrial sector value from Jones (2014).

For the industrial sector, EnergySub relies almost exclusively on demand elasticities from Jones (2014) as defaults. Although Serletis *et al.* (2010) estimate elasticity values for the industrial sector, the values in Jones (2014) are based on fuel consumption data that exclude fuel use for purposes other than energy (e.g., petroleum products used as lubricants). As described above, Jones (2014) estimates long-run demand elasticities with two specifications, one including biomass as a substitute and another excluding biomass. Based on the statistical significance of the elasticities with biomass included, EnergySub uses the elasticities from the specification that includes biomass. The two exceptions to this are the cross-price elasticity of demand for oil with respect to the price of electricity and the cross-price elasticity of electricity in response to oil prices, as Jones' estimates for these values are not statistically significant. For these values, EnergySub uses estimates from Serletis *et al.* (2010).

Table 1 also shows EnergySub's default own-price demand elasticities for the transport sector and various miscellaneous demand categories. For these categories, EnergySub relies upon elasticity values from multiple sources. For oil demand in the transportation sector, EnergySub uses a U.S.-specific elasticity value obtained from Dahl's (2012) review of price elasticities estimated for more than 100 countries. This value represents the average of the elasticity values identified in the empirical literature. For non-U.S. oil demand, EnergySub applies the value reported in a Huntington *et al.* (2019) review of crude oil demand elasticities in major industrializing economies. For U.S. natural gas exports, EnergySub uses estimates from Dahl's prior (2010) review of the elasticity literature as defaults.

Two categories for which appropriate demand elasticity values were not identified in the literature are miscellaneous coal demand and demand for U.S. coal exports. EnergySub uses the same industrial sector value obtained from Jones (2014) for the former and assumes a value of -1.00 for the latter.

11.2 Supply Elasticities

EnergySub includes default supply elasticities, summarized in Table 2, for every production category modeled for a given fuel (e.g., onshore tight oil production in the lower 48 states). Consistent with the demand elasticities summarized above, several of EnergySub's supply elasticities were obtained from the economic literature, with data sources varying by fuel type.

For tight oil and other lower 48 onshore oil, EnergySub uses elasticities from a recent study by Newell and Prest (2019). The paper specifically compares the price responses of conventional and unconventional (tight) oil drilling and production. Using micro-data for more than 150,000 oil wells in Texas, North Dakota, California, Oklahoma, and Colorado, Newell and Prest (2019) estimate the elasticity of well drilling and the elasticity of oil production, separately for conventional and unconventional wells. To estimate drilling elasticities, they use multiple model specifications, estimating changes in drilling activity as a function of price in some cases and as a function of revenue in other cases. The production elasticities estimated by Newell and Prest (2019), however, all represent the change in production as a function of the change in revenue, rather than price. To align the supply elasticities in EnergySub with the specification of supply, EnergySub uses the elasticity of well drilling with respect to the oil price from Newell and Prest (2019), which they estimate separately for both conventional and unconventional wells.

Luchansky and Monks (2009) serves as the source for EnergySub's default supply elasticity for domestic biodiesel. This paper uses monthly data for 1997 through 2006 to estimate the market supply and demand for ethanol at the national level. Applying these data to four specifications of supply, Luchansky and Monks (2009) estimated supply elasticities ranging from 0.224 to 0.258. EnergySub uses the midpoint of this range (0.24) as the default supply elasticity for biodiesel.

For a number of oil supply elasticities, EnergySub relies on values included in BOEM's MarketSim model based on expert input provided to BOEM by three energy economists: Dr. Charles Mason of the University of Wyoming, Dr. Seth Blumsack of Penn State University, and Dr. Gavin Roberts of Weber State University. EnergySub relies on input provided to BOEM by these experts for the oil supply elasticities related to lower 48 offshore, rest-of-world oil production, Canadian pipeline imports, natural gas plant liquids, and other oil production. For oil production in Alaska, EnergySub uses supply elasticities derived from specialized simulations of NEMS, as described in detail below.

For gas production, EnergySub draws on a variety of sources for elasticities, depending on the production source. For domestic onshore conventional and unconventional shale gas production in the lower 48, EnergySub uses values from Newell, Prest & Vissing (2019), who use data from approximately

62,000 gas wells drilled in Texas between 2000-2015 to determine price-responsiveness across the supply process. The study assesses the decision to drill the well, well completion, and produce gas over time and, of these, finds drilling activity to be the most responsive to changes in price. EnergySub makes use of the gas price response values broken out for conventional and unconventional wells, though the study notes that these values may not differ significantly from each other statistically. For offshore production in the lower 48, EnergySub uses the same 0.19 elasticity as for offshore oil production in the lower 48, obtained through the expert input process described above. For onshore and offshore production in Alaska, EnergySub uses elasticity values derived from specialized simulations of NEMS, as detailed below.
For other gas production, EnergySub applies the supply elasticity reported in Brown (1998).

Table 2. EnergySub Default Supply Elasticities

Fuel	Source/ Supply Elasticity			
Oil	Lower 48 Onshore Non-Tight[1]	0.93	Other[2]	0.67
	Lower 48 Onshore Tight[1]	0.73	Biodiesel[4]	0.24
	Lower 48 Offshore[2]	0.19	Rest of World[2]	0.28
	Alaska Onshore[3]	0.42	Natural Gas Plant Liquids[2]	0.67
	Alaska Offshore[3]	0.58	Canadian Pipeline Imports[2]	0.38
Natural Gas	Lower 48 Conventional[5]	0.75	Alaska Offshore[3]	1.29
	Lower 48 Unconventional[5]	0.68	Other[7]	0.51
	Lower 48 Offshore[6]	0.19	Pipeline Imports[8]	0.52
	Alaska Onshore[3]	1.29	LNG Tanker Imports[9]	1.00
Electricity	Oil[10]	0.22	Hydro[3]	0.05
	Natural Gas[3]	1.50	Wind Onshore[3]	0.65
	Coal[10]	0.27	Wind Offshore[3]	0.01
	Nuclear[3]	0.53	Solar[3]	2.03
	Other Electric[3]	0.68	Imports[3]	0.36
Coal	Northern Appalachia[11]	2.66	WY PRB – North[10]	5.50
	Central Appalachia[11]	4.62	WY PRB – South[11]	3.15
	Southern Appalachia[11]	1.50	Western Wyoming[11]	0.73
	East Interior[11]	7.40	Rocky Mountain[11]	2.43
	West Interior[11]	0.47	Arizona/New Mexico[11]	3.78
	Gulf Lignite[11]	1.72	Alaska/Washington[11]	0.60
	Dakota Lignite[11]	4.46	Imports[3]	1.00
	Western Montana[11]	5.46		

Notes:

1. Newell and Prest (2019).
2. Expert input from C. Mason, G. Roberts, & S. Blumsack, as cited in Industrial Economics Inc. (2021).
3. Derived from AEO (2020).
4. Luchansky and Monks (2009).
5. Newell, Prest & Vissing (2019)
6. Assumed to be the same as Oil, Lower 48 Offshore
7. Brown (1998).
8. Derived from specialized NEMS run of the AEO 2015 provided to DOI by EIA.
9. Assumed value.
10. Derived from AEO 2018a, as provided by BOEM (2018).
11. Derived from NEMS 2019 Reference Case supplemental data provided to BLM by EIA.

For coal supply, EnergySub uses supply elasticities unique to each of the 14 coal supply regions, as derived from annual supply curve data generated by NEMS' Coal Market Module.[7] The annual supply curve data provided by EIA represent 41 distinct coals for a given year for combinations of coal supply region, sulfur content, mining method, and rank. For example, the Central Appalachia coal supply region has five different supply curves for a given year, representing a mix of low- and medium-sulfur coal,

[7] While not publicly available, EIA provided these supply curve data for the purposes of this project and provides them to other modelers on a regular basis.

underground and surface mines, and premium and bituminous coals. In addition, the annual supply curve for each of the 41 coals is represented as 11 data points, with each data point representing production at a given price point.

Using the EIA data, we estimated supply elasticities for each of the 41 coal types, for every year between 2019 and 2040. To generate elasticity values, we applied the standard econometric method of regressing the log-transformed price on the log-transformed quantity, which yielded the elasticity of supply as the coefficient. Each regression was performed over the three central points of the appropriate supply curve. The following equation displays this regression:

$$\ln\left(Q_{s,t}\right) = \beta_{s,t}\ln\left(P_{s,t}\right) + \beta_0$$

Where:

$Q_{s,t}$ represents the quantity supplied on supply curve *s* in year *t*,

$\beta_{s,t}$ represents the elasticity of supply for supply curve *s* in year *t*[8],

$P_{s,t}$ represents the price of coal on supply curve *s* in year *t*, and

β_0 represents the regression constant.

Running the above regression for each of the 41 supply curves for every year between 2019 and 2040 yields an initial set of elasticities. To convert the year-specific and supply curve-specific results to regional supply elasticities, we developed a weighted average coal supply elasticity for each of the 14 coal supply regions across all years, using the quantity associated with the coals produced by each coal supply region as weights. Table 2 above displays the results of the supply elasticity calculation for each coal supply region.

Where appropriate economic research does not exist or could not be obtained for a specific supply elasticity value, projections from the *AEO* were used to infer these values.[9] Elasticity estimates may be inferred from the *AEO* projection for a given year by comparing the differences in energy prices between two scenarios with the differences in energy quantities. For a given energy source and fuel, an annual inferred elasticity value was calculated three times: (1) based on the low oil price case vs. the high oil price case, (2) the low price case vs. the reference case, and (3) the reference case vs. the high price case, for all *AEO* projection years from 2017 through 2040. The formula for this annual inferred elasticity is as follows.

$$\eta_t = \frac{\ln\left(\frac{Q_{A,t}}{Q_{B,t}}\right)}{\ln\left(\frac{P_{A,t}}{P_{B,t}}\right)}$$

Where η_t is the inferred elasticity in year *t*, $Q_{A,t}$ and $Q_{B,t}$ represent the quantities supplied in year *t* for cases *A* and *B* respectively (each case is compared with both of the other cases), and $P_{A,t}$ and $P_{B,t}$ are the prices at time *t* for cases *A* and *B*. The resulting series of inferred elasticities are averaged, excluding extreme outlier results derived from the *AEO* data.[10]

For a limited number of producing sectors, elasticity values were unavailable from the literature and the data generated by the constrained NEMS run or recent editions of the AEO yielded elasticity values that

[8] Coal supply elasticities are also represented as η_{cr} in Equation 1.

[9] In some cases, the supply elasticities were derived from prior releases of the AEO rather than AEO 2020 when results from the 2020 data resulted in unrealistic elasticity values.

[10] More specifically, elasticities were estimated based on differentials between the low-price case and reference case, the reference case and the high-price case, and the low-price case and the high-price case. They then were averaged across these three variants and across years.

appeared unrealistically high or were insufficient to support estimation of a supply elasticity. In such cases, EnergySub uses a default supply elasticity of 1.0.

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Willow Master Development Plan

Appendix E.3
Air Quality Technical Information

June 2022

Appendix E.3A
Air Quality Technical Appendix

Appendix E.3B
Air Quality Technical Support Documents

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Willow Master Development Plan

Appendix E.3A
Air Quality Technical Information

June 2022

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List of Acronyms

AAAQS	Alaska Ambient Air Quality Standards
ADEC	Alaska Department of Environmental Conservation
AOGCC	Alaska Oil and Gas Conservation Commission
AQRVs	air quality related values
BLM	Bureau of Land Management
CAP	criteria air pollutant
CASTNET	Clean Air Status and Trends Network
CPAI	ConocoPhillips Alaska, Inc.
dv	deciview
EPA	Environmental Protection Agency
FLM	Federal Land Manager
HAP	hazardous air pollutant
F	Fahrenheit
IMPROVE	Interagency Monitoring of Protected Visual Environments
kg N/ha/year	kilograms nitrogen per hectare per year
kg S/ha/year	kilograms sulfur per hectare per year
km	kilometers
MACT	maximum achievable control technology
m/s	meters per second
NAAQS	National Ambient Air Quality Standards
NADP	National Atmospheric Deposition Program
NH_4^-	ammonium
NO_2	nitrogen dioxide
NO_3^-	nitrate
NOx	nitrogen oxides
NPR-A	National Petroleum Reserve in Alaska
NTL	Notice to Lessees and Operators
NTN	National Trends Network
NWS	National Weather Service
$PM_{2.5}$	particulate matter less than 2.5 microns in aerodynamic diameter
PM_{10}	particulate matter less than or equal to 10 microns in aerodynamic diameter
Project	Willow Master Development Plan Project
PSD	Prevention of Significant Deterioration
RHR	Regional Haze Rule
SO_2	sulfur dioxide
SO_4^{2-}	sulfate

1.0 AIR QUALITY

The U.S. Environmental Protection Agency (EPA) has determined that 50 kilometers (km) (31 miles) is sufficient to determine whether an emissions source will cause or contribute to exceedances of ambient air quality standards and is the approved distance for regulatory near-field air quality models (40 CFR 51, Appendix W). The far-field (regional) modeling domain is more than 300 km (186 miles) from the Willow Master Development Plan Project (Project) in all directions except south of the Project, where the closest point is approximately 250 km (155 miles).

1.1 Affected Environment

1.1.1 Regulatory Framework

In Alaska, the Alaska Department of Environmental Conservation (ADEC) has the authority to implement and enforce the Alaska Air Quality Control Regulations (18 AAC 50) through an EPA-approved State Implementation Plan. The Alaska Ambient Air Quality Standards (AAAQS) were promulgated in 18 AAC 50.010. The National Ambient Air Quality Standards (NAAQS) and AAAQS are provided in Table E.3.1.

Table E.3.1. National and Alaska Ambient Air Quality Standards

Pollutant[a]	Averaging Time	NAAQS[b] Primary	NAAQS[b] Secondary	AAAQS[c,d]	Form
CO	8 hours	9 ppm	N/A	10 mg/m^3	Not to be exceeded more than once per year
CO	1 hour	35 ppm	N/A	40 mg/m^3	Not to be exceeded more than once per year
NO_2	1 hour	100 ppb	N/A	188 μg/m^3	98th percentile of 1-hour daily maximum concentrations, averaged over 3 years
NO_2	Annual	53 ppb	53 ppb	100 μg/m^3	Annual mean, not to be exceeded
O_3	8 hours	0.070 ppm	0.070 ppm	0.070 ppm	Annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years
$PM_{2.5}$	Annual	12 μg/m^3	15 μg/m^3	12 μg/m^3	Annual mean, averaged over 3 years
$PM_{2.5}$	24 hours	35 μg/m^3	35 μg/m^3	35 μg/m^3	98th percentile, averaged over 3 years
PM_{10}	24 hours	150 μg/m^3	150 μg/m^3	150 μg/m^3	Not to be exceeded more than once per year on average over three years
SO_2	1 hour	75 ppb	N/A	196 μg/m^3	99th percentile of 1-hour daily maximum concentrations, averaged over 3 years
SO_2	3 hours	N/A	0.5 ppm	1,300 μg/m^3	Not to be exceeded more than once per year
SO_2	24 hours	N/A	N/A	365 μg/m^3	Not to be exceeded more than once per year
SO_2	Annual	N/A	N/A	80 μg/m^3	Annual mean, not to be exceeded

Note: AAAQS (Alaska Ambient Air Quality Standards); CO (carbon monoxide); N/A (not applicable); NAAQS (National Ambient Air Quality Standards); NO_2 (nitrogen dioxide); O_3 (ozone); $PM_{2.5}$ (particulate matter less than 2.5 microns in aerodynamic diameter); PM_{10} (particulate matter less than or equal to 10 microns in aerodynamic diameter); ppb (parts per billion); ppm (parts per million); SO_2 (sulfur dioxide); μg/m^3 (micrograms per cubic meter).
[a] Lead and ammonia are not shown as they are not pollutants of concern in the analysis area.
[b] Source: 40 CFR 50
[c] Source: 18 AAC 50.010
[d] All AAAQS are primary except for 3-hour SO_2.

EPA designates geographic areas demonstrating compliance with the NAAQS as “attainment,” while areas that exceed the NAAQS are designated as “nonattainment.” If there is insufficient data to designate an area as “attainment” or “nonattainment,” the area will be designated as “unclassifiable.” The analysis area for air quality is designated as “attainment/unclassifiable” for all criteria air pollutants (CAP).

The closest Class I area to the Project is Denali National Park, which is located more than 700 km (435 miles) south of the Project and is not in the analysis area for air quality. The three assessment areas within the far-field analysis area for air quality are Gates of the Arctic National Park, Noatak National

Preserve, and the Arctic National Wildlife Refuge (Figure E.3.1). The Class II prevention of significant deterioration (PSD) increments are presented in Table E.3.2.

The air quality related values (AQRVs) are resources that may be affected by a change in air quality (NPS 2011). The Federal Land Managers' Air Quality Related Values Work Group identifies AQRVs as "visibility or a specific scenic, cultural, physical, biological, ecological, or recreational resource identified by the FLM [federal land manager] for a particular area" (FLAG 2010).

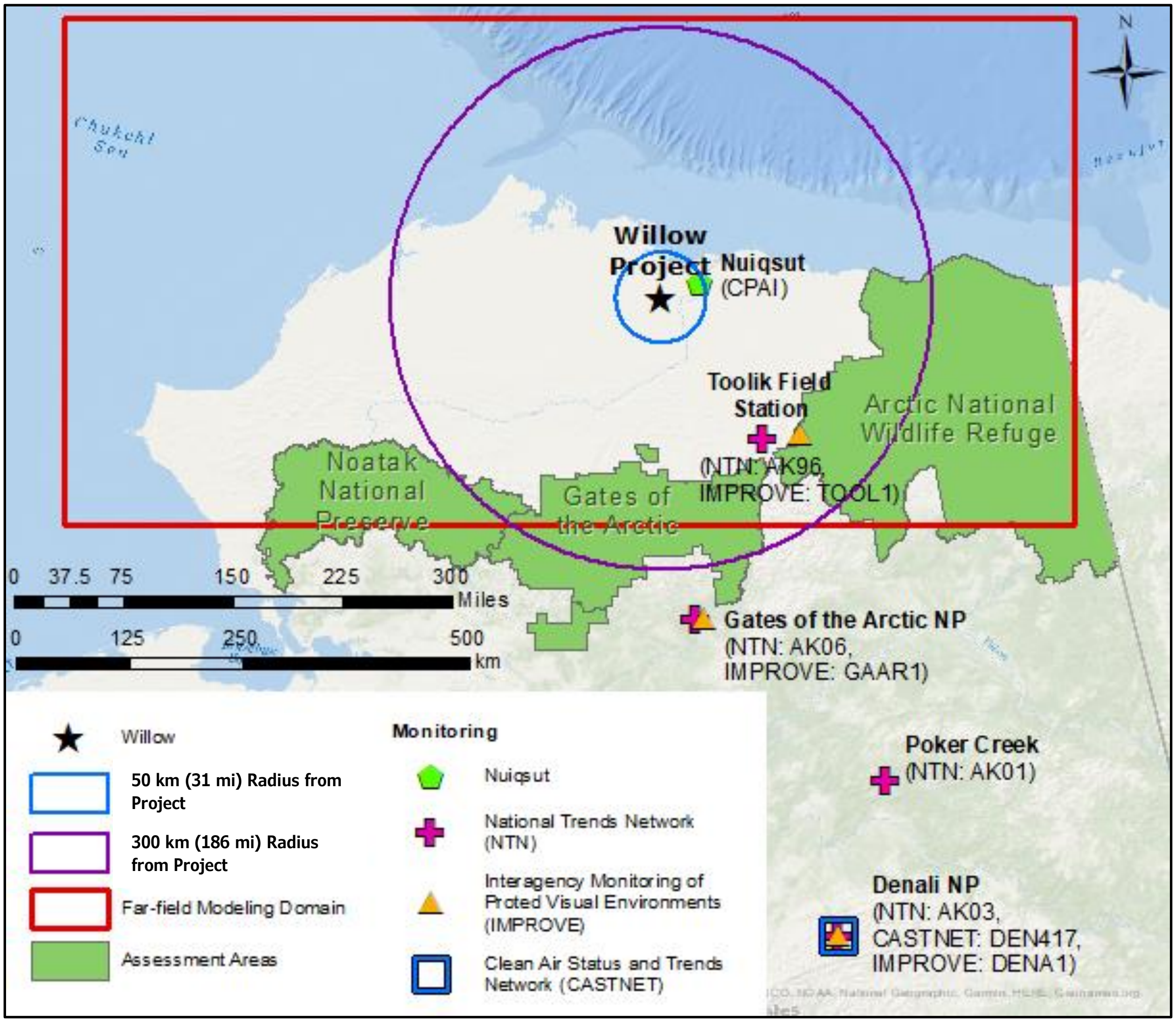


Figure E.3.1. Analysis Areas for Air Quality and Regional Ambient Air Quality Monitors, Three Federally Managed Assessment Areas, and the Far-Field (Regional) Modeling Domain

Table E.3.2. Prevention of Significant Deterioration Increments for Class II Areas

Pollutant	Averaging Time	Class II PSD Increment ($\mu g/m^3$)	Form
NO_2	Annual	25	Annual mean, not to be exceeded
SO_2	3 hours	512	Not to be exceeded more than once per year
SO_2	24 hours	91	Not to be exceeded more than once per year
SO_2	Annual	20	Annual mean, not to be exceeded
$PM_{2.5}$	24 hours	9	Not to be exceeded more than once per year
$PM_{2.5}$	Annual	4	Annual mean, not to be exceeded
PM_{10}	24 hours	30	Not to be exceeded more than once per year
PM_{10}	Annual	17	Annual mean, not to be exceeded

Source: 40 CFR 52.21

Note: NO_2 (nitrogen dioxide); $PM_{2.5}$ (particulate matter less than 2.5 microns in aerodynamic diameter); PM_{10} (particulate matter less than or equal to 10 microns in aerodynamic diameter); PSD (prevention of significant deterioration); SO_2 (sulfur dioxide); $\mu g/m^3$ (micrograms per cubic meter).

Visibility is a measure of how far and well we can see into the distance and is sensitive to changes in air quality. Visibility impairment (i.e., haze) occurs when sunlight is absorbed or scattered by tiny particles (e.g., sulfates [SO_4^{2-}], nitrates [NO_3^-]) and gases (e.g., nitrogen dioxide [NO_2]) (EPA 2017).
The absorption and scattering of light impairs visibility conditions (i.e., visual range, contrast, coloration). Haze causing pollutants can be directly emitted or formed through the reaction of precursor gases emitted into the atmosphere (e.g., formation of SO_4^- from sulfur dioxide [SO_2]). The Regional Haze Rule (RHR) was promulgated in 1999 to improve and protect visibility in Class I areas (40 CFR 51.308). The Project area is not a Class I area; however, the RHR can be treated as a guideline for the Project. The RHR defines reasonable progress goals to improve visibility on the most impaired days and ensure no degradation on the least impaired days, with the goal of attaining natural conditions (i.e., estimated visibility conditions in the absence of human-made air pollution) in each Class I area by 2064. Under the RHR, visibility is quantified using the deciview (dv) haze index, which is derived from light extinction. An incremental change in dv corresponds to a uniform and incremental change in visual perception for the entire range of visibility conditions. Single-source impacts on visibility are assessed by comparing the 98th percentile of the source contribution to the haze index to defined thresholds. A source that exceeds 0.5 dv (approximate 5% change in light extinction) is considered to contribute to visibility impairment, while a source that exceeds 1.0 dv (approximate 10% change in light extinction) is considered to cause visibility impairment (FLAG 2010).

Atmospheric deposition can negatively affect ecosystems and other AQRVs. Dry deposition is continuous while wet deposition can only occur in the presence of precipitation. Potential deposition impacts include, but are not limited to, acidification of soils and waterbodies and nutrient enrichment (FLAG 2010). Wet or dry deposition of acidic pollutants formed from emitted SO_2 and nitrogen oxides (NOx) is referred to as acid rain (EPA 2018b). There are currently no federal standards for atmospheric deposition, but FLMs use critical loads and Deposition Analysis Thresholds for assessing both cumulative impacts and source-specific impacts from new or modified PSD sources. A critical load is the level of deposition below which no harmful effects to an ecosystem are expected. Deposition Analysis Thresholds are screening thresholds that define the additional amount of deposition within an FLM’s area below which impacts are considered negligible.

The National Emission Standards for Hazardous Air Pollutants defines maximum achievable control technology (MACT) standards that are technology-based standards for each regulated source category. MACT is applicable to all major sources (potential to emit more than 10 tons per year of a single hazardous air pollutant [HAP] or 25 tons per year of any combination of HAPs) and some area sources (any stationary source of HAPs not classified as a major source) in specific source categories.

1.1.1.1 Flaring Regulations

Flaring in Alaska is regulated by three agencies: the Alaska Oil and Gas Conservation Commission (AOGCC), the ADEC, and the Bureau of Land Management (BLM). Flares are important safety devices that are used to ensure controlled combustion of natural gas to avoid a potentially explosive environment if the gas were to be vented to the atmosphere rather than flared. Flares would be used for gas released to prevent over pressurizing piping and equipment, to handle gas removal from systems during maintenance, and to address gas released during an emergency rapid depressurization of Willow Processing Facility gas handling systems (SLR 2022).

AOGCC prohibits the waste of oil and natural gas in accordance with the Alaska Oil and Gas Conservation Act (Section 31.05.170 (15)(H)). The Act specifies that the release, burning, or escape of oil or natural gas from an oil or gas producing well is prohibited unless authorized by AOGCC (USDOE 2019). Any wasted oil or natural gas must also be reported to AOGCC with a statement of compliance actions (USDOE 2019). The State of Alaska also prohibits flaring except in the case of emergencies or system testing (20 AAC 25.235). This regulation authorizes flaring under several conditions, including for periods less than one hour if resulting from emergencies, operational upsets, or planned lease operation. For flaring longer than 1 hour, AOGCC would consider authorization if flaring was necessary for safety in emergencies, in which case operators must report the volume of gas flared. In addition, if the Willow Processing Facility is subject to “major” source permitting requirements, any flares planned to be constructed at the facility would be subject to best available control technology requirements to minimize emissions from flares, as well as any other applicable equipment (SLR 2022).

BLM also has flaring provisions in the *Notice to Lessees and Operators of Onshore Federal and Indian Oil and Gas Leases, Royalty or Compensation for Oil and Gas Lost*, commonly referred to as NTL-4 (44 Federal Register 76600 [1979]), that are applicable to operators of federal oil and gas leases. Currently, the provision requires payment of royalties for oil or gas that is flared without authorization or if it is determined to be “avoidably lost.”

1.1.2 <u>Characterization of Existing Air Quality in the Analysis Area</u>

Regional air quality is affected by a variety of factors, including climate, meteorology, and the magnitude and location of air pollutant sources. This section provides descriptions of the regional climate, meteorology, and existing regional sources of air pollution that affect air quality in the analysis area. Existing air quality in the analysis area is assessed through a review of recent ambient air quality monitoring data and AQRVs.

1.1.2.1 Climate and Meteorology

The Project is located on the North Slope within the National Petroleum Reserve in Alaska (NPR-A). Several monitoring stations were used to characterize climate and meteorology in the analysis area. Monthly average precipitation and temperature data were acquired from the National Oceanic and Atmospheric Administration National Weather Service (NWS) stations at Umiat, Kuparuk, Utqiaġvik (Barrow), and Nuiqsut (Figure E.3.2). A monitoring station operated by ConocoPhillips Alaska, Inc. (CPAI) at Nuiqsut was used to characterize prevailing wind patterns.

Table E.3.3 provides summaries of the average monthly temperature and precipitation from the NWS stations shown in Figure E.3.2. The annual average temperature in the NPR-A is approximately 10 degrees Fahrenheit (F), with monthly average maximum temperatures below freezing from October to May (BLM 2012). The coldest temperatures (usually in February) range from -10 degrees to -15 degrees F at the maximum and -25 degrees to -30 degrees F at minimum on average (Table E.3.3). Summer temperatures rise above freezing, with the highest temperatures typically occurring in July. The average maximum and minimum temperatures in July range from 45 degrees F to 65 degrees F and 35 degrees F to 40 degrees F, respectively.

Precipitation in the analysis area is low, with Nuiqsut receiving 2.74 inches of precipitation per year on average (Table E.3.3). Precipitation is highest during summer, with over three-fourths of the total annual precipitation falling between June and September. Although snowfall is sparser during the summer months, it can occur during any month; the highest average snowfall rates occur in October. Snow is generally on the ground from October to May (BLM 2012).

The wind rose in Figure E.3.3 shows the distribution of wind direction and speeds measured at the CPAI Nuiqsut monitoring station, located approximately 46 km (28.5 miles) east-northeast of the Project, from 2016 to 2020. The prevailing wind direction at Nuiqsut was from the northeast with wind speeds averaging 4.9 meters per second (m/s) (11.0 miles per hour). The maximum observed wind speed was 22.4 m/s (50.1 miles per hour) and calm winds were infrequent, occurring for less than 1.5 % of hours during the 5-year period. Figures E.3.4 through E.3.7 provide seasonal wind patterns for the winter, spring, summer, and fall seasons, respectively, for the 5-year period.

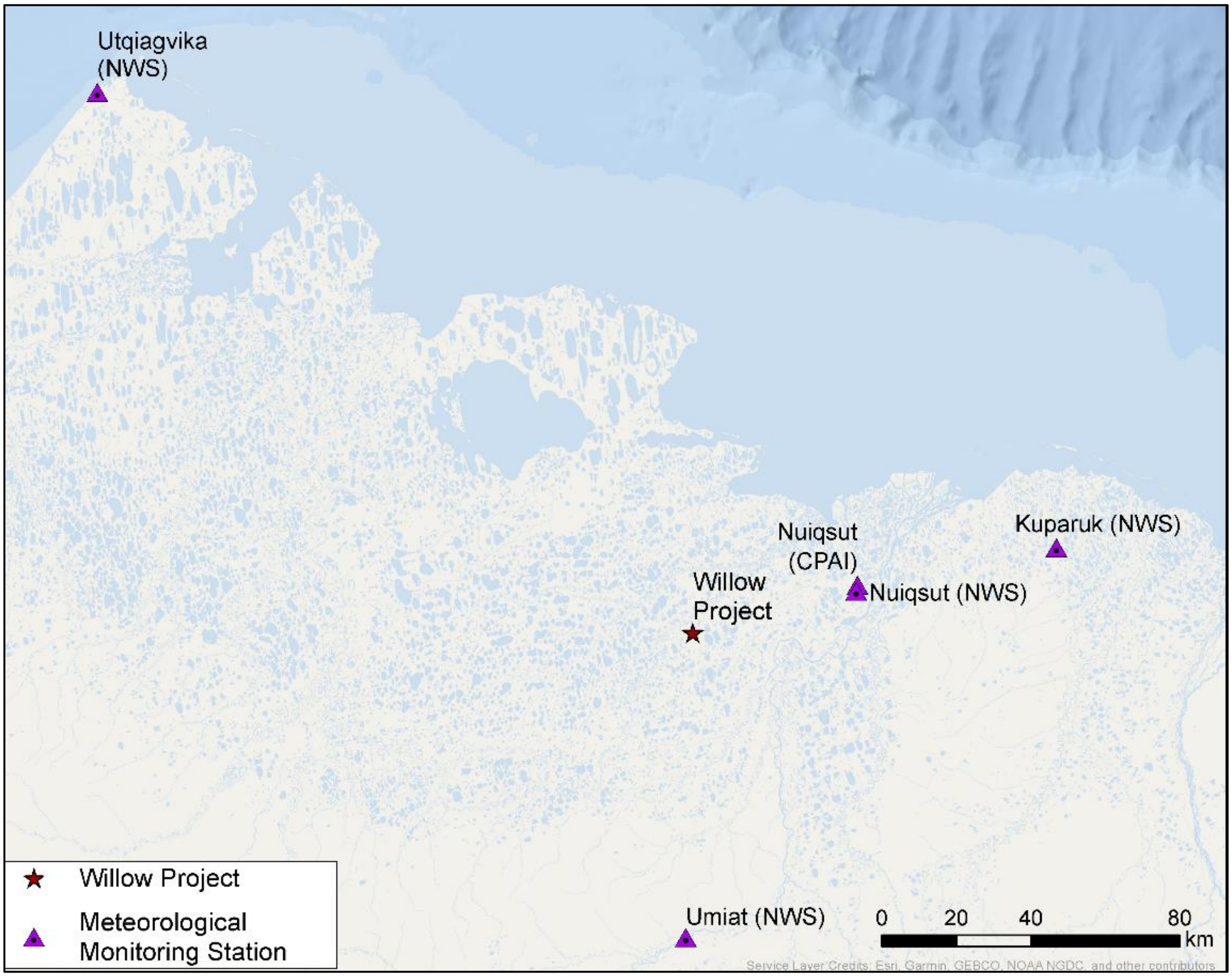


Figure E.3.2. Monitoring Stations Used to Characterize Climate and Meteorology in the Project Area

Table E.3.3. Monthly Climate Summary Data at Monitoring Stations in the Air Quality Analysis Area

Utqiaġvik (Barrow)[a]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
Average Max. Temperature (degrees F)	-7.4	-10.6	-7.9	7.0	24.7	38.9	45.8	43.3	34.9	20.7	5.8	-4.4	15.9
Average Min. Temperature (degrees F)	-19.9	-22.7	-20.6	-6.8	15.3	30.1	34.1	34	28.2	11.6	-5.4	-16.2	5.1
Average Total Precipitation (in)[b]	0.18	0.17	0.13	0.18	0.17	0.34	0.91	1.02	0.68	0.49	0.25	0.17	4.67
Average Total Snowfall (in)	2.4	2.7	2.0	2.8	2.3	0.6	0.3	0.7	4.0	7.7	4.3	2.8	32.5
Average Snow Depth (in)	9	10	11	11	7	1	0	0	1	4	7	8	6
Kuparuk[a]	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Annual**
Average Max. Temperature (ºF)	-11.3	-10.9	-8.4	8.7	28.1	47.4	56	50.8	39.2	21.5	4.0	-4.7	18.4
Average Min. Temperature (ºF)	-23.9	-24.0	-22.6	-6.3	17.0	33.0	39.0	36.9	28.9	10.9	-8.9	-17.8	5.2
Average Total Precipitation (in)[b]	0.13	0.17	0.08	0.14	0.07	0.32	0.87	1.06	0.48	0.35	0.16	0.13	3.96
Average Total Snowfall (in)	2.6	2.5	2.2	2.8	1.7	0.5	0.0	0.3	3.0	8.4	4.6	3.5	32.0
Average Snow Depth (in)	9	9	9	10	5	0	0	0	0	3	6	7	5
Umiat[a]	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Annual**
Average Max. Temperature (degrees F)	-12.7	-13.8	-6.7	11.5	32.4	57.5	66.2	57.7	41.4	18.2	-0.7	-11.9	19.9
Average Min. Temperature (degrees F)	-28.9	-31.2	-26.8	-11.0	15.7	37.0	42.5	37.2	26.1	2.4	-16.8	-28.0	1.5
Average Total Precipitation (in)[b]	0.38	0.26	0.16	0.21	0.07	0.68	0.79	1.06	0.47	0.68	0.38	0.33	5.46
Average Total Snowfall (in)	4.5	2.4	2.3	1.9	1.2	0.2	0.0	0.2	2.6	8.5	5.2	4.2	33.2
Average Snow Depth (in)	14	16	17	17	9	0	0	0	0	5	9	12	8
Nuiqsut	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Annual**
Average Max. Temperature (ºF)[c]	-7.1	-9.6	-8.4	10.0	29.6	51.1	58.2	51.6	40.1	21.8	5.1	-2.5	20
Average Min. Temperature (ºF)[c]	-22.9	-23.3	-21.5	-6.0	18.2	35.4	41.6	38.7	31.5	14.2	-8.7	-15.7	6.8
Average Total Precipitation (in)[b,d]	0.10	0.05	0.03	0.19	0.17	0.31	1.04	1.04	0.40	0.04	0.05	0.14	2.74

Note: F (Fahrenheit); in (inches); Max. (maximum); Min. (minimum). The sum of the monthly precipitation totals may not equal the annual total because of different data completeness requirements for monthly and annual data.

[a] Source: National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) data, obtained from the Western Regional Climate Center(https://wrcc.dri.edu/summary/Climsmak.html). Period of record: Utqiaġvik (1901 to 2016); Umiat (1945 to 2001); Kuparuk (1983 to 2016). Historical records are under Utqiaġvik's former name of Barrow.

[b] Units of total precipitation are inches of liquid water equivalent.

[c] Source: NOAA NWS data obtained from NOAA National Centers for Environmental Information (https://www.ncdc.noaa.gov/cdo-web/datatools/normals). Period of record: 1981 to 2010. As of January 6, 2022, the 1981-2010 period is the most recent climate normal (i.e., 3 decades) available.

[d] Source: NOAA NWS data obtained from Natural Resources Conservation Service (http://agacis.rcc-acis.org/?fips=02185). Period of record: 1998 to 2021. Months within each year with > 1 missing day are omitted from averages. Annual data with > 1 missing day is also omitted from averages. Due to this, the sum of monthly averages does not equal the annual average. The annual value is based on 2002, 2004. 2009, and 2011 years only, since only those years satisfied the data completeness criteria.

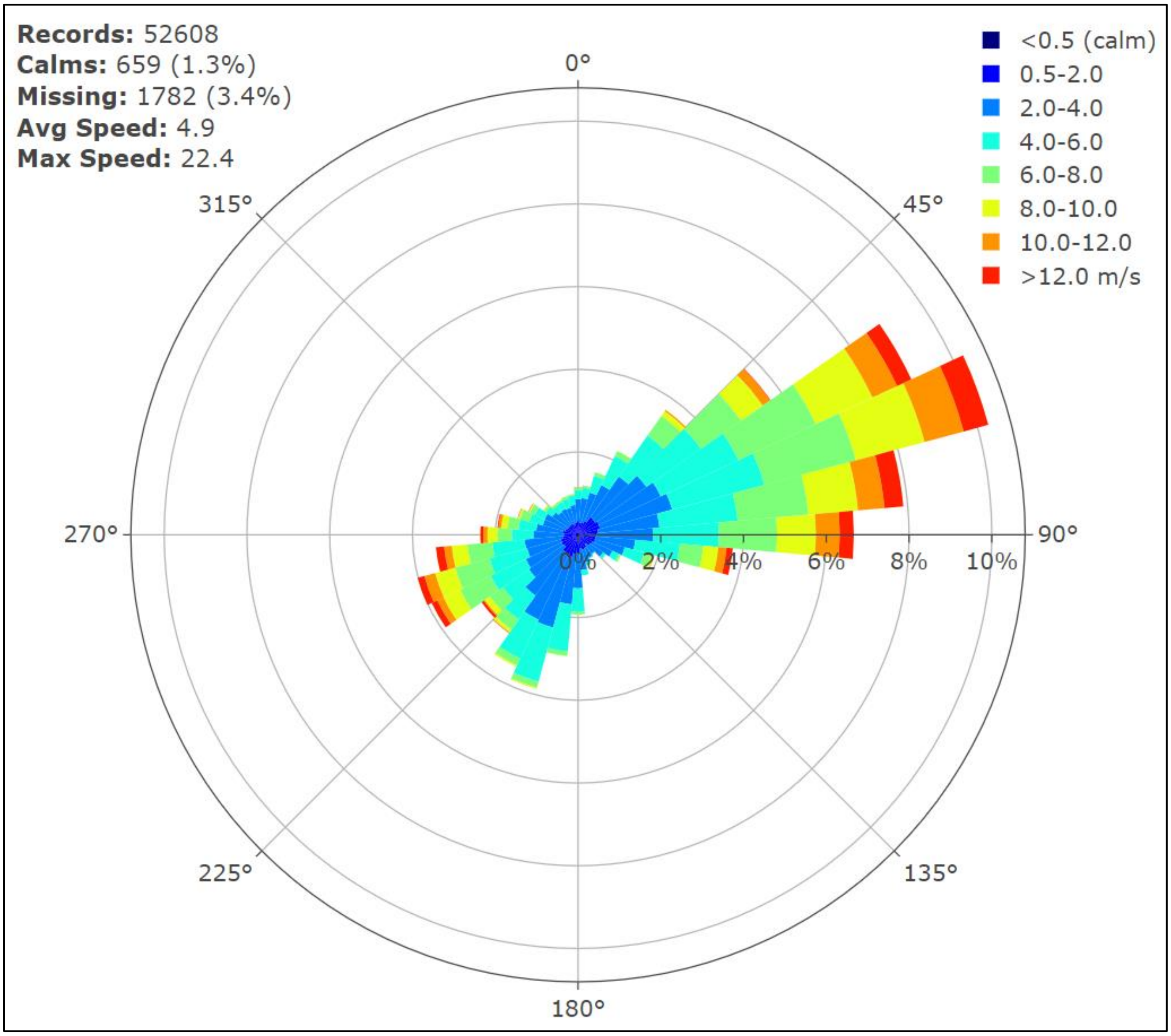


Figure E.3.3. Wind Rose Data from the ConocoPhillips Alaska, Inc. Nuiqsut Monitoring Station for the Period 2016 to 2020*

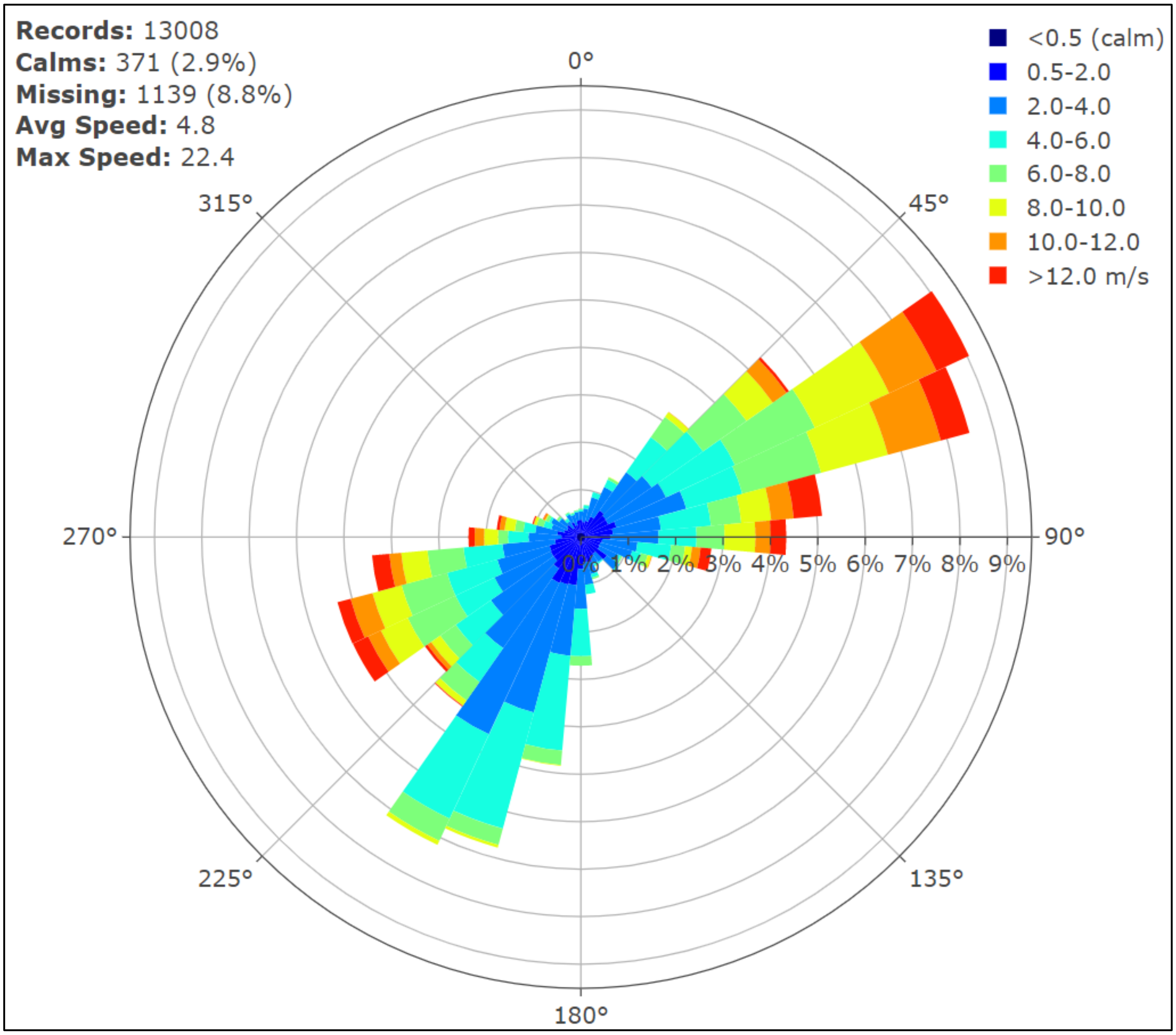


Figure E.3.4. Wind Rose Data from the ConocoPhillips Alaska, Inc. Nuiqsut Monitoring Station for the Winter Months (December, January, and February) during 2016 to 2020*

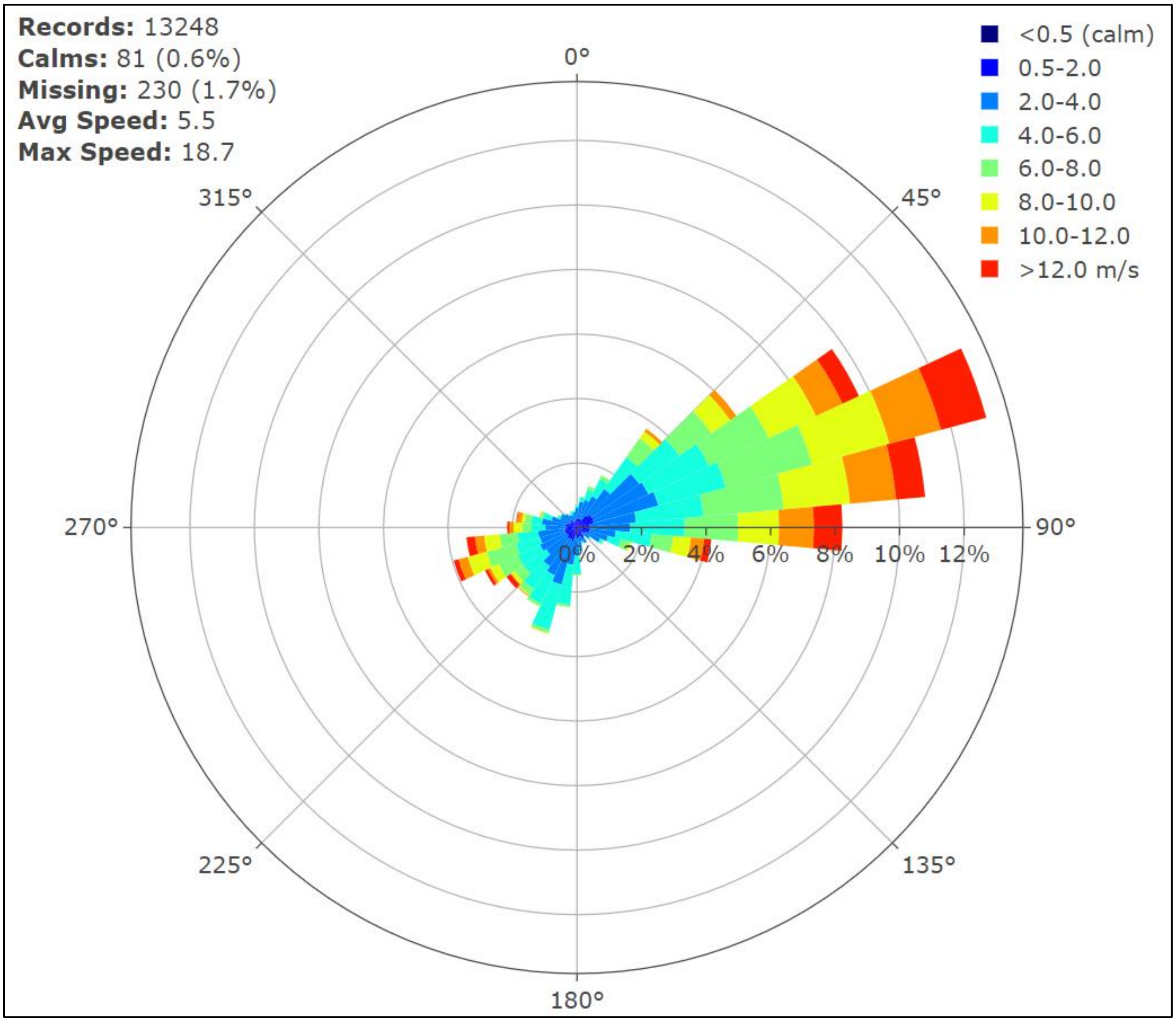


Figure E.3.5. Wind Rose Data from the ConocoPhillips Alaska, Inc. Nuiqsut Monitoring Station for the Spring Months (March, April, and May) during 2016 to 2020*

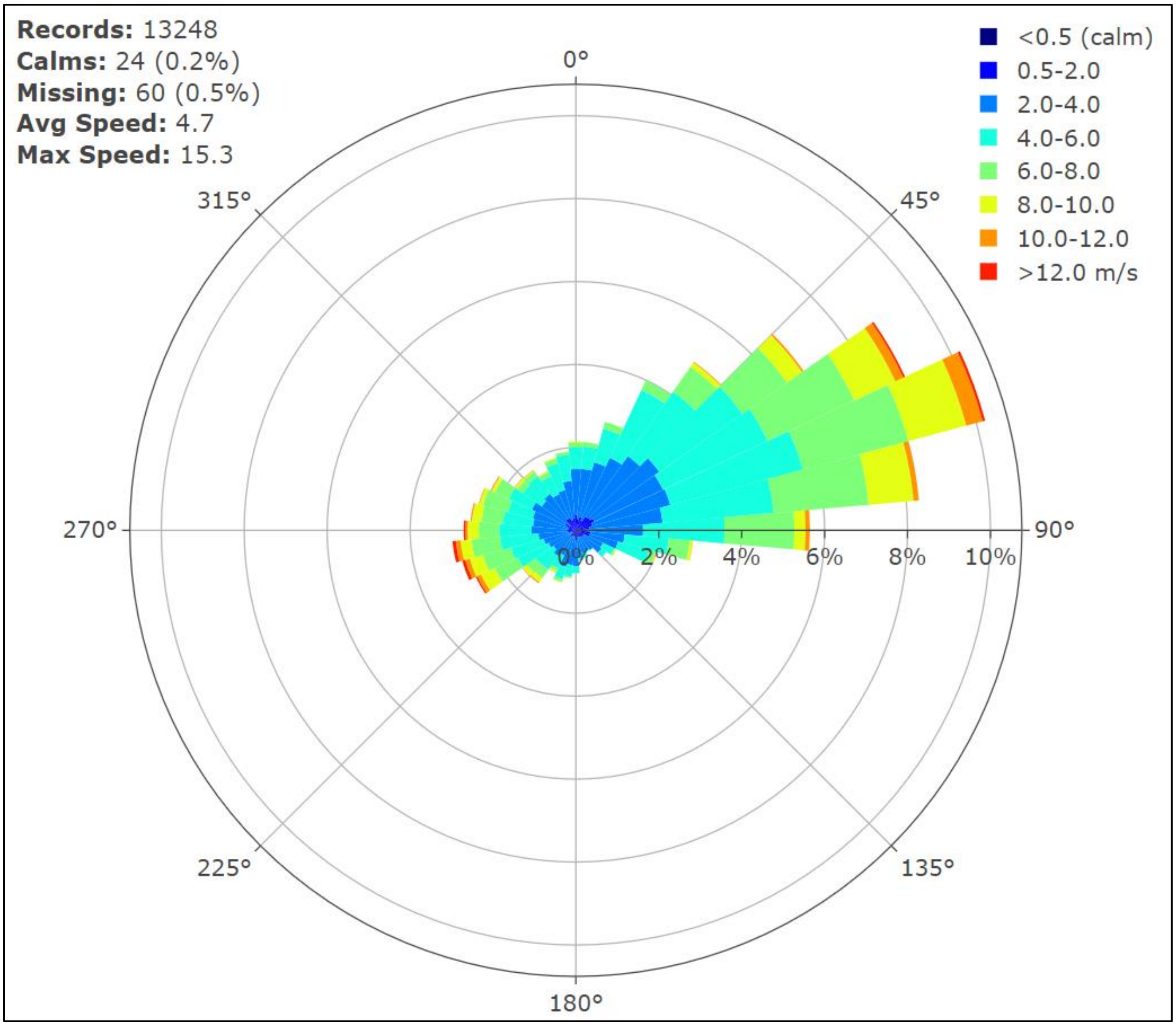


Figure E.3.6. Wind Rose Data from the ConocoPhillips Alaska, Inc. Nuiqsut Monitoring Station for the Summer Months (June, July, and August) during 2016 to 2020*

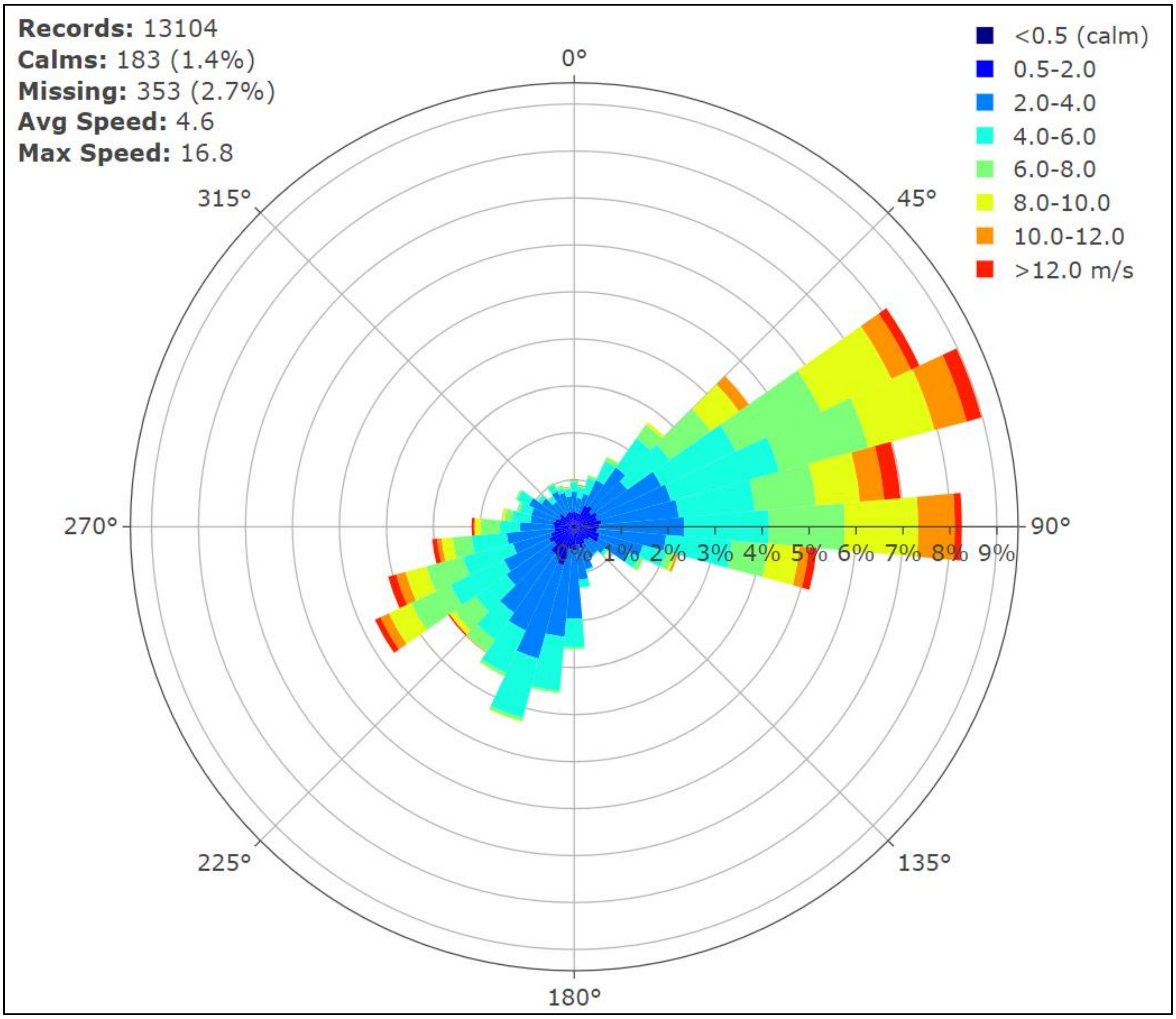


Figure E.3.7. Wind Rose Data from the ConocoPhillips Alaska, Inc. Nuiqsut Monitoring Station for the Fall Months (September, October, and November) during 2016 to 2020*

1.1.2.2 Existing Regional Sources of Air Pollution

A summary of existing regional emissions for the North Slope and adjacent waters (Beaufort Sea and Chukchi Sea Planning Areas) is available from the 2012 baseline scenario of the Bureau of Ocean Energy Management *Arctic Air Quality Modeling Study: Emissions Inventory, Final Task Report* (Fields Simms, Billings et al. 2014). Existing emissions from onshore sources (e.g., oil and gas production and exploration, airports, pipelines, non-oil- and gas-related stationary and mobile sources) comprise the majority of the total existing emissions, and emissions from offshore sources (e.g., drilling rigs, survey/drilling vessels and aircraft, commercial vessels) are small in comparison (Fields Simms, Billings et al. 2014). Overall, onshore oil and gas sources comprise the largest fraction of existing emissions for all CAPs except particulate matter less than or equal to 10 microns in aerodynamic diameter (PM_{10}) and particulate matter less than 2.5 microns in aerodynamic diameter ($PM_{2.5}$) for which dust from unpaved roads comprises the largest fraction (Fields Simms, Billings et al. 2014). The major existing sources of HAPs in the region are onshore oil and gas, other nonroad vehicles and equipment, on-road vehicles, and waste incineration, landfills, and other combustion sources.

1.1.3 Air Quality Monitoring

1.1.3.1 Criteria Air Pollutants

CPAI operates the Nuiqsut Monitoring Station, which is the most representative station in the region of the Project (Figure E.3.1) (BLM 2018). Monitoring data from the CPAI Nuiqsut monitoring station are provided in Table E.3.4 for 2018 through 2020. All CAPs are monitored except for lead, for which there are no monitoring stations in the analysis area. All of the monitored concentrations are well below the NAAQS and AAAQS. This is consistent with the existing air quality of the larger analysis area, which is designated as "attainment/unclassifiable" for all CAPs.

Table E.3.4. Measured Criteria Air Pollutant Concentrations at the Nuiqsut Monitoring Station*

Pollutant (units)	Averaging Period	Rank	2018	2019	2020	Avg	NAAQS/ AAAQS	Below NAAQS/ AAAQS?
CO (ppm)	1 hour	2nd highest daily max	1	1	9	3	35	Yes
CO (ppm)	8 hours	2nd highest daily max	1	1	3	2	9	Yes
NO_2 (ppb)	1 hour	99th percentile of daily max	23.9	31.8	32.4	29.4	100	Yes
NO_2 (ppb)	Annual	Annual average	2	2	2	2	53	Yes
SO_2 (ppb)	1 hour	99th percentile of daily max	2.6	3.5	4.2	3.3	75	Yes
SO_2 (ppb)	3 hours	2nd highest daily max	2.6	3.5	3.8	3.3	500	Yes
SO_2 (ppb)	24 hours	2nd highest	2.5	3.3	3.6	3.1	139	Yes
SO_2 (ppb)	Annual	Average	0.7	0.3	0.0	0.3	31	Yes
PM_{10} (µg/m^3)	24 hours	2nd highest	140	130	60	110	150	Yes
$PM_{2.5}$ (µg/m^3)	24 hours	98th percentile	8	7	6	7	35	Yes
$PM_{2.5}$ (µg/m^3)	Annual	Average	1.9	1.7	1.2	1.6	12	Yes
O_3 (ppb)	8 hours	4th highest daily max	46	46	41	44	70	Yes

Note: AAAQS (Alaska Ambient Air Quality Standards); Avg. (average); CO (carbon monoxide); max (maximum); NAAQS (National Ambient Air Quality Standards); NO_2 (nitrogen oxides); O_3 (ozone); PM_{10} (particulate matter less than or equal to 10 microns in aerodynamic diameter); $PM_{2.5}$ (particulate matter less than 2.5 microns in aerodynamic diameter); ppb (parts per billion); ppm (parts per million); SO_2 (sulfur dioxide); µg/m^3 (micrograms per cubic meter). NAAQS/AAAQS for ozone (O_3) were converted from ppm to ppb and sulfur dioxide (SO_2) 24-hour and annual standards were converted from µg/m^3 to ppb. Data used in the table has not been reviewed by the Alaska Department of Environmental Conservation for Prevention of Significant Deterioration quality; however, the selection of the Nuiqsut station for monitoring data was made during the development of the Willow Environmental Impact Statement modeling protocol, which was reviewed by air specialists at the Alaska Department of Environmental Conservation and other agencies.

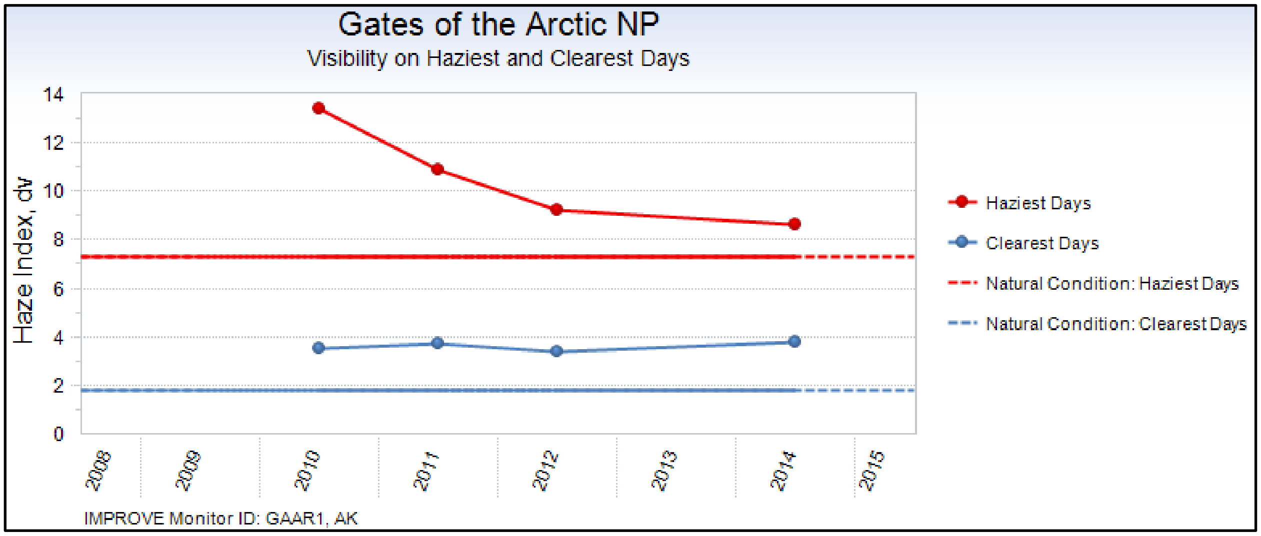
1.1.3.2 Visibility*

Visibility and air pollutant concentration data is collected by Interagency Monitoring of Protected Visual Environments at monitoring sites close to Class I areas across the country. The three closest monitors to the Project with available data are Toolik Lake Field Station, Gates of the Arctic National Park and Preserve (a Class II area), and Denali National Park (a Class I area) (Figure E.3.1). Data from these monitors are presented in Figures E.3.8 through E.3.13 and Table E.3.5. Denali National Park is outside the analysis area for air quality but is included here as it is the closest Class I area. Denali National Park has the longest visibility data record from 1989 through 2019. Gates of the Arctic National Park has available visibility data from 2010 through 2014, and Toolik Lake Field Station only has data for 2019 because it is a new Interagency Monitoring of Protected Visual Environments (IMPROVE) site that became operational in November 2018. Data is shown for the 20% haziest and 20% clearest days.

The 20% haziest days include anthropogenic and natural influences following the algorithm of EPA (2003) as revised by IMPROVE in December 2019 and is influenced by natural emission sources such as wildfires. At Gates of the Arctic, the haze index on the haziest days shows a consistent downward trend (through the years of the plot available from IMPROVE) that is near estimated natural visibility conditions[1] of 7.7 dv (visual range of approximately 129 miles), while the haze index on the clearest days has consistently been between 3 and 4 dv, which is slightly above the estimated natural conditions of

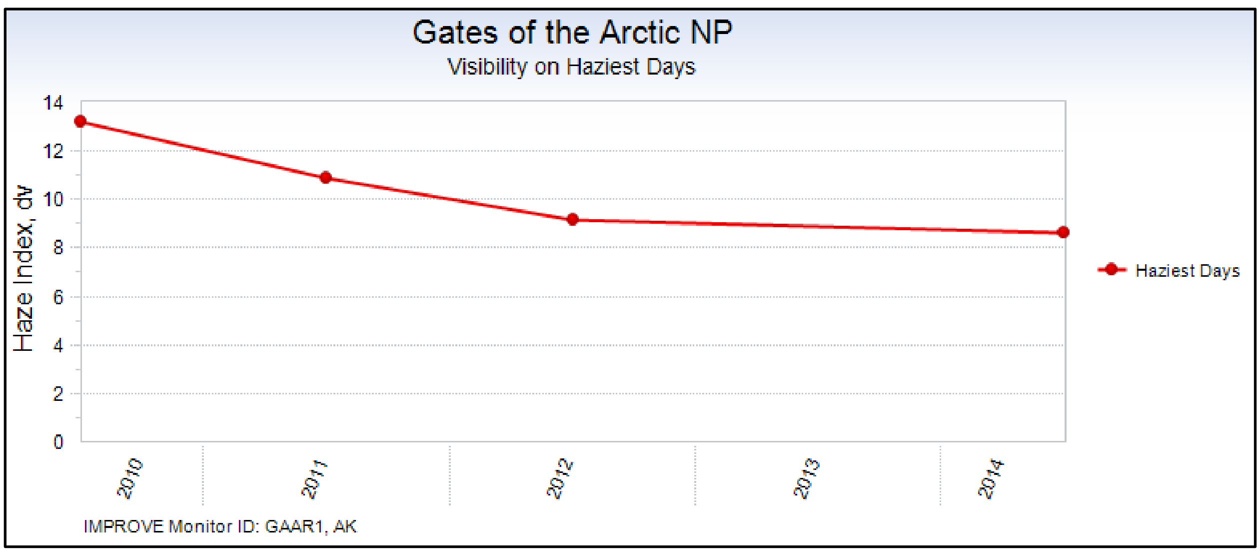
[1] http://vista.cira.colostate.edu/IMPROVE/Data/NaturalConditions/nc2_12_2019_2p.csv

2.8 dv (visual range of approximately 349 km [217 miles]). At Denali National Park, the haze index shows generally decreasing trends for both the haziest days and the clearest days, but the haziest days have some outlier years, most notably 2004, likely due to wildfires. Estimated natural visibility conditions[1] at Denali National Park are 7.3 dv (visual range of approximately 209 km [130 miles]) and 1.8 dv (visual range of approximately 360 km [224 miles]) for the haziest and clearest days, respectively. In recent years, the haze index values approach those estimated for natural conditions. The visibility at Toolik Lake Field Station in 2019 is comparable to the other sites analyzed.



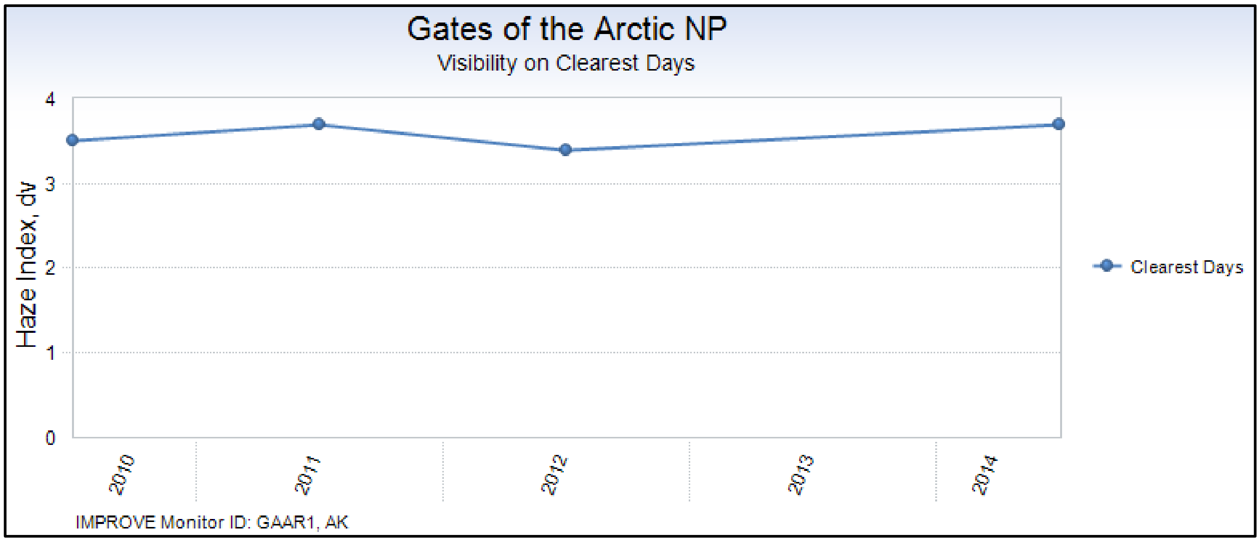
Source: FED 2020

Figure E.3.8. Visibility Data for Gates of the Arctic National Park



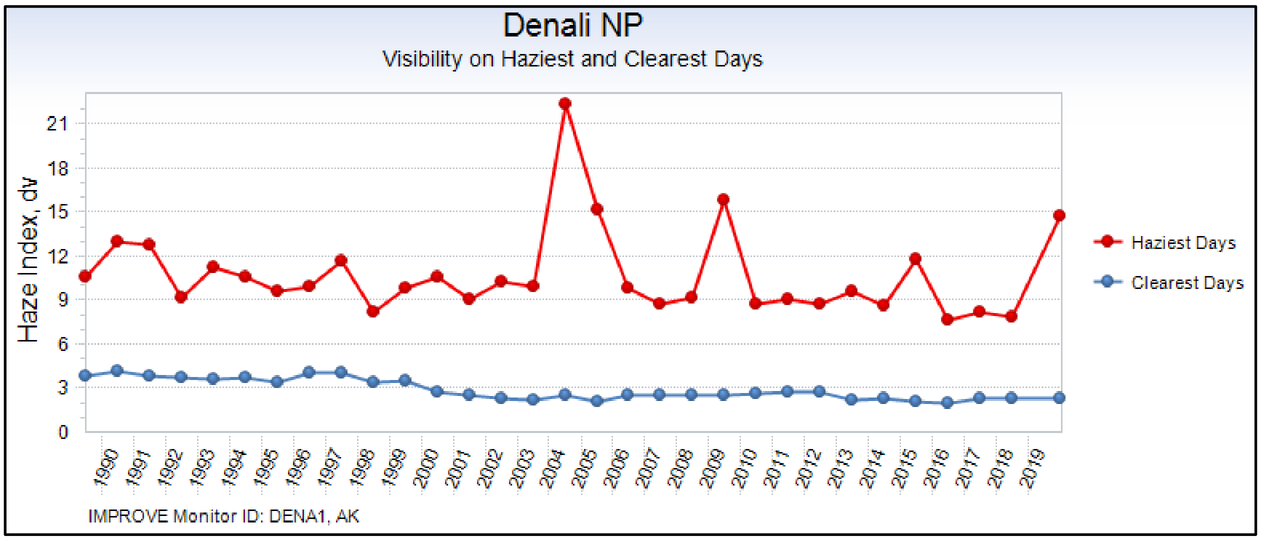
Source: FED 2020

Figure E.3.9. Visibility on the Haziest Days for Gates of the Arctic National Park



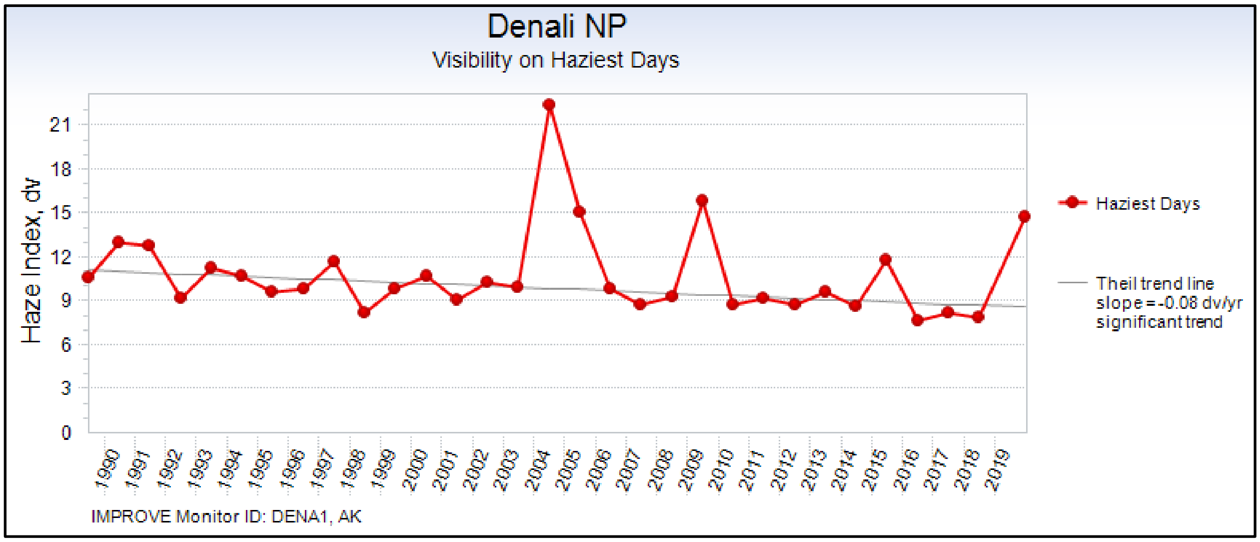
Source: FED 2020

Figure E.3.10. Visibility on the Clearest Days for Gates of the Arctic National Park



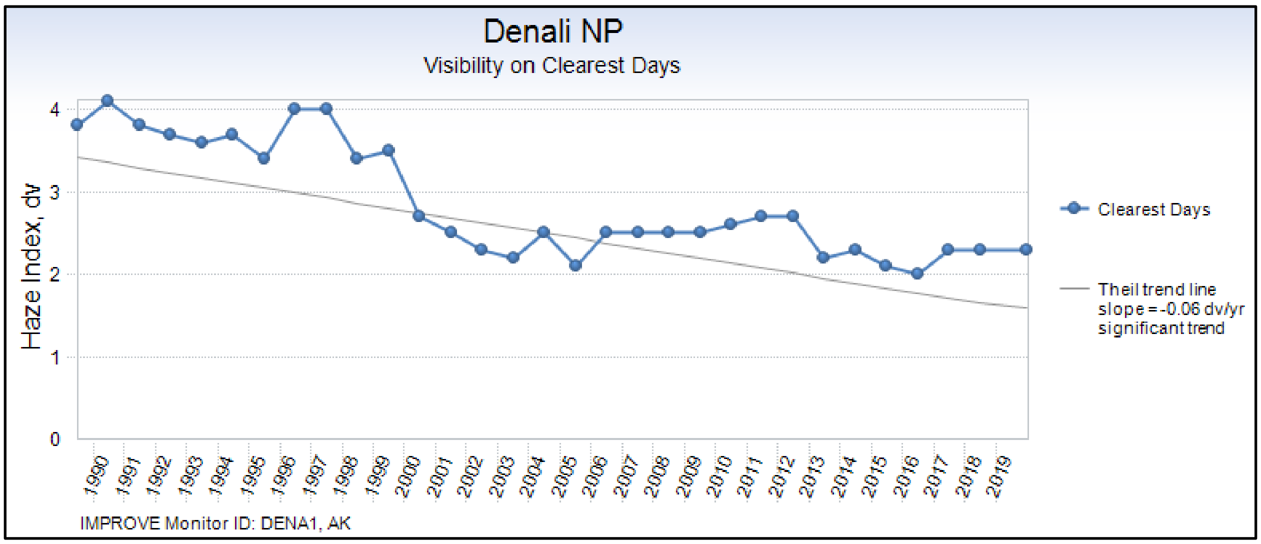
Source: https://views.cira.colostate.edu/fed/SiteBrowser/Default.aspx?appkey=SBCF_VisSum

Figure E.3.11. Visibility Data for Denali National Park*



Source: https://views.cira.colostate.edu/fed/SiteBrowser/Default.aspx?appkey=SBCF_VisSum

Figure E.3.12. Visibility on the Haziest Days for Denali National Park*



Source: https://views.cira.colostate.edu/fed/SiteBrowser/Default.aspx?appkey=SBCF_VisSum

Figure E.3.13. Visibility on the Clearest Days for Denali National Park

Table E.3.5. Visibility Data for Toolik Lake Field Station (TOOL1)*

Parameter	Statistic	Year	Value	Units	Network	Monitor ID	State
Visibility	Annual average haze index, haziest days	2019	11	dv	IMPROVE	TOOL1	AK
Visibility	Annual average haze index, clearest days	2019	3.6	dv	IMPROVE	TOOL1	AK

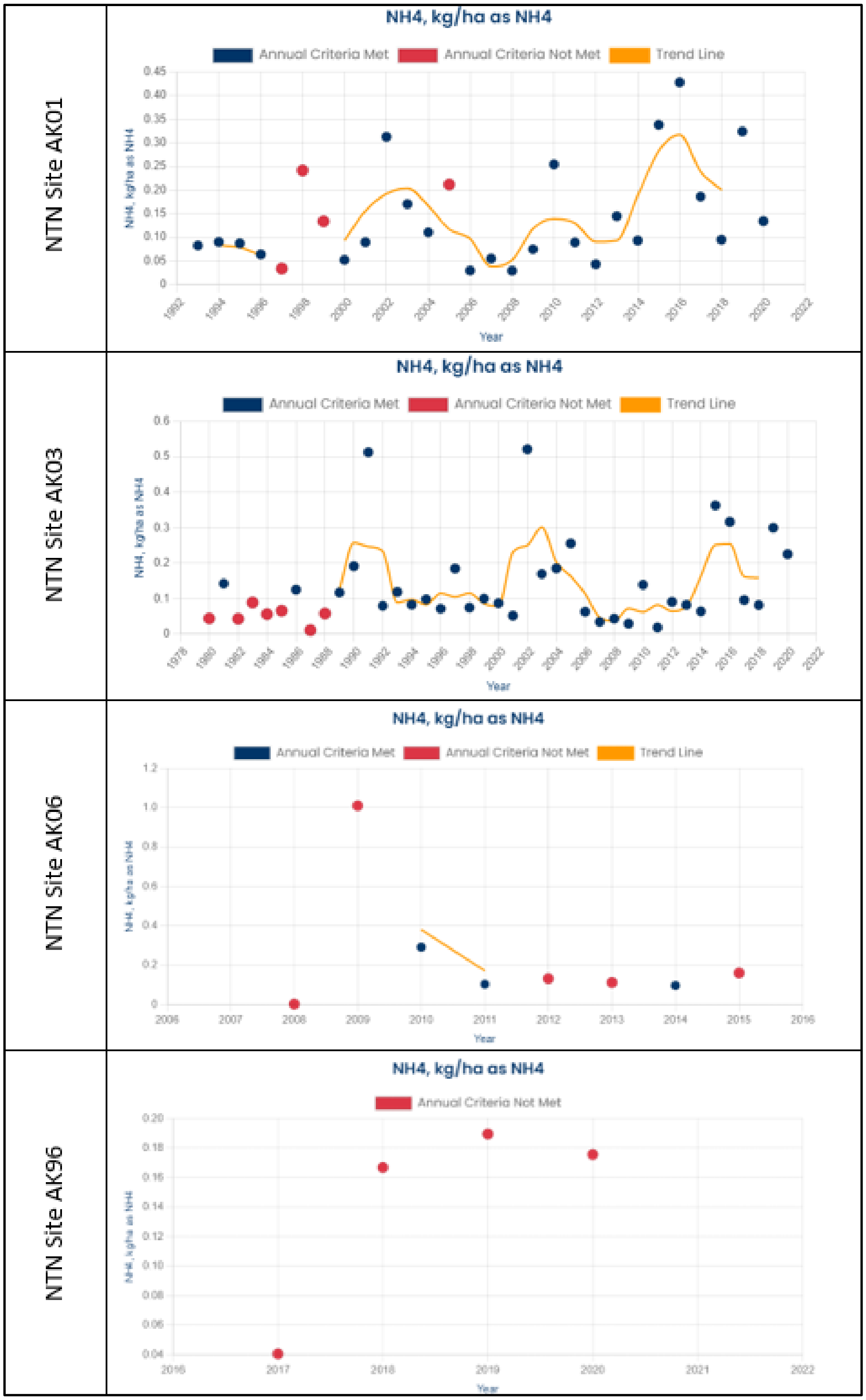
Note: AK (Alaska); dv (deciview); IMPROVE (Interagency Monitoring of Protected Visual Environments)
Source: https://views.cira.colostate.edu/fed/SiteBrowser/Default.aspx?appkey=SBCF_VisSum

1.1.3.3 Acid Deposition*

The National Trends Network (NTN) of the National Atmospheric Deposition Program (NADP) has monitoring stations throughout the United States. that monitor precipitation chemistry and measure wet deposition (NADP 2018). The closest active monitoring stations to the Project are at Gates of the Arctic National Park (NTN Site AK06), Poker Creek (NTN Site AK01), and Denali National Park (NTN Site

AK03), as shown in Figure E.3.1. The Toolik Lake Field Station (NTN Site AK96) began collecting acid deposition data in 2017. Trends in monitored wet deposition fluxes of ammonium (NH_4^-), NO_3^-, and SO_4^{2-} at each site are provided in Figures E.3.14, E.3.15, and E.3.16, respectively. The blue dots on the graphs indicate yearly concentrations that have met the annual completeness criteria, while the red dots indicate that yearly concentrations have not met the annual completeness criteria. Trendlines are also shown in black and represent a 3-year moving average where the minimum data completeness criteria are met for that 3-year period. The wet deposition fluxes of NH_4^-, NO_3^-, and SO_4^{2-} are small at all monitors (most annual values below 1.0 kilogram per hectare per year) with no apparent trend in most cases. However, the wet deposition fluxes of NO_3^- at Poker Creek have shown an upward trend over the last decade, and 2019 and 2020 had the two highest measurements in over two decades.

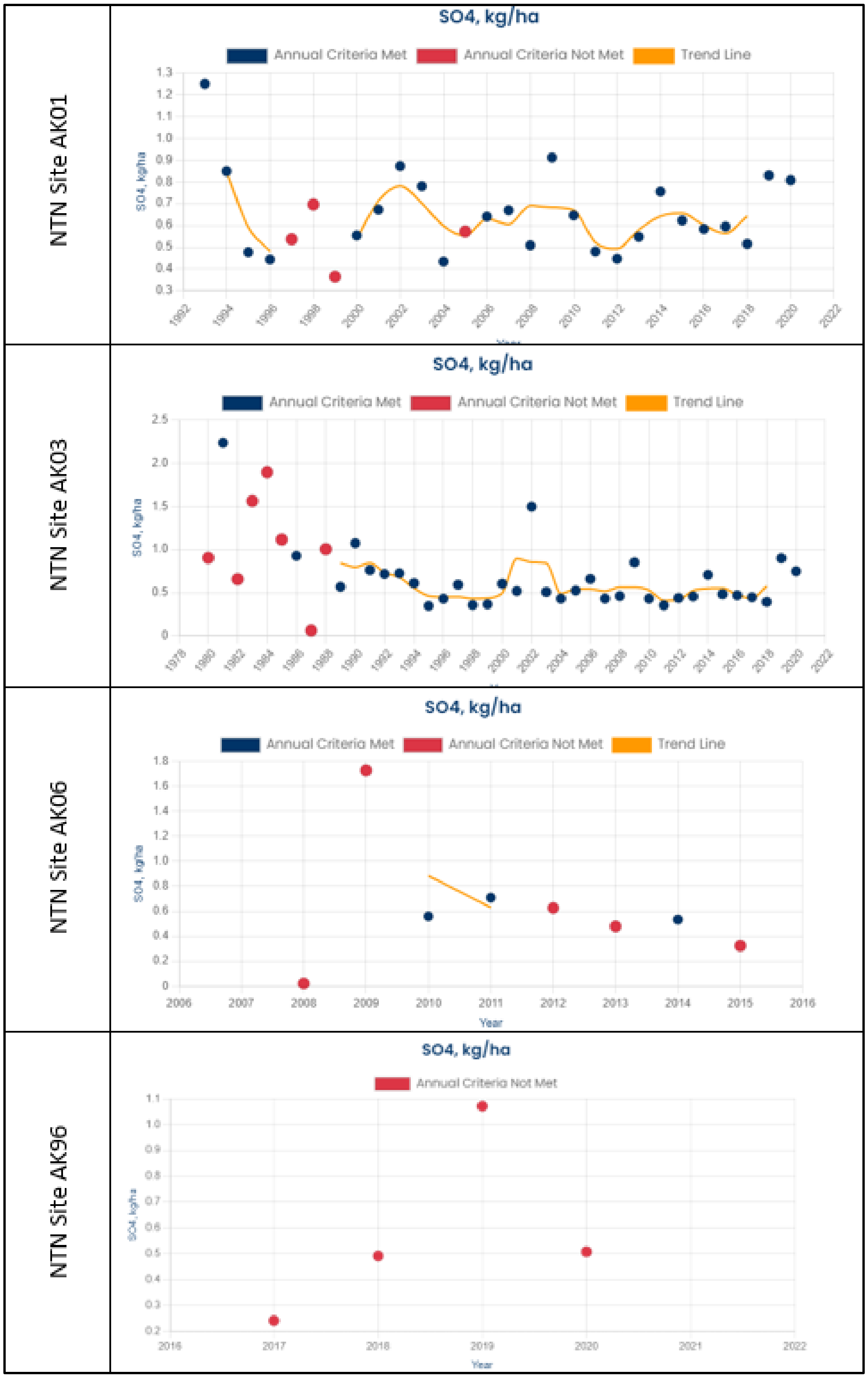
The NADP also provides estimates of total (wet and dry) sulfur and nitrogen deposition for critical load analysis and other ecological studies using a hybrid approach with modeled and monitoring data (NADP 2014). Wet deposition data from NTN, along with air concentration data from networks such as the Clean Air Status and Trends Network (CASTNET), is used (EPA 2018a). The estimated total deposition flux of nitrogen and sulfur is provided in Figure E.3.17 for Denali National Park for 1999 through 2020, which is the only monitor in Alaska with recent CASTNET data (DEN417 in Figure E.3.1). The highest monitored total deposition fluxes of nitrogen and sulfur occurred in 2002 and were 0.741 kilograms of nitrogen per hectare per year (kg N/ha/year) and 0.601 kilograms sulfur per hectare per year (kg S/ha/year), respectively. The mean deposition fluxes of nitrogen and sulfur are 0.297 kg N/ha/year and 0.287 kg S/ha/year, respectively. The total deposition flux of nitrogen was well below the critical load for nitrogen deposition defined by the FLMs for the tundra ecoregion of Alaska (1.0 to 3.0 kg N/ha/year) in all years.



Source: https://nadp.slh.wisc.edu/sites/ntn-AK03/

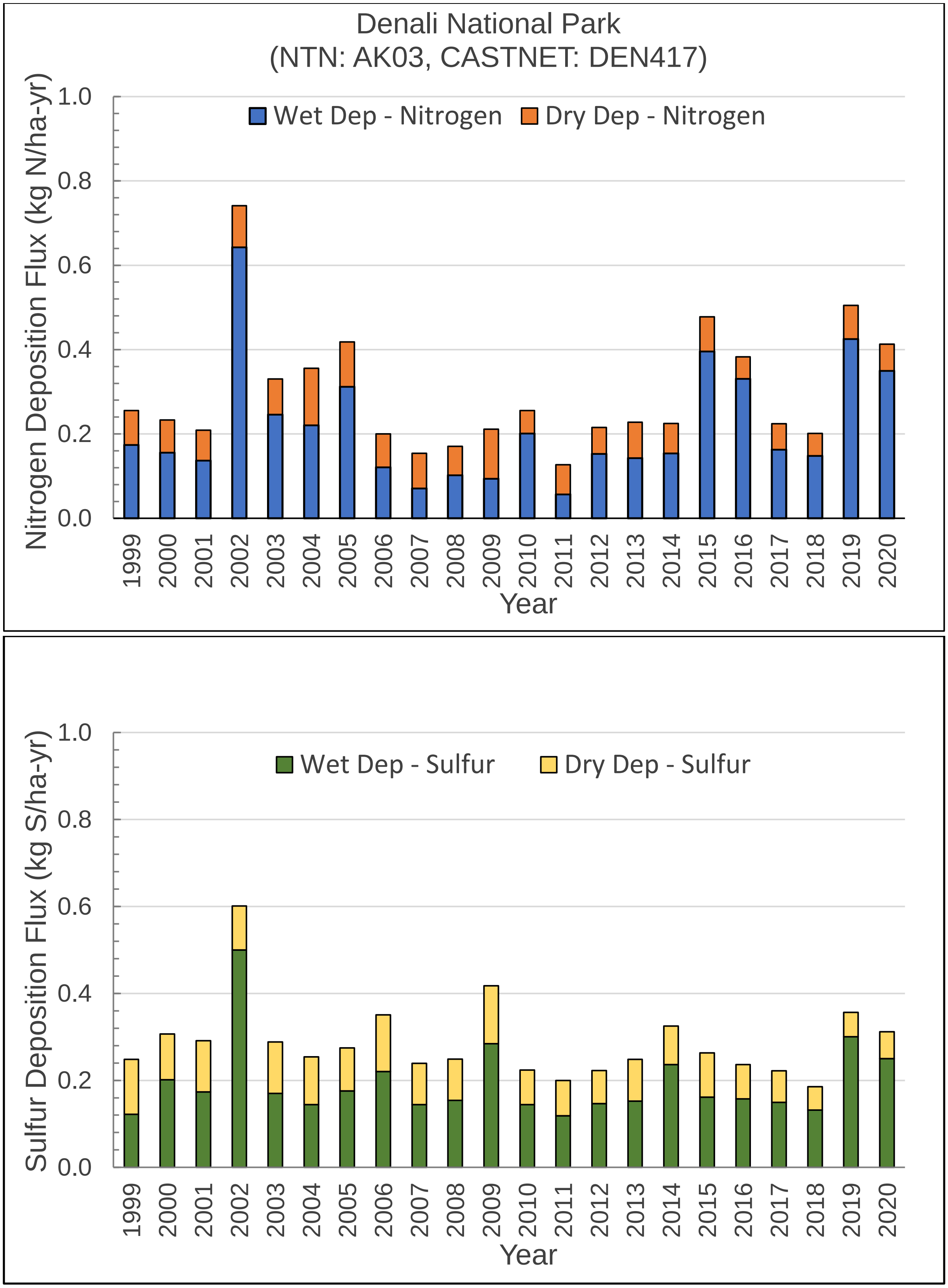
Figure E.3.14. Trends in Wet Deposition of Ammonium (NH_4^-) at Poker Creek (NTN Site AK01), Denali National Park (NTN Site AK03), Gates of the Arctic National Park (NTN Site AK06), and Toolik Lake Field Station (NTN Site AK96)*

Figure E.3.15. Trends in Wet Deposition of Nitrates (NO_3^-) at Poker Creek (NTN Site AK01), Denali National Park (NTN Site AK03), Gates of the Arctic National Park (NTN Site AK06), and Toolik Lake Field Station (NTN Site AK96)*



Source: https://nadp.slh.wisc.edu/sites/ntn-AK03/

Figure E.3.16. Trends in Wet Deposition of Sulfates (SO_4^{2-}) at Poker Creek (NTN Site AK01), Denali National Park (NTN Site AK03), Gates of the Arctic National Park (NTN Site AK06), and Toolik Lake Field Station (NTN Site AK96)*



Source: EPA 2018a

Figure E.3.17. Total Nitrogen and Sulfur Deposition Flux at Denali National Park*

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Willow Master Development Plan

Appendix E.3B
Air Quality Technical Support Documents

June 2022

Willow Master Development Plan
Draft Supplemental Environmental Impact Statement
Air Quality Technical Support Document

Prepared for:

United States Bureau of Land Management

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Date:
May, 2022

Project Number:
1690016338-010

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ATTACHMENTS*

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Attachment B Willow MDP CAMx Model Performance Evaluation
Attachment C Willow Development Emissions Inventory Report Alternative B and Module Delivery Option 3 (Proponent's Proposed Project)
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ACRONYMS AND ABBREVIATIONS

AAAQS	Alaska Ambient Air Quality Standards
AAB	Ambient Air Boundary
AAQS	Ambient Air Quality Standards
ACF	Alpine Central Processing Facility
ADEC	Alaska Department of Environmental Conservation
ANC	acid neutralizing capacity
ANCSA	Alaska Native Claims Settlement Act
AQRVs	air quality related values
AQTSD	Air Quality Technical Support Document
BLM	Bureau of Land Management
BOEM	Bureau of Ocean Energy Management
BT1	Drill Site BT1
BT2	Drill Site BT2
BT3	Drill Site BT3
BT4	Drill Site BT5
BT5	Drill Site BT5
BTU	Bear Tooth Unit
CAMx	Comprehensive Air Quality Model with Extensions
CCF	cloud cover fraction
CD1	Colville Delta 1
CD4	Colville Delta 4
CD4N	Colville Delta 4 North
CD8	Colville Delta 8
CH_4	methane
CMAQ	Community Multiscale Air Quality
CO	carbon monoxide
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CPAI	ConocoPhillips Alaska, Inc.
CPF2	Central Processing Facility 2
DAT	deposition analysis threshold
ddv	delta deciview
DS3S	Drill Site 3S
DS3T	Drill Site 3T
dv	deciview
DVC	current design values
DVF	future-year design values
EC	elemental carbon
EDGAR	Emissions Database for Global Atmospheric Research
EPS3	Emissions Processing System version 3
EIS	Environmental Impact Statement
ENEWS	Eastern Northeast West Sak
FB	fractional bias
FE	fractional error
FLAG	Federal Land Mangers' Air Quality Related Values Work Group
FINN	Fire Inventory
g	gram

GEOS	Goddard Earth Observing System
GIS	Geographical Information System
GHG	greenhouse gas
GMT1	Greater Mooses Tooth – 1
GMT2	Greater Mooses Tooth – 2
GMTU	Greater Mooses Tooth Unit
HAP	hazardous air pollutant
HDD	Horizontal Directional Drilling
HI	Haze Index
IOA	Index of Agreement
ICBC	initial and lateral boundary conditions
IMPROVE	Interagency Monitoring of Protected Visual Environments
IP	infrastructure pad
kbbl/day	thousand barrels per day
kg/ha-yr	kilograms per hectare per year
km	kilometer
kmile	thousand miles
kWe	thousand watts
LSM	land surface model
m/s	meters per second
MCICA	Monte-Carlo Independent Column Approximation
MCY	million cubic yards
MEGAN	Model of Emissions of Gases and Aerosols from Nature
MEI	maximally exposed individual
MI	miscible injectant
mg/m^3	milligrams per cubic meter
MLE	most likely exposure
MISR	Multi-angle Imaging Spectro-Radiometer
Mm-1	inverse megameters
MPE	model performance evaluation
MTI	Module Transfer Island
N_2O	nitrous oxide
NAAQS	National Ambient Air Quality Standards
NCAR	National Center for Atmospheric Research
NCDC	National Climate Data Center
NEPA	National Environmental Policy Act
NH_4	ammonium
NMB	normalized mean bias
NME	normalized mean error
NO_2	nitrogen dioxide
NO_3	nitrate
NODC	National Oceanographic Data Center
NP	National Park
NSB	North Slope Borough
NPS	National Park Service
NPR-A	National Petroleum Reserve - Alaska
NPRPA	Naval Petroleum Reserve Production Act
NWS	National Weather Service
O_3	ozone

OC	organic carbon
OLM	ozone limiting method
OMI	ozone monitoring system
PBL	planetary boundary layer
PGM	photochemical grid model
PM_{10}	particulate matter with an aerodynamic diameter less than or equal to 10 microns
$PM_{2.5}$	particulate matter with an aerodynamic diameter less than or equal to 2.5 microns
POI	periods of interest
ppb	parts per billion
ppm	parts per million
PRISM	Parameter-elevation Regressions on Independent Slopes Model
PSD	Prevention of Significant Deterioration
QA	quality assurance
QAPP	Quality Assurance Project Plan
QC	quality control
REL	reference exposure level
RfC	Reference Concentrations for Chronic Inhalation
RFFA	reasonably foreseeable future action
RMSE	root mean square error
RRF	relative response factor
RRTMG	Rapid Radiative Transfer Model for GCMs
SCAS	Spatial Climate Analysis Service
SEIS	Supplemental Environmental Impact Statement
sigma-w	vertical wind speed
sigma-theta	horizontal wind direction
SIP	State Implementation Plan
SMAT-CE	Software for Model Attainment Test - Community Edition
SMOKE	Sparse Matrix Operator Kernel Emissions
SO_2	sulfur dioxide
TOMS	Total Ozone Mapping Spectrometer
tpy	tons per year
TSD	Technical Support Document
TUV	total ultraviolet
URBOPT	urban option
US	United States
USDA	United States Department of Agriculture
USDOI	United States Department of the Interior
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
VMT	vehicle miles traveled
VOC	volatile organic compound
WRF	Weather Research and Forecasting model
Willow MDP	Willow Master Development Plan
TAPS	Trans Alaska Pipeline System
WPF	Willow Processing Facility
WOC	Willow Operations Center
YSU	Yonsei University
$\mu g/m^3$	micrograms per cubic meter

1.0 INTRODUCTION

The Bureau of Land Management (BLM) is preparing an Environmental Impact Statement (EIS) for the Willow Master Development Plan (Willow MDP, or simply 'Project') in compliance with the National Environmental Policy Act (NEPA). The Alaska State Office serves as the lead office for the EIS. The EIS for the Willow MDP analyses the Project's environmental consequences.

The Willow MDP could result in air emissions from construction, drilling and completion of new wells, operation and maintenance activities, and processing, storage, and transfer of liquid and gas products. Willow MDP's impacts on air quality and air quality related values (AQRVs) are analyzed by Ramboll under the direction of BLM Alaska. This Air Quality Technical Support Document (AQTSD) for the Willow MDP provides a detailed description of the Project's estimated emissions, air quality impact assessment methods, analysis and resulting impacts. The intent of the AQTSD is to supplement the information provided in the EIS.

1.1 Willow Master Development Plan

The Willow MDP is an oil and natural gas development project proposed by ConocoPhillips Alaska, Inc. (CPAI). The CPAI notified BLM that they propose to explore and develop hydrocarbon resources from oil and gas leases owned by CPAI within the Northeast Planning Area of the National Petroleum Reserve – Alaska (NPR-A). The Willow MDP EIS addresses a series of infrastructure components that would be constructed over an approximately 10-year period for oil and gas development in the NPR-A. With the Project area, CPAI may submit permit applications for up to five drill sites, a central processing facility, an operations center (previously referred to as infrastructure pad), gravel access roads, an airstrip, module delivery via sealift barges, import/export pipelines, and gravel mine sites on federal land in the NPR-A. The construction and operation of these facilities require permits from BLM.

CPAI's purpose for the Project is the economic production and transportation to market of oil and gas resources from Bear Tooth Unit (BTU), while protecting important surface resources and ensuring safe operations. To serve this purpose, CPAI needs permit approval to enable construction of drill sites, access and infield roads, pipelines, a processing plant, and other ancillary facilities. The Willow MDP would produce multiphase product (oil, gas, and water) that would be carried by pipeline to new processing facilities at the Willow Processing Facility (WPF). Sales-quality crude oil produced at WPF would be transported to Colville Delta 4 North (CD4N) at Alpine, where it would tie into the existing Alpine Sales Oil Pipeline. From the tie-in point, it would be transported to the Kuparuk Sales Pipeline and to the Trans-Alaska Pipeline System (TAPS) for shipment to market.

The BLM Alaska State Office manages the affected public lands in accordance with the Federal Land Policy and Management Act of 1982 (FLPMA), which mandates that BLM consider multiple uses for the lands it administers. FLPMA requires BLM to consider the land's natural and cultural resources as well as its mineral resources when making land management decisions. BLM's responsibility extends to environmental protection, public health, and safety associated with oil and gas operations on public lands. In compliance with NEPA, BLM evaluates a range of alternatives and analyzes and discloses the environmental effects of the alternatives. For the Willow MDP, BLM has developed five alternatives and three options related to the Module Delivery[1]:

- Alternative A (No Action)
- Alternative B (Proponent's Project)
- Alternative C (Disconnected Infield Roads)
- Alternative D (Disconnected Access)
- Alternative E (Three-Pad Alternative)
- Module Delivery Option 1 (Atigaru Point Module Transfer Island)
- Module Delivery Option 2 (Point Lonely Module Transfer Island)
- Module Delivery Option 3 (Colville River Crossing)

Action alternatives (B, C, and D) presented in the Final EIS include variations on specific Willow MDP components (e.g., project access). The Willow MDP Supplemental EIS (SEIS) also includes Alternative E, a three-pad alternative discussed below. Either of the three module delivery options could be combined with any of the action alternatives to provide the modules for the Project. The range of alternatives was developed to address the resource impact issues and conflicts identified during internal scoping with the BLM Interdisciplinary Team and external scoping with the public and cooperating agencies. Alternative E was developed to respond to the Alaska District Court's August 18, 2021 summary judgment order in the Willow litigation. The EIS analyzes and discloses impacts that would result from all four alternatives and three module delivery options. This AQTSD supplements information on the air quality and climate change impacts analyses reported in the EIS.

For the purposes of optimizing production efficiency in the future, CPAI evaluated connecting GMT2 with the WPF (CPAI, 2021). The Willow EIS air quality impact analysis accounts for the effect of potentially processing GMT2 produced fluids at the WPF as described below. If the development concept of connecting GMT2 to the WPF is implemented, during Willow construction, new infield pipelines would be constructed between GMT2 and the WPF. Additionally, power and fiber optic cables would be suspended beneath the pipelines from the WPF to GMT2 via messenger cable. There would be an increase in vehicular traffic during construction due to the additional construction of pipelines and vertical support members. The Willow EIS near-field air dispersion modeling accounts for the construction traffic increases to implement the additional processing capacity. There would be no change to the WPF size or to the capacity of fuel burning equipment at the WPF due to processing GMT2 production at the WPF (CPAI, 2021) as the equipment already account for the potential for additional production.

1.1.1 Alternative A (No Action)

Under the No Action Alternative, the Willow MDP would not be constructed; however, oil and gas exploration in the area would continue. The analysis of this alternative is included to provide a baseline for the comparison of impacts of the action alternatives (Section 6.6.2 of BLM NEPA Handbook H-1790-1; 40 CFR 1502.14(d)) (BLM, 2008).

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[1] Project modules would be transported to the vicinity of the Project Area by sea barge in the summer and stored until winter when the modules can be transported to the Project area over ice road. The exact location and method to store the modules are not yet finalized. Three module delivery options are assessed as part of the analysis and either option could be selected for any of the analyzed action alternatives.

1.1.2 Alternative B (Proponent's Project)

Under Alternative B, CPAI plans to drill 251 wells over a period of 10 years on five multi-well pads and to conduct drilling and development operations within the Project area on a year-round basis. The Project area shown in Figure 1.1-1 includes the full extent of the BTU and portions of the Greater Mooses Tooth Unit (GMTU) east toward the Colville River and north to include the offshore waters of Harrison Bay. Most of the proposed facilities associated with the Willow MDP are on leased federal lands within the northeastern portion of the NPR-A.

Supporting infrastructure would be in the GMTU, on un-unitized lands within the NPR-A, on lands owned by the Kuukpik Corporation, the Alaska Native Claims Settlement Act (ANCSA) village corporation for Nuiqsut, and on lands owned and managed by the State of Alaska. The proposed road corridor would tie into the access road in the GMTU to the east. Proposed pipelines would tie into existing pipeline infrastructure at CD4N, the Alpine Central Processing Facility (ACF), and the Kuparuk River Unit Central Processing Facility 2 (CPF2). Proposed pipelines cross lands owned by Kuukpik Corporation and the State of Alaska. A gravel site is proposed on federally managed lands within the GMTU and in un-unitized lands. In addition, infrastructure modules for the Project would be transported to the North Slope via sea barge. The method and location to transport the modules to the Project area still is under development. None of the proposed Willow facilities would be located on or near Native allotments or private land, except that the pipelines would use existing pipeline corridors, some of which are on private land.

Alternative B (Proponent's Project) would extend an all-season gravel road from the CPAI Greater Mooses Tooth-2 (GMT2) development southwest, paralleling Judy Creek toward the Project area (Figure 1.1-1). The access road would end at the WPF, and adjacent to an airstrip and Willow Operation Centre (WOC). Gravel infield roads would extend north and south of the access road to connect drill sites and Project infrastructure. Alternative B would construct 7 bridges (one on the access road extending from GMT2 and six on the infield roads). Infield (multiphase) pipelines would connect individual drill sites to the WPF and export/import pipelines would connect the WPF to existing infrastructure on the North Slope.

The proposed road alignment provides the shortest road access from the existing gravel road network in the GMTU to the Project facilities.

1.1.3 Alternative C (Disconnected Infield Roads)

Alternative C would have the same gravel access road between GMT2 and the Project area as Alternative B but would not include a gravel road connection from the WPF to Drill Site BT1 (BT1) (Figure 1.1-1).

With no gravel infield road between these two facilities, there would be no bridge across Judy Creek. A gravel infield road would connect BT1 with Drill Site BT2 (BT2) and Drill Site BT4 (BT4).

As there would not be a gravel road connection between the northern drill sites (BT1, BT2 and BT4) and the WPF and GMTU, additional equipment and infrastructure would be required under this Alternative. A second operation center (North WOC) and associated airstrip, storage and staging facilities, and camp would be located near BT1 or BT2 to accommodate the personnel and materials transport between the North WOC and BT1, BT2, and BT4. A seasonal ice road would be constructed annually to allow for the movement of large equipment and consumable materials to the northern three drill sites. Infield pipelines would connect all drill sites to the WPF; an import pipeline would connect BT1, BT2, and BT4 to the WPF and export/import lines would connect the WF to existing infrastructure on the North Slope.

Under Alternative C, the WPF, South WOC, and airstrip would be located approximately 5 miles east of their location in Alternative B, near the GMTU and BTU boundary. The gravel access road would end at the WPF and a gravel infield road would continue to BT3, WOC, Project airstrip, and BT5.

1.1.4 Alternative D (Disconnected Access)

Alternative D would not be connected by an all-season gravel access road to GMTU (Figure 1.1-1); however, it would employ the same gravel infield roads as proposed under Alternative B. Under this alternative the WPF is co-located with drill site BT3. All other Project components would be the same as those described under Alternative B (e.g., drill sites, airstrip, water source) with variations to roads and only 6 bridges.

Due to the lack of gravel access road to GMTU, a seasonal ice road would be required to transport materials and supplies into the Project area. Also, since the Project area would not be connected to Alpine, additional facilities including a grind and inject facility; additional warehouse space; a wireline/coil maintenance shop; a light duty fleet shop; storage and equipment laydown space; and biocide, methanol, and corrosion inhibitor tanks at the WOC would be required. There would be two additional Class I injection wells required at the WOC in addition to the two required for all alternatives. Larger permanent gravel pad space would also be required at both the WPF and WOC.

1.1.5 Alternative E (Three-Pad Alternative)*

Alternative E includes a WPF and four drill sites. Additional support facilities include a WOC, four valve pads, four pipeline pads, five water source access pads at lakes, , a gravel mine, gravel roads connecting the project to GMTU and all drill sites to the WPF, an airstrip, and three subsistence boat ramps (Figure 1.1-1).

Project facilities proposed at the WPF, drill sites, gravel pads, and WOC for Alternative E are generally the same as Alternative B, except that Alternative E would not include construction of drill site BT4, and drill site BT2 would be located farther north than under Alternative B. Also, BT5 would be located east of the location proposed for other action alternatives to avoid two yellow-billed loon nest setbacks; this would also reduce the length of the BT5 road and infield pipelines.

Alternative E would have a total of approximately 219 wells (CPAI, 2021). Eliminating drill site BT4 from the project design would reduce the gravel footprint, although the BT1 and BT2 drill sites would be approximately 100 feet longer to accommodate additional wells (up to 80 wells) to access portions of the resource that would otherwise be accessed from BT4. Eliminating BT4 from the project design would reduce the total length of infield lines, gravel and ice roads, and reduce freshwater use.

1.1.6 Module Delivery Options

Sealift barges would be used to deliver processing and drill site modules to the North Slope. Two of the three module delivery options analyzed would deliver modules to a nearshore staging area (NSA) referred to as a Module Transfer Island (MTI) west of the Colville River, either at Atigaru Point or Point Lonely, and use ice roads to reach the Willow Development. The third module delivery option (Colville River Crossing) would use existing gravel roads and land-based ice road for delivery.

1.1.6.1 Option 1: Atigaru Point MTI

Option 1 (Atigaru Point Module Transfer Island) would include the construction of a gravel MTI, with a design life of 5 to 10 years, near Atigaru Point in Harrison Bay (Figure 1.1-2). The MTI would be in State of Alaska-owned waters approximately 2 miles north of Atigaru Point. Modules would be offloaded onto the MTI and then transported to the Plan Area on ice roads.

1.1.6.2 Option 2: Point Lonely MTI

Option 2 (Point Lonely Module Transfer Island) would include the construction of an MTI, with a design life of 5 to 10 years, at Point Lonely (Figure 1.1-2). The MTI would be in State of Alaska-owned waters approximately 15 miles east of Smith Bay near the Point Lonely Distant Early Warning site. Key differences from Option 1 (Atigaru Point Module Transfer Island) include the length of ice road needed to reach the MTI location, and the use of existing gravel at Point Lonely to facilitate module offload.

1.1.6.3 Option 3: Colville River Crossing

Option 3 (Colville River Crossing) would use the existing Oliktok Dock for sealift module delivery and then move the modules to the Plan Area via an ice-road crossing of the Colville River near Ocean Point (Figure 1.1-3). Option 3 would use existing gravel roads and land-based ice roads for transporting modules along a southerly route from Oliktok Dock, via Kuparuk drill site 2P (DS2P) and GMT2, to the WPF.

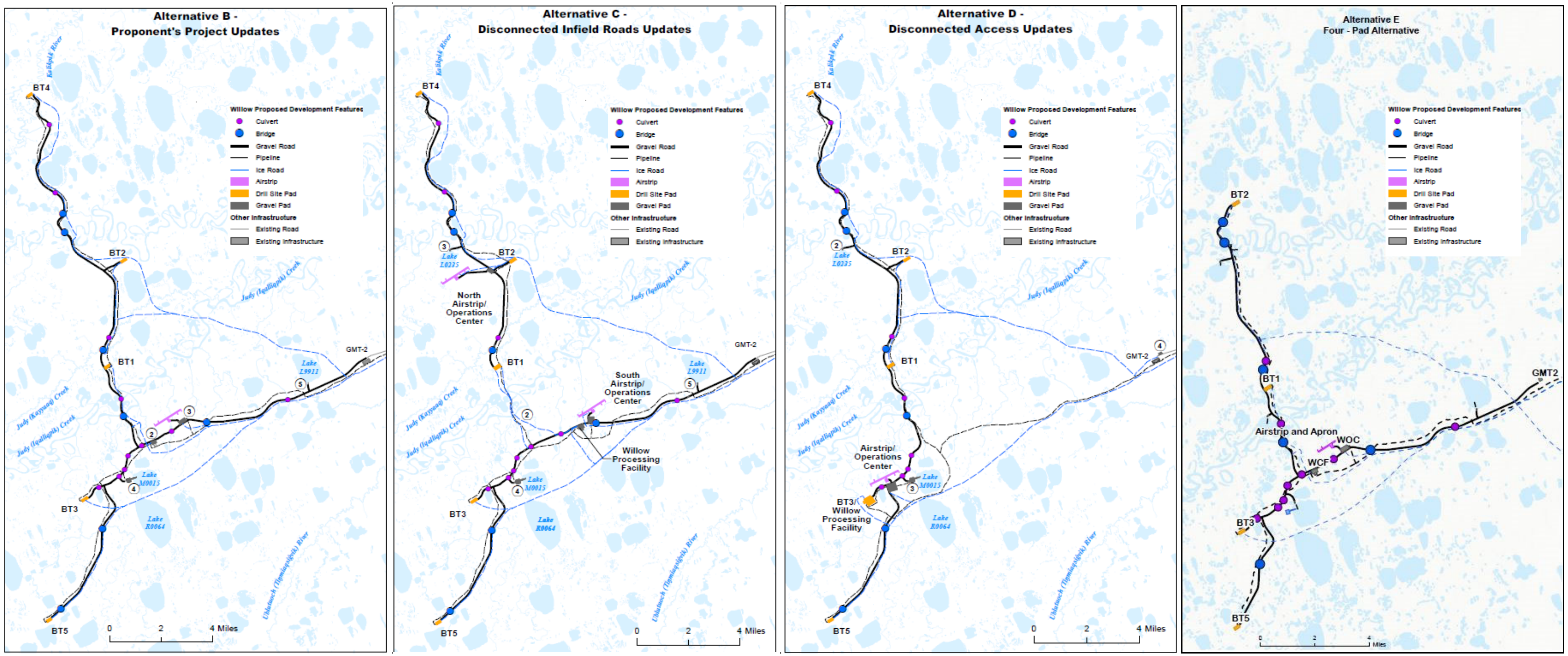


Figure 1.1.1 Project Features Map for Alternatives B, C, D and E

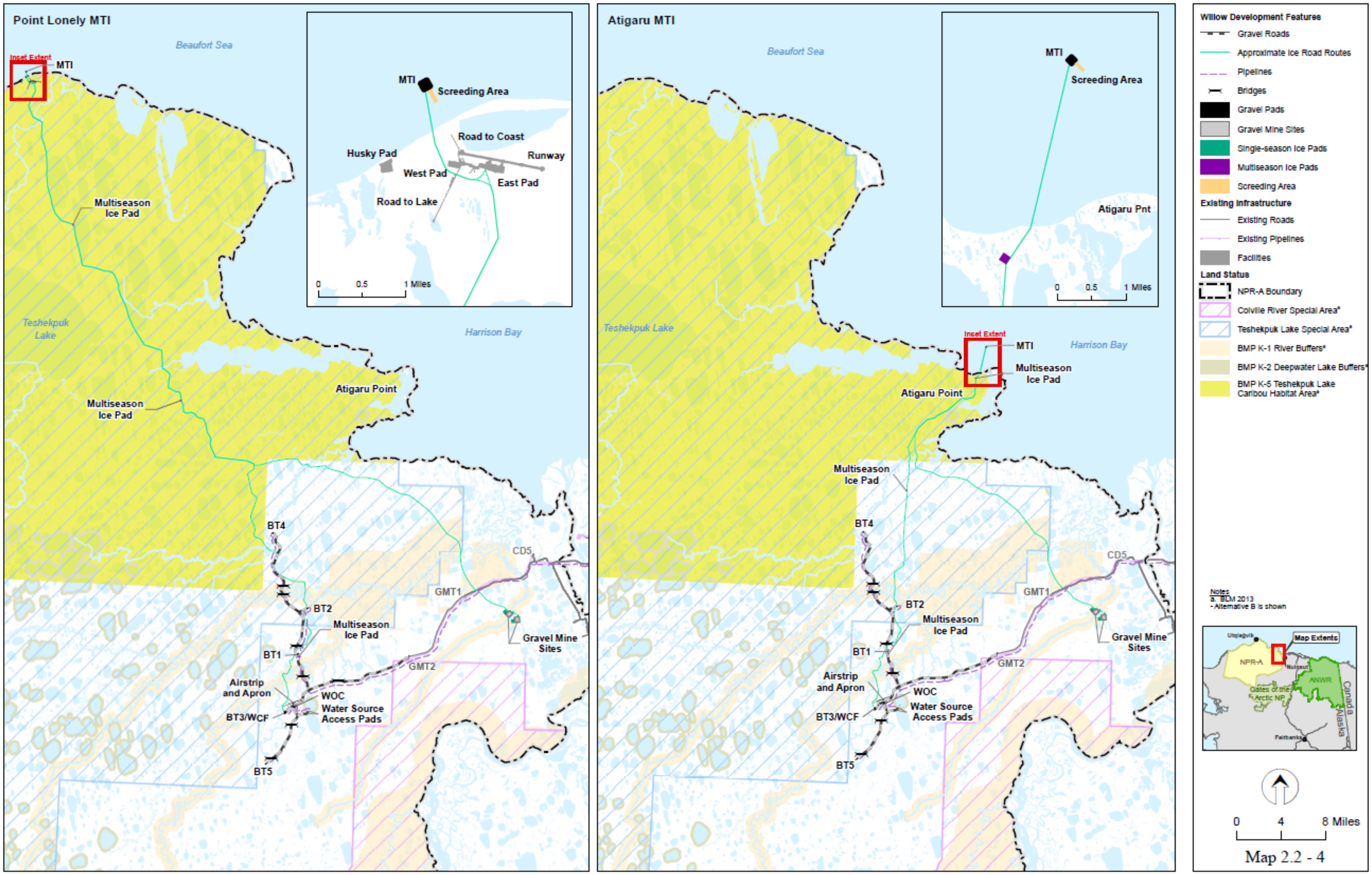


Figure 1.1.2 Module Delivery Options 1 and 2 Map

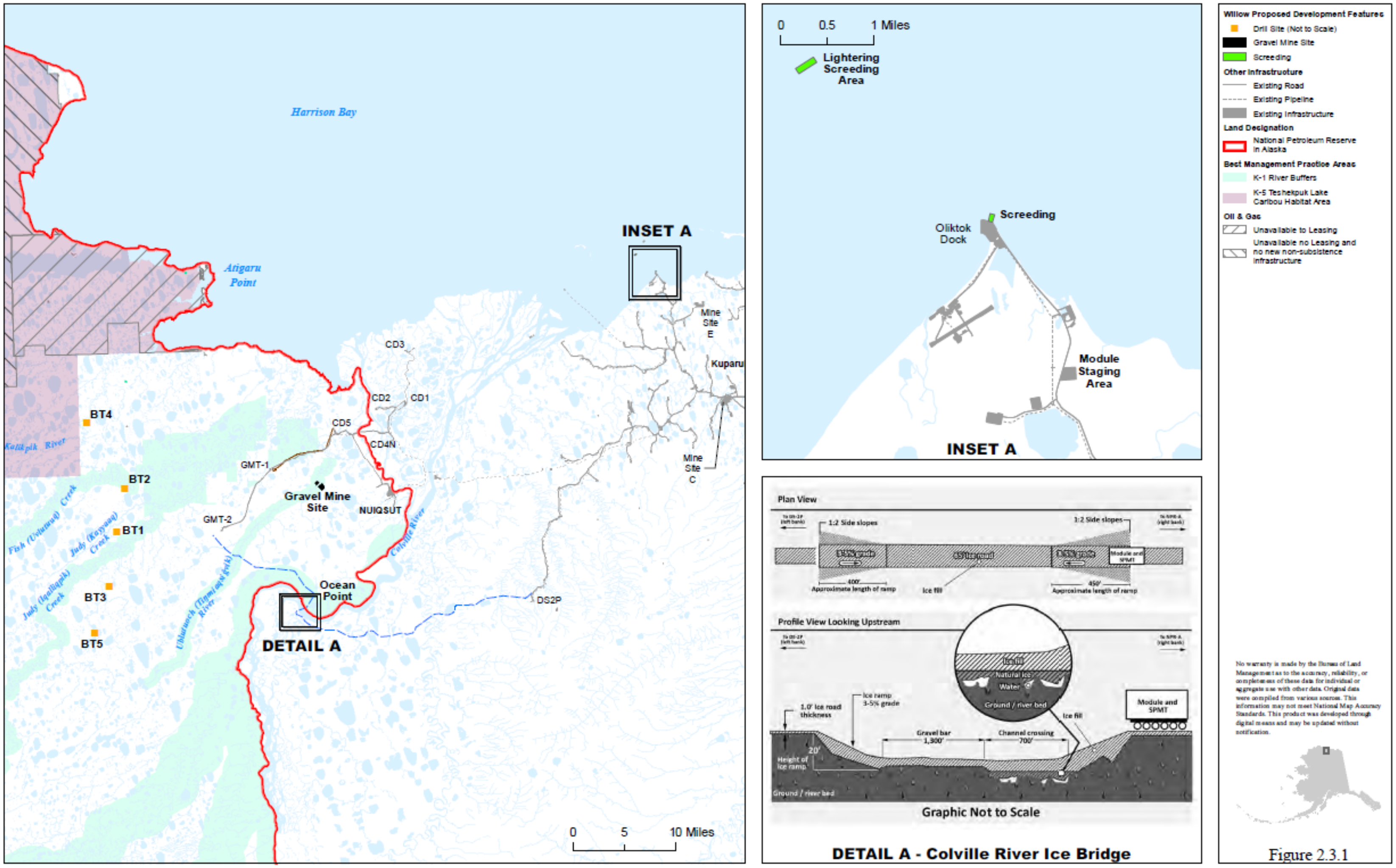


Figure 1.1.3 Module Delivery Options 3 Map

1.2 Air Quality Assessment Overview

BLM Alaska convened Air Resource Specialists at key cooperating agencies to review and comment on the analyses for the Willow MDP EIS. The Agency Air Resource Specialists included representatives from USEPA, National Park Service (NPS), U.S. Fish and Wildlife Service (USFWS), Alaska State Department of Environmental Conservation (ADEC), the Bureau of Ocean and Energy Management (BOEM) and others. The Agency Air Resource Specialists reviewed and commented on the Willow MDP Air Modeling and Assessment Protocol, referred to hereafter as "Willow MDP Protocol (Ramboll 2018)". Some air resource specialists also participated in the review of air quality and AQRV impact analyses documented in this AQTSD for the Willow MDP.

As prescribed in the Willow MDP Protocol (Ramboll 2018), the USEPA guideline air quality model, AERMOD, is used to estimate air quality impacts in the near-field (within 50 kilometers (km)) of the Willow MDP while the Comprehensive Air Quality Model with Extensions (CAMx) modeling system is used to estimate regional impacts (approximately within 300 km). AERMOD is used to predict the potential localized impacts while CAMx is to predict the potential impacts on larger spatial scales that reflect the long-range transport and chemical reaction of atmospheric pollutants. This section provides an overview of the modeling objectives and the approach used to assess impacts to air quality and AQRVs for the Willow MDP.

1.2.1 Modeling Objective

The objective of this analysis is to estimate the potential Willow MDP and cumulative air quality and ARQV impacts for each action alternative. Air quality and AQRV impacts were assessed within the vicinity of the Project area, at discrete sensitive receptor locations, and at three federally managed areas with receptor locations of interest, referred to hereafter as the "three assessment areas": Arctic National Wildlife Refuge (ANWR), Gates of the Arctic National Park, and Noatak National Preserve. Specifically, the air quality modeling includes:

- An assessment of air quality impacts for criteria pollutants, including ozone (O_3), particulate matter (PM) with an aerodynamic diameter less than or equal to 2.5 microns ($PM_{2.5}$), PM with an aerodynamic diameter less than or equal to 10 microns (PM_{10}), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon monoxide (CO)
- Hazardous Air Pollutant (HAP) impact assessment of benzene, toluene, ethylbenzene, xylene (collectively referred to as BTEX), n-hexane, and formaldehyde[2]; and
- An AQRV analysis to assess changes in visibility and atmospheric deposition.[3]

The near-field impact assessment is conducted with the AERMOD model to assess criteria pollutants (excluding ozone and lead) and the hazardous air pollutants (HAPs) listed above within 50 km of the Willow MDP. The regional impact assessment is conducted with the CAMx modeling system to assess criteria pollutants (except lead) and AQRVs within the vicinity of the Project area and at three assessment areas within 300 km of the Project area.

[2] These six HAPs were selected for analysis as BTEX and n-hexane are present in the raw natural gas and oil. Formaldehyde is formed from the combustion of small chain alkanes that predominate in natural gas.
[3] An analysis of the change to ANC of sensitive lakes is not conducted since lake data to assess the change in ANC are not currently available.

In accordance with Required Operating Procedure (ROP) A-7 described in Table 3.3.4 in Section 3.3 *Air Quality*, BLM may require additional air quality modeling for analyzing project direct, indirect, or cumulative impacts on air quality, air quality-related values, and hazardous air pollutants. BLM may require air quality modeling depending on the following:

* The magnitude of potential air emissions from the project

* Proximity to a federally mandated Class I area

* Proximity to a population center

* Proximity to a non-attainment or maintenance area

* Meteorological or geographic conditions

* Existing air quality conditions

* Magnitude of existing development in the area

* Issues identified during the NEPA process

BLM will determine the information required for a project-specific modeling analysis through the development of a modeling protocol for each analysis.

BLM may require the proponent to provide an emissions reduction plan that includes a detailed description of permittee-committed measures to reduce project-related air pollutant emissions.

1.2.2 Modeling Description

*1.2.2.1 Near-Field Modeling**

AERMOD (USEPA 2017 and 2018) is the current USEPA-approved regulatory model to assess near-source effects of primary pollutants. The AERMOD model was developed by the American Meteorological Society/USEPA Regulatory Model Improvement Committee (AERMIC) and was intended to incorporate an improved understanding of the planetary boundary layer (PBL) meteorology into air dispersion calculations. The AERMOD modeling system also includes the meteorological preprocessor AERMET, which was used for processing the meteorological data for the Project analysis. AERMOD is a refined dispersion model for simple and complex terrain for receptors within 50 km of a modeled source. For the Willow MDP EIS, AERMOD has been used to assess near-field impacts of criteria pollutants (except ozone and lead), and a subset of HAPs (as listed in Section 1.2.1 “Modeling Objective”) near the Project area for comparison to applicable National Ambient Air Quality Standards (NAAQS) and Alaska Ambient Air Quality Standards (AAAQS) (collectively referred to as Ambient Air Quality Standards [AAQS]) and Prevention of Significant Deterioration (PSD) Class II increments.

The latest version of AERMOD (v21112) was not available at the time the Project analysis was performed. AERMOD (v19191) was used for all Project analyses. The changes made to AERMOD version 21112 as documented by EPA (2021a) are expected to have negligible effect on model-predicted Project impacts given the modeled Project sources and model settings.

Action alternatives (Alternative B, C and D) were modeled in the near-field modeling analysis.
The modeled Project features represented the actual features under each of those alternative with one exception. The proponent (CPAI) included some design changes in Alternatives B and D that resulted in small changes to the locations (moved by 0.25 miles or less) and size, shape and orientation of the WPF, Willow Operations Center (WOC), and airstrip. Following discussions with the Agency Air Resource Specialists, the original configuration was modeled as it was determined that it would provide an acceptable assessment of the revised Project design because the changes were expected to have a minimal effect on the air quality assessment conclusions. Action Alternative E was not explicitly

modeled in the near-field analysis because several design features are similar to Alternative B, and instead air quality impacts under Alternative E are assessed based on project design differences and emissions inventory differences relative to Alternative B.

*1.2.2.2 Regional Modeling**

CAMx is a publicly available state-of-the-art photochemical modeling system. It has been used to analyze air quality impacts in previous modeling studies in the U.S., including State Implementation Plans (SIPs), NAAQS assessments (Tyler Fox 2017) and other EISs, and to support USEPA rulemaking. The BOEM Arctic Air Quality Modeling Study (referred to as the BOEM modeling platform or BOEM study) offers a CAMx modeling platform that serves as the starting point to assess regional air quality and AQRVs for the Willow MDP EIS. The BOEM study is intended to facilitate air resource analyses for federal and state stakeholders as part of the NEPA process for offshore oil and gas development activities. The BOEM modeling platform was selected for this project since it provides input photochemical modeling data for the region suitable for this study. The Weather Research and Forecast (WRF) Model and the Sparse Matrix Operator Kernel Emissions (SMOKE) models provide meteorological and emissions inputs respectively to the CAMx photochemical grid model. Collectively, these three models are referred as the CAMx modeling system. The CAMx modeling system applied for this assessment includes:

- WRF (version 3.6.1): State-of-science mesoscale numerical weather prediction system capable of supporting urban- and regional-scale photochemical and regional haze regulatory modeling studies.
- SMOKE (version 3.6): Emissions modeling system that generates hourly, gridded, and speciated emissions inputs of onroad, nonroad, area, point, fire, biogenic emissions and other sources for photochemical grid models.

CAMx (version 6.5): State-of-science ‘One-Atmosphere’ photochemical grid model capable of addressing ozone and other criteria pollutants, visibility, and atmospheric deposition. The latest version of CAMx (v7.20) was not available at the time the regional modeling was performed. The changes made to CAMx version 7.20 (Ramboll 2022) are expected to have negligible effects on the model-predicted Project impacts given the model settings and Project sources considered in this analysis.

The CAMx modeling system is applied to model the air quality in the following emissions scenarios:

- **2012 Base Year**. The 2012 Base Year is based on the BOEM emissions inventory, described in more detail in Section 2.3.2 “Regional Emissions Inventories”. The 2012 Base Year simulation provides a retrospective assessment of model performance relative to measured 2012 ambient air quality conditions. Results from this simulation are also used in the estimation of future year cumulative visibility impacts (see Section 4.5.4.2 “Cumulative Impacts”).
- **Cumulative No Project Scenario**. This is a scenario with all cumulative sources except the Project sources. The Cumulative No Project Scenario is based on the future year scenario developed for the BOEM modeling platform and includes updated estimates of Reasonably Foreseeable Future Action (RFFA) emissions without the contribution from the Project-specific emissions. This scenario includes emissions from all projects other than the Willow MDP to provide a baseline for the comparison of impacts of the action alternatives. The emissions inventory for this analysis is described in more detail in Section 2.2 “Cumulative Emissions for

the Willow Alternatives". The effects of long-range transport are modeled through the use of boundary conditions (background concentrations).

- **Cumulative Alternative B (Proponent's Project) Scenario**. CPAI developed a project-specific emissions inventory for the Willow MDP EIS. BLM reviewed and revised the emissions inventory. To assess future cumulative impacts in Alternative B, the Alternative B emissions inventory is modeled along with the RFFAs and regional sources included in the Cumulative No Project Scenario. The effects of long-range transport are modeled through the use of the same boundary conditions used in the previous scenario.
- **Cumulative Alternative C (Disconnected Infield Access) Scenario**. BLM developed an emissions inventory for Alternative C (see Section 2.1.4 "Alternative C") based on the emissions inventory for Alternative B. To assess future cumulative impacts for Alternative C, the Alternative C emissions inventory is modeled along with the RFFAs and regional sources included in the Cumulative No Project Scenario. The effects of long-range transport are modeled through the use of the same boundary conditions used in the other scenarios.

BLM developed an emissions inventory for Alternatives D and E as well (see Sections 2.1.5 "Alternative D" and 2.1.6 "Alternative E"). Willow MDP NOx emissions in Alternative D are lower than Alternative C (see Sections 2.1.4 "Alternative C" and 2.1.5 "Alternative D"). Willow MDP NOx emissions in Alternative E are lower than Alternative B (see Sections 2.1.3 "Alternative B" and 2.1.6 "Alternative E"). Therefore, as discussed with the Agency Air Resource Specialists, Alternatives D and E were not modeled in the regional modeling and their impacts are expected to be lower than those of Alternative C and B respectively. Similarly, Alternative E was not modeled in the regional modeling as its regional impacts are expected to be lower or comparable to those of Alternative B considering the differences in emissions between those two alternatives (see Sections 2.1.3 and 2.1.6).

The potential air quality impacts due to the Project are derived using a "brute force" method by subtracting the Cumulative No Project Scenario from the Cumulative Alternative B or C Scenario. The CAMx model results were used to assess Project and cumulative effects on:

1. NAAQS, AAAQS and PSD Class II increments
2. Visibility
3. Atmospheric deposition rates of sulfur (S) and nitrogen (N)

1.2.3 Overview of Modeling Approach and Thresholds for Comparison

1.2.3.1 National and Alaska Ambient Air Quality Standards

NAAQS and AAAQS are shown in Table 1.2-1 for all applicable criteria pollutants and averaging periods.[4] Note that the standards are either in parts per million (ppm), parts per billion (ppb), milligrams per cubic meter (mg/m^3) and micrograms per cubic meter (μg/m^3).

[4] As described in the Willow MDP Protocol (Ramboll 2018), both federal and state ambient air quality standards include lead and state standards include ammonia; however, neither lead nor ammonia was assessed due to low emission rates of these pollutants. Willow MDP combustion sources are either diesel- or natural gas-fired. Diesel fueled combustion sources contain only trace amounts of lead, if any at all. Natural gas fueled combustion sources do not contain any lead. Lastly, the proposed Willow MDP equipment produces negligible ammonia emissions.

Table 1.2-1 NAAQS and AAAQS Values

Pollutant	Average Time	NAAQS[a]	AAAQS[b]	Form of the Standard
CO	1-hour	35 (ppm) (40,000 µg/m^3)	40 (mg/m^3) (40,000 µg/m^3)	Not to be exceeded more than once per year
	8-hour	9 ppm (10,000 µg/m^3)	10 mg/m^3 (10,000 µg/m^3)	Not to be exceeded more than once per year
NO_2	1-hour	100 (ppb) (188 µg/m^3)	188 µg/m^3	98th percentile of 1-hour daily maximum concentrations, averaged over three years
	Annual	53 ppb (100 µg/m^3)	100 µg/m^3	Annual mean
SO_2	1-hour	75 ppb (196 µg/m^3)	196 µg/m^3	99th percentile of 1-hour daily maximum concentrations, averaged over three years
	3-hour	0.5 ppm (1300 µg/m^3)	1300 µg/m^3	Not to be exceeded more than once per year
	24-hour	NA	365 µg/m^3	Not to be exceeded more than once per year
	Annual	NA	80 µg/m^3	Annual mean
Ozone	8-hour	0.070 ppm (137 µg/m^3)	0.070 ppm	Annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years
PM_{10}	24-hour	150 µg/m^3	150 µg/m^3	Not to be exceeded more than once per year on average over three years
$PM_{2.5}$	24-hour	35 µg/m^3	35 µg/m^3	98th percentile avg over three years
	Annual	12 µg/m^3	12 µg/m^3	Annual mean averaged over three years

[a] 40 CFR Part 50
[b] 18 AAC 50.010

1.2.3.2 Prevention of Significant Deterioration Increments

Project impacts were assessed relative to PSD increments (shown in Table 1.2-2) for informational purposes. It is important to note that a PSD increment assessment is the jurisdiction of ADEC and the proposed analysis differs from a formal increment consumption assessment in several important ways:

1. It has not been determined that Project emissions would trigger PSD permitting requirements. Such an assessment would be conducted as part of the air quality permitting preconstruction process as part of New Source Review Clean Air Act permitting requirements.
2. If PSD permitting and associated modeling analyses are required, the increment consumption analysis would only assess Project emissions that are required to be assessed; however, this assessment of Project impacts includes all Project emissions sources which would result in a conservatively high estimate of potential increment consumption.

Modeled Project impacts due to the action alternatives are compared to PSD increments shown in Table 1.2-2. Near-field Project impacts at the Nuiqsut receptor location and far-field Project impacts at three assessment areas were compared to PSD increments.

Table 1.2-2 PSD Increments for Class II Areas

Pollutant	Average Time	Class II PSD Increment[1]
NO_2	Annual	25 µg/m^3
SO_2	3-hour	512 µg/m^3
	24-hour	91 µg/m^3
	Annual	20 µg/m^3
PM_{10}	24-hour	30 µg/m^3
	Annual	17 µg/m^3
$PM_{2.5}$	24-hour	9 µg/m^3
	Annual	4 µg/m^3

[1]Referenced from 40 CFR Part 52 Subpart A

1.2.3.3 Hazardous Air Pollutant Thresholds of Comparison

Model-predicted and background measured 1-hour concentrations of HAPs were assessed against the USEPA Reference Exposure Levels (RELs) shown in Table 1.2-3. Emissions were calculated for benzene, toluene, ethylbenzene, xylenes, n-hexane, and formaldehyde. Acute RELs are defined as concentrations at, or below which, no adverse health effects are expected. No RELs are available for ethylbenzene or n-hexane; instead, Acute Exposure Guideline Levels (AEGLs) have been used as thresholds. In addition, exposures were assessed for 8-hour average impacts. RELs and relevant exposure guidelines were obtained from USEPA's Air Toxics Database (USEPA 2021b).

Table 1.2-3 Air Toxic Acute and Reference Exposure Levels[1]

Select HAPs	Acute REL (mg/m^3)	AEGLs (mg/m^3)
Benzene	0.027	29
Toluene	5	250
Ethyl benzene	--[2]	140[2]
Xylene	22	560
n-Hexane	--[2]	10,000[2]
Formaldehyde	0.055	1.1

1 USEPA Dose-Response Assessment for Assessing Health Risks Associated with Exposure to Hazardous Air Pollutants - Table 2 (USEPA 2021b).
2 No REL available for these HAPs. Values shown are from acute exposure guideline levels for mild or moderate effects (USEPA 2021b).

In addition, modeled long-term (annual) concentrations were assessed against non-carcinogenic RfCs for chronic inhalation (USEPA 2021c). A Reference Concentration for Chronic Inhalation (RfC) is defined by the USEPA as the threshold at which no long-term adverse health effects are expected. Annual modeled air toxic concentrations were compared directly to the non-carcinogenic chronic RfCs shown in Table 1.2-4. For the carcinogenic HAPs being analyzed (benzene, ethylbenzene, and formaldehyde), cancer risks were also calculated and assessed against a 1-in-1 million cancer threshold. The threshold range was determined from the Superfund National Oil and Hazardous Substances Pollution Contingency Plan (U.S. Government Printing Office 2011), which states that "For known or suspected carcinogens, acceptable exposure levels are generally concentration levels that represent an excess upper bound lifetime cancer risk to an individual of between 10^{-4} and 10^{-6} using information on the relationship between dose and response." The thresholds 10^{-4} and 10^{-6} correspond to a level of 1 in 10,000 and 1 in 1 million, respectively.

Cancer inhalation risk due to long-term exposure to respective air toxic was calculated by multiplying the annual modeled concentration by the cancer unit risk factor and multiplying this product by an applicable exposure adjustment factor, as shown in Table 1.2-5. These exposure factors are intended to represent the ratio of projected exposure time to 70 years. The adjustment factors represent two assessments: the maximum exposed individual (MEI) and the maximum likelihood estimate (MLE). To estimate impacts for the MEI, the maximum annual concentration from all modeled meteorological years were used to calculate the cancer inhalation risk while to estimate impacts for the MLE, the average annual concentration from all modeled meteorological years were used to calculate the cancer inhalation risk. The only receptor where the cancer risk was calculated is the community of Nuiqsut where individuals would be potentially exposed on a long-term basis. The calculated cancer risk was compared to a risk range of one in a million (USEPA, 2006a).

Table 1.2-4 Air Toxic Non-Carcinogenic Chronic Reference Concentrations

Select HAPs	Non-Carcinogenic Chronic RfC (mg/m^3)[1]
Benzene	0.03
Toluene	5.0
Ethyl benzene	0.26
Xylenes	0.1
n-Hexane	0.7
Formaldehyde	0.0098

1 USEPA Dose-Response Assessment for Assessing Health Risks Associated with Exposure to Hazardous Air Pollutants - Table 1 (USEPA 2021c).

Table 1.2-5 Cancer Unit Risk factors and Exposure Adjustment Factors for Select HAPs

Pollutant	Cancer Unit Risk Factors (1/(µg/m^3))[1]	Exposure Adjustment Factor[2]
Benzene	7.8E-06	0.43
Ethylbenzene	2.5E-06	
Formaldehyde	1.3E-05	

[1]Values referenced from USEPA, 2021c

[2]The MLE scenario assumes the same exposure as the MEI. The MEI scenario assumes that the individual is at home 100% of the time for the life of the Project. The life of the Project is assumed to be 30 years (i.e., an assumed typical life of a project), corresponding to an adjustment factor of 30/70 =0.43

In addition to the individual HAP carcinogenic assessment discussed in above sections, a cumulative carcinogenic assessment was performed. The assessment described in this section is unique in that it considered the potential combined effects of multiple carcinogenic agents emitted. It is possible that cancer risks due to the individual carcinogens emitted (benzene, ethylbenzene, and formaldehyde) may compound and overlap during specific meteorological conditions. The assessment included calculating a total cancer risk (for comparison to the 1-in-1 million threshold). For each HAPs impact assessment modeled configuration, the following process was used with these calculations:

1. For each of the three carcinogenic pollutants (benzene, ethylbenzene, and formaldehyde), the maximum modeled annual concentration over the 5 years modeled at the Nuiqsut receptor was determined.
2. The individual cancer risk for each of the three pollutants was obtained by multiplying the maximum concentration by the pollutant's respective unit risk factors and exposure adjustment factors (found in Table 1.2-5).

3. The individual cancer risks from each pollutant were added to estimate the total cancer risk.

This assessment conservatively takes the highest modeled impact over five years' worth of meteorology data. However, it is important to remember that it is uncertain how cancer risks associated with multiple carcinogens would actually compound (i.e., combine). Here, it is assumed that they would be additive.

1.2.3.4 Air Quality Related Values

Cumulative and Project impacts on AQRVs were assessed at three assessment areas with the far-field model.

1.2.3.4.1 Deposition

Project nitrogen and sulfur impacts were compared to Deposition Analysis Thresholds (DAT) of 0.005 kilograms per hectare per year (kg/ha-yr). Cumulative nitrogen deposition impacts were compared to critical load of atmospheric nitrogen deposition thresholds for Alaskan tundra which range from 1.0-3.0 kg/ha-yr (Sullivan 2016). More background information is provided in Section 4.5.5.

1.2.3.4.2 Visibility

Project visibility impacts were compared to 0.5 delta deciview (dv) and 1.0 delta dv consistent with Federal Land Manager Air Quality Related Values Work group (FLAG) guidance (2010). Cumulative visibility impacts are not compared with a specific threshold, rather are qualitatively assessed relative to baseline visibility conditions. More background information is provided in Section 4.5.4 "Visibility".

1.3 AQTSD Organization

The air quality impacts for the Project alternatives are evaluated by estimating the air emissions and using near-field and regional modeling. The model results are then compared with applicable standards and thresholds. The AQTSD presents this information organized in the following chapters:

- **Chapter 2** provides a summary of the emissions inventory for the Willow MDP alternatives and describes how the emissions inventory was prepared for near-field and far-field modeling. This chapter also describes the cumulative and regional emissions inventories used for modeling.
- **Chapter 3** describes the near-field model configuration, meteorological data, scenarios, assessment receptors, emissions rates, and corresponding impact assessment.
- **Chapter 4** provides an overview of the regional system configuration, the domains and assessment areas, meteorological data, emissions inputs, and assessment methods used to derive the air quality and AQRVs impacts.
- **Chapter 5** presents the regional model impacts to ozone, $PM_{2.5}$ and other criteria pollutants. This chapter also provides impacts on visibility as well as atmospheric deposition of nitrogen and sulfur compounds.
- **Chapter 6** provides a complete list of the references cited in the main body of the AQTSD.

2.0 EMISSIONS INVENTORIES

In this section, we describe the emission inventories that were used in the air quality and greenhouse gas impacts analysis. Willow MDP emission inventories are used to estimate impacts to air quality and AQRVs using the near-field model, AERMOD (described in Chapter 3) and the regional, photochemical grid model, Comprehensive Air Quality Model with Extensions (CAMx, described in Chapter 4). In addition, Willow MDP emission inventories include estimates of greenhouse gas (GHG) emissions that are reported in the Section on Climate and Climate Change in the EIS. Emissions inventories developed for the project are shown in Section 2.1, cumulative sources and emissions are described in Section 2.2, and Section 2.3 describes how these emissions are processed for modeling. Note that the project emissions inventories used for near-field modeling are consistent with Section 2.1 while emissions inventories used for regional modeling are described in Section 2.3.

Near-field models and photochemical grid models are used for different air quality analysis purposes and as a result require different information on air emissions. For near-field modeling, only emissions from sources proximate to planned operations are required as input to the model and very detailed information about the activities and surrounding environment is necessary. For photochemical modeling, the analysis incorporates information for a much larger area and requires emissions for all sources included in the modeling domain. Therefore, in addition to the Willow MDP emissions inventory, regional emissions inventories were developed for the CAMx model for the model scenarios: the 2012 Base Year, the Cumulative No Action Alternative, the Cumulative Alternative B Scenario, and the Cumulative Alternative C Scenario (see Chapter 4). Alternative C was selected for the far-field modeling analysis rather than Alternatives D or E because the peak annual emissions for Alternative C is greatest of these three action alternatives. The following sections discuss the Willow MDP emissions inventory and the regional inventories.

Emission inventories were developed for Willow MDP Alternatives B, C, D and E. Emissions were also developed for the three Module Delivery options because a final determination of Module Delivery transportation routes had not yet been made. An emission inventory was not necessary for Alternative A (No Action).

Willow MDP emissions were developed for criteria pollutants, volatile organic compounds (VOCs), HAPs, and GHGs. Criteria pollutants include NO_x, CO, SO_2, particulate matter less than 10 microns in diameter (PM_{10}), and particulate matter less than 2.5 microns in diameter ($PM_{2.5}$). VOCs include “any compound of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate, which participates in atmospheric photochemical reactions”[5].

Lead was not modeled because emissions would be low resulting in very small air quality impacts. The emission inventory includes lead emission estimates from diesel- and natural gas-fueled combustion sources; lead emissions from these sources are small because diesel and natural gas fuel and exhaust contain only trace amounts of lead, if any at all. Likewise, lead emissions from flaring and incinerator activities are expected to be small. The only potential for a lead additive would be in aviation gasoline for piston-engine aircraft. Piston-engine aircraft used in the proposed project and alternatives are not expected to use gasoline with lead additive.

[5] 40 CFR Part 51.100(s)

HAPs analyzed include those commonly emitted from oil and gas development – benzene, toluene, ethylbenzene, xylenes, n-hexane, and formaldehyde. The Oil and Natural Gas Production Facilities: National Emission Standards for Hazardous Air Pollutants (NESHAP; 40 CFR Part 63, subpart HH, Table 2) includes several additional HAPs[6]; impacts from additional HAPs, not included in this analysis, are expected to be less substantial than those from the six included HAPs.

GHGs analyzed include those commonly emitted from oil and gas development – carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).

Detailed emission inventory calculation spreadsheets are provided separately.

2.1 Willow Alternatives Emissions Inventories

2.1.1 Emission Inventory Summary*

Table 2.1-1, Table 2.1-2, and Table 2.1-3 present total life-of-Project emissions for each alternative by Module Delivery option (Option 1 – Atigaru Point, Option 2 – Point Lonely, and Option 3 – Colville River Crossing). The emissions shown are the sum of Project and Module Delivery emissions. Alternative A (No Action) has zero emissions. For all three Module Delivery Options, Alternative C has the highest emissions across all three action alternatives for all criteria pollutants (except PM_{10}), primarily because of increased equipment and infrastructure requirements required because a gravel road between the Willow Processing Facility (WPF) and drill site Bear Tooth (BT) 1 is not developed under this Alternative. Instead, Alternative C will feature an ice road between BT1 and BT3. In Alternative D, a gravel road is not constructed connecting GMT-2 to the project area. For all three Module Delivery Options, Alternative D has slightly higher PM_{10} emissions than Alternative C as a result of higher routine operations traffic activity for Alternative D and Alternative D has slightly higher emissions (except VOC and HAPs) than Alternative B as a result of the extended Project schedule for Alternative D[7]. For all three Module Delivery Options, Alternative E emissions of VOC, CO, SO_2 and HAPs are slightly lower than Alternative B while NOx, PM_{10} and $PM_{2.5}$ emissions are slightly higher in. The main difference affecting the emissions inventory between Alternative E than and Alternative B is that drill site BT4 would not be constructed under Alternative E. A complete description of each Alternative is available in Chapter 2 of the SEIS.

[6] acetaldehyde, carbon disulfide, carbonyl sulfide, ethylene glycol, naphthalene, and 2,2,4-trimethylpentane
[7] The emission inventory for Alternative D was extended one year longer than Alternative B and Alternative C to account for the delayed production schedule for Alternative D

Table 2.1-1 Total Life-of-Project Emissions due to the Project and Module Delivery Option 1 (Atigaru Point) in each Alternative

Alternative	Total Criteria Emissions (tons)						Total HAPs (tons)	Total CO_2e (thousand metric tons)
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC		
Alternative A (No Action)	0	0	0				0	0
Alternative B (Proponent's Project)	20,273	19,608	1,364	6,549	2,394	16,652	2,336	24,124
Alternative C (Disconnected Infield Roads)	24,331	23,078	1,458	7,213	2,858	17,166	2,352	25,423
Alternative D (Disconnected Access)	20,696	19,758	1,367	7,883	2,575	16,545	2,322	23,360
Alternative E (Three-pad Alternative)	20,290	19,520	1,362	6,626	2,405	15,568	2,238	23,281

* Total CO2e emissions due to the Project are zero in the No Action Alternative. Emissions from substitute energy sources are discussed in the EIS Section on Climate Change.

Table 2.1-2 Total Life-of-Project Emissions due to the Project and Module Delivery Option 2 (Point Lonely) in each Alternative

Alternative	Total Criteria Pollutant Emissions (tons)						Total HAPs (tons)	Total CO2e (thousand metric tons)
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC		
Alternative A (No Action)	0	0	0	0	0	0	0	0
Alternative B (Proponent's Project)	20,839	20,254	1,366	6,596	2,420	16,746	2,347	24,325
Alternative C (Disconnected Infield Roads)	24,897	23,724	1,460	7,260	2,885	17,259	2,364	25,623
Alternative D (Disconnected Access)	21,262	20,404	1,369	7,930	2,602	16,639	2,334	23,560
Alternative E (Three-pad Alternative)	20,856	20,166	1,364	6,673	2,432	15,661	2,249	23,482

* Total CO2e emissions due to the Project are zero in the No Action Alternative. Emissions from substitute energy sources are discussed in the EIS Section on Climate Change.

Table 2.1-3 Total Life-of-Project Emissions due to the Project and Module Delivery Option 3 (Colville River Crossing) in each Alternative

Alternative	Total Criteria Emissions (tons)						Total HAPs (tons)	Total CO2e (thousand metric tons)
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC		
Alternative A (No Action)	0	0	0	0	0	0	0	0
Alternative B (Proponent's Project)	19,906	19,145	1,361	6,581	2,382	16,589	2,328	24,024
Alternative C (Disconnected Infield Roads)	23,963	22,616	1,456	7,245	2,846	17,102	2,344	25,323
Alternative D (Disconnected Access)	20,344	19,299	1,365	7,915	2,564	16,483	2,315	23,263
Alternative E (Three-pad Alternative)	19,922	19,057	1,359	6,657	2,393	15,504	2,230	23,181

* Total CO2e emissions due to the Project are zero in the No Action Alternative. Emissions from substitute energy sources are discussed in the EIS Section on Climate Change.

Table 2.1-4 shows the key activity metrics for each Project phase (construction, drilling, and routine operations) for each alternative. These activities are the basis for the emissions inventory calculations and resulting emission inventories summarized in Table 2.1-1, Table 2.1-2, and Table 2.1-3 and presented in detail in Section 2.1.2 "Alternative A (No Action)" to Section 2.1.7 "Module Delivery Options"

Table 2.1-4 Activity Inputs by Alternative for each Project Phase

Phase	Activity	Parameter	Alternative B (Proponent's Project)	Alternative C (Disconnected Infield Roads)	Alternative D (Disconnected Access)	Alternative E (Three-pad Alternative)	Unit
Construction	All Drill Pads	Total Acres	79.9	88.3	62.9	68.1	acres
	All Bridge	Total Length	0.22	0.15	0.21	0.21	miles
	Gravel Roads, Valve Pads, and Water Access Pads	Total Acres	272	257	208	228	acres
	Ice Pads*	Total Acres	1,037	1,266	1,341	901	acres
	Ice Roads	Total Miles	495	650	962	431	miles
	Total Powerline and Fiber Optics	Total Length	40	40	40	40	miles
	Pipelines	Total Length	153	206	243	151.6	miles
	Willow Processing Facility	Total Acres	23	23	48	22.8	acres

Phase	Activity	Parameter	Alternative B (Proponent's Project)	Alternative C (Disconnected Infield Roads)	Alternative D (Disconnected Access)	Alternative E (Three-pad Alternative)	Unit
	WOC+ Airstrip	Total Acres	73	138	107	73.4	acres
	Gravel Mining	Total Gravel Requirement	5,874,260	6,816,260	6,902,260	4,740,200	million cubic yards (MCY)
	Construction Total Traffic	Vehicle Miles Travelled (VMT)	28,031	36,724	39,274	25,850	thousand miles (kmile)
	Power at WOC	Total Rating Output of Power Generation	14,600	29,200	14,600	14,600	thousand watts (kWe)
Drilling	Total Wells Drilled	Number of Wells	251	251	251	219	number
	Drilling Total Traffic	VMT	4,815	3,267	3,149	5,248	kmile
Operations	All Drill Pads	Number of Well Pads	5	5	5	4	number
	Willow Processing Facility	Operating Capacity**	200	200	200	200	thousand barrels per day (kbbl/day)
	All Aircraft	Total Flights	14,522	16,071	21,570	14,404	number
	Operations Total Traffic	VMT	13,594	14,957	21,076	13,540	kmile
	Power Generation at Willow Processing Facility	Total Rating Output of Power Generation	84,500	84,500	84,500	84,500	kWe
	Injection Turbine at Willow Processing Facility	Total Rating of Injection Turbine power	50,579	50,579	50,579	50,579	kWe
	Power at WOC	Total Rating Output of Power Generation	14,600	29,200	14,600	14,600	kWe

*Ice pad total acres are for all Project years including single season and multi-season ice pads

** This conservatively also includes capacity required to process fluids from GMT2 which is an option being considered by the project proponent (see additional information provided in Section 1.1 of the AQTSD). Willow peak annual production is estimated at 131 kbbl/day.

Table 2.1-5 shows key operational and control inputs for each Project phase (construction, drilling, and routine operations) for each alternative. These operational and control inputs are used in emission inventory calculations and have substantial impacts on emission magnitudes. Comprehensive emission inventory inputs and calculations may be found in emission inventory calculation spreadsheets, which are provided separately.

Table 2.1-5 Key emission inventory operational and control inputs.*

Source Category	Source Type	Operational / Control Input	Alternative B	Alternative C	Alternative D	Alternative E
Fugitive Dust (All Phases)						
Fugitive Dust	Wind Erosion	Watering	50%	50%	50%	50%
	Road Dust	Watering	50%	50%	50%	50%
Construction Phase						
Temporary Stationary Engines[a]	Power Generation Turbine	Rated-power (HP)	2 engines X 7376 HP	2 engines X 7376 HP	2 engines X 7376 HP	2 engines X 7376 HP
		Fuel Type	ULSD	ULSD	ULSD	ULSD
		Annual Activity (hr/engine)	8,760	8,760	8,760	8,760
		Certification Level/Control	Dry Low NOx and Inlet Air Conditioning (Pre-Heat)	Dry Low NOx and Inlet Air Conditioning (Pre-Heat)	Dry Low NOx and Inlet Air Conditioning (Pre-Heat)	Dry Low NOx and Inlet Air Conditioning (Pre-Heat)
	Power Generation Reciprocating Internal Combustion Engine	Rated-power (HP)	3 engines X 1609 HP	3 engines X 1609 HP	3 engines X 1609 HP	3 engines X 1609 HP
		Fuel Type	ULSD	ULSD	ULSD	ULSD
		Annual Activity (hr/engine)	4,380	4,380	4,380	4,380
		Certification Level/Control	Tier IV interim	Tier IV interim	Tier IV interim	Tier IV interim
Traffic	On-road Vehicles	Total trips LOP	1,501,890	1,881,980	1,973,440	1,431,410
		Total miles travelled LOP	28,031,115	36,724,275	39,273,598	25,849,718
	Air Traffic	Total trips LOP	1,943	5,904	4,011	2,320
	Ocean-going Vessels	Total trips LOP	319	319	319	319

Source Category	Source Type	Operational / Control Input	Alternative B	Alternative C	Alternative D	Alternative E
Pre- Drilling Phase						
Pre- Drilling Equipment	Primary Engines	Rated-power (HP)	3 engines X 1476 HP	3 engines X 1476 HP	3 engines X 1476 HP	3 engines X 1476 HP
		Fuel Type	ULSD	ULSD	ULSD	ULSD
		Annual Activity (hr/engine)	8,760	8,760	8,760	8,760
		Certification Level/Control	Tier IV gen set	Tier IV gen set	Tier IV gen set	Tier IV gen set
	Cement Pump Units	Rated-power (HP)	2 engines X 241 HP	2 engines X 241 HP	2 engines X 241 HP	2 engines X 241 HP
		Fuel Type	ULSD	ULSD	ULSD	ULSD
		Annual Activity (hr/engine)	500	500	500	500
		Certification Level/Control	Tier IV final	Tier IV final	Tier IV final	Tier IV final
	Support Engines	Rated-power (HP)	2 engines X 706 HP 10 engine X 11 HP 1 engine X 71 HP	2 engines X 706 HP 10 engine X 11 HP 1 engine X 71 HP	2 engines X 706 HP 10 engine X 11 HP 1 engine X 71 HP	2 engines X 706 HP 10 engine X 11 HP 1 engine X 71 HP
		Fuel Type	ULSD	ULSD	ULSD	ULSD
		Annual Activity (hr/engine)	8,760	8,760	8,760	8,760
		Certification Level/Control	Tier II or Tier III	Tier II or Tier III	Tier II or Tier III	Tier II or Tier III
Hydraulic Fracturing	Well Frac Engines	Rated-power (HP)	1 engine X 120 HP 1 engine X 990 HP 1 engine X 14400 HP	1 engine X 120 HP 1 engine X 990 HP 1 engine X 14400 HP	1 engine X 120 HP 1 engine X 990 HP 1 engine X 14400 HP	1 engine X 120 HP 1 engine X 990 HP 1 engine X 14400 HP
		Fuel Type	ULSD	ULSD	ULSD	ULSD
		Annual Activity (hr/engine)	1,920	1,920	1,920	1,920
		Certification Level/Control	Tier IV final	Tier IV final	Tier IV final	Tier IV final
Development Drilling Phase						
Drilling Equipment	Primary Engines	Rated-power (HP)	1 engine X 1476 HP	1 engine X 1476 HP	1 engine X 1476 HP	1 engine X 1476 HP
		Fuel Type	ULSD	ULSD	ULSD	ULSD
		Annual Activity (hr/engine)	8,760	8,760	8,760	8,760
		Certification Level/Control	Tier IV gen set	Tier IV gen set	Tier IV gen set	Tier IV gen set

Source Category	Source Type	Operational / Control Input	Alternative B	Alternative C	Alternative D	Alternative E
	Cement Pump Units	Rated-power (HP)	2 engines X 241 HP	2 engines X 241 HP	2 engines X 241 HP	2 engines X 241 HP
		Fuel Type	ULSD	ULSD	ULSD	ULSD
		Annual Activity (hr/engine)	500	500	500	500
		Certification Level/Control	Tier IV final	Tier IV final	Tier IV final	Tier IV final
	Support Engines	Rated-power (HP)	2 engines X 706 HP 10 engine X 11 HP 1 engine X 71 HP	2 engines X 706 HP 10 engine X 11 HP 1 engine X 71 HP	2 engines X 706 HP 10 engine X 11 HP 1 engine X 71 HP	2 engines X 706 HP 10 engine X 11 HP 1 engine X 71 HP
		Fuel Type	ULSD	ULSD	ULSD	ULSD
		Annual Activity (hr/engine)	8,760	8,760	8,760	8,760
		Certification Level/Control	Tier II and Tier III	Tier II and Tier III	Tier II and Tier III	Tier II and Tier III
Hydraulic Fracturing	Well Frac Engine	Rated-power (HP)	Highline Power Source, Zero Direct Emissions	Highline Power Source, Zero Direct Emissions	Highline Power Source, Zero Direct Emissions	Highline Power Source, Zero Direct Emissions
		Number of engines				
		Annual Activity (hr/engine)				
		Tier Standard				
Traffic[b]	On-road Vehicles	Total trips LOP	327,720	401,790	318,360	365,030
		Total miles travelled LOP	4,815,054	3,267,163	3,149,251	5,247,886
	Air Traffic	Total trips LOP	1,248	1,875	2,496	3,404
Routine Operation Phase						
Fugitive Components		Control	LDAR	LDAR	LDAR	LDAR
Stationary Engines at WOC[a]	Power Generation Turbine	Rated-power (HP)	2 engines X 7376 HP	2 engines X 7376 HP	2 engines X 7376 HP	2 engines X 7376 HP
		Fuel Type	Fuel Gas	Fuel Gas	Fuel Gas	Fuel Gas
		Annual Activity (hr/engine)	8,760	8,760	8,760	8,760
		Certification Level/Control	Dry Low NOx and Inlet Air Conditioning (Pre-Heat)	Dry Low NOx and Inlet Air Conditioning (Pre-Heat)	Dry Low NOx and Inlet Air Conditioning (Pre-Heat)	Dry Low NOx and Inlet Air Conditioning (Pre-Heat)

Source Category	Source Type	Operational / Control Input	Alternative B	Alternative C	Alternative D	Alternative E
	Power Generation Reciprocating Internal Combustion Engine	Rated-power (HP)	3 engines X 1609 HP	3 engines X 1609 HP	3 engines X 1609 HP	3 engines X 1609 HP
		Fuel Type	ULSD	ULSD	ULSD	ULSD
		Annual Activity (hr/engine)	4,380	4,380	4,380	4,380
		Certification Level/Control	Tier IV interim	Tier IV interim	Tier IV interim	Tier IV interim
Stationary Engines at WPF	Injection/Compression Turbine	Rated-power (HP)	2 engines X 33900 HP	2 engines X 33900 HP	2 engines X 33900 HP	2 engines X 33900 HP
		Fuel Type	Fuel Gas	Fuel Gas	Fuel Gas	Fuel Gas
		Annual Activity (hr/engine)	8,760	8,760	8,760	8,760
		Certification Level/Control	Dry Low NOx and Inlet Air Conditioning (Pre-Heat)	Dry Low NOx and Inlet Air Conditioning (Pre-Heat)	Dry Low NOx and Inlet Air Conditioning (Pre-Heat)	Dry Low NOx and Inlet Air Conditioning (Pre-Heat)
	Power Generation Turbines	Rated-power (HP)	3 engines X32855 HP	3 engines X32855 HP	3 engines X32855 HP	3 engines X32855 HP
		Fuel Type	Fuel Gas	Fuel Gas	Fuel Gas	Fuel Gas
		Annual Activity (hr/engine)	8,760	8,760	8,760	8,760
		Certification Level/Control	Dry Low NOx and Inlet Air Conditioning (Pre-Heat)	Dry Low NOx and Inlet Air Conditioning (Pre-Heat)	Dry Low NOx and Inlet Air Conditioning (Pre-Heat)	Dry Low NOx and Inlet Air Conditioning (Pre-Heat)
	Backup Power Generation Turbines (Fuel Gas)	Rated-power (HP)	2 engines X 7376 HP	2 engines X 7376 HP	2 engines X 7376 HP	2 engines X 7376 HP
		Fuel Type	Fuel Gas	Fuel Gas	Fuel Gas	Fuel Gas
		Annual Activity (hr/engine)	8,260	8,260	8,260	8,260
		Certification Level/Control	Dry Low NOx and Inlet Air Conditioning (Pre-Heat)	Dry Low NOx and Inlet Air Conditioning (Pre-Heat)	Dry Low NOx and Inlet Air Conditioning (Pre-Heat)	Dry Low NOx and Inlet Air Conditioning (Pre-Heat)
	Backup Power Generation Turbines (Diesel Fuel)	Rated-power (HP)	2 engines X 7376 HP	2 engines X 7376 HP	2 engines X 7376 HP	2 engines X 7376 HP

Source Category	Source Type	Operational / Control Input	Alternative B	Alternative C	Alternative D	Alternative E
		Fuel Type	ULSD	ULSD	ULSD	ULSD
		Annual Activity (hr/engine)	500	500	500	500
		Certification Level/Control	Dry Low NOx and Inlet Air Conditioning (Pre-Heat)	Dry Low NOx and Inlet Air Conditioning (Pre-Heat)	Dry Low NOx and Inlet Air Conditioning (Pre-Heat)	Dry Low NOx and Inlet Air Conditioning (Pre-Heat)
	Black Start Engines	Rated-power (HP)	1 engine X 805 HP	1 engine X 805 HP	1 engine X 805 HP	1 engine X 805 HP
		Fuel Type	ULSD	ULSD	ULSD	ULSD
		Annual Activity (hr/engine)	500	500	500	500
		Certification Level/Control	Tier II	Tier II	Tier II	Tier II
Traffic	On-road Vehicles	Total trips LOP	1,359,300	1,928,740	2,085,090	1,349,430
		Total miles travelled LOP	13,594,275	14,956,585	21,075,829	13,540,217
	Air Traffic	Total trips LOP	11,331	14,705	15,034	8,680

[a] For Alternative C, applicable to both the North and South WOC
[b] Includes traffic for pre- and developmental drilling phases

2.1.2 Alternative A (No Action)

Under this alternative, the BLM and/or other federal permitting agencies would not issue permits for the Willow Development, and no development would occur. As a result, no oil in the Project area would be produced in the near future, and no new roads, airstrips, pipelines, or other oil facilities would be constructed. Therefore, there are no direct Project emissions anticipated to result under the No Action Alternative.

2.1.3 Alternative B (Proponent's Project)*

Alternative B (Proponent's Project) would consist of the development and operation of 251 wells over a period of 10 years on five multi-well pads and associated facilities in the Project area needed to support extraction of hydrocarbons including a Central Processing Facility, Operations Center, Airstrip, pipelines, roads and bridges, and module transfer island. Section 1.1.2 "Alternative B: Proponent's Project" provides a description of Alternative B.

A general description highlighting emission generating activities and sources under Alternative B is provided below. AECOM (documented the Alternative B emission inventory, which is included as Attachment C to this Air Quality Technical Support Document. A more detailed description of emission generating activities and sources can be found in Attachment C.

Criteria pollutants, VOCs, HAP, and GHG emissions are emitted during construction, drilling, and routine operation Project phases. Emissions would result from activities such as well installation, development, and operation; operation of engines and boilers; and vehicle transportation of equipment and service crews in the Project area. Project emission sources would include non-mobile combustion sources, mobile on-road and nonroad tailpipe combustion sources, fugitive dust sources, fugitive leak sources, venting sources, ships, and aircraft sources.

Emissions estimates presented herein were developed using Willow-specific data and information from CPAI's other North Slope projects including the GMT2 Drill site in the GMTU and the ACF in the Colville River Unit. Willow-specific input design data from CPAI were used where available and these were supplemented by information from the GMT2 EIS emissions inventory (BLM, 2018b). The emissions inventory for the WPF, WOC and module delivery and transport activities are based on similar facilities and activities supporting the construction and operation of the ACF, supplemented by equipment sizing information, newer emissions control and equipment technologies, and other Willow-specific design information developed by CPAI.

CPAI plans to construct 251 wells at five drill sites, approximately evenly split between production and injection wells. Production wells are hydraulically fractured and then undergo a well cleanout process known as a flowback in which the fluids and solids produced during the drilling process are allowed to flow out until no excessive solids or drilling fluids are left. Injection wells only go through the flowback process and are not hydraulically fractured. Gas produced from the flowback will be captured, flared, or vented depending on available infrastructure. Oil, gas, and water extracted from production wells will be sent to the WPF for processing. Injection wells will be used to inject gas, produced water, seawater, and miscible injectant (MI) back into the producing formation.

After the wells are developed, processing, transport, and storage of the produced oil and natural gas will emit criteria pollutants, VOCs, HAPs, and GHGs. Heaters, generators, pumps, well intervention (i.e., workover), and other support equipment used at well sites emit criteria pollutants, VOCs, HAPs, and GHGs. Storage tanks and fugitive leaks from valves, flanges, open-ended lines, connectors, and other connection points at well pads will emit VOCs, HAPs, and GHGs.

The WPF would separate and process production fluids and produce sales-quality crude oil. Produced water would be processed at the WPF and reinjected to the subsurface as part of pressure maintenance/water flood for secondary recovery. Emission sources at the WPF would include turbine and internal combustion engine generators, compressors, storage tanks, pumps, and other treating equipment. CPAI is evaluating whether to connect GMT2 with the WPF. As discussed in Section 1.1, the Willow EIS air quality impact analysis accounts for the effect of potentially processing GMT2 produced fluids at the WPF.

The base of operations for the Willow Development would be at the WOC. The WOC would be near to but separated from the WPF and adjacent to the airstrip. Emission sources at the WOC would include internal combustion engine generators, turbines, non-mobile support equipment (e.g., boilers, incinerators), storage tanks, and aircraft from the adjacent airstrip.

Fugitive dust emissions estimates assume a conservative (low) 50% control efficiency for watering, consistent with the BOEM Arctic modeling study (Fields Simms et al 2018, Stoeckenius et al 2017). Fugitive dust emissions are only calculated for months from May through October, consistent with the months for which fugitive dust emissions were estimated in the BOEM Arctic modeling study (Fields Simms et al 2018, Stoeckenius et al 2017). Fugitive dust emissions may also occur in other months, especially during dry snowless conditions or when the ground is dry and frozen. Although fugitive dust emissions during such months may affect air concentrations of particulate matter, these would be to a smaller extent than fugitive dust emitted from May through October when there is much less (or no) snow cover.

Table 2.1-6 shows annual criteria pollutant, VOCs, HAP, and GHG emissions in Alternative B for construction activities by year. The “Year 0” refers to the first year of construction which is a partial year. Table 2.1-7 shows annual Alternative B criteria pollutant, VOCs, HAP, and GHG emissions for drilling (including pre-drilling and developmental drilling) activities. Table 2.1-8 shows annual Alternative B criteria pollutant, VOCs, HAP, and GHG emissions for routine operation activities. Table 2.1-9 shows annual Alternative B criteria pollutant, VOCs, HAP, and GHG emissions summed across all Project activities. Alternative B annual emissions are shown graphically for each criteria pollutant by Project phase in Figure 2.1-1 to Figure 2.1-6.

Construction emissions increase from project start to year 4, then, generally, decrease to the end of construction activities in year 9. From year 5 to year 6, there is an increase in gaseous pollutant construction emissions and a decrease in particulate matter emissions. Increases in non-vehicle construction phase activities from year 5 to year 6 result in increased gaseous emissions while decreases in on-road vehicle activity reduce on-road fugitive dust emissions (the largest particulate matter emissions source category).

The drilling phase includes three different activities: disposal well drilling at the WOC in year 3, pre-drilling from years 4 to -5, and developmental drilling from years 6 to -9. For most pollutants, the largest drilling phase emissions occur during pre-drilling when diesel engines are used to power drill rigs, prior to developmental drilling during which highline electricity is used to power drill rigs. PM_{10} and $PM_{2.5}$ emissions are highest in year 7 and year 9 when drilling phase on-road vehicle activity and hence fugitive dust emissions are highest.

Routine operations at the WPF are expected to commence in the fourth quarter of year 5 with commissioning of the WPF and the first drill site (BT1). Subsequent drill sites will be commissioned in the following years and continue operating until the end of field life in year 30. Routine operation emissions generally increase as routine operation facilities (e.g., WOC, WPF, and drill sites) are brought online and thereafter remain relatively constant.

Table 2.1-6 Alternative B (Proponent's Project) Annual Emissions from Construction Activities

Project Year	Total Emissions (tons per year [tpy])												
	Criteria Pollutants						HAP						GHGs
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Benzene	Toluene	EthylBenzene	Xylene	n-Hexane	Formaldehyde	CO_2e
0	20.5	32.7	0.9	1.3	0.5	1.3	0.0	0.0	0.0	0.0	0.0	0.3	3,503
1	440.4	376.8	3.8	81.5	20.6	26.5	0.4	0.4	0.1	0.4	0.1	3.2	142,632
2	461.7	384.4	4.8	102.3	23.2	26.5	0.4	0.4	0.1	0.4	0.0	3.0	138,742
3	535.8	418.4	4.4	212.4	37.6	35.9	0.5	0.6	0.1	0.6	0.1	4.8	169,070
4	591.2	431.9	3.5	213.8	41.2	44.6	0.6	0.7	0.1	0.6	0.1	5.2	187,533
5	150.6	92.6	1.3	183.2	26.8	16.1	0.4	0.4	0.1	0.3	0.0	3.3	55,912
6	166.1	144.8	3.2	109.5	18.4	16.1	0.4	0.4	0.1	0.4	0.1	3.5	55,924
7	92.7	92.2	1.9	93.4	13.0	9.6	0.2	0.2	0.0	0.2	0.0	1.9	31,811
8	29.5	14.2	0.1	39.7	5.5	3.4	0.1	0.1	0.0	0.1	0.0	0.6	10,810
9	6.2	1.8	0.0	0.3	0.2	0.6	0.0	0.0	0.0	0.0	0.0	0.1	1,697
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
16-30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-

Table 2.1-7 Alternative B (Proponent's Project) Annual Emissions from Drilling Activities

Project Year	Total Emissions (tons per year [tpy])												
	Criteria Pollutants						HAP						GHGs
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Benzene	Toluene	EthylBenzene	Xylene	n-Hexane	Formaldehyde	CO_2e
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
3	3.8	5.3	0.0	0.3	0.3	0.4	0.0	0.0	0.0	0.0	0.0	0.0	1,728
4	143.5	379.5	1.1	106.1	18.5	73.6	1.8	1.4	0.1	0.5	8.3	40.8	90,671
5	145.0	380.1	1.1	138.5	21.8	73.8	1.8	1.4	0.1	0.5	8.3	40.9	91,385
6	101.9	142.2	0.5	178.3	24.1	45.1	1.1	1.0	0.1	0.3	5.9	28.9	49,098
7	106.6	141.3	0.5	291.9	35.7	36.2	0.8	0.7	0.1	0.2	4.2	20.5	50,516
8	99.9	138.5	0.5	147.4	20.9	35.3	0.8	0.7	0.0	0.2	4.2	20.4	47,383
9	106.6	141.3	0.5	291.9	35.7	36.2	0.8	0.7	0.1	0.2	4.2	20.5	50,516
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
16-30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-

Table 2.1-8 Alternative B (Proponent's Project) Annual Emissions from Routine Operation Activities

Project Year	Total Emissions (tons per year [tpy])												
	Criteria Pollutants						HAP						GHGs
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Benzene	Toluene	EthylBenzene	Xylene	n-Hexane	Formaldehyde	CO_2e
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	49.2
2	0.5	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	86.1
3	1.7	3.1	0.2	0.1	0.1	0.7	0.0	0.0	0.0	0.0	0.0	0.1	502.1
4	5.2	7.3	0.6	2.1	0.5	1.3	0.0	0.0	0.0	0.0	0.0	0.2	1714.2
5	251.5	238.2	16.8	51.2	30.5	89.8	0.2	0.5	0.7	1.5	3.1	3.1	305518.2
6	635.7	606.9	52.4	165.0	78.6	405.9	0.8	1.9	5.4	10.7	18.8	11.6	947941.5
7	643.4	612.7	52.6	169.1	79.4	507.1	0.9	2.2	8.0	15.8	25.1	11.6	952919.8
8	644.3	613.4	52.6	171.5	79.7	507.1	0.9	2.2	8.0	15.8	25.1	11.6	953070.6
9	650.1	618.1	52.6	177.7	80.7	587.7	1.0	2.4	10.0	19.8	30.1	11.6	957174.0
10	654.5	620.7	52.6	178.0	80.9	666.7	1.0	2.6	12.0	23.8	35.1	11.5	960917.5
11	654.5	620.7	52.6	178.0	80.9	666.7	1.0	2.6	12.0	23.8	35.1	11.5	960917.5
12	654.5	620.7	52.6	170.0	79.7	666.3	1.0	2.6	12.0	23.8	35.1	11.5	960917.5
13	654.5	620.7	52.6	170.0	79.7	666.3	1.0	2.6	12.0	23.8	35.1	11.5	960917.5
14	654.5	620.7	52.6	170.0	79.7	666.3	1.0	2.6	12.0	23.8	35.1	11.5	960917.5
15	654.5	620.7	52.6	170.0	79.7	666.3	1.0	2.6	12.0	23.8	35.1	11.5	960917.5
16-30	654.5	620.7	52.6	170.0	79.7	666.3	1.0	2.6	12.0	23.8	35.1	11.5	960917.5

Table 2.1-9 Alternative B (Proponent's Project) Annual Emissions from All Project Activities

Project Year	Total Emissions (tons per year [tpy])												
	Criteria Pollutants						HAP						GHGs
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Benzene	Toluene	EthylBenzene	Xylene	n-Hexane	Formaldehyde	CO_2e
0	20.5	32.7	0.9	1.3	0.5	1.3	0.0	0.0	0.0	0.0	0.0	0.3	3503.2
1	440.9	377.0	3.8	81.5	20.6	26.5	0.4	0.4	0.1	0.4	0.1	3.2	142680.9
2	462.2	385.9	4.8	102.4	23.3	26.5	0.4	0.4	0.1	0.4	0.0	3.0	138828.0
3	541.3	426.8	4.6	212.7	38.0	37.1	0.6	0.6	0.1	0.6	0.1	4.9	171300.0
4	739.9	818.6	5.2	322.0	60.1	119.5	2.4	2.1	0.2	1.1	8.4	46.2	279917.4
5	547.1	710.9	19.1	372.9	79.1	179.6	2.4	2.3	0.9	2.3	11.5	47.3	452815.2
6	903.8	893.9	56.2	452.9	121.1	467.1	2.3	3.3	5.6	11.4	24.8	43.9	1052963.3
7	842.7	846.2	55.1	554.3	128.1	552.9	1.9	3.2	8.1	16.3	29.3	34.0	1035246.7
8	773.6	766.2	53.2	358.5	106.1	545.8	1.8	3.0	8.0	16.1	29.3	32.6	1011263.2
9	762.9	761.1	53.1	469.8	116.6	624.4	1.8	3.2	10.1	20.0	34.3	32.2	1009386.1
10	654.5	620.7	52.6	178.0	80.9	666.7	1.0	2.6	12.0	23.8	35.1	11.5	960917.5
11	654.5	620.7	52.6	178.0	80.9	666.7	1.0	2.6	12.0	23.8	35.1	11.5	960917.5
12	654.5	620.7	52.6	170.0	79.7	666.3	1.0	2.6	12.0	23.8	35.1	11.5	960917.5
13	654.5	620.7	52.6	170.0	79.7	666.3	1.0	2.6	12.0	23.8	35.1	11.5	960917.5
14	654.5	620.7	52.6	170.0	79.7	666.3	1.0	2.6	12.0	23.8	35.1	11.5	960917.5
15	654.5	620.7	52.6	170.0	79.7	666.3	1.0	2.6	12.0	23.8	35.1	11.5	960917.5
16-30	654.5	620.7	52.6	170.0	79.7	666.3	1.0	2.6	12.0	23.8	35.1	11.5	960917.5

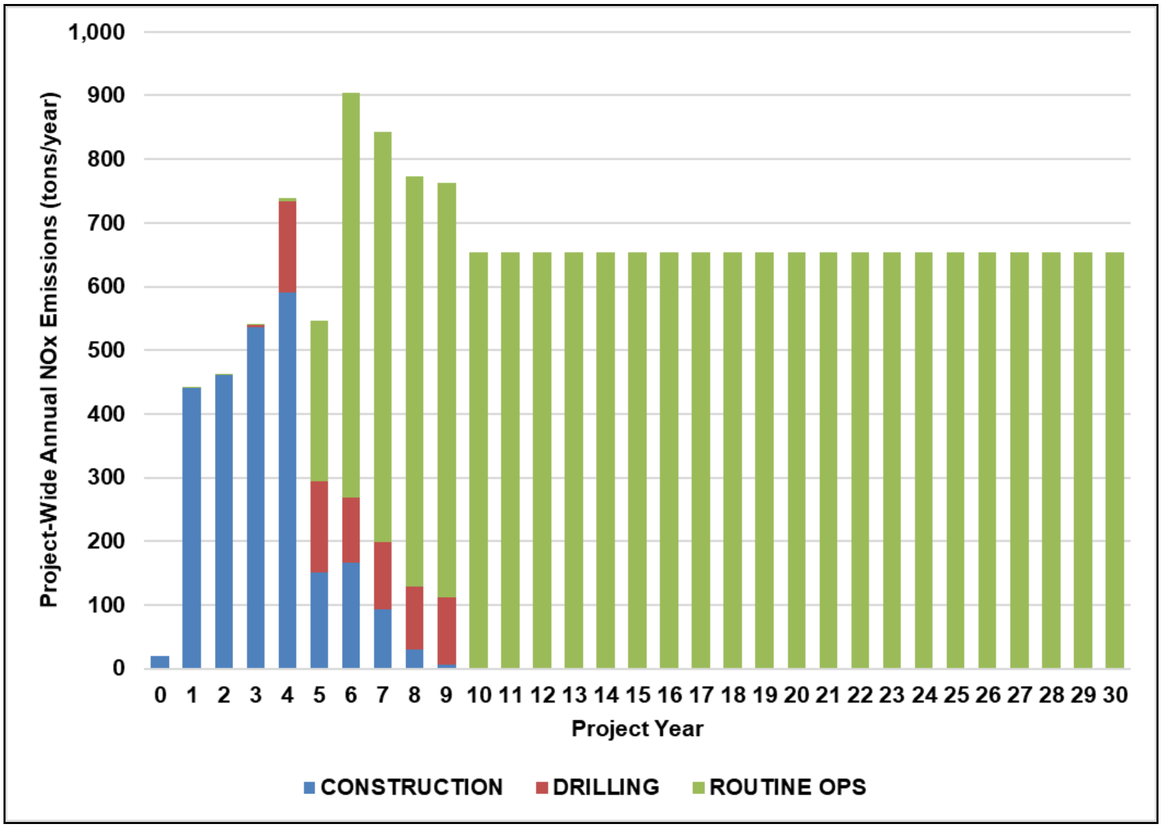


Figure 2.1.1 Alternative B (Proponent's Project) Annual NOx Emissions by Project Phase*

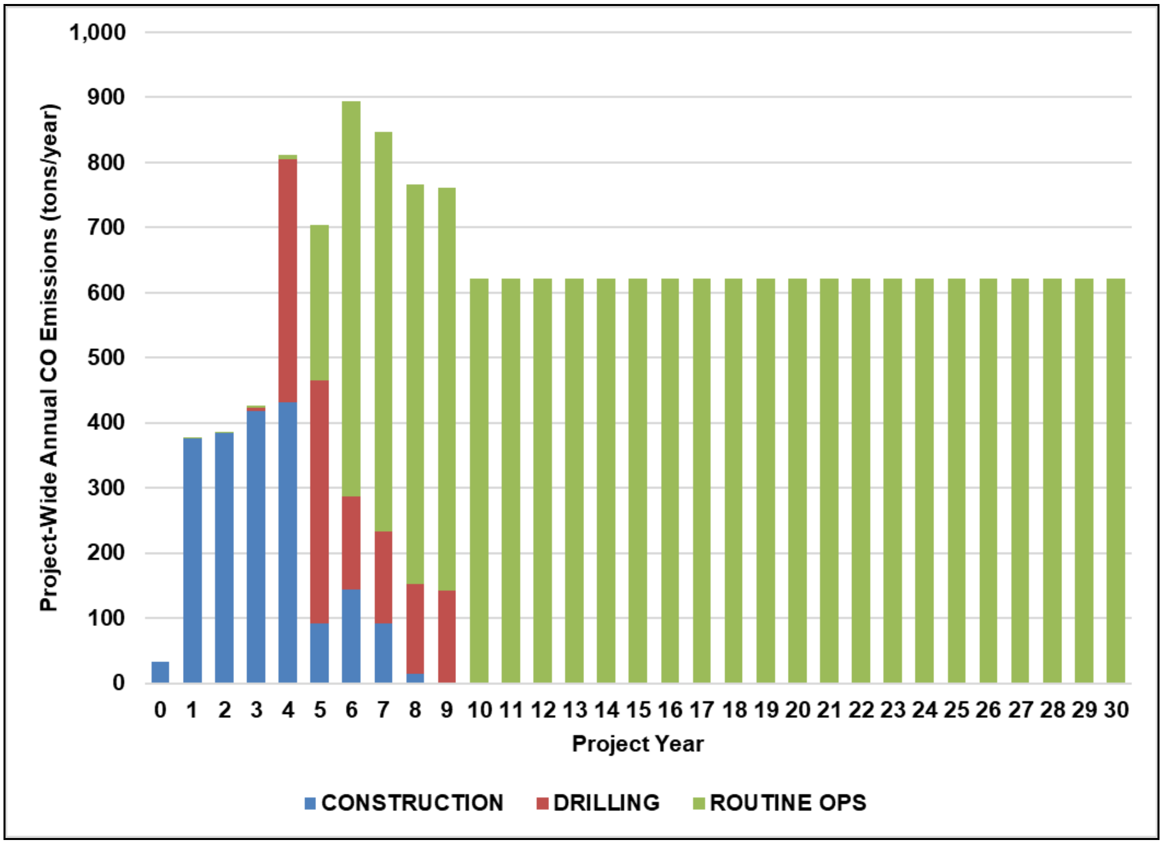


Figure 2.1.2 Alternative B (Proponent's Project) Annual CO Emissions by Project Phase*

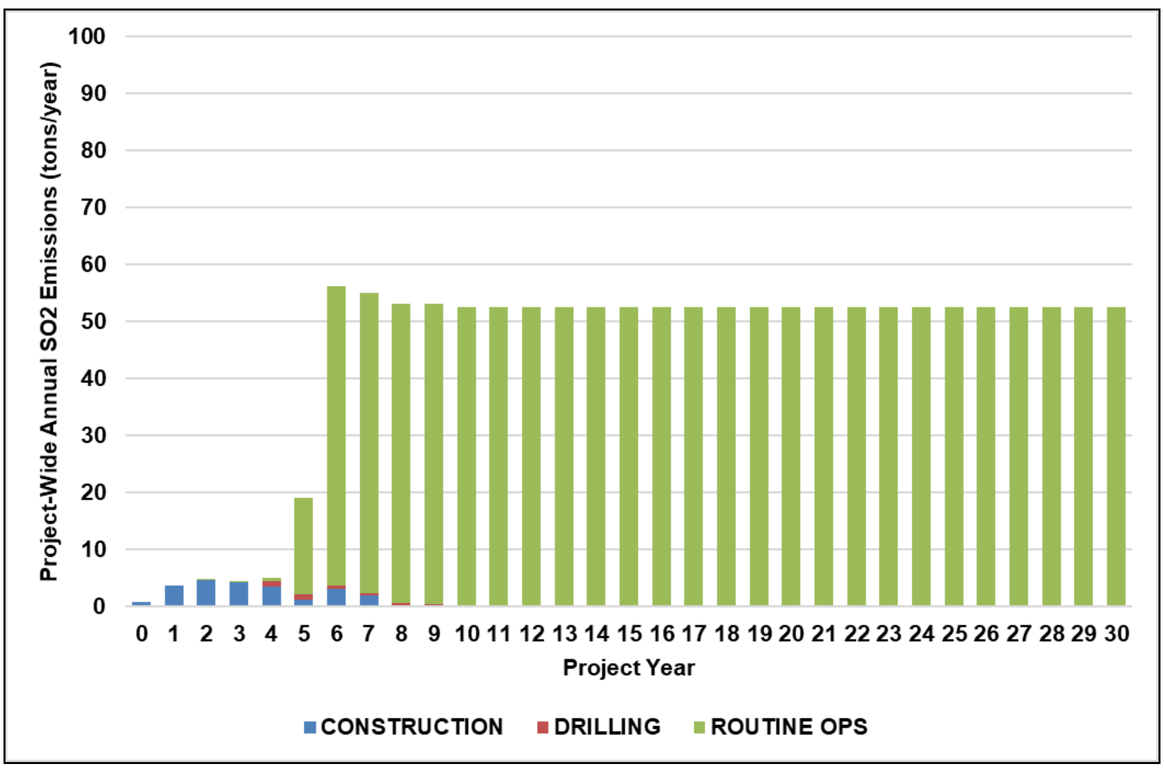


Figure 2.1.3 Alternative B (Proponent's Project) Annual SO_2 Emissions by Project Phase*

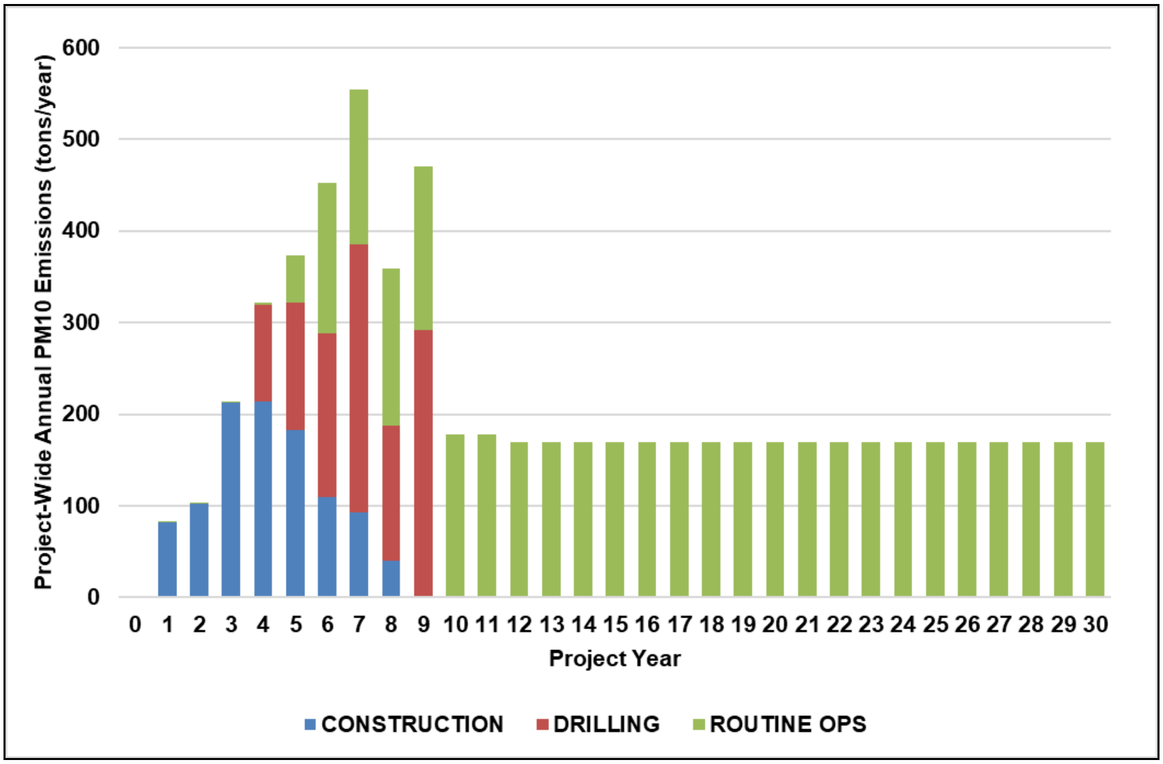


Figure 2.1.4 Alternative B (Proponent's Project) Annual PM_{10} Emissions by Project Phase*

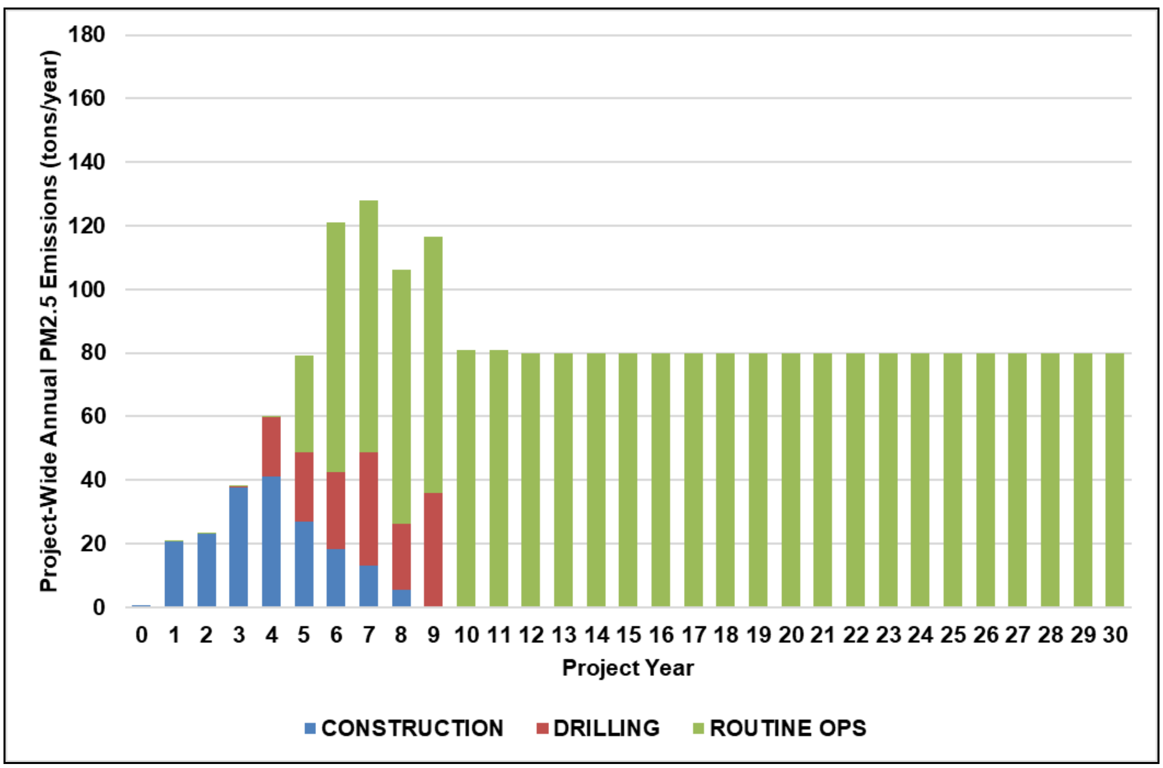


Figure 2.1.5 Alternative B (Proponent's Project) Annual $PM_{2.5}$ Emissions by Project Phase*

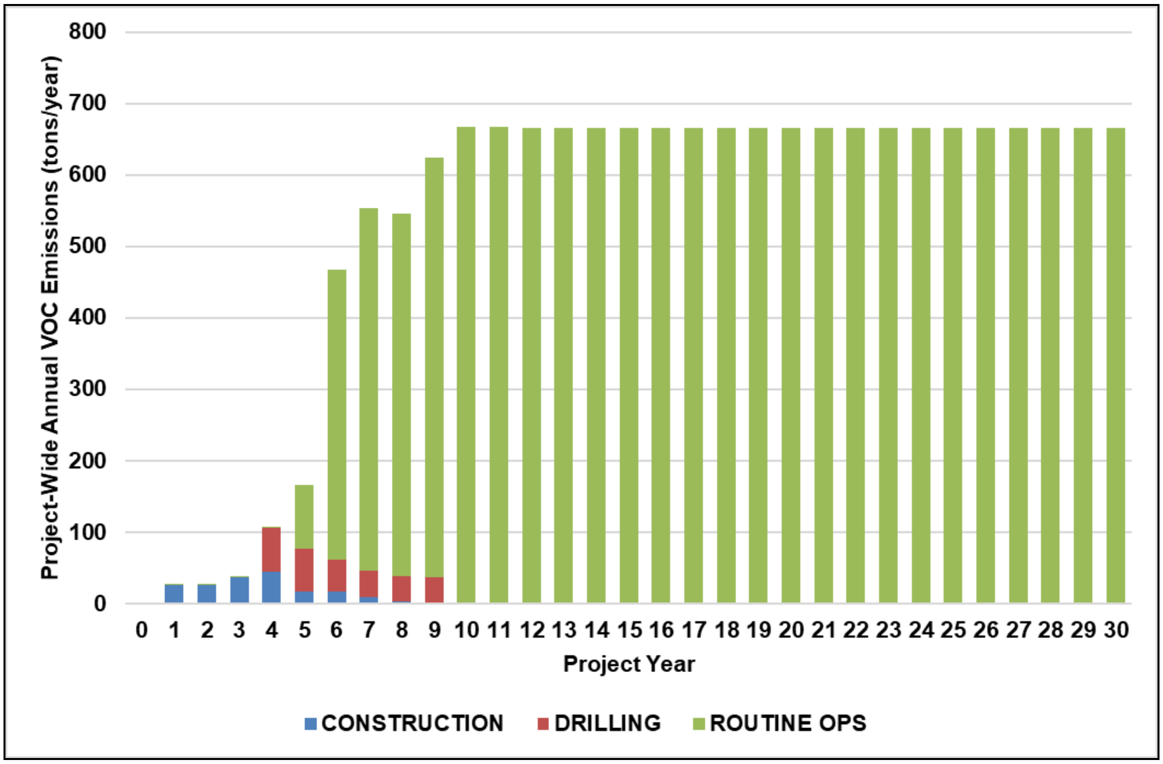


Figure 2.1.6 Alternative B (Proponent's Project) Annual VOC Emissions by Project Phase*

Alternative B flaring activities are limited to a low pressure flare and high pressure flare at the WPF and flowback flaring at drill sites. Flares are safety devices that are operated to prevent over pressurizing piping and equipment, to handle gas removal from systems during maintenance, and to deal with gas released during an emergency rapid depressurization of WPF gas handling systems (SLR 2022). Flares will be in operation at the WPF from project year 5 to end of project. At the WPF there will be a low pressure flare and high pressure flare which will include year-round, 24-hour per day operation of a pilot/purge assist and operation for 10 hours per year at a maximum flowrate of 9 million standard cubic-feet per hour (MMSCF/hr) for the low pressure flare and 11 MMSCF/hr for the high pressure flare.

Permanent infrastructure is not expected to be in place immediately following the construction of each drill site to handle gas from flowbacks. Until the necessary gas transmission and processing infrastructure is built, flowback gas will be routed to a portable flare located at the drill site. Once the gas transmission and processing infrastructure is available, gas from flowbacks will be routed from drill sites to the WPF and processed for on-site use or reinjected back into the producing reservoir. Willow flowback flaring emissions from drill sites are accounted for in the SEIS as follows. Flaring at drill sites would occur from project year 4 to 9 under Alternatives B. Typically, there would be 1 flowback event per well drilled with a duration of 3 days of flaring per flowback event. There will be 4 flowbacks per month during project years 4 and 5; in project year 6, 4 flowbacks per month will occur from January through May; and from June in project year 6 to end of project year 9, there will be 2 flowbacks per month.

Flaring volumes assumed at the WPF were compared to recent flaring conducted at Alpine Central Facility. Table 2.1-10 shows Alpine Central Facility flared volumes for recent years 2020 and 2021 as well as annual Willow WPF flared volume under Alternative B. The annual event flared volume from the Alpine Central Facility in 2020 was 176.2 MMSCF/yr and 304.0 MMSCF/yr, respectively. Annual event flared volume at the WPF is 197.1 MMSCF/yr which is about 12% larger than Alpine Central Facility 2020 flared volume and about 35% smaller than Alpine Central Facility 2021 flared volume. Therefore, the assumed annual flaring volume at WPF is comparable to recent annual flared volumes at the Alpine Central Facility.

Table 2.1-10 Recent years flaring at the Alpine Central Facility and Future Flaring under Alternative B.

Flare Type	Alpine Annual Flaring for 2020 and 2021 (MMSCF/yr)		Alternative B WPF Flaring by Year (MMSCF/yr)	
	2020	2021	Year 5	Year 6+
LP Flare Pilot/Purge	34.6	33.0	8.6	34.4
HP Flare Pilot/Purge	40.5	43.7	8.6	34.4
Pilot/Purge Subtotal	**75.1**	**76.6**	**17.2**	**68.7**
Total Flared (All Events) - LP Flare	165.1	260.1	22.1	88.3
Total Flared (All Events) - HP Flare	11.1	43.9	27.2	108.8
Total Flared (All Events) Subtotal	**176.2**	**304.0**	**49.3**	**197.1**

Table 2.1-11 shows life of project flaring emissions under Alternative B for criteria pollutant, VOCs, HAP, and GHG emissions.

Table 2.1-11 Alternative B Annual Flaring Emissions.

Project Year	Total Emissions (tons per year [tpy])												
	Criteria Pollutants						HAP						GHGs
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Benzene	Toluene	EthylBenzene	Xylene	n-Hexane	Formaldehyde	CO_2e
WPF	311.0	1,036.6	22.7	72.4	72.4	2,890.8	8.6	7.7	0.5	2.2	144.9	239.9	807,727
Drill sites	8.7	47.3	0.5	0.0	0.0	167.7	6.2	5.6	0.4	1.6	34.9	170.3	19,042
Total	**319.8**	**1,083.9**	**23.2**	**72.4**	**72.4**	**3,058.6**	**14.8**	**13.2**	**0.9**	**3.8**	**179.9**	**410.2**	**826,769**

2.1.4 Alternative C (Disconnected Infield Roads)

Alternative C would be identical to Alternative B with respect to the number of wells drilled, main Project features, and oil production. The main differences for Alternative C relative to Alternative B are the elimination of a gravel road connection between the WPF and drill site BT1, and the inclusion of a second airstrip, storage and staging facilities and camp near drill site BT1 or drill site BT2. Additionally, the WPF, WOC, and airstrip would be located approximately 5 miles east of their location in Alternative B, near the GMTU and BTU boundary. Section 1.1.3 "Alternative C: Disconnected Infield Roads" provides a description of Alternative C. Alternative B emission inventory spreadsheets were modified with Alternative C inputs provided by the Project proponent and information from the Project description to estimate Alternative C emissions. More information about the Alternative C emissions inventory is provided in Attachment D to this Air Quality Technical Support Document.

Table 2.1-12 shows annual criteria pollutant, VOCs, HAP and GHG emissions for construction activities by year in Alternative C. The "Year 0" refers to the first year of construction which is a partial year. Table 2.1-13 shows annual Alternative C criteria pollutant, VOCs, HAP, and GHG emissions for drilling (including pre-drilling and developmental drilling) activities. Table 2.1-14 shows annual Alternative C criteria pollutant, VOCs, HAP, and GHG emissions for routine operation activities. Table 2.1-13 shows annual Alternative C criteria pollutant, VOCs, HAP, and GHG emissions summed across all Project activities. Alternative C annual emissions are shown graphically for each criteria pollutant by Project phase in Figure 2.1-7 to Figure 2.1-12.

Construction emissions increase from project start to year 4, then, generally, decrease to the end of construction activities in year 9. There is a substantial decrease in construction emissions from project year 5 to year 6, due primarily to replacement of construction phase temporary power generation in year 5 with production phase generation in year 6 and the slowing down or completion of several key construction activities such as multi-season ice pads, gravel mining, drill site gravel pad construction, WPF construction, pipeline construction, and bridge construction. Emissions increase again from year 6 to year 7 as several construction activities start again including gravel mining, drill site gravel pad construction, and bridge construction.

The drilling phase includes three different activities: disposal well drilling at the North and South WOC in year 3 and year 4, respectively, pre-drilling activities from years 4-5, and developmental drilling activity from years 6-9. For most pollutants, the largest drilling phase emissions occur during pre-drilling during which diesel engines are used to power drill rigs, prior to developmental drilling during which highline electricity is used to power drill rigs. PM_{10} and $PM_{2.5}$ emissions are highest in year 9 when drilling phase on-road vehicle activity and hence fugitive dust emissions are highest.

Routine operations at the WPF are expected to commence in the fourth quarter of year 5 with commissioning of the WPF and the first drill site (BT1). Subsequent drill sites will be commissioned in the following years and continue operating until the end of life in year 30. Routine operation emissions generally increase as routine operation facilities (e.g., WOC, WPF, and drill sites) are brought online and thereafter remain relatively constant.

Table 2.1-12 Alternative C (Disconnected Infield Roads) Annual Emissions from Construction Activities

Project Year	Total Emissions (tons per year [tpy])												
	Criteria Pollutants						HAP						GHGs
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Benzene	Toluene	EthylBenzene	Xylene	n-Hexane	Formaldehyde	CO_2e
0	20.4	32.6	0.9	1.2	0.5	1.3	0.0	0.0	0.0	0.0	0.0	0.3	3,475
1	434.0	372.1	4.0	65.8	25.6	27.3	0.3	0.3	0.1	0.3	0.0	2.4	137,708
2	805.4	642.9	6.2	136.2	49.4	47.9	0.5	0.4	0.1	0.4	0.1	3.2	252,012
3	901.3	679.7	5.9	274.5	67.6	59.9	0.7	0.7	0.1	0.7	0.1	5.7	291,495
4	913.6	705.2	5.8	301.0	71.2	62.5	0.7	0.6	0.1	0.6	0.1	4.7	289,110
5	496.6	375.3	3.3	261.1	49.4	35.1	0.5	0.5	0.1	0.4	0.1	3.8	167,010
6	75.5	55.8	1.3	55.9	9.3	7.0	0.2	0.2	0.0	0.2	0.0	1.5	24,441
7	124.5	121.5	2.8	170.8	21.1	11.5	0.2	0.3	0.1	0.3	0.0	2.4	37,070
8	112.2	93.4	2.0	176.7	21.9	11.2	0.2	0.3	0.1	0.3	0.0	2.3	37,121
9	23.0	10.1	0.1	48.1	6.0	2.6	0.1	0.1	0.0	0.1	0.0	0.5	8,650
10	2.6	0.7	0.0	0.1	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.1	583
11	2.6	0.7	0.0	0.1	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.1	583
12	2.6	0.7	0.0	0.1	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.1	583
13	2.6	0.7	0.0	0.1	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.1	583
14	2.6	0.7	0.0	0.1	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.1	583
15	2.6	0.7	0.0	0.1	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.1	583
16-30	2.6	0.7	0.0	0.1	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.1	583

Table 2.1-13 Alternative C (Disconnected Infield Roads) Annual Emissions from Drilling Activities

Project Year	Total Emissions (tons per year [tpy])												
	Criteria Pollutants						HAP						GHGs
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Benzene	Toluene	EthylBenzene	Xylene	n-Hexane	Formaldehyde	CO_2e
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
3	3.8	5.3	0.0	0.3	0.3	0.4	0.0	0.0	0.0	0.0	0.0	0.0	1,728
4	147.8	385.0	1.1	118.0	19.9	74.1	1.8	1.4	0.1	0.5	8.3	40.9	92,675
5	142.7	379.1	1.0	95.9	17.4	73.4	1.8	1.4	0.1	0.5	8.3	40.8	90,4242
6	98.2	140.5	0.5	113.0	17.4	44.6	1.1	1.0	0.1	0.3	5.9	28.8	47,587
7	99.0	138.1	0.5	134.6	19.6	35.1	0.8	0.7	0.0	0.2	4.2	20.4	47,072
8	98.0	137.6	0.5	118.5	18.0	35.0	0.8	0.7	0.0	0.2	4.2	20.4	46,684
9	106.7	141.6	0.5	245.3	31.1	36.3	0.8	0.7	0.1	0.2	4.2	20.5	49,890
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
16-30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-

Table 2.1-14 Alternative C (Disconnected Infield Roads) Annual Emissions from Routine Operation Activities

Project Year	Total Emissions (tons per year [tpy])												
	Criteria Pollutants						HAP						GHGs
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Benzene	Toluene	EthylBenzene	Xylene	n-Hexane	Formaldehyde	CO_2e
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
1	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	49
2	0.5	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	63
3	0.8	1.0	0.1	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	185
4	1.6	3.5	0.2	0.1	0.1	0.5	0.0	0.0	0.0	0.0	0.0	0.1	472
5	135.0	139.1	12.6	23.3	15.1	73.9	0.2	0.4	0.7	1.4	3.1	3.0	222,531
6	663.1	641.1	55.6	129.9	78.7	409.2	0.8	2.0	5.4	10.8	18.8	11.7	1,008,906
7	752.5	717.7	56.1	142.5	89.9	523.3	1.0	2.3	8.0	15.8	25.1	11.7	1,033,261
8	755.8	720.1	56.1	166.6	92.4	543.6	1.0	2.4	8.5	16.8	26.4	11.7	1,034,821
9	763.4	719.3	56.2	205.7	96.7	623.5	1.1	2.6	10.5	20.8	31.4	11.6	1,039,558
10	767.0	721.5	56.3	206.4	97.0	683.0	1.1	2.7	12.0	23.8	35.1	11.6	1,042,527
11	767.0	721.5	56.3	206.4	97.0	683.0	1.1	2.7	12.0	23.8	35.1	11.6	1,042,527
12	767.0	721.5	56.3	198.8	95.8	683.0	1.1	2.7	12.0	23.8	35.1	11.6	1,042,527
13	767.0	721.5	56.3	198.8	95.8	683.0	1.1	2.7	12.0	23.8	35.1	11.6	1,042,527
14	767.0	721.5	56.3	198.8	95.8	683.0	1.1	2.7	12.0	23.8	35.1	11.6	1,042,527
15	767.0	721.5	56.3	198.8	95.8	683.0	1.1	2.7	12.0	23.8	35.1	11.6	1,042,527
16-30	767.0	721.5	56.3	198.8	95.8	683.0	1.1	2.7	12.0	23.8	35.1	11.6	1,042,527

Table 2.1-15 Alternative C (Disconnected Infield Roads) Annual Emissions from All Project Activities

Project Year	Total Emissions (tons per year [tpy])												
	Criteria Pollutants						HAP						GHGs
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Benzene	Toluene	EthylBenzene	Xylene	n-Hexane	Formaldehyde	CO_2e
0	20.4	32.6	0.9	1.2	0.5	1.3	0.0	0.0	0.0	0.0	0.0	0.3	3,475
1	434.5	372.4	4.0	65.8	25.6	27.3	0.3	0.3	0.1	0.3	0.0	2.4	137,757
2	805.9	643.4	6.2	136.2	49.4	48.0	0.5	0.4	0.1	0.4	0.1	3.2	252,075
3	905.9	686.1	5.9	274.8	67.8	60.5	0.7	0.7	0.1	0.7	0.1	5.7	293,408
4	1063.0	1093.7	7.0	419.0	91.2	137.1	2.4	2.0	0.2	1.0	8.4	45.6	382,257
5	774.3	893.5	17.0	380.3	81.9	182.4	2.4	2.3	0.9	2.3	11.5	47.6	479,965
6	836.9	837.4	57.4	298.8	105.4	460.8	2.1	3.1	5.5	11.2	24.8	42.0	1,080,934
7	976.0	977.2	59.4	448.0	130.6	569.9	2.0	3.3	8.1	16.4	29.3	34.5	1,117,404
8	966.0	951.1	58.6	461.8	132.2	589.8	2.0	3.3	8.6	17.3	30.6	34.3	1,118,626
9	893.2	870.9	56.8	499.1	133.7	662.4	1.9	3.4	10.6	21.1	35.5	32.6	1,098,098
10	769.6	722.2	56.3	206.5	97.1	683.2	1.1	2.8	12.0	23.8	35.1	11.6	1,043,110
11	769.6	722.2	56.3	206.5	97.1	683.2	1.1	2.8	12.0	23.8	35.1	11.6	1,043,110
12	769.6	722.2	56.3	198.9	95.9	683.2	1.1	2.8	12.0	23.8	35.1	11.6	1,043,110
13	769.6	722.2	56.3	198.9	95.9	683.2	1.1	2.8	12.0	23.8	35.1	11.6	1,043,110
14	769.6	722.2	56.3	198.9	95.9	683.2	1.1	2.8	12.0	23.8	35.1	11.6	1,043,110
15	769.6	722.2	56.3	198.9	95.9	683.2	1.1	2.8	12.0	23.8	35.1	11.6	1,043,110
16-30	769.6	722.2	56.3	198.9	95.9	683.2	1.1	2.8	12.0	23.8	35.1	11.6	1,043,110

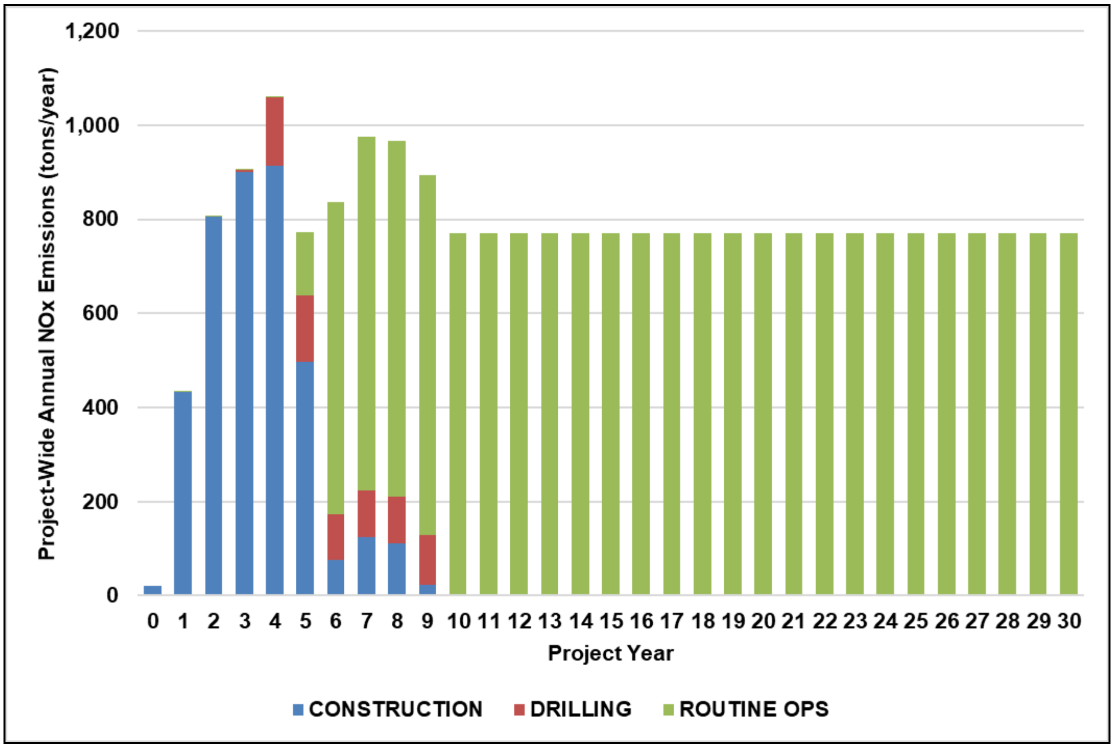


Figure 2.1.7 Alternative C (Disconnected Infield Roads) Annual NOx Emissions by Project Phase*

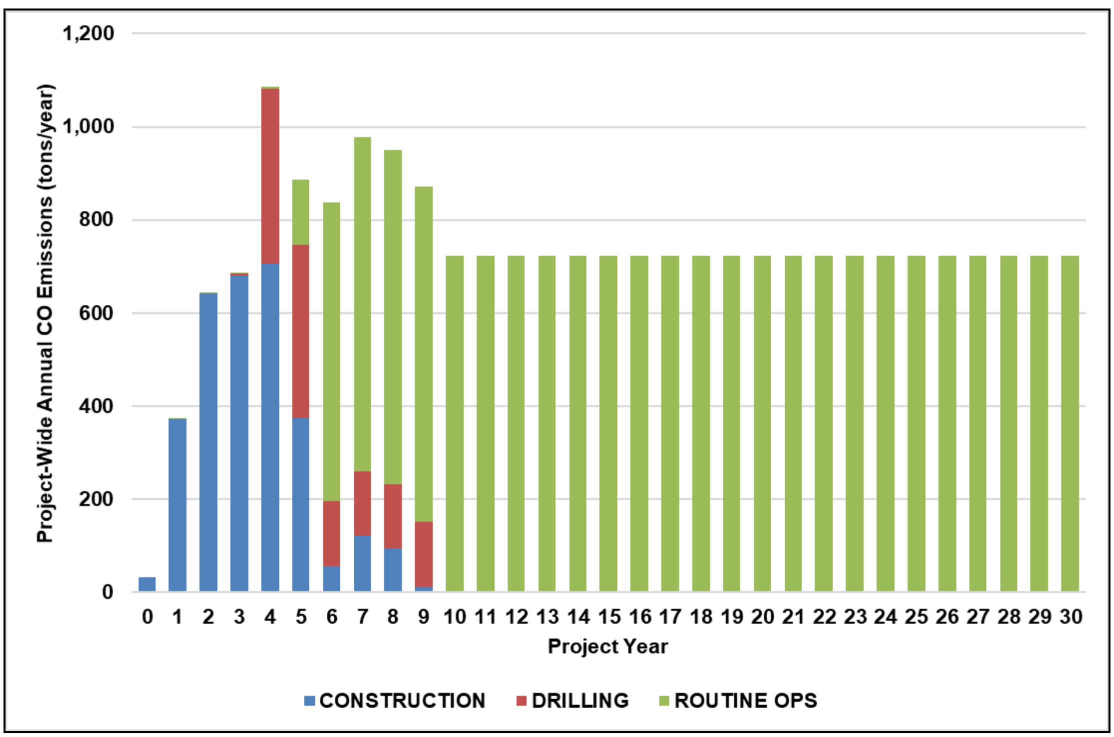


Figure 2.1.8 Alternative C (Disconnected Infield Roads) Annual CO Emissions by Project Phase*

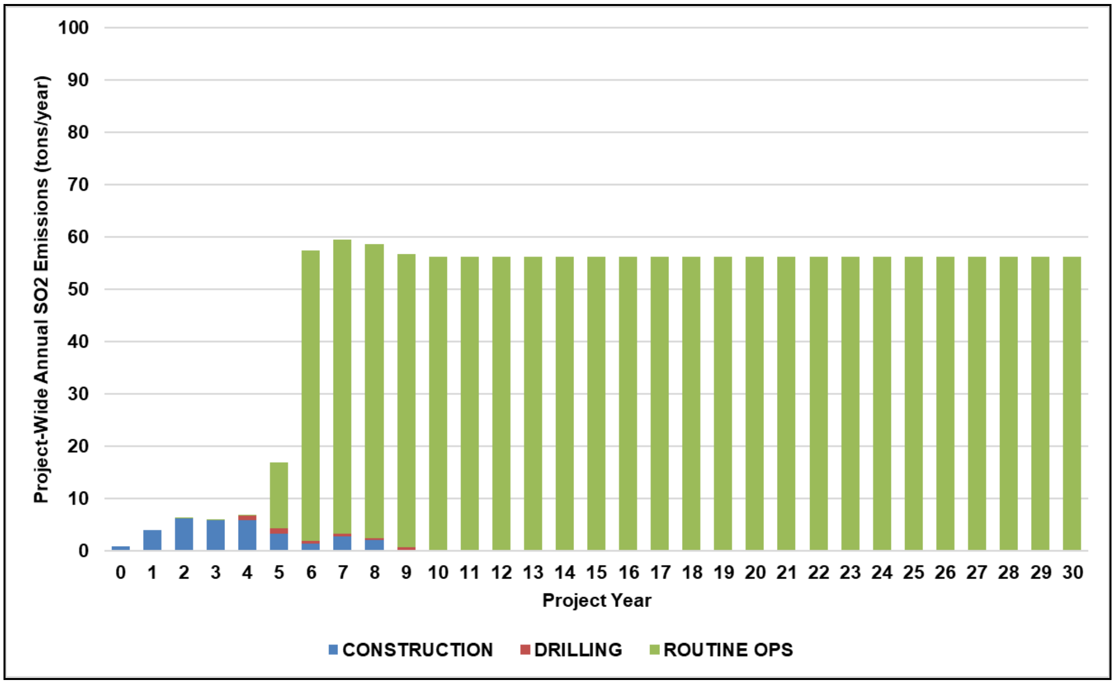


Figure 2.1.9 Alternative C (Disconnected Infield Roads) Annual SO_2 Emissions by Project Phase*

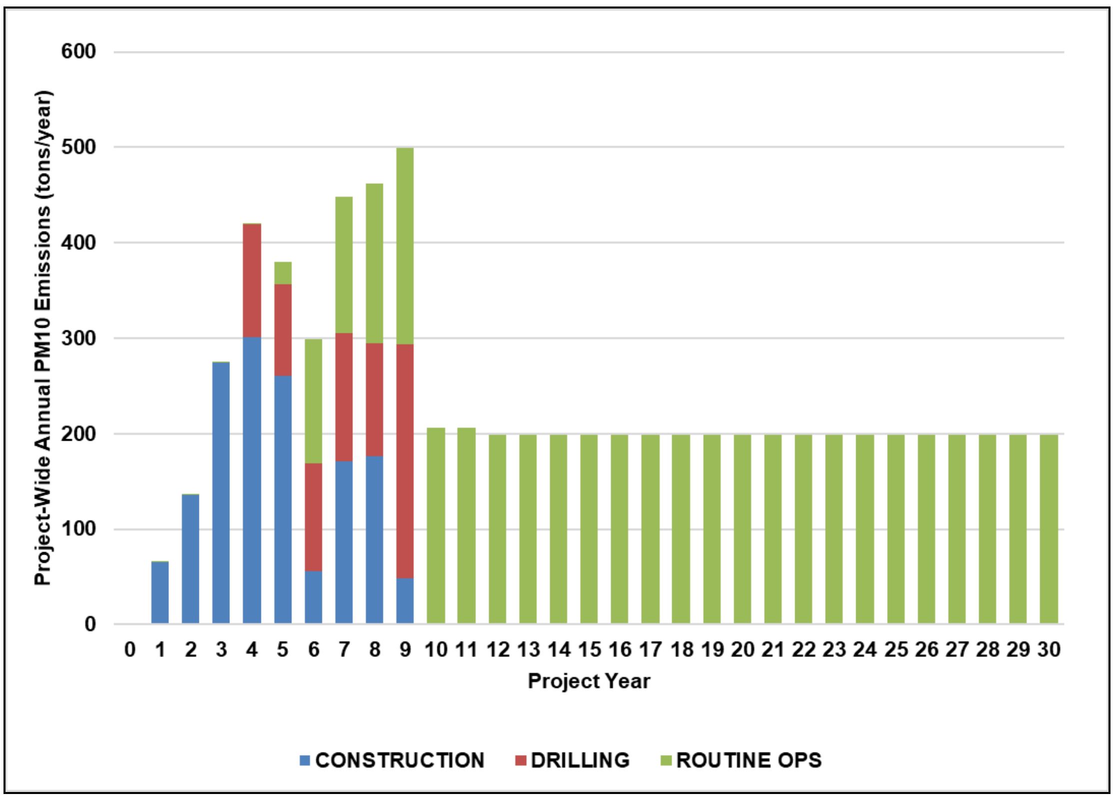


Figure 2.1.10 Alternative C (Disconnected Infield Roads) Annual PM_{10} Emissions by Project Phase*

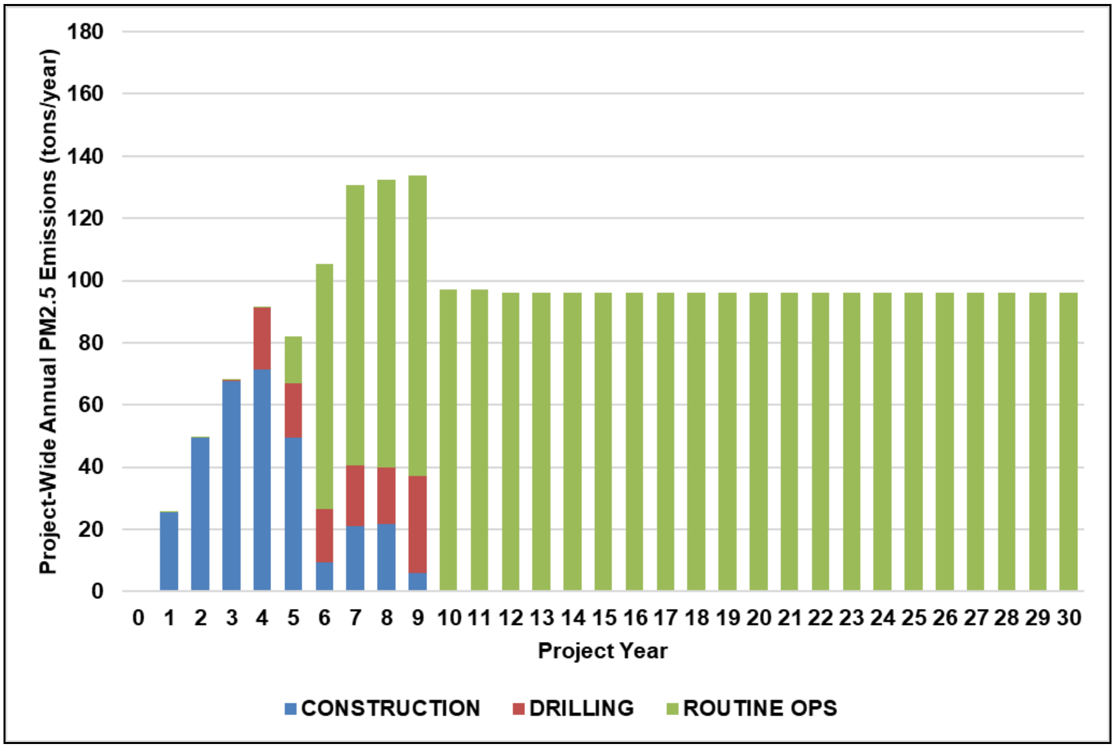


Figure 2.1.11 Alternative C (Disconnected Infield Roads) Annual $PM_{2.5}$ Emissions by Project Phase*

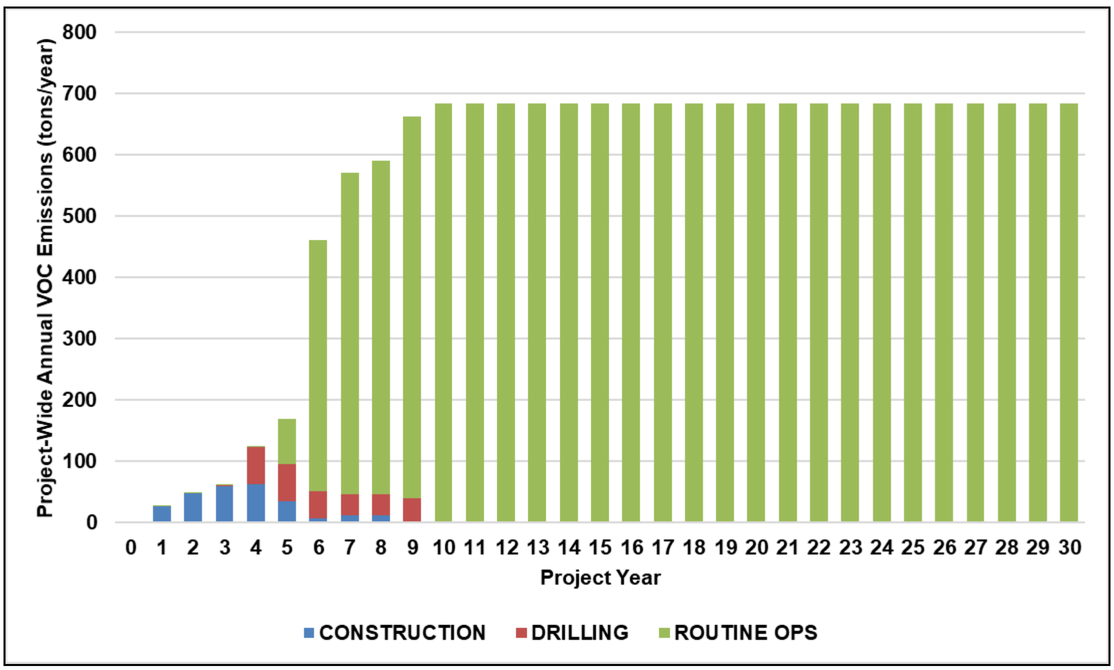


Figure 2.1.12 Alternative C (Disconnected Infield Roads) Annual VOC Emissions by Project Phase*

Similar to Alternative B, Alternative C flaring activities are limited to a low pressure flare and high pressure flare at the WPF and flowback flaring during the drilling phase.

As in Alternative B, under Alternative C, flares will be in operation at the WPF from project year 5 to end of project. At the WPF there will be a low pressure flare and high pressure flare which will include year-round, 24-hour per day operation of a pilot/purge assist and operation for 10 hours per year at a maximum flowrate of 9 million standard cubic-feet per hour (MMSCF/hr) for the low pressure flare and 11 MMSCF/hr for the high pressure flare.

As in Alternative B, under Alternative C, flaring at drill sites would occur from project year 4 to 9. Typically, there would be 1 flowback event per well drilled with a duration of 3 days of flaring per flowback event. There will be 4 flowbacks per month during project years 4 and 5; in project year 6, 4 flowbacks per month will occur from January through May; and from June in project year 6 to end of project year 9, there will be 2 flowbacks per month.

Table 2.1-16 shows life of project flaring emissions under Alternative C for criteria pollutant, VOCs, HAP, and GHG emissions.

Table 2.1-16 Alternative C Annual Flaring Emissions

Project Year	Total Emissions (tons per year [tpy])												
	Criteria Pollutants						HAP						GHGs
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Benzene	Toluene	EthylBenzene	Xylene	n-Hexane	Formaldehyde	CO_2e
WPF	311.0	1,036.6	22.7	72.4	72.4	2,890.8	8.6	7.7	0.5	2.2	144.9	239.9	807,727
Drill sites	8.7	47.3	0.5	0.0	0.0	167.7	6.2	5.6	0.4	1.6	34.9	170.3	19,042
Total	**319.8**	**1,083.9**	**23.2**	**72.4**	**72.4**	**3,058.6**	**14.8**	**13.2**	**0.9**	**3.8**	**179.9**	**410.2**	**826,769**

2.1.5 Alternative D (Disconnected Access)

Alternative D would be identical to Alternative B with respect to the number of wells drilled, main Project features, and oil production. The main difference for Alternative D relative to Alternative B is the elimination of all-season gravel access road from the Willow Development Area to GMTU. The emission inventory for Alternative D was extended one year longer than Alternative B and Alternative C to account for the delayed production schedule for Alternative D. Section 1.1.4 "Alternative D: Disconnected Access" provides a description of Alternative D. Alternative B emission inventory spreadsheets were modified with Alternative D inputs provided by the Project proponent and information from the Project description to estimate Alternative D emissions. More information about the Alternative D emissions inventory is provided in Attachment D to this Air Quality Technical Support Document.

Table 2.1-14 shows annual criteria pollutant, VOCs, HAP, and GHG emissions for construction activities by year in Alternative D. The "Year 0" refers to the first year of construction which is a partial year. Table 2.1-15 shows annual Alternative D criteria pollutant, VOCs, HAP, and GHG emissions for drilling (including pre-drilling and developmental drilling) activities. Table 2.1-16 shows annual Alternative D criteria pollutant, VOCs, HAP, and GHG emissions for routine operation activities. Table 2.1-17 shows annual Alternative D criteria pollutant, VOCs, HAP, and GHG emissions summed across all Project activities. Alternative D annual emissions are shown graphically for each criteria pollutant by Project phase in Figure 2.1-13 to Figure 2.1-18.

Construction emissions increase from project start to their peak in year 3 or year 4, then decrease substantially from year 4 to year 5 before increasing to a second, smaller peak in project year 8, then decreasing to year 10 when most construction activities are complete. Alternative D construction emissions peak in year 3 and year 4 when construction activity is highest and temporary power generators are being used exclusively to generate electricity. In year 5, routine operation phase power generation comes online, replacing construction phase temporary power generation. The cessation of construction phase temporary power generation results in substantial construction phase emissions reductions. Additionally, several key construction activities are slowing or have been completed by year 5: multi-season ice pads, gravel mining, drill site gravel pad construction, WOC construction, and bridge construction. In year 8, construction emissions reach a second peak as several construction activities start again: gravel mining, drill site gravel pad construction, bridge construction. Construction activities and emissions decrease after year 8.

The drilling phase includes three different activities: disposal well drilling at the WOC in year 3, pre-drilling from years 5-6, and developmental drilling from years 7-10. For most pollutants, the largest drilling phase emissions occur during pre-drilling when diesel engines are used to power drill rigs, prior to developmental drilling during which highline electricity is used to power drill rigs. PM_{10} emissions are highest in year 10 when drilling phase on-road vehicle activity and hence fugitive dust emissions are highest.

Routine operations at the WPF are expected to commence in the fourth quarter of year 6with commissioning of the WPF and the first drill site (BT1). Subsequent drill sites will be commissioned in the following years and continue operating until the end of field life in year 31. Routine operation emissions generally increase as routine operation facilities (e.g., WOC, WPF, and drill sites) are brought online and thereafter remain relatively constant.

Table 2.1-17 Alternative D (Disconnected Access) Annual Emissions from Construction Activities

Project Year	Total Emissions (tons per year [tpy])												
	Criteria Pollutants						HAP						GHGs
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Benzene	Toluene	EthylBenzene	Xylene	n-Hexane	Formaldehyde	CO_2e
0	22.6	33.3	0.9	1.3	0.6	1.5	0.0	0.0	0.0	0.0	0.0	0.3	4,057
1	456.2	379.0	4.0	65.9	26.4	29.7	0.4	0.4	0.1	0.4	0.0	3.0	144,607
2	510.8	397.9	4.1	152.0	37.1	34.4	0.5	0.5	0.1	0.5	0.1	3.8	157,681
3	595.1	429.8	5.3	255.0	51.1	44.4	0.7	0.7	0.1	0.7	0.1	5.9	190,198
4	597.5	422.9	3.9	280.7	54.1	47.2	0.6	0.6	0.1	0.6	0.1	4.9	188,413
5	92.5	36.5	0.5	124.8	16.8	10.0	0.2	0.2	0.1	0.2	0.0	2.0	31,833
6	61.3	26.5	0.2	95.5	13.0	6.7	0.2	0.2	0.0	0.1	0.0	1.4	23,786
7	76.0	55.6	1.3	125.7	16.0	7.2	0.2	0.2	0.0	0.2	0.0	1.4	24,202
8	136.5	129.9	2.9	152.9	20.0	12.9	0.3	0.3	0.1	0.3	0.0	2.7	40,787
9	116.1	95.8	2.0	183.9	22.7	11.7	0.2	0.3	0.1	0.3	0.0	2.4	38,148
10	27.7	11.1	0.1	77.1	9.0	3.0	0.1	0.1	0.0	0.1	0.0	0.6	10,109
11	9.0	2.5	0.0	0.3	0.3	0.8	0.0	0.0	0.0	0.0	0.0	0.2	2,025
12	9.0	2.5	0.0	0.3	0.3	0.8	0.0	0.0	0.0	0.0	0.0	0.2	2,025
13	7.8	2.2	0.0	0.3	0.3	0.7	0.0	0.0	0.0	0.0	0.0	0.2	1,761
14	7.8	2.2	0.0	0.3	0.3	0.7	0.0	0.0	0.0	0.0	0.0	0.2	1,761
15	7.8	2.2	0.0	0.3	0.3	0.7	0.0	0.0	0.0	0.0	0.0	0.2	1,761
16-31	7.8	2.2	0.0	0.3	0.3	0.7	0.0	0.0	0.0	0.0	0.0	0.2	1,761

Table 2.1-18 Alternative D (Disconnected Access) Annual Emissions from Drilling Activities

Project Year	Total Emissions (tons per year [tpy])												
	Criteria Pollutants						HAP						GHGs
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Benzene	Toluene	EthylBenzene	Xylene	n-Hexane	Formaldehyde	CO_2e
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
3	3.8	5.3	0.0	0.3	0.3	0.4	0.0	0.0	0.0	0.0	0.0	0.0	1,728
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
5	143.9	379.7	1.1	131.7	21.0	73.6	1.8	1.4	0.1	0.5	8.3	40.8	90,339
6	143.9	379.7	1.1	131.7	21.0	73.6	1.8	1.4	0.1	0.5	8.3	40.8	90,339
7	98.2	140.6	0.5	129.7	19.0	44.6	1.1	1.0	0.1	0.3	5.9	28.8	47,635
8	97.1	137.1	0.5	99.9	16.0	34.9	0.8	0.7	0.0	0.2	4.2	20.4	46,242
9	97.7	137.5	0.5	129.7	19.0	35.0	0.8	0.7	0.0	0.2	4.2	20.4	46,600
10	98.4	137.9	0.5	146.3	20.7	35.1	0.8	0.7	0.0	0.2	4.2	20.4	46,913
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
16-31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-

Table 2.1-19 Alternative D (Disconnected Access) Annual Emissions from Routine Operation Activities

Project Year	Total Emissions (tons per year [tpy])												
	Criteria Pollutants						HAP						GHGs
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Benzene	Toluene	EthylBenzene	Xylene	n-Hexane	Formaldehyde	CO_2e
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
1	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	49
2	0.5	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	62
3	2.1	4.2	0.2	0.1	0.1	0.8	0.0	0.0	0.0	0.0	0.0	0.1	661
4	2.5	4.5	0.3	2.9	0.5	0.8	0.0	0.0	0.0	0.0	0.0	0.1	780
5	119.6	112.5	4.7	17.1	14.7	17.9	0.1	0.1	0.0	0.1	0.0	0.4	84,017
6	250.1	238.1	16.9	45.1	29.9	64.9	0.2	0.4	0.1	0.2	1.6	3.2	304,545
7	633.8	607.3	52.5	136.2	75.6	331.3	0.7	1.7	3.5	7.0	14.1	11.7	945,272
8	637.2	609.4	52.6	136.9	75.9	431.8	0.8	2.0	6.1	12.0	20.4	11.7	948,567
9	642.0	613.4	52.6	140.2	76.4	526.2	0.9	2.3	8.5	16.7	26.2	11.7	951,122
10	648.5	618.3	52.7	146.3	77.4	606.5	1.0	2.5	10.5	20.7	31.2	11.7	955,453
11	653.6	619.7	52.5	240.7	87.2	665.4	1.0	2.6	12.0	23.7	34.9	11.5	959,165
12	653.6	619.7	52.5	234.6	86.2	665.0	1.0	2.6	12.0	23.7	34.9	11.5	959,165
13	653.6	619.7	52.5	234.6	86.2	665.0	1.0	2.6	12.0	23.7	34.9	11.5	959,165
14	653.6	619.7	52.5	234.6	86.2	665.0	1.0	2.6	12.0	23.7	34.9	11.5	959,165
15	653.6	619.7	52.5	234.6	86.2	665.0	1.0	2.6	12.0	23.7	34.9	11.5	959,165
16-31	653.6	619.7	52.5	234.6	86.2	665.0	1.0	2.6	12.0	23.7	34.9	11.5	959,165

Table 2.1-20 Alternative D (Disconnected Access) Annual Emissions from All Project Activities

Project Year	Total Emissions (tons per year [tpy])												
	Criteria Pollutants						HAP						GHGs
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Benzene	Toluene	EthylBenzene	Xylene	n-Hexane	Formaldehyde	CO_2e
0	22.6	33.3	0.9	1.3	0.6	1.5	0.0	0.0	0.0	0.0	0.0	0.3	4,057
1	456.7	379.3	4.0	65.9	26.4	29.8	0.4	0.4	0.1	0.4	0.0	3.0	144,656
2	511.3	398.2	4.1	152.0	37.1	34.4	0.5	0.5	0.1	0.5	0.1	3.8	157,744
3	601.0	439.3	5.5	255.3	51.4	45.6	0.7	0.8	0.1	0.7	0.1	6.0	192,587
4	599.9	427.5	4.2	283.6	54.6	47.9	0.6	0.6	0.1	0.6	0.1	5.0	189,193
5	356.0	528.6	6.2	273.6	52.5	101.5	2.1	1.8	0.2	0.7	8.3	43.2	206,781
6	455.2	644.3	18.1	272.3	63.9	145.2	2.1	2.0	0.2	0.8	9.9	45.4	419,262
7	808.1	803.6	54.4	391.7	110.6	383.1	2.0	2.9	3.6	7.4	20.0	42.0	1,017,109
8	870.8	876.4	55.9	389.7	111.9	479.6	1.9	3.0	6.2	12.5	24.6	34.7	1,035,596
9	855.8	846.7	55.1	453.9	118.2	572.9	2.0	3.3	8.6	17.2	30.4	34.4	1,035,870
10	774.5	767.3	53.3	369.6	107.2	644.6	1.9	3.3	10.5	21.0	35.4	32.6	1,012,475
11	662.6	622.2	52.5	241.0	87.5	666.2	1.1	2.7	12.0	23.7	34.9	11.7	961,190
12	662.6	622.2	52.5	234.9	86.5	665.8	1.1	2.7	12.0	23.7	34.9	11.7	961,190
13	661.4	621.9	52.5	234.8	86.5	665.7	1.1	2.7	12.0	23.7	34.9	11.7	960,927
14	661.4	621.9	52.5	234.8	86.5	665.7	1.1	2.7	12.0	23.7	34.9	11.7	960,927
15	661.4	621.9	52.5	234.8	86.5	665.7	1.1	2.7	12.0	23.7	34.9	11.7	960,927
16-31	661.4	621.9	52.5	234.8	86.5	665.7	1.1	2.7	12.0	23.7	34.9	11.7	960,927

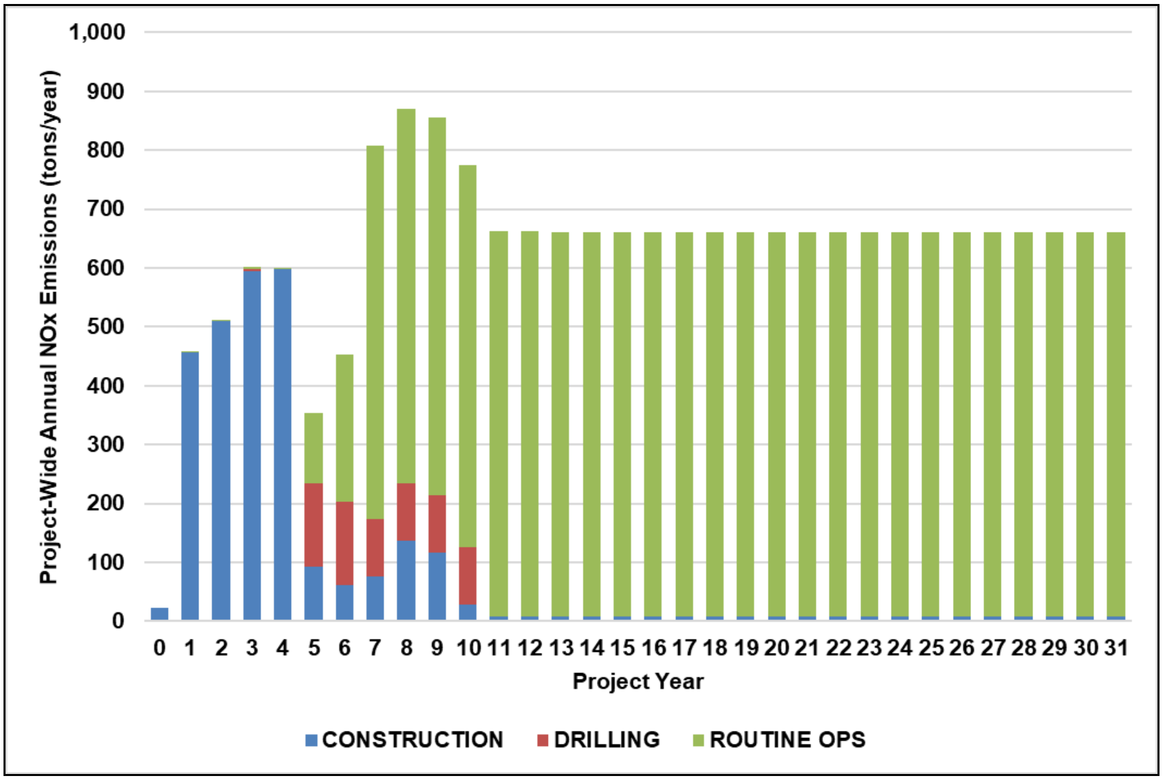


Figure 2.1.13 Alternative D (Disconnected Access) Annual NOx Emissions by Project Phase*

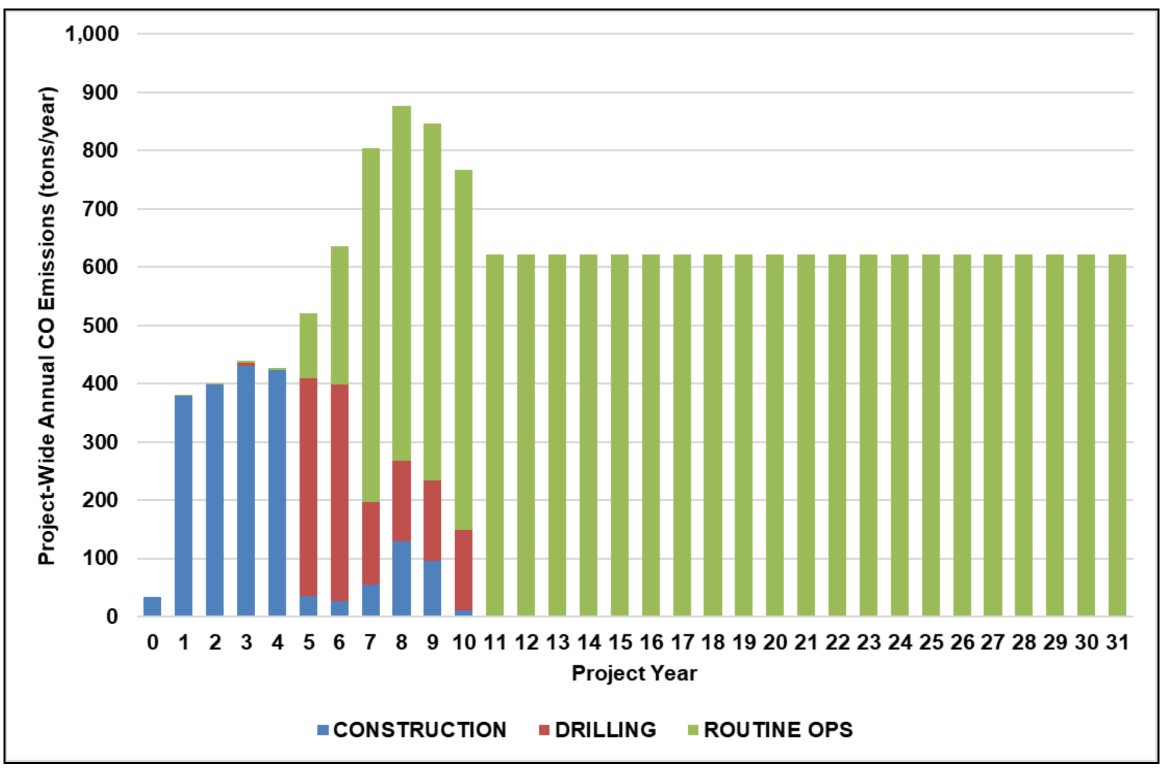


Figure 2.1.14 Alternative D (Disconnected Access) Annual CO Emissions by Project Phase*

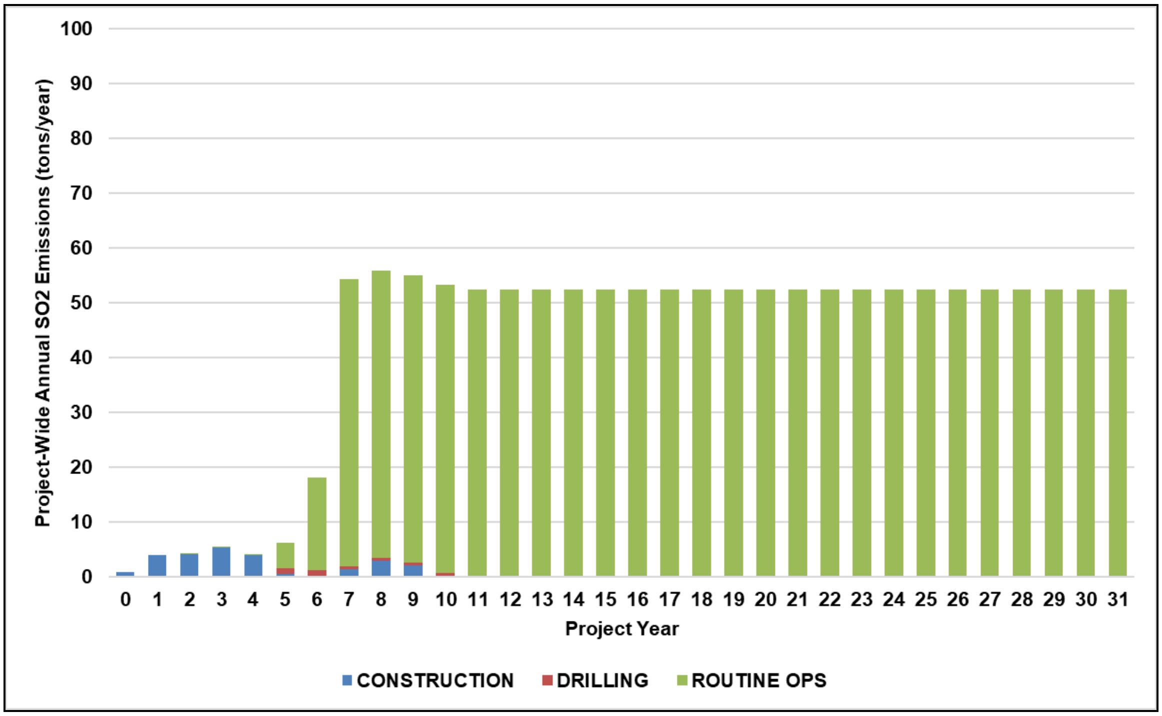


Figure 2.1.15 Alternative D (Disconnected Access) Annual SO_2 Emissions by Project Phase*

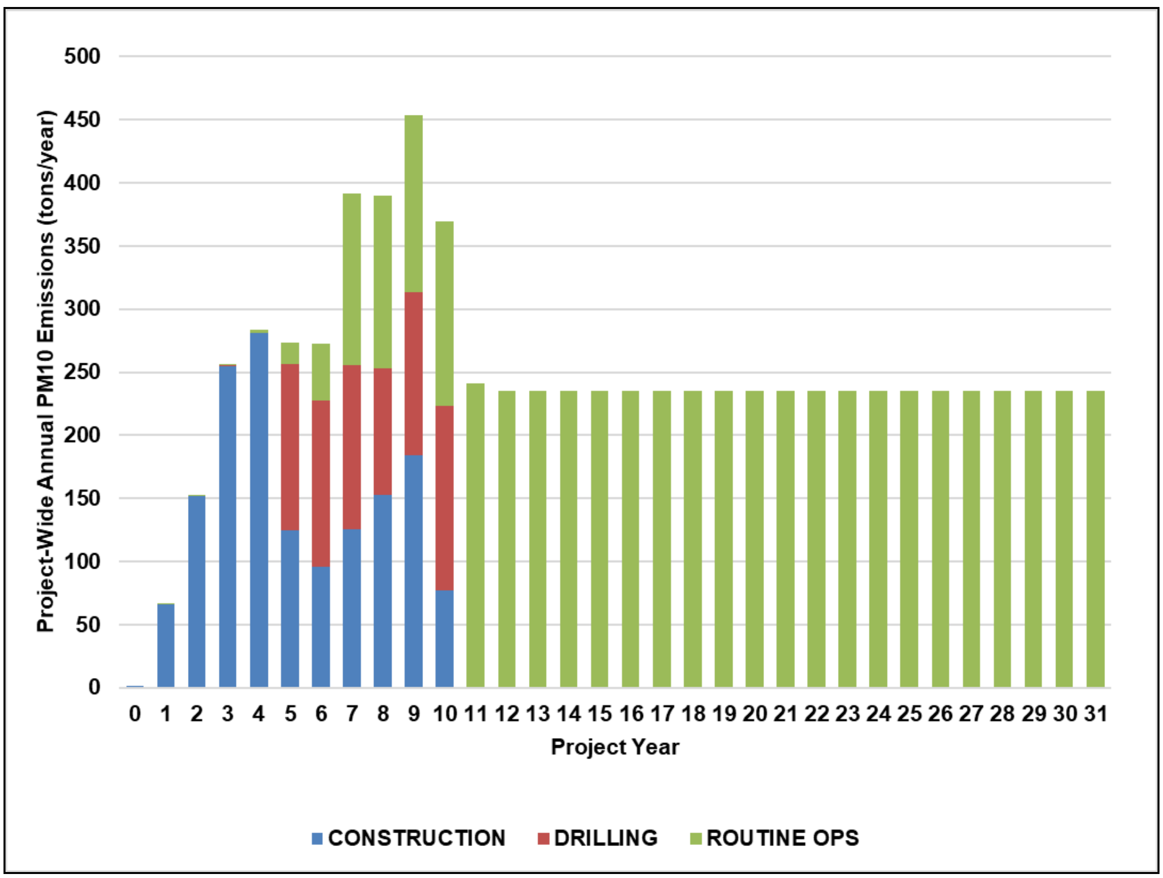


Figure 2.1.16 Alternative D (Disconnected Access) Annual PM_{10} Emissions by Project Phase*

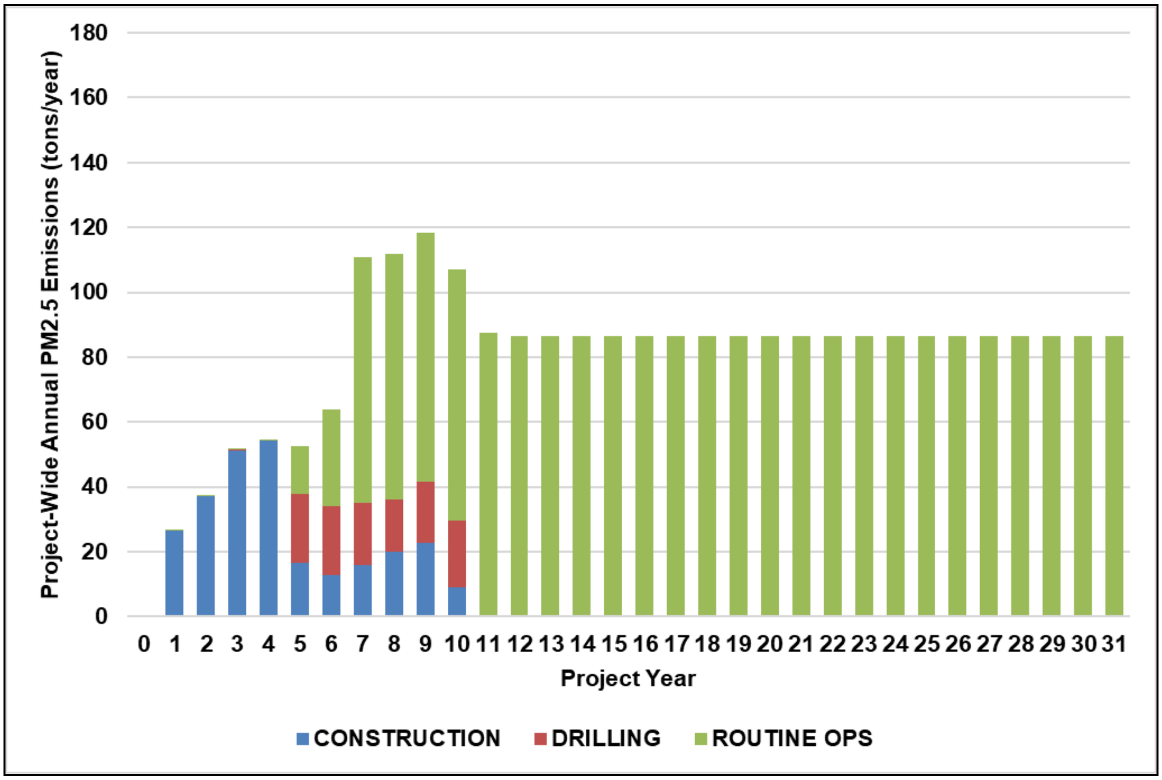


Figure 2.1.17 Alternative D (Disconnected Access) Annual $PM_{2.5}$ Emissions by Project Phase*

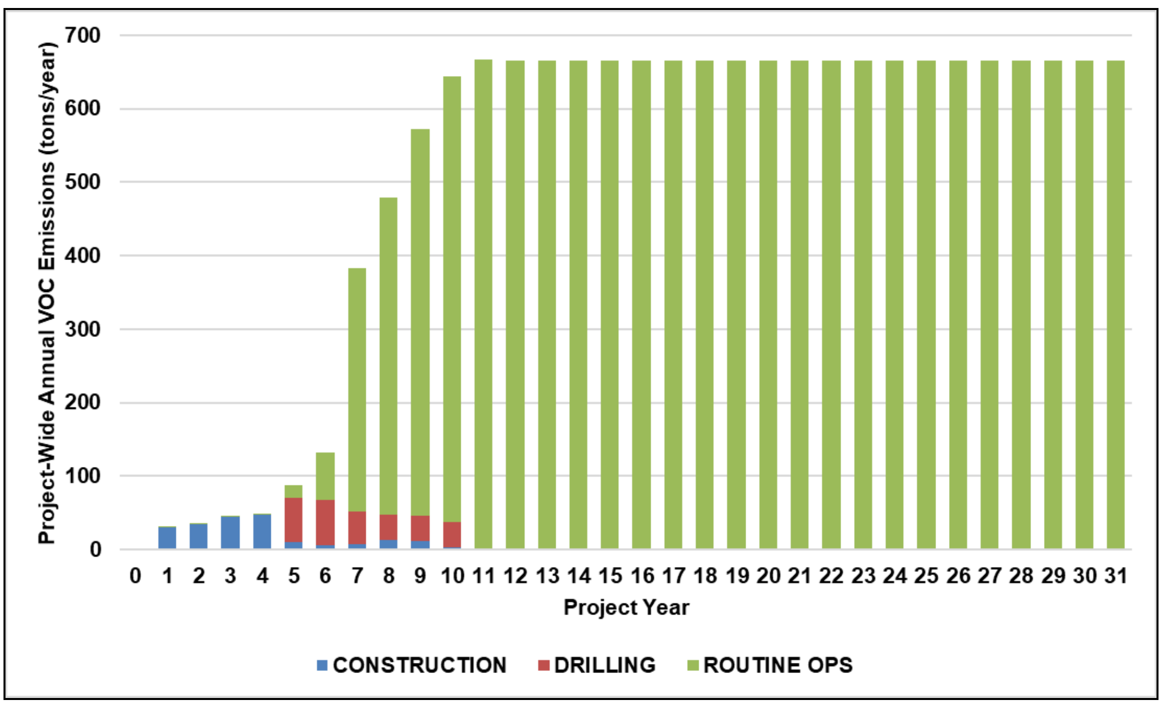


Figure 2.1.18 Alternative D (Disconnected Access) Annual VOC Emissions by Project Phase*

Similar to Alternative B, under Alternative D flaring activities are limited to a low pressure flare and high pressure flare at the WPF and flowback flaring at drill sites.

Flares will be in operation at the WPF from project year 6 to end of project for Alternatives D. At the WPF there will be a low pressure flare and high pressure flare which will include year-round, 24-hour per day operation of a pilot/purge assist and operation for 10 hours per year at a maximum flowrate of 9 million standard cubic-feet per hour (MMSCF/hr) for the low pressure flare and 11 MMSCF/hr for the high pressure flare.

Flaring at drill sites would occur from project year 5 to 10 under Alternative D. Typically, there would be 1 flowback event per well drilled with a duration of 3 days of flaring per flowback event. Under Alternative D, there will be 4 flowbacks per month during project years 5 and 6; in project year 7, 4 flowbacks per month will occur from January through May; and from June in project year 7 to end of project year 10, there will be 2 flowbacks per month.

Table 2.1-21 shows life of project flaring emissions under Alternative D for criteria pollutant, VOCs, HAP, and GHG emissions.

Table 2.1-21 Alternative D Annual Flaring Emissions

Project Year	Total Emissions (tons per year [tpy])												
	Criteria Pollutants						HAP						GHGs
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Benzene	Toluene	EthylBenzene	Xylene	n-Hexane	Formaldehyde	CO_2e
WPF	311.0	1,036.6	22.7	72.4	72.4	2,890.8	8.6	7.7	0.5	2.2	144.9	239.9	807,727
Drill sites	8.7	47.3	0.5	0.0	0.0	167.7	6.2	5.6	0.4	1.6	34.9	170.3	19,042
Total	**319.8**	**1,083.9**	**23.2**	**72.4**	**72.4**	**3,058.6**	**14.8**	**13.2**	**0.9**	**3.8**	**179.9**	**410.2**	**826,769**

2.1.6 Alternative E (Three-Pad Alternative)*

Alternative E would be similar to Alternative B with respect to several Project features. The main difference in Alternative E relative to Alternative B that affects the emissions inventory is that drill site BT4 would not be constructed. There would also only be 219 wells under Alternative E compared to 251 wells under Alternative B. Section 1.1.5 "Alternative E: Three-Pad Alternative" provides a description of Alternative E. The Alternative E emission inventory from the Project proponent was reviewed and revised by the BLM. More information about the Alternative E emissions inventory is provided in Attachment G to this Air Quality Technical Support Document.

Table 2.1-22 shows annual criteria pollutant, VOCs, HAP, and GHG emissions in Alternative E for construction activities by year. The "Year 0" refers to the first year of construction which is a partial year. Table 2.1-23 shows annual Alternative E criteria pollutant, VOCs, HAP, and GHG emissions for drilling (including pre-drilling and developmental drilling) activities. Table 2.1-24 shows annual Alternative E criteria pollutant, VOCs, HAP, and GHG emissions for routine operation activities.

Table 2.1-25 shows annual Alternative E criteria pollutant, VOCs, HAP, and GHG emissions summed across all Project activities. Alternative E annual emissions are shown graphically for each criteria pollutant by Project phase in Figure 2.1-19 to Figure 2.1-24.

Construction emissions increase from project start to year 4, then, generally decrease to the end of construction activities in year 8. All pollutants generally follow this trend of increasing emissions until year 4 followed by decreases in emissions, with slight exceptions for sulfur dioxide, carbon monoxide, and certain HAPs (n-hexane and formaldehyde) and.

The drilling phase includes three different activities: disposal well drilling at the WOC in year 3, pre-drilling from years 4 to -5, and developmental drilling from years 6 to 9. For most pollutants, the largest drilling phase emissions occur during pre-drilling when diesel engines are used to power drill rigs, prior to developmental drilling during which highline electricity is used to power drill rigs. PM_{10} and $PM_{2.5}$ emissions are highest in year 7 when drilling phase on-road vehicle activity and hence fugitive dust emissions are highest.

Routine operations at the WPF are expected to commence in the fourth quarter of year 5 with commissioning of the WPF and the first drill site (BT1). Subsequent drill sites will be commissioned in the following years and continue operating until the end of field life in year 30. Routine operation emissions generally increase as routine operation facilities (e.g., WOC, WPF, and drill sites) are brought online and thereafter remain relatively constant.

Table 2.1-22 Alternative E (Three-Disconnected Access Three-Pad Alternative) Annual Emissions from Construction Activities*

Project Year	Total Emissions (tons per year [tpy])												
	Criteria Pollutants						HAP						GHGs
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Benzene	Toluene	EthylBenzene	Xylene	n-Hexane	Formaldehyde	CO_2e
0	17.1	25.0	0.7	1.0	0.5	1.1	0.0	0.0	0.0	0.0	0.0	0.3	3,082
1	430.6	354.0	3.2	80.3	20.3	26.1	0.4	0.4	0.1	0.4	0.1	3.1	141,826
2	452.3	361.6	4.1	100.6	22.9	26.1	0.4	0.4	0.1	0.3	0.0	2.9	137,855
3	531.3	397.3	3.7	211.1	37.5	36.1	0.6	0.6	0.1	0.6	0.1	4.9	169,815
4	592.4	419.2	3.1	216.7	41.6	45.1	0.6	0.7	0.1	0.6	0.1	5.3	188,910
5	131.3	60.2	0.4	209.4	29.0	14.9	0.3	0.3	0.1	0.3	0.0	3.0	52,746
6	86.2	57.0	1.0	84.7	13.4	8.9	0.2	0.2	0.0	0.2	0.0	1.9	32,591
7	69.1	66.4	1.4	51.7	7.7	7.1	0.1	0.2	0.0	0.2	0.0	1.5	24,016
8	19.2	10.5	0.1	39.4	5.1	2.3	0.0	0.0	0.0	0.0	0.0	0.4	7,950
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
16-30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-

Table 2.1-23 Alternative E (Three-Pad Alternative) Annual Emissions from Drilling Activities*

Project Year	Total Emissions (tons per year [tpy])												
	Criteria Pollutants						HAP						GHGs
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Benzene	Toluene	EthylBenzene	Xylene	n-Hexane	Formaldehyde	CO_2e
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
3	3.8 0.0	5.3 0.0	0.0	0.30	0.30	0.40	0.0	0.0	0.0	0.0	0.0	0.0	1,728 -
4	142.2	372.1	1.0	116.6	19.5	60.4	1.0	0.8	0.1	0.3	4.9	20.6	88,435
5	143.8	372.8	1.0	152.5	23.2	60.6	1.0	0.8	0.1	0.3	4.9	20.6	89,182
6	102.7	146.5	0.6	191.1	25.4	58.5	1.5	1.4	0.1	0.4	8.3	40.7	50,615
7	108.5	148.9	0.6	324.7	39.0	59.3	1.6	1.4	0.1	0.4	8.3	40.8	53,391
8	54.2	74.5	0.3	153.2	18.6	29.7	0.8	0.7	0.0	0.2	4.2	20.4	26,560
9	54.2	74.4	0.3	161.6	19.4	29.6	0.8	0.7	0.0	0.2	4.2	20.4	26,681
10	54.2	74.4	0.3	161.6	19.4	29.6	0.8	0.7	0.0	0.2	4.2	20.4	26,681
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
16-30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-

Table 2.1-24 Alternative E (Three-Pad Alternative) Annual Emissions from Routine Operation Activities*

Project Year	Total Emissions (tons per year [tpy])												
	Criteria Pollutants						HAP						GHGs
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Benzene	Toluene	EthylBenzene	Xylene	n-Hexane	Formaldehyde	CO_2e
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
1	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	49
2	0.5	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	86
3	1.7	3.1	0.2	0.1	0.1	0.7	0.0	0.0	0.0	0.0	0.0	0.1	502
4	15.0	15.8	0.6	2.6	1.0	2.5	0.0	0.0	0.0	0.0	0.0	0.2	3,413
5	261.8	247.2	16.9	51.9	31.1	93.8	0.3	0.5	0.8	1.6	3.3	3.1	307,888
6	649.8	619.0	52.7	165.3	79.3	431.7	0.8	2.0	6.0	11.9	20.4	11.6	954,999
7	657.3	624.6	52.9	169.3	80.1	532.8	0.9	2.3	8.6	17.0	26.7	11.6	959,927
8	656.7	623.6	52.8	171.2	80.3	532.4	0.9	2.3	8.6	17.0	26.7	11.5	959,718
9	656.8	623.6	52.7	177.0	80.9	532.4	0.9	2.3	8.6	17.0	26.7	11.5	959,626
10	662.6	628.2	52.8	177.3	81.2	612.1	1.0	2.5	10.6	20.9	31.7	11.5	963,837
11	661.9	627.2	52.7	177.3	81.2	611.8	1.0	2.5	10.6	20.9	31.7	11.5	963,604
12	661.9	627.2	52.7	170.6	80.2	611.4	1.0	2.5	10.6	20.9	31.7	11.5	963,604
13	661.9	627.2	52.7	170.6	80.2	611.4	1.0	2.5	10.6	20.9	31.7	11.5	963,604
14	661.9	627.2	52.7	170.6	80.2	611.4	1.0	2.5	10.6	20.9	31.7	11.5	963,604
15	661.9	627.2	52.7	170.6	80.2	611.4	1.0	2.5	10.6	20.9	31.7	11.5	963,604
16-30	661.9	627.2	52.7	170.6	80.2	611.4	1.0	2.5	10.6	20.9	31.7	11.5	963,604

Table 2.1-25. Alternative E (Three-Pad Alternative) Annual Emissions from All Project Activities*

Project Year	Total Emissions (tons per year [tpy])												
	Criteria Pollutants						HAP						GHGs
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Benzene	Toluene	EthylBenzene	Xylene	n-Hexane	Formaldehyde	CO_2e
0	17.1	25.0	0.7	1.0	0.5	1.1	0.0	0.0	0.0	0.0	0.0	0.3	3,082
1	431.1	354.2	3.2	80.4	20.4	26.1	0.4	0.4	0.1	0.4	0.1	3.1	141,874
2	452.8	363.1	4.1	100.6	23.0	26.1	0.4	0.4	0.1	0.3	0.0	2.9	137,941
3	536.8	405.7	3.9	211.4	37.9	37.2	0.6	0.6	0.1	0.6	0.1	4.9	172,045
4	749.6	807.2	4.7	335.8	62.1	108.1	1.7	1.5	0.2	0.9	5.0	26.1	280,759
5	536.8	680.1	18.2	413.9	83.3	169.4	1.6	1.6	0.9	2.2	8.3	26.8	449,817
6	838.6	822.5	54.3	441.2	118.1	499.1	2.6	3.6	6.2	12.5	28.7	54.1	1,038,206
7	835.0	839.9	54.9	545.7	126.9	599.1	2.6	3.8	8.7	17.6	35.0	53.8	1,037,335
8	730.1	708.6	53.2	363.8	104.0	564.4	1.7	3.0	8.6	17.2	30.9	32.3	994,228
9	711.0	698.0	53.0	338.6	100.3	562.1	1.7	3.0	8.6	17.2	30.9	31.9	986,307
10	716.8	702.6	53.1	338.9	100.7	641.8	1.8	3.2	10.6	21.2	35.8	31.9	990,519
11	661.9	627.2	52.7	177.3	81.2	611.8	1.0	2.5	10.6	20.9	31.7	11.5	963,604
12	661.9	627.2	52.7	170.6	80.2	611.4	1.0	2.5	10.6	20.9	31.7	11.5	963,604
13	661.9	627.2	52.7	170.6	80.2	611.4	1.0	2.5	10.6	20.9	31.7	11.5	963,604
14	661.9	627.2	52.7	170.6	80.2	611.4	1.0	2.5	10.6	20.9	31.7	11.5	963,604
15	661.9	627.2	52.7	170.6	80.2	611.4	1.0	2.5	10.6	20.9	31.7	11.5	963,604
16-30	661.9	627.2	52.7	170.6	80.2	611.4	1.0	2.5	10.6	20.9	31.7	11.5	963,604

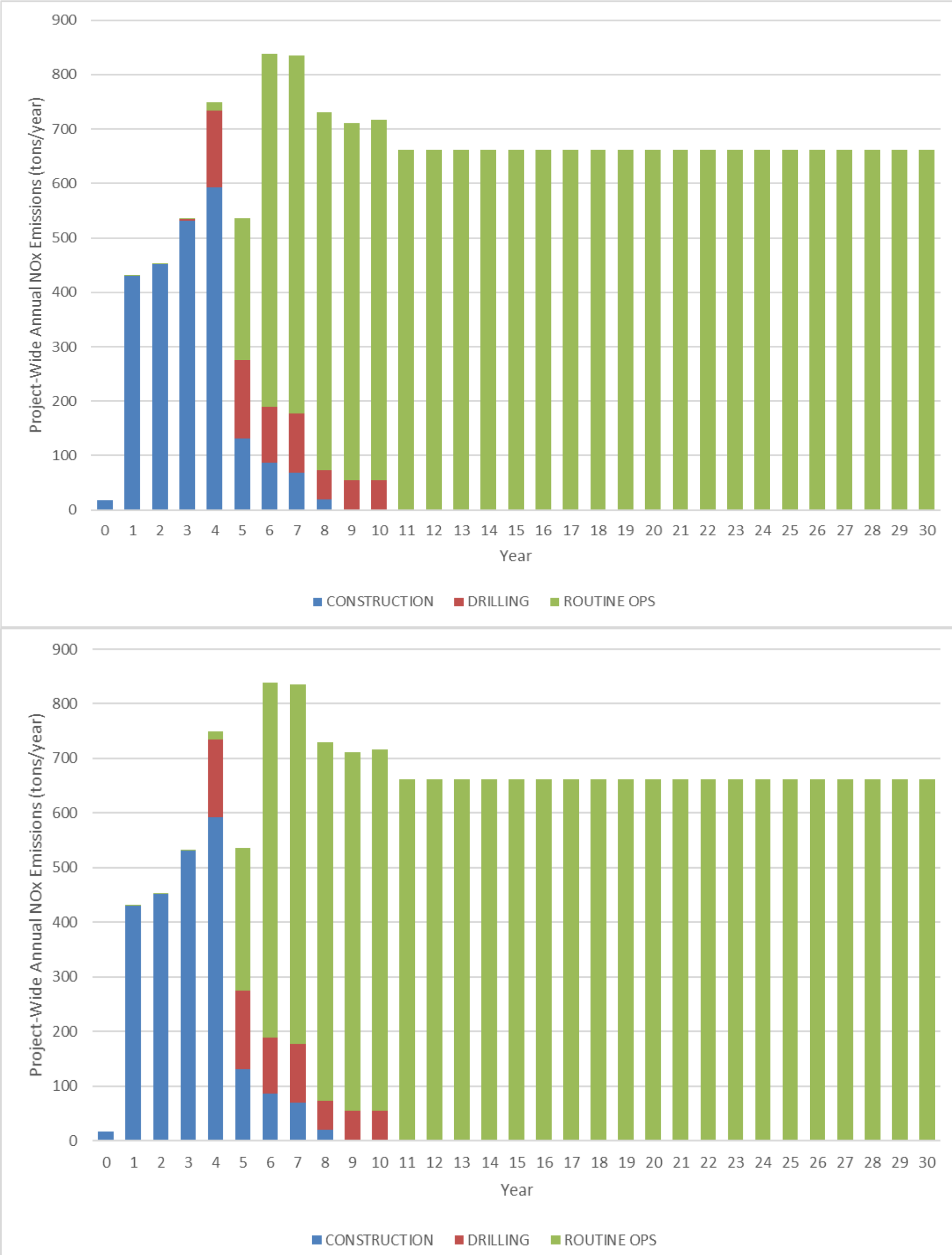
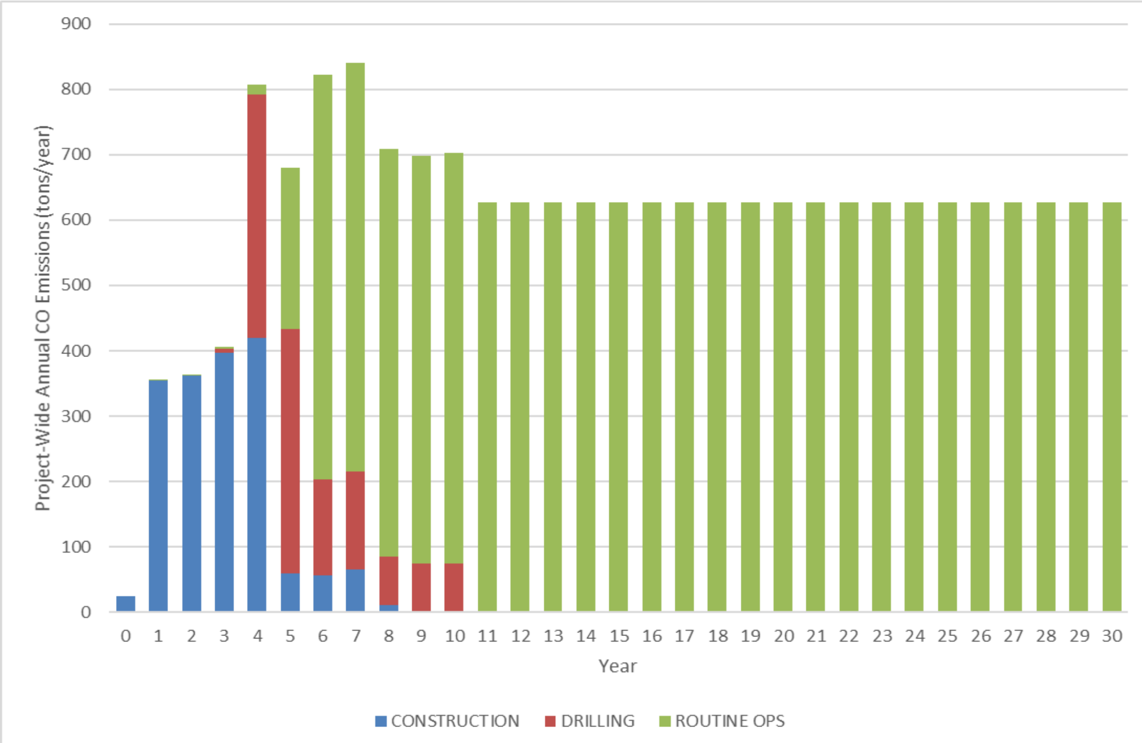


Figure 2.1.19 Alternative E (Three-Pad Alternative) Annual NOx Emissions by Project Phase*



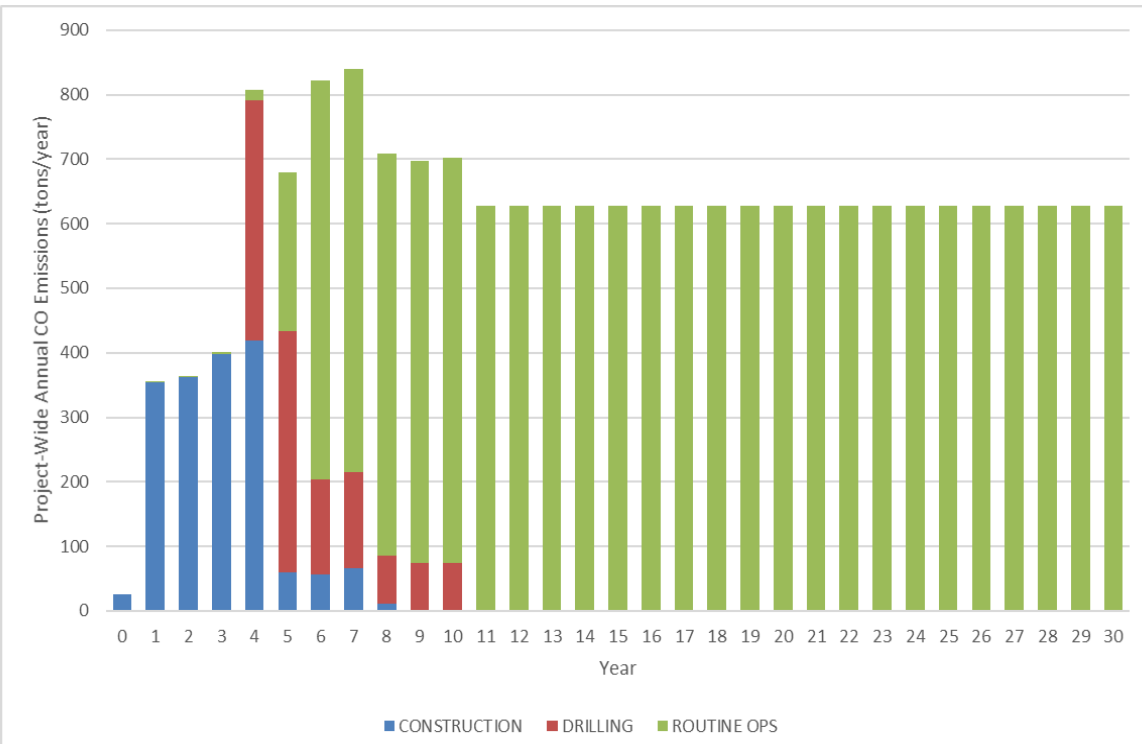
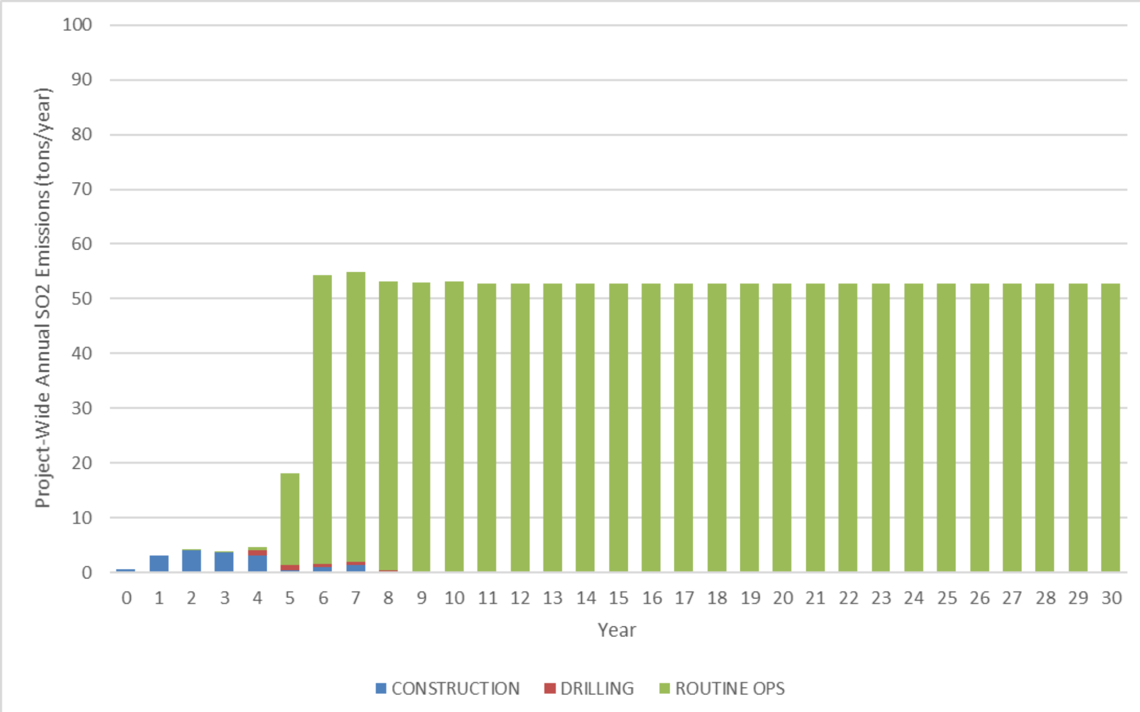


Figure 2.1.20 Alternative E (Three-Pad Alternative) Annual CO Emissions by Project Phase*



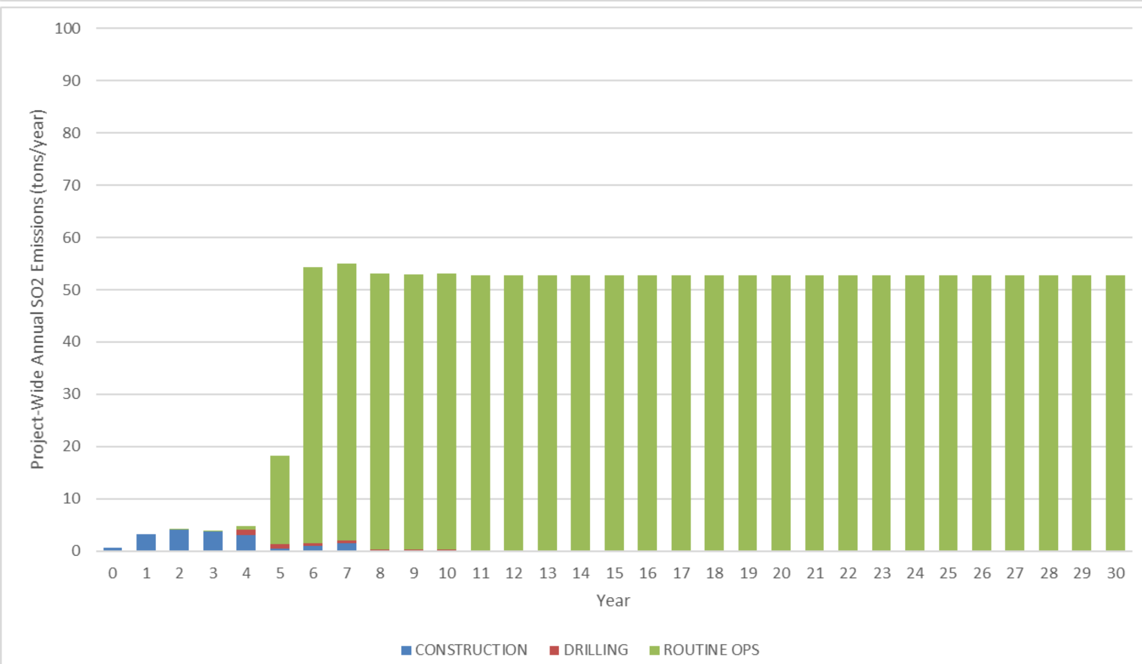


Figure 2.1.21 Alternative E (Three-Pad Alternative) Annual SO_2 Emissions by Project Phase*

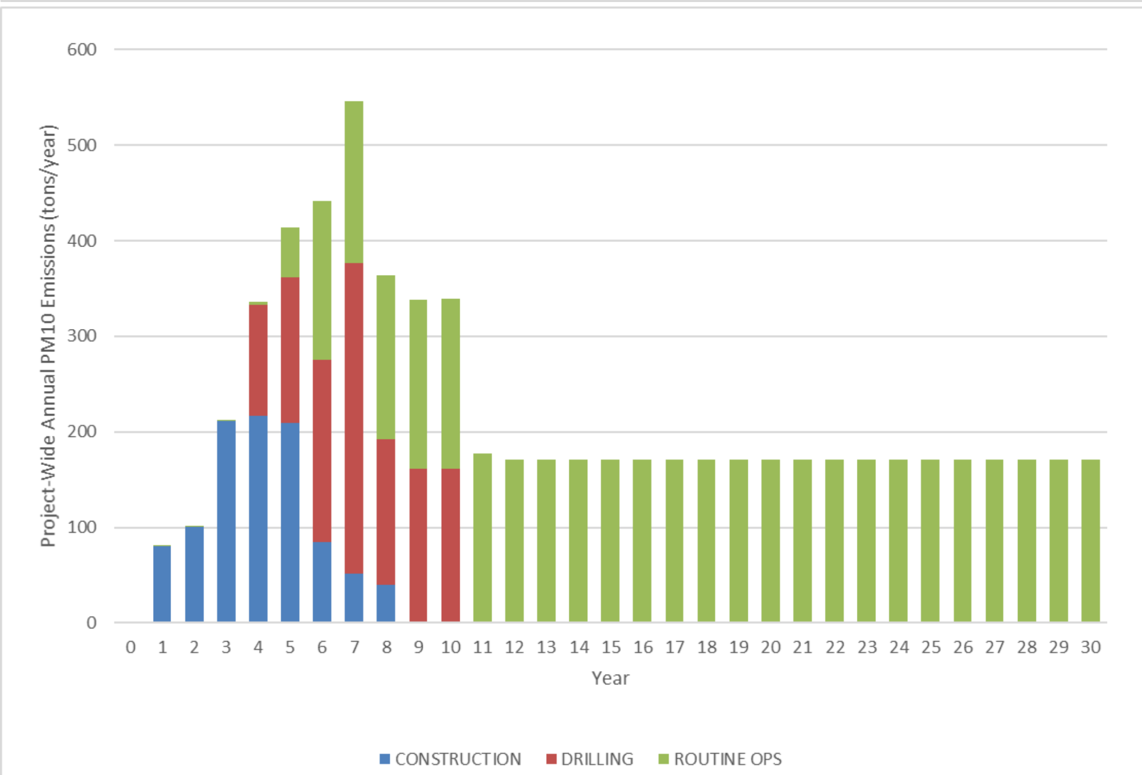


Figure 2.1.22 Alternative E (Three-Pad Alternative) Annual PM_{10} Emissions by Project Phase*

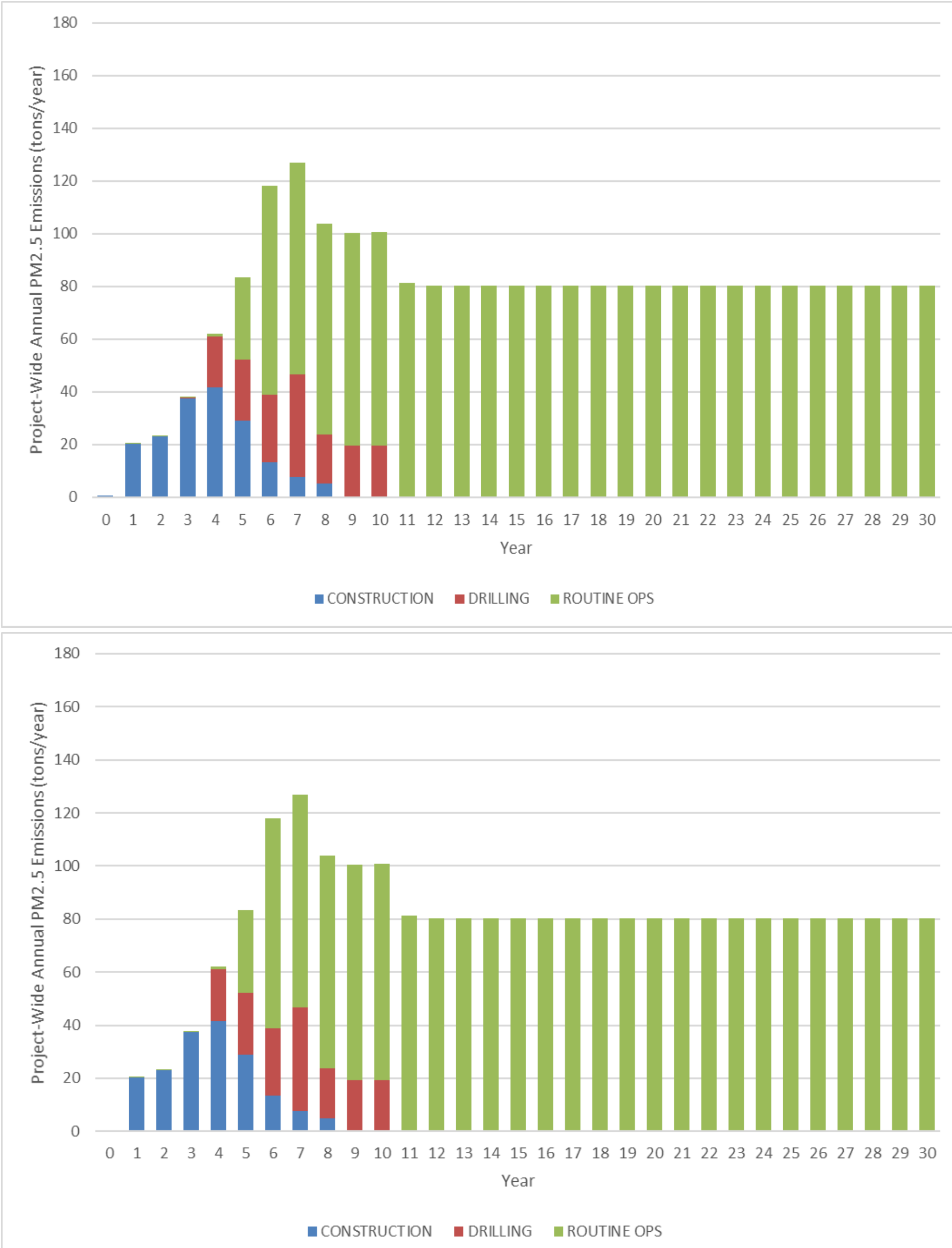


Figure 2.1.23 Alternative E (Three-Pad Alternative) Annual $PM_{2.5}$ Emissions by Project Phase*

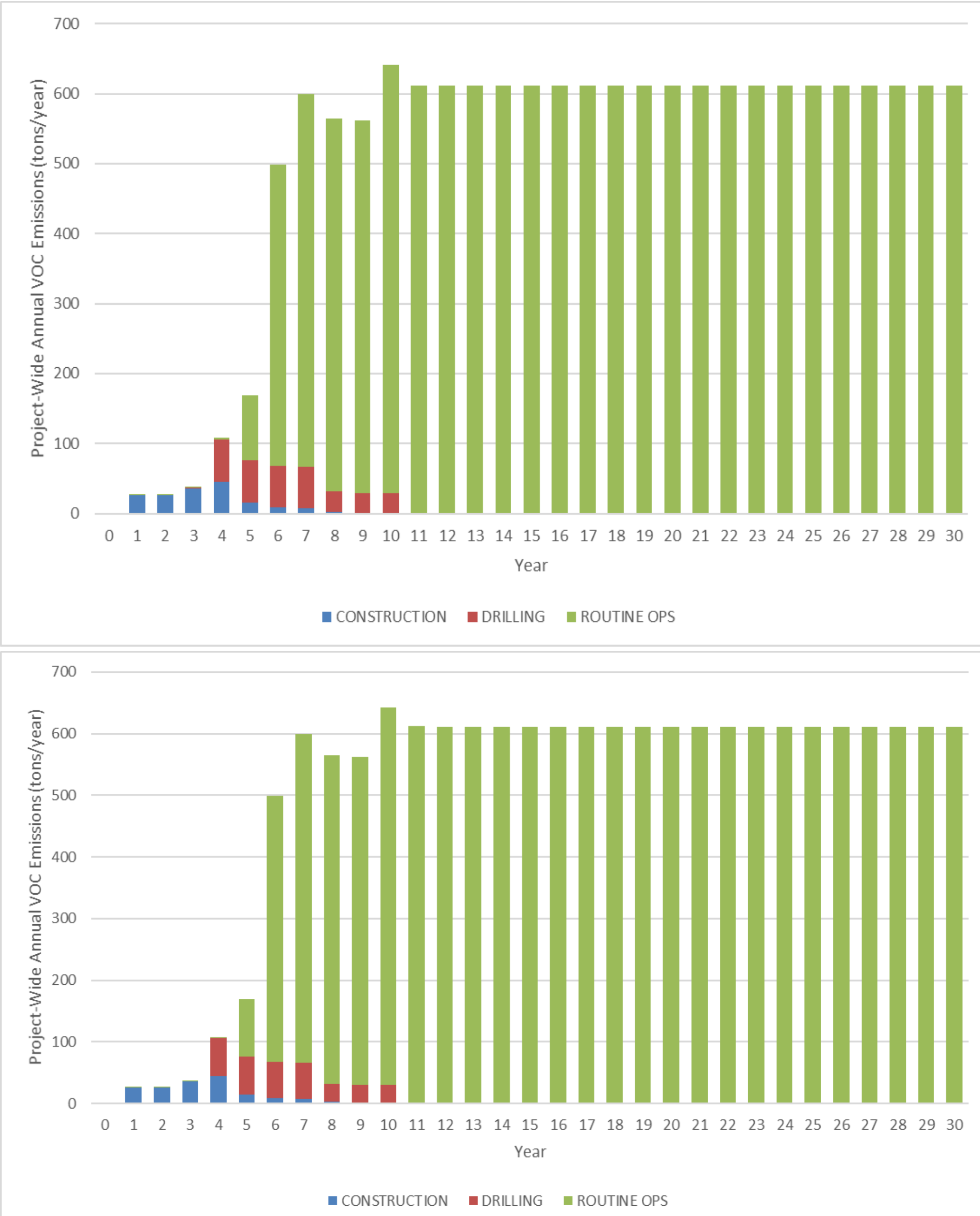


Figure 2.1.24 Alternative E (Three-Pad Alternative) Annual VOC Emissions by Project Phase

Similar to Alternative B, under Alternative E flaring activities are limited to a low pressure flare and high pressure flare at the WPF and flowback flaring at drill sites.

Flares will be in operation at the WPF from project year 5 to end of project under Alternative E. At the WPF there will be a low pressure flare and high pressure flare which will include year-round, 24-hour per day operation of a pilot/purge assist and operation for 10 hours per year at a maximum flowrate of

9 million standard cubic-feet per hour (MMSCF/hr) for the low pressure flare and 11 MMSCF/hr for the high pressure flare.

Flaring at drill sites would occur from project year 4 to 10 under Alternative E. Typically, there would be 1 flowback event per well drilled with a duration of 3 days of flaring per flowback event. Under Alternative E, there will be 4 flowbacks per month during project years 4 to 7; from project year 8 to end of project year 10, there will be 2 flowbacks per month.

Table 2.1-26 shows life of project flaring emissions under Alternative E for criteria pollutant, VOCs, HAP, and GHG emissions.

Table 2.1-26 Alternative E Annual Flaring Emissions

Project Year	Total Emissions (tons per year [tpy])												
	Criteria Pollutants						HAP						GHGs
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Benzene	Toluene	EthylBenzene	Xylene	n-Hexane	Formaldehyde	CO_2e
WPF	311.0	1,036.6	22.7	72.4	72.4	2,890.8	8.6	7.7	0.5	2.2	144.9	239.9	807,727
Drill sites	12.2	66.3	0.7	0.0	0.0	227.3	8.1	7.3	0.5	2.1	45.6	222.6	26,325
Total	**323.3**	**1,102.9**	**23.4**	**72.4**	**72.4**	**3,118.1**	**16.7**	**14.9**	**1.0**	**4.3**	**190.6**	**462.5**	**834,052**

2.1.7 Module Delivery Options

Sealift barges would be used to deliver processing and drill site modules near the Willow Development area under Alternatives B, C, D, and E. At the time that this inventory was developed, all three Module Delivery Options were being considered for Alternatives B, C, D, and E. Emission inventories were developed for activity associated with three Module Delivery options, Option 1, 2, and 3. Total life-of-Project emissions from the Module Delivery Options are the same under each Alternative except as follows: 1) for Alternative D, the Module Delivery Option schedule is delayed by one year, and 2) for Alternative D, Colville River Crossing (Option 3) requires increased ice road length, resulting in higher emissions for this option for Alternative D compared to Alternatives B, C, and E. Section 1.1.5 "Module Delivery Options" provides a description of Module Delivery Options. Emissions for Module Delivery Options 1 and 2 are described in more detail in Attachment D to this Air Quality Technical Support Document and Module Delivery Option 3 is described in Attachment C.

Table 2.1-27 presents total life-of-Project emissions from each Module Delivery Option. Table 2.1-28 shows activity inputs for each Module Delivery Option. Option 2 emissions are higher than Option 1 and 3 emissions primarily as a result of longer distances required for vehicular travel between the Project area and the Point Lonely module delivery area (Option 2) compared to travel between the Project area and either the Point Atigaru nearshore staging area (Option 1) or Colville River Crossing (Oliktok Dock) (Option 3). Option 3 emissions are smaller than Option 1 emissions for all pollutants (except PM_{10}) because Option 1 includes greater emissions from construction of the module delivery area at Point Atigaru compared to construction emissions at Oliktok Dock. PM_{10} emissions are higher for Option 3 because Option 3 includes more vehicle travel during the months of May to October during which road dust emissions are estimated to occur.

Table 2.1-27 Total Emissions for each Module Delivery Option

Module Delivery Option	Total Criteria Emissions (tons)						Total HAPs (tons)	Total CO_2e (thousand metric tons)
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC		
Option 1: Atigaru Point MTI	493	554	4	36	23	79	11	140
Option 2: Point Lonely MTI	1,059	1,200	6	83	50	172	22	341
Option 3 - Alt B/C/E	126	91	1	68	11	16	3	40
Option 3 - Alt D	141	95	1	68	12	17	3	43

Table 2.1-28 Activity Inputs for each Module Delivery Option

Activity	Parameter	Option 1: Atigaru Point MTI	Option 2: Point Lonely MTI	Option 3 – Alt B/C/E	Option 3 – Alt D	Unit
Ice Pads	Total Acres	59	128	30	30	acres
Ice Roads	Total Miles	111	225	80	105	miles
Gravel Mining	Total Gravel Requirement	397,000	446,000	118,700	118,700	million cubic yards (MCY)
Construction Total Traffic	Vehicle Miles Travelled (VMT)	91,154	242,621	20,996	20,996	thousand miles (kmile)
All Vessel	Total Sea Traffic	265	265	76	76	number
All Aircraft	Total Flights	680	776	86	86	number

2.1.7.1 Module Delivery Option 1 (Atigaru Point Module Transfer Island)

Table 2.1-29 presents annual emissions from Option 1 Module Delivery-related activities for Alternatives B and C and Table 2.1-30 presents annual emissions for Option 1 Module Delivery-related activities for Alternative D.

In Table 2.1-29 and Table 2.1-30 emissions drop substantially in project year 6 for Alternatives B, C, E and year 7 for Alternative D. Vehicle traffic is the largest emissions source category for all pollutants and vehicle traffic is highest during module transport. Module transport occurs in the winter months after the module has been delivered in the previous summer. The module option schedule for Alternatives B, C, and E indicate that there is no module delivered in the summer of year 5 (year 6 for Alternative D), hence little activity and emissions from module transport in the winter of year 6 (year 7 for Alternative D).

Table 2.1-29 Option 1: Proponent's Module Transfer Island Annual Emissions – Alternatives B, C, and E

Project Year	Total Emissions (tons per year [tpy])												
	Criteria Pollutants						HAP						GHGs
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Benzene	Toluene	EthylBenzene	Xylene	n-Hexane	Formaldehyde	CO_2e
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
1	1.9	1.6	0.0	0.2	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	830
2	25.2	24.0	0.4	1.7	1.0	2.8	0.0	0.0	0.0	0.0	0.0	0.4	7493
3	71.5	52.8	1.9	4.4	2.9	7.3	0.1	0.1	0.0	0.1	0.0	1.2	19236
4	74.3	77.4	0.6	5.4	3.6	12.0	0.1	0.1	0.0	0.1	0.0	1.2	23745
5	139.1	171.3	0.4	10.4	6.7	24.5	0.2	0.2	0.1	0.2	0.1	2.3	45604
6	62.7	70.4	0.2	4.6	3.0	10.6	0.1	0.1	0.0	0.1	0.0	1.1	20392
7	118.3	156.1	0.3	8.7	5.7	21.5	0.2	0.2	0.1	0.2	0.0	2.0	37294
8	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
9	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
10	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
11+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0

Table 2.1-30 Option 1: Proponent's Module Transfer Island Annual Emissions – Alternative D (Disconnected Access)

Project Year	Total Emissions (tons per year [tpy])												
	Criteria Pollutants						HAP						GHGs
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Benzene	Toluene	EthylBenzene	Xylene	n-Hexane	Formaldehyde	CO_2e
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	1.9	1.6	0.0	0.2	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	830.4
3	25.2	24.0	0.4	1.7	1.0	2.8	0.0	0.0	0.0	0.0	0.0	0.4	7492.7
4	71.5	52.8	1.9	4.4	2.9	7.3	0.1	0.1	0.0	0.1	0.0	1.2	19235.9
5	74.3	77.4	0.6	5.4	3.6	12.0	0.1	0.1	0.0	0.1	0.0	1.2	23744.8
6	139.1	171.3	0.4	10.4	6.7	24.5	0.2	0.2	0.1	0.2	0.1	2.3	45603.7
7	62.7	70.4	0.2	4.6	3.0	10.6	0.1	0.1	0.0	0.1	0.0	1.1	20392.4
8	118.3	156.1	0.3	8.7	5.7	21.5	0.2	0.2	0.1	0.2	0.0	2.0	37294.1
9	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11+	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

2.1.7.2 Module Delivery Option 2 (Point Lonely Module Transfer Island)

Table 2.1-31 presents annual emissions from Option 2 Module Delivery-related activities for Alternatives B, C, and E and Table 2.1-32 presents annual emissions from Option 2 Module Delivery-related activities for Alternative D.

In Table 2.1-31 and Table 2.1-32 emissions drop substantially in project year 6 for Alternative B/C and year 7 for Alternative D. Vehicle traffic is the largest emissions source category for all pollutants and vehicle traffic is highest during module transport. Module transport occurs in the winter months after the module has been delivered in the previous summer. The module option schedule for Alternatives B, C, and E indicate that there is no module delivered in the summer of year 5 (year 6 for Alternative D), hence little activity and emissions from module transport in the winter of year 6 (year 7 for Alternative D).

Table 2.1-31 Option 2: Point Lonely Module Transfer Island Annual Emissions – Alternatives B, C, and E

Project Year	Total Emissions (tons per year [tpy])												
	Criteria Pollutants						HAP						GHGs
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Benzene	Toluene	EthylBenzene	Xylene	n-Hexane	Formaldehyde	CO_2e
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
1	3.1	3.0	0.0	0.3	0.2	0.5	0.0	0.0	0.0	0.0	0.0	0.0	1470
2	52.9	45.7	0.5	3.9	2.1	6.4	0.1	0.1	0.0	0.1	0.0	0.8	18572
3	151.7	106.6	2.2	10.3	6.6	18.1	0.3	0.3	0.1	0.3	0.1	2.7	52506
4	145.3	164.4	0.8	11.5	7.0	24.1	0.2	0.2	0.1	0.2	0.1	2.3	51788
5	307.8	381.0	0.9	24.9	14.7	53.5	0.4	0.4	0.2	0.4	0.1	4.6	111262
6	127.6	150.8	0.4	10.0	6.1	21.8	0.2	0.2	0.1	0.2	0.1	2.1	45356
7	270.8	348.0	0.8	21.5	13.0	47.9	0.4	0.3	0.1	0.3	0.1	4.2	94699
8	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
9	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
10	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
11+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0

Table 2.1-32 Option 2: Point Lonely Module Transfer Island Annual Emissions – Alternative D (Disconnected Access)

Project Year	Total Emissions (tons per year [tpy])												
	Criteria Pollutants						HAP						GHGs
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Benzene	Toluene	EthylBenzene	Xylene	n-Hexane	Formaldehyde	CO_2e
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	3.1	3.0	0.0	0.3	0.2	0.5	0.0	0.0	0.0	0.0	0.0	0.0	1469.8
3	52.9	45.7	0.5	3.9	2.1	6.4	0.1	0.1	0.0	0.1	0.0	0.8	18571.8
4	151.7	106.6	2.2	10.3	6.6	18.1	0.3	0.3	0.1	0.3	0.1	2.7	52506.0
5	145.3	164.4	0.8	11.5	7.0	24.1	0.2	0.2	0.1	0.2	0.1	2.3	51788.1
6	307.8	381.0	0.9	24.9	14.7	53.5	0.4	0.4	0.2	0.4	0.1	4.6	111261.5
7	127.6	150.8	0.4	10.0	6.1	21.8	0.2	0.2	0.1	0.2	0.1	2.1	45356.3
8	270.8	348.0	0.8	21.5	13.0	47.9	0.4	0.3	0.1	0.3	0.1	4.2	94698.8
9	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11+	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

2.1.7.3 Module Delivery Option 3 (Colville River Crossing)

Table 2.1-33 presents annual emissions from Option 3 Module Delivery-related activities for Alternatives B, C, E and Table 2.1-34 presents annual emissions from Option 3 Module Delivery-related activities for Alternative D.

In Table 2.1-33 and Table 2.1-34 emissions drop substantially in project year 6 for Alternative B, C, E and year 7 for Alternative D. Vehicle traffic is the largest emissions source category for all pollutants and vehicle traffic is highest during module transport. Module transport occurs in the winter months after the module has been delivered in the previous summer. The module option schedule for Alternatives B, C, and E indicate that there is no module delivered in the summer of year 5 (year 6 for Alternative D), hence little activity and emissions from module transport in the winter of year 6 (year 7 for Alternative D).

Table 2.1-33 Option 3: Colville River Crossing Annual Emissions – Alternatives B, C, and E

Project Year	Total Emissions (tons per year [tpy])												
	Criteria Pollutants						HAP						GHGs
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Benzene	Toluene	EthylBenzene	Xylene	n-Hexane	Formaldehyde	CO_2e
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
2	1.2	3.6	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	137
3	7.2	9.6	0.2	53.0	5.6	0.7	0.0	0.0	0.0	0.0	0.0	0.2	2154
4	18.4	11.3	0.3	4.5	1.1	2.2	0.0	0.0	0.0	0.0	0.0	0.3	6029
5	41.1	27.8	0.1	2.9	1.7	5.3	0.1	0.1	0.0	0.1	0.0	0.6	14920
6	16.7	11.1	0.1	4.4	1.0	2.1	0.0	0.0	0.0	0.0	0.0	0.3	5948
7	41.0	27.7	0.1	2.9	1.7	5.3	0.1	0.1	0.0	0.1	0.0	0.6	14874
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
11+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0

Table 2.1-34 Option 3: Colville River Crossing Annual Emissions – Alternative D (Disconnected Access)

Project Year	Total Emissions (tons per year [tpy])												
	Criteria Pollutants						HAP						GHGs
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Benzene	Toluene	EthylBenzene	Xylene	n-Hexane	Formaldehyde	CO_2e
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
3	1.2	3.6	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	137
4	7.2	9.6	0.2	53.0	5.6	0.7	0.0	0.0	0.0	0.0	0.0	0.2	2154
5	20.6	11.9	0.4	4.5	1.1	2.4	0.0	0.0	0.0	0.0	0.0	0.3	6529
6	46.6	29.3	0.1	3.1	1.9	5.8	0.1	0.1	0.0	0.1	0.0	0.7	16168
7	18.9	11.7	0.1	4.4	1.1	2.3	0.0	0.0	0.0	0.0	0.0	0.3	6448
8	46.5	29.2	0.1	3.1	1.9	5.8	0.1	0.1	0.0	0.1	0.0	0.7	16123
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
11+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0

2.2 Cumulative Emissions for the Willow Alternatives

Cumulative emissions for the Willow MDP were developed as part of the DEIS. Cumulative emissions include emissions for the Willow Alternatives and the Greater Willow Potential Drill Sites #1 and #2. The emissions from Greater Willow Potential Drill Sites #1 and #2 would occur as part of any Willow alternative and module delivery option. In addition to the Willow MDP cumulative emissions, emissions from Reasonably Foreseeable Future Action (RFFA) were included in the cumulative modeling analyses. The following sections describe the cumulative emissions inventory development process and the resulting emission estimates.

2.2.1 Greater Willow Potential Drill Sites #1 and #2

Cumulative emissions were estimated for the two Greater Willow Potential drill sites that would be developed after year 2035. The CPAI Environmental Effects Document (CPAI 2019) explains that the potential drill sites are part of the Willow MDP: "To support long-term planning, the Willow MDP also addresses potential future drill sites, the number and location of which depend on the results of potential future exploration activities. These potential future drill sites are addressed in the EED as reasonably foreseeable future developments for the purposes of analyzing cumulative impacts."

The following development phases are included in the cumulative Greater Willow Potential Drill Sites #1 and #2 emissions estimates:

- Construction emissions: Annual average emissions were calculated for BT1, BT2, BT4 and BT5 by calculating the monthly average emissions over all months of construction and multiplying by 12. BT3 construction emissions were not included as it is co-located with the WPF.
- Developmental drilling emissions: Annual emissions were calculated as the total emissions from the year 2032, which was chosen as representative as only one drill rig was operational in that year.
- Non-construction emissions: Annual emissions for BT1, BT2, BT4 and BT5 were calculated as the total emissions from the year 2036, as a representative year with all routine-operation activities occurring during the year.

Table 2.2-1 below summarizes total cumulative annual average emissions from Greater Willow Potential Drill Sites #1 and #2. Emissions from activities that do not occur on the pads, such as materials and personal transportation, are not included in emissions estimates. It is anticipated that routine operation emissions for the final years of the Project shown above in Table 2.1-9 for Alternative B would continue following development of Greater Willow Potential Drill Sites #1 and #2. Routine operation emissions would be in addition to the emissions explicitly calculated for the Greater Willow Potential Drill Sites #1 and #2 (shown below in Table 2.2-1). The GWP Drill sites 1 and 2 are assumed to use the Project WPF and WOC. Peak Project production is estimated to occur in either 2029 or 2030, before the operations of the Potential Drill Sites. The production declines subsequent to peak production, so the WPF and WOC are expected to be able to accommodate additional production from GWP Drill sites 1 and 2.

Table 2.2-1 Annual Emissions from Greater Willow Potential Drill Sites #1 and #2 Combined

Pollutant		Phase		
		Construction	Developmental Drilling	Routine Operations
Criteria Pollutants (tpy)	NO_x	17.0	118.5	13.5
	CO	7.2	115.4	11.2
	SO_2	0.1	0.5	0.3
	PM_{10}	1.6	30.8	1.0
	$PM_{2.5}$	1.3	9.9	0.8
	VOC	2.3	17.7	220.1
HAP (tpy)	Benzene	0.1	0.1	0.2
	Toluene	0.1	0.1	0.6
	Ethylbenzene	0.0	0.0	5.5
	Xylene	0.1	0.0	10.8
	n-Hexane	0.0	0.0	13.6
	Formaldehyde	0.5	0.1	0.0
GHGs (metric tpy)	CO_2e	8,468	48,504	8,476

2.2.2 Reasonably Foreseeable Future Actions*

Table 2.2-2 lists the existing sources that have planned modifications, current known RFFAs, and projects that were considered but lacked sufficient information and thus were eliminated from further consideration. RFFAs were included in the cumulative near-field modeling (routine operations scenario) and cumulative far-field modeling analysis. All RFFAs located within the near-field analysis area (defined as being within 50 km of the Willow Alternative B Infrastructure Pad) were included in the near-field analysis. Several of the RFFAs located within the 4 km resolution far-field model domain are included in the cumulative far-field modeling if the project was not already included as part of the BOEM regional emissions database used for this Project. The locations of the RFFAs carried forward in the cumulative near-field and far-field modeling are shown in Figure 2.2-1. Table 2.2-2 also indicates those RFFAs which are analyzed qualitatively and not modeled either because they were (i) outside the modeling domain, or (ii) identified after the FEIS or (iii) they are not expected to operate during the modeling year (2025) or (iv) due to lack of sufficient information on the source needed for modeling.

As shown in Table 2.2-2, half of the RFFAs were explicitly included in the cumulative regional modeling analysis. For those RFFAs that were not explicitly modeled, the impacts are implicitly included in the cumulative regional modeling analysis which is discussed in Section 2.3.2.2. The cumulative regional modeling results presented in Chapter 5 show that when RFFAs are considered in combination with the Project, air quality and AQRV conditions would be below applicable thresholds for all alternatives.
In addition to the cumulative modeling analysis, the near-field modeling analysis explicitly included GMT-1, GMT-2, Greater Willow Potential Drill Site #1 and Greater Willow Potential Drill Site #2. Near-field model results presented in Chapter 3 indicate that all cumulative air quality impacts would be below applicable thresholds for all alternatives.

The AQTSD (Appendix E.3B, Table 2.2-3) provides an estimate of the total potential project emissions for individual RFFAs. Emissions from those new RFFAs identified since the FEIS are very small (1 percent or less) compared to the cumulative emissions included in the regional modeling analysis. Emissions estimates depend on both available information about anticipated activities and representative emission factors.

Table 2.2-3 provides an estimate of the emissions for those RFFAs identified after the FEIS, these estimates depend on both available information about their proposed activity and representative emission factors. Emissions factors were developed for gravel pad construction, gravel road construction, ice road construction, and disposal well drilling based on Alternative B. Turbine emission factors are based on AP-42 Chapter 3.4 large stationary diesel engines. Production-based emission factors were developed based on peak annual emissions estimate for Alternative B divided by the project production in that year. The RFFA emissions are then estimated by multiplying the emission factors by the activities for each RFFA project, as appropriate. Carbon dioxide equivalent values are calculated in accordance with the methodology used in SEIS Chapter 3.2. The following RFFAs were identified after the FEIS and are assessed below:

- Alpine Central Facility Expansion – Turbine
- Colville Delta 1 (CD1) Expansion – Disposal well drilling
- Colville Delta 4 (CD4) Expansion – Disposal well drilling, gravel pad construction
- Colville Delta 8 (CD8) Expansion – Disposal well drilling
- Eastern Northeast West Sak (ENEWS) – All project phases based on peak year production
- Narwhal – Disposal well drilling
- 88 Energy's Peregrine Exploration – Ice road construction, disposal well drilling, gravel pad construction
- Drill Site 3T(DS3T) Expansion – Gravel pad construction
- CPAI Exploration – Disposal well drilling

The emissions for the RFFA at Alpine Center Facility, Colville Delta 1, Colville Delta 4, Drill Site 3T, Drill Site 3S, and CPAI Exploration are small compared to those from either Alternatives B or E of this Project and therefore any potential air quality impacts would not change this analysis. The Eastern Northeast West Sak (ENEWS), the 88 Energy's Peregrine Exploration and the Oil Search' Pikka Discovery may also be developed in the future. These RFFAs are located more than 35 miles from the Project. Impacts from these and other RFFAs are either implicitly or explicitly included in the cumulative regional modeling analysis (see Section 2.3.2.2) and air quality and AQRV conditions would be below applicable thresholds for all alternatives.

Table 2.2-2 Existing and RFFA for Cumulative Assessment*

Name of Facility	Miles from Willow Infrastructure Pad	Kilometers from Willow Infrastructure Pad	Included in Near-field Modeling	Included in Far-field Modeling	Notes
Modifications to Existing Sources					
TDX Deadhorse Power Plant	77	124	No	Yes	

Name of Facility	Miles from Willow Infrastructure Pad	Kilometers from Willow Infrastructure Pad	Included in Near-field Modeling	Included in Far-field Modeling	Notes
ExxonMobil Point Thomson Facility Expansion	133	214	No	Yes	Project is already included in the BOEM Future Year database used in the Willow EIS, so duplicate emissions were not added explicitly to the cumulative far-field modeling analysis
Alpine Central Facility Power Expansion	28	45	No	No	
Colville Delta 4 (CD4) Expansion	26	42	No	No	
Colville Delta 1 (CD1) Expansion	29	47	No	No	
Drill Site 3T (DS3T) Expansion	46	74	No	No	
RFFA Sources					
Nanushuk Pad (proposed)	41	66	No	Yes	
Nanushuk Drill Site 2 (proposed)	37	60	No	Yes	
Nanushuk Drill Site 3 (proposed)	34	55	No	Yes	
Nanushuk Operations Center (proposed)	41	66	No	Yes	
Eni Nikaitchuq Development	60	97	No	Yes	
Pioneer Oooguruk Development	47	76	No	Yes	
BPXA Liberty	106	171	No	Yes	Project is already included in the BOEM Future Year database used in the Willow EIS, so duplicate emissions were not added explicitly to the cumulative far-field modeling analysis
CPAI GMT1	17	27	Yes	Yes	Project is already included in the BOEM Future Year database used in the Willow EIS, so duplicate emissions were not added explicitly to the cumulative far-field modeling analysis
CPAI GMT2	11	18	Yes	Yes	

Name of Facility	Miles from Willow Infrastructure Pad	Kilometers from Willow Infrastructure Pad	Included in Near-field Modeling	Included in Far-field Modeling	Notes
Mustang Pad	44	71	No	Yes	
Greater Willow Potential Drill Site #1	14	23	Yes	No	Source not anticipated to be operational in 2025, the selected analysis year for the cumulative far-field modeling.
Greater Willow Potential Drill Site #2	8	13	Yes	No	Source not anticipated to be operational in 2025, the selected analysis year for the cumulative far-field modeling.
Colville Delta 8 (CD8)	27	43	No	No	
Eastern Northeast West Sak (ENEWS)	59	95	No	No	
Narwhal	27	43	No	No	
88 Energy’s Peregrine Exploration	46	74	No	No	
Oil Search’s Pikka Discovery	36	58	No	No	
Drill Site 3S (DS3S)	46	74	No	No	
CPAI Exploration	26	42	No	No	
RFFA Sources Considered and Eliminatated					
Brooks Range Petroleum North Shore (source #2)					Project concluded to be cancelled. Project was presented as RFFA in GMT1, but removed for GMT2. Internet research provided no information indicating project development
Shell Discover Camden Bay (source #2)					Insufficient information about this project

Table 2.2-3 Estimated Emissions for Recent RFFA*

Name of RFFA[1]	Total Criteria Emissions (tpy)						Total HAPs (tons)	Total CO_2e (thousand metric tons) AR4 100-Year GWPs	Total CO_2e (thousand metric tons) AR6 100-Year GWPs	Total CO_2e (thousand metric tons) AR6 20-Year GWPs
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC				
Alpine Central Facility Expansion	103.7	37.9	20.8	5.3	5.3	5.6	0.3	286	286	287
Colville Delta 1 (CD1) Expansion	1.9	2.7	>0.1	0.1	0.1	0.2	>0.1	0.8	0.8	0.8
Colville Delta 4 (CD4) Expansion	39.6	52.0	0.2	2.9	2.8	4.7	0.3	16.9	16.9	17.0
Colville Delta 8 (CD8) Expansion	76.0	106.7	0.3	5.7	5.4	8.7	0.2	31.4	31.4	31.4
Eastern Northeast West Sak (ENEWS)	388	375	26	125	46	318	37	445	446	445
Narwhal	22.8	32.0	0.1	1.7	1.6	2.6	0.1	9.4	9.4	9.4
88 Energy's Peregrine Exploration	80.0	26.2	0.2	3.6	3.4	8.8	2.8	25.4	25.4	25.5
Drill Site 3T (DS3T) Expansion	3.2	1.2	>0.1	0.2	0.2	0.5	0.2	1.9	1.9	1.9
CPAI Exploration	1.9	2.7	>0.1	0.1	0.1	0.2	>0.1	0.8	0.8	0.8

[1]Emissions of NOx, CO, SO2, PM10, PM2.5 and VOC for the Alpine Central Facility turbine were obtained from https://dec.alaska.gov/Applications/Air/airtoolsweb/AirPermitsApprovalsAndPublicNotices (permit AQ0489MSS12P). All other emissions reported in this table were calculated using the representative emission factor methods discussed above.

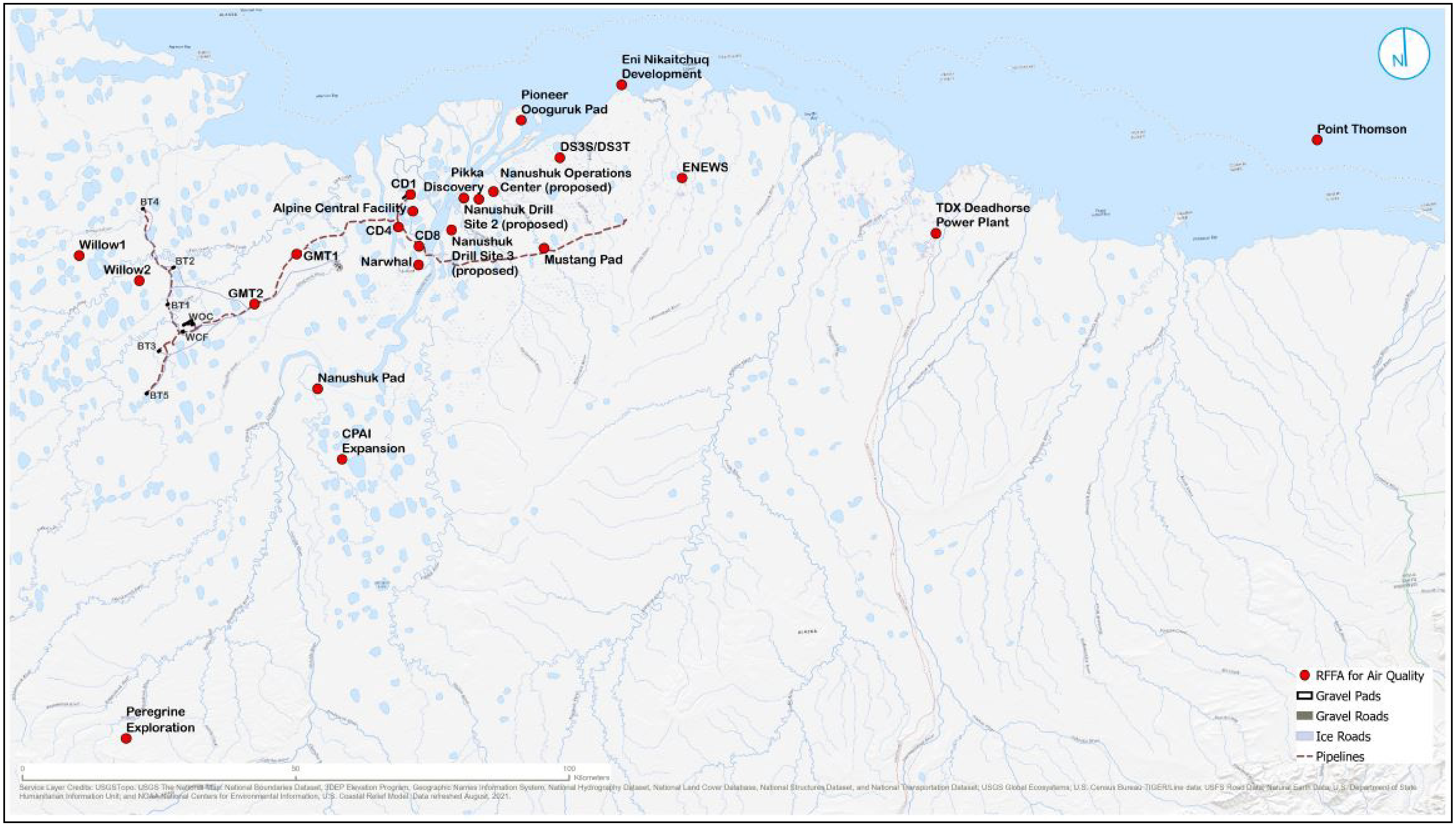


Figure 2.2.1 Approximate Locations of RFFA Sources Relative to Willow Master Development Plan Project Area.*

2.3 Emissions Inventories Prepared for Modeling

The Willow MDP emissions inventories developed for Alternatives B, C, and D as described and reported in Section 2.1 "Willow Alternatives Emissions Inventories" were used for the near-field model.
The Willow MDP emissions inventories developed for Alternatives B, and C as described in the DEIS (Appendix E.3B Section 2.1) were used for the regional photochemical grid model, the reason for which is described in Section 3.3.2.3.2 of the FEIS. The development of these inventories for use in modeling are described in more detail in the following sections.

2.3.1 Near-field Emissions Inventories

The AERMOD model incorporates detailed information about the sources, emission rates over various averaging periods, emission release parameters, and effects of any structures on emission dispersion properties. Information provided as part of the emissions inventory were used to estimate peak emission rates for each modeled source over the averaging periods assessed with the AERMOD model. These averaging periods are based on AAQS and include 1-hour, 3-hour, 8-hour, 24-hour and annual periods. The variation in averaging times based on AAQS affects how the emissions from the emission inventory (described in Section 2.1 "Willow Alternatives Emissions Inventories") is prepared for near-field modeling. For example, for a hypothetical source that operates for only three hours a day, the 1-hour average and 3-hour average emissions rate for that source is calculated based on operation over the period; however, for longer averaging periods the emissions over that averaging period are averaged (i.e., total emissions over a three-hour period are divided by the modeled averaging period).

Other factors are also considered during the development of the near-field emissions inputs including the timing and location of emissions sources. For example, when it is known that emissions sources could not be active simultaneously, these sources are not modeled in the same location at the same time. More detailed information the near-field emissions inventory input preparation process is provided in Chapter 3.

The AERMOD model also requires detailed information about the emissions release parameters. Release parameters are commonly referred to as "stack parameters" even though in some cases the emissions are not emitted from a "stack". Necessary stack parameters depend on the source. Point sources require inputs such as stack height aboveground, temperature of the exhaust gas, velocity of exhaust gas, and stack diameter. Volume and area sources require information including release height, source height, length and width. Often this type of information is estimated based on the type of source and common best practices. The modeled source locations, stack parameters, and emission rates are included in Attachment A.

2.3.2 Regional Emissions Inventories

This section provides a brief overview of the regional emissions scenarios modeled for the Willow MDP EIS: the 2012 Base Year, the Cumulative No Project scenario, Cumulative Alternative B, and Cumulative Alternative C. Alternative C was selected for the far-field modeling analysis rather than Alternatives D or E because the peak emissions for Alternative C is greater than Alternative D (shown via a comparison of Table 2.1-15 and Table 2.1-20) and Alternative E (shown via a comparison of Table 2.1-15 and Table 2.1-25). The Cumulative No Project scenario has all emissions in the Cumulative Alternative B (or C) scenario except for Project emissions. Importantly, regional air quality was not remodeled using the emissions inventory developed for the Project in this Final EIS because the regional air impact assessment for the Draft

EIS showed that cumulative and Project-specific impacts were below all applicable thresholds throughout the modeling domain. Additionally, Project emissions of CAPs are small relative to regional emissions (up to 6.0 % of regional emissions depending on pollutant) and changes to Project emissions between Draft EIS and Final EIS are an even smaller fraction of regional emissions (up to 4.3% depending on pollutant). For background information on the emissions, see the emissions inventories discussed in Sections 2.3.2.2 and 2.3.2.3 of this AQTSD and in Chapter 2 of the AQTSD for the Draft EIS.

The maximum NOx emissions year was selected for far-field modeling analysis based on input from the Willow MDP EIS Air Quality Technical Workgroup. For both Alternative B and C, the peak NO_X emissions year based on the emissions inventory for the Draft EIS is Project Year 5, which corresponds with calendar year 2025, so 2025 was used for the Alternative A (No Action) and C regional emissions.

Willow MDP emissions scenarios were modeled with the CAMx modeling system to estimate cumulative and Project-specific impacts to ambient air quality and AQRVs as described in Chapter 4. The SMOKE model was used to prepare and process emissions inputs into the format required by CAMx. An emissions inventory for all sources within the model domains is required for regional modeling (a map of the model domains is provided in Chapter 4). A complete emissions inventory for photochemical modeling includes point sources, area sources, nonroad and on-road mobile sources, as well as sea salt, dust, biogenic emissions, lightning-related emissions, and fire emissions. These emissions were developed for year 2012 and, are from the BOEM modeling platform (Fields Simms et al 2018, Stoeckenius et al 2017), described in Section 1.2.2.2 “Regional Modeling”. Windblown dust emissions are not included in the BOEM modeling platform (and therefore the Willow EIS) as well as other typical regional photochemical applications. Not including windblown dust emissions might ordinarily have a potential to result in an underestimate in model results; however, this is unlikely as noted below because soil (dust) concentrations are still overestimated in the model as discussed below. The BOEM modeling platform sea salt and regional unpaved road dust emissions were revised for the Willow MDP EIS due to observable overestimates noted in the BOEM study as discussed below and subsequent analyses conducted for the Willow MDP EIS (see below and Attachment B for more information).

The BOEM study (Fields Simms et al 2018) reported an overestimation of the sea salt emissions that resulted in an overestimation of particulate nitrate. Updated sea salt emissions were subsequently developed by BOEM for sensitivity analyses (Stoeckenius et al 2017). For the Willow MDP EIS the updated sea salt emissions were applied throughout all scenarios including the 2012 Base Year, model performance evaluation and future year scenarios. Estimates of the magnitude of road dust emissions were highly uncertain in the BOEM study emissions inventory due mainly to the necessary use of non-local data for estimating emissions (Fields Simms et al., 2014). As discussed in Attachment B “Willow MDP Model Performance Evaluation” Section B.2.5, it was determined that modeled ground-level dust concentrations due to the BOEM regional unpaved road dust emissions were considerably overestimated relative to monitored dust concentrations and therefore, the regional unpaved road dust emissions from the BOEM modeling platform revised downwards; the revised model performance improved considerably as a result of the correction. See Attachment B “Willow MDP Model Performance Evaluation” Section B.2.5 for more information regarding the revisions to the regional unpaved road dust emissions and the associated improvement in the model performance. For the future year analyses, three emissions inventories were developed and processed with SMOKE. The Cumulative No Project scenario emissions inventory was developed based on the BOEM modeling platform with the RFFA emissions sources updated to be consistent with the most recent available sources of information, as described in Section 2.2.2 “Reasonably Foreseeable Development”. The Cumulative Willow MDP emissions include two potential drill sites that are part of the Willow Master Development Plan, as described in

Section 2.2.1 "Greater Willow Potential Drill Sites #1 and #2". The potential future drill sites are not anticipated to begin development until after 2035. Therefore, the Greater Willow Potential Drill Sites #1 and #2 are not included in the regional cumulative emissions inventory (but modeled in the near-field cumulative analysis).

The Cumulative Alternative B Alternative emissions inventory was developed by combining the Alternative B 2025 emissions inventory with the Cumulative No Project scenario inventory. The Cumulative Alternative C Alternative emissions inventory was developed by combining the Alternative C 2025 emissions inventory with the Cumulative No Project scenario inventory.

2.3.2.1 2012 Base Year

Table 2.3-1 through 2.3-3 below shows the 2012 4 km domain Base Year emissions including the emissions for key source groups. Table 2.3-1 shows the BOEM modeling platform 4 km resolution domain emissions (Fields Simms et al 2018, Stoeckenius et al 2017) prior to sea salt and unpaved road dust modifications. Sodium (Na) emissions are provided to disclose changes to the sea salt emissions. Table 2.3-2 shows the 2012 Willow MDP Base Year emissions modeled in the far-field model which include reductions to sea salt and unpaved road dust. Table 2.3-3 shows the difference between the 2012 Willow MDP Base Year 4 km domain emissions and the BOEM 4 km domain emissions. The 2012 4 km domain Base Year emissions spatial distribution used for the far-field modeling is shown in Figure 2.3-1.

Table 2.3-1 BOEM 4 km Domain Base Year Emissions Inventory

Source Sector	BOEM 4 km Domain 2012 Base Year Emissions (tpy)						
	NO_X	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Na
North Slope Borough Baseline Emissions Excluding Oil and Gas	2,221	3,598	165	34,441	3,599	818	9
North Slope Borough Baseline Oil and Gas	45,509	10,748	1,119	1,243	1,203	2,241	-
Emissions Outside North Slope Borough	25,055	550	22	13,774	11,269	127	102,407
Biogenic	1,782	25,106	-	-	-	150,967	-
Fire	482	8,829	88	392	1,207	392	-
Total 4 km Domain	**75,049**	**48,831**	**1,394**	**49,850**	**17,278**	**154,545**	**102,416**

Table 2.3-2 Willow MDP EIS 4 km Domain Base Year Emissions Inventory

Source Sector	Willow 4 km Domain 2012 Base Year Emissions (tpy)						
	NO_X	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Na
North Slope Borough Baseline Emissions Excluding Oil and Gas	2,221	3,598	165	3,607	513	818	2
North Slope Borough Baseline Oil and Gas	45,509	10,748	1,119	1,243	1,203	2,241	-
Emissions Outside North Slope Borough	25,147	573	24	3,929	1,423	130	6,130
Biogenic	1,782	25,106	-	-	-	150,967	-
Fire	482	8,829	88	392	1,207	392	-
Total 4 km Domain	**75,141**	**48,854**	**1,396**	**9,171**	**4,346**	**154,548**	**6,132**

Table 2.3-3 Emission Differences between Willow and BOEM 4 km Domain Base Year Emissions

Source Sector	Willow 4 km Domain 2012 Base Year Emissions Minus BOEM 2012 Emiss. (tpy)						
	NO_X	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Na
North Slope Borough Baseline Emissions Excluding Oil and Gas	0	0	0	-30,834	-3,086	0	-7
North Slope Borough Baseline Oil and Gas	0	0	0	0	0	0	-
Emissions Outside North Slope Borough	91	23	3	-9,845	-9,846	3	-96,277
Biogenic	0	0	-	-	-	0	-
Fire	0	0	0	0	0	0	-
Total 4 km Difference[a]	**91**	**23**	**3**	**-40,679**	**-12,932**	**3**	**-96,284**

[a] Small differences of less than 1 percent of the 4 km domain emissions occur due to updated species mapping used for the Willow MDP emissions processing

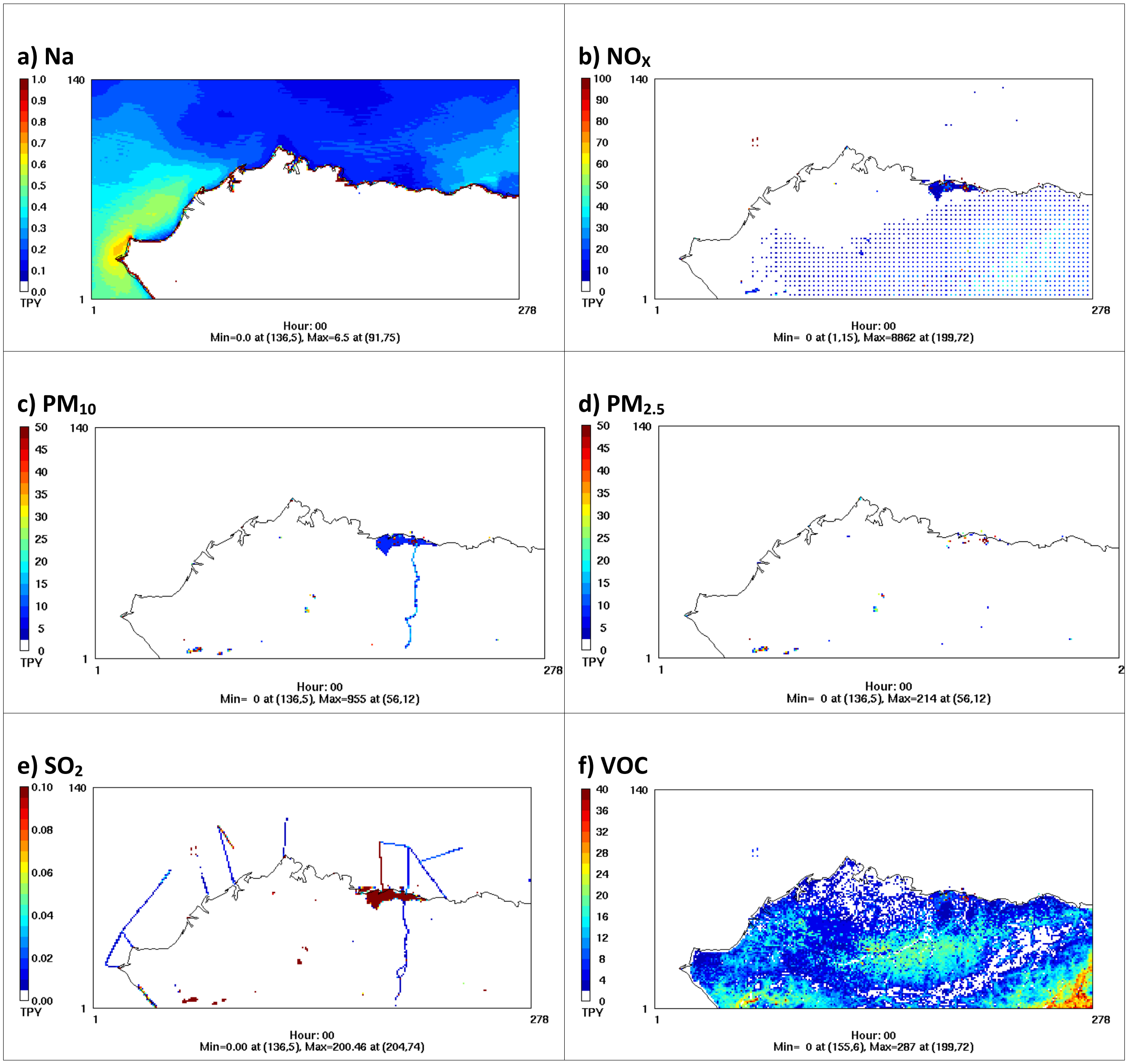


Figure 2.3.1 Willow Base Year Emissions a) Na, b) NO_X, c) PM_{10}, d) $PM_{2.5}$, e) SO_2, f) VOC

2.3.2.2 Cumulative 2025 No Project Scenario

Table 2.3-4 though Table 2.3-6 below shows the Cumulative 2025 No Project emissions including the emissions for key source groups. Table 2.3-4 shows the BOEM modeling platform 2020 4 km resolution domain emissions (Fields Simms et al 2018, Stoeckenius et al 2017) prior to sea salt and unpaved road dust modifications. Table 2.3-5 shows the Cumulative 2025 No Project emissions modeled in the far-field model which include revisions reductions to sea salt and unpaved road dust and additions of RFFA sources (described in Section 2.2.2 "Reasonably Foreseeable Future Actions"). After the FEIS, additional RFFA were identified. The complete list of RFFAs is provided in Table 2.2-2. RFFA that were not explicitly included in the cumulative regional modeling are implicitly included in the cumulative assessment by use of the BOEM 2020 Oil and Gas emissions. As shown via a comparison of the "BOEM 2020 Oil and Gas Development" and the "North Slope Borough Baseline Oil and Gas Emissions" in Table 2.3-4, the projected future year oil and gas emissions are 67 percent to 173 percent higher than the 2012 North Slope Borough oil and gas baseline, depending on the air quality pollutant. This provides a conservatively high estimate of cumulative emissions given that the U.S. Energy Information Administration reports that Alaska North Slope crude oil production declined by 15% over this same period (USEIA 2022). The modeled cumulative emissions used in the regional modeling analysis include both specific RFFA projects as listed in Table 2.2-2 and also RFFA projects that were not explicitly modeled through emissions that account for oil and gas development within the model domain. Table 2.3-6 shows the difference between the Cumulative 2025 No Project 4 km domain emissions and the BOEM modeling platform 2020 4 km domain emissions. The Cumulative 2025 No Project 4 km domain emissions spatial distribution used for the far-field modeling is shown with Alternative B in Figure 2.3-2.

Table 2.3-4 BOEM 4 km Domain 2020 Future Year Emissions Inventory

Source Sector	BOEM 4 km Domain 2020 Future Year Emissions (tpy)						
	NO_X	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Na
North Slope Borough Baseline Emissions Excluding Oil and Gas	2,368	3,651	103	34,442	3,600	826	9
North Slope Borough Baseline Oil and Gas	45,627	11,942	1,130	1,260	1,220	2,302	0
BOEM 2020 Oil and Gas Development	30,751	7,829	1,955	1,860	1,433	1,769	0
Non-Oil and Gas Emissions Outside North Slope Borough	24,680	510	18	13,758	11,254	40	102,407
Biogenic	1,782	25,106	-	-	-	150,967	-
Fire	482	8,829	88	392	1,207	392	-
Total 4 km	**105,690**	**57,867**	**3,294**	**51,712**	**18,714**	**156,296**	**102,416**

Table 2.3-5 Willow 4 km Domain 2025 No Project Emissions Inventory

Source Sector	Willow 4 km Domain 2025 Future Year (No Project) Emissions (tpy)						
	NO_X	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Na
North Slope Borough Baseline Emissions Excluding Oil and Gas	2,368	3,651	103	3,649	555	826	2
North Slope Borough Baseline Oil and Gas	45,627	11,942	1,130	1,260	1,220	2,302	0
BOEM 2025 Oil and Gas Development	35,757	7,829	2,509	3,041	1,708	2,612	0
Non-Oil and Gas Emissions Outside North Slope Borough	24,668	510	16	3,908	1,405	37	6,130
Biogenic	1,782	25,106	-	-	-	150,967	-

Source Sector	Willow 4 km Domain 2025 Future Year (No Project) Emissions (tpy)						
	NO_X	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Na
Fire	482	8,829	88	392	1,207	392	-
Total 4 km	**110,684**	**57,867**	**3,846**	**12,250**	**6,095**	**157,136**	**6,132**

Table 2.3-6 Differences between Willow 4 km Domain 2025 No Project Emissions and BOEM 4 km Domain 2020 Emissions

Source Sector	Willow 4 km Domain 2025 Future Year (No Project) Emissions- BOEM 2020 (tpy)						
	NO_X	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Na
North Slope Borough Baseline Emissions Excluding Oil and Gas	0	0	0	-30,793	-3,046	0	-7
North Slope Borough Baseline Oil and Gas	0	0	0	0	0	0	0
BOEM 2020 Oil and Gas Development	5,005	0	554	1,181	275	843	0
Non-Oil and Gas Emissions Outside North Slope Borough	-11	0	-1	-9,850	-9,849	-2	-96,277
Biogenic	0	0	-	-	-	0	-
Fire	0	0	0	0	0	0	-
Total 4 km Difference[a]	**4,994**	**0**	**553**	**-39,462**	**-12,620**	**841**	**-96,284**

[a] Small differences of less than 1 percent of the 4 km domain emissions occur due to updated species mapping used for the Willow MDP emissions processing

2.3.2.3 Cumulative 2025 Alternative B (Proponent's Project)

Table 2.3-7 shows the Alternative B annual emissions processed in SMOKE.[8] The emissions at the drill sites, the WPF, IP, Willow airstrip, gravel mine and horizontal directional drilling under the Colville River were modeled as point sources at the pad center. All other Project emissions such as general construction, mobile sources, pigging, and fugitive dust emissions were modeled as area sources and allocated to the Project area using a combination of linear features (i.e., roads) and all Project features. Note that the Project fugitive dust emissions of PM_{10} and $PM_{2.5}$ used in the modeling shown below for Alternative B (as well as Alternative C) were based on the emissions inventory developed for the Willow MDP Draft EIS which included a fugitive dust control (reduction) efficiency of 76% resulting from

[8] Note that as described in Section 2.3.2, the regional modeling was not revised for the Final EIS because the regional air impact assessment for the Draft EIS showed that cumulative and Project-specific impacts were found to be below all applicable thresholds throughout the modeling domain. Air emissions presented and described for the far-field modeling correspond with the Project emissions inventory developed for the Draft EIS.

watering and a vehicle speed limit of 35 miles per hour (described in Attachment C to the Air Quality Technical Support Document, Appendix E.3B in the Willow MDP Draft EIS). The near field air dispersion modeling uses a lower dust control efficiency of 50% to estimate dust impacts within 50 km of the Project. The impacts on dust (particulate matter) concentrations due to the choice of control efficiency are expected to be minimal beyond this distance and therefore are not considered in the regional modeling. Table 2.3-8 shows the total Cumulative 2025 Alternative B emissions obtained by combining Alternative B emissions with the Cumulative 2025 No Project emissions described in Section 2.3.2.2 "Cumulative 2025 No Project Scenario".

The Cumulative 2025 Alternative B 4 km domain emissions spatial distribution used for the far-field modeling is shown in Figure 2.3-2. The Willow MDP PM_{10} and SO_2 emissions can be distinguished from other cumulative emissions sources, but other criteria pollutants are not visible relative to regional sources.

Table 2.3-7 Willow 4 km Domain 2025 Alternative B (Proponent's Project) Emissions

Source Type	Willow 4 km Domain Alt B Project Emissions (tpy)						
	NO_X	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Na
Area sources	71	27	0	87	12	8	0
Point sources	811	772	54	81	79	597	0
Total Alternative B	**882**	**799**	**55**	**168**	**91**	**605**	**0**

Table 2.3-8 Cumulative 2025 Alternative B (Proponent's Project) Emissions

Emissions	Willow 4 km Domain 2025 Future Year Alt B Project Emissions (tpy)						
	NO_X	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Na
2025 Future Year No Project	109,427	57,809	3,845	12,237	6,087	157,135	6,132
Project – Alternative B	882	799	55	168	91	605	0
Cumulative Alternative B	**110,306**	**58,607**	**3,899**	**12,405**	**6,177**	**157,736**	**6,132**

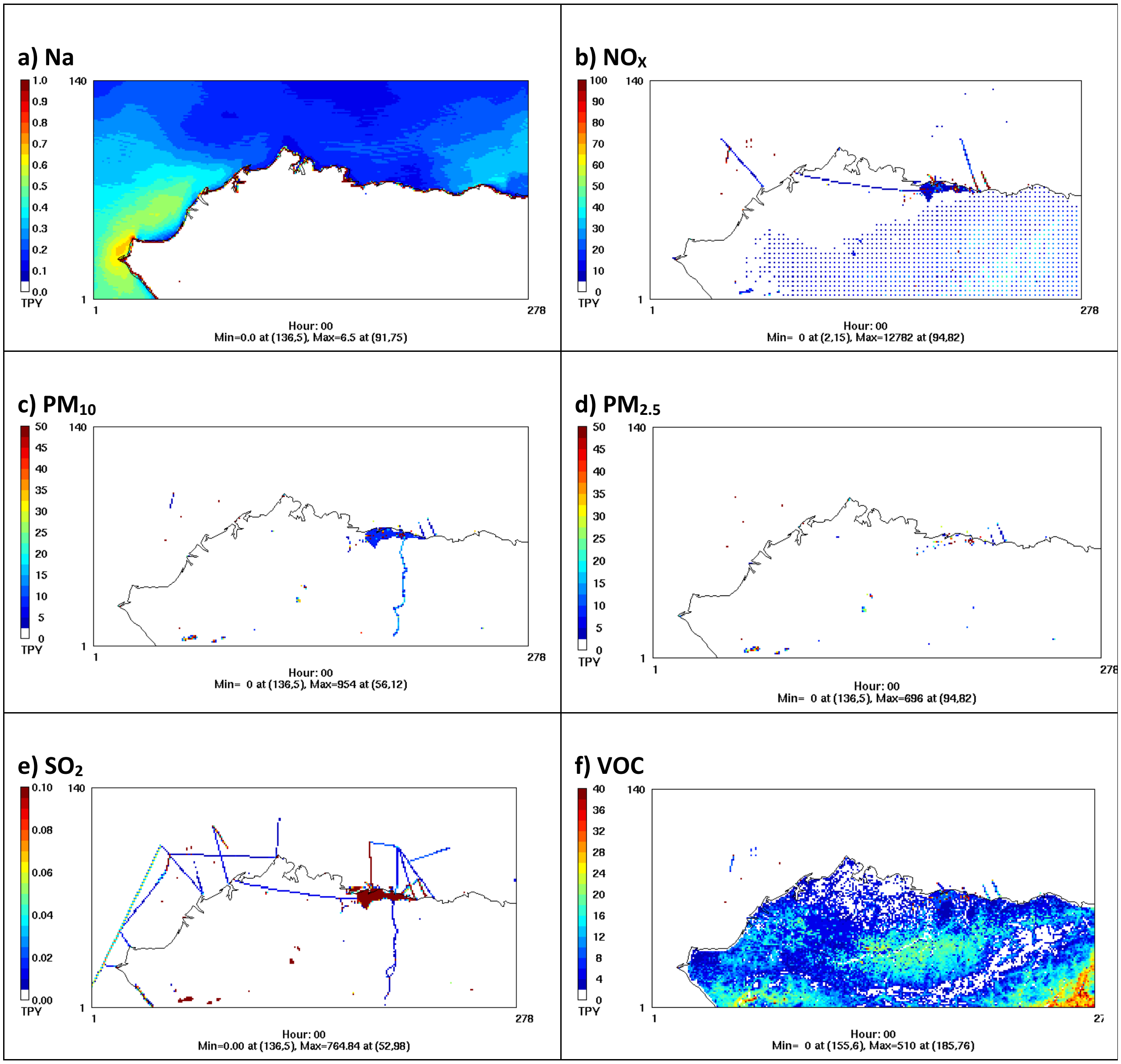


Figure 2.3.2 Willow 2025 Future Year Alternative B (Proponent's Project) Emissions a) Na, b) NO_X, c) PM_{10}, d) $PM_{2.5}$, e) SO_2, f) VOC

2.3.2.4 Cumulative 2025 Alternative C (Disconnected Infield Roads)

Table 2.3-9 shows the Alternative C annual emissions processed in SMOKE.[9] The emissions at the drill sites, the WPF, WOC North, WOC South, North Airstrip, South Airstrip, gravel mine and horizontal directional drilling under the Colville River were modeled as point sources at the center of each pad. All other Project emissions such as general construction, mobile sources, pigging, and fugitive dust emissions were modeled as area sources and allocated to the Project area using a combination of linear features (i.e., roads) and all Project features. Table 2.3-10 shows the total Cumulative 2025 Alternative C emissions obtained by combining Alternative C emissions with the Cumulative 2025 No Project emissions described Section 2.3.2.2 “Cumulative 2025 No Project Scenario”.

The Cumulative 2025 Alternative C 4 km domain emissions spatial distribution used for the far-field modeling is shown in Figure 2.3-3. The Willow MDP PM_{10}, $PM_{2.5}$ and SO_2 emissions can be distinguished from other cumulative emissions sources, but other criteria pollutants are not visible relative to the regional source signal.

Table 2.3-9 Willow 4 km Domain 2025 Alternative C (Disconnected Infield Roads) Emissions

Source Type	Willow 4 km Domain Alternative C Project Emissions (tpy)						
	NO_X	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Na
Area sources	56	19	0	67	10	5	0
Point sources	1,103	968	55	98	95	479	0
Total Alternative C	1,159	987	55	165	105	484	0

Table 2.3-10 Cumulative 2025 Alternative C (Disconnected Infield Roads) Emissions

Source Sector	Willow 4 km Domain 2025 Future Year Alt C Project Emissions (tpy)						
	NO_X	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC	Na
2025 Future Year No Project	109,427	57,809	3,845	12,237	6,087	157,135	6,132
Project - Alt C	1,159	987	55	165	105	484	0
Cumulative Alternative C	**110,586**	**58,796**	**3,899**	**12,401**	**6,192**	**157,619**	**6,132**

[9] Note that as described in Section 2.3.2, the regional modeling was not revised for the Final EIS because the regional air impact assessment for the Draft EIS showed that cumulative and Project-specific impacts were found to be below all applicable thresholds throughout the modeling domain. Air emissions presented and described for the far-field modeling correspond with the Project emissions inventory developed for the Draft EIS.

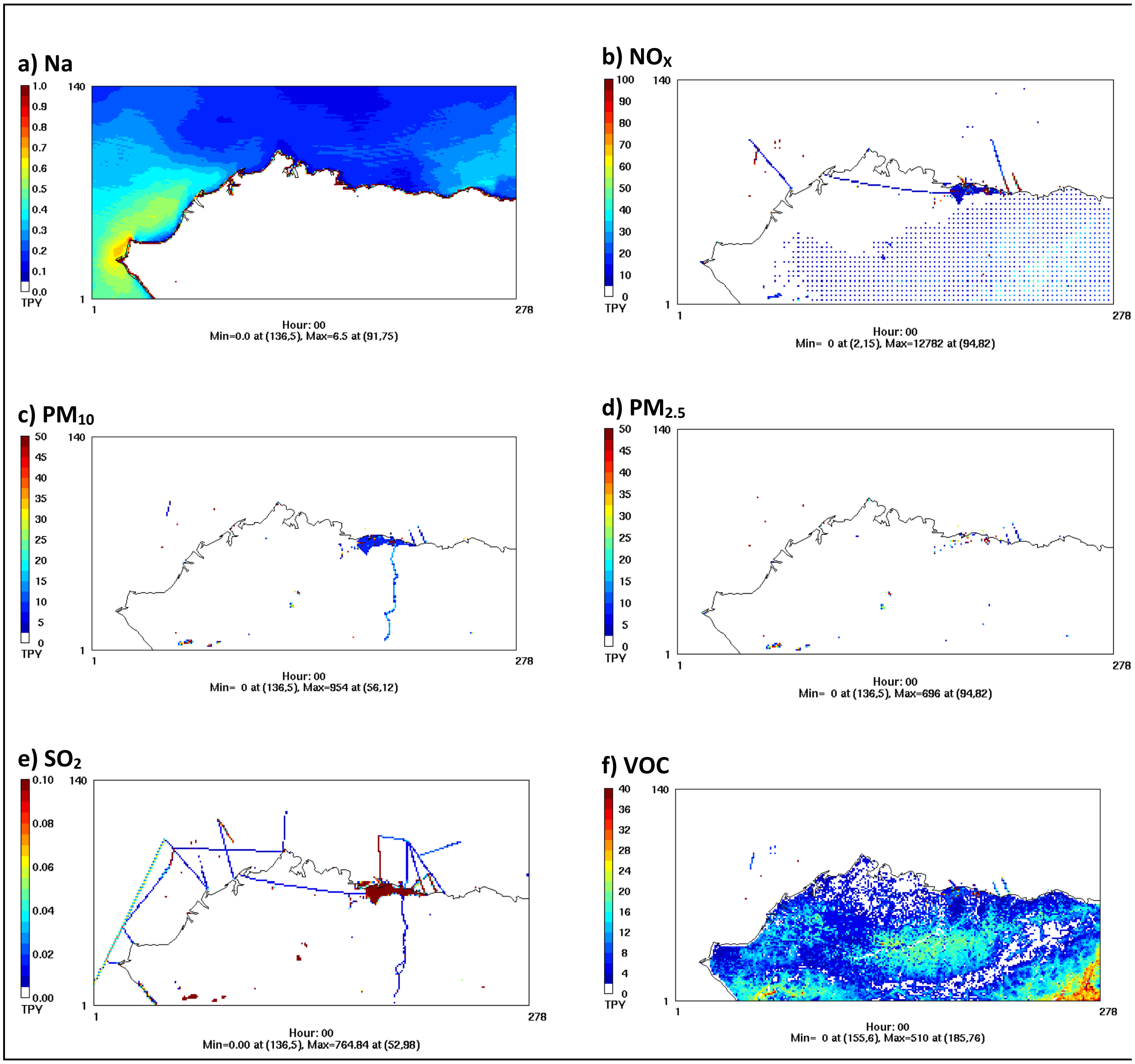


Figure 2.3.3 Willow 2025 Future Year Alternative C (Disconnected Infield Roads) Emissions a) Na, b) NO_X, c) PM_{10}, d) $PM_{2.5}$, e) SO_2, f) VOC

3.0 NEAR-FIELD MODELING ANALYSES

This chapter presents the near-field modeling approach, scenarios analyzed, development of model inputs, and model-predicted impacts.

3.1 Approach Overview and Results Summary*

The USEPA regulatory air dispersion model, AERMOD, was used to assess near-field Project impacts and cumulative impacts within 50 km of the proposed Willow MDP. As described in Section 1.2.3 "Overview of Modeling Approach and Thresholds for Comparison", AERMOD model results, which provide an estimate of air quality concentrations from the Project and RFFA sources, are added to background ambient air concentrations from existing emissions sources to calculate the total air quality concentrations. Total air quality concentrations are compared to the applicable air quality standards (both the NAAQS and AAAQS) and averaging periods shown in Table 1.2-1 to assess Project and cumulative impacts for criteria pollutants. Note that for this analysis background ambient air concentrations have been updated from the values used in the FEIS (years 2015-2017) to the most recent 3-year period available (2018-2020).

In addition to assessing impacts on criteria pollutants, the hazardous air pollutants benzene, toluene, ethylbenzene, xylenes, n-hexane, and formaldehyde are assessed with the AERMOD model. Model results are compared to non-cancer acute and chronic pollutant specific threshold levels shown in Table 1.2-3 and Table 1.2-4, respectively. Chronic cancer risk is calculated for the analyzed HAPs that have published cancer risk factors and risk from the Project is compared to a one-in-one million risk threshold.

Scenarios were developed to characterize potential peak localized impacts from the Project for various pollutants or spatial locations. The near-field modeling scenarios were selected to capture high impacts with careful consideration of peak emissions, spatial and temporal emissions variations, and in consultation with air quality specialists at key cooperating agencies. Based on the anticipated emissions activities, source types, and development schedule, five near-field scenarios are analyzed for each alternative:

1. Construction
2. Bear Tooth (BT)1 Pre-drilling
3. BT1 and BT2 Pre-drilling
4. Development Drilling
5. Routine Operations

The Construction scenario models the maximum annual construction emissions for each alternative and assesses impacts from key activities expected to occur during the construction phase, including gravel mining and horizontal directional drilling to install pipelines under the Coleville River. The Pre-drill scenario assesses impacts associated with concurrent diesel-fired drilling and hydraulic fracturing activities before electricity is available for electric drill rigs to operate. The Pre-drill BT1 scenario assesses two diesel-fired drill rigs, hydraulic fracturing units, portable flares, and supporting ancillary equipment at BT1. The Pre-drill BT1 and BT2 scenario assesses a single diesel-fired drill rig, hydraulic fracturing units, portable flare and ancillary equipment operating concurrently at BT1 and BT2. Once the Willow Processing Facility is operational and is generating electric power, diesel-fired drilling activities would no longer occur and electric drill rigs and hydraulic fracturing units would be used. Impacts associated with concurrent operation of two electric drill rigs, hydraulic fracturing units, drill site facilities installation, as well as operation of the WPF (including flaring) and all other routine operations are assessed as part of the Development Drilling scenario. The Development Drilling scenario analyzes concurrent drilling, facility construction, and operations for the peak emissions year for each alternative. The Routine Operations scenario assesses impacts from Project operational emissions (including flaring) after temporary and transient activities associated with construction and drilling are complete.

The impacts associated with Module Delivery Options are also assessed. Peak year emissions for Option 1 (Atigaru Point Module Transfer Island) occur in year 2025 and 2026 (depending on Alternative) and are lower than peak year emissions for Option 2 (Point Lonely Module Transfer Island). Impacts for Option 1 Atigaru Point are expected to be lower than impacts for Option 2; therefore, Option 1 is not assessed quantitatively.

The near-field impact assessment method, data, and results are detailed for each alternative and scenario in the following sections. As described in Section 1.2.2.1 Action Alternatives B, C and D were modeled in the near-field modeling analysis. Alternative E was not explicitly modeled in the near-field analysis because its design is similar to Alternative B. Instead of explicitly modeling Alternative E, air quality impacts under Alternative E are assessed based on project design differences and emissions inventory differences relative to Alternative B.. Table 3.1-1 shows a summary of the modeled Willow MDP impacts on air quality and hazardous air pollutants for all alternatives and scenarios analyzed. Impacts on air quality and HAPs are below all applicable standards and thresholds for all alternatives and scenarios.

Table 3.1-1 Summary of Near-field Air Quality and HAPs Impacts*

Alternative	Development Scenario	Criteria Air Pollutants	HAPs
Alternative A (No Action)	Not Applicable	No impacts to criteria air pollutants. Pollutant concentrations would be similar to existing background levels.	No impacts to HAPs. Pollutant concentrations would be similar to current levels.
Alternative B (Proponent's Project)	Construction	Impacts would be below all ambient air quality standards.	HAPs impacts were not directly assessed with a model because HAPs emissions from these activities would be lower than Routine Operations.
	BT1 Pre-Drill	Impacts would be below all ambient air quality standards. Impacts would be identical to Alternative D.	HAPs impacts were not directly assessed with a model because HAPs emissions from these activities would be lower than Routine Operations.
	BT1 and BT2 Pre-Drill	Impacts would be below all ambient air quality standards. Impacts would be identical to Alternative D.	HAPs impacts were not directly assessed with a model because HAPs emissions from these activities would be lower than Routine Operations.
	Development Drilling	Impacts would be below all ambient air quality standards.	HAPs emissions from Development Drilling are comparable to Routine Operations. Since the HAPs impacts were well below thresholds for Routine Operations, HAPs were not directly assessed for this scenario.

Alternative	Development Scenario	Criteria Air Pollutants	HAPs
	Routine Operations	Impacts would be below all ambient air quality standards.	*Non-carcinogenic:* All analyzed HAPs would be below respective Reference Exposure Levels (RELs) and Reference Concentrations (RfCs). *Carcinogenic:* Cancer risks for individual HAPs as well as total cancer risk across all pollutants were modeled to be less than a 1-in-1 million risk for all carcinogenic HAPs analyzed.
Alternative C (Disconnected Infield Roads)	Construction	Impacts would be below all ambient air quality standards.	HAPs impacts were not directly assessed with a model because HAPs emissions from these activities would be lower than Routine Operations.
	BT1 Pre-Drill	Impacts would be below all ambient air quality standards.	HAPs impacts were not directly assessed with a model because HAPs emissions from these activities would be lower than Routine Operations.
	BT1 and BT2 Pre-Drill	Impacts would be below all ambient air quality standards.	HAPs impacts were not directly assessed with a model because HAPs emissions from these activities would be lower than Routine Operations.
	Development Drilling	Impacts would be below all ambient air quality standards.	HAPs emissions from these activities are comparable to Routine Operations. Since the HAPs impacts were well below thresholds for Routine Operations, HAPs were not directly assessed for this scenario.
	Routine Operations	Impacts would be below all ambient air quality standards.	*Non-carcinogenic:* All analyzed HAPs would be below respective RELs and RfCs. *Carcinogenic:* Cancer risks for individual HAPs as well as total cancer risk across all pollutants were modeled to be less than a 1-in-1 million risk for all carcinogenic HAPs analyzed.
Alternative D (Disconnected Access)	Construction	Impacts would be below all ambient air quality standards.	HAPs impacts were not directly assessed with a model because HAPs emissions from these activities would be lower than Routine Operations.
	BT1 Pre-Drill	Impacts would be below all ambient air quality standards.	HAPs impacts were not directly assessed with a model because HAPs emissions from these activities would be lower than Routine Operations.
	BT1 and BT2 Pre-Drill	Impacts would be below all ambient air quality standards. Impacts would be identical to Alternative B.	HAPs impacts were not directly assessed with a model because HAPs emissions from these activities would be lower than Routine Operations.

Alternative	Development Scenario	Criteria Air Pollutants	HAPs
	Development Drilling	Impacts would be below all ambient air quality standards.	HAPs emissions from these activities are comparable to Routine Operations. Since the HAPs impacts were well below thresholds for Routine Operations, HAPs were not directly assessed for this scenario.
	Routine Operations	Impacts would be below all ambient air quality standards.	*Non-carcinogenic:* All analyzed HAPs would be below respective RELs and RfCs. *Carcinogenic:* Cancer risks for individual HAPs as well as total cancer risk across all pollutants were modeled to be less than a 1-in-1 million risk for all carcinogenic HAPs analyzed.
Alternative E	Construction	Impacts would be below all ambient air quality standards although impacts in the vicinity of BT1 and BT2 would be slightly higher than the impacts modeled for Alternative B but less than those Alternative C.	HAPs impacts were not directly assessed with a model because HAPs emissions from these activities would be lower than Alternative B Routine Operations HAPs emissions.
	BT1 Pre-Drill	Impacts would be similar to Alternative B and would be below all ambient air quality standards.	HAPs impacts were not directly assessed with a model because HAPs emissions from these activities would be lower than Alternative B Routine Operations HAPs emissions.
	BT1 and BT2 Pre-Drill	Impacts would be similar to Alternative B and would be below all ambient air quality standards.	HAPs impacts were not directly assessed with a model because HAPs emissions from these activities would be lower than Alternative B Routine Operations HAPs emissions.
	Development Drilling	Impacts would be similar to Alternative B and would be below all ambient air quality standards.	HAPs emissions from Development Drilling are comparable to Routine Operations. Since the Alternative B Routine Operations HAPs impacts were well below thresholds, HAPs were not directly assessed for this scenario.

Alternative	Development Scenario	Criteria Air Pollutants	HAPs
	Routine Operations	Impacts would be similar to Alternative B and would be below all ambient air quality standards.	*Non-carcinogenic:* All analyzed HAPs would be similar to Alternative B and would be below respective Reference Exposure Levels (RELs) and Reference Concentrations (RfCs). *Carcinogenic:* Cancer risks for individual HAPs as well as total cancer risk across all pollutants would be similar to Alternative B, which were modeled to be less than a 1-in-1 million risk for all carcinogenic HAPs analyzed.
Module Delivery	Option 1: Atigaru Point MTI	Onshore impacts are not directly assessed. Impacts are anticipated to be lower than Option 2: Point Lonely MTI and below all ambient air quality standards.	HAPs impacts were not directly assessed with a model because HAPs emissions from MTI activities would be lower than Routine Operations under Alternatives B, C, and D.
	Option 2: Point Lonely MTI	Onshore impacts would be below all ambient air quality standards and higher than Option 1: Atigaru Point MTI.	HAPs impacts were not directly assessed with a model because HAPs emissions from these activities would be lower than Routine Operations under Alternatives B, C, and D.
	Option 3: Colville River Crossing	Onshore impacts would be below all ambient air quality standards.	HAPs impacts were not directly assessed with a model because HAPs emissions from these activities would be lower than Routine Operations under Alternatives B, C, and D.

3.2 Modeling Approach*

This section describes the dispersion model, inputs and settings used to analyze impacts from Alternatives B, C, and D. Instead of explicitly modeling Alternative E, air quality impacts under Alternative E are assessed based on project design differences and emissions inventory differences relative to Alternative B. Model inputs and settings used to analyze impacts from Module Delivery Option 2 and Option 3 are presented in Section 3.6 and 3.7, respectively.

3.2.1 Dispersion Model*

The most recent version of AERMOD available at the time of the modeling was version 19191, which was the version used for the near-field analysis. The latest version of AERMOD (v21112) was not available at the time the Project analysis was performed. The changes made to AERMOD version 21112 as documented by EPA (2021a) are expected to have negligible effect on model-predicted Project impacts given the modeled Project sources and model settings.

3.2.2 Applicable Air Quality Standards and Hazardous Air Pollutant Thresholds

Modeling results were compared to applicable NAAQS and AAAQS, collectively referred to as AAQS (shown in Table 1.2-1). AAQS represent the total concentrations of a given pollutant allowed to protect public health. Table 1.2-1 does not include AAQS for lead and ammonia because the Project is not anticipated to emit lead or ammonia and hence these pollutants are not issues of concern. Pollutants analyzed are based on the form of the AAQS, PSD Class II increments or HAPs thresholds as shown in Table 1.2-1 though Table 1.2-5. Near-field modeled Project impacts due to the action alternatives are compared to PSD increments at only the Nuiqsut receptor location.

AERMOD was used to assess the near-field impacts for the following criteria pollutants and averaging periods:

- CO for 1-hour and 8-hour averaging periods
- NO_2 for 1-hour and annual averaging periods
- $PM_{2.5}$ for 24-hour and annual averaging periods
- PM_{10} for 24-hour and annual averaging periods
- SO_2 for 1-hour, 3-hour, 24-hour and annual averaging periods.

The 1-hour NO_2, 1-hour SO_2, and 24-hour $PM_{2.5}$ standards are based on three-year average concentrations. For these standards, yearly maximum impacts were estimated for each of the five years of meteorological data and the top three values were averaged to calculate a value for comparison to the applicable AAQS.

While the regional modeling analysis conducted with CAMx includes estimates of all emissions sources including naturally occurring emissions, the near-field modeling analysis conducted with AERMOD evaluates only anthropogenic emissions sources within 50 km of the Willow MDP. The AERMOD model is configured to assess Willow MDP activities for various alternatives in combination with existing emissions sources. For routine activities anticipated to extend into the future for typical operations, the modeling analysis included emissions from all RFFAs within the modeling domain in addition to Willow MDP sources. RFFA emission sources are described in Section 2.2 “Cumulative Emissions for the Willow Alternatives”.

To estimate total ambient air quality conditions with AERMOD, modeled impacts are added to representative background concentrations. The background concentrations representative of the Project area are discussed in Section 3.2.6 “Ambient Background Data”. Ozone impacts and secondary $PM_{2.5}$ ($PM_{2.5}$ formed in the atmosphere from chemical reactions) impacts are assessed with the CAMx model. These pollutants are not assessed using the AERMOD model because the model does not include the necessary chemical reactions to estimate concentrations of pollutants not directly emitted from sources. In order to estimate the contribution of secondary $PM_{2.5}$ to near-field impacts, results from the regional CAMx model were used. The secondary $PM_{2.5}$ concentrations from CAMx were derived by removing chemical species that are primary emissions sources. The secondary $PM_{2.5}$ calculated here is the total $PM_{2.5}$ without the contributions of primary organic aerosol, fine crustal particulate matter, fine other primary particulate matter with a diameter less than 2.5 microns and primary elemental carbon. This methodology likely provides an over-estimate of secondary $PM_{2.5}$ since some species included as completely secondary $PM_{2.5}$, like sulfate, can be emitted directly as primary $PM_{2.5}$.

The estimated secondary $PM_{2.5}$ concentrations resulting from Project alternative emissions were derived from the CAMx regional modeling described in Chapter 4 of this Technical Support Document (TSD) for the far field modeling. For Alternative B and Alternative C scenarios, the maximum 24-hour $PM_{2.5}$ daily average and the annual average $PM_{2.5}$ concentrations were calculated for each CAMx grid cell in area that surrounds the Project which is consistent with the modeling domain where near-field impacts are assessed (see Figure 3.2-1 for the study area). The maximum 24-hour and annual values from each alternative were selected. The maximum 24-hour 98th percentile value over all the grid cells over 365 days is 0.47902 μg/m^3. This value is used to estimate the maximum potential secondary 24-hour $PM_{2.5}$ impact in the near-field modeling domain of the Willow MDP. For annual average concentrations the value of 0.04831 μg/m^3 is the maximum annual average secondary $PM_{2.5}$ impact in the near-field modeling domain of the Willow MDP. These values are added to all near-field AERMOD modeled PM_{10} and $PM_{2.5}$ concentrations presented for all Alternatives below.

Note that the CAMx performance analysis indicated that $PM_{2.5}$ concentrations were biased low overall, and therefore the secondary $PM_{2.5}$ impacts, although low, could potentially be higher than predicted based on the findings from the performance analysis.

Emissions for benzene, toluene, ethylbenzene, xylenes, n-hexane, and formaldehyde are modeled for a 1-hour average to compare to the acute reference exposure limits (REL) shown in Table 1.2-3, 8-hour average to compare to the Acute Exposure Guideline Levels (AEGLs) shown in Table 1.2-3, and an annual average period to compare to the non-cancer RfC shown in Table 1.2-4 and chronic carcinogenic exposure to compare to the one-in-one million risk threshold. No ambient air background levels were added to the HAP model results. Based on analysis of the HAP emissions inventory, HAP emissions from construction and drilling activities are lower than operations. Therefore, impacts to HAPs are only assessed for the Routine Operations scenario for all Alternatives.

3.2.3 Meteorological Data*

Meteorological data for the AERMOD modeling system were prepared using the AERMET meteorological processor applied to representative surface and regional upper air observations. USEPA modeling guidance recommends either five years of National Weather Service (NWS) hourly surface observations or at least one year of onsite/site-specific meteorological observations. As such, five years (2013 -2017) of available meteorological data from the Nuiqsut monitoring station, and upper data from Utqiaġvik, Alaska were processed with AERMET and were used for the near-field modeling analysis. More recent meteorological data from the period 2016-2020 were compared to the 2013-2017 meteorological data used for modeling and the datasets are nearly identical. More information about these datasets are presented below.

The meteorological observation dataset collected at the CPAI Nuiqsut monitoring site were the only source of hourly surface data for the AERMOD simulations. These data meet USEPA modeling guidance for calendar quarter 90 percent data recovery for wind speed and direction, solar radiation, and differential temperature measurements. The surface data and upper data from Utqiaġvik were processed with AERMET into AERMOD surface and profile data formats using AERMET default options and surface parameters data as described in the Willow MDP Protocol (Ramboll 2018).

The Nuiqsut site shown in Figure 3.2-1 is located at the northern edge of the City of Nuiqsut approximately 41 km (26 miles) east northeast of the Willow Bear Tooth (BT)3 pad. The Nuiqsut data were collected in a physical setting geographically similar to the proposed Willow MDP Drill Pads and in the absence of intervening terrain are considered to be representative of surface meteorological conditions in the Project area. The Utqiaġvik station location used for the upper air data is also shown in Figure 3.2-1. The Nuiqsut surface data and Utqiaġvik upper air data were also used for the dispersion modeling analyses supporting the GMT1 and GMT2 projects approved by ADEC.

The Nuiqsut site collects hourly horizontal wind speed, wind direction, vertical wind speed, temperature, differential temperature (between 2 meters and 10 meters in height and on an hourly basis), and solar radiation data (on an hourly basis). The wind observations are measured at about 10 m above the surface. In addition, turbulence parameters are also calculated at the site. The supplemental data include the standard deviation of the vertical wind speed (sigma-w) and standard deviation of horizontal wind direction (sigma-theta). The instrumentation, quality assurance (QA), and quality control (QC) procedures meet the requirements of USEPA guidance for PSD regulatory modeling (SLR, 2016) and are performed according to an ADEC-approved Quality Assurance Project Plan (QAPP) (SLR, 2012).

Figure 3.2-2 below shows a wind rose constructed from the Nuiqsut site surface observations. The winds at Nuiqsut show the characteristic east-northeast to west-southwest bimodal pattern commonly observed on the North Slope. The average wind speed during 2013-2017 was 5 meters per second (m/s) and calm winds were infrequent, occurring for less than 1 percent of hours during the five-year period.

Figure 3.2-2 shown below presents a wind rose constructed from the Nuiqsut site surface observations for a more recent five-year period (2016-2020). As indicated in this figure the winds at Nuiqsut for this more recent five-year period (2016-2020) show the same east-northeast to west-southwest bimodal pattern as the 2013-2017 dataset. The average wind speed and percentage of calm winds for the two datasets are nearly identical.

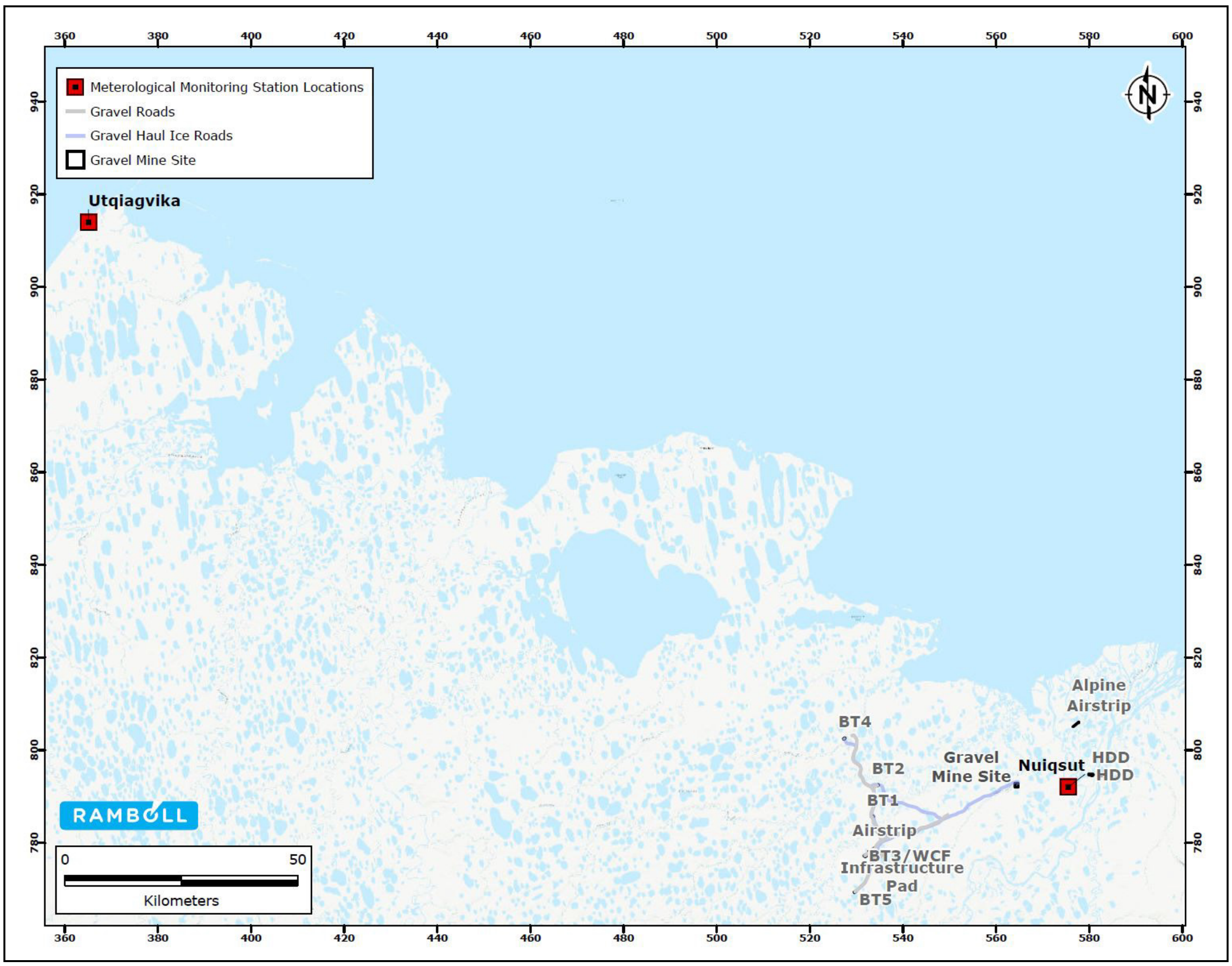


Figure 3.2.1 Meteorological Monitoring Stations used for AERMET

3.2.4 Building Downwash

Downwash effects from buildings and structures were included for the Development Drilling and Routine Operations scenarios for all Alternatives (see Sections 3.3.1 “Alternative B - Overview of Scenarios”, 3.4.1 “Alternative C – Overview of Scenarios”, and 3.5.1 “Alternative D – Overview of Scenarios” for a description of model scenarios for all action alternatives). During construction and pre-drilling activities, buildings and structures are not onsite, therefore, building downwash is not included in Construction, BT1 Pre-Drill, and BT1 and BT2 Pre-Drill scenarios. To estimate downwash effects, dimensions of buildings and structures were input into BPIP-PRIME (version 04274) in combination with source locations for each action alternative. The BPIP-PRIME results were then included in the AERMOD modeling for Development Drilling and Routine Operation scenarios.

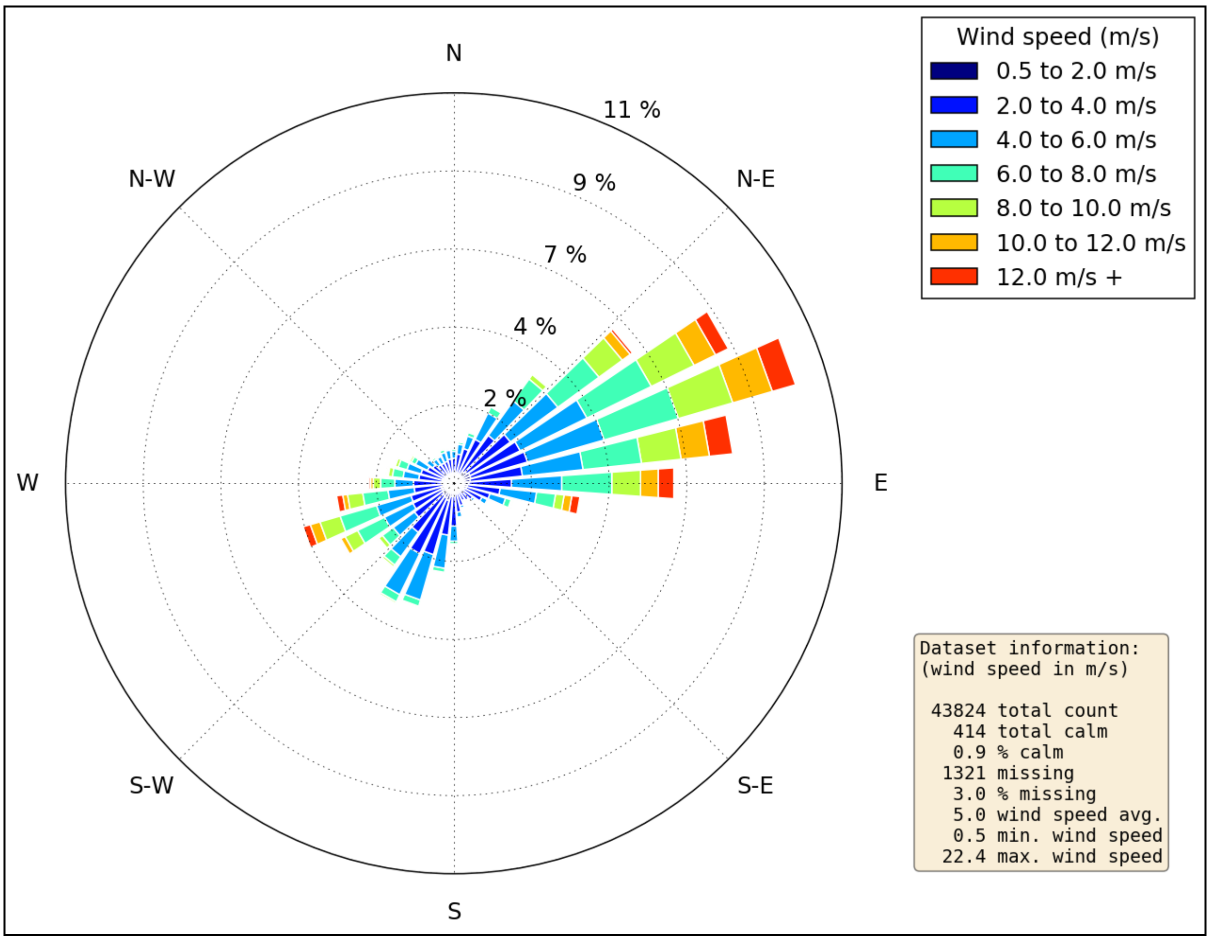


Figure 3.2.2 Nuiqsut Air Monitoring Station 2013-2017 Wind Rose

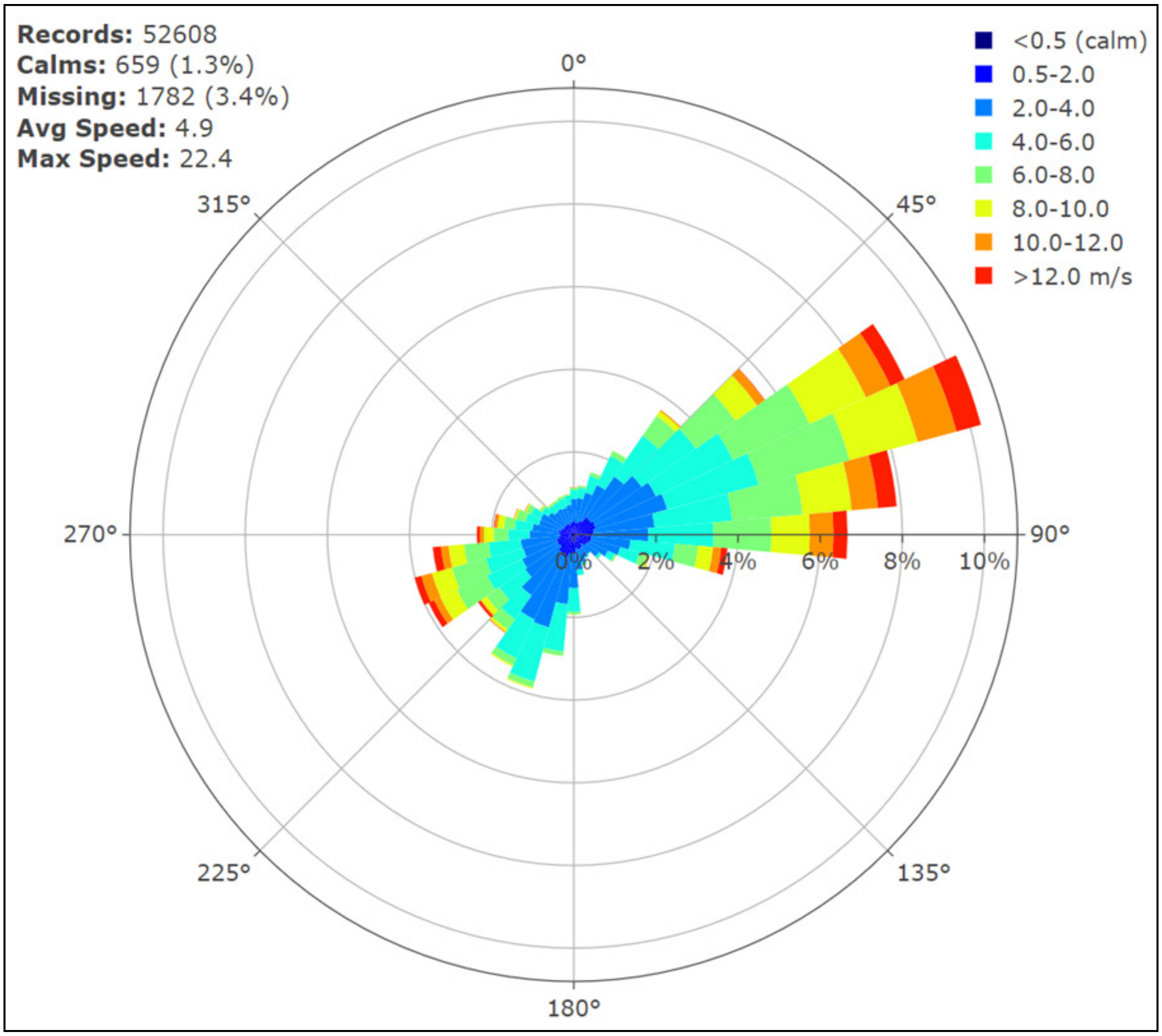


Figure 3.2.3 Nuiqsut Air Monitoring Station 2016-2020 Wind Rose *

3.2.5 Model Options

AERMOD model options were set to their regulatory default values, unless otherwise noted below in additional subsections of this chapter related to meteorological data processing and NO_2 modeling.

3.2.5.1 Urban vs Rural

None of the area in the vicinity of the Project is classified as urban; therefore, the urban option (URBOPT) keyword was not used in AERMOD.

3.2.5.2 Adjusted U-star

Due to the use of turbulence parameters collected at Nuiqsut meteorological station, adjusted u-star option is not used.

*3.2.5.3 NO_2 Modeling Approach**

For modeling NO_2, the Ozone Limiting Method (OLM) is used to estimate the NO_x to NO_2 conversion. The hourly ozone data measured at Nuiqsut shown in Figure 3.2-4 are used for 2013-2017, the same calendar years as the meteorological data presented in Section 3.2.3 "Meteorological Data". More recent ozone concentrations from 2016-2020 were comparable to measured concentrations during the 2013-2017 period. Current ozone concentrations are comparable to the values used in the modeling analysis. The in-stack ratios are shown for the various types of equipment in Table 3.2-1 below and an equilibrium ratio of 0.9 was used for all sources. Unless noted, the ratios were derived from data contained in a spreadsheet available from ADEC with approved in-stack ratio values (ADEC, 2013). Data were averaged over all loads available for similar equipment to what would be used in the Project. The USEPA also has an in-stack ratio database (USEPA, n.d.); however, most of the data contained in this database for the emission sources in Table 3.2-1 were from the ADEC spreadsheet. In the absence of any available data, the USEPA default value of 0.5 was used (USEPA, 2011).

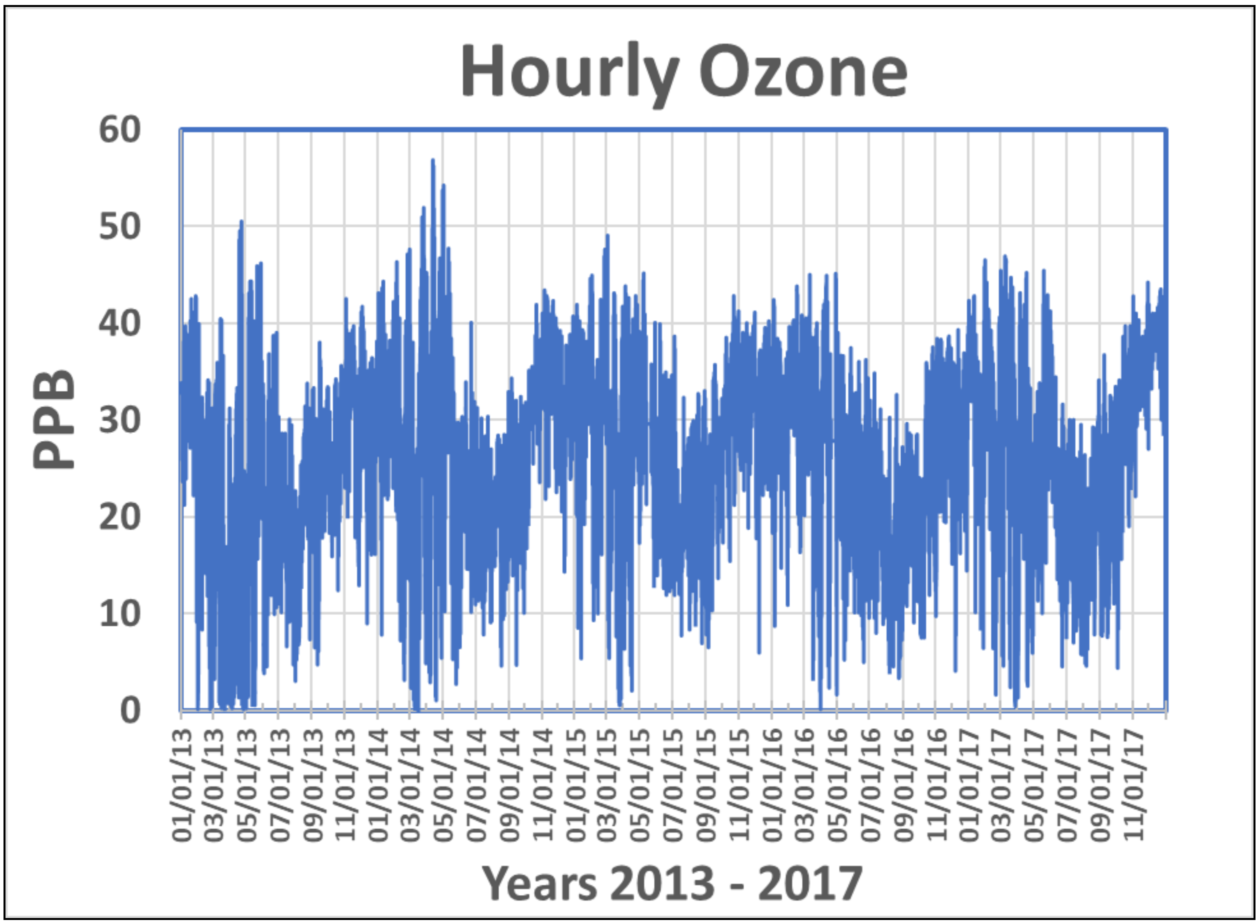


Figure 3.2.4 Hourly ozone data at Nuiqsut monitoring station in years between 2013 to 2017.

Table 3.2-1 In-Stack NO_2/NOx Ratios for use with OLM.

Type of Emission Source	NO2/NOx Ratio	Source of Data for Ratio
Diesel Engines	0.1	Average rounded to the nearest tenth of data from Trident Akutan, Tok Power Generation Station, Dutch Harbor Power Plant, Dillingham Power Plant, Peter Pan Seafoods, and DU-JBER Services engines (ADEC, 2013)
Diesel fueled heaters and boiler	0.05	Ambient Demonstration for the North Slope Portable Oil and Gas Operation Simulation report (AECOM, 2017)
Flares	0.5	USEPA default value (USEPA, 2011)
Natural gas heaters	0.05	Data for natural gas-fired heaters and boilers from EPA and ADEC NO-to-NO2 instack ratio database (ADEC, 2013; EPA, n.d.)
Diesel tailpipe from nonroad equipment	0.2	GMT1 and GMT2 value
Diesel tailpipe from on-road vehicles	0.15	GMT1 and GMT2 value
Natural-gas-fired turbines	0.3	In-stack ratio used for natural-gas fired turbines in Nanushuk EIS AQIA (SLR, 2017a)
Cumulative Sources	Variable	Were based on the values contained in this table and the predominant source at each facility

3.2.6 Ambient Background Data*

The ambient air monitoring stations closest to the proposed Project are the Nuiqsut Monitoring Station, a station at the CD1 Facility, and a station at the CD5 Pad. As discussed in the Willow MDP Protocol (Ramboll 2018), the Nuiqsut Monitoring Station is representative of ambient air background concentrations anticipated for the Project. The Nuiqsut Monitoring Station is located at the north end of Nuiqsut approximately 400 meters northwest of the Nuiqsut Power Plant and approximately 41 km (26 miles) east northeast of the Willow BT3 pad. The monitoring program, which began in 1999, is being conducted primarily to address community concerns in Nuiqsut. The Nuiqsut Monitoring Station also collects wind direction and speed, among other meteorological data as discussed in Section 3.2.3 “Meteorological Data”. Based on the wind roses (Figure 3.2-2 and Figure 3.23) from data collected at the Nuiqsut Monitoring Station, the wind predominately blows from the east northeast and east directions (SLR, 2016, 2017b, 2018, 2019, 2020, 2021).

Background concentrations at the Nuiqsut Monitoring Station are calculated using approaches defined in Kleinfelder, 2017, and are discussed below. Data for CO, NO_x, nitric oxide (NO), NO_2, SO_2, O_3, particulate matter less than $PM_{2.5}$, and PM_{10} are provided.

Many of the NAAQS are based on a three-year average and thus three years of background data are needed to calculate values used in the near-field impact analysis. Three years of Nuiqsut Monitoring Station data were used to calculate background data and hourly ozone data was processed for OLM modeling (see Section 3.2.5.3 “NO_2 Modeling Approach”). The background data have been updated from the analysis performed for the project FEIS (years 2015-2017) to the most recent 3-year period (2018-2020). Table 3.2-2 shows the values from 2018 – 2020 along with the final background value and the form of the data value chosen. The values in Table 3.2-2 are referenced directly from the Annual Data Reports (ADRs) (SLR, 2019, 2020, 2021) except for SO_2, NO_2 and PM_{10}.

SO_2 1-hour values were referenced directly from the ADRs; however, the 3-hour, 24-hour and annual background values used to calculate total air quality impacts were derived from hourly data, rather than use the valued directly from the ADRs because the ADRs did not contain adequate significant digits.

NO_2 and PM_{10} concentrations have been revised as described below. Consistent with USEPA guidance, a constant background value representative of each pollutant and averaging time was added to the model results except for 1-hour NO_2 and 24-hour PM_{10}. For 1-hour background NO_2 values, a seasonally-varying hourly concentration is determined based on 2018-2020 monitoring data following USEPA's March 1, 2011 Memorandum "Additional Clarification Regarding Application of Appendix W Modeling Guidance for the 1-hour NO_2 National Ambient Air Quality Standard" (EPA, 2011) for modeling assessments of 1-hour NO_2 impacts. For this analysis the 3rd highest hourly values were determined for each season and averaged for each hour of day and season over the 3-year period. Table 3.2-3 shows the 3rd highest NO_2 value for each hour of each day within each of the seasons for 2018, 2019, and 2020, and a three-year average for each hour of each season. Season 1 is December, January, and February; Season 2 is March, April, and May; Season 3 is June, July, and August; and Season 4 is September, October, and November in Table 3.2-3. Since NO_2 3rd highest values are determined for each year and are dependent on the number of days with valid data for each season, we show the percentage of valid observations of hourly NO_2 by hour and season in Table 3.2-4. To ensure that outliers and inaccurate data are excluded, only sufficiently valid observations were averaged. Since all hours, all seasons, and all years had at least 70 percent valid observations, all values were included in the three-year averages shown in Table 3.2-4.

Table 3.2-2 Ambient Background Concentrations at Nuiqsut

Pollutant	Average Time	2018	2019	2020	Final Value	Data Value
CO	1-hour[a]	1 ppm/ 1144.5 μg/m³	1 ppm/ 1,144.5 μg/m³	9 ppm/ 10,300.5 μg/m³	9 ppm/ 10,300.5 μg/m³	Maximum second high value from three years of data
	8-hour[a]	1 ppm/ 1,144.5 μg/m³	1 ppm/ 1,144.5 μg/m³	3 ppm/ 3,433.5 μg/m³	3 ppm/ 3,433.5 μg/m³	Maximum second high value from three years of data
NO_2	1-hour	-	-	-	-	See Table 3.2-3 for the 3-year average seasonally-varying hourly background concentrations
	Annual	2 ppb / 3.8μg/m³	2 ppb/ 3.8μg/m³	2 ppb/ 3.8μg/m³	2 ppb/ 3.8μg/m³	Maximum value from three years of data
SO_2	1-hour	2.6 ppb / 6.8μg/m³	3.5 ppb/ 9.2μg/m³	4.2 ppb/ 11.0μg/m³	3.4 ppb/ 9.0μg/m³	99th percentile of daily 1-hr maximum averaged over three years
	3-hour	2.6 ppb / 6.7μg/m³	3.5 ppb/ 9.1μg/m³	3.8 ppb/ 10.0μg/m³	3.8 ppb/ 10.0μg/m³	Maximum second high value from three years of data
	24-hour	2.5 ppb/ 6.5μg/m³	3.3 ppb/ 8.7μg/m³	3.6 ppb/ 9.3μg/m³	3.6 ppb/ 9.3μg/m³	Maximum second high value from three years of data
	Annual	0.7 ppb/ 1.8μg/m³	0.3 ppb/ 0.8μg/m³	0.0 ppb/ 0.0μg/m³	0.7 ppb/ 1.8μg/m³	Maximum value from three years of data
PM_{10}	24-hour	-	-	-	-	See Table 3.2-66 for the 3-year average monthly background concentrations

Pollutant	Average Time	2018	2019	2020	Final Value	Data Value
$PM_{2.5}$	24-hour	8 µg/m^3	7 µg/m^3	6 µg/m^3	7.0 µg/m^3	98th percentile averaged over three years
	Annual	1.9 µg/m^3	1.7 µg/m^3	1.2 µg/m^3	1.6 µg/m^3	Annual mean averaged over three years

Data from SLR 2019, SLR 2020, and SLR 2021. Values from reports that are presented in units of ppb are also provided in units of µg/m^3 for consistency with values and units used in the modeling analyses.
[a] 1-hour and 8-hour CO values are reported as the same value based on precision in the report.

The PM_{10} data collected at Nuiqsut during 2018 through 2020 were analyzed to determine a background level representative of the Project area. Previous analyses (AECOM 2013), and (Kleinfelder and Ramboll Environ 2017b) have shown that the elevated PM_{10} values at the Nuiqsut Monitoring Station are due to the monitoring station's proximity to the exposed silt banks of the Nigliq Channel. Figure 3.2-5 illustrates the proximity of the Nuiqsut Monitoring Station to these silt banks. In general, the highest PM_{10} values occur on days with strong winds from the east between 60° and 100° (from the Nigliq Channel). High wind events that entrain silt from the Nigliq Channel lead to elevated concentrations of PM_{10} that are not reasonably controllable or preventable and are a natural event. As recommended in EPA's "Guideline on Air Quality Models" (USEPA 2017) modeling results should use representative PM_{10} background concentrations with natural exceptional events removed. Therefore, the PM_{10} data from the Nuiqsut Monitoring Station coupled with wind speed and direction data were analyzed in detail to determine a more representative background for the Project area. Previous projects including GMT1 (AECOM 2013), GMT2 SEIS (Kleinfelder and Ramboll Environ 2017b), excluded unrepresentative hourly and daily PM_{10} values from background concentrations for days with high winds and with the wind direction between 60° and 100°. For this Project a similar analysis was performed to determine if there were high wind events during the 2018 – 2020 period that caused unrepresentative hourly and daily PM_{10} measurements. Table 3.2-5 shows the days that were excluded along with the daily average wind speed and wind direction, and the PM_{10} concentration measured on that day. Also indicated in Table 3.2-5 is the number of hours in the day where the winds were between 60° and 100° (from the Nigliq Channel). Table 3.2-6 shows the highest first high PM_{10} background values by month used for monthly background concentrations.

Consistent with 40 CFR Part 50 Appendix K, the average of the highest first high PM_{10} (H1H) background values for each month are rounded to the nearest 1 µg/m^3, and then rounded to the nearest 10 µg/m^3 for the purposes of determining exceedances (40 CFR Part 50 Appendix K 4.2(b)), the monthly background values in the Average PM_{10} H1H Background Value are rounded to nearest ten µg/m^3. These monthly values, provided in Table 3.2-6, were added to AERMOD modeled 24-hour PM_{10} impacts from Project and cumulative sources.

For the use of OLM for NO_2 modeling, raw ozone data from the Nuiqsut Monitoring Station ADR reports (SLR, 2015, 2016, 2017) were used. More recent ozone concentrations from 2016-2020 were comparable to measured concentrations during the 2013-2017 period. Current ozone concentrations are comparable to the values used in the modeling analysis. For days and hours when ozone values are missing due to missing data, calibration, or sampling, the average ozone value from that month was used to fill in the missing hours.

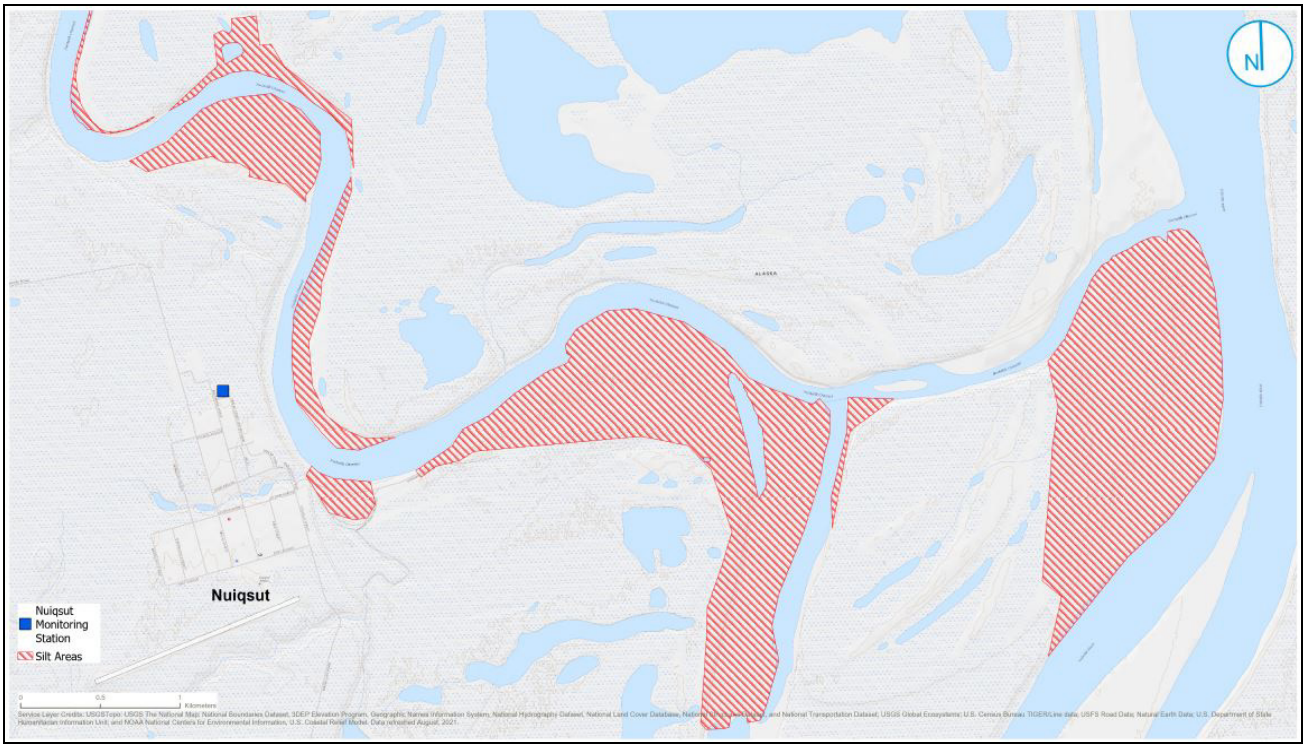


Figure 3.2-5 Proximity of Nuiqsut Monitoring Station to the Nigliq (Nechelik) Channel (potential Sources of Particulate Matter are Shaded in Red).

Table 3.2-3 3rd Highest Hourly NO_2 Values by Hour and Season (ppb)*

3-Year Average	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Season 1	15.87	18.20	16.27	12.00	17.33	15.20	17.30	17.57	17.13	17.47	14.97	16.17	17.13	19.43	19.37	19.23	23.13	20.27	16.20	16.23	17.43	14.07	16.87	16.80
Season 2	13.33	10.33	11.80	11.20	15.13	14.53	10.30	7.67	9.73	9.53	7.30	6.73	6.53	6.37	5.77	6.57	7.17	8.40	10.30	8.30	9.00	12.23	11.93	12.93
Season 3	6.33	6.67	8.57	6.97	6.17	5.93	5.67	5.07	5.37	4.60	4.47	3.63	4.30	3.57	4.10	3.77	3.73	4.17	5.00	6.00	7.20	6.70	7.90	6.90
Season 4	5.10	5.40	4.40	4.10	4.23	5.17	5.43	5.47	4.87	5.17	5.97	4.83	4.43	5.30	6.23	7.03	6.13	6.27	6.70	4.93	6.77	4.63	4.20	4.60
2018	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Season 1	16.30	16.10	16.00	10.50	13.60	16.50	12.40	14.90	14.30	22.70	14.10	13.80	16.70	16.50	13.40	16.50	14.80	13.80	13.50	16.30	16.30	14.40	13.40	16.20
Season 2	9.10	10.70	10.40	8.10	11.30	8.90	9.70	6.10	6.30	4.30	4.70	5.60	4.80	4.30	4.40	5.70	5.80	4.60	7.90	5.30	6.00	8.50	8.70	6.60
Season 3	5.50	6.30	8.70	7.00	5.10	5.30	4.40	4.80	4.30	4.10	3.70	3.50	4.30	3.00	3.20	3.00	3.00	3.20	2.80	3.70	4.30	5.80	5.30	3.60
Season 4	4.30	4.10	2.20	2.40	2.90	5.70	5.70	4.50	5.40	5.80	8.40	5.20	4.70	5.20	7.10	8.60	8.30	7.40	7.10	6.80	7.00	6.70	6.10	5.40
2019	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Season 1	18.90	19.70	13.50	11.70	18.70	14.90	21.50	21.00	19.80	12.30	15.70	16.90	20.00	13.80	14.40	18.20	27.90	20.60	19.60	15.10	19.20	13.10	20.10	20.10
Season 2	15.40	6.50	8.30	12.10	14.70	12.20	9.30	8.10	13.50	13.40	9.60	6.40	7.90	6.00	5.50	5.60	4.40	7.80	7.30	6.50	9.50	9.10	9.20	12.70
Season 3	7.60	6.60	6.50	9.50	7.40	6.20	6.20	5.60	5.30	4.60	4.40	4.10	5.20	4.50	5.70	4.10	3.90	4.10	6.50	5.90	8.10	8.60	10.40	8.20
Season 4	5.60	5.60	6.70	5.00	5.30	4.60	4.60	4.80	4.50	5.00	5.40	5.20	4.10	5.40	7.70	8.40	6.10	7.20	8.70	5.40	9.60	3.40	3.50	4.60
2020	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Season 1	12.40	18.80	19.30	13.80	19.70	14.20	18.00	16.80	17.30	17.40	15.10	17.80	14.70	28.00	30.30	23.00	26.70	26.40	15.50	17.30	16.80	14.70	17.10	14.10
Season 2	15.50	13.80	16.70	13.40	19.40	22.50	11.90	8.80	9.40	10.90	7.60	8.20	6.90	8.80	7.40	8.40	11.30	12.80	15.70	13.10	11.50	19.10	17.90	19.50
Season 3	5.90	7.10	10.50	4.40	6.00	6.30	6.40	4.80	6.50	5.10	5.30	3.30	3.40	3.20	3.40	4.20	4.30	5.20	5.70	8.40	9.20	5.70	8.00	8.90
Season 4	5.40	6.50	4.30	4.90	4.50	5.20	6.00	7.10	4.70	4.70	4.10	4.10	4.50	5.30	3.90	4.10	4.00	4.20	4.30	2.60	3.70	3.80	3.00	3.80

Table 3.2-4 Valid Observations of Hourly NO_2 by Hour and Season*

Year/Season	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour
2018	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Season 1	100%	100%	100%	87%	99%	98%	98%	98%	98%	97%	98%	97%	97%	96%	96%	97%	96%	98%	98%	100%	100%	100%	100%	100%
Season 2	100%	100%	100%	88%	100%	99%	100%	100%	99%	99%	97%	96%	99%	99%	98%	95%	96%	99%	99%	100%	100%	100%	100%	100%
Season 3	82%	82%	82%	70%	79%	80%	80%	82%	82%	82%	82%	82%	80%	80%	79%	80%	78%	80%	82%	82%	83%	83%	83%	83%
Season 4	100%	99%	99%	86%	100%	99%	98%	98%	98%	98%	98%	99%	99%	98%	98%	98%	96%	97%	99%	99%	99%	100%	100%	100%
2019	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Season 1	99%	99%	99%	84%	98%	93%	92%	97%	97%	94%	93%	98%	99%	98%	98%	98%	98%	97%	97%	97%	98%	98%	97%	99%
Season 2	100%	100%	100%	86%	100%	99%	99%	99%	99%	99%	98%	98%	97%	96%	98%	97%	97%	98%	97%	98%	100%	100%	100%	100%

Year/Season	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour	Hour
Season 3	84%	84%	84%	73%	84%	84%	84%	84%	83%	78%	78%	79%	84%	83%	80%	84%	84%	84%	83%	80%	80%	83%	84%	84%
Season 4	97%	97%	97%	86%	98%	97%	98%	98%	98%	98%	97%	90%	92%	93%	93%	93%	93%	95%	97%	96%	96%	97%	97%	97%
2020	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Season 1	97%	99%	98%	78%	99%	99%	98%	98%	99%	99%	97%	99%	98%	96%	96%	99%	98%	99%	98%	98%	98%	98%	97%	98%
Season 2	100%	100%	100%	91%	100%	100%	100%	100%	100%	100%	99%	99%	98%	100%	99%	99%	96%	97%	99%	98%	99%	98%	98%	99%
Season 3	96%	96%	95%	83%	95%	96%	93%	93%	93%	95%	93%	92%	92%	93%	91%	93%	95%	93%	95%	96%	95%	95%	95%	96%
Season 4	88%	88%	88%	70%	86%	86%	87%	86%	86%	86%	86%	86%	86%	87%	87%	87%	87%	88%	89%	89%	87%	88%	88%	88%

Table 3.2-5 Days and Meteorology Removed from PM_{10} Background Analysis*

Date	24-hour PM_{10} Concentration (µg/m³)	Average Daily Wind Speed (m/s)	Average Daily Wind Direction (degrees)	Number of Hours Wind Direction is Within 60-100 degrees
October 3, 2018	137.2	8.9	88.2	24
October 4, 2018	142.2	9.5	86.7	24
May 17, 2019	79.7	11.9	86.3	24
July 2, 2019	126.0	5.2	127.7	4
October 18, 2019	70.8	10.5	97.0	23
October 27, 2019	196.0	7.5	89.0	23
June 27, 2020	107.3	5.8	92.6	14

Table 3.2-6 Highest First High PM_{10} Background Values by Month*

Month	2018 PM_{10} H1H Background Value (µg/m³)	2019 PM_{10} H1H Background Value (µg/m³)	2020 PM_{10} H1H Background Value (µg/m³)	Average PM_{10} H1H Background Value (µg/m³)	Average PM_{10} H1H Background Value to nearest ten (µg/m³)
January	17.3	8.8	6.2	10.8	10
February	15.0	7.8	6.6	9.8	10
March	8.2	15.4	12.5	12.0	10
April	53.4	69.1	12,8	45.1	50
May	41.4	43.0	41.4	41.9	40
June	48.6	24.3	59.1	44.0	40
July	16.1	38.8	31.5	28.8	30
August	22.8	12.5	28.8	21.4	20
September	23.1	37.8	8.8	23.2	20
October	34.7	27.6	35.0	32.4	30
November	13.7	17.3	5.3	12.1	10
December	18.6	12.3	15.0	15.3	20

3.2.7 Receptors

An ambient air boundary and receptor grid was developed to assess near-field impacts for each modeling scenario. Each scenario required different ambient air boundaries and receptors based on the actives occurring with each scenario. In particular, the access to pads during construction activities uses ice roads in a different location than the gravel road that is used once the pads are constructed and operational. In general, the approach for developing ambient boundaries for Willow MDP are:

- Drill sites and other pads (Willow Processing Facility (WPF), Willow Operations Centers (WOC), airstrip) use the edge of the gravel pad.
- The mine uses the mine edge in combination with the surrounding ice pads.
- Roads use 1-plume width from either side of the center line of the road, following the approach for GMT2 (Kleinfelder and Ramboll Environ, 2017b).

Receptors were placed around the ambient air boundaries using the following spacing:

- 10 meter spacing along the ambient air boundary
- 25 meter spacing from the ambient air boundary to 100 meters
- 100 meter spacing from 100m to 1km
- 250 meter spacing from 1 km to 2 km
- 500 meter spacing from 2 km to 5 km
- 1,000 meter spacing from 5 km to 50 km

All receptors were in the UTM NAD83 Zone 5N coordinate system.

Receptors along the access road section were placed at the spacing noted above; however, receptors were at a minimum distance of one volume source width from the road volume sources due to model instabilities when the receptors are placed too close to volume sources. It should be noted that while roads exist throughout the development, road emissions were evaluated within 100 meters of the pads where proximity to other sources would have the maximum impact.

To capture cumulative source impacts that may interact with the Willow MDP impacts, the receptors with a grid spacing of 1,000 meters extended up to 50km from the center of the Project area. Because the intent was not to specifically analyze individual non-Willow source impacts, but rather any interaction of the cumulative sources with Willow MDP impacts, the coarse grid receptors were not placed closer than 200 meters to any cumulative source. An additional discrete modeling receptor was placed at Nuiqsut to characterize impacts to sensitive receptors for both criteria pollutant impacts and the six selected HAPs.

The area surrounding the proposed Willow MDP drill sites and infrastructure pads (including WPF) is generally flat on a local scale, with the terrain sloping downward generally to the north. There are not any prominent elevation features surrounding the proposed Willow MDP. The proposed WOC would be at the highest elevation when compared to the cumulative sources and the town of Nuiqsut with the greatest elevation difference being roughly 26 m between the proposed WOC and the lowest cumulative source, which would be approximately 35 km away. Because of the relatively small elevation difference over this large distance, flat terrain was assumed for all receptors and cumulative source elevations.

All emissions sources have a base elevation value established based on the location of the gravel pad or road and the estimated gravel thickness of that pad or road as documented in the Willow MDP Environmental Effect Document (CPAI 2019).

3.3 Alternative B (Proponent's Project)

This section describes the selection of scenarios designed to characterize the potential impacts anticipated under Alternative B, the modeled receptors, source types, emissions, and resulting impacts.

3.3.1 Overview of Scenarios

Based on Alternative B emissions activities, source types, and development phases, five scenarios are analyzed:

1. Construction
2. Pre-drilling activities at Bear Tooth (BT)1
3. Pre-drilling activities at BT1 and BT2
4. Development drilling
5. Routine Operations

All scenarios include emissions of criteria pollutants, HAPs and GHGs. As shown in Section 2.1 "Willow Alternatives Emissions Inventories", HAPs from construction and drilling activities are substantially lower than routine operations. Therefore, HAP impacts are explicitly modeled for Routine Operations only and HAP impacts from all other scenarios would be lower than Routine Operations.

Modeled sources include point source emissions, area sources, and volume sources. Equipment modeled as point sources include stationary sources, such as engines, heaters and flares, as well as large portable equipment and nonroad engines. Groupings of similar low-level equipment were generally aggregated as area sources. Fugitive dust and mobile sources tailpipe emissions were modeled as volume sources. For example, the gravel access road was modeled as a series of volume sources to represent dust or tailpipe emissions from vehicle traffic. Point source stack parameters were provided by CPAI for most stationary sources, including flares. For those sources without stack parameter information, stack parameters are selected to be consistent with stack parameters used for modeling GMT2 or other public information. For area and volume sources release heights, initial vertical dimensions, and initial horizontal dimensions were based on the equipment as well as Table 3-2 from the AERMOD User's Guide (USEPA, 2019).

Based on AERMOD/ISCST guidance for modeling (USEPA 2019), road segment volume source dimensions are based on the road width and placed along the road segments at calculated spacing intervals. Therefore, volume source dimensions and spacing are calculated as follows:

- For gravel haul roads 24 feet (7.32 m) wide, volume sources are spaced 14.63 meters (48 feet) apart, use a sigma-y of 6.80 m (14.63/2.15) and exclude receptors along 15 meters on each side of the road. For gravel haul roads 32 feet (9.75 m) wide volume sources are spaced 19.51 meters (64 feet) apart, use a sigma-y of 9.07 m (19.51/2.15), and exclude receptors along 20 meters on each side of the road.

- For the gravel haul ice roads 50 feet (15.24 m) wide, volume sources are spaced 30.48 meters apart, use a sigma-y of 14.18 m (30.48/2.15) and exclude receptors within 30 meters on each side of the road.
- For the module delivery ice roads 60 feet (18.29 m) wide, volume sources are spaced 36.58 meters apart, use a sigma-y of 17.01 m (36.58/2.15) and exclude receptors within 35 meters on each side of the road.

See Attachment A for detailed information about the sources included in each scenario. All sources modeled for each scenario are shown in figures in Attachment A depicting the layout of the sources relative to ambient air boundaries, structures, roads, and other Project features. In addition, Attachment A includes detailed tables that provide a description of each modeled source, source emissions rates for all modeled pollutants and averaging periods, in-stack NO_2-to-NOx ratio, modeled location, and stack parameters.

3.3.1.1 Construction

The construction of Willow MDP is on a ten-year schedule beginning late in Year 0 and completing in Year 9. This ten-year period will include construction of five drill sites, processing facility, Willow Operations Center, airstrip, gravel access roads, pipelines, communications facilities, living quarters and other infrastructure to support long-term operations. In addition, construction and cooperation of temporary facilities including a gravel mine, seasonal ice roads, single-season and multi-season ice pads, and temporary camp facilities for worker housing to support construction activities are proposed in the Willow MDP. Two mine sites within the Tiŋmiaqsiuġvik Area (located about 20 miles from the Willow Operations Center) are proposed to supply the gravel needed to construct the Willow Development. The gravel mines would be accessed seasonally via ice road and the mine pit would be opened during winter construction seasons to support construction of the drill sites, the WPF, Willow Operations Center, MTI, airstrip, and associated roads.

As shown in Section 2.1 “Willow Alternatives Emissions Inventories”, the annual criteria pollutant emissions totals during construction phases are expected to peak during Year 4 when emissions activities occur during construction of WPF, Willow Operation Center, BT1 drill site, BT2 drill site, BT3 drill site along with installation of major pipeline and roads/bridges. Therefore, emissions activities occurring in Year 4 are modeled for the Alternative B construction scenario. In Year 4, BT4 and BT5 are not yet under construction so those drill sites are not included in the construction scenario. Although Alternative B could be authorized with either Module Delivery Option, emissions activities involving module delivery requiring trucking trips through Project areas are independent of the module delivery Option selected and are thus included as part of the construction scenario.

3.3.1.2 BT1 Pre-drill

Willow MDP is proposing to construct 251 wells at the five proposed drill sites (BT1 – BT5). It is estimated that it will take approximately 15-30 days to drill each well and drill all wells consecutively beginning in Year 4 at the BT1 drill site. While drilling operations are anticipated to be conducted predominantly with drill rigs operating on highline supplied electrical power, highline power would not be available during BT1 construction and initial drilling until the WPF is fully operational. Therefore, two diesel-fired drill rigs, hydraulic fracturing units, and associated ancillary support equipment two drill rigs will operate at BT1 until highline power is available. In addition, until the infrastructure is in place to handle gas from flowbacks, any gas will be routed to a portable flare located at the drill site. Drilling activities may include emissions from the operation of the drill rig engine, rig boiler, and associated drilling equipment. Drilling and hydraulic fracturing activities could occur at a single drill site concurrently. Hydraulic fracturing activities includes emissions from hydraulic fracturing units, including hydraulic fracturing performed to increase fluid movement from the rock into the well bore, and vehicle emissions.

3.3.1.3 BT1 and BT2 Pre-drill

BT1 and BT2 Pre-drill scenario is similar to BT1 Pre-drill scenario with the exception that a single diesel-fired drill rig and hydraulic fracturing equipment operate at both BT1 and BT2 pads concurrently.

3.3.1.4 Development Drilling

Starting in Year 6 drilling and hydraulic fracturing equipment would operate on highline power.
The Development Drilling scenario is designed to assess potential peak short-term and annual air quality impacts from drilling and hydraulic fracturing operations occurring at the same time as localized construction and operational activities throughout the rest of the Project area. This modeling scenario is based on electric drill rigs and hydraulic fracturing units operating concurrently at BT2 and BT3 as these well sites are in closest proximity to each other spatially and are likely to be drilled concurrently based on the drilling schedule in the Environmental Evaluation Document (Revision No. 3): Willow Master Development Plan (CPAI 2019). Modeled activities would be similar to the Routine Operation scenario with the addition of drilling activities conducted with electric drill rigs and hydraulic fracturing units at BT2 and BT3 and construction activities occurring at BT2 and BT3. Portable flares would be used at BT2 and BT3 to handle gas from flowbacks, and low pressure and high pressure flares would be operational at the WPF. Since drilling would be complete by 2029 in Alternative B, impacts from Development Drilling would not occur after Year 9.

3.3.1.5 Routine operation and production of wells

Routine operation and production emissions include well pad production equipment; product storage, transfer, and transport; product processing and disposal facilities; as well as vehicle traffic for routine inspection and maintenance. Low pressure and high pressure flares would be operational at the WPF. These types of activities are associated with the planned production and processing of oil, gas, and produced water. The annual criteria pollutant emissions for production and operations will steadily increase and reach the highest starting in Year 2030 as shown in Section 2.1 “Willow Alternatives Emissions Inventories”. During production operations, produced water and oil from wells would be stored in tanks on processing facilities. The Routine Operation scenario also explicitly models emissions from other projects anticipated to be developed within the near-field of the Willow MDP Project as shown in Table 2.2-2 to assess expected cumulative long-term impacts.

3.3.2 <u>Construction</u>

3.3.2.1 Receptors and Source Configurations

See Attachment A for detailed information regarding the modeled sources, emission rates, locations, and in-stack NO_2-to-NOx ratios.

The ambient air boundaries and receptors (consistent with Section 3.2.7 “Receptors”) are shown in in Attachment E.

3.3.2.2 Emissions Calculations

Emission rates for all modeled sources are provided in Attachment A. Emission rates used in the model were based on maximum hourly or average annual emissions depending on the ambient air threshold for the pollutant of interest. For example, 1-hour NO_2 was modeled using maximum hourly potential emissions as calculated in the approved emissions inventory. Most emission sources were assumed to operate 24 hours per day, 7 days per week, and 52 weeks per year unless the emissions inventory includes information indicating a shorter period of operation. Fugitive dust emissions are estimated for months from May through October, consistent with the months for which fugitive dust emissions were estimated in the BOEM Arctic modeling study (Fields Simms et al 2018, Stoeckenius et al 2017). Fugitive dust may also occur in other months, especially during dry snowless conditions and from dry and frozen roads. Thus, fugitive dust emissions outside May through October may affect air concentrations of particulate matter, but likely to a smaller extent than fugitive dust emitted during May through October when there is much less (or no) snow cover. Likewise, some operations would only be expected to occur during daytime hours. Appropriate adjustments to the gram (g) per second emission rates were made for sources that do not operate continuously. Emission rates for activities that operate exclusively during specific periods were “turned on” and “turned off” to match the expected seasonality as appropriate. Annual emissions for sources that do not occur year-round were “annualized” to the period that the model is turned on. For example, if a source in the model is turned on for 4,380 hours per year, the source’s annual emissions will be converted to gram per second by using 4,380 hours per year.

In general, for nonroad equipment operating during construction a category specific utilization factor was applied to approximate the fraction of the nonroad equipment that would be operating simultaneously at a given time. The utilization factor accounts for the fact that not all the equipment operates simultaneously within the same hour. The factor is derived using average operating hours of equipment spread over a 24 hours period. The factor is calculated as the fleet-wide average of fractional hours of operation per day and applied hourly emissions. This utilization factor is not applied to all nonroad sources that are treated as point sources including heaters, off-highway-trucks (B-70s), air compressors, generator sets, pumps, and bore/drill rigs unless explicitly stated below.

BT1 Facilities Installation, Pipeline Installation, and Vertical Support Member Construction Nonroad Equipment – Individual hourly emission and annual rates are calculated using the general approach outlined above and by applying its respective nonroad utilization factor to hourly emissions. A category-wide emission rate is then calculated for hourly and annual emissions by summing emission rates of all nonroad equipment not treated explicitly as point sources across its respective category.

BT2 and BT3 Pad Construction Nonroad Equipment – Hourly and annual emission rates are initially calculated using the general approach outlined above. Monthly emission factors are then applied to annual emission rates to allocate emissions to each month of the year based on based on the level of pad construction activity occurring during that month. For all sources not treated explicitly as point sources a utilization factor is applied to hourly emission rates. A category-wide emission rate is then calculated for hourly and annual emissions by summing these individual nonroad equipment emission rates in its respective category.

Gravel Mining Nonroad Equipment - Individual hourly emission and annual rates are calculated using the general approach outlined above and by applying the respective nonroad utilization factor to hourly emissions. A category-wide emission rate is then calculated for hourly and annual emissions by summing emission rates of all nonroad equipment not treated explicitly as point sources across its respective category. These hourly and annual emission rates are then split into nine (9) equivalent volume sources.

Ice Road Construction Nonroad Equipment – Individual hourly and annual emissions rates are calculated using the general approach outlined above. The equipment needed by Willow is scaled up or down from equipment needed by GMT1 based on the ratio of annual ice road needed to be constructed annually in Willow vs ice road constructed in GMT1 based on ice road mileage needed in Willow. Thus, a Willow/GMT1 annual activity scaling factor based on the ice road constructed annually to ice road constructed in GMT1 is applied to account for fluctuations in annual activity. For all sources not treated explicitly as point sources a utilization factor is applied to hourly emission rates. A category-wide emission rate is then calculated for hourly and annual emissions by summing these individual nonroad equipment emission rates in its respective category. These nonroad emissions are then scaled based on the ratio of total length of the ice road within the modeling domain to the total ice road length constructed in 2024 and split into four (4) equivalent volume sources.

Single Season Ice Pad Construction Nonroad Equipment – Individual hourly and annual emissions rates are calculated using the general approach outlined above. A Willow/GMT1 annual activity scaling factor based on the ice pad constructed annually to ice pad constructed in GMT1 is then applied to account for the fluctuations in annual activity. For all sources not treated explicitly as point sources a utilization factor is applied to hourly emission rates. A category-wide emission rate is then calculated for hourly and annual emissions by summing these individual nonroad equipment emission rates in its respective category. These nonroad emissions are then placed on six different locations within the ice pad scaled based on the ratio of total acreage of the ice pad within the modeling domain to the total ice pad acreage constructed in 2024 and split into the. The locations are broken down as follows:

- Housing Construction Equipment at the mine – 1 equivalent volume sources
- Organic Stockpile at the mine – 44 volume sources
- Inorganic Stockpile at the mine – 44 equivalent volume sources
- Ice Pad Perimeter at the mine – 44 equivalent volume sources
- HDD Pad #1 – 1 volume source
- HDD Pad #2 – 1 volume sources

Multi-Season Ice Pad Construction Nonroad Equipment – Individual hourly and annual emissions rates are calculated using the general approach outlined above. A Willow/GMT1 annual activity scaling factor based on the ice pad constructed annually to ice pad constructed in GMT1 is then applied to account for the fluctuations in annual activity. For all sources not treated explicitly as point sources a utilization factor is applied to hourly emission rates. A category-wide emission rate is then calculated for hourly and annual emissions by summing these individual nonroad equipment emission rates in its respective category. All sources associated with multi-season ice pad construction are conservatively assumed to operate at the mine site, WOC, and GMT2 multi-season ice pads.

Willow and Alpine Airstrip Aircraft Activity – Hourly and annual emission rates are calculated by extracting takeoff and landing emission factors for each aircraft type. Emission factors for each aircraft type are then multiplied by the number of flights for each aircraft type in the model year, 2024. Since each flight constitutes one takeoff and one landing the takeoff and landing emission rates are summed across their respective aircraft type. The total aircraft emission rates are then calculated by summing across the aircraft types and converted to g/s. The total emission rates are split into three separate areas, based on release height, and divided by the respective airstrip area.

Blasting Emissions – Hourly emission rates are calculated using the emission rate extracted from the emissions inventory. Emission rates in lbs/day are divided by the number of hours in a day and converted to g/s to get hourly emission rates. Annual emission rates are then calculated using the same method as the general approach outlined above using weeks of operation instead of hours of operation. Short-term blasting is modeled using hourly emission rates while long-term blasting is modeled using annual emission rates.

Willow Operations Center Temporary Power Generation Turbine – Hourly and annual emission rates are calculated using the general approach outlined above. Monthly emission factors are applied to hourly and annual emission rates to account for fluctuations in emission rates. Monthly fluctuations in emission rates are caused by variations in ambient temperatures affecting the air density which affects fuel capacity into the turbine at full load.

Willow Operations Center and WPF Facilities Installation Nonroad Equipment – Individual hourly emission and annual rates are calculated using the general approach outlined above and by applying its respective nonroad utilization factor to hourly emissions. A category-wide emission rate is then calculated for hourly and annual emissions by summing emission rates of all nonroad equipment not treated explicitly as point sources across its respective category. Monthly emission factors are then applied to annual emission rates to allocate emissions to each month of the year based on based on the level of facilities installation activity occurring during that month.

Mobile Tailpipe Emissions – Hourly and annual emission rates are calculated by extracting the running and idling emission factors for each vehicle type. Running emission factors are then multiplied by annual mileage travelled for each vehicle type to get the total running emissions per year. Idling emission factors are multiplied by the total idling hours per year to get total idling emissions per year. Emissions are then converted into g/s by assuming operation through all hours of the operating months. Hourly and annual emission rates are then scaled within their “respective modeling area” by applying the ratio of the one-way trip mileage within in the modeling domain to the total mileage per one-way trip. The “respective modeling area” here and below refers to the pad or drill site activity with which the emissions are associated in the modeling. Running and idling emission rates are summed across all vehicle types for their respective modeling area and split in the following manner:

- BT1-3 – 4 equivalent volume sources
- Willow Operations Center – 4 equivalent volume sources
- WPF – 4 equivalent volumes sources
- Gravel Mine – 4 equivalent volume sources

Mobile Equipment Fugitive Dust – Hourly and annul emission rates are calculated by extracting the fugitive dust emission factors for each vehicle type. Fugitive dust emission factors are then multiplied by annual vehicle miles travelled to get total fugitive dust emissions per year and converted to g/s by assuming operation through all hours of the operating months. Hourly and annual emission rates are then scaled within their respective modeling area by applying the ratio of the one-way trip mileage within in the modeling domain to the total mileage per one-way trip. Fugitive dust emission rates are summed across all vehicle types for their respective modeling area and split in the same manner as their tailpipe equivalent.

Gravel Road Construction, Pipeline Installation, Vertical Member Support Construction, and Fiber Optics Installation Nonroad Equipment – Individual hourly emission and annual rates are calculated using the general approach outlined above. and by applying its respective nonroad utilization factor to hourly emissions. A category-wide emission rate is then calculated for hourly and annual emissions by summing emission rates of all nonroad equipment not treated explicitly as point sources across its respective category. These hourly and annual emission rates are then scaled within their respective modeling area by applying the ratio of the segment road length within the modeling domain to the total road length constructed in 2024. Hourly and annual emissions rates are then split into four equivalent volume sources. Gravel road construction is assumed to be occurring at BT2 and BT3.

Bridge Installation Nonroad Equipment - Individual hourly emission and annual rates are calculated using the general approach outlined above. and by applying its respective nonroad utilization factor to hourly emissions. A category-wide emission rate is then calculated for hourly and annual emissions by summing emission rates of all nonroad equipment not treated explicitly as point sources across its respective category. Hourly and annual emission rates for all sources associated with bridge installation are then divided by the number of bridges based on the assumption only one bridge is being installed at any moment.

Willow Operations Center Snowmelters and Portable Heaters – Hourly and annual emissions are calculated using the general approach outlined above. Emissions are then summed and treated as a single volume source.

Off-Highway Trucks (B-70s) – Individual hourly emission and annual rates are calculated using the general approach outlined above. Emission rates are then scaled down to a per unit basis. Two B-70 trucks are then placed on BT2, BT3, the gravel mine, and the gravel road split into 4 equivalent volume sources for the pads and 9 equivalent volume sources for the mine. The B-70s along the gravel road are scaled based on the ratio road length in the modeling domain to total road length constructed in Year 4 and split into 4 equivalent volume sources along the gravel road segment along BT2 and the road segment along BT3.

3.3.2.3 Criteria Pollutant Impacts

Table 3.3-1 shows the modeled impacts to air quality everywhere in the model domain and Table 3.3-2 shows the model impacts at Nuiqsut. Representative background concentrations are added to model results prior to comparing the total concentration to applicable AAQS. As shown, impacts would be below applicable AAQS for all criteria pollutants and averaging periods.

Table 3.3-1 Construction Activity AAQS Impacts – Alternative B (Proponent's Project)*

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	526.4	10,300.5	10,826.9	40,000	40,000	27%	27%
	8-Hour	390.0	3,433.5	3,823.5	10,000	10,000	38%	38%
NO_2	1-Hour	111.4	22.4	133.8	188	188	71%	71%
	Annual	17.0	3.8	20.8	100	100	21%	21%
SO_2	1-Hour	3.6	9.0	12.6	196	196	6%	6%
	3-Hour	5.2	10.0	15.2	1,300	1,300	1%	1%
	24-Hour	1.2	9.3	10.6	--	365	--	3%
	Annual	0.1	1.8	1.9	--	80	--	2%
PM_{10}	24-Hour	61.9	30.0	91.9	150	150	61%	61%
$PM_{2.5}$	24-Hour	11.6	7.0	18.6	35	35	53%	53%
	Annual	2.6	1.6	4.2	12	12	35%	35%

Notes:
Modeled highest second-high values from 5 modeled years shown for all short-term averaging times, with the exception of the following:
NO_2 1-hour value is calculated as the 3-year average of the 8th highest daily maximum 1-hour concentrations, and the background value shown is the average of the 1-hour values that are paired in time with the modeled values;
SO_2 1-hour value is calculated as the 3-year average of the 4th highest daily maximum 1-hour concentrations;
PM_{10} 24-hour value is the 6th highest value from 5-year modeling period; and
$PM_{2.5}$ 24-hour value is calculated as the 3-year average of the 8th highest values.
Maximum annual values are shown for NO_2 and SO_2 and the $PM_{2.5}$ annual value is the annual mean averaged over the maximum 3 years.
PM_{10} and $PM_{2.5}$ 24-hour, and $PM_{2.5}$ annual modeled impacts include secondary $PM_{2.5}$ impacts (0.48 µg/m³ - 24-hour and 0.05 µg/m³ - annual) from CAMx modeling.

Table 3.3-2 Construction Activity AAQS Impacts at Nuiqsut – Alternative B (Proponent's Project)*

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	45.1	10,300.5	10,345.7	40,000	40,000	26%	26%
	8-Hour	15.2	3,433.5	3,448.7	10,000	10,000	34%	34%
NO_2	1-Hour	31.4	18.0	49.4	188	188	26%	26%
	Annual	0.4	3.8	4.2	100	100	4%	4%
SO_2	1-Hour	0.7	9.0	9.7	196	196	5%	5%
	3-Hour	0.5	10.0	10.5	1,300	1,300	1%	1%
	24-Hour	0.1	9.3	9.4	--	365	--	3%
	Annual	0.002	1.8	1.8	--	80	--	2%

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
PM_{10}	24-Hour	1.0	50.0	51.0	150	150	34%	34%
$PM_{2.5}$	24-Hour	0.75	7.0	7.7	35	35	22%	22%
	Annual	0.074	1.6	1.7	12	12	14%	14%

Notes:
Modeled highest second-high values from 5 modeled years shown for all short-term averaging times, with the exception of the following:
NO_2 1-hour value is calculated as the 3-year average of the 8th highest daily maximum 1-hour concentrations, and the background value shown is the average of the 1-hour values that are paired in time with the modeled values;
SO_2 1-hour value is calculated as the 3-year average of the 4th highest daily maximum 1-hour concentrations;
PM_{10} 24-hour value is the 6th highest value from 5-year modeling period; and
$PM_{2.5}$ 24-hour value is calculated as the 3-year average of the 8th highest values.
Maximum annual values are shown for NO_2 and SO_2 and the $PM_{2.5}$ annual value is the annual mean averaged over the maximum 3 years.
PM_{10} and $PM_{2.5}$ 24-hour, and $PM_{2.5}$ annual modeled impacts include secondary $PM_{2.5}$ impacts (0.48 µg/m³ - 24-hour and 0.05 µg/m³ - annual) from CAMx modeling.

3.3.3 BT1 Pre-Drill

3.3.3.1 Receptors and Source Configurations

See Attachment A for detailed information regarding the modeled sources, emission rates, locations, and in-stack NO_2-to-NOx ratios.

See Attachment E for the ambient air boundaries and receptors.

3.3.3.2 Emissions Calculations

Emission rates for all modeled sources are provided in Attachment A.

Mobile Tailpipe Emissions - Hourly and annual emission rates are calculated by extracting the running emission factors. Running emission factors are then multiplied by annual mileage travelled for each vehicle type to get the total running emissions per year. Emissions are then converted into g/s by assuming operation through all hours of the operating months. Hourly and annual emission rates are then scaled within their respective modeling area by applying the ratio of the one-way trip mileage within in the modeling domain to the total mileage per one-way trip. Running emission rates are summed across all vehicle types for their respective modeling area and split into nine (9) equal volume sources at its respective modeling domain.

Mobile Equipment Fugitive Dust – Hourly and annul emission rates are calculated by extracting the fugitive dust emission factors for each vehicle type. Fugitive dust emission factors are then multiplied annual vehicle miles travelled to get total fugitive dust emissions per year and converted to g/s by assuming operation through all hours of the operating months. Hourly and annual emission rates are then scaled within their respective modeling area by applying the ratio of the one-way trip mileage within in the modeling domain to the total mileage per one-way trip. Mobile fugitive dust emissions are then split into volume sources equivalent to mobile tailpipe.

Snowmelters and Portable Heaters – Hourly and annual emissions are calculated using the general approach outlined above. Emissions are then summed and treated as a single volume source. Monthly emission factors are then applied. No operation is assumed during summer months (June-August).

Drill Rigs and Drilling Support Equipment – Hourly and annual emissions are calculated using the general approach outlined above and two drill rigs are active at BT1 during Pre-Drill.

Hydraulic Fracturing Engines – Hourly emission rates are calculated by extracting from the emission inventory. Hourly emission rates are then halved under the assumption fracturing engines will operate at 50% load for sixteen hours instead of 100% load for eight hours for 120 days per year. Annual emission rates are then calculated by smearing hourly emissions over the entire year based on a sixteen hour work day. Hourly emission factors are then applied to annual emissions to allocated emissions during operational hours (5 am – 9 pm). Hourly emission factors are calculated in consideration of two concurrent drill rigs active at BT1 during Pre-Drill.

Well Flowback and Flaring – Hourly and annual emissions are calculated using the general approach outlined above and two drill rigs are active at BT1 during Pre-Drill.

3.3.3.3 Criteria Pollutant Impacts

Table 3.3-3 shows the modeled impacts to air quality everywhere in the model domain and Table 3.3-4 shows the model impacts at Nuiqsut. Representative background concentrations are added to model results prior to comparing the total concentration to applicable AAQS. As shown, impacts would be below applicable AAQS for all criteria pollutants and averaging periods. Note that impacts from drill site flaring are included in the modeling analysis and the contribution from flare emissions to the maximum concentrations shown in Table 3.3-3 and Table 3.3-4 is minimal.

Table 3.3-3 BT1 Pre-Drill Activity AAQS Impacts – Alternative B (Proponent's Project)*

Pollutant	Averaging Time	Maximum Modeled Concentration (μg/m³)	Background Concentration (μg/m³)	Total Concentration (μg/m³)	NAAQS (μg/m³)	AAAQS (μg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	1,483.3	10,300.5	11,783.8	40,000	40,000	29%	29%
	8-Hour	1,103.9	3,433.5	4,537.4	10,000	10,000	45%	45%
NO_2	1-Hour	64.3	26.7	91.0	188	188	48%	48%
	Annual	10.8	3.8	14.6	100	100	15%	15%
SO_2	1-Hour	4.2	9.0	13.1	196	196	7%	7%
	3-Hour	3.6	10.0	13.6	1,300	1,300	1%	1%
	24-Hour	2.0	9.3	11.4	--	365	--	3%
	Annual	0.2	1.8	2.0	--	80	--	3%
PM_{10}	24-Hour	16.7	20.0	36.7	150	150	24%	24%

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
$PM_{2.5}$	24-Hour	10.0	7.0	17.0	35	35	49%	49%
	Annual	2.0	1.6	3.6	12	12	30%	30%

Notes:
Modeled highest second-high values from 5 modeled years shown for all short-term averaging times, with the exception of the following:
NO_2 1-hour value is calculated as the 3-year average of the 8th highest daily maximum 1-hour concentrations, and the background value shown is the average of the 1-hour values that are paired in time with the modeled values;
SO_2 1-hour value is calculated as the 3-year average of the 4th highest daily maximum 1-hour concentrations;
PM_{10} 24-hour value is the 6th highest value from 5-year modeling period; and
$PM_{2.5}$ 24-hour value is calculated as the 3-year average of the 8th highest values.
Maximum annual values are shown for NO_2 and SO_2 and the $PM_{2.5}$ annual value is the annual mean averaged over the maximum 3 years.
PM_{10} and $PM_{2.5}$ 24-hour, and $PM_{2.5}$ annual modeled impacts include secondary $PM_{2.5}$ impacts (0.48 µg/m³ - 24-hour and 0.05 µg/m³ - annual) from CAMx modeling.

Table 3.3-4 BT1 Pre-Drill Activity AAQS Impacts at Nuiqsut – Alternative B (Proponent's Project)*

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	26.1	10,300.5	10,326.6	40,000	40,000	26%	26%
	8-Hour	3.4	3,433.5	3,436.9	10,000	10,000	34%	34%
NO_2	1-Hour	3.3	27.9	31.2	188	188	17%	17%
	Annual	0.02	3.8	3.8	100	100	4%	4%
SO_2	1-Hour	0.07	9.0	9.1	196	196	5%	5%
	3-Hour	0.04	10.0	10.1	1,300	1,300	1%	1%
	24-Hour	0.006	9.3	9.3	--	365	--	3%
	Annual	1.4E-04	1.8	1.8	--	80	--	2%
PM_{10}	24-Hour	0.51	10	11	150	150	7%	7%
$PM_{2.5}$	24-Hour	0.49	7.0	7.5	35	35	21%	21%
	Annual	0.05	1.6	1.6	12	12	14%	14%

Notes:
Modeled highest second-high values from 5 modeled years shown for all short-term averaging times, with the exception of the following:
NO_2 1-hour value is calculated as the 3-year average of the 8th highest daily maximum 1-hour concentrations, and the background value shown is the average of the 1-hour values that are paired in time with the modeled values;
SO_2 1-hour value is calculated as the 3-year average of the 4th highest daily maximum 1-hour concentrations;
PM_{10} 24-hour value is the 6th highest value from 5-year modeling period; and
$PM_{2.5}$ 24-hour value is calculated as the 3-year average of the 8th highest values.
Maximum annual values are shown for NO_2 and SO_2 and the $PM_{2.5}$ annual value is the annual mean averaged over the maximum 3 years.
PM_{10} and $PM_{2.5}$ 24-hour, and $PM_{2.5}$ annual modeled impacts include secondary $PM_{2.5}$ impacts (0.48 µg/m³ - 24-hour and 0.05 µg/m³ - annual) from CAMx modeling.

3.3.4 BT1 and BT2 Pre-Drill

Pre-drilling at BT1 and BT2 pads is similar to the pre-drilling activities planned for BT1.

3.3.4.1 Receptors and Source Configurations

See Attachment A for detailed information regarding the modeled sources, emission rates, locations, and in-stack NO_2-to-NOx ratios.

See Attachment E for the ambient air boundaries and receptors.

3.3.4.2 Emissions Calculations

Emission rates for all modeled sources are provided in Attachment A.

Mobile Tailpipe Emissions - Hourly and annual emission rates are calculated by extracting the running emission factors. Running emission factors are then multiplied by annual mileage travelled for each vehicle type to get the total running emissions per year. Emissions are then converted into g/s by assuming operation through all hours of the operating months. Hourly and annual emission rates are then scaled within their respective modeling area by applying the ratio of the one-way trip mileage within in the modeling domain to the total mileage per one-way trip. Running emission rates are summed across all vehicle types for their respective modeling area and split into nine (9) equal volume sources at BT1 and six (6) at BT2.

Mobile Equipment Fugitive Dust – Hourly and annul emission rates are calculated by extracting the fugitive dust emission factors for each vehicle type. Fugitive dust emission factors are then multiplied annual vehicle miles travelled to get total fugitive dust emissions per year and converted to g/s by assuming operation through all hours of the operating months. Hourly and annual emission rates are then scaled within their respective modeling area by applying the ratio of the one-way trip mileage within in the modeling domain to the total mileage per one-way trip. Mobile fugitive dust emissions are then split into volume sources equivalent to mobile tailpipe.

Snowmelters and Portable Heaters – Hourly and annual emissions are calculated using the general approach outlined above. Emissions are then summed and treated as a single volume source. Monthly emission factors are then applied. No operation is assumed during summer months (June-August).

Hydraulic Fracturing Engines – Hourly emission rates are calculated by extracting from the emission inventory. Hourly emission rates are then halved under the assumption fracturing engines will operate at 50% load for sixteen hours instead of 100% load for eight hours for 120 days per year. Annual emission rates are then calculated by smearing hourly emissions over the entire year based on a sixteen-hour day. Hourly emission factors are then applied to annual emissions to allocated emissions during operational hours (5 am – 9 pm).

3.3.4.3 Criteria Pollutant Impacts

Table 3.3-5 shows the modeled impacts to air quality everywhere in the model domain and Table 3.3-6 shows the model impacts at Nuiqsut. Representative background concentrations are added to model results prior to comparing the total concentration to applicable AAQS. As shown, impacts would be below applicable AAQS for all criteria pollutants and averaging periods. Note that impacts from flaring are included in the modeling analysis and the contribution from drill site flare emissions to the maximum concentrations shown in Table 3.3-5 and Table 3.3-6 is minimal.

Table 3.3-5 BT1 and BT2 Pre-Drill Activity AAQS Impacts – Alternative B (Proponent's Project)*

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	833.2	10,300.5	11,133.8	40,000	40,000	28%	28%
	8-Hour	641.0	3,433.5	4,074.5	10,000	10,000	41%	41%
NO_2	1-Hour	55.8	26.6	82.4	188	188	44%	44%
	Annual	6.7	3.8	10.4	100	100	10%	10%
SO_2	1-Hour	3.1	9.0	12.1	196	196	6%	6%
	3-Hour	2.8	10.0	12.8	1,300	1,300	1%	1%
	24-Hour	1.3	9.3	10.6	--	365	--	3%
	Annual	0.1	1.8	1.9	--	80	--	2%
PM_{10}	24-Hour	17.1	40.0	57.1	150	150	38%	38%
$PM_{2.5}$	24-Hour	7.5	7.0	14.5	35	35	41%	41%
	Annual	0.9	1.6	2.5	12	12	21%	21%

Notes:

Modeled highest second-high values from 5 modeled years shown for all short-term averaging times, with the exception of the following:

NO_2 1-hour value is calculated as the 3-year average of the 8th highest daily maximum 1-hour concentrations, and the background value shown is the average of the 1-hour values that are paired in time with the modeled values;

SO_2 1-hour value is calculated as the 3-year average of the 4th highest daily maximum 1-hour concentrations;

PM_{10} 24-hour value is the 6th highest value from 5-year modeling period; and

$PM_{2.5}$ 24-hour value is calculated as the 3-year average of the 8th highest values.

Maximum annual values are shown for NO_2 and SO_2 and the $PM_{2.5}$ annual value is the annual mean averaged over the maximum 3 years.

PM_{10} and $PM_{2.5}$ 24-hour, and $PM_{2.5}$ annual modeled impacts include secondary $PM_{2.5}$ impacts (0.48 µg/m³ - 24-hour and 0.05 µg/m³ - annual) from CAMx modeling.

Table 3.3-6 BT1 and BT2 Pre-Drill Activity AAQS Impacts at Nuiqsut – Alternative B (Proponent's Project)*

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	17.7	10,300.5	10,318.2	40,000	40,000	26%	26%
	8-Hour	3.7	3,433.5	3,437.2	10,000	10,000	34%	34%
NO_2	1-Hour	2.4	18.9	21.4	188	188	11%	11%
	Annual	0.02	3.8	3.8	100	100	4%	4%
SO_2	1-Hour	0.05	9.0	9.0	196	196	5%	5%
	3-Hour	0.03	10.0	10.1	1,300	1,300	1%	1%
	24-Hour	0.006	9.3	9.3	--	365	--	3%
	Annual	0.0001	1.8	1.8	--	80	--	2%

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
PM_{10}	24-Hour	0.50	10.0	10.5	150	150	7%	7%
$PM_{2.5}$	24-Hour	0.49	7.0	7.5	35	35	21%	21%
	Annual	0.05	1.6	1.6	12	12	14%	14%

Notes:
Modeled highest second-high values from 5 modeled years shown for all short-term averaging times, with the exception of the following:
NO_2 1-hour value is calculated as the 3-year average of the 8th highest daily maximum 1-hour concentrations, and the background value shown is the average of the 1-hour values that are paired in time with the modeled values;
SO_2 1-hour value is calculated as the 3-year average of the 4th highest daily maximum 1-hour concentrations;
PM_{10} 24-hour value is the 6th highest value from 5-year modeling period; and
$PM_{2.5}$ 24-hour value is calculated as the 3-year average of the 8th highest values.
Maximum annual values are shown for NO_2 and SO_2 and the $PM_{2.5}$ annual value is the annual mean averaged over the maximum 3 years.
PM_{10} and $PM_{2.5}$ 24-hour, and $PM_{2.5}$ annual modeled impacts include secondary $PM_{2.5}$ impacts (0.48 µg/m³ - 24-hour and 0.05 µg/m³ - annual) from CAMx modeling.

3.3.5 Development Drilling

3.3.5.1 Receptors and Source Configurations

See Attachment A for detailed information regarding the modeled sources, emission rates, locations, and in-stack NO_2-to-NOx ratios.

See Attachment E for the ambient air boundaries and receptors.

3.3.5.2 Emissions Calculations

Emission rates for all modeled sources are provided in Attachment A. The emissions development methods for Development Drilling drill rigs and hydraulic fracturing activities follows an approach identical to that described for BT1 Pre-Drilling in Section 3.3.3.2 “Emissions Calculations”. The underlying emission rates are different from the BT1 Pre-Drilling (as shown via a comparison of emission rates provided in Attachment A); however, the methodology is identical.

Hydraulic Fracturing Engines – Hourly and annual emissions for hydraulic fracturing engines are zero due to highline power being used rather than diesel engines.

Similarly, the emissions development methods for the operational activities included in Development Drilling are identical to Routine Operations in Section 3.3.6.2 “Emissions Calculations”. Construction emissions from facility installation activities at BT2 and BT3 are also included in this scenario. Sources associated with facility installation activities included heaters, shop heaters, generator sets, non-road equipment, B-70s, and fugitive dust at BT2 and BT3.

3.3.5.3 Criteria Pollutant Impacts

Table 3.3-7 shows the modeled impacts to air quality everywhere in the model domain and Table 3.3-8 shows the model impacts at Nuiqsut. Representative background concentrations are added to model results prior to comparing the total concentration to applicable AAQS. As shown, impacts would be below applicable AAQS for all criteria pollutants and averaging periods. Note that impacts from drill site flaring and routine operations flaring at the WPF are included in the modeling analysis and the contribution from flare emissions to the maximum concentrations shown in Table 3.3-7 and Table 3.3-8 is minimal.

Table 3.3-7 Development Drilling Activity AAQS Impacts– Alternative B (Proponent's Project)*

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	1,389.5	10,300.5	11,690.0	40,000	40,000	29%	29%
	8-Hour	921.7	3,433.5	4,355.2	10,000	10,000	44%	44%
NO_2	1-Hour	138.5	20.4	158.9	188	188	85%	85%
	Annual	24.9	3.8	28.7	100	100	29%	29%
SO_2	1-Hour	17.9	9.0	26.9	196	196	14%	14%
	3-Hour	16.6	10.0	26.6	1,300	1,300	2%	2%
	24-Hour	10.2	9.3	19.5	--	365	--	5%
	Annual	0.8	1.8	2.7	--	80	--	3%
PM_{10}	24-Hour	65.7	30.0	95.7	150	150	64%	64%
$PM_{2.5}$	24-Hour	22.6	7.0	29.6	35	35	85%	85%
	Annual	4.2	1.6	5.8	12	12	49%	49%

Notes:

Modeled highest second-high values from 5 modeled years shown for all short-term averaging times, with the exception of the following:

NO_2 1-hour value is calculated as the 3-year average of the 8th highest daily maximum 1-hour concentrations, and the background value shown is the average of the 1-hour values that are paired in time with the modeled values;

SO_2 1-hour value is calculated as the 3-year average of the 4th highest daily maximum 1-hour concentrations;

PM_{10} 24-hour value is the 6th highest value from 5-year modeling period; and

$PM_{2.5}$ 24-hour value is calculated as the 3-year average of the 8th highest values.

Maximum annual values are shown for NO_2 and SO_2 and the $PM_{2.5}$ annual value is the annual mean averaged over the maximum 3 years.

PM_{10} and $PM_{2.5}$ 24-hour, and $PM_{2.5}$ annual modeled impacts include secondary $PM_{2.5}$ impacts (0.48 µg/m³ - 24-hour and 0.05 µg/m³ - annual) from CAMx modeling.

Table 3.3-8 Development Drilling Activity AAQS Impacts at Nuiqsut – Alternative B (Proponent's Project)*

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	30.4	10,300.5	10,330.9	40,000	40,000	26%	26%
	8-Hour	9.4	3,433.5	3,442.9	10,000	10,000	34%	34%
NO_2	1-Hour	19.0	24.7	43.7	188	188	23%	23%
	Annual	0.18	3.8	3.9	100	100	4%	4%
SO_2	1-Hour	0.86	9.0	9.8	196	196	5%	5%
	3-Hour	0.51	10.0	10.5	1,300	1,300	1%	1%
	24-Hour	0.14	9.3	9.5	--	365	--	3%
	Annual	0.008	1.8	1.8	--	80	--	2%
PM_{10}	24-Hour	1.4	50.0	51.4	150	150	34%	34%
$PM_{2.5}$	24-Hour	0.63	7.0	7.6	35	35	22%	22%
	Annual	0.07	1.6	1.7	12	12	14%	14%

Notes:
Modeled highest second-high values from 5 modeled years shown for all short-term averaging times, with the exception of the following:
NO_2 1-hour value is calculated as the 3-year average of the 8th highest daily maximum 1-hour concentrations, and the background value shown is the average of the 1-hour values that are paired in time with the modeled values;
SO_2 1-hour value is calculated as the 3-year average of the 4th highest daily maximum 1-hour concentrations;
PM_{10} 24-hour value is the 6th highest value from 5-year modeling period; and
$PM_{2.5}$ 24-hour value is calculated as the 3-year average of the 8th highest values.
Maximum annual values are shown for NO_2 and SO_2 and the $PM_{2.5}$ annual value is the annual mean averaged over the maximum 3 years.
PM_{10} and $PM_{2.5}$ 24-hour, and $PM_{2.5}$ annual modeled impacts include secondary $PM_{2.5}$ impacts (0.48 µg/m³ - 24-hour and 0.05 µg/m³ - annual) from CAMx modeling.

3.3.6 Routine Operations

3.3.6.1 Receptors and Source Configurations

See Attachment A for detailed information regarding the modeled sources, emission rates, locations, and in-stack NO_2-to-NOx ratios.

See Attachment E for the ambient air boundaries and receptors.

3.3.6.2 Emission Calculations

Emission rates for all modeled sources are provided in Attachment A.

Gravel Pad Routine Operations Non-Mobile Support Equipment – Individual emission rates are extracted from the emissions inventory and converted to g/s. A category-wide emission rate is then calculated by summing the individual nonroad equipment hourly emission rates in its respective category. A category-wide annual emission rate is then quantified using the hourly emission rate and assuming equipment operates continuously across all hours of operating months. Emissions are allocated within each modeling domain by dividing hourly and annual emission rates by the acreage of the modeling domain.

Gravel Pad Well Intervention Non-Mobile Support Equipment – see *Gravel Pad Routine Operations Non-Mobile Support*, above, for calculation method. A minor difference relative to the Gravel Pad Routine Operations Non-Mobile Support is that total engine emissions are not included in summation and treated as separate point sources.

WOC Internal Combustion Equipment, Nonroad Engines – *see Gravel Pad Routine Operations Non-Mobile Support for calculation method.* Equipment defined as internal combustion equipment includes pumps, light plants, snowmelter boilers, and other engines.

WOC Portable External Combustion Equipment – *see Gravel Pad Routine Operations Non-Mobile Support for calculation method.* Equipment defined as portable external combustion equipment includes heaters, heater engine fans, and snowmelter engines.

WOC Stationary External Combustion Equipment – *see Gravel Pad Routine Operations Non-Mobile Support for calculation method.* Equipment defined as stationary external combustion equipment include non-portable natural gas heaters.

Mobile Tailpipe Emissions – See mobile tailpipe emissions in section 3.3.3.2. Additional emission volumes sources are added to WOC and adjacent airstrip road.

Mobile Equipment Fugitive Dust - See mobile equipment fugitive dust in section 3.3.3.2. Additional emission volumes sources are added to WOC and adjacent airstrip road.

WPF Injection and Power Generation Turbines - Hourly and annual emission rates are initially calculated using the general approach outlined above. Extracted emissions rates are taken as an annual average so monthly emission factors are applied to hourly and annual emission rates to account for fluctuations in emission rates. Monthly fluctuations in emission rates are caused by variations in ambient temperatures affecting the air density which affects fuel capacity into the turbine at full load.

WPF Internal Combustion Equipment, Small Nonroad Engines - Individual emission rates are extracted from the emissions inventory and converted to g/s. Equipment defined as small nonroad engines include pumps, compressors, light plants, pressure washers, and other engines under 140 horsepower.
A category-wide emission rate is then calculated by summing the individual nonroad equipment hourly emission rates in its respective category. A category-wide annual emission rate is then quantified using the hourly emission rate and assuming equipment operates continuously across all hours of operating months. Emissions are split into seven equal area sources and divided by the acreage of the modeling domain.

WPF Portable External Combustion Equipment – See *WPF Internal Combustion Equipment, Small Nonroad Engines* for calculation method. Equipment defined as portable external combustion equipment includes heaters, heater engine fans, and aircraft de-icers.

WPF Stationary External Combustion Equipment – *See WPF Internal Combustion Equipment, Small Nonroad Engines* for calculation method. Equipment defined as stationary external combustion equipment include non-portable natural gas heaters.

WPF Low Pressure and High Pressure Flaring – Hourly and annual emissions are calculated for normal (pilot/purge/assist) operation 8760 hours per year and for upset (maximum flow) operation 10 hours per year.

Willow Airstrip Aircraft Activity – Hourly and annual emission rates are calculated by extracting takeoff and landing emission factors for each aircraft type. Emission factors for each aircraft type are then multiplied by the number of flights for each aircraft type in the Year 13. Since each flight constitutes one takeoff and one landing, the takeoff and landing emission rates are summed across their respective aircraft type. Total aircraft emission rates are then calculated by summing across the aircraft types and converted to g/s. The total emission rates are split into three separate areas, based on release height, and divided by the respective airstrip area.

3.3.6.3 Structure Locations and Building Downwash

See Attachment A for figures depicting the structure locations relative to emissions sources.

3.3.6.4 Criteria Pollutant Impacts

Table 3.3-9 shows the modeled impacts to air quality everywhere in the domain (the analysis area) while Table 3.3-10 shows the modeled impacts at Nuiqsut. Representative background concentrations are added to model results prior to comparing the total concentration to applicable AAQS. As shown, impacts would be below applicable AAQS for all criteria pollutants and averaging periods. Table 3.3-11 provides the modeled impacts at Nuiqsut for comparison to PSD Class II increments. Impacts at Nuiqsut are below applicable PSD increments for all pollutants and averaging times. It is important to note that a PSD increment assessment is the jurisdiction of ADEC and the proposed analysis differs from a formal increment consumption assessment in several important ways. See Section 1.2.3.2 for more information. With regards to the $PM_{2.5}$ analysis shown here and for the other alternatives, the secondary $PM_{2.5}$ concentration from CAMx (see footnote of Table 3.3-10) was added to the AERMOD primary $PM_{2.5}$ modeled concentration prior to comparison with the AAQS. Thus, the $PM_{2.5}$ concentration would be affected by potential biases in the secondary nitrate and sulfate. Also note that impacts from routine operations flaring at the WPF are included in the modeling analysis and the contribution from flare emissions to the maximum concentrations shown in Table 3.3-9, Table 3.3-10 and Table 3.3-11 is minimal.

Table 3.3-9 Routine Operations AAQS Impacts – Alternative B (Proponent's Project)*

Pollutant	Averaging Time	Maximum Modeled Concentration (μg/m³)	Background Concentration (μg/m³)	Total Concentration (μg/m³)	NAAQS (μg/m³)	AAAQS (μg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	1,389.5	10,300.5	11,690.0	40,000	40,000	29%	29%
	8-Hour	921.7	3,433.5	4,355.2	10,000	10,000	44%	44%
NO_2	1-Hour	138.5	20.4	158.9	188	188	85%	85%
	Annual	24.9	3.8	28.6	100	100	29%	29%
SO_2	1-Hour	17.9	9.0	26.9	196	196	14%	14%
	3-Hour	16.6	10.0	26.6	1,300	1,300	2%	2%
	24-Hour	10.2	9.3	19.5	--	365	--	5%
	Annual	0.8	1.8	2.7	--	80	--	3%
PM_{10}	24-Hour	65.6	30.0	95.6	150	150	64%	64%

Pollutant	Averaging Time	Maximum Modeled Concentration (μg/m³)	Background Concentration (μg/m³)	Total Concentration (μg/m³)	NAAQS (μg/m³)	AAAQS (μg/m³)	Percent of NAAQS	Percent of AAAQS
$PM_{2.5}$	24-Hour	22.6	7.0	29.6	35	35	85%	85%
	Annual	4.2	1.6	5.8	12	12	49%	49%

Notes:
Modeled highest second-high values from 5 modeled years shown for all short-term averaging times, with the exception of the following:
NO_2 1-hour value is calculated as the 3-year average of the 8th highest daily maximum 1-hour concentrations, and the background value shown is the average of the 1-hour values that are paired in time with the modeled values;
SO_2 1-hour value is calculated as the 3-year average of the 4th highest daily maximum 1-hour concentrations;
PM_{10} 24-hour value is the 6th highest value from 5-year modeling period; and
$PM_{2.5}$ 24-hour value is calculated as the 3-year average of the 8th highest values.
Maximum annual values are shown for NO_2 and SO_2 and the $PM_{2.5}$ annual value is the annual mean averaged over the maximum 3 years.
PM_{10} and $PM_{2.5}$ 24-hour, and $PM_{2.5}$ annual modeled impacts include secondary $PM_{2.5}$ impacts (0.48 μg/m³ - 24-hour and 0.05 μg/m³ - annual) from CAMx modeling.

Table 3.3-10 Routine Operations AAQS Impacts at Nuiqsut – Alternative B (Proponent's Project)*

Pollutant	Averaging Time	Maximum Modeled Concentration (μg/m³)	Background Concentration (μg/m³)	Total Concentration (μg/m³)	NAAQS (μg/m³)	AAAQS (μg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	29.7	10,300.5	10,330.2	40,000	40,000	26%	26%
	8-Hour	9.6	3,433.5	3,443.1	10,000	10,000	34%	34%
NO_2	1-Hour	18.9	24.7	43.6	188	188	23%	23%
	Annual	0.16	3.8	3.9	100	100	4%	4%
SO_2	1-Hour	0.86	9.0	9.8	196	196	5%	5%
	3-Hour	0.51	10.0	10.5	1,300	1,300	1%	1%
	24-Hour	0.14	9.3	9.5	--	365	--	3%
	Annual	0.01	1.8	1.8	--	80	--	2%
PM_{10}	24-Hour	1.42	50.0	51.4	150	150	34%	34%
$PM_{2.5}$	24-Hour	0.63	7.0	7.6	35	35	22%	22%
	Annual	0.06	1.6	1.7	12	12	14%	14%

Notes:
Modeled highest second-high values from 5 modeled years shown for all short-term averaging times, with the exception of the following:
NO_2 1-hour value is calculated as the 3-year average of the 8th highest daily maximum 1-hour concentrations, and the background value shown is the average of the 1-hour values that are paired in time with the modeled values;
SO_2 1-hour value is calculated as the 3-year average of the 4th highest daily maximum 1-hour concentrations;
PM_{10} 24-hour value is the 6th highest value from 5-year modeling period; and
$PM_{2.5}$ 24-hour value is calculated as the 3-year average of the 8th highest values.
Maximum annual values are shown for NO_2 and SO_2 and the $PM_{2.5}$ annual value is the annual mean averaged over the maximum 3 years.
PM_{10} and $PM_{2.5}$ 24-hour, and $PM_{2.5}$ annual modeled impacts include secondary $PM_{2.5}$ impacts (0.48 μg/m³ - 24-hour and 0.05 μg/m³ - annual) from CAMx modeling.

Table 3.3-11 Routine Operation Activity PSD Increment Impacts at Nuiqsut – Alternative B (Proponent's Project)

Pollutant	Average Time [a]	Modeled Concentration[b] (μg/m³)	Class II PSD Increment (μg/m³)
NO_2	Annual	0.16	25
SO_2	3-hour	0.51	512
	24-hour	0.14	91
	Annual	0.01	20
PM_{10}	24-hour	1.49	30
	Annual	0.11	17
$PM_{2.5}$	24-hour	0.81	9
	Annual	0.06	4

Notes:
[a] For comparison to annual PSD increments, the maximum annual arithmetic mean value from any of 5-years of modeled impacts were used. For comparison to short-term (3- and 24-hour) PSD increments, the maximum 2nd high value from any of 5-years of modeled.
[b] PM_{10} and $PM_{2.5}$ 24-hour, and $PM_{2.5}$ annual modeled impacts include secondary $PM_{2.5}$ impacts (0.48 μg/m³ - 24-hour and 0.05 μg/m³ - annual) from CAMx modeling.

*3.3.6.5 HAPs Impacts**

For comparison to RELs and RfCs, toxic modeling was conducted and evaluated for the 6 HAPs shown in Table 3.3-12. The evaluations against the RELs and RfCs were done using the HAP emission rates documented in Attachment A. Cancer risk was evaluated for the Nuiqsut community using the procedures discussed in Chapter 1. As shown in Table 3.3-10, the concentrations of all HAPs everywhere in the analysis area are well below their respective RELs on an hourly period, and RfCs on an annual period. As shown in Table 3.3-13, the estimated cancer risk due to the Project is much less than the threshold of one in one million (1.0e-06) at Nuiqsut. Note that the HAPs considered for this analysis only include those most commonly emitted from oil and gas development (benzene, toluene, ethylbenzene, xylenes, n-hexane, and formaldehyde) and that the Total HAPs reported in Table 3.3-13 are the sum of only a subset of HAPs. Also note that impacts from flaring during routine operations are included in the maximum HAP impacts in the analysis area (Table 3.3-12) and in the estimated cancer risk at Nuiqsut (Table 3.3-13) and the contribution from flare emissions to the maximum HAP concentrations shown is minimal.

Table 3.3.3 in the main body of the Supplemental DEIS presents HAPs concentrations measured at Nuiqsut monitoring station starting in 2014 through March 2021. As shown in Table 3.3.3, measured HAPs concentrations are well below Acute REL and AEGLs. HAP measurements at Nuiqsut frequently have been below the measurement detection limit which indicates that HAP concentrations in ambient air are typically low. Note that some of health thresholds used for this assessment have become more stringent.

Table 3.3-12 Routine Operation Activity Acute and Non-carcinogenic HAPs Impacts – Alternative B (Proponent's Project)

Pollutant	Max 1-hour in analysis area (μg/m³)	Acute REL (μg/m³)	Max 8-hour in analysis area (μg/m³)	AEGLs (μg/m³)	Max Annual in analysis area (μg/m³)	RfC (μg/m³)
Benzene	8.8	27.0	6.0	29,000.0	0.2	30.0
Ethylbenzene	230.7	140,000.0	155.4	140,000.0	5.0	260.0
Formaldehyde	1.4	55.0	0.8	1,100.0	0.0	9.8
n-hexane	562.9	10,000,000.0	379.1	10,000,000.0	12.1	700.0

Pollutant	Max 1-hour in analysis area (µg/m³)	Acute REL (µg/m³)	Max 8-hour in analysis area (µg/m³)	AEGLs (µg/m³)	Max Annual in analysis area (µg/m³)	RfC (µg/m³)
Toluene	25.7	5,000.0	17.3	250,000.0	0.6	5,000.0
Xylene	454.5	22,000.0	306.2	560,000.0	9.8	100.0

Notes:
[1] No REL available for these air toxics. Values shown are Acute Exposure Guideline Levels for mild effects (AELG-1) (ethyl benzene) and moderate effects (AEGL-2) (n-hexane).

Table 3.3-13 Routine Operation Activity Carcinogenic HAPs Impacts – Alternative B)

Pollutant	Max Annual (µg/m³)	Cancer Unit Risk Factor thresholds (1/(µg/m³))	Exposure Adjustment Factor	Cancer Risks
Benzene	9.70E-04	7.80E-06	4.30E-01	3.25E-09
Ethylbenzene	3.97E-03	2.50E-06		4.27E-09
Formaldehyde	3.70E-04	1.30E-05		2.07E-09
			Total Cancer Risk:	9.6.E-09

3.4 Alternative C (Disconnected Infield Roads)

This section describes the selection of scenarios designed to characterize the potential impacts anticipated under Alternative C, the modeled receptors, source types, emissions, and resulting impacts.

3.4.1 Overview of Scenarios

Based on Alternative C emissions activities, source types, and development phases, five scenarios are analyzed:

1. Construction
2. Pre-drilling activities at BT1
3. Pre-drilling activities at BT1 and BT2
4. Development drilling
5. Routine Operations

As in the case of Alternative B, all scenarios consider emission of criteria pollutants, HAPs and GHGs. As shown in Section 2.1 "Willow Alternatives Emissions Inventories", HAPs from construction and drilling activities are substantially lower than routine operations. Therefore, HAP impacts are explicitly modeled for Routine Operations and HAP impacts from all other scenarios would be lower than Routine Operations.

Modeled sources include point source emissions, area sources, and volume sources. Equipment modeled as point sources include stationary sources, such as engines and heaters, as well as large portable equipment and nonroad engines. Groupings of similar low-level equipment were generally aggregated as area sources. Fugitive dust and mobile sources tailpipe emissions were modeled as volume sources. For example, the gravel access road was modeled as a series of volume sources to represent dust or tailpipe emissions from vehicle traffic. Point source stack parameters were provided by CPAI for most stationary sources, for those sources without stack parameter information, stack parameters are selected to be consistent with stack parameters used for modeling GMT2 or other public information. For area and volume sources release heights, initial vertical dimensions, and initial horizontal dimensions were based on the equipment as well as Table 3-2 from the AERMOD User's Guide (USEPA, 2019).

See Attachment A for detailed information about the sources included in each scenario. All sources modeled for each scenario are shown in figures in Attachment A depicting the layout of the sources relative to ambient air boundaries, structures, roads, and other Project features. In addition, Attachment A includes detailed tables that provide a description of each modeled source, source emissions rates for all modeled pollutants and averaging periods, in-stack NO_2-to-NOx ratio, modeled location, and stack parameters.

3.4.1.1 Construction

The construction of Willow MDP is similar to Alternative B except that due to the disconnected access of the northern portion of the Project area from the southern portion Alternative C includes construction of additional operational facilities, including a WOC North and WOC South (which consists of the same functions as the WOC in Alternatives B and D), and a northern airstrip in addition to the southern airstrip included in Alternatives B and D.

3.4.1.2 BT1 Pre-drilling

Alternative C BT1 pre-drilling phase is identical to Alternative B with the exception of the number of mobile tailpipe and mobile fugitive dust volume sources due to change in modeled road length along BT1.

3.4.1.3 BT1 and BT2 Pre-drilling

Alternative C BT1 and BT2 pre-drilling phase identical to Alternative B BT1 and BT2 Pre-drill with the exception that BT2 has a larger pad size for Alternative C than Alternative B, so the impacts for Alternative C BT1 and BT2 Pre-Drill are explicitly modeled. This scenario is similar to BT1 Pre-drilling with the exception that the drill rig and hydraulic fracturing equipment are active at both BT1 and BT2 pads. Development Drilling

The development drilling under Alternative C would consist of drilling on highline power at BT2 and BT3 and would be identical to development drilling for Alternative B except for the drill sites and infrastructure differences.

3.4.1.4 Routine operation and production of wells

Routine operations under Alternative C would be similar to the types of sources modeled in Alternative B except that due to the disconnected infield access, additional facilities operate, including WOC North and WOC South (which has the same functions as the WOC in Alternatives B and D), and a northern airstrip in addition to the southern airstrip included in Alternatives B and D. Just like Alternative B, in order to assess expected cumulative long-term impacts, the Alternative C Routine Operation scenario explicitly modeled emissions from other projects anticipated to be developed within the near-field of the Willow MDP Project, as shown in Table 2.2-2.

3.4.2 Construction

3.4.2.1 Receptors and Source Configurations

See Attachment A for detailed information regarding the modeled sources, emission rates, locations, and in-stack NO_2-to-NOx ratios.

See Attachment E for the ambient air boundaries and receptors.

3.4.2.2 Emissions Calculations

Emissions calculations were identical to Alternative B Construction except for the 1) exclusion of BT2 pad construction; 2) relocation of sources from WOC to WOC North and WOC South; 3) select sources from Alternative B Routine Operations that did not operate during construction, would operate during construction for Alternative C; and 4) there would be increased road lengths due to road alignments along the pads. Specifically,

1. BT3 Pad Construction Nonroad Equipment is included in the Alternative C Construction scenario while BT1 and BT2 Pad Construction Nonroad Equipment is not because for Alternative C, BT3 Pad Construction occurs during the model year, 2024, and BT1 Pad Construction occurs during 2023 and BT2 Pad Construction occurs during 2025. Emissions calculations for BT3 Pad Construction Nonroad Equipment are identical to those described for BT3 Pad Construction Nonroad Equipment in Section 3.3.2.2 ”Emissions Calculations”.
2. Alternative C involves the construction of WOC North and WOC South rather than one WOC. Sources located at the WOC in Alternative B, including sources related to facilities installation nonroad equipment, power generation, pipeline installation, vertical member support construction, drill rigs, drilling non-mobile support equipment, aircraft activity, mobile tailpipe emissions, ice road construction, mobile equipment fugitive dust, and wind erosion fugitive dust, are re-located to WOC North and WOC South. Emissions calculation methods are identical to those described in section 3.3.2.2 except emissions for wind erosion fugitive dust at WOC South are scaled by the respective pad sizes at WOC North and WOC South to obtain emissions for wind erosion fugitive dust at WOC North. Additionally, sources related to fiber optics installation are located at the WPF for Alternative B Construction. For Alternative C, these sources occur at WOC North and WOC South rather than the WPF. The emissions associated with fiber optics installation are split in half and then allocated to WOC North and WOC South because the total emissions remain the same despite the installation occurring at two different locations. Additionally, sources associated with disposal well drilling at the WOC North including drill rigs engines, boilers, heaters, and drilling nonmobile support equipment were added and emissions rates were calculated using the general approach.
3. Certain sources only included in Routine Operations for Alternative B, including WOC internal Combustion Equipment - Nonroad Engines, WOC Portable External Combustion Equipment, WOC Stationary External Combustion Equipment, and two incinerators, are included in the Alternative C Construction scenario. Description of emission calculations for these sources is in Section 3.3.6.2 “Emission Calculations”.
4. For Alternative B Construction, Pipeline Installation, Vertical Member Support Construction, Fiber Optics Installation, and WPF Mobile Equipment are split into various volume sources. For Alternative C, these sources are split into differing equivalent volume sources due to the change in the road lengths and alignment relative to the gravel pads. See figures of sources in Attachment A for a visual depiction.

Description of emissions calculations for all other sources is included in Section 3.3.2.2 “Emission Calculations”.

3.4.2.3 Criteria Pollutant Impacts

Table 3.4-1 shows the modeled impacts to air quality everywhere in the model domain and Table 3.4-2 shows the model impacts at Nuiqsut. Representative background concentrations are added to model results prior to comparing the total concentration to applicable AAQS. As shown, impacts would be below applicable AAQS for all criteria pollutants and averaging periods everywhere in the model domain and, in particular, at Nuiqsut.

Table 3.4-1 Construction Activity AAQS Impacts – Alternative C (Disconnected Infield Roads)*

Pollutant	Averaging Time	Maximum Modeled Concentration (μg/m^3)	Background Concentration (μg/m^3)	Total Concentration (μg/m^3)	NAAQS (μg/m^3)	AAAQS (μg/m^3)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	643.2	10,300.5	10,943.8	40,000	40,000	27%	27%
	8-Hour	488.1	3,433.5	3,921.6	10,000	10,000	39%	39%
NO_2	1-Hour	136.0	13.4	149.4	188	188	79%	79%
	Annual	35.4	3.8	39.1	100	100	39%	39%
SO_2	1-Hour	4.3	9.0	13.3	196	196	7%	7%
	3-Hour	5.2	10.0	15.2	1,300	1,300	1%	1%
	24-Hour	1.3	9.3	10.6	--	365	--	3%
	Annual	0.2	1.8	2.1	--	80	--	3%
PM_{10}	24-Hour	90.4	20.0	110.4	150	150	74%	74%
$PM_{2.5}$	24-Hour	16.7	7.0	23.7	35	35	68%	68%
	Annual	5.4	1.6	7.0	12	12	59%	59%

Notes:

Modeled highest second-high values from 5 modeled years shown for all short-term averaging times, with the exception of the following:

NO_2 1-hour value is calculated as the 3-year average of the 8th highest daily maximum 1-hour concentrations, and the background value shown is the average of the 1-hour values that are paired in time with the modeled values;

SO_2 1-hour value is calculated as the 3-year average of the 4th highest daily maximum 1-hour concentrations;

PM_{10} 24-hour value is the 6th highest value from 5-year modeling period; and

$PM_{2.5}$ 24-hour value is calculated as the 3-year average of the 8th highest values.

Maximum annual values are shown for NO_2 and SO_2 and the $PM_{2.5}$ annual value is the annual mean averaged over the maximum 3 years.

PM_{10} and $PM_{2.5}$ 24-hour, and $PM_{2.5}$ annual modeled impacts include secondary $PM_{2.5}$ impacts (0.48 μg/m^3 - 24-hour and 0.05 μg/m^3 - annual) from CAMx modeling.

Table 3.4-2 Construction Activity AAQS Impacts at Nuiqsut – Alternative C (Disconnected Infield Roads)*

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	45.1	10,300.5	10,345.6	40,000	40,000	26%	26%
	8-Hour	15.1	3,433.5	3,448.6	10,000	10000	34%	34%
NO_2	1-Hour	31.9	22.0	54.0	188	188	29%	29%
	Annual	0.49	3.8	4.2	100	100	4%	4%
SO_2	1-Hour	0.83	9.0	9.8	196	196	5%	5%
	3-Hour	0.51	10.0	10.5	1,300	1,300	1%	1%
	24-Hour	0.12	9.3	9.4	--	365	--	3%
	Annual	0.003	1.8	1.8	--	80	--	2%
PM_{10}	24-Hour	1.0	50.0	51.0	150	150	34%	34%
$PM_{2.5}$	24-Hour	0.75	7.0	7.8	35	35	22%	22%
	Annual	0.07	1.6	1.7	12	12	14%	14%

Notes:
Modeled highest second-high values from 5 modeled years shown for all short-term averaging times, with the exception of the following:
NO_2 1-hour value is calculated as the 3-year average of the 8th highest daily maximum 1-hour concentrations, and the background value shown is the average of the 1-hour values that are paired in time with the modeled values;
SO_2 1-hour value is calculated as the 3-year average of the 4th highest daily maximum 1-hour concentrations;
PM_{10} 24-hour value is the 6th highest value from 5-year modeling period; and
$PM_{2.5}$ 24-hour value is calculated as the 3-year average of the 8th highest values.
Maximum annual values are shown for NO_2 and SO_2 and the $PM_{2.5}$ annual value is the annual mean averaged over the maximum 3 years.
PM_{10} and $PM_{2.5}$ 24-hour, and $PM_{2.5}$ annual modeled impacts include secondary $PM_{2.5}$ impacts (0.48 µg/m³ - 24-hour and 0.05 µg/m³ - annual) from CAMx modeling.

3.4.3 BT1 Pre-Drill

Alternative C BT1 pre-drilling phase is similar to Alternative B

3.4.3.1 Receptors and Source Configurations

See Attachment A for detailed information regarding the modeled sources, emission rates, locations, and in-stack NO_2-to-NOx ratios.

See Attachment E for the ambient air boundaries and receptors.

3.4.3.2 Emissions Calculations

Emissions calculations procedures were identical to Alternative B. See Attachment A for the emissions rates.

3.4.3.3 Criteria Pollutant Impacts

Table 3.4-3 shows the modeled impacts to air quality everywhere in the model domain and Table 3.4-4 shows the model impacts at Nuiqsut. Representative background concentrations are added to model results prior to comparing the total concentration to applicable AAQS. As shown, impacts would be below applicable AAQS for all criteria pollutants and averaging periods. Note that impacts from flaring are included in the modeling analysis and the contribution from drill site flare emissions to the maximum concentrations shown in Table 3.4-3 and Table 3.4-4 is minimal.

Table 3.4-3 BT1 Pre-Drill Activity AAQS Impacts – Alternative C (Disconnected Infield Roads)*

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	1,471.5	10,300.5	11,772.0	40,000	40,000	29%	29%
	8-Hour	1,128.2	3,433.5	4,561.7	10,000	10,000	46%	46%
NO_2	1-Hour	65.7	23.9	89.6	188	188	48%	48%
	Annual	12.7	3.8	16.5	100	100	16%	16%
SO_2	1-Hour	4.2	9.0	13.2	196	196	7%	7%
	3-Hour	4.1	10.0	14.2	1,300	1,300	1%	1%
	24-Hour	2.2	9.3	11.5	--	365	--	3%
	Annual	0.2	1.8	2.1	--	80	--	3%
PM_{10}	24-Hour	18.0	10.0	28.0	150	150	19%	19%
$PM_{2.5}$	24-Hour	11.4	7.0	18.4	35	35	53%	53%
	Annual	2.3	1.6	3.9	12	12	32%	32%

Notes:
Modeled highest second-high values from 5 modeled years shown for all short-term averaging times, with the exception of the following:
NO_2 1-hour value is calculated as the 3-year average of the 8th highest daily maximum 1-hour concentrations, and the background value shown is the average of the 1-hour values that are paired in time with the modeled values;
SO_2 1-hour value is calculated as the 3-year average of the 4th highest daily maximum 1-hour concentrations;
PM_{10} 24-hour value is the 6th highest value from 5-year modeling period; and
$PM_{2.5}$ 24-hour value is calculated as the 3-year average of the 8th highest values.
Maximum annual values are shown for NO_2 and SO_2 and the $PM_{2.5}$ annual value is the annual mean averaged over the maximum 3 years.
PM_{10} and $PM_{2.5}$ 24-hour, and $PM_{2.5}$ annual modeled impacts include secondary $PM_{2.5}$ impacts (0.48 µg/m³ - 24-hour and 0.05 µg/m³ - annual) from CAMx modeling.

Table 3.4-4 BT1 Pre-Drill Activity AAQS Impacts at Nuiqsut – Alternative C (Disconnected Infield Roads)*

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	26.1	10,300.5	10,326.6	40,000	40,000	26%	26%
	8-Hour	3.4	3,433.5	3,436.9	10,000	10,000	34%	34%
NO_2	1-Hour	3.3	27.9	31.2	188	188	17%	17%
	Annual	0.02	3.8	3.8	100	100	4%	4%

Pollutant	Averaging Time	Maximum Modeled Concentration (μg/m³)	Background Concentration (μg/m³)	Total Concentration (μg/m³)	NAAQS (μg/m³)	AAAQS (μg/m³)	Percent of NAAQS	Percent of AAAQS
SO_2	1-Hour	0.07	9.0	9.1	196	196	5%	5%
	3-Hour	0.04	10.0	10.1	1,300	1,300	1%	1%
	24-Hour	0.006	9.3	9.3	--	365	--	3%
	Annual	0.0001	1.8	1.8	--	80	--	2%
PM_{10}	24-Hour	0.51	10.0	10.5	150	150	7%	7%
$PM_{2.5}$	24-Hour	0.49	7.0	7.5	35	35	21%	21%
	Annual	0.05	1.6	1.6	12	12	14%	14%

Notes:
Modeled highest second-high values from 5 modeled years shown for all short-term averaging times, with the exception of the following:
NO_2 1-hour value is calculated as the 3-year average of the 8th highest daily maximum 1-hour concentrations, and the background value shown is the average of the 1-hour values that are paired in time with the modeled values;
SO_2 1-hour value is calculated as the 3-year average of the 4th highest daily maximum 1-hour concentrations;
PM_{10} 24-hour value is the 6th highest value from 5-year modeling period; and
$PM_{2.5}$ 24-hour value is calculated as the 3-year average of the 8th highest values.
Maximum annual values are shown for NO_2 and SO_2 and the $PM_{2.5}$ annual value is the annual mean averaged over the maximum 3 years.
PM_{10} and $PM_{2.5}$ 24-hour, and $PM_{2.5}$ annual modeled impacts include secondary $PM_{2.5}$ impacts (0.48 μg/m³ - 24-hour and 0.05 μg/m³ - annual) from CAMx modeling.

3.4.4 BT1 and BT2 Pre-Drill

Alternative C BT1 and BT2 pre-drilling phase is similar to Alternative B.

3.4.4.1 Receptors and Source Configurations

See Attachment A for detailed information regarding the modeled sources, emission rates, locations, and in-stack NO_2-to-NOx ratios.

See Attachment E for the ambient air boundaries and receptors.

3.4.4.2 Emissions Calculations

Emissions calculations procedures were identical to Alternative B. See Attachment A for emissions rates.

3.4.4.3 Criteria Pollutant Impacts

Table 3.4-5 shows the modeled impacts to air quality everywhere in the model domain and Table 3.4-6 shows the model impacts at Nuiqsut. Representative background concentrations are added to model results prior to comparing the total concentration to applicable AAQS. As shown, impacts would be below applicable AAQS for all criteria pollutants and averaging periods. Note that impacts from flaring are included in the modeling analysis and the contribution from drill site flare emissions to the maximum concentrations shown in Table 3.4-5 and Table 3.4-6 is minimal.

Table 3.4-5 BT1 and BT2 Pre-Drill Activity AAQS Impacts – Alternative C (Disconnected Infield Roads)*

Pollutant	Averaging Time	Maximum Modeled Concentration (μg/m³)	Background Concentration (μg/m³)	Total Concentration (μg/m³)	NAAQS (μg/m³)	AAAQS (μg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	826.4	10,300.5	11,126.9	40,000	40,000	28%	28%
	8-Hour	635.7	3,433.5	4,069.2	10,000	10,000	41%	41%
NO_2	1-Hour	57.6	15.6	73.2	188	188	39%	39%
	Annual	12.6	3.8	16.3	100	100	16%	16%
SO_2	1-Hour	4.2	9.0	13.1	196	196	7%	7%
	3-Hour	4.1	10.0	14.1	1,300	1,300	1%	1%
	24-Hour	1.8	9.3	11.1	--	365	--	3%
	Annual	0.2	1.8	2.0	--	80	--	3%
PM_{10}	24-Hour	17.9	10.0	27.9	150	150	19%	19%
$PM_{2.5}$	24-Hour	11.4	7.0	18.4	35	35	53%	53%
	Annual	2.3	1.6	3.9	12	12	32%	32%

Notes:
Modeled highest second-high values from 5 modeled years shown for all short-term averaging times, with the exception of the following:
NO_2 1-hour value is calculated as the 3-year average of the 8th highest daily maximum 1-hour concentrations, and the background value shown is the average of the 1-hour values that are paired in time with the modeled values;
SO_2 1-hour value is calculated as the 3-year average of the 4th highest daily maximum 1-hour concentrations;
PM_{10} 24-hour value is the 6th highest value from 5-year modeling period; and
$PM_{2.5}$ 24-hour value is calculated as the 3-year average of the 8th highest values.
Maximum annual values are shown for NO_2 and SO_2 and the $PM_{2.5}$ annual value is the annual mean averaged over the maximum 3 years.
PM_{10} and $PM_{2.5}$ 24-hour, and $PM_{2.5}$ annual modeled impacts include secondary $PM_{2.5}$ impacts (0.48 μg/m³ - 24-hour and 0.05 μg/m³ - annual) from CAMx modeling.

Table 3.4-6 BT1 and BT2 Pre-Drill Activity AAQS Impacts at Nuiqsut – Alternative C (Disconnected Infield Roads)*

Pollutant	Averaging Time	Maximum Modeled Concentration (μg/m³)	Background Concentration (μg/m³)	Total Concentration (μg/m³)	NAAQS (μg/m³)	AAAQS (μg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	21.8	10,300.5	10,322.3	40,000	40,000	26%	26%
	8-Hour	3.4	3,433.5	3,436.9	10,000	10,000	34%	34%
NO_2	1-Hour	3.0	22.4	0,025.3	188	188	13%	13%
	Annual	0.02	3.8	3.8	100	100	4%	4%
SO_2	1-Hour	0.05	9.0	9.0	196	196	5%	5%
	3-Hour	0.03	10.0	10.1	1,300	1,300	1%	1%
	24-Hour	0.006	9.3	9.3	--	365	--	3%
	Annual	1.4E-04	1.8	1.8	--	80	--	2%

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m^3)	Background Concentration (µg/m^3)	Total Concentration (µg/m^3)	NAAQS (µg/m^3)	AAAQS (µg/m^3)	Percent of NAAQS	Percent of AAAQS
PM_{10}	24-Hour	0.51	10.0	10.5	150	150	7%	7%
$PM_{2.5}$	24-Hour	0.49	7.0	7.5	35	35	21%	21%
	Annual	0.05	1.6	1.6	12	12	14%	14%

Notes:
Modeled highest second-high values from 5 modeled years shown for all short-term averaging times, with the exception of the following:
NO_2 1-hour value is calculated as the 3-year average of the 8th highest daily maximum 1-hour concentrations, and the background value shown is the average of the 1-hour values that are paired in time with the modeled values;
SO_2 1-hour value is calculated as the 3-year average of the 4th highest daily maximum 1-hour concentrations;
PM_{10} 24-hour value is the 6th highest value from 5-year modeling period; and
$PM_{2.5}$ 24-hour value is calculated as the 3-year average of the 8th highest values.
Maximum annual values are shown for NO_2 and SO_2 and the $PM_{2.5}$ annual value is the annual mean averaged over the maximum 3 years.
PM_{10} and $PM_{2.5}$ 24-hour, and $PM_{2.5}$ annual modeled impacts include secondary $PM_{2.5}$ impacts (0.48 µg/m^3 - 24-hour and 0.05 µg/m^3 - annual) from CAMx modeling.

3.4.5 Development Drilling

3.4.5.1 Receptors and Source Configurations

See Attachment A for detailed information regarding the modeled sources, emission rates, locations, and in-stack NO_2-to-NOx ratios.

See Attachment E for the ambient air boundaries and receptors.

3.4.5.2 Emissions Calculations

Emissions calculations procedures were identical to Alternative B. See Attachment A for emissions rates.

3.4.5.3 Criteria Pollutant Impacts

Table 3.4-7 shows the modeled impacts to air quality everywhere in the model domain and Table 3.4-8 shows the model impacts at Nuiqsut. Representative background concentrations are added to model results prior to comparing the total concentration to applicable AAQS. As shown, impacts would be below applicable AAQS for all criteria pollutants and averaging periods. Note that impacts from drill site flaring and routine operations flaring at the WPF are included in the modeling analysis and the contribution from flare emissions to the maximum concentrations shown in Table 3.4-7 and Table 3.4-8 is minimal.

Table 3.4-7 Developmental Drilling Activity AAQS Impacts – Alternative C (Disconnected Infield Roads)*

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	1308.0	10,300.5	11,608.5	40,000	40,000	29%	29%
	8-Hour	930.9	3,433.5	4,364.4	10,000	10,000	44%	44%
NO_2	1-Hour	147.6	25.1	172.7	188	188	92%	92%
	Annual	24.1	3.8	27.8	100	100	28%	28%
SO_2	1-Hour	19.3	9.0	28.2	196	196	14%	14%
	3-Hour	16.9	10.0	26.9	1,300	1,300	2%	2%
	24-Hour	10.4	9.3	19.8	--	365	--	5%
	Annual	0.9	1.8	2.8	--	80	--	3%
PM_{10}	24-Hour	91.4	30.0	121.4	150	150	81%	81%
$PM_{2.5}$	24-Hour	19.0	7.0	26.0	35	35	74%	74%
	Annual	5.0	1.6	6.6	12	12	55%	55%

Notes:
Modeled highest second-high values from 5 modeled years shown for all short-term averaging times, with the exception of the following:
NO_2 1-hour value is calculated as the 3-year average of the 8th highest daily maximum 1-hour concentrations, and the background value shown is the average of the 1-hour values that are paired in time with the modeled values;
SO_2 1-hour value is calculated as the 3-year average of the 4th highest daily maximum 1-hour concentrations;
PM_{10} 24-hour value is the 6th highest value from 5-year modeling period; and
$PM_{2.5}$ 24-hour value is calculated as the 3-year average of the 8th highest values.
Maximum annual values are shown for NO_2 and SO_2 and the $PM_{2.5}$ annual value is the annual mean averaged over the maximum 3 years.
PM_{10} and $PM_{2.5}$ 24-hour, and $PM_{2.5}$ annual modeled impacts include secondary $PM_{2.5}$ impacts (0.48 µg/m³ - 24-hour and 0.05 µg/m³ - annual) from CAMx modeling.

Table 3.4-8 Development Drilling Activity AAQS Impacts at Nuiqsut – Alternative C (Disconnected Infield Roads)*

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	36	10,300.5	10,336.4	40,000	40,000	26%	26%
	8-Hour	12.6	3,433.5	3,446.1	10,000	10,000	34%	34%
NO_2	1-Hour	19.9	19.5	39.3	188	188	21%	21%
	Annual	0.19	3.8	4.0	100	100	4%	4%
SO_2	1-Hour	0.86	9.0	9.8	196	196	5%	5%
	3-Hour	0.51	10.0	10.5	1,300	1,300	1%	1%
	24-Hour	0.14	9.3	9.5	--	365	--	3%
	Annual	0.008	1.8	1.8	--	80	--	2%
PM_{10}	24-Hour	1.5	10.0	11.5	150	150	8%	8%
$PM_{2.5}$	24-Hour	0.65	7.0	7.6	35	35	22%	22%
	Annual	0.07	1.6	1.7	12	12	14%	14%

Notes:
Modeled highest second-high values from 5 modeled years shown for all short-term averaging times, with the exception of the following:
NO_2 1-hour value is calculated as the 3-year average of the 8th highest daily maximum 1-hour concentrations, and the background value shown is the average of the 1-hour values that are paired in time with the modeled values;
SO_2 1-hour value is calculated as the 3-year average of the 4th highest daily maximum 1-hour concentrations;
PM_{10} 24-hour value is the 6th highest value from 5-year modeling period; and
$PM_{2.5}$ 24-hour value is calculated as the 3-year average of the 8th highest values.
Maximum annual values are shown for NO_2 and SO_2 and the $PM_{2.5}$ annual value is the annual mean averaged over the maximum 3 years.
PM_{10} and $PM_{2.5}$ 24-hour, and $PM_{2.5}$ annual modeled impacts include secondary $PM_{2.5}$ impacts (0.48 µg/m³ - 24-hour and 0.05 µg/m³ - annual) from CAMx modeling.

3.4.6 Routine Operations

3.4.6.1 Receptors and Source Configurations

See Attachment A for detailed information regarding the modeled sources, emission rates, locations, and in-stack NO_2-to-NOx ratios.

See Attachment E for the ambient air boundaries and receptors.

3.4.6.2 Emissions Calculations

Emissions calculations were identical to Alternative B Construction except for 1) relocation of sources from WOC to WOC North and WOC South, and 2) increased road lengths due to road alignments along the pads. Specifically,

1. Alternative C involves operations at WOC North and WOC South rather than at one Operating Center. Sources located at the WOC in Alternative B, including sources related to gravel pad routine operations nonroad equipment, power generation, aircraft activity, mobile tailpipe emissions, mobile equipment fugitive dust, and wind erosion fugitive dust, are re-located to

WOC North and WOC South. Emissions calculation methods are identical to those described in Section 3.3.2.2 “Emissions Calculations” except emissions for wind erosion fugitive dust at WOC South are scaled by the respective pad sizes at WOC North and WOC South to obtain emissions for wind erosion fugitive dust at WOC North.

2. For Alternative C, mobile tailpipe emissions and mobile fugitive dust emissions at WPF, WOC North, and WOC South are split into a number of equivalent volume sources differing from Alternative B due to increased road segment associated with the road alignment along gravel pads. See Attachment A for a visual depiction.

Description of emissions calculations for all other sources is included in Section 3.3.2.2 “Emissions Calculations”.

3.4.6.3 Structure Locations and Building Downwash

See Attachment A for figures depicting the structure locations relative to emissions sources.

3.4.6.4 Criteria Pollutant Impacts

Table 3.4-9 shows the modeled impacts to air quality everywhere in the model domain. Representative background concentrations are added to model results prior to comparing the total concentration to applicable AAQS. All pollutants are below the applicable AAQS. Table 3.4-10 shows the modeled impacts at Nuiqsut for comparisons to applicable AAQS and Table 3.4-11 provides the impacts at Nuiqsut for comparison to applicable PSD Class II increments. Impacts at Nuiqsut are below AAQS and PSD increments for all pollutants and averaging times. It is important to note that a PSD increment assessment is the jurisdiction of ADEC and the proposed analysis differs from a formal increment consumption assessment in several important ways. See Section 1.2.3.2 for more information. Also note that impacts from routine operations flaring at the WPF are included in the modeling analysis and the contribution from flare emissions to the maximum concentrations shown in Table 3.4-9, Table 3.4-10 and Table 3.4-11 is minimal.

Table 3.4-9 Routine Operation AAQS Impacts – Alternative C (Disconnected Infield Roads)*

Pollutant	Averaging Time	Maximum Modeled Concentration (μg/m^3)	Background Concentration (μg/m^3)	Total Concentration (μg/m^3)	NAAQS (μg/m^3)	AAAQS (μg/m^3)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	1,308.0	10,300.5	11,608.5	40,000	40,000	29%	29%
	8-Hour	930.9	3,433.5	4,364.4	10,000	10,000	44%	44%
NO_2	1-Hour	147.6	25.1	172.7	188	188	92%	92%
	Annual	24.0	3.8	27.8	100	100	28%	28%
SO_2	1-Hour	19.2	9.0	28.2	196	196	14%	14%
	3-Hour	16.9	10.0	26.9	1,300	1,300	2%	2%
	24-Hour	10.4	9.3	19.8	--	365	--	5%
	Annual	0.9	1.8	2.8	--	80	--	3%
PM_{10}	24-Hour	77.8	40.0	117.8	150	150	79%	79%

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
$PM_{2.5}$	24-Hour	19.0	7.0	26.0	35	35	74%	74%
	Annual	5.0	1.6	6.6	12	12	55%	55%

Notes:
Modeled highest second-high values from 5 modeled years shown for all short-term averaging times, with the exception of the following:
NO_2 1-hour value is calculated as the 3-year average of the 8th highest daily maximum 1-hour concentrations, and the background value shown is the average of the 1-hour values that are paired in time with the modeled values;
SO_2 1-hour value is calculated as the 3-year average of the 4th highest daily maximum 1-hour concentrations;
PM_{10} 24-hour value is the 6th highest value from 5-year modeling period; and
$PM_{2.5}$ 24-hour value is calculated as the 3-year average of the 8th highest values.
Maximum annual values are shown for NO_2 and SO_2 and the $PM_{2.5}$ annual value is the annual mean averaged over the maximum 3 years.
PM_{10} and $PM_{2.5}$ 24-hour, and $PM_{2.5}$ annual modeled impacts include secondary $PM_{2.5}$ impacts (0.48 µg/m³ - 24-hour and 0.05 µg/m³ - annual) from CAMx modeling.

Table 3.4-10 Routine Operations AAQS Impacts at Nuiqsut – Alternative C (Disconnected Infield Roads)*

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	33.6	10,300.5	10,334.1	40,000	40,000	26%	26%
	8-Hour	11.4	3,433.5	3,444.9	10,000	10,000	34%	34%
NO_2	1-Hour	19.9	19.5	39.3	188	188	21%	21%
	Annual	0.17	3.8	3.9	100	100	4%	4%
SO_2	1-Hour	0.86	9.0	9.8	196	196	5%	5%
	3-Hour	0.51	10.0	10.5	1,300	1,300	1%	1%
	24-Hour	0.14	9.3	9.5	--	365	--	3%
	Annual	0.01	1.8	1.8	--	80	--	2%
PM_{10}	24-Hour	1.45	10.0	11.5	150	150	8%	8%
$PM_{2.5}$	24-Hour	0.64	7.0	7.6	35	35	22%	22%
	Annual	0.07	1.6	1.7	12	12	14%	14%

Notes:
Modeled highest second-high values from 5 modeled years shown for all short-term averaging times, with the exception of the following:
NO_2 1-hour value is calculated as the 3-year average of the 8th highest daily maximum 1-hour concentrations, and the background value shown is the average of the 1-hour values that are paired in time with the modeled values;
SO_2 1-hour value is calculated as the 3-year average of the 4th highest daily maximum 1-hour concentrations;
PM_{10} 24-hour value is the 6th highest value from 5-year modeling period; and
$PM_{2.5}$ 24-hour value is calculated as the 3-year average of the 8th highest values.
Maximum annual values are shown for NO_2 and SO_2 and the $PM_{2.5}$ annual value is the annual mean averaged over the maximum 3 years.
PM_{10} and $PM_{2.5}$ 24-hour, and $PM_{2.5}$ annual modeled impacts include secondary $PM_{2.5}$ impacts (0.48 µg/m³ - 24-hour and 0.05 µg/m³ - annual) from CAMx modeling.

Table 3.4-11 Routine Operation Activity PSD Increment Impacts at Nuiqsut – Alternative C (Disconnected Infield Roads)

Pollutant	Average Time [a]	Modeled Concentration[b] (µg/m³)	Class II PSD Increment (µg/m³)
NO_2	Annual	0.17	25
SO_2	3-hour	0.51	512
	24-hour	0.14	91
	Annual	0.01	20
PM_{10}	24-hour	1.56	30
	Annual	0.11	17
$PM_{2.5}$	24-hour	0.88	9
	Annual	0.07	4

Notes:

[a] For comparison to annual PSD increments, the maximum annual arithmetic mean value from any of 5-years of modeled impacts were used. For comparison to short-term (3- and 24-hour) PSD increments, the maximum 2nd high value from any of 5-years of modeled.

[b] PM_{10} and $PM_{2.5}$ 24-hour, and $PM_{2.5}$ annual modeled impacts include secondary $PM_{2.5}$ impacts (0.48 µg/m³ - 24-hour and 0.05 µg/m³ - annual) from CAMx modeling.

*3.4.6.5 HAPs Impacts**

For comparison to RELs and RfCs, toxic modeling was conducted and evaluated for the six HAPs shown in Table 3.4-12. The evaluations against the RELs and RfCs were done using the HAP emission rates documented in Attachment A. Cancer risk was evaluated for the Nuiqsut community using the procedures discussed in Chapter 1. As shown in Table 3.4-12, the concentrations of all HAPs are well below their respective RELs on an hourly period, and RfCs on an annual period. As shown in Table 3.4-13, the estimated cancer risk is much less than the threshold of one in one million (1.0E-06) at Nuiqsut. Note that the HAPs considered for this analysis only include those most commonly emitted from oil and gas development (benzene, toluene, ethylbenzene, xylenes, n-hexane, and formaldehyde) and that the Total HAPs reported in Table 3.4-13 are the sum of only a subset of HAPs. Also note that impacts from flaring during routine operations are included in the maximum HAP impacts in the analysis area (Table 3.4-12) and in the estimated cancer risk at Nuiqsut (Table 3.4-13) and the contribution from flare emissions to the maximum HAP concentrations shown is minimal.

Table 3.3.3 in the main body of the Supplemental DEIS presents HAPs concentrations measured at Nuiqsut monitoring station starting in 2014 through March 2021. As shown in Table 3.3.3, measured HAPs concentrations are well below Acute REL and AEGLs. HAP measurements at Nuiqsut frequently have been below the measurement detection limit which indicates that HAP concentrations in ambient air are typically low. Note that some of health thresholds used for this assessment have become more stringent.

Table 3.4-12 Routine Operation Activity Acute and Non-carcinogenic HAPs Impacts – Alternative C (Disconnected Infield Roads)

Pollutant	Max 1-hour in analysis area (µg/m³)	Acute REL (µg/m³)	Max 8-hour in analysis area (µg/m³)	AEGLs (µg/m³)	Max Annual in analysis area (µg/m³)	RfC (µg/m³)
Benzene	8.7	27.0	5.9	29,000.0	0.2	30.0
Ethylbenzene	226.8	140,000.0	152.5	140,000.0	4.8	260.0
Formaldehyde	1.4	55.0	0.8	1,100.0	0.0	9.8
n-hexane	553.3	10,000,000.0	372.0	10,000,000.0	11.6	700.0

Pollutant	Max 1-hour in analysis area (µg/m³)	Acute REL (µg/m³)	Max 8-hour in analysis area (µg/m³)	AEGLs (µg/m³)	Max Annual in analysis area (µg/m³)	RfC (µg/m³)
Toluene	25.3	5,000.0	17.0	250,000.0	0.5	5,000.0
Xylene	446.8	22,000.0	300.4	560,000.0	9.4	100.0

Notes:
[1] No REL available for these air toxics. Values shown are Acute Exposure Guideline Levels for mild effects (AELG-1) (ethyl benzene) and moderate effects (AEGL-2) (n-hexane).

Table 3.4-13 Routine Operation Activity Carcinogenic HAPs Impacts – Alternative C (Disconnected Infield Roads)

Pollutant	Max Annual (µg/m³)	Cancer Unit Risk Factor thresholds (1/(µg/m³))	Exposure Adjustment Factor	Cancer Risks
Benzene	1.03E-03	7.80E-06	4.30E-01	3.45E-09
Ethylbenzene	3.97E-03	2.50E-06		4.27E-09
Formaldehyde	3.80E-04	1.30E-05		2.12E-09
			Total Cancer Risk:	9.8.E-09

3.5 Alternative D (Disconnected Access)

This section describes the scenarios designed to characterize the potential impacts anticipated under Alternative D, the modeled receptors and source types, emissions, and resulting impacts.

3.5.1 Overview of Scenarios

Based on Alternative D emissions activities, source types, and development phases, five scenarios are analyzed:

1. Construction
2. Pre-drilling activities at BT1
3. Pre-drilling activities at BT1 and BT2
4. Development drilling
5. Routine Operations

All scenarios consider emission of criteria pollutants, HAPs and GHGs. As shown in Section 2.1 “Willow Alternatives Emissions Inventories”, HAPs from construction and drilling activities are substantially lower than routine operations. Therefore, HAP impacts are explicitly modeled for Routine Operations only; HAP impacts from all other scenarios would be lower than Routine Operations.

Modeled sources include point source emissions, area sources, and volume sources. Equipment modeled as point sources include stationary sources, such as engines and heaters, as well as large portable equipment and nonroad engines. Groupings of similar low-level equipment were generally aggregated as area sources. Fugitive dust and mobile sources tailpipe emissions were modeled as volume sources. For example, the gravel access road was modeled as a series of volume sources to represent dust or tailpipe emissions from vehicle traffic. Point source stack parameters were provided by CPAI for most stationary sources, for those sources without stack parameter information, stack parameters are selected to be consistent with stack parameters used for modeling GMT2 or other public information. For area and volume sources release heights, initial vertical dimensions, and initial horizontal dimensions were based on the equipment as well as Table 3-2 from the AERMOD User's Guide (USEPA, 2019).

See Attachment A for detailed information about the sources included in each scenario. All sources modeled for each scenario are shown in figures in Attachment A depicting the layout of the sources relative to ambient air boundaries, structures, roads, and other Project features. In addition, Attachment A includes detailed tables that provide a description of each modeled source, source emissions rates for all modeled pollutants and averaging periods, in-stack NO_2-to-NOx ratio, modeled location, and stack parameters.

3.5.1.1 Construction

The construction of Willow MDP is similar to Alternative B except that due to the disconnected access the Alternative D construction phase takes longer to complete.

3.5.1.2 BT1 Pre-drilling

Alternative D BT1 pre-drilling phase is identical to Alternative B and so is not re-evaluated further. See Section 3.3.3 "BT1 Pre-Drill" for more information about BT1 Pre-drilling.

3.5.1.3 BT1 and BT2 Pre-drilling

Alternative D BT1 and BT2 pre-drilling phase is identical to Alternative B BT1 and BT2 pre-drilling and so is not re-evaluated further. See Section 3.3.4 "BT1 and BT2 Pre-Drill" for more information about BT1 and BT2 Pre-drilling.

3.5.1.4 Development Drilling

The development drilling under Alternative D is identical to Alternative B except that the WPF is located further to the west and collocated with BT3. The WPF/BT3 and WOC pad boundary is larger under Alternative D to provide additional storage capacity necessary without access to the rest of the North Slope.

*3.5.1.5 Routine operation and production of wells**

Routine operations under Alternative D would be identical to Alternative B except that due to the disconnected access to the rest of the North Slope it takes longer to construct the Project area and as a result production from BT2 through BT5 comes on-line later and the overall Project lifetime is extended to 2052. In addition, the WPF is located further to the west and collocated with BT3. The WPF/BT3 and WOC pad boundaries are larger under Alternative D to provide additional storage capacity necessary without access to the rest of the North Slope. Just like Alternative B, in order to assess expected cumulative long-term impacts, the Alternative D Routine Operation scenario explicitly modeled emissions from other projects anticipated to be developed within the near-field of the Willow MDP Project, as shown in Table 2.2-2.

3.5.2 Construction

3.5.2.1 Receptors and Source Configurations

See Attachment A for detailed information regarding the modeled sources, emission rates, locations, and in-stack NO_2-to-NOx ratios.

See Attachment E for the ambient air boundaries and receptors.

3.5.2.2 Emissions Calculations

Emissions development methods are identical to those presented for Alternative B Construction (see Section 3.3.2.2 "Emissions Calculations" for details) except that 1) BT1 facilities, pipeline, and VSM installation is not occurring in year 2024; and 2) WCF facilities installation and associated mobile source emissions are not occurring in year 2024. These activities would start in 2025 under Alternative D.
Criteria Pollutant Impacts

Table 3.5-1 shows the modeled impacts to air quality everywhere in the model domain and Table 3.5-2 shows the model impacts at Nuiqsut. Representative background concentrations are added to model results prior to comparing the total concentration to applicable AAQS. As shown, impacts would be below applicable AAQS for all criteria pollutants and averaging periods everywhere in the model domain and, in particular, at Nuiqsut.

Table 3.5-1 Construction Activity AAQS Impacts – Alternative D (Disconnected Access)*

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	528.1	10,300.5	10,828.6	40,000	40,000	27%	27%
	8-Hour	390.1	3,433.5	3,823.6	10,000	10,000	38%	38%
NO_2	1-Hour	111.5	22.4	133.9	188	188	71%	71%
	Annual	15.6	3.8	19.4	100	100	19%	19%
SO_2	1-Hour	3.6	9.0	12.6	196	196	6%	6%
	3-Hour	5.2	10.0	15.2	1,300	1,300	1%	1%
	24-Hour	1.2	9.3	10.6	--	365	--	3%
	Annual	0.1	1.8	1.9	--	80	--	2%
PM_{10}	24-Hour	102.8	30.0	132.8	150	150	89%	89%
$PM_{2.5}$	24-Hour	9.2	7.0	16.2	35	35	46%	46%
	Annual	2.4	1.6	4.0	12	12	34%	34%

Notes:
Modeled highest second-high values from 5 modeled years shown for all short-term averaging times, with the exception of the following:
NO_2 1-hour value is calculated as the 3-year average of the 8th highest daily maximum 1-hour concentrations, and the background value shown is the average of the 1-hour values that are paired in time with the modeled values;
SO_2 1-hour value is calculated as the 3-year average of the 4th highest daily maximum 1-hour concentrations;
PM_{10} 24-hour value is the 6th highest value from 5-year modeling period; and
$PM_{2.5}$ 24-hour value is calculated as the 3-year average of the 8th highest values.
Maximum annual values are shown for NO_2 and SO_2 and the $PM_{2.5}$ annual value is the annual mean averaged over the maximum 3 years.
PM_{10} and $PM_{2.5}$ 24-hour, and $PM_{2.5}$ annual modeled impacts include secondary $PM_{2.5}$ impacts (0.48 µg/m³ - 24-hour and 0.05 µg/m³ - annual) from CAMx modeling.

Table 3.5-2 Construction Activity AAQS Impacts at Nuiqsut – Alternative D (Disconnected Access)*

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	45.2	10,300.5	10,345.8	40,000	40,000	26%	26%
	8-Hour	15.2	3,433.5	3,448.7	10,000	10,000	34%	34%
NO_2	1-Hour	31.4	18.0	49.4	188	188	26%	26%
	Annual	0.40	3.8	4.2	100	100	4%	4%
SO_2	1-Hour	0.73	9.0	9.7	196	196	5%	5%
	3-Hour	0.46	10.0	10.5	1,300	1,300	1%	1%
	24-Hour	0.09	9.3	9.4	--	365	--	3%
	Annual	0.001	1.8	1.8	--	80	--	2%
PM_{10}	24-Hour	0.99	50.0	51.0	150	150	34%	34%
$PM_{2.5}$	24-Hour	0.75	7.0	7.8	35	35	22%	22%
	Annual	0.07	1.6	1.7	12	12	14%	14%

Notes:
Modeled highest second-high values from 5 modeled years shown for all short-term averaging times, with the exception of the following:
NO_2 1-hour value is calculated as the 3-year average of the 8th highest daily maximum 1-hour concentrations, and the background value shown is the average of the 1-hour values that are paired in time with the modeled values;
SO_2 1-hour value is calculated as the 3-year average of the 4th highest daily maximum 1-hour concentrations;
PM_{10} 24-hour value is the 6th highest value from 5-year modeling period; and
$PM_{2.5}$ 24-hour value is calculated as the 3-year average of the 8th highest values.
Maximum annual values are shown for NO_2 and SO_2 and the $PM_{2.5}$ annual value is the annual mean averaged over the maximum 3 years.
PM_{10} and $PM_{2.5}$ 24-hour, and $PM_{2.5}$ annual modeled impacts include secondary $PM_{2.5}$ impacts (0.48 µg/m³ - 24-hour and 0.05 µg/m³ - annual) from CAMx modeling.

3.5.3 BT1 Pre-Drill

Alternative D BT1 pre-drilling phase is identical to Alternative B and so modeled impacts are anticipated to be identical to impacts presented in Table 3.3-3 and Table 3.3-4.

3.5.4 BT1 and BT2 Pre-Drill

Alternative D BT1 and BT2 pre-drilling phase is identical to Alternative B and so modeled impacts are anticipated to be identical to impacts presented in Table 3.3-5 and Table 3.3-6.

3.5.5 Development Drilling

3.5.5.1 Receptors and Source Configurations

See Attachment A for detailed information regarding the modeled sources, emission rates, locations, and in-stack NO_2-to-NOx ratios.

See Attachment E for the ambient air boundaries and receptors.

3.5.5.2 Emissions Calculations

Emissions development methods are identical to those presented for Alternative B Development Drilling, with the only difference being the changes to the WPF/BT3 and WOC pad layout and source locations. See Section 3.3.5.2 "Emissions Calculations" for details regarding the emissions preparation approach and Attachment A for visual depictions of the source layout and locations.

3.5.5.3 Criteria Pollutant Impacts

Table 3.5-3 shows the modeled impacts to air quality everywhere in the model domain and Table 3.5-4 shows the model impacts at Nuiqsut. Representative background concentrations are added to model results prior to comparing the total concentration to applicable AAQS. As shown, impacts would be below applicable AAQS for all criteria pollutants and averaging periods. Note that impacts from drill site flaring and routine operations flaring at the WPF are included in the modeling analysis and the contribution from flare emissions to the maximum concentrations shown in Table 3.5-3 and Table 3.5-4 is minimal.

Table 3.5-3 Developmental Drilling Activity AAQS Impacts – Alternative D (Disconnected Access)*

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	1,535.5	10,300.5	11,836.0	40,000	40,000	30%	30%
	8-Hour	599.7	3,433.5	4,033.2	10,000	10,000	40%	40%
NO_2	1-Hour	150.7	25.0	175.7	188	188	93%	93%
	Annual	23.6	3.8	27.4	100	100	27%	27%
SO_2	1-Hour	18.0	9.0	27.0	196	196	14%	14%
	3-Hour	15.6	10.0	25.7	1,300	1,300	2%	2%
	24-Hour	12.2	9.3	21.5	--	365	--	6%
	Annual	0.9	1.8	2.7	--	80	--	3%
PM_{10}	24-Hour	66.2	30.0	96.2	150	150	64%	64%
$PM_{2.5}$	24-Hour	21.1	7.0	28.1	35	35	80%	80%
	Annual	5.1	1.6	6.7	12	12	56%	56%

Notes:
Modeled highest second-high values from 5 modeled years shown for all short-term averaging times, with the exception of the following:
NO_2 1-hour value is calculated as the 3-year average of the 8th highest daily maximum 1-hour concentrations, and the background value shown is the average of the 1-hour values that are paired in time with the modeled values;
SO_2 1-hour value is calculated as the 3-year average of the 4th highest daily maximum 1-hour concentrations;
PM_{10} 24-hour value is the 6th highest value from 5-year modeling period; and
$PM_{2.5}$ 24-hour value is calculated as the 3-year average of the 8th highest values.
Maximum annual values are shown for NO_2 and SO_2 and the $PM_{2.5}$ annual value is the annual mean averaged over the maximum 3 years.
PM_{10} and $PM_{2.5}$ 24-hour, and $PM_{2.5}$ annual modeled impacts include secondary $PM_{2.5}$ impacts (0.48 µg/m³ - 24-hour and 0.05 µg/m³ - annual) from CAMx modeling.

Table 3.5-4 Development Drilling Activity AAQS Impacts at Nuiqsut – Alternative D (Disconnected Access)*

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	30	10,300.5	10,331.0	40,000	40,000	26%	26%
	8-Hour	8.9	3,433.5	3,442.4	10,000	10,000	34%	34%
NO_2	1-Hour	15.5	16.6	32.0	188	188	17%	17%
	Annual	0.17	3.8	3.9	100	100	4%	4%
SO_2	1-Hour	0.87	9.0	9.8	196	196	5%	5%
	3-Hour	0.51	10.0	10.5	1,300	1,300	1%	1%
	24-Hour	0.14	9.3	9.5	--	365	--	3%
	Annual	0.008	1.8	1.8	--	80	--	2%
PM_{10}	24-Hour	1.40	10.0	11.4	150	150	8%	8%
$PM_{2.5}$	24-Hour	0.62	7.0	7.6	35	35	22%	22%
	Annual	0.06	1.6	1.7	12	12	14%	14%

Notes:
Modeled highest second-high values from 5 modeled years shown for all short-term averaging times, with the exception of the following:
NO_2 1-hour value is calculated as the 3-year average of the 8th highest daily maximum 1-hour concentrations, and the background value shown is the average of the 1-hour values that are paired in time with the modeled values;
SO_2 1-hour value is calculated as the 3-year average of the 4th highest daily maximum 1-hour concentrations;
PM_{10} 24-hour value is the 6th highest value from 5-year modeling period; and
$PM_{2.5}$ 24-hour value is calculated as the 3-year average of the 8th highest values.
Maximum annual values are shown for NO_2 and SO_2 and the $PM_{2.5}$ annual value is the annual mean averaged over the maximum 3 years.
PM_{10} and $PM_{2.5}$ 24-hour, and $PM_{2.5}$ annual modeled impacts include secondary $PM_{2.5}$ impacts (0.48 µg/m³ - 24-hour and 0.05 µg/m³ - annual) from CAMx modeling.

3.5.6 Routine Operations

3.5.6.1 Receptors and Source Configurations

See Attachment A for detailed information regarding the modeled sources, emission rates, locations, and in-stack NO_2-to-NOx ratios.

See Attachment E for the ambient air boundaries and receptors.

3.5.6.2 Emissions Calculations

Emissions development methods are identical to those presented for Alternative B Routine Operations, with the only difference being the change to the WPF/BT3 and WOC pad layout and source locations. See Section 3.3.6.2 “Emission Calculations” for details regarding the emissions preparation approach and Attachment A for visual depictions of the source layout and locations.

3.5.6.3 Structure Locations and Building Downwash

See Attachment A for figures depicting the structure locations relative to emissions sources.

3.5.6.4 Criteria Pollutant Impacts

Table 3.5-5 shows the modeled impacts to air quality everywhere in the model domain and Table 3.5-6 shows the model impacts at Nuiqsut. Representative background concentrations are added to model results prior to comparing the total concentration to applicable AAQS. As shown, impacts would be below applicable AAQS and PSD increments for all criteria pollutants and averaging periods. Table 3.5-7 provides the modeled impacts at Nuiqsut for comparison to PSD Class II increments. Impacts at Nuiqsut are below applicable PSD increments for all pollutants and averaging times. It is important to note that a PSD increment assessment is the jurisdiction of ADEC and the proposed analysis differs from a formal increment consumption assessment in several important ways. See Section 1.2.3.2 for more information. Also note that impacts from routine operations flaring at the WPF are included in the modeling analysis and the contribution from flare emissions to the maximum concentrations shown in Table 3.5-5, Table 3.5-6 and Table 3.5-7 is minimal.

Table 3.5-5 Routine Operations Activity AAQS Impacts – Alternative D (Disconnected Access)*

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	1,535.5	10,300.5	11,836.0	40,000	40,000	30%	30%
	8-Hour	566.0	3,433.5	3,999.5	10,000	10,000	40%	40%
NO_2	1-Hour	143.6	25	168	188	188	89%	89%
	Annual	22.1	3.8	26	100	100	26%	26%
SO_2	1-Hour	17.9	9.0	27	196	196	14%	14%
	3-Hour	15.1	10.0	25	1,300	1,300	2%	2%
	24-Hour	11.8	9.3	21	--	365	--	6%
	Annual	0.8	1.8	2.6	--	80	--	3%
PM_{10}	24-Hour	63.9	20	84	150	150	56%	56%
$PM_{2.5}$	24-Hour	18.5	7.0	26	35	35	73%	73%
	Annual	3.9	1.6	5.5	12	12	46%	46%

Notes:

Modeled highest second-high values from 5 modeled years shown for all short-term averaging times, with the exception of the following:

NO_2 1-hour value is calculated as the 3-year average of the 8th highest daily maximum 1-hour concentrations, and the background value shown is the average of the 1-hour values that are paired in time with the modeled values;

SO_2 1-hour value is calculated as the 3-year average of the 4th highest daily maximum 1-hour concentrations;

PM_{10} 24-hour value is the 6th highest value from 5-year modeling period; and

$PM_{2.5}$ 24-hour value is calculated as the 3-year average of the 8th highest values.

Maximum annual values are shown for NO_2 and SO_2 and the $PM_{2.5}$ annual value is the annual mean averaged over the maximum 3 years.

PM_{10} and $PM_{2.5}$ 24-hour, and $PM_{2.5}$ annual modeled impacts include secondary $PM_{2.5}$ impacts (0.48 µg/m³ - 24-hour and 0.05 µg/m³ - annual) from CAMx modeling.

Table 3.5-6 Routine Operations AAQS Impacts at Nuiqsut – Alternative D (Disconnected Access)*

Pollutant	Averaging Time	Maximum Modeled Concentration (μg/m³)	Background Concentration (μg/m³)	Total Concentration (μg/m³)	NAAQS (μg/m³)	AAAQS (μg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	29.7	10,300.5	10,330.2	40,000	40,000	26%	26%
	8-Hour	7.7	3,433.5	3,441.2	10,000	10,000	34%	34%
NO_2	1-Hour	14.4	25.8	40.3	188	188	21%	21%
	Annual	0.15	3.8	3.9	100	100	4%	4%
SO_2	1-Hour	0.91	9.0	9.9	196	196	5%	5%
	3-Hour	0.51	10.0	10.5	1,300	1,300	1%	1%
	24-Hour	0.14	9.3	9.5	--	365	--	3%
	Annual	0.01	1.8	1.8	--	80	--	2%
PM_{10}	24-Hour	1.38	11.4	12.8	150	150	9%	9%
$PM_{2.5}$	24-Hour	0.62	7.0	7.6	35	35	22%	22%
	Annual	0.06	1.6	1.7	12	12	14%	14%

Notes:
Modeled highest second-high values from 5 modeled years shown for all short-term averaging times, with the exception of the following:
NO_2 1-hour value is calculated as the 3-year average of the 8th highest daily maximum 1-hour concentrations, and the background value shown is the average of the 1-hour values that are paired in time with the modeled values;
SO_2 1-hour value is calculated as the 3-year average of the 4th highest daily maximum 1-hour concentrations;
PM_{10} 24-hour value is the 6th highest value from 5-year modeling period; and
$PM_{2.5}$ 24-hour value is calculated as the 3-year average of the 8th highest values.
Maximum annual values are shown for NO_2 and SO_2 and the $PM_{2.5}$ annual value is the annual mean averaged over the maximum 3 years.
PM_{10} and $PM_{2.5}$ 24-hour, and $PM_{2.5}$ annual modeled impacts include secondary $PM_{2.5}$ impacts (0.48 μg/m³ - 24-hour and 0.05 μg/m³ - annual) from CAMx modeling.

Table 3.5-7 Routine Operation Activity PSD Increment Impacts at Nuiqsut – Alternative D (Disconnected Access)

Pollutant	Average Time[a]	Modeled Concentration[b] (μg/m³)	Class II PSD Increment (μg/m³)
NO_2	Annual	0.15	25
SO_2	3-hour	0.51	512
	24-hour	0.14	91
	Annual	0.01	20
PM_{10}	24-hour	1.42	30
	Annual	0.10	17
$PM_{2.5}$	24-hour	0.73	9
	Annual	0.06	4

Notes:
[a] For comparison to annual PSD increments, the maximum annual arithmetic mean value from any of 5-years of modeled impacts were used. For comparison to short-term (3- and 24-hour) PSD increments, the maximum 2nd high value from any of 5-years of modeled.
[b] PM_{10} and $PM_{2.5}$ 24-hour, and $PM_{2.5}$ annual modeled impacts include secondary $PM_{2.5}$ impacts (0.48 μg/m³ - 24-hour and 0.05 μg/m³ - annual) from CAMx modeling.

*3.5.6.5 HAPs Impacts**

For comparison to RELs and RfCs, toxic modeling was conducted and evaluated for the six HAPs shown in Table 3.5-8. The evaluations against the RELs and RfCs were done using the HAP emission rates documented in Attachment A. Cancer risk was evaluated for the Nuiqsut community using the procedures discussed in Chapter 1. As shown in Table 3.5-8, the concentrations of all HAPs are well below their respective RELs on an hourly period, and RfCs on an annual period. As shown in Table 3.5-9, the cancer risk is much less than the threshold of one in one million (1.0E-06) at Nuiqsut. Note that the HAPs considered for this analysis only include those most commonly emitted from oil and gas development (benzene, toluene, ethylbenzene, xylenes, n-hexane, and formaldehyde) and that the Total HAPs reported in Table 3.3-9 are the sum of only a subset of HAPs. Also note that impacts from flaring during routine operations are included in the maximum HAP impacts in the analysis area (Table 3.5-8) and in the estimated cancer risk at Nuiqsut (Table 3.5-9) and the contribution from flare emissions to the maximum HAP concentrations shown is minimal.

Table 3.3.3 in the main body of the Supplemental DEIS presents HAPs concentrations measured at Nuiqsut monitoring station starting in 2014 through March 2021. As shown in Table 3.3.3, measured HAPs concentrations are well below Acute REL and AEGLs. HAP measurements at Nuiqsut frequently have been below the measurement detection limit which indicates that HAP concentrations in ambient air are typically low. Note that some of health thresholds used for this assessment have become more stringent.

Table 3.5-8 Routine Operation Activity Acute and Non-carcinogenic HAPs Impacts – Alternative D (Disconnected Access)

Pollutant	Max 1-hour in analysis area (µg/m³)	Acute REL (µg/m³)	Max 8-hour in analysis area (µg/m³)	AEGLs (µg/m³)	Max Annual in analysis area (µg/m³)	RfC (µg/m³)
Benzene	8.8	27.0	5.9	29,000.0	0.2	30.0
Ethylbenzene	232.3	140,000.0	155.4	140,000.0	5.0	260.0
Formaldehyde	1.4	55.0	0.8	1,100.0	0.0	9.8
n-hexane	566.7	10,000,000.0	379.1	10,000,000.0	12.1	700.0
Toluene	25.9	5,000.0	17.3	250,000.0	0.6	5,000.0
Xylene	457.7	22,000.0	306.2	560,000.0	9.8	100.0

Notes:
1 No REL available for these air toxics. Values shown are Acute Exposure Guideline Levels for mild effects (AELG-1) (ethyl benzene) and moderate effects (AEGL-2) (n-hexane).

Table 3.5-9 Routine Operation Activity Carcinogenic HAPs Impacts – Alternative D (Disconnected Access)

Pollutant	Max Annual (µg/m³)	Cancer Unit Risk Factor thresholds (1/(µg/m³))	Exposure Adjustment Factor	Cancer Risks
Benzene	1.00E-03	7.80E-06	4.30E-01	3.35E-09

Pollutant	Max Annual (µg/m³)	Cancer Unit Risk Factor thresholds (1/(µg/m³))	Exposure Adjustment Factor	Cancer Risks
Ethylbenzene	3.96E-03	2.50E-06		4.26E-09
Formaldehyde	3.70E-04	1.30E-05		2.07E-09
			Total Cancer Risk:	9.7.E-09

3.6 Alternative E (Three-Pad Alternative)*

This section describes the scenarios designed to evaluate the potential impacts anticipated under Alternative E and resulting impacts.

3.6.1 Overview of Scenarios*

Based on Alternative E emissions activities, source types, and development phases discussed in Section 2.1.6, five scenarios are analyzed:

- Construction
- Pre-drilling activities at BT1
- Pre-drilling activities at BT1 and BT2
- Development drilling
- Routine Operations

All scenarios consider emission of criteria pollutants, HAPs and GHGs. As shown in Section 2.1 "Willow Alternatives Emissions Inventories", HAPs from construction and drilling activities are substantially lower than routine operations. Therefore, HAP impacts are evaluated for Routine Operations only; HAP impacts from all other scenarios would be lower than Routine Operations.

*3.6.1.1 Construction**

The construction of project facilities proposed at the WPF, drill sites, gravel pads, and WOC for Alternative E are the same as Alternative B, with the exception that Alternative E would not include construction of drill site BT4, and drill site BT2 would be located farther north of the BT2 location proposed for Alternative B. The well pad sizes for BT1 and BT2 would be slightly larger than the BT1 and BT2 pad sizes proposed for the other action alternatives. In addition, BT5 would be located north of the location proposed for other action alternatives.

*3.6.1.2 BT1 Pre-drilling**

Alternative E BT1 pre-drilling phase is identical to Alternative B, with the exception that a larger well pad size proposed under Alternative E.

*3.6.1.3 BT1 and BT2 Pre-drilling**

Alternative E BT1 and BT2 pre-drilling phase is identical to Alternative B with the exception that there are larger well pad sizes proposed for BT1 and BT2 under Alternative E. In addition, the location of BT2 proposed under Alternative E is further north of the location under Alternative B.

*3.6.1.4 Development Drilling**

Alternative E development drilling phase would be similar to Alternative B at the WPF, drill sites, and WOC, with the exception that Alternative E would not include drill site BT4, drill site BT2 would be located farther north of the BT2 location proposed for Alternative B, and drilling would occur for an additional year. The well pad sizes for BT1 and BT2 would be slightly larger than the BT1 and BT2 pad sizes proposed for the other action alternatives. BT1 and BT2 will also include two line heaters at each site whereas only one line heater will be used at each site under the other action alternatives. In addition, BT5 would be located north of the location proposed for other action alternatives and developed at a later date.

*3.6.1.5 Routine operation and production of wells**

Routine operations under Alternative E would be similar to Alternative B at the WPF, drill sites, and WOC, with the exception that Alternative E would not include drill site BT4, and drill site BT2 would be located farther north of the BT2 location proposed for Alternative B. The well pad sizes for BT1 and BT2 would be slightly larger than the BT1 and BT2 pad sizes proposed for the other action alternatives. BT1 and BT2 will also include two line heaters at each site whereas only one line heater will be used at each site under the other action alternatives. In addition, BT5 would be located north of the location proposed for other action alternatives and developed at a later date.

3.6.2 Construction*

The peak annual Alternative E construction emissions are similar to peak annual Alternative B construction emissions (see Alternative B emissions in Table 2.1-6 as compared to Alternative E emissions in Table 2.1-18). However, the emissions from the construction of well sites BT1 and BT2 would be slightly larger than the construction emissions for these well sites under Alternative B. The increase in emissions at these well sites is primary due to the increase in well pad sizes under Alternative E. The percent increase in construction emissions at BT1 includes: NO_x (4%), CO (4%), SO_2 (5%), PM_{10} (6%), and $PM_{2.5}$ (4%). At BT2 the construction emissions increases are: NO_x (9%), CO (8%), SO_2 (8%), PM_{10} (8%), and $PM_{2.5}$ (8%). As a result, the maximum impacts nearby these wells sites, resulting from construction activities under Alternative E, could be slightly higher than those modeled for Alternative B shown in Table 3.3-1 and Table 3.3-2, but below the impacts presented for Alternative C in Table 3.4-1 and Table 3.4-2. Construction impacts from the development of BT5 would occur at a later date than the other pads; however, the CAP impacts from the development of BT5 alone would be lower than those presented for Alternative C in Table 3.4.1 and Table 3.4-2 which include the development emissions from BT1, BT2, BT3, BT4, BT5, and all other project facilities. Impacts would be below applicable AAQS for all criteria pollutants and averaging periods everywhere in the model domain including at Nuiqsut.

3.6.3 BT1 Pre-Drill*

Alternative E BT1 pre-drilling phase is identical to Alternative B, with the exception of use of two line heaters instead of one and Alternative E proposes a larger well pad size. The peak annual Alternative E drilling emissions are similar to peak annual Alternative B drilling emissions (see Alternative B emissions in Table 2.1-7 as compared to Alternative E emissions in Table 2.1-19). Modeled impacts for this scenario, which are primarily influenced by the drilling equipment and not affected by pad size, would to be similar to the impacts presented for Alternative B in Table 3.3-3 and Table 3.3-4. Impacts would be below applicable AAQS for all criteria pollutants and averaging periods everywhere in the model domain including at Nuiqsut.

3.6.4 BT1 and BT2 Pre-Drill*

Alternative E BT1 and BT2 pre-drilling phase is identical to Alternative B with the exception of use of two line heaters instead of one and that larger well pad sizes are proposed for BT1 and BT2. Also, under Alternative E and the location of BT2 proposed under Alternative E is further north of the location proposed under Alternative B. The peak annual Alternative E drilling emissions are similar to peak annual Alternative B drilling emissions (see Alternative B emissions in Table 2.1-7 as compared to Alternative E emissions in Table 2.1-19). Modeled impacts for this scenario, which are primarily influenced by the drilling equipment and not affected by pad size, would be similar to the impacts presented for Alternative B in Table 3.3-5 and Table 3.3-6. Impacts would be below applicable AAQS for all criteria pollutants and averaging periods everywhere in the model domain including at Nuiqsut.

3.6.5 Development Drilling*

The total Alternative E development drilling operation emissions are comparable to those of Alternative B. The scenario modeled for Alternative B included production activities at BT1 and simultaneous drilling and production activities at BT2. At BT2, where both drilling and production simultaneously occur, Alternative E emissions percent increase relative to Alternative B are: NO_x (12%), CO (5%), SO_2 (63%), PM_{10} (13%), and $PM_{2.5}$ (15%). As a result, the maximum impacts at locations near these well sites, resulting from production activities under Alternative E, could be larger than those modeled for Alternative B. However, the maximum modeled impacts for Alternative B occur near the WCF and the WOC. Given that the emissions for the WCF and WOC are the same under Alternative B and E and the large distance to the BT1 and BT2 well sites, the impacts for Alternative E would be only slightly larger than the impacts presented for Alternative B in Table 3.3-7 and Table 3.3-8. Alternative E impacts would be below applicable AAQS for all criteria pollutants and averaging periods everywhere in the model domain including at Nuiqsut.

3.6.6 Routine Operations*

*3.6.6.1 Criteria Pollutant Impacts**

The peak annual Alternative E routine operation emissions are similar to peak annual Alternative B routine operation emissions (see Alternative B emissions in Table 2.1-8 as compared to Alternative E emissions in Table 2.1-20). Routine operations under Alternative E would be similar to Alternative B at the WPF and WOC. Under Alternative E, there would not be a BT4 wellsite. BT1 and BT2 will also include two line heaters at each site whereas only one line heater will be used at each site under the other action alternatives. In addition, BT5 would be located east of the location proposed for other action alternatives. For Alternative E the percent increases in emissions above Alternative B at both BT1 and BT2 are: NO_x (32%), CO (32%), SO_2 (93%), PM_{10} (24%), and $PM_{2.5}$ (39%). As a result, the maximum impacts at locations near these well sites, resulting from routine operations under Alternative E, would be slightly larger than those modeled for Alternative B. However, the maximum modeled impacts for Alternative B occur near the WCF and the WOC and given the distant locations that these facilities are from the BT1 and BT2 drill sites the modeled impacts for Alternative E would be only slightly larger than the impacts presented for Alternative B in Table 3.3-9 and Table 3.3-10. Alternative E impacts and would be below applicable AAQS for all criteria pollutants and averaging periods everywhere in the model domain including at Nuiqsut.

The peak Alternative E routine operation emissions are comparable to those of Alternative B. Therefore, the modeled impacts at Nuiqsut, for comparison to PSD Class II increments, would be similar to those of

Alternative B as shown in Table 3.3-11. Impacts at Nuiqsut are below applicable PSD increments for all pollutants and averaging times. It is important to note that a PSD increment assessment is the jurisdiction of ADEC and the proposed analysis differs from a formal increment consumption assessment in several important ways. See Section 1.2.3.2 for more information.

*3.6.6.2 HAPs Impacts**

The peak annual Alternative E routine operation HAPs emissions are similar to peak annual Alternative B routine operation HAPs emissions (see Alternative B emissions in Table 2.1-8 as compared to Alternative E emissions in Table 2.1-20). Therefore, HAP impacts under Alternative E would be less that the impacts presented for Alternative B in Table 3.3-12 and Table 3.3-13. The concentrations of all HAPs are well below their respective RELs on an hourly period, and RfCs on an annual period. The cancer risk is much less than the threshold of one in one million (1.0E-06) at Nuiqsut.

Table 3.3.3 in the main body of the Supplemental DEIS presents HAPs concentrations measured at Nuiqsut monitoring station starting in 2014 through March 2021. As shown in Table 3.3.3, measured HAPs concentrations are well below Acute REL and AEGLs. HAP measurements at Nuiqsut frequently have been below the measurement detection limit which indicates that HAP concentrations in ambient air are typically low. Note that some of health thresholds used for this assessment have become more stringent.

3.7 Module Delivery Option 2

Sections 3.6 and 3.7 describe the analysis of scenarios designed to characterize the potential impacts anticipated from transport of process and drill site modules to the North Slope via sealift barges. These sections also describe the modeled receptors, source types, emissions, and resulting impacts.

3.7.1 Overview of Scenario

Three options are analyzed for delivery of modules to the North Slope, any of which may be authorized with any of the action alternatives presented in the previous sections of this chapter:

1. Option 1 (Atigaru Point Module Transfer Island) – not modeled due to emissions being lower than Option 2 as explained below
2. Option 2 (Point Lonely Module Transfer Island)
3. Option 3 (Colville River Crossing) – modeling described in Section 3.8

In this section, Option 1 and Option 2 will be discussed and presented, while Option 3 is further described in Section 3.8.

As described in earlier sections, sealift barges would be used to deliver processing and drill site modules to the North Slope as part of the module delivery options. Module Delivery Option 1 and Option 2 would deliver modules to an MTI west of the Colville River, either at Atigaru Point or Point Lonely, and use ice roads to reach the Willow Development (See Figure 3.7-1 below).

The emissions for Module Delivery Options are shown in Section 2.1 “Willow Alternatives Emissions Inventories” (Table 2.1-29 and Table 2.1-31) for Option 1 (Atigaru Point Module Transfer Island) and Option 2 (Point Lonely Module Transfer Island). Peak year emissions for Option 1 (Atigaru Point Module Transfer Island) occur in year 2025 and 2026 (depending on Alternative) and are lower than peak year emissions for Option 2 (Point Lonely Module Transfer Island). As such, the Point Lonely option (MTI Option 2) was selected for a conservatively high quantitative analysis of potential air quality impacts.

This section provides a summary of the near-field modeling analysis that was performed to estimate the potential air quality impacts that could result from the construction and operation of a module transfer island (MTI). The AERMOD (version 18081) dispersion model was used to estimate criteria pollutant (CO, NO_2, SO_2, PM_{10} and $PM_{2.5}$) impacts from the construction and operation of the Point Lonely MTI. Version 18081 was the latest version of AERMOD available when the modeling was conducted. The change of model version would not change the impact analysis conclusions for the Point Lonely MTI. The meteorological data, model options, modeled receptors and source types and emissions utilized, and resulting impacts are described below.

As shown below, modeled impacts for Option 2 (Point Lonely) diminish with distance from the MTI and are negligible 25 km away. Modeled criteria air pollutant impacts are lower than the NAAQS and AAAQS. Impacts for HAPs were not directly modeled for Module Delivery Options because HAPs emissions (and hence impacts) from these activities would be substantially lower than the Routine Operations scenario in all action alternatives.

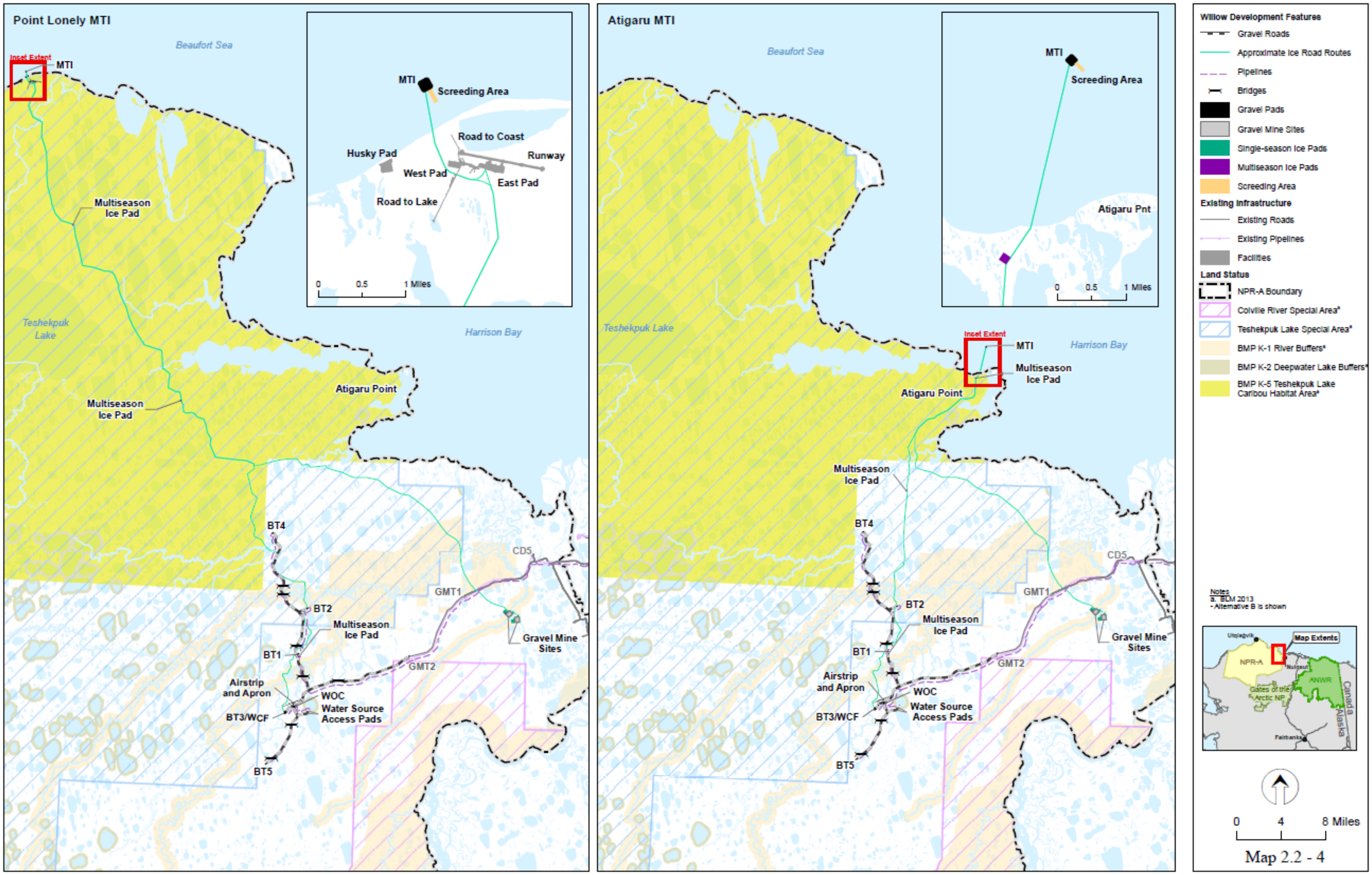


Figure 3.7.1 Module Transport Options Map: Options 1 and 2

3.7.2 Meteorological Data

Meteorological data for AERMOD were prepared using the Mesoscale Model Interface (MMIF) Program (Version 3.4.1) to extract five years (2009-2013) of AERMOD hourly surface and profile meteorological data sets for the Point Lonely MTI location from a Weather Research and Forecasting (WRF) model run for the North Slope of Alaska. This WRF model meteorological dataset was prepared for the Bureau of Ocean Energy Management (BOEM) to be utilized for air quality (AQ) modeling analyses in the Arctic (Ramboll 2016, 2017).

Figure 3.7-2 below shows a wind rose constructed from the Point Lonely location. The winds show the characteristic east-northeast to west-southwest bimodal pattern commonly observed on the North Slope. The average wind speed during 2009-2013 was 5.3 meters per second (m/s) and calm winds were infrequent, occurring for less than 1 percent of hours during the five-year period.

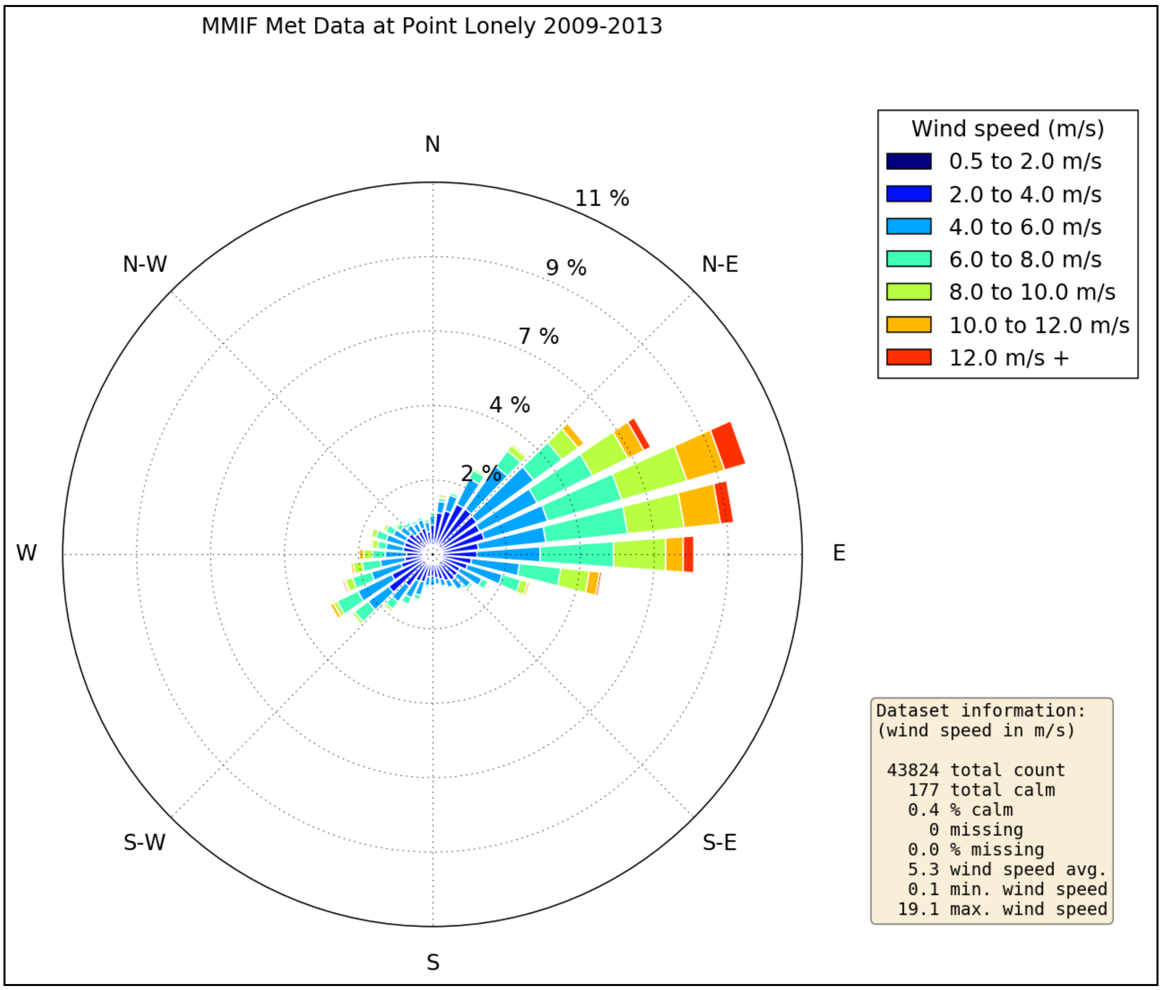


Figure 3.7.2 Point Lonely Location 2009-2013 Wind Rose

3.7.3 AERMOD Model Options

Regulatory default model settings were used, with the exception of the Ozone Limiting Method (OLM) model option, which was used for modeling NO_2 concentration estimates. Hourly ozone data is required to implement OLM. Since the best available meteorological dataset is not available for the period with the most current ozone measurements used for the AERMOD analyses described in Section 3.2.6, seasonal diurnal ozone concentration profiles were used instead of measurements that were concurrent with the meteorological data period. The seasonal diurnal ozone values used with OLM to analyze the Module Delivery impacts on NO_2 were developed using hourly ozone data measured at Nuiqsut during 2015-2017. These are the same calendar years that were used for developing the background NO_2 data presented in Section 3.2.6. The seasonal diurnal ozone data are shown in Table 3.7-1.

Downwash effects from buildings and structures were not considered in the analysis due to the large distance from the structures on the MTI and the closest onshore receptors.

Table 3.7-1 Nuiqsut 2015-2017 Seasonal Diurnal Ozone Concentrations (ppb)

Hour	Winter	Spring	Summer	Fall
01	40.2	38.8	26.1	36.7
02	40.4	38.4	26.1	37.0
03	39.8	38.4	25.5	36.9
04	39.8	37.9	24.2	36.5
05	40.0	38.1	25.0	37.0
06	40.2	38.2	25.4	36.7
07	40.0	38.3	26.0	36.6
08	40.0	38.7	26.4	36.8
09	40.0	38.2	27.1	36.7
10	40.2	38.5	28.3	36.8
11	39.8	39.2	28.3	36.7
12	39.4	39.1	28.3	36.6
13	39.5	39.3	29.1	36.4
14	39.5	39.2	29.1	36.6
15	39.5	39.5	30.4	36.3
16	39.3	39.6	30.3	36.8
17	39.6	40.5	30.0	36.6
18	39.2	40.9	30.2	36.5
19	39.6	40.1	29.6	36.6
20	39.9	39.2	29.2	36.6
21	39.7	39.2	28.5	36.3
22	39.6	38.9	27.5	36.5
23	39.8	39.7	27.2	36.8
24	39.8	39.1	26.2	36.9

3.7.4 Analysis Area and Model Receptors

The MTI analysis area is a 2,500 square kilometer area centered on the MTI. Model receptors were placed at 500-meter increments along the coastline and at inland locations extending to the southern edge of the analysis area. The receptors are shown in Figure F.1-1 of Attachment F. Flat terrain was assumed for all receptors.

3.7.5 Sources and Emissions

The Point Lonely MTI would include the construction of a gravel island with a design life of 5 to 10 years. Sources and emissions are described in the AQTSD under Section 2.1.6.

Modeled sources include point source emissions and volume sources. Equipment modeled as point sources include generator engines and heaters. Tug and barge, gravel island construction fugitive dust, and mobile sources tailpipe emissions were modeled as volume sources. A section along gravel access road was modeled as a series of volume sources to represent dust or tailpipe emissions from vehicle traffic. Stack parameters and volume sources characteristics selected are consistent with the parameters used for modeling Project Construction and Routine Operations activities.

Module Delivery Option 2 source locations are shown in Figure F.1-2 of Attachment F. Source descriptions and in-stack NO2/NOx ratios, stack parameters, and sources emissions rates for all modeled pollutants and averaging periods are included in Tables F.1-1, F.1-2, and F.1-3, respectively, within Attachment F.

3.7.6 Criteria Pollutant Impacts

Table 3.7-2 shows the modeled impacts to air quality anywhere in the analysis area for Module Delivery Option 2. Representative background concentrations are added to model results prior to comparing the total concentration to applicable AAQS. As shown, impacts would be below applicable AAQS for all criteria pollutants and averaging periods.

Table 3.7-2 Module Delivery Option 2 AAQS Impacts*

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	474.0	10,300.5	10,774.5	40,000	40,000	27%	27%
	8-Hour	106.8	3,433.5	3,540.3	10,000	10,000	35%	35%
NO_2	1-Hour	125.9	15.3	141.2	188	188	75%	75%
	Annual	0.6	3.8	4.4	100	100	4%	4%
SO_2	1-Hour	1.6	9.0	10.6	196	196	5%	5%
	3-Hour	1.1	10.0	11.1	1,300	1,300	1%	1%
	24-Hour	0.2	9.3	9.5	--	365	--	3%
	Annual	0.002	1.8	1.8	--	80	--	2%
PM_{10}	24-Hour	5.1	20.0	25.1	150	150	17%	17%
$PM_{2.5}$	24-Hour	2.1	7.0	9.1	35	35	26%	26%
	Annual	0.09	1.6	1.7	12	12	14%	14%

Notes:
Modeled highest second-high values from 5 modeled years shown for all short-term averaging times, with the exception of:
NO_2 1-hour value is calculated as the 3-year average of the 8th highest daily maximum 1-hour concentrations, and the background value shown is the average of the 1-hour values that are paired in time with the modeled values;
SO_2 1-hour value is calculated as the 3-year average of the 4th highest daily maximum 1-hour concentrations;
PM_{10} 24-hour value is the 6th highest value from 5-year modeling period; and
$PM_{2.5}$ 24-hour value is calculated as the 3-year average of the 8th highest values.
Maximum annual values are shown for NO_2 and SO_2 and the $PM_{2.5}$ annual value is the annual mean averaged over the maximum 3 years.
PM_{10} and $PM_{2.5}$ 24-hour, and $PM_{2.5}$ annual modeled impacts include secondary $PM_{2.5}$ impacts (0.48 µg/m³ - 24-hour and 0.05 µg/m³ - annual) from CAMx modeling.

3.8 Module Delivery Option 3

3.8.1 Overview of Scenario

Module Delivery Option 3 would make use of the existing Oliktok Dock for module delivery to the north slope by sealift barges. From Oliktok Dock, the modules would be transported to an existing 12-acre gravel staging pad approximately two miles south of the Dock for storage during and after sealift barge delivery. Modules would later be transported along existing gravel roads to Kuparuk DS2P. The modules would then travel on a heavy-haul ice road to GMT2, crossing the Colville River via grounded ice in the area of Ocean Point. From GMT2 to the WPF, the modules would be transported on the Willow access road under Alternatives B and C. Under Alternative D modules would be transported via the seasonal ice road between GMT2 and the WPF.

As stated in section 3.6.1, the Module Delivery Option 3 modeling scenario considers only emissions of criteria air pollutants. Impacts for HAPs were not directly modeled for module delivery options because HAP emissions and subsequent impacts from these activities would be substantially lower than the routine operations scenario in all action alternatives. Modeled sources include point source emissions and volume sources. Equipment modeled as point sources include stationary sources, such as engines and heaters, as well as large portable equipment and nonroad engines. Fugitive dust and mobile sources tailpipe emissions were modeled as volume sources.

Further information regarding sources of emissions can be found in Section 3.7.5; figures showing modeled sources relative to ambient air boundaries, structures, roads, and other Project features are presented in Attachment F. In addition, Attachment F includes detailed tables that provide a description of each modeled source, source emissions rates for all modeled pollutants and averaging periods, in-stack NO2-to-NOx ratio, modeled location, and stack- or volume-specific source parameters.

3.8.2 Meteorological Data

Meteorological data for Option 3 modeling was prepared using identical methods to Option 2 (see Section 3.6.2) but processed for the Oliktok Dock location (latitude of 70.51283, longitude of -149.86681).

Figure 3.8-1 below shows a wind rose constructed from the Oliktok location. The winds show the characteristic east-northeast to west-southwest bimodal pattern commonly observed on the North Slope. The average wind speed during 2009-2013 was 5.7 meters per second (m/s) and calm winds were infrequent, occurring for less than 1 percent of hours during the five-year period.

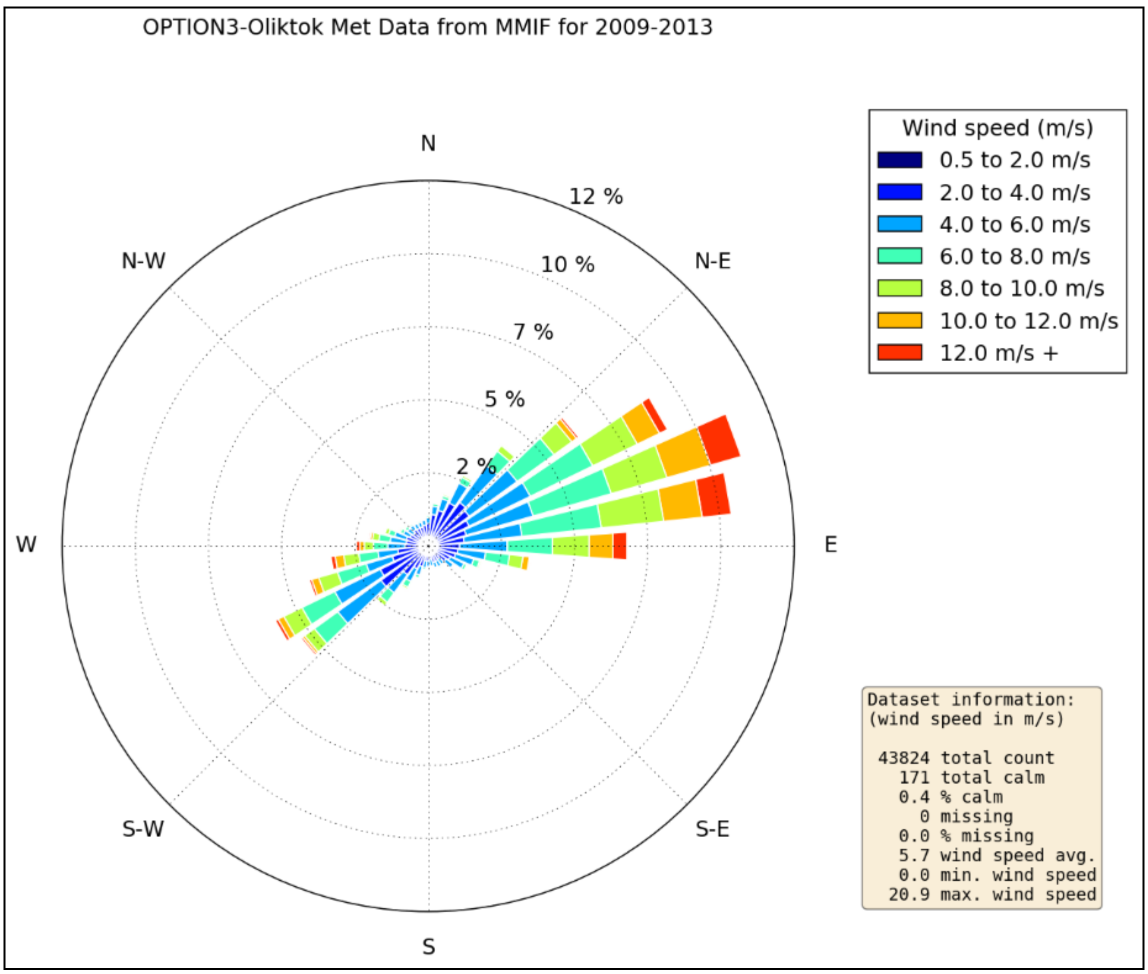


Figure 3.8.1 Oliktok Location 2009-2013 Wind Rose

3.8.3 AERMOD Model Options

Model options for Module Delivery Option 3 are identical to those used in Option 2 modeling except that a newer version of AERMOD (v19191) was used to estimate the criteria pollutant (CO, NO_2, SO_2, PM_{10} and $PM_{2.5}$) impacts during the modules transfer. For details on all model options, refer to Section 3.6.3.

3.8.4 Analysis Area and Model Receptors

The Module Delivery Option 3 analysis area is a 2,500 square kilometer area centered on Oliktok Dock. Model receptors were placed around the ambient air boundaries following the same spacing as the modeling for Project alternatives:

- 10 meter spacing along the ambient air boundary of Oliktok Dock and Staging Pad areas.
- 25 meter spacing from the ambient air boundary of Oliktok Dock and Staging Pad to 100 meters inland locations.
- 100 meter spacing from 100m of the ambient air boundary of Oliktok Dock and Staging Pad to 1km
- 250 meter spacing from 1 km of the ambient air boundary of Oliktok Dock and Staging Pad to 2 km
- 500 meter spacing from 2 km of the ambient air boundary of Oliktok Dock and Staging Pad to 5 km, as well as along the coastline
- 1,000 meter spacing from 5 km of the ambient air boundary of Oliktok Dock and Staging Pad at inlad locations extending to the southern edge of the analysis area

Flat terrain was assumed for all receptors. Receptor locations are shown in Figures F.2-1 to F.2-3 of Attachment F.

3.8.5 Sources and Emissions

Module Delivery Option 3 involves utilization of the existing Oliktok Dock for module offloading from sealift barges, as well as existing gravel roads and an existing 12-acre staging pad approximately two miles south of the dock. Minor improvements to gravel roads and the gravel staging pad are required, involving the addition of approximately 118,700 cubic yards of gravel to cover various roads and the staging pad. Additional gravel would also be required to raise the height of Oliktok Dock. Emissions from non-road construction equipment (including heater) and fugitive dust are modeled as volume sources at construction locations. Approximately 532 meters of roadway is modeled (100 meters exiting the dock offload area, plus 216 meters each to the north and south of the gravel staging pad), representing segments of road in the vicinity of construction and operational activities. Roadway sources are represented as series of separated volume sources, and include emissions of vehicle exhaust, module transport equipment exhaust, and fugitive road dust. Fugitive dust from the gravel staging pad is represented as a single volume source.

Emissions from vessel traffic are represented as distinct sources for each vessel type (Harbor Assist Tugs, Support Vessels, and Ocean-Going Vessels); all vessel traffic emissions are represented as series of separated volume sources. AERMOD source parameters were reviewed in publicly available dispersion modeling studies for marine sources. AERMOD release parameters for modeling Willow Option 3 are based on modeling of harbor craft and ocean-going vessels (LAHD, 2019). Dispersion parameters such as release heights, volume source spacing, initial lateral dimension (sigma y) and vertical dimension (sigma z) for ocean tugs/barges modeled for Willow Option 3 were assumed to be similar to those of cargo vessels. Similarly, the modeling parameters for assist tugs and support vessels in Willow Option 3 were assumed to be equivalent to harbor assist.

As a conservative approach, maximum-year emissions across all Option 3 activities were modeled. This includes construction improvements to gravel roads, staging pad, and Oliktok Dock in 2023; Vessel traffic in 2024; vehicle exhaust in 2025; staging pad fugitive dust from 2024; and module transport from 2024 into 2025. As additional conservative measure, fugitive road dust was modeled assuming emissions from both 2023 (during roadway construction activity) and 2026 (module transport operations).

Module Delivery Option 3 source locations are shown in Figure F.2-4 through F.2-9 of Attachment F. Source descriptions and in-stack NO_2/NOx ratios, stack parameters, and sources emissions rates for all modeled pollutants and averaging periods are included in Tables F.2-1, F.2-2, and F.2-3, respectively, within Attachment F.

3.8.6 Criteria Pollutant Impacts

Figure 3.8-2 shows the modeled impacts to air quality anywhere in the Option 3 analysis area. Representative background concentrations are added to model results prior to comparing the total concentration to applicable AAQS. As shown, impacts would be below applicable AAQS for all criteria pollutants and averaging periods.

Figure 3.8.2 Module Delivery Option 3 Activity AAQS Impacts*

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	255.6	10,300.5	10,556.1	40,000	40,000	26%	26%
	8-Hour	117.6	3,433.5	3,551.1	10,000	10,000	36%	36%
NO_2	1-Hour	112.6	10.1	122.7	188	188	65%	65%
	Annual	3.3	3.8	7.1	100	100	7%	7%
SO_2	1-Hour	1.4	9.0	10.4	196	196	5%	5%
	3-Hour	1.0	10.0	11.1	1,300	1,300	1%	1%
	24-Hour	0.4	9.3	9.7	--	365	--	3%
	Annual	0.1	1.8	1.9	--	80	--	2%
PM_{10}	24-Hour	23.4	30.0	53.4	150	150	36%	36%
$PM_{2.5}$	24-Hour	6.3	7.0	13.3	35	35	38%	38%
	Annual	0.4	1.6	2.0	12	12	17%	17%

Notes:
Modeled highest second-high values from 5 modeled years shown for all short-term averaging times, with the exception of:
NO_2 1-hour value is calculated as the 3-year average of the 8th highest daily maximum 1-hour concentrations, and the background value shown is the average of the 1-hour values that are paired in time with the modeled values;
SO_2 1-hour value is calculated as the 3-year average of the 4th highest daily maximum 1-hour concentrations;
PM_{10} 24-hour value is the 6th highest value from 5-year modeling period; and
$PM_{2.5}$ 24-hour value is calculated as the 3-year average of the 8th highest values.

Maximum annual values are shown for NO_2 and SO_2 and the $PM_{2.5}$ annual value is the annual mean averaged over the maximum 3 years. PM_{10} and $PM_{2.5}$ 24-hour, and $PM_{2.5}$ annual modeled impacts include secondary $PM_{2.5}$ impacts (0.48 µg/m^3 - 24-hour and 0.05 µg/m^3 - annual) from CAMx modeling.

3.9 Speed Limit Change Analysis

In the Willow near-field modeling, the estimated impacts of Project activities were analyzed using emissions developed with a road speed limit of 25 mph throughout the Willow Project area. However, there are some roads in the Project area that would have a 35 mph speed limit. As a result, the modeled impacts described above are re-assessed in this section in consideration of the expected emissions changes. Shown below are the emissions increases that would potentially occur as well as a discussion of how those changes could influence the estimated air quality impacts.

3.9.1 Emission Rate Changes

The emissions that would increase due to the higher speed limit are vehicle tailpipe emissions that are based on emission rates from the MOVES model. Fugitive dust emissions are not affected because those are calculated using the AP-42 emission factor for industrial unpaved roads which depend on silt content and vehicle weight and not speed (USEPA, 2006b). For the emissions inventory for this project, the MOVES 2014a model was run in on-road emission factor mode for each pollutant of interest, vehicle type of interest, all averaging speeds, and all processes. The MOVES output result was then aggregated across processes to determine the emission factor for each averaging speed based on vehicle type and pollutant. To account for increased emissions for vehicles driving at 35 mph instead of 25 mph, the percent increase in the emissions factor was first calculated for each pollutant; these are shown in Table 3.9-1. A weighted average percent increase for the vehicle fleet calculated based on the vehicle miles travelled (VMT) (shown in Table 3.9-2) in Project Year 4 for the construction scenario for all alternatives and Year 6 for all other scenarios for Alternatives B, C and E and Year 7 for Alternative D. The resulting VMT-weighted average percent emissions increases for the on-road tailpipe emissions are shown in Table 3.9-3. These are a conservative over-estimate of actual emissions increases as it assumes that the speed limit on all Project roads is 35 mph.

Table 3.9-1. Percent Increase in On-Road Vehicle Tailpipe Emission Factors by Vehicle Type

Vehicle Type	Pollutant														
	VOC	CO	NOx	PM_{10}	$PM_{2.5}$	SO_2	CO_2	CH_4	N_2O	Benzene	Toluene	Ethylbenzene	Xylenes	n-Hexane	Formaldehyde
Passenger Truck	18%	18%	13%	20%	23%	10%	10%	18%	25%	18%	18%	18%	18%	17%	18%
Light Commercial Truck	17%	23%	15%	14%	19%	10%	10%	19%	25%	18%	18%	18%	18%	16%	19%
Intercity Bus	17%	13%	12%	42%	30%	9%	9%	25%	25%	22%	20%	20%	21%	15%	25%
Single Unit Short-haul Truck	21%	14%	17%	40%	28%	15%	15%	24%	25%	22%	22%	22%	23%	20%	23%
Combination Short-haul Truck	14%	12%	11%	14%	11%	7%	7%	18%	25%	17%	15%	15%	16%	12%	18%

Table 3.9-2 Vehicle Miles Traveled by Vehicle Type*

Vehicle Type	Scenario							
	Alt B Construction –-– Year 4	Alt B All Non-construction –-– Year 6	Alt C Construction –-– Year 4	Alt C All Non-construction –-– Year 6	Alt D Construction – Year 4Alt D Construction – Year 4	Alt D All Non-construction –-– Year 7	Alt E Construction – Year 4	Alt E All Non-construction – Year 6
Passenger Truck	2,107,420	204,727	2,468,620	102,872	2,340,380	177,040	2,147,740	201,712
Light Commercial Truck	228,900	72,234	226,100	39,647	187,320	43,768	238,980	70,962
Intercity Bus	495,880	77,248	554,680	34,356	524,720	33,263	509,320	77,247
Single Unit Short-haul Truck	2,069,830	302,742	2,521,330	135,270	2,848,440	172,219	2,074,870	291,288
Combination Short-haul Truck	322,000	571,586	317,800	396,973	169,540	442,238	335,440	635,336

Table 3.9-3 Percent Increase in On-Road Vehicle Tailpipe Emissions Rates*

Alternative and Model Scenario	Pollutant														
	VOC	CO	NOx	PM_{10}	$PM_{2.5}$	SO_2	CO_2	CH_4	N_2O	Benzene	Toluene	Ethylbenzene	Xylenes	n-Hexane	Formaldehyde
Alt B Construction –-– Year 4	19%	16%	14%	29%	25%	12%	12%	21%	25%	20%	20%	20%	20%	18%	21%
Alt B All Non-Construction Scenarios –-– Year 6	17%	14%	13%	23%	19%	10%	10%	20%	25%	19%	18%	18%	18%	15%	20%
Alt C Construction –-– Year 4	19%	16%	14%	30%	25%	12%	12%	21%	25%	20%	20%	20%	20%	18%	21%
Alt C All Non-Construction Scenarios –-– Year 6	17%	14%	13%	21%	18%	9%	9%	20%	25%	18%	17%	17%	18%	15%	20%
Alt D Construction –-– Year 4	19%	16%	15%	31%	26%	12%	12%	21%	25%	20%	20%	20%	20%	18%	21%
Alt D All Non-Construction Scenarios – Year 7Alt D All Non-Construction Scenarios – Year 7	17%	14%	13%	22%	18%	10%	10%	20%	25%	18%	18%	18%	18%	15%	20%
Alt E Construction – Year 4	19%	16%	14%	29%	25%	12%	12%	21%	25%	20%	20%	20%	20%	18%	21%
Alt E All Non-Construction Scenarios – Year 6	17%	14%	13%	23%	19%	10%	10%	20%	25%	18%	18%	18%	18%	15%	20%

3.9.2 Potential Speed Adjusted Impacts

A conservatively high screening assessment was conducted to assess if a 35 mph speed limit affects the conclusions drawn from the air quality impact modeling analyses presented in Section 3.3 through 3.5. Through the screening assessment for all alternatives and scenarios and a refined assessment for a subset of model scenarios discussed below, it is determined that a speed limit of 35 mph would not change the conclusions of the near-field modeling analysis.

The conservatively high screening assessment was performed by applying the emissions rate changes for a 35 mph speed limit (shown above in Table 3.9-3) to the maximum modeled concentrations that occur anywhere in the analysis area. The screening assessment assumes that the total Project impact would increase due to the increase in vehicle speed, not just the fraction of the maximum impact that is due to the on-road tailpipe emissions. This screening assessment was performed for all scenarios and alternatives. The resulting impacts are shown in Table 3.9-4 through Table 3.9-16 for criteria pollutants and Table 3.8-17 through Table 3.8-22 for hazardous air pollutants. Since Alternative E was not explicitly modeled, the screening assessment presented below was not warranted for Alternative E. The results of the screening assessment are not anticipated to affect the air quality impacts under Alternative E, discussed in Section 3.6, since maximum model-predicted impacts are predominantly from equipment on the gravel pads and not on the roadway. This screening assessment results in an over-estimate of actual impacts because on-road tailpipe emissions contribute to only a portion of the total Project impacts. With regards to greenhouse gas (GHG) emissions, the estimated GHG emissions from on-road vehicle tailpipe emissions at the Project would be potentially higher by up to the percent increases shown for CO_2, CH_4 and N_2O in Table 3.8-3 due to increase in speed from 25 mph to 35 mph.

When using this conservatively high screening assessment, criteria pollutant cumulative impacts were below the NAAQS and AAAQS for all scenarios except four scenarios for which a refined assessment was conducted, as explained below. The four scenarios for which a refined assessment was conducted are: Alternative C Development Drilling 1-hour NO_2, Alternative C Routine Operations 1-hour NO_2, Alternative D Construction 24-hour PM_{10}, and Alternative D Development Drilling 1-hour NO_2. The refined assessment analyzes the impacts of increasing the emissions for just the mobile source impacts. For these four alternative/scenario combinations, as discussed below, all impacts would be well below the NAAQS and AAQS with a 35 mph speed limit. When using the conservatively high screening assessment, hazardous air pollutant impacts continue to be below relevant health-based thresholds with the change in speed limit from 25 mph to 35 mph.

The criteria pollutant impacts attributed to just on-road mobile sources were analyzed explicitly for those alternative/scenario/pollutant cases where the screening assessment showed values higher than the AAQS, i.e., Alternative C Development Drilling 1-hour NO_2, Alternative C Routine Operations 1-hour NO_2, Alternative D Construction 24-hour PM_{10}, and Alternative D Development Drilling 1-hour NO_2 by determining the on-road source contribution to receptors within 100 meters of the pads with maximum impacts. Then the on-road impacts were adjusted based on the emissions rates in Table 3.9-3 to evaluate the overall increase to the impacts.

For Alternative C Development Drilling, on-road sources contribute a maximum of 0.175 and 0.183 $\mu g/m^3$ to the three-year 1-hour NO_2 values in the vicinity of the WPF and South WOC, respectively. Increasing the traffic speed to 35mph (a 13% increase in emissions for this scenario as shown in Table 3.9-3) has a negligible effect on the maximum concentrations. The maximum increase in 1-hour NO_2 impacts under Alternative C Development Drilling would be approximately 0.023 $\mu g/m^3$ and

0.024 µg/m³ at the WCF and South WOC, respectively. This shows that overall impacts for Alternative C Development Drilling, when adjusted for speed increases, would be well below NAAQS and AAAQS. The maximum 1-hour NO_2 impact for Alternative C Routine Operations is identical to Alternative C Development Drilling and thus the overall impacts for Alternative C Routine Operations, when adjusted for speed increases, would also be well below NAAQS and AAAQS.

For Alternative D Construction, on-road sources contribute a maximum of 7.02, 7.89 and 0.25 ug/m³ to the maximum 24-hour average PM_{10} values in the vicinity of the BT2, WPF-BT3 and WOC, respectively. Increasing the traffic speed to 35mph (a 31% increase in emissions for this scenario as shown in Table 3.8-3) has an insignificant effect on the maximum concentrations. The maximum increase in 24-hour PM_{10} impacts under Alternative D Construction would be approximately 2.11, 2.37 and 0.08 ug/m3 at the BT2, WPF-BT3 and WOC, respectively. This demonstrates that overall impacts for Alternative D Construction, when adjusted for speed increases, would be well below NAAQS and AAAQS.

For Alternative D Development Drilling, on-road sources contribute a maximum of 0.353 and 0.048 ug/m³ to the three-year average 1-hour NO_2 values in the vicinity of the WPF-BT3 and WOC, respectively. Increasing the traffic speed to 35mph (a 13% increase in emissions for this scenario as shown in Table 3.8-3) has a negligible effect on the maximum concentrations. The maximum increase in 1-hour NO2 impacts under Alternative D Development Drilling would be approximately 0.046 ug/m3 and 0.006 ug/m3 at the WPF-BT3 and WOC, respectively. The shows that overall impacts for Alternative D Development Drilling, when adjusted for speed increases, would be well below NAAQS and AAAQS.

In summary, as discussed above, all air quality impacts in all alternatives and scenarios would be below the NAAQS and AAAQS even with a 35 mph speed limit. This is shown either with the screening assessment in Table 3.9-4 through Table 3.9-16, or a detailed analysis of the on-road source contribution at peak receptors. Hazardous air pollutant impacts, shown in Table 3.8-17 through Table 3.8-22, would be below relevant health-based thresholds.

Table 3.9-4 Screening Test: BT1 Pre-Drill Activity AAQS Impacts with Speed Adjustment in Alternative B**

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Speed Adjusted Concentration * (µg/m³)	Background Concentration (µg/m³)	Total Concentration * (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS*	Percent of AAAQS*
CO	1-Hour	1,483.3	1,716.0	10,300.5	12,016.6	40,000	40,000	30%	30%
	8-Hour	1,103.9	1,277.1	3,433.5	4,710.6	10,000	10,000	47%	47%
NO_2	1-Hour	64.3	73.5	26.7	100.2	188	188	53%	53%
	Annual	10.8	12.4	3.8	16.1	100	100	16%	16%
SO_2	1-Hour	4.2	4.7	9.0	13.6	196	196	7%	7%
	3-Hour	3.6	4.0	10.0	14.0	1,300	1,300	1%	1%
	24-Hour	2.0	2.3	9.3	11.6	--	365	--	3%
	Annual	0.2	0.2	1.8	2.0	--	80	--	3%
PM_{10}	24-Hour	16.7	21.6	20	41.6	150	150	28%	28%

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Speed Adjusted Concentration * (µg/m³)	Background Concentration (µg/m³)	Total Concentration * (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS*	Percent of AAAQS*
$PM_{2.5}$	24-Hour	10.0	12.5	7.0	19.5	35	35	56%	56%
	Annual	2.0	2.5	1.6	4.1	12	12	34%	34%

Numbers may not add exactly due to rounding
* Values are an over-estimate of actual impacts because only a fraction of the total Project impact is due to tailpipe emissions but in this screening test, the total Project impact is conservatively increased by the percent increase for each pollutant due to the speed increase

Table 3.9-5 Screening Test: BT1 and BT2 Pre-Drill Activity AAQS Impacts with Speed Adjustment in Alternative B*

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Speed Adjusted Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	833.2	964.0	10,300.5	11,264.5	40,000	40,000	28%	28%
	8-Hour	641.0	741.6	3,433.5	4,175.1	10,000	10,000	42%	42%
NO_2	1-Hour	55.8	63.8	26.6	90.4	188	188	48%	48%
	Annual	6.7	7.6	3.8	11.4	100	100	11%	11%
SO_2	1-Hour	3.1	3.4	9.0	12.4	196	196	6%	6%
	3-Hour	2.8	3.1	10.0	13.1	1,300	1,300	1%	1%
	24-Hour	1.3	1.4	9.3	10.8	--	365	--	3%
	Annual	0.1	0.1	1.8	1.9	--	80	--	2%
PM_{10}	24-Hour	17.1	22.1	40	62.1	150	150	41%	41%
$PM_{2.5}$	24-Hour	7.5	9.3	7.0	16.3	35	35	47%	47%
	Annual	0.9	1.2	1.6	2.8	12	12	23%	23%

Numbers may not add exactly due to rounding
* Values shown are an over-estimate of actual impacts because only a fraction of the total Project impact is due to tailpipe emissions but in this screening test, the total Project impact is conservatively increased by the percent increase for each pollutant due to the speed increase.

Table 3.9-6 Screening Test: Routine Operations Activity AAQS Impacts with Speed Adjustment in Alternative B**

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Speed Adjusted Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	1,389.5	1,585.2	10,300.5	11,885.7	40,000	40,000	30%	30%
	8-Hour	921.7	1,051.5	3,433.5	4,485.0	10,000	10,000	45%	45%
NO_2	1-Hour	138.5	156.9	20.4	177.3	188	188	94%	94%
	Annual	24.9	28.2	3.8	31.9	100	100	32%	32%

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Speed Adjusted Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
SO_2	1-Hour	17.9	19.7	9.0	28.7	196	196	15%	15%
	3-Hour	16.6	18.2	10.0	28.2	1,300	1,300	2%	2%
	24-Hour	10.2	11.2	9.3	20.5	--	365	--	6%
	Annual	0.8	0.9	1.8	2.8	--	80	--	3%
PM_{10}	24-Hour	65.6	80.7	30	110.7	150	150	74%	74%
$PM_{2.5}$	24-Hour	22.6	26.9	7.0	33.9	35	35	97%	97%
	Annual	4.2	5.0	1.6	6.6	12	12	55%	55%

Numbers may not add exactly due to rounding

* Values shown are an over-estimate of actual impacts because only a fraction of the total Project impact is due to tailpipe emissions but in this screening test, the total Project impact is conservatively increased by the percent increase for each pollutant due to the speed increase.

Table 3.9-7 Screening Test: Construction Activity AAQS Impacts with Speed Adjustment in Alternative B**

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Speed Adjusted Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	526.4	609.0	10,300.5	10,909.5	40,000	40,000	27%	27%
	8-Hour	390.0	451.2	3,433.5	3,884.7	10,000	10,000	39%	39%
NO_2	1-Hour	111.4	127.4	22.4	149.8	188	188	80%	80%
	Annual	17.0	19.4	3.8	23.2	100	100	23%	23%
SO_2	1-Hour	3.6	4.0	9.0	13.0	196	196	7%	7%
	3-Hour	5.2	5.8	10.0	15.8	1,300	1,300	1%	1%
	24-Hour	1.2	1.4	9.3	10.7	--	365	--	3%
	Annual	0.1	0.1	1.8	1.9	--	80	--	2%
PM_{10}	24-Hour	61.9	80.0	30	110.0	150	150	73%	73%
$PM_{2.5}$	24-Hour	11.6	14.3	7.0	21.3	35	35	61%	61%
	Annual	2.6	3.2	1.6	4.8	12	12	40%	40%

Numbers may not add exactly due to rounding

* Values shown are an over-estimate of actual impacts because only a fraction of the total Project impact is due to tailpipe emissions but in this screening test, the total Project impact is conservatively increased by the percent increase for each pollutant due to the speed increase. See refined analysis in Section 3.8.2 for scenarios/pollutants where screening values are higher than AAQS.

Table 3.9-8 Screening Test: Development Drilling Activity AAQS Impacts with Speed Adjustment in Alternative B**

Pollutant	Averaging Time	Maximum Modeled Concentration (μg/m³)	Speed Adjusted Concentration (μg/m³)	Background Concentration (μg/m³)	Total Concentration (μg/m³)	NAAQS (μg/m³)	AAAQS (μg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	1,389.5	1,585.2	10,300.5	11,885.7	40,000	40,000	30%	30%
	8-Hour	921.7	1,051.5	3,433.5	4,485.0	10,000	10,000	45%	45%
NO_2	1-Hour	138.5	156.9	20.4	177.3	188	188	94%	94%
	Annual	24.9	28.2	3.8	32.0	100	100	32%	32%
SO_2	1-Hour	17.9	19.7	9.0	28.7	196	196	15%	15%
	3-Hour	16.6	18.2	10.0	28.2	1,300	1,300	2%	2%
	24-Hour	10.2	11.2	9.3	20.5	--	365	--	6%
	Annual	0.8	0.9	1.8	2.8	--	80	--	3%
PM_{10}	24-Hour	65.6	80.8	30	110.8	150	150	74%	74%
$PM_{2.5}$	24-Hour	22.6	26.9	7.0	33.9	35	35	97%	97%
	Annual	4.2	5.0	1.6	6.6	12	12	55%	55%

Numbers may not add exactly due to rounding
* Values shown are an over-estimate of actual impacts because only a fraction of the total Project impact is due to tailpipe emissions but in this screening test, the total Project impact is conservatively increased by the percent increase for each pollutant due to the speed increase. See refined analysis in Section 3.8.2 for scenarios/pollutants where screening values are higher than AAQS.

Table 3.9-9 Screening Test: BT1 Pre-Drill Activity AAQS Impacts with Speed Adjustment in Alternative C**

Pollutant	Averaging Time	Maximum Modeled Concentration (μg/m³)	Speed Adjusted Concentration (μg/m³)	Background Concentration (μg/m³)	Total Concentration (μg/m³)	NAAQS (μg/m³)	AAAQS (μg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	1,471.5	1,702.0	10,300.5	12,002.5	40,000	40,000	30%	30%
	8-Hour	1,128.2	1,304.9	3,433.5	4,738.4	10,000	10,000	47%	47%
NO_2	1-Hour	65.7	75.2	23.9	99.1	188	188	53%	53%
	Annual	12.7	14.6	3.8	18.3	100	100	18%	18%
SO_2	1-Hour	4.2	4.7	9.0	13.6	196	196	7%	7%
	3-Hour	4.1	4.6	10.0	14.6	1,300	1,300	1%	1%
	24-Hour	2.2	2.4	9.3	11.8	--	365	--	3%
	Annual	0.2	0.3	1.8	2.1	--	80	--	3%
PM_{10}	24-Hour	18.0	23.3	10	33.3	150	150	22%	22%
$PM_{2.5}$	24-Hour	11.4	14.3	7.0	21.3	35	35	61%	61%
	Annual	2.3	2.9	1.6	4.5	12	12	37%	37%

Numbers may not add exactly due to rounding
* Values shown are an over-estimate of actual impacts because only a fraction of the total Project impact is due to tailpipe emissions but in this screening test, the total Project impact is conservatively increased by the percent increase for each pollutant due to the speed increase. See refined analysis in Section 3.8.2 for scenarios/pollutants where screening values are higher than AAQS.

Table 3.9-10 Screening Test: BT1 and BT2 Pre-Drill Activity AAQS Impacts with Speed Adjustment in Alternative C**

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Speed Adjusted Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	826.4	955.9	10,300.5	11,256.4	40,000	40,000	28%	28%
	8-Hour	635.7	735.3	3,433.5	4,168.8	10,000	10,000	42%	42%
NO_2	1-Hour	57.6	65.9	15.6	81.5	188	188	43%	43%
	Annual	12.6	14.4	3.8	18.1	100	100	18%	18%
SO_2	1-Hour	4.2	4.7	9.0	13.6	196	196	7%	7%
	3-Hour	4.1	4.6	10.0	14.6	1,300	1,300	1%	1%
	24-Hour	1.8	2.0	9.3	11.3	--	365	--	3%
	Annual	0.2	0.2	1.8	2.1	--	80	--	3%
PM_{10}	24-Hour	17.9	23.2	10	33.2	150	150	22%	22%
$PM_{2.5}$	24-Hour	11.4	14.2	7.0	21.2	35	35	61%	61%
	Annual	2.3	2.8	1.6	4.4	12	12	37%	37%

Numbers may not add exactly due to rounding
* Values shown are an over-estimate of actual impacts because only a fraction of the total Project impact is due to tailpipe emissions but in this screening test, the total Project impact is conservatively increased by the percent increase for each pollutant due to the speed increase. See refined analysis in Section 3.8.2 for scenarios/pollutants where screening values are higher than AAQS.

Table 3.9-11 Screening Test: Routine Operations Activity AAQS Impacts with Speed Adjustment in Alternative C**

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Speed Adjusted Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	1,308.0	1,488.5	10,300.5	11,789.0	40,000	40,000	29%	29%
	8-Hour	930.9	1,059.4	3,433.5	4,492.9	10,000	10,000	45%	45%
NO_2	1-Hour	147.6	166.6	25.1	191.7	188	188	102.0%	102.0%
	Annual	24.0	27.1	3.8	30.9	100	100	31%	31%
SO_2	1-Hour	19.2	21.0	9.0	30.0	196	196	15%	15%
	3-Hour	16.9	18.5	10.0	28.5	1,300	1,300	2%	2%
	24-Hour	10.4	11.4	9.3	20.8	--	365	--	6%
	Annual	0.9	1.0	1.8	2.9	--	80	--	4%
PM_{10}	24-Hour	77.8	94.2	40	134.2	150	150	89%	89%
$PM_{2.5}$	24-Hour	19.0	22.3	7.0	29.3	35	35	84%	84%
	Annual	5.0	5.8	1.6	7.4	12	12	62%	62%

Numbers may not add exactly due to rounding
* Values shown are an over-estimate of actual impacts because only a fraction of the total Project impact is due to tailpipe emissions but in this screening test, the total Project impact is conservatively increased by the percent increase for each pollutant due to the speed increase. See refined analysis in Section 3.8.2 for scenarios/pollutants where screening values are higher than AAQS.

Table 3.9-12 Screening Test: Construction Activity AAQS Impacts with Speed Adjustment in Alternative C**

Pollutant	Averaging Time	Maximum Modeled Concentration (μg/m³)	Speed Adjusted Concentration (μg/m³)	Background Concentration (μg/m³)	Total Concentration (μg/m³)	NAAQS (μg/m³)	AAAQS (μg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	643.2	744.0	10,300.5	11,044.5	40,000	40,000	28%	28%
	8-Hour	488.1	564.5	3,433.5	3,998.0	10,000	10,000	40%	40%
NO_2	1-Hour	136.0	155.6	13.4	169.0	188	188	90%	90%
	Annual	35.4	40.5	3.8	44.2	100	100	44%	44%
SO_2	1-Hour	4.3	4.8	9.0	13.8	196	196	7%	7%
	3-Hour	5.2	5.8	10.0	15.8	1,300	1,300	1%	1%
	24-Hour	1.3	1.5	9.3	10.8	--	365	--	3%
	Annual	0.2	0.3	1.8	2.1	--	80	--	3%
PM_{10}	24-Hour	90.4	117.3	20	137.3	150	150	92%	92%
$PM_{2.5}$	24-Hour	16.7	20.7	7.0	27.7	35	35	79%	79%
	Annual	5.4	6.8	1.6	8.4	12	12	70%	70%

Numbers may not add exactly due to rounding
* Values shown are an over-estimate of actual impacts because only a fraction of the total Project impact is due to tailpipe emissions but in this screening test, the total Project impact is conservatively increased by the percent increase for each pollutant due to the speed increase.

Table 3.9-13 Screening Test: Development Drilling Activity AAQS Impacts with Speed Adjustment in Alternative C**

Pollutant	Averaging Time	Maximum Modeled Concentration (μg/m³)	Speed Adjusted Concentration (μg/m³)	Background Concentration (μg/m³)	Total Concentration (μg/m³)	NAAQS (μg/m³)	AAAQS (μg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	1,308.0	1,488.5	10,300.5	11,789.0	40,000	40,000	29%	29%
	8-Hour	930.9	1,059.4	3,433.5	4,492.9	10,000	10,000	45%	45%
NO_2	1-Hour	147.6	166.6	25.1	191.7	188	188	102.0%	102.0%
	Annual	24.1	27.2	3.8	30.9	100	100	31%	31%
SO_2	1-Hour	19.3	21.1	9.0	30.1	196	196	15%	15%
	3-Hour	16.9	18.5	10.0	28.5	1,300	1,300	2%	2%
	24-Hour	10.4	11.4	9.3	20.8	--	365	--	6%
	Annual	0.9	1.0	1.8	2.9	--	80	--	4%
PM_{10}	24-Hour	91.4	110.6	30	140.6	150	150	94%	94%
$PM_{2.5}$	24-Hour	19.0	22.3	7.0	29.3	35	35	84%	84%
	Annual	5.0	5.8	1.6	7.4	12	12	62%	62%

Numbers may not add exactly due to rounding
* Values shown are an over-estimate of actual impacts because only a fraction of the total Project impact is due to tailpipe emissions but in this screening test, the total Project impact is conservatively increased by the percent increase for each pollutant due to the speed increase. See refined analysis in Section 3.8.2 for scenarios/pollutants where screening values are higher than AAQS.

Table 3.9-14 Screening Test: Routine Operations Activity AAQS Impacts with Speed Adjustment in Alternative D**

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Speed Adjusted Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	1,535.5	1,752.1	10,300.5	12,052.6	40,000	40,000	30%	30%
	8-Hour	566.0	645.9	3,433.5	4,079.4	10,000	10,000	41%	41%
NO_2	1-Hour	143.6	162.2	24.5	186.7	188	188	99%	99%
	Annual	22.1	25.0	3.8	28.7	100	100	29%	29%
SO_2	1-Hour	17.9	19.6	9.0	28.6	196	196	15%	15%
	3-Hour	15.1	16.6	10.0	26.6	1,300	1,300	2%	2%
	24-Hour	11.8	13.0	9.3	22.3	--	365	--	6%
	Annual	0.8	0.9	1.8	2.7	--	80	--	3%
PM_{10}	24-Hour	63.9	77.5	20	97.5	150	150	65%	65%
$PM_{2.5}$	24-Hour	18.5	21.8	7.0	28.8	35	35	82%	82%
	Annual	3.9	4.6	1.6	6.2	12	12	52%	52%

Numbers may not add exactly due to rounding
* Values shown are an over-estimate of actual impacts because only a fraction of the total Project impact is due to tailpipe emissions but in this screening test, the total Project impact is conservatively increased by the percent increase for each pollutant due to the speed increase.

Table 3.9-15 Screening Test: Construction Activity AAQS Impacts with Speed Adjustment in Alternative D**

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Speed Adjusted Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	528.1	610.3	10,300.5	10,910.8	40,000	40,000	27%	27%
	8-Hour	390.1	450.8	3,433.5	3,884.3	10,000	10,000	39%	39%
NO_2	1-Hour	111.5	127.9	22.4	150.3	188	188	80%	80%
	Annual	15.6	17.9	3.8	21.7	100	100	22%	22%
SO_2	1-Hour	3.6	4.0	9.0	13.0	196	196	7%	7%
	3-Hour	5.2	5.8	10.0	15.8	1,300	1,300	1%	1%
	24-Hour	1.2	1.4	9.3	10.7	--	365	--	3%
	Annual	0.1	0.1	1.8	1.9	--	80	--	2%
PM_{10}	24-Hour	102.8	134.5	30	164.5	150	150	110%	110%
$PM_{2.5}$	24-Hour	9.2	11.4	7.0	18.4	35	35	52%	52%
	Annual	2.4	3.0	1.6	4.6	12	12	39%	39%

Numbers may not add exactly due to rounding
* Values shown are an over-estimate of actual impacts because only a fraction of the total Project impact is due to tailpipe emissions but in this screening test, the total Project impact is conservatively increased by the percent increase for each pollutant due to the speed increase. See refined analysis in Section 3.8.2 for scenarios/pollutants where screening values are higher than AAQS.

Table 3.9-16 Screening Test: Development Drilling Activity AAQS Impacts with Speed Adjustment in Alternative D**

Pollutant	Averaging Time	Maximum Modeled Concentration (µg/m³)	Speed Adjusted Concentration (µg/m³)	Background Concentration (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)	AAAQS (µg/m³)	Percent of NAAQS	Percent of AAAQS
CO	1-Hour	1,535.5	1,752.2	10,300.5	12,052.7	40,000	40,000	30%	30%
	8-Hour	599.7	684.3	3,433.5	4,117.8	10,000	10,000	41%	41%
NO_2	1-Hour	150.7	170.2	25.0	195.2	188	188	104%	104%
	Annual	23.6	26.7	3.8	30.5	100	100	30%	30%
SO_2	1-Hour	18.0	19.7	9.0	28.7	196	196	15%	15%
	3-Hour	15.6	17.1	10.0	27.2	1,300	1,300	2%	2%
	24-Hour	12.2	13.4	9.3	22.7	--	365	--	6%
	Annual	0.9	0.9	1.8	2.8	--	80	--	3%
PM_{10}	24-Hour	66.2	80.3	30	110.3	150	150	74%	74%
$PM_{2.5}$	24-Hour	21.1	24.8	7.0	31.8	35	35	91%	91%
	Annual	5.1	6.1	1.6	7.7	12	12	64%	64%

Numbers may not add exactly due to rounding
* Values shown are an over-estimate of actual impacts because only a fraction of the total Project impact is due to tailpipe emissions but in this screening test, the total Project impact is conservatively increased by the percent increase for each pollutant due to the speed increase. See refined analysis in Section 3.8.2 for scenarios/pollutants where screening values are higher than AAQS.

Table 3.9-17 Screening Test: Routine Operation Activity Acute and Non-carcinogenic HAPs Impacts with Speed Adjustment– Alternative B*

Pollutant	Max 1-hour (µg/m³)	Speed Adjusted Max 1-hour Concentration (ug/m3)	Acute REL (µg/m³)	Max 8-hour (µg/m³)	Speed Adjusted Max 8-hour Concentration (ug/m3)	Sub-Chronic AEGLs (µg/m³)	Max Annual (µg/m³)	Speed Adjusted max Annual Concentration (ug/m3)	RfC (µg/m³)
Benzene	8.8	10.4	27.0	6.0	7.1	29,000.0	0.2	0.2**	30.0
Ethylbenzene	230.7	272.1	140,000.0	155.4	183.3	140,000.0	5.0	5.8	260.0
Formaldehyde	1.4	1.7	55.0	0.8	0.9	1,100.0	0.0	0.0	9.8
n-hexane	562.9	648.4	10,000,000.0	379.1	436.8	10,000,000.0	12.1	13.9	700.0
Toluene	25.7	30.3	5,000.0	17.3	20.4	250,000.0	0.6	0.7	5,000.0
Xylene	454.5	538.4	22,000.0	306.2	362.7	560,000.0	9.8	11.6	100.0

Numbers may not add exactly due to rounding
* Values shown are an over-estimate of actual impacts because only a fraction of the total Project impact is due to tailpipe emissions but in this screening test, the total Project impact is conservatively increased by the percent increase for each pollutant due to the speed increase.
**The max annual concentration with and without the speed impact are the same because of rounding.

Table 3.9-18 Screening Test: Routine Operation Activity Carcinogenic HAPs Impacts with Speed Adjustment in Alternative B*

Pollutant	Max Annual (µg/m³)	Speed Adjustment Annual Concentration (ug/m3)	RfC (µg/m³)	Max Annual as a % of RfC	Cancer Unit Risk Factor thresholds (1/(µg/m³))	Exposure Adjustment Factor	Cancer Risk
Benzene	9.70E-04	1.15E-03	3.00E+01	0.004%	7.80E-06	4.30E-01	3.86E-09
Ethylbenzene	3.97E-03	4.68E-03	1.00E+03	0.0005%	2.50E-06		5.03E-09
Formaldehyde	3.70E-04	4.44E-04	9.80E+00	0.005%	1.30E-05		2.48E-09
						Total Cancer Risk:	1.1E-08

Numbers may not add exactly due to rounding
* Values shown are an over-estimate of actual impacts because only a fraction of the total Project impact is due to tailpipe emissions but in this screening test, the total Project impact is conservatively increased by the percent increase for each pollutant due to the speed increase.

Table 3.9-19 Screening Test: Routine Operation Activity Acute and Non-carcinogenic HAPs Impacts with Speed Adjustment– Alternative C*

Pollutant	Max 1-hour (µg/m³)	Speed Adjusted max 1-hour Concentration (ug/m3)	Acute REL (µg/m³)	Max 8-hour (µg/m³)	Speed Adjusted max 8-hour Concentration (ug/m3)	Sub-Chronic AEGLs (µg/m³)	Max Annual (µg/m³)	Speed Adjusted max Annual Concentration (ug/m3)	RfC (µg/m³)
Benzene	8.7	10.2	27.0	5.9	6.9	29,000.0	0.2	0.2**	30.0
Ethylbenzene	226.8	266.3	140,000.0	152.5	179.1	140,000.0	4.8	5.6	260.0
Formaldehyde	1.4	1.7	55.0	0.8	0.9	1100.0	0.0	0.0	9.8
n-hexane	553.3	633.9	10,000,000.0	372.0	426.2	10,000,000.0	11.6	13.3	700.0
Toluene	25.3	29.7	5,000.0	17.0	20.0	250,000.0	0.5	0.6	5,000.0
Xylene	446.8	527.1	22,000.0	300.4	354.4	560,000.0	9.4	11.1	100.0

Numbers may not add exactly due to rounding
* Values shown are an over-estimate of actual impacts because only a fraction of the total Project impact is due to tailpipe emissions but in this screening test, the total Project impact is conservatively increased by the percent increase for each pollutant due to the speed increase.
**The max annual concentration with and without the speed impact are the same because of rounding.

Table 3.9-20 Screening Test: Routine Operation Activity Carcinogenic HAPs Impacts with Speed Adjustment in Alternative C*

Pollutant	Max Annual (µg/m³)	Speed Adjustment Annual Concentration (ug/m3)	RfC (µg/m³)	Max Annual as a % of RfC	Cancer Unit Risk Factor thresholds (1/(µg/m³))	Exposure Adjustment Factor	Cancer Risk
Benzene	1.03E-03	1.22E-03	3.00E+01	0.004%	7.80E-06	4.30E-01	4.08E-09
Ethylbenzene	3.97E-03	4.66E-03	1.00E+03	0.0005%	2.50E-06		5.01E-09
Formaldehyde	3.80E-04	4.55E-04	9.80E+00	0.005%	1.30E-05		2.54E-09
						Total Cancer Risk:	1.2E-08

Numbers may not add exactly due to rounding
* Values shown are an over-estimate of actual impacts because only a fraction of the total Project impact is due to tailpipe emissions but in this screening test, the total Project impact is conservatively increased by the percent increase for each pollutant due to the speed increase.

Table 3.9-21 Screening Test: Routine Operation Activity Acute and Non-carcinogenic HAPs Impacts with Speed Adjustment– Alternative D*

Pollutant	Max 1-hour (µg/m³)	Speed Adjusted max 1-hour Concentration (ug/m3)	Acute REL (µg/m³)	Max 8-hour (µg/m³)	Speed Adjusted max 8-hour Concentration (ug/m3)	Sub-Chronic AEGLs (µg/m³)	Max Annual (µg/m³)	Speed Adjusted max Annual Concentration (ug/m3)	RfC (µg/m³)
Benzene	8.8	10.5	27.0	5.9	7.0	29,000.0	0.2	0.2**	30.0
Ethylbenzene	232.3	273.1	140,000.0	155.4	182.7	140,000.0	5.0	5.8	260.0
Formaldehyde	1.4	1.7	55.0	0.8	0.9	1,100.0	0.0	0.0	9.8
n-hexane	566.7	651.2	10,000,000.0	379.1	435.6	10,000,000.0	12.1	13.9	700.0
Toluene	25.9	30.4	5,000.0	17.3	20.3	250,000.0	0.6	0.7	5,000.0
Xylene	457.7	540.2	22,000.0	306.2	361.4	560,000.0	9.8	11.5	100.0

Numbers may not add exactly due to rounding
* Values shown are an over-estimate of actual impacts because only a fraction of the total Project impact is due to tailpipe emissions but in this screening test, the total Project impact is conservatively increased by the percent increase for each pollutant due to the speed increase.
**The max annual concentration with and without the speed impact are the same because of rounding.

Table 3.9-22 Screening Test: Routine Operation Activity Carcinogenic HAPs Impacts with Speed Adjustment in Alternative D*

Pollutant	Max Annual (µg/m³)	Speed Adjustment Annual Concentration (ug/m3)	RfC (µg/m³)	Max Annual as a % of RfC	Cancer Unit Risk Factor thresholds (1/(µg/m³))	Exposure Adjustment Factor	Cancer Risk
Benzene	1.00E-03	1.18E-03	3.00E+01	0.004%	7.80E-06	4.30E-01	3.97E-09
Ethylbenzene	3.96E-03	4.65E-03	1.00E+03	0.0005%	2.50E-06		5.00E-09
Formaldehyde	3.70E-04	4.42E-04	9.80E+00	0.005%	1.30E-05		2.47E-09
						Total Cancer Risk:	1.1E-08

Numbers may not add exactly due to rounding
* Values shown are an over-estimate of actual impacts because only a fraction of the total Project impact is due to tailpipe emissions but in this screening test, the total Project impact is conservatively increased by the percent increase for each pollutant due to the speed increase.

4.0 REGIONAL MODEL CONFIGURATION AND ASSESSMENT METHODS

4.1 Overview and Modeling Domains

The photochemical grid model (PGM) CAMx was used to conduct the far-field analysis in this study. PGMs calculate the time-varying air quality concentrations of various pollutants in a spatial grid using emissions and meteorological data inputs. A PGM is a three-dimensional Eulerian model (horizontal and vertical) that simulates both chemical and physical (transport and removal) processes in the atmosphere. PGMs can be used to estimates source impacts for pollutants that are both directly emitted and those formed in the atmosphere through chemical reactions. The schematic in Figure 4.1-1 shows the various components in the regional modeling platform proposed for this study.

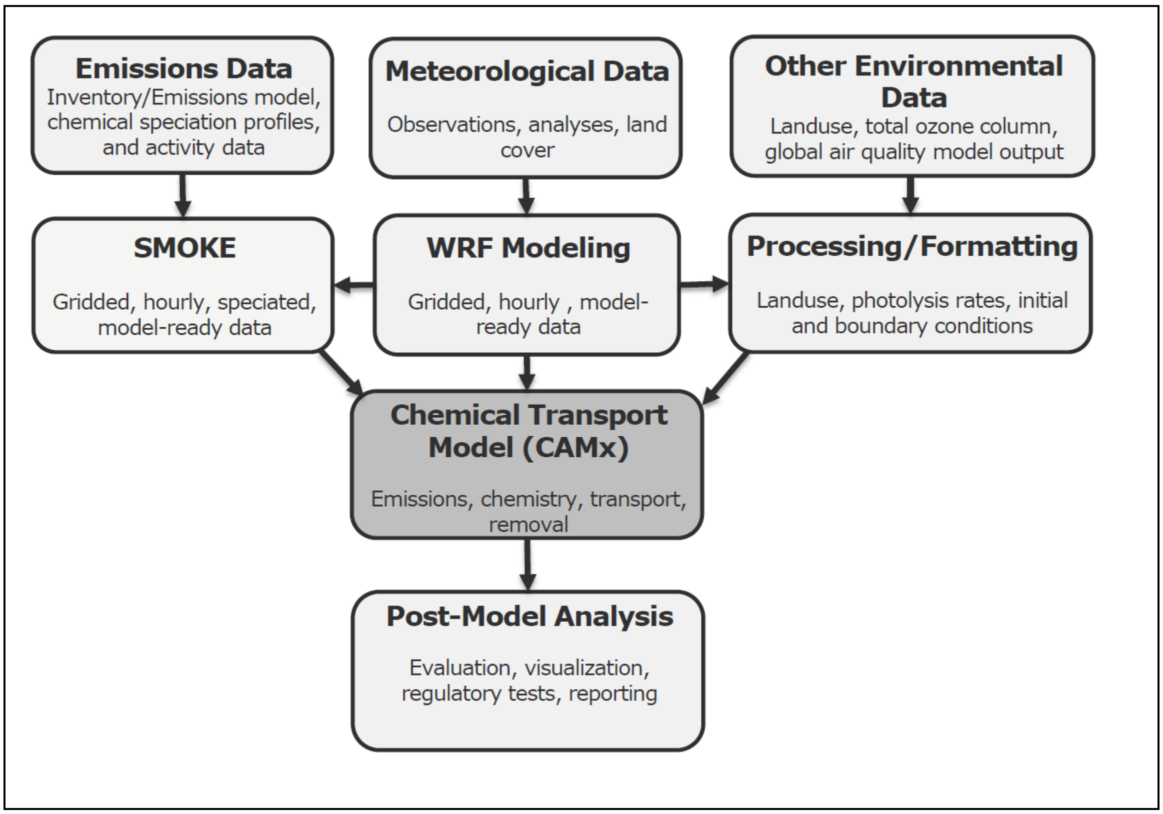


Figure 4.1.1 Schematic showing the overall regional modeling approach.

The CAMx regional air quality modeling methods and results for the Willow MDP Draft EIS were used for the Final EIS as well as this SEIS; the reasons are provided in Section 5.1. The CAMx air quality modeling was conducted on the same 4 km and 12 km grid resolution domains used in the BOEM Arctic modeling study (BOEM, 2017). The BOEM study included a model performance evaluation for ozone, $PM_{2.5}$ and precursors. The 4 km domain is centered on the northern Alaska coast, encompassing the North Slope Borough, and the 12 km domain includes the northern portion of Alaska and the Beaufort and Chukchi Seas as shown in Figure 4.1-2. The 4 km domain covers almost roughly 300 km distance from the Willow drill sites in the north-south direction and more than 300 km in the east-west direction. Table 4.1-1 provides the 12 km and 4 km modeling domain horizontal definitions. The WRF model was run using

33 layers in the vertical dimension; these layers are collapsed to 24 layers in CAMx to improve computational efficiency (Table 4.1-2).

Table 4.1-1 CAMx and WRF Domain Definitions for 12 km and 4 km Domains

Resolution	Origin (lower-left corner)	Dimension
CAMx – 12 km	(-930 km, -822 km)	146 x 119
CAMx – 4 km	(-550 km, -238 km)	278 x 140
WRF – 12 km	(-990 km, -882 km)	157 x 130
WRF – 4 km	(-570km, -258 km)	289 x 151

Polar stereographic projection: 70°N, 155°W with true latitudes at 70°N

Table 4.1-2 Vertical Layer Interface Definition for WRF Simulations and the Layer-Collapsing Scheme for the CAMx Layers.

WRF					CAMx		
Layer Interface	Eta (η)	Pressure (mb)	Height (m)	Thickness (m)	Layer	Height (m)	Thickness (m)
33	0	100	15725.8	1208.7	24	15725.8	2449.2
32	0.027	124	14517	1240.5			
31	0.06	154	13276.6	1266.3	23	13276.6	2600.3
30	0.1	190	12010.2	1333.9			
29	0.15	235	10676.3	1140.8	22	10676.3	2141.6
28	0.2	280	9535.5	1000.8			
27	0.25	325	8534.8	894.2	21	8534.8	1704.2
26	0.3	370	7640.6	810			
25	0.35	415	6830.5	741.8	20	6830.5	1492.7
24	0.4	460	6088.8	750.9			
23	0.455	510	5337.9	814.8	19	5337.9	1508.6
22	0.52	568	4523.1	693.8			
21	0.58	622	3829.3	646.7	18	3829.3	1252.7
20	0.64	676	3182.6	606.1			
19	0.7	730	2576.5	384.2	17	2576.5	754
18	0.74	766	2192.3	369.8			
17	0.78	802	1822.5	356.6	16	1822.5	616
16	0.82	838	1465.9	259.4			
15	0.85	865	1206.5	252.9	15	1206.5	252.9
14	0.88	892	953.6	165.2	14	953.6	165.2
13	0.9	910	788.4	122.2	13	788.4	122.2
12	0.915	924	666.2	120.7	12	666.2	120.7
11	0.93	937	545.5	79.7	11	545.5	79.7
10	0.94	946	465.8	79.1	10	465.8	79.1
9	0.95	955	386.7	78.5	9	386.7	78.5
8	0.96	964	308.2	77.9	8	308.2	77.9
7	0.97	973	230.3	77.3	7	230.3	77.3
6	0.98	982	152.9	53.8	6	152.9	53.8
5	0.987	988	99.2	38.2	5	99.2	38.2
4	0.992	993	60.9	22.9	4	60.9	22.9
3	0.995	996	38	15.2	3	38	15.2
2	0.997	997	22.8	11.4	2	22.8	11.4

WRF					CAMx		
Layer Interface	Eta (η)	Pressure (mb)	Height (m)	Thickness (m)	Layer	Height (m)	Thickness (m)
1	0.9985	999	11.4	11.4	1	11.4	11.4
0	1	1000	0				

By convention, a 300 km distance from the Project is chosen for identifying areas of interest and assessing impacts from these sources. There are no Class I areas within 300 km of the Willow MDP; the nearest one is Denali National Park which is over 700 km away. Two federally managed areas that are within 300 km – the Gates of the Arctic National Park and Preserve, and the Arctic National Wildlife Refuge – have been previously identified by cooperating agencies for the previous GMT1 and GMT2 far-field analysis; these two areas were likewise evaluated for the Willow far-field analysis. In addition, a third area, the Noatak National Preserve, portions of which are within 300 km, has also been added for analysis. These three assessment areas are Class II areas, as is any area in Alaska that is not a designated Class I area. The assessment areas are shown in Figure 4.1-2. As shown Figure 4.1-2, the 4 km domain does not completely include the 300 km assessment area; however, all three assessment areas that are within 300 km of the project are partially within the 4 km domain. Therefore, only the 4 km domain was modeled and impacts for each of the three assessment areas within the 4 km domain were reported. Table 4.1-3 provides the list of the three assessment areas that are within 300 km of Willow (and thus also inside the 4 km modeling domain).

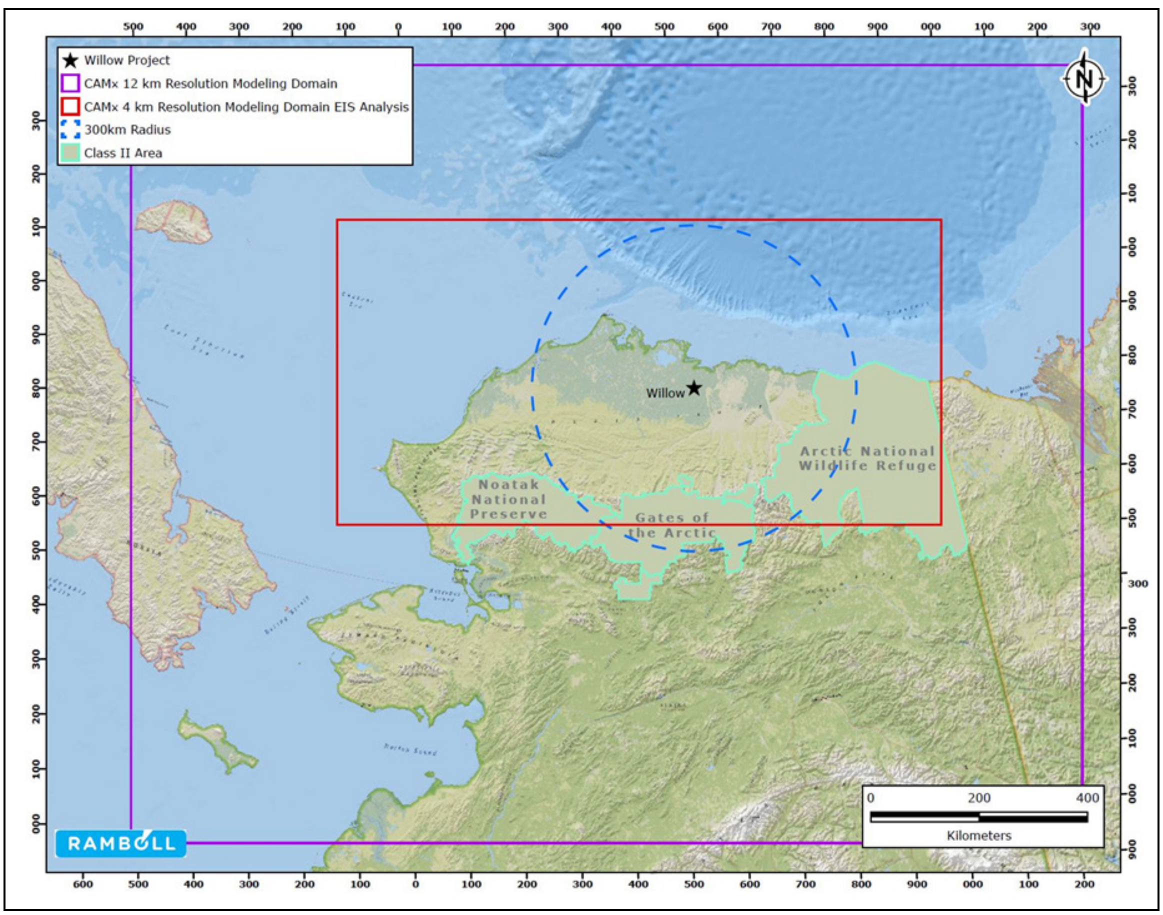


Figure 4.1.2 4 km and 12 km resolution model domains and three assessment areas analyzed.

Table 4.1-3 Three assessment areas considered for air quality analysis.

Area	Administrative Agency
Arctic National Wildlife Refuge	USFWS
Gates of the Arctic National Park	NPS
Noatak National Preserve	NPS

4.2 Meteorological Data

The BOEM Arctic study meteorological data were used for this modeling assessment. WRF v3.6.1 was used for the 4 km and 12 km domains, both these grids were defined on a Polar secant stereographic projection centered at 70°N, 155°W with true latitudes at 70°N. As stated in Brashers et al. (2016), version 3.6.1 of WRF was developed to improve the arctic modeling capabilities. Key physics options selected for the BOEM WRF modeling are shown in Table 4.2-1.

Table 4.2-1 Physics options used in BOEM Arctic WRF modeling

Physics	Parameterization Scheme	Description
Long/Shortwave Radiation	Rapid Radiative Transfer Model for GCM (RRTMG)	Scheme with the MCICA method of random cloud overlap
Micro physics	Thompson	Scheme with ice, snow and graupel processes suitable for high-resolution simulations
Cumulus physics	Grell-Freitas	Scheme that tries to smooth the transition to the cloud-resolving scales
PBL	Yonsei University (YSU)	Scheme with explicit entrainment layer and parabolic K profile in unstable mixed layer
Land surface model (LSM)	Noah land surface model with Polar WRF modifications	Scheme with soil temperature and moisture in four layers, fractional snow cover and frozen soil physics

The model performance of the BOEM Arctic WRF simulation was evaluated using METSTAT tool for both onshore and offshore analysis during 2009-2013 at a 4 km resolution (Brashers et al., 2016). The model BOEM Arctic WRF simulation provides outputs for onshore and offshore wind direction, humidity, wind speed, and temperature. These results are compared against the global-scale National Climate Data Center (NOAA-NCDC, 2014, 2015) DS-3505 observational data for onshore and data from the NOAA National Oceanographic Data Center (NOAA-NODC, 2014) database for offshore. METSTAT uses results for wind direction, humidity, wind speed, and temperature from the BOEM Arctic WRF simulation, NCDC datasets, and NODC datasets to calculate statistical performance metrics (bias, error) for the BOEM Arctic WRF simulation. These metrics were then compared against meteorological model performance benchmarks for simple and complex conditions as an indicator for model performance. Table 4.2-2 provides the simple and complex conditions from literature for various meteorological parameters. Onshore modeling for wind direction and humidity performed very well for all months within simple conditions benchmark. Onshore modelling for wind speed and temperature performed well with most months falling within complex conditions benchmark and several months falling within simple conditions benchmark. Overall, the WRF performed well when compared to onshore surface observations for wind speed, wind direction, humidity, and temperatures for all months of the 2009-2013 simulation period. For 2012, overall the model performance is good and only one or two-month parameter combinations fell outside the complex condition benchmark.

Offshore modeling for humidity performed very well for all open-water months within the simple conditions benchmark. Offshore modeling for wind direction performed satisfactory with most months displaying a slight positive bias and average direction error of 20-45 degree. Temperature performance was also satisfactory with slight negative bias and suggesting that in the warmer months WRF is underpredicting temperatures. The model had difficulties modeling wind speed in the transition month of October, however performed satisfactory in all other months. Overall, the WRF offshore performance did not perform as well as the onshore model. The METSTAT performance discrepancy can be partially attributed to the difficulty of taking offshore measurements due to size and limited number of available buoys for data collection when compared to onshore stations.

The WRF estimated precipitation data was compared with the Parameter-elevation Regressions on Independent Slopes Model (PRISM) datasets, which are spatial maps of climate elements across the United States built by the Spatial Climate Analysis Service (SCAS-OSU, 2001). The high-resolution Alaska PRISM contains 30 year average monthly precipitation for the entire onshore Alaska area at 400 m resolution which are compared with the 5 year average WRF precipitation. Overall WRF is able to reflect the spatial trend similar to PRISM and performed well. However, WRF slightly underpredicted winter-spring precipitation totals throughout much of the Brooks Mountain Range (southern border of North Slope) and underpredicted precipitation totals at areas with highest rainfall over more complex conditions.

For upper–air model evaluation, WRF performs well representing temperature and moisture vertical profiles of the atmosphere including the surface and subsidence-type inversion when compared with upper air data from Point Barrow (Nuvuk) radiosonde dataset. WRF estimated cloud cover fraction (CCF) reasonably well when compared with the Multi-angle Imaging Spectro-Radiometer (MISR) instrument satellite cloud retrievals and overall on average WRF CCF over land appear to show 5 – 15 % high bias.

Table 4.2-2 Meteorological Model Performance Benchmarks for Simple and Complex Conditions

Parameter	Emery et al. (2001)	Kemball-Cook et al., 2005; McNally et al., 2009
Conditions	Simple	Complex
Temperature Bias	⩽ ±0.5 K	⩽ ±1.0 K
Temperature Error	⩽ 2.0 K	⩽ 3.0 K
Temperature IOA	0.8	0.8
Humidity Bias	⩽ ±1.0 g/kg	⩽ ±1.0 g/kg
Humidity Error	⩽ 2.0 g/kg	⩽ 2.0 g/kg
Humidity IOA	0.6	0.6
Wind Speed Bias	⩽ ±0.5 m/s	⩽ ±1.5 m/s
Wind Speed Root Mean Square Error (RMSE)	⩽ 2.0 m/s	⩽ 2.5 m/s
Wind Speed IOA	0.6	0.6
Wind Dir. Bias	⩽ ±10 degrees	⩽ ±10 degrees
Wind Dir. Error	⩽ 30 degrees	⩽ 55 degrees

The WRF model output files were processed in the BOEM study using WRFCAMx v4.4 processor to generate CAMx model-ready meteorological data (Brashers et al., 2016). The Willow EIS used the same meteorological data. Some of the key updates in WRFCAMx v4.4 are the KVPATCH method that improves the surface layer ozone and an option to process sub-grid clouds.

4.3 Emissions Processing

The development and preparation of the regional emissions is described in Section 2.3.2 "Regional Emissions Inventories". In brief, the non-Willow emissions are based on data developed in the BOEM Arctic study (Field Simms et al., 2014) and the data sources for the regional emissions and natural emissions are summarized in Table 4.3-1. As described in Field Simms et al. (2014), the future year emissions are representative of full build-out scenarios that are based on the projections of anticipated development. The BOEM emissions were adjusted to reduce sea salt and unpaved road dust and to incorporate additional emissions for onshore RFD.

Table 4.3-1 Data Sources for BOEM Emission Inventory Platform

Emission sector	Data Source
North Slope Borough (NSB), Chukchi and Beaufort Sea Anthropogenic Emissions	BOEM Arctic Air Quality study developed for Onshore and Offshore sources.
Anthropogenic emissions for Canada	US EPA 2011 based modeling platform v6.2
Anthropogenic emissions outside US and Canada	GEOS-Chem global model (retrospective inventory and EDGAR inventory)
Biogenic	Model of Emissions of Gases and Aerosols from Nature (MEGAN) version 2.03
Fire	Day-specific Fire Inventory (FINN) from the National Center for Atmospheric Research (NCAR) processed using Emissions Processing System version 3 (EPS3) model
Sea Salt emissions	The seasalt emissions are processed using revised seasalt v3.3 processor.
Lightning emissions	Inline lightning emissions derived from Community Multiscale Air Quality (CMAQ) model using the convective precipitation rate from meteorological data

The SMOKE system (version 3.6) was used to generate model ready emissions for the regional emissions shown in Section 2.3.2 "Regional Emissions Inventories" to develop hourly, speciated and gridded CAMx-ready emission inputs.

4.4 Regional Model Configuration

The CAMx photochemical grid model was applied over the 12 km and 4 km modeling domains shown in Figure 4.4-1. The NEPA analysis area for far-field air quality impacts is the spatial extent of the 4 km domain which is approximately 300 km north-south from Willow and farther out in the east-west directions. CAMx version 6.5 was applied with the CB6r4 gas phase mechanism. The CAMx model setup options for this modeling assessment are summarized in Table 4.4-1.

As described in Section 1.2.2.2 "Regional Modeling", CAMx was used to simulate various future year scenarios. Each Cumulative Alternative scenario includes all the cumulative sources detailed in Section 2.2 "Cumulative Emissions for the Willow Alternatives" as well as those sources specific to the Willow MDP alternatives. Willow MDP impacts are estimated using the difference between the cumulative 2025 Alternative (B or C) simulation and the Cumulative 2025 No Project simulation. The impacts derived using this approach are referred as using the "Brute Force" method. The cumulative No Action Alternative simulation includes all the cumulative sources except those specific to each Willow MDP alternative. The only purpose of the Cumulative 2025 No Project simulation is to derive those impacts and no other modeling results from that simulation are reported here. The simulations were conducted over the spatial extent of the 4 km resolution modeling domain. The cumulative effects for NEPA were obtained directly from the Cumulative Alternative B (Proponent's Project) and C (Disconnected Infield Roads) Scenarios.

Table 4.4-1 CAMx Model Setup Configuration and Description

Science option	Configuration	Description
Gas phase chemistry	CB6r4	Updated isoprene chemistry; heterogeneous hydrolysis of organic nitrates; active methane chemistry and ECH4 excess methane tracer species (Ruiz and Yarwood, 2013).
Aerosol phase chemistry	SOAP2.1+ISORROPIA	Updated photolysis rates in SOAP2.1
Photolysis Rate	TUV V4.8 preprocessor	Clear-sky photolysis rates based on day-specific Total Ozone Mapping Spectrometer (TOMS) data; CAMx in-line adjustment based on modeled aerosol loading
Horizontal Diffusion	Explicit horizontal diffusion	Spatially varying horizontal diffusivities determined based on the methods of Smagorinsky (1963)
Vertical Diffusion	K-theory 1st-order closure	Vertical diffusivities from WRFCAMx and KVPATCH; land-use dependent minimum diffusivity (minimum vertical eddy diffusivity = 0.1 to 1.0 square meters/second)
Dry Deposition	ZHANG03	Dry deposition scheme by Zhang et al. (2001; 2003)
Wet deposition	CAMx-specific formulation	Scavenging model for gases and aerosols (Seinfeld and Pandis, 1998)

The initial and lateral boundary conditions (ICBC) for the 4 km modeling domain for all scenarios were derived from the 3-D model outputs of corresponding 12 km simulations. Note that for the 4 km Base Year scenario the ICBC are derived from the corresponding 12 km 2012 simulation, while the future year simulations are derived from a 12 km 2020 simulation. The hourly varying boundary conditions for the 4 km domain are generated for each day in the modeling period. The CAMx simulations were conducted by splitting the runs into four quarters and initializing the runs with a 10-day spin-up period as is conventionally done.

The day specific ozone column data were based on the TOMS data measured using the Ozone Monitoring Instrument (OMI) satellite. The in-line photolysis rates were calculated using Tropospheric Ultraviolet Visible (TUV) v4.8 preprocessor to generate day-specific lookup tables. The cloud cover and aerosol loadings effects on photolysis rates are crucial, so CAMx was configured to use in-line TUV with these adjustments. The same clear-sky rates were used for both base and future years.

The EIS did not include any Source Apportionment model runs. Instead impacts for each alternative were derived via "brute force", that is by direct difference between scenarios and the No Action Alternative modeling results. Cumulative impacts were derived from the total concentrations estimated in the Cumulative Alternative B (Proponent's Project) and C (Disconnected Infield Roads) scenarios.

A model performance evaluation (MPE) was conducted on the 2012 Base Year scenario in the 4 km domain. The model data were compared with the ambient observational data at the monitoring sites available in the 4 km domain. As mentioned in previous reports (ADEC, 2011; BOEM, 2017) the ambient data available near the Arctic region is very limited and sparse. Table 4.4-2 lists the air monitoring sites in the 4 km domain and the chemical species that were evaluated. Figure 4.4-1 shows the locations of the monitoring sites. The sites are in coastal portions of the North Slope and were originally established to satisfy PSD permitting requirements for new major sources. The monitoring data at these sites are from the BOEM study (BOEM 2017); additionally, Nuiqsut, Deadhorse and Wainwright sites have been included in the analysis. Additional details on how the MPE was conducted can be found in Attachment B.

Table 4.4-2 Monitoring Sites Used in Model Performance Evaluation

Site Name	Site ID	Source[a]	Lat	Lon	Species
APAD	02185APAD	AK Permit Data	70.26611	-148.7563	O_3
DS1F	02185DS1F	AK Permit Data	70.29917	-149.6847	O_3
BRW	02185XBRW	NOAA	71.323	-156.6114	O_3
CCP	02185XCCP	AK Permit Data	70.31936	-148.5166	O_3, $PM_{2.5}$
Nuiqsut		CPAI	70.22361	-150.9996	$PM_{2.5}$
Deadhorse		ADEC	70.22201	-148.4223	$PM_{2.5}$ components (Nitrate [NO3], SO4, EC, Organic Carbon (OC), Ammonium [NH4])
Wainwright		ADEC	70.64111	-160.007	$PM_{2.5}$ components (NO3, SO4, EC, OC, NH4)

[a] AK Permit Data from ADEC air quality permit files as supplied for use in BOEM study by the ADEC; NOAA ESRL published data for the Barrow Atmospheric Baseline Observatory (http://www.esrl.noaa.gov/gmd/obop/brw/); ConocoPhillips Alaska, Inc. (CPAI)

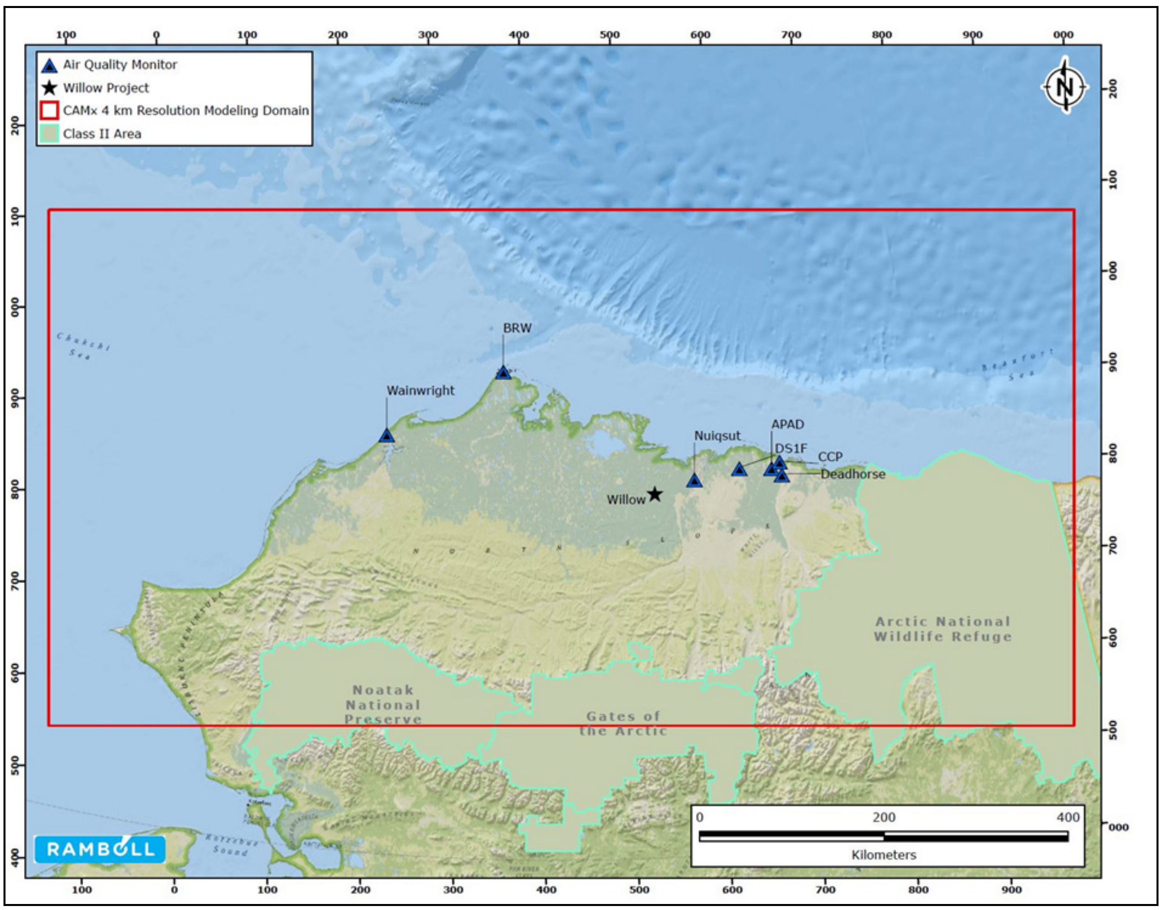


Figure 4.4.1 4 km model domain and the monitoring sites considered for the MPE analysis.

The CAMx model data were spatially and temporally paired with the monitoring data. As performed in BOEM study, the model data were averaged over the 9-grid cell block centered on the individual monitoring site and were used to conduct the site-by-site comparison. The paired model and observational data were used to calculate the Normalized Mean Bias, Normalized Mean Error, Fractional Bias and Fractional Error statistical metrics as shown in Table 4.4-3. These metrics were compared with the photochemical modeling performance goals and criteria standards shown in Table 4.4-4 for O_3 and $PM_{2.5}$ (Emery et al., 2017) to understand the model performance in this Arctic region. The benchmark "Goal" indicates the performance that the best current models are expected to achieve, and the "Criteria" indicates the performance most of the models have achieved. These goals and criteria standards are developed mainly for model applications within the continental US, but as no other information exists the same standards were applied to this arctic modeling application. In the EIS, plots were provided for the sites listed in Table 4.4-2 to document the model performance for the 4 km domain. Model performance for the speciated $PM_{2.5}$ components listed in Table 4.4-2 were evaluated using the criteria in Table 4.4-4 from Emery et al. (2017) and by using the "bugle plots" of Boylan and Russell (2006).

Table 4.4-3 Normalized Mean Bias and Error Statistical Metrics Formulae

Statistical Measure	Mathematical Expression
Normalized Mean Error (NME) (%)	$\frac{\sum_{i=1}^{N} \lvert P_i - O_i \rvert}{\sum_{i=1}^{N} O_i}$
Normalized Mean Bias (NMB) (%)	$\frac{\sum_{i=1}^{N} (P_i - O_i)}{\sum_{i=1}^{N} O_i}$
Fractional Bias (FB)	$\frac{2}{N} \sum \frac{(P_j - O_j)}{(P_j + O_j)} \times 100$
Fractional Error (FE)	$\frac{2}{N} \sum \frac{\lvert P_j - O_j \rvert}{(P_j + O_j)} \times 100$

Table 4.4-4 Photochemical Model Performance Goals and Criteria from Emery et al., 2017.

Species	Normalized Mean Bias		Normalized Mean Error	
	Goal	Criteria	Goal	Criteria
1-hr or MDA8 Ozone	< ±5%	< ±15%	< 15%	< 25%
24-hr $PM_{2.5}$, SO_4, NH_4	< ±10%	< ±30%	< 35%	< 50%
24-hour NO_3	< ±15%	< ±65%	< 65%	< 115%
24-hour OC	< ±15%	< ±50%	< 45%	< 65%
24-hour EC	< ±20%	< ±40%	< 50%	< 75%

4.5 Assessment Methods

The CAMx modeling system was used to estimate the potential cumulative air quality and AQRV impacts in the three assessment areas in Table 4.1-3 as well as the overall 4 km domain. Model predicted concentrations were further post-processed in the form of the NAAQS for multiple pollutants and for visibility impairment from particulate matter and nitrogen and sulfur deposition. The modeled hourly values were carefully averaged to the appropriate time range for comparison with standards and criteria.

4.5.1 Air Quality Impacts

CAMx simulation outputs were processed to analyze the air quality impacts with respect to the NAAQS, PSD increments and AQRV metrics. Presented below is the description for each analysis. These metrics were processed for analyzing both the cumulative effects and the project specific impacts.

Impacts for the three assessment areas have been derived using Geographical Information Systems (GIS) and by intersecting the three assessment areas with the modeling domain to extract the 4 km model grid-cells that lie in these areas. The impacts are predicted for the three assessment areas by considering the air quality impacts from these modeling grids.

4.5.2 NAAQS and AAAQS

The cumulative and project air quality impacts were calculated from the CAMx modeling results for the criteria pollutants CO, O_3, $PM_{2.5}$, PM_{10}, NO_2 and SO_2 and compared to the NAAQS primary and secondary standards and the AAAQS. The primary NAAQS protect public health including sensitive populations and the secondary NAAQS protect public welfare. The photochemical grid model provides hourly concentrations for multiple pollutants at each grid cell in the modeling domain. To provide model predictions consistent with the NAAQS and AAAQS, these model results are post-processed and summarized in tables. The criteria pollutants concentrations for each grid cell in the modeling domain are compared with the respective species' AAQS standard to evaluate the impacts due to each alternative plus other cumulative sources. Tabulated results and spatial plots of concentrations are provided in Chapter 5 in the form of the applicable AAQS.

For ozone, there is one averaging period to evaluate and the level of the standard is identical for both primary and secondary NAAQS and the AAAQS. The following steps were conducted to process model results for comparison to the ozone standard. First the maximum daily 8-hour average (MDA8) is calculated for each day in the annual simulation, then the fourth-highest concentration (H4MDA8) is determined for each grid cell in the modeling domain. Finally, the cumulative values reported for the three assessment areas correspond to the maximum H4MDA8 from the collection of modeling grid cells that lie in these areas. As mentioned above project impacts are derived using the brute force method. For ozone, this is performed by calculating the difference between the cumulative H4MDA8 values of the action alternative and the No Action Alternative. Note that the difference is performed over the maximum H4MDA8 without matching cumulative values in either space (different cells) or time (different days).

For CO, there are two averaging times to evaluate for comparison to NAAQS and AAAQS; both of the averaging periods are primary standards. The 8-hour standard is calculated from the hourly concentrations using non-overlapping 8-hour averages (3 values for each day). After this averaging is performed the second-highest value for the annual simulations is saved for each grid cell in the modeling domain. The 1-hour standard is calculated by first keeping the 1-hour maximum for each day and then selecting the second-highest value for the annual simulations for each grid cell in the modeling domain. Finally, the cumulative values reported for the three assessment areas correspond to the maximum value for each standard for those model grid cells that lie in these areas. Project impacts are derived using the brute force method.

For NO_2, there are two averaging times to evaluate for comparison to NAAQS and AAAQS: a 1-hr averaging time, which is a primary NAAQS, and an annual averaging time, which is both a primary and secondary NAAQS. The 1-hr standard is calculated by first calculating the 1-hour maximum for each day and then selecting the eighth-highest value for the annual simulations (equivalent to the 98^{th} percentile) for each grid cell in the modeling domain. The annual standard is calculated from the annual average of hourly concentrations for each grid cell in the modeling domain. Finally, the cumulative values reported for the three assessment areas correspond to the maximum value for each standard for those model grid cells that lie in these areas. Project impacts are derived using the brute force method.

For $PM_{2.5}$ there are two averaging times to evaluate for comparison to NAAQS and AAAQS: a 24-hour averaging time, which is both a primary and secondary NAAQS, and an annual averaging time, which is has two separate NAAQS. The primary annual $PM_{2.5}$ NAAQS is of 12 $\mu g/m^3$ and the secondary annual $PM_{2.5}$ NAAQS is 15 $\mu g/m^3$. The annual average results are compared to the annual average of hourly concentrations for each cell in the domain. The 24-hr average results are calculated from the hourly concentrations by first producing daily 24-hr averages and then selecting the eighth-highest value (equivalent to the 98^{th} percentile) for each grid cell in the modeling domain. Finally, the cumulative values reported for the three assessment areas correspond to the maximum value for each standard for those model grid cells that lie in these areas. Project impacts are derived using the brute force method.

For PM_{10} averaging period to evaluate and the level of the standard is identical for both primary and secondary NAAQS and the AAAQS. The 24-hr average results are calculated from the hourly concentrations by first producing daily 24-hr averages and then selecting the second-highest value for each grid cell in the modeling domain. Finally, the cumulative values reported for the three assessment areas correspond to the maximum value for each standard for those model grid cells that lie in these areas. Project impacts are derived using the brute force method.

For SO_2 there are four averaging periods to evaluate for comparison to NAAQS and AAAQS: a 1-hour averaging time, which is a primary NAAQS; a 3-hour averaging time, which is a secondary NAAQS; a 24-hour averaging time, which is only an AAAQS; and an annual averaging time, which is only an AAAQS. The 1-hr average results are calculated by first keeping the 1-hour maximum for each day and then selecting the fourth-highest value for the annual simulations (equivalent to the 99th percentile) for each modeling grid cell. The 3-hr average results are calculated from the hourly concentrations using non-overlapping 3-hours averages (8 values for each day). After this averaging is performed the second-highest value over the full annual simulation is reported for each cell in the modeling domain. For the Alaska, the 24-hr average results are calculated by selecting the second-highest value from the daily 24-hr averages, while the annual average results are calculated from the annual average of hourly concentrations for each cell in the modeling domain. Finally, the cumulative values reported for the three assessment areas correspond to the maximum value for each standard for those model grid cells that lie in these areas. Project impacts are derived using the brute force method.

4.5.3 PSD Impacts

Project impacts at the three assessment areas are compared with PSD Class II increments listed in Table 1.2-2. The comparison to the Class II increments does not represent a regulatory PSD increment consumption analysis and is presented for information only. Note that PSD increments are reported in $\mu g/m^3$ and when the species is a gaseous pollutant the mixing ratio has been converted to concentration using standard ambient temperature and pressure.[10]

For NO_2 the PSD increment is calculated from the annual average of hourly concentrations for each cell in the modeling domain. Finally, the cumulative values reported for the three assessment areas correspond to the maximum value for those model grid cells that lie in these areas.

For both the 24-hour PM_{10} and $PM_{2.5}$ PSD increment, the hourly concentrations are first averaged to daily 24-hr averages and then the second-highest value selected for each modeling grid cell in the computational domain. The annual PM_{10} and $PM_{2.5}$ PSD increment is calculated from the annual average of hourly concentrations for each cell in the modeling domain. Finally, the cumulative values reported for the three assessment areas correspond to the maximum value for those model grid cells that lie in these areas.

For the 3-hr SO_2 PSD increment, hourly concentrations are averaged using non-overlapping 3-hours periods (8 values for each day). After this averaging is performed the second-highest value for the annual simulations is saved for each cell in the computational domain. For the 24-hr SO_2 PSD increment, the hourly concentrations are first averaged to daily 24-hr averages and then the second-highest value selected for each modeling grid cell in the computational domain. The annual SO_2 PSD increment is calculated from the annual average of hourly concentrations for each cell in the modeling domain. Finally, the cumulative values reported for the three assessment areas correspond to the maximum value for those model grid cells that lie in these areas.

4.5.4 Visibility

4.5.4.1 Project Impacts

Particulate matter concentrations in the atmosphere contribute to the visibility degradation by both scattering and absorption of visible light. The combined effect of scattered and absorbed light is called light extinction. Changes in the light extinction for each modeling scenario was calculated at the three assessment areas. The visibility metric used in this analysis is called Haze Index (HI) which is measured in dv units and is defined as follows:

$$HI = 10 \times \ln [b_{ext}/10]$$

Where b_{ext} is the atmospheric light extinction measured in inverse megameters (Mm^{-1}) and is calculated primarily from atmospheric concentrations of particulates.

The project's contribution is determined by calculating the incremental changes in the extinction from background concentrations due to the project emissions. This quantity that measures the extinction changes in the Haze Index is referred to as "delta deciview" (Δdv):

[10] T= 298K, P= 1 atm

$$\Delta dv = 10 \times \ln[b_{ext(SC+background)}/10] - 10 \times \ln[b_{ext(background)}/10]$$

$$\Delta dv = 10 \times \ln[b_{ext(SC+background)}/b_{ext(background)}]$$

Here $b_{ext(SC+background)}$ refers to atmospheric light extinction due to impacts from the source category plus background concentrations, and $b_{ext(background)}$ refers to atmospheric light extinction due to natural background concentrations only.

For this study we calculated the project impacts on visibility from the CAMx modeling results using a brute force method. These are the overall steps followed in calculating the visibility impacts:

1. The project impacts are derived from the difference in the hourly modeling results between the Cumulative Alternative Scenario and the No Action Alternative Scenario. The differences are then averaged to daily concentrations in the 4 km modeling domain.
2. The concentration differences in (1) are extracted from the grid cells that fall in the three assessment areas.
3. The Interagency Monitoring of Protected Visual Environments (IMPROVE) equation is used to calculate reconstructed extinction for the impacts (b_{ext_SC}) following the FLAG (2010) procedures at the three assessment areas.
4. The natural (background) monthly extinction ($b_{ext\_background}$) is calculated using the IMPROVE equation and the relative humidity adjustment factors reported in FLAG (2010) tables 5 to 9.
5. With the results in (2) and (3) delta deciviews are calculated using the Δdv formula above. The highest Δdv across all grid cells overlapping an assessment area is selected to represent the daily value at each of the three assessment areas.
6. Results in (5) are sorted from lowest to highest Δdv and then the maximum, the 98th percentile (eighth-highest value) and the number of days with a Δdv greater than 0.5 and 1.0 are reported for each assessment area. Also, the 20th percentile and 80th percentiles are reported and used to represent the 20% best days (B20) and 20% worst days (W20) respectively.

Note that the relative humidity adjustment factors reported in FLAG (2010) tables 5 and 9 are only provided for Class I areas. The calculations described in this section rely on the adjustment factors for Denali National Park (NP) which is the closest Class I area to the project but located outside the 4 km computational domain.

4.5.4.2 Cumulative Impacts

For this analysis cumulative visibility design values are assessed using the Software for Model Attainment Test- Community Edition (SMAT-CE) version 1.2 (South China University of Technology, 2015). SMAT-CE provides model-adjusted visibility design values that are consistent with USEPA's "Modeling Guidance for Demonstrating Air Quality Goals for Ozone, $PM_{2.5}$, and Regional Haze" (USEPA 2018). Photochemical models are affected by biases, i.e., model results are a simplification of natural phenomena and, as such, model results tend to over- or under-estimate particulate matter concentrations. The use of SMAT-CE aids in mitigating model bias for visibility calculations by pairing model estimates with actual measured concentrations.

SMAT-CE calculates baseline and future-year visibility levels for both the 20 percent best and 20 percent most impaired days for each of the 156 Class I Areas. To do this, SMAT-CE adjusts the modeled air quality concentrations based on measured air quality concentrations to account for possible model bias utilizing the relative response factor approach described below. Within SMAT-CE, model-predicted concentrations of chemical compounds that scatter or absorb light are converted to estimates of light extinction using the IMPROVE equation (Hand and Malm 2006). The IMPROVE equation reflects empirical relationships derived between measured mass of PM components and measurements of light extinction at IMPROVE monitoring sites in Class I areas. The IMPROVE equation calculates light extinction as a function of relative humidity for large and small particulate matter. As a final step in SMAT-CE, light extinction values are converted into dv, a measure for describing the ability for the human eye to perceive changes in visibility.

The USEPA guidance for estimating future-year visibility levels recommends using the photochemical grid model results in a relative sense to scale the visibility current design values (DVC). The visibility DVCs are based on a 5-year average of monitored IMPROVE data centered on the typical modeling year. For this analysis, the Typical Year is 2012, so the 5-year period centered on 2012 is 2010 through 2014.

Scaling factors, called relative response factors (RRFs), are calculated from the modeling results. RRFs are applied to the DVC to predict future-year design values (DVF) at a given monitoring location using the following equation:

$$DVF = DVC \text{ x Relative Response Factor (RRF)}$$

RRFs are the ratio between the model-predicted concentrations in the future-year modeling scenario and the Typical Year modeling scenario. RRFs are calculated for each individual chemical component that contributes to light extinction based on the model grid cells surrounding a monitoring site.

SMAT-CE depends on IMPROVE monitors to assess visibility impacts. Note that there are no Class I areas within the 4 km computational domain. So the Denali NP IMPROVE monitor was selected for this analysis. The following steps indicate how the analysis was performed for each assessment area in the study:

1. Hourly concentrations of modeled particulate matter were averaged to daily values for each component of the IMPROVE equation for all the grid cells in the 4 km domain. This is step is performed for both the 2012 Base scenario and the corresponding Cumulative Alternative scenario modeling results.
2. Modeled concentrations from (1) were extracted for a 3x3 matrix centered around the corresponding assessment area centroid. The centroid was determined by the area left within the 4 km domain using GIS.
3. The latitude and longitude values that correspond to the IMPROVE monitor at Denali and the surrounding 3x3 points at a 4 km distance to the monitor were assigned to the modeled concentrations in step (2).
4. The files in step 3 were used as the model input for SMAT-CE Denali NP data.

All the steps described above are applied to all the three assessment areas for this study.

SMAT-CE was configured using the settings provided in Table 4.5-1 and was run with the modeling results for each of the future-year 2025 modeling scenarios. The changes in Table 4.5-1 from SMAT-CE defaults and other changes necessary to accurately incorporate the model year selected for the Typical Year and other data that is dependent on the Typical Year.

Table 4.5-1 SMAT-CE Configuration Settings

Option	Main category	Setting	Default	This Study
Desired Output	Scenario Name	Name		
	Forecast	Temporally-adjust visibility levels at class 1 area	Yes	Yes
		Improve algorithm	use new version	use new version
		Use model grid cells at monitors	Yes	Yes
		Use model grid cells at class 1 area centroid	No	No
	Actions on run completion	Automatically extract all selected output files	Yes	Yes
Data Input	Monitor data	File name	Class1areas_NEWIMPROVEALG_2000to2015_2017feb13_TOTAL.csv	Class1areas_NEWIMPROVEALG_2000to2015_2017april27_IMPARIMENT.csv[a]
	Model data	Baseline file	SMAT.PM.Large.12.SE_US2.2011eh.camx.grid.csv	Willow base output 2012[b]
		Forecast file	SMAT.PM.Large.12.SE_US2.2017eh.camx.grid.csv	Willow Run 3 output Year 2025[c]
	Using model data	Temporal adjustment at monitor	3x3	3x3
Filtering	Choose visibility data years	Start monitor year	2009	2010[d]
		End monitor year	2013	2014[d]
		Base model year	2011	2012[d]
	Valid visibility monitors	Minimum years required for valid monitor	3	3

[a] Monitor data that selects the 20% most impaired days is used instead of the 20% worst days

[b] Baseline file changed from default (2011) to the Year (2012) base modeling year.

[c] Forecast file changed from default year to the modeled future-year (2025) scenario for this analysis. SMAT-CE was run three times once for the three assessment areas since the model data required translating for SMAT program to spatially match an IMPROVE monitor (Denali) with co-located model data.

[d] The values for the Start, End and Base model years are set to reflect a year centered on the Base Year (2012) and to perform the current deciview calculation with the 5-year period surrounding this year (2010 to 2014).

4.5.5 Deposition

Model-predicted fluxes of total sulfur (S) and nitrogen (N) compounds have been used to estimate the deposition impacts at the three assessment areas for this project. Total deposition includes the sum of wet and dry deposition fluxes for all modeled sulfur and nitrogen containing compounds presented in Table 4.5-2. Total nitrogen and sulfur deposition cumulative model estimates are derived by adding the hourly model output to annual totals for each individual grid cell in the computational domain. This study reports both the maximum and the average total deposition from all the cells in a given assessment area.

Table 4.5-2. List of Modeled Species Included in Calculation of Total Nitrogen and Sulfur Deposition

Deposition	Species Included
Nitrogen	NO: Nitric oxide NO2: Nitrogen dioxide PAN: Peroxyacetyl nitrate NO3: Nitrate radical N2O5: Dinitrogen pentoxide PNA: Peroxynitric acid HONO: Nitrous acid HNO3: Nitric Acid NTR1: Simple organic nitrate NTR2: Multi-functional organic nitrates PANX: C3 and higher peroxyacyl nitrate NH3: Ammonia OPAN: Peroxyacyl nitrate (PAN compound) from peroxyacyl radical from Aromatic ring opening product (unsaturated dicarbonyl) PNH4: Particulate ammonium PNO3: Particulate nitrate
Sulfur	SO2: Sulfur dioxide SULF: Sulfur acid (gaseous) PSO4: Particulate sulfate

Cumulative assessment is performed by comparing the modeled predictions for total nitrogen deposition from all sources with critical loads derived by NPS. A critical load is the level of deposition below which no harmful effects are expected to an ecosystem. The critical load values available from the NPS website (NPS, 2018) for Alaska are protective of the tundra ecoregion and range from 1.0 to 3.0 kg/ha-yr.

The project impacts, annual nitrogen and sulfur deposition fluxes due to each alternative at the three assessment areas is compared with the DAT developed by the NPS and USFWS of 0.005 kg/ha-yr for nitrogen and sulfur deposition as specified by FLAG (2010). Note that the deposition analysis threshold is not an adverse impact threshold; rather, it is an approximate value of the naturally occurring deposition where values below are considered negligible. The project impacts are derived from the difference in total deposition between each Cumulative Alternative scenario and the No Action Alternative scenario.

4.5.5.1 Acid Neutralizing Capacity

Previous studies in the region such as GMT2 did not include an analysis of the effect on the acid neutralizing capacity (ANC) of sensitive lakes due to the lack of ANC data. Since the necessary ANC data are not available for sensitive lakes in the region, the change in ANC was not calculated for this study.

5.0 REGIONAL AIR QUALITY IMPACT ASSESSMENT RESULTS

CAMx simulation outputs were processed to analyze the air quality impacts with respect to NAAQS and AAAQS metrics, Prevention of Significant Deterioration (PSD) increments and AQRV metrics. These metrics were processed for analyzing Project impacts in Alternative B and Alternative C as well as Cumulative Effects. The Project impacts were obtained via "brute force" modeling method by difference between the Cumulative No Action Alternative scenario and the Cumulative Alternative scenario. Cumulative impacts were derived from the total concentrations estimated in the Cumulative scenario, i.e., the CAMx run with all regional sources included.

Impacts at the three assessment areas shown in Figure 4.1-2 were obtained using GIS and intersecting the three assessment areas evaluated within the modeling domain (Arctic National Wildlife Refuge, Gates of the Arctic National Park and Preserve, and Noatak National Preserve) to identify the 4 km model grid cells that lie in these areas. The impacts are predicted for the three assessment areas by considering the air quality impacts from these modeling grid cells.

The cumulative and Project air quality impacts were calculated from the CAMx modeling results for the criteria pollutants CO, O_3, $PM_{2.5}$, PM_{10}, NO_2 and SO_2 and compared to the NAAQS and AAAQS standards in Table 1.2-1. The criteria pollutants concentrations for each grid cell in the modeling domain are compared with the respective NAAQS metric to evaluate the impacts due to the Project plus other cumulative sources. Tabulated results and figures are provided below to illustrate the spatial representation of the overall modeled impacts in terms of the standards.

Project impacts at the three assessment areas (shown in Figure 4.1-2) were also compared with PSD Class II increments listed in Table 1.2-2. The comparison to the Class II increments does not represent a regulatory PSD increment consumption analysis and is presented for information only. Sulfur and Nitrogen deposition values are calculated as described in Chapter 4 and are compared with the Critical loads and Deposition Analysis Thresholds (DATs).

5.1 Summary of Air Quality and Air Quality Related Value Impacts*

Impacts are discussed for Alternative B and Alternative C which were previously modeled and for Alternative D and Alternative E that were not modeled.

Modeling was performed for Alternative B and Alternative C with the Willow MDP emissions inventories developed during the DEIS. Remodeling with updated emissions inventories for this SDEIS was not necessary and therefore not performed for the reasons discussed below. The air concentrations modeled in the DEIS due to all cumulative sources were below applicable air quality thresholds. The modeled air concentrations due to Project sources alone were well below the ambient air quality standards anywhere in the modeling domain and the cumulative concentrations are primarily due to other regional sources rather than Project emissions. Emissions from the Project are responsible for a very small fraction of regional emissions (up to 6.0% depending on pollutant). Moreover, peak annual Project emissions under Alternative E are lower than under Alternative B. In addition, changes to Project emissions between this SDEIS and those modeled in the DEIS and included in the FEIS constitute a very small fraction of regional emissions (up to 4.5% depending on pollutant). For details, see the emissions inventories discussed in Chapter 2 of this AQTSD and in Chapter 2 of the AQTSD for the Draft EIS.

The modeled cumulative and Project-specific impacts under Alternative B and Alternative C were compared with the NAAQS and AAAQS standards for criteria pollutants and were found to be below all standards throughout the modeling domain. The cumulative air quality impacts at the three assessment areas are well below the NAAQS and AAAQS standards. The Project-specific impacts are higher near the Willow MDP area and drop off rapidly with distance from the Project. The Project impacts are below the PSD increment thresholds for all criteria pollutants at all three assessment areas. Project-specific impacts of both nitrogen and sulfur deposition at three assessment areas are below the 0.005 kg/ha-yr DATs. The nitrogen cumulative deposition impacts were compared with the critical loads value of 1.0 – 3.0 kg/ha-yr and were found to be below or within this range at all three assessment areas. Visibility was examined for Project specific impacts with the FLAG (2010) screening method and also cumulatively using the SMAT-CE tool. At all three assessment areas examined, the Project visibility impairment impacts did not exceed either 1 or 0.5 delta deciview thresholds. With regards to cumulative visibility impairment, modeled results show that among the three assessment areas examined the area with the worst cumulative visibility during the 20 percent best days is Noatak, while Gates of the Arctic has the worst cumulative visibility during the 20 percent most impaired days.

Alternative D impacts would likely be lower than those in Alternative C due to lower emissions in the former in general. Alternative E impacts would likely be lower than those in Alternative B due to lower peak annual emissions.

5.2 Base Year Model Performance Evaluation

The CAMx 2012 Base Case simulation at 4 km resolution was evaluated for maximum daily 8-hour ozone (MDA8) and 24-hr averaged $PM_{2.5}$ and $PM_{2.5}$ species (sulfate, nitrate, ammonium, elemental carbon (EC), organic carbon (OC), crustal soil, and sodium). Details of the model performance evaluation (MPE) are provided in Attachment B.

Overall, the model performs reasonably well, with the best annual-based performances for MDA8 ozone and the worst annual-based performance for crustal soil. Specifically, annual-based NMB for ozone fall within the goal range listed in Emery, et al. (2017) of ±5%. However, the model presents temporal biases for MDA8 ozone and $PM_{2.5}$ with underprediction in the colder months and overprediction in the warmer months, especially when observations are very low. The performance for these species during individual quarters is worse than the annual-based performance, and annual-based errors are generally higher than annual-based biases because the opposing signs of the biases throughout the year cancel each other out. For example, the annual-based NMB for MDA8 ozone falls within the goal range listed in Emery, et al (2017) while the annual-based and quarterly-based NME values for MDA8 ozone fall outside the criteria value of 25% listed in Emery, et al. (2017). These and other criteria discussed here are not bright-line (pass/fail) thresholds. A similar trend is observed for $PM_{2.5}$, with annual NMB values falling within the criteria range for $PM_{2.5}$ listed in Emery, et al. (2017) of ±30% but NMB values for each quarter, excluding the 2nd quarter (Q2) for the domain-wide analysis, falling outside the criteria range and annual-based NME values above the criteria value of 30%.

For $PM_{2.5}$ species, the model performs best for nitrate and ammonium with MFE and MFB values throughout the year at Deadhorse and Wainwright within criteria ranges established in bugle plots. Most of the MFB and MFE values for EC and sodium fall within criteria ranges. MFB and MFE results for sulfate and crustal soil are more mixed. Similar to $PM_{2.5}$, speciated data like sulfate, nitrate, and ammonium are biased high in quarter 3 when observational data tends to be very low. Crustal soil is generally overpredicted in the year. OC is systematically biased low with all MFB and MFE values falling outside criteria ranges.

In summary, the model performs reasonably well excluding difficulties reproducing very low observational data and systematic biases for OC and soil. Details of the model performance evaluation are provided in Attachment B.

5.3 Alternative B (Proponent's Project)

This section presents the analysis for Project and cumulative impacts for Alternative B. The model outputs are processed following the methodology discussed in Chapter 4. The concentrations are compared with NAAQS and AAAQS standards, PSD increments and deposition thresholds for the full domain and at the three assessment areas.

5.3.1 NAAQS and AAAQS Analysis

Table 5.3-1 provides a summary of maximum ambient air quality concentrations from the cumulative scenario for all criteria pollutants at all assessment areas. In the modeling domain, the air quality concentrations for all criteria pollutants are below the NAAQS and AAAQS.

Table 5.3-2 shows the maximum Project impacts for all criteria pollutants in terms of the standards. The Project impacts for all pollutants are well below the NAAQS and AAAQS standards and show negligible contribution to the cumulative air quality concentrations.

Table 5.3-1 Comparison of Modeled Cumulative Concentrations under Alternative B (Proponent's Project) with AAQS

	CO		NO_2		O_3	$PM_{2.5}$		PM_{10}	SO_2			
	8 hours	1 hour	1 hour	Annual	8 hours	Annual	24 hours	24 hours	1 hour	3 hours	24 hours	Annual
	ppm	ppm	ppb	ppb	ppb	µg/m³	µg/m³	µg/m³	ppb	ppm	ppm	ppm
Primary NAAQS and AAAQS[a, b]	9	35	100	53	70	12	35	150	75	0.5	0.14	0.03
Secondary NAAQS[b]	NA	NA	NA	53	70	15	35	150	NA	0.5	NA	NA
	Modeled Concentrations											
Full Domain[1]	3.1	0.9	72.4	22.0	55.5	10.1	31.4	121.3	58.1	0.057	0.035	0.009
Arctic National Wildlife Refuge	0.6	0.4	21.0	1.6	55.5	2.5	7.3	30.5	0.7	0.002	0.001	0.000
Gates of the Arctic	0.2	0.2	1.2	0.2	53.4	1.4	3.9	9.9	0.7	0.001	0.001	0.000
Noatak National Preserve	3.1	0.9	13.0	0.5	46.8	2.6	8.8	105.6	3.2	0.010	0.002	0.000

NA indicates "not applicable"
1 Full Domain values represent the maximum modeled concentration in the numerical form of the air quality standard in the entire domain.
[a] AAAQS are presented in units consistent with the Primary NAAQS to assist with comparison to modeled impacts.
[b] The methods to prepare model results for comparison to the primary and secondary NAAQS and AAAQS are described in Chapter 4.

Table 5.3-2 Comparison of Modeled Project Concentrations under Alternative B (Proponent's Project) with AAQS

	CO		NO_2		O_3	$PM_{2.5}$		PM_{10}	SO_2			
	8 hours	1 hour	1 hour	Annual	8 hours	Annual	24 hours	24 hours	1 hour	3 hours	24 hours	Annual
	ppm	ppm	ppb	ppb	ppb	µg/m^3	µg/m^3	µg/m^3	ppb	ppm	ppm	ppm
Primary NAAQS and AAAQS[a, b]	9	35	100	53	70	12	35	150	75	0.5	0.14	0.03
Secondary NAAQS[b]	NA	NA	NA	53	70	15	35	150	NA	0.5	NA	NA
	Modeled Concentrations											
Full Domain[1]	0.0	0.0	7.1	2.6	1.1	0.7	0.3	2.3	0.2	0.0	0.0	0.0
Arctic National Wildlife Refuge	0.0000	0.0000	0.0000	0.0004	0.0000	0.0007	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Gates of the Arctic	0.0000	0.0000	0.0000	0.0003	0.0014	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Noatak National Preserve	0.0000	0.0000	0.0006	0.0002	0.0000	0.0002	0.0000	0.0029	0.0000	0.0000	0.0000	0.0000

NA indicates "not applicable"

1 Full Domain values represent the maximum modeled concentration in the numerical form of the air quality standard in the entire domain.

[a] AAAQS are presented in units consistent with the Primary NAAQS to assist with comparison to modeled impacts.

[b] The methods to prepare model results for comparison to the primary and secondary NAAQS and AAAQS are described in Chapter 4.

Figure 5.3-1 through Figure 5.3-6 show the spatial distribution of cumulative and Project impacts for O_3, NO_2, $PM_{2.5}$, PM_{10}, SO_2 and CO concentrations respectively.

The 4th highest 8-hour cumulative O_3 impacts (Figure 5.3-1(left)) are below the NAAQS throughout the domain and the maximum of 55.5 ppb is modeled near the Arctic National Wildlife Refuge. The Project contribution to this maximum is negligible at this location. The maximum Project impact in the modeling domain is 1.1 ppb (Figure 5.3-1 (right)) and is modeled near the Project Area. Some of the Project impacts ranging from 0.1-1 ppb occurred further downwind south of the Project area. The Project has little to no impact on O_3 concentrations for the vast majority of the modeling domain, including within the three assessment areas.

The spatial maximum of annual average and 8th highest daily average $PM_{2.5}$ cumulative impacts (Figure 5.3-2, left) are 10.1 and 31.4 µg/m^3 respectively. Both of these maximum impacts are below NAAQS and occurred near the northern coastline close to Wainwright monitoring station. The annual $PM_{2.5}$ cumulative concentrations are less than 2 µg/m^3 for the vast majority of the modeling domain, including the three assessment areas, although certain areas near the coast and along roadways show concentrations between 2 to 4 µg/m^3. The cumulative 8th highest daily average $PM_{2.5}$ near the Project area falls in the range of 4 to 6 µg/m^3. Overall the Project area and all three assessment areas are well below the NAAQS. The annual average and 8th highest daily average $PM_{2.5}$ Project impacts (Figure 5.3-2, right) from Alternative B shows a spatial maxima of 0.7 µg/m^3 and 0.3 µg/m^3 respectively. The Project impacts are the highest near the Willow MDP and decrease in magnitude rapidly with distance. For the rest of the modeling domain, including the three assessment areas, the impacts from the Project are essentially negligible.

The maximum second-highest daily cumulative PM_{10} of 121.3 µg/m^3 is modeled near the Noatak National Preserve as shown in Figure 5.3-3; this value is below the NAAQS of 150 µg/m^3. The maximum Project impact of 2.3 µg/m^3 is modeled near the Project area. The high PM_{10} concentrations modeled near Noatak are due to the emissions from wildland fires as modeled in the BOEM base case 2012 regional inventory. The modeled maximum cumulative concentrations of the annual average NO_2 and 8th highest (98th percentile) daily maximum NO_2 are 22 ppb and 72.4 ppb respectively and occurred near coastline and off the coast as shown in Figure 5.3-4. These high values are mainly due to the offshore oil and gas emissions sources and shipping activity in the Chukchi Sea. Near the Project area, the cumulative concentrations for annual average NO_2 and 8th highest daily max NO_2 are in the range of 2-5 ppb and 5-20 ppb and the Project impacts from Alternative B show spatial maxima of 2.6 ppb and 7.1 ppb for annual mean and 98th percentile, respectively. The Project impacts maximum occurred mainly near the Project area and decrease with distance from the Project area. The 8th highest 1-hour NO_2 spatial distribution shows some Project impacts offshore in the Beaufort Sea (up to approximately 0.8 ppb) and southwest of the Project area (up to approximately 7 ppb).

The spatial maxima of the cumulative impacts of the annual average SO_2 (9.1 ppb), second-highest 24-hour SO_2 (34.6 ppb), second-highest 3-hour SO_2 (57.4 ppb) and fourth-highest daily maximum 1-hour SO_2 (58.1 ppb) occurred off the coast and well away from the Project area. Cumulative SO_2 concentrations in the inland portion of the modeling domain, including near the Project area and the three assessment areas, are generally less than 2 ppb. The maximum Project impacts of SO_2 occur southwest of the Willow MDP area and the maximum increases are less than 0.2 ppb.

The spatial distributions of cumulative impacts on 1-hour and 8-hour CO concentrations are shown in Figure 5.3-6**.** The spatial maxima of the second-highest 1-hour and 8-hour CO are 3.1 ppm and 0.9 ppm, both are well below the corresponding NAAQS (35 ppm for 1-hour and 9 ppm for 8-hour). These high CO concentrations are modeled near Noatak and are due to the emissions from wildland fires as modeled in the BOEM base case 2012 regional inventory. The Project impacts from Alternative B are almost negligible with zero impacts farther away from the Project.

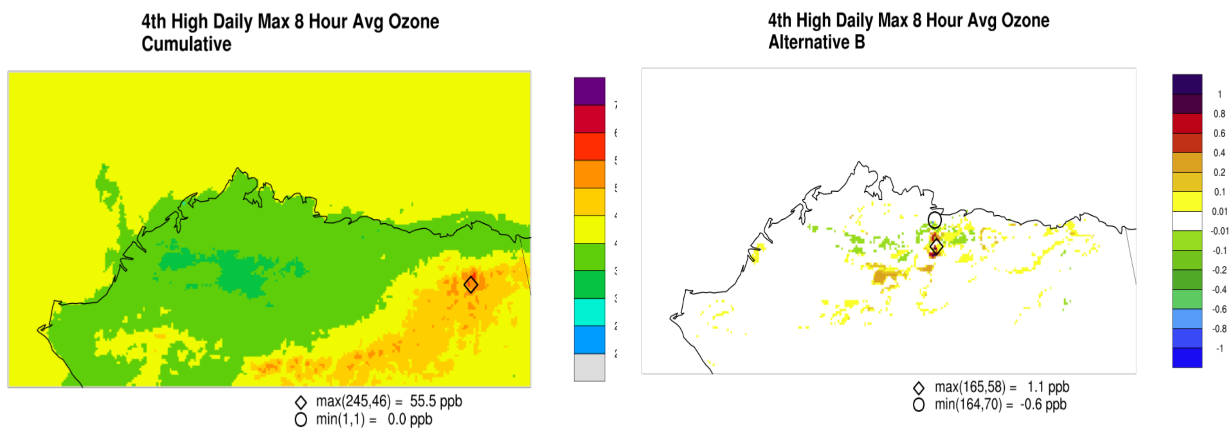


Figure 5.3.1 Alternative B (Proponent's Project): Fourth-Highest Daily Maximum 8-hour Ozone Cumulative (left) and Project Impacts (right)

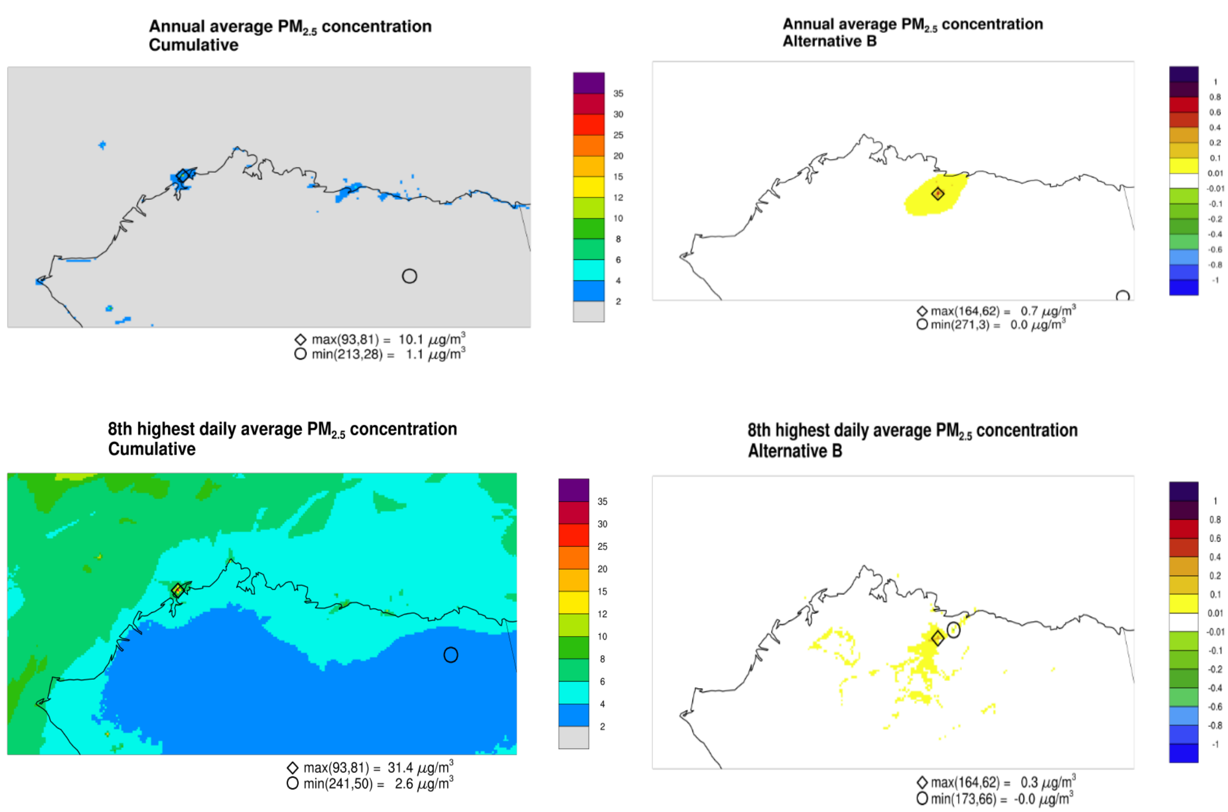


Figure 5.3.2 Alternative B (Proponent's Project): Annual Average (top) and 8th Highest Daily Average (bottom) $PM_{2.5}$ Cumulative (left) and Project (right) Impacts

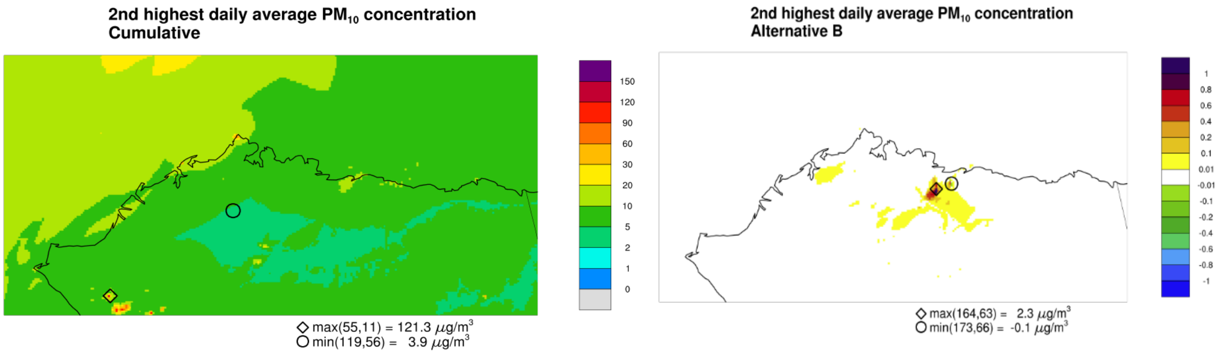


Figure 5.3.3 Alternative B (Proponent's Project): 2nd Highest Daily Average PM_{10} Cumulative (left) and Project (right) Impacts

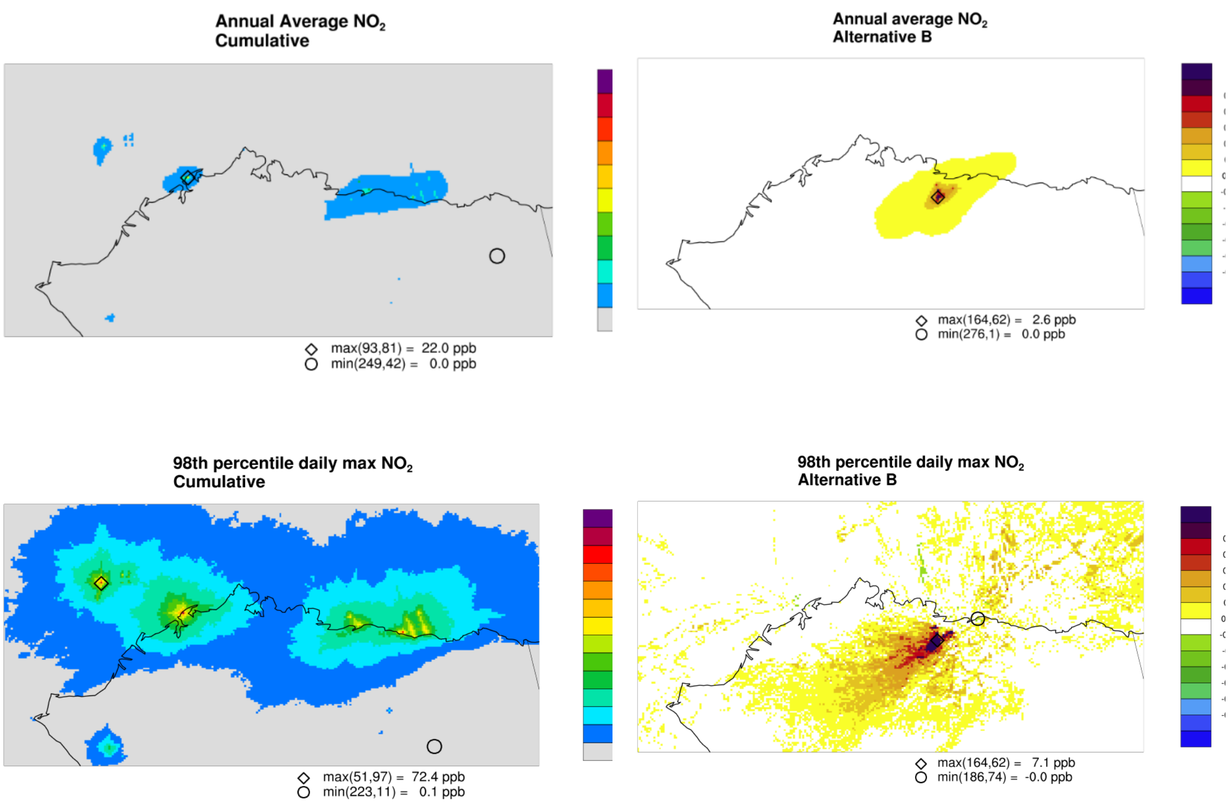


Figure 5.3.4 Alternative B (Proponent's Project): Annual Average (top) and 8th Highest 1-hr Daily Maximum (bottom) NO_2 Cumulative (left) and Project (right) Impacts

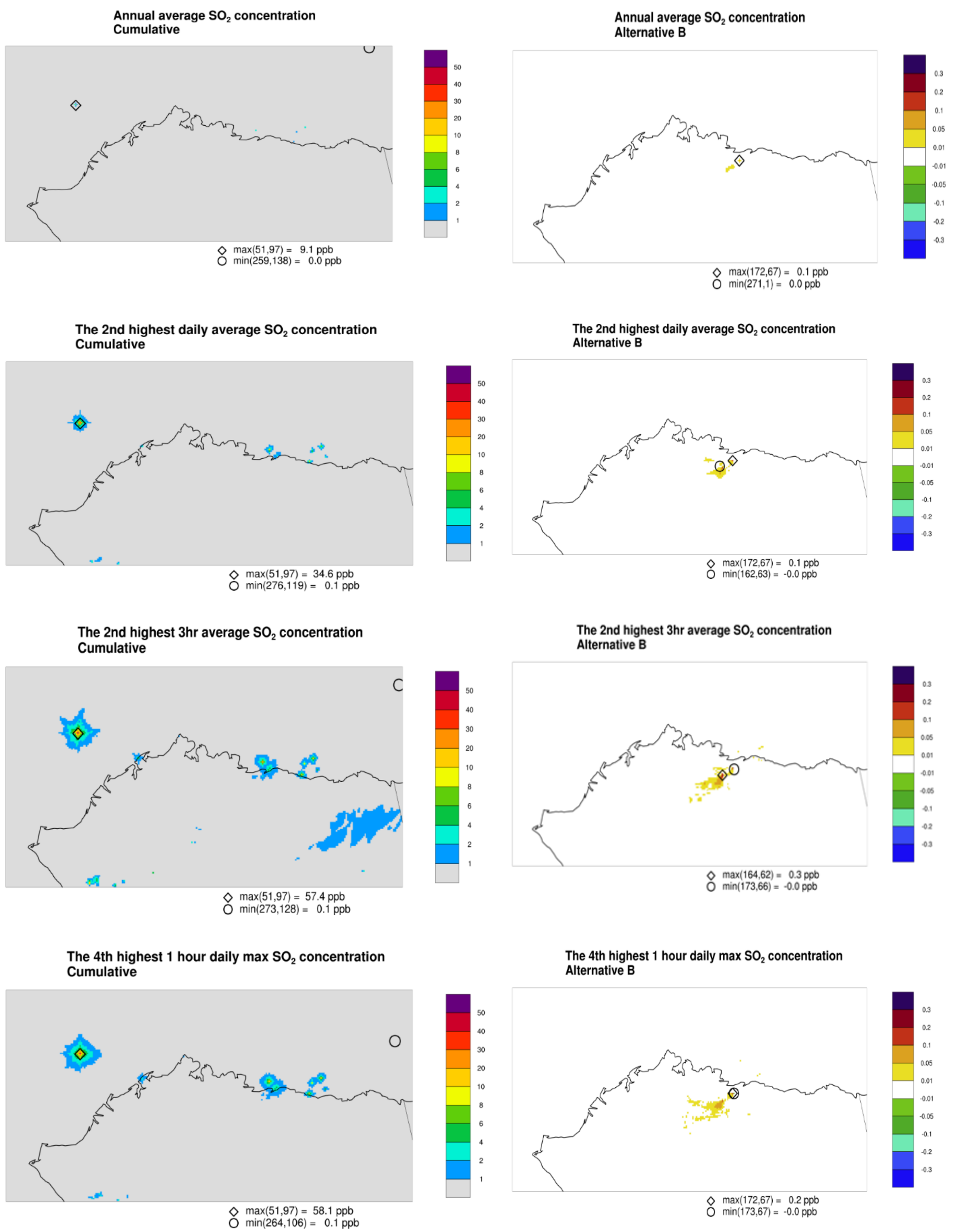


Figure 5.3.5 Alternative B (Proponent's Project): Annual Average, 2nd Highest Daily Average, 2nd Highest 3-hr Average and 4th Highest 1-hr Daily Maximum SO_2 Cumulative (left) and Project (right) Impacts

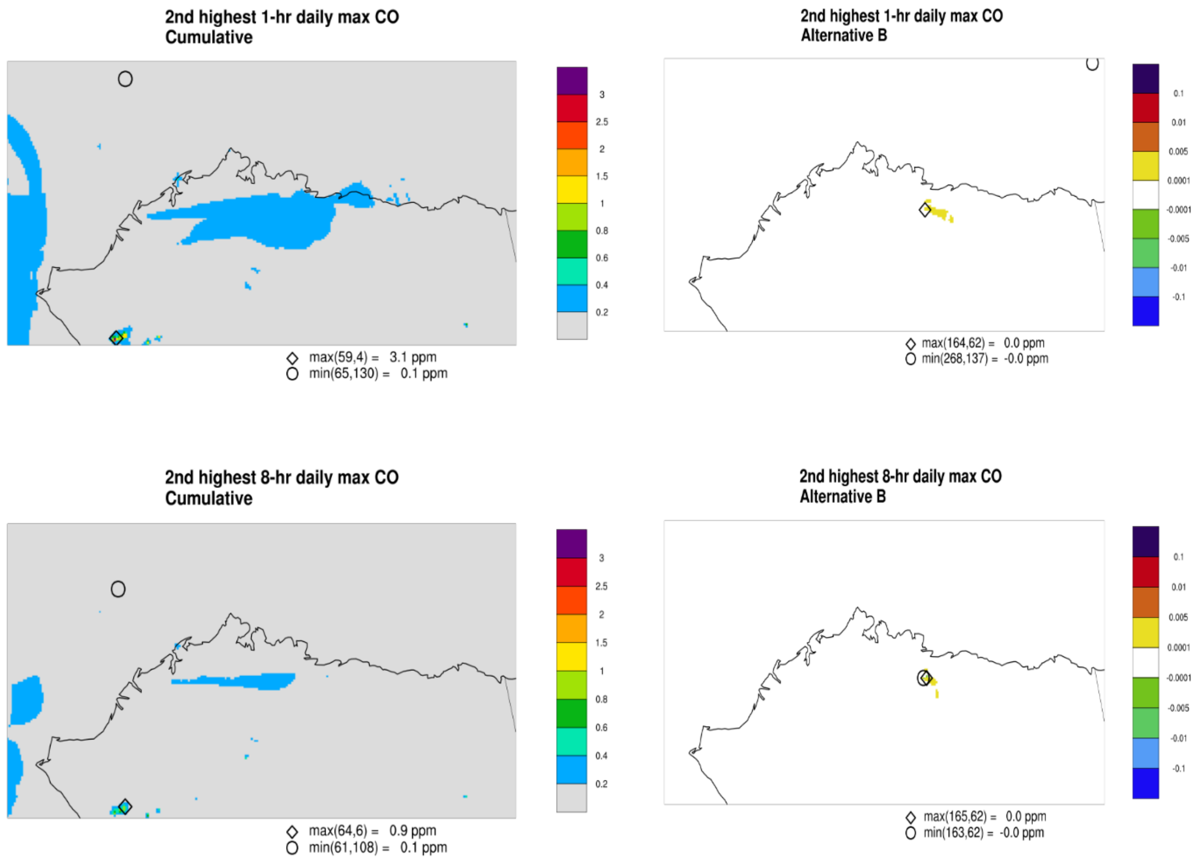


Figure 5.3.6 Alternative B (Proponent's Project): 2nd Highest 1-hr and 8-hr Average Daily Maximum CO Cumulative (left) and Project (right) Impacts

5.3.2 PSD Increments

The PSD regulations are established to prevent significant deterioration of air quality in the areas that already meet the NAAQS. In this section we compare the Alternative B Project modeled impacts at the three assessment areas and for the full domain with the respective Class II area PSD increments.
As shown in Table 5.3-3 throughout the modeling domain and at the three assessment areas, the Alternative B maximum Project increments for all pollutants (NO_2, PM_{10}, $PM_{2.5}$, SO_2) are significantly below the PSD increments. Near the three assessment areas the impacts ranges between 0.0001 – 0.02 µg/m^3. Overall the modeled PSD increments indicate that the Project impacts are very small and are unlikely to deteriorate the air quality values at the three assessment areas.

Table 5.3-3 Alternative B (Proponent's Project) Model-Predicted Project Maximum Impacts Compared with Class II Area PSD Increments

	NO_2		PM_{10}		PM_{25}		SO_2	
	Annual	24-hour	Annual	24-hour	Annual	3-hour	24-hour	Annual
	PSD Class II Increment (μg/m³)							
Standard	25	30	17	9	4	512	91	20
	Modeled Concentrations							
Full Domain[1]	4.86	5.45	1.06	1.84	0.65	1.55	0.71	0.14
Arctic National Wildlife Refuge	0.0053	0.0288	0.0017	0.0287	0.0015	0.0116	0.0047	0.0003
Gates of the Arctic	0.0022	0.0233	0.0011	0.0192	0.0009	0.0067	0.0041	0.0002
Noatak National Preserve	0.0029	0.0115	0.0008	0.0114	0.0008	0.0098	0.0043	0.0002

[1] Full Domain values represent the maximum modeled concentration in the numerical form of the air quality standard in the entire domain.

5.3.3 Deposition Analysis

The modeled deposition fluxes were processed as discussed in Chapter 4 to estimate the total annual nitrogen (N) and sulfur (S) values at each of the three assessment areas. Table 5.3-4 and Table 5.3-5 show the summary of the spatial maximum and average across each of the three assessment areas for cumulative impacts and Project impacts. As shown in Table 5.3-4 the nitrogen cumulative impacts are below or within the critical load range at all three assessment areas. Annual cumulative nitrogen deposition varies from 0.5 -1.1 kg/ha-yr across these three assessment areas when considering the spatial maximum and varies from 0.3-0.5 kg/ha-yr when considering the average of each area. Annual cumulative sulfur deposition varies from 0.6 -1.5 kg/ha-yr across these three assessment areas when considering the spatial maximum and varies from 0.3 – 0.6 kg/ha-yr when considering the average of each area. Among the three assessment areas, Noatak National Preserve is modeled to experience the highest nitrogen deposition and sulfur deposition due to cumulative impacts.

Table 5.3-5 shows the maximum and average Alternative B Project impacts for nitrogen and sulfur impacts. These Project impacts are below the DAT of 0.005 kg/ha-yr. Overall both the maximum and average Project impacts at all three assessment areas are small and contribute little to the total cumulative impacts.

Figure 5.3-7 presents the spatial distribution of the cumulative and Project impacts for sulfur and nitrogen deposition. The Alternative B cumulative sulfur deposition (Figure 5.3-7, top-left) maximum impact of 15.2 kg/ha-yr is modeled off the coast due to offshore oil and gas activity. Overall, the rest of the domain shows impacts in the range of 0.2 – 1.2 kg/ha-yr. The cumulative nitrogen deposition maximum impact of 2.1 kg/ha-yr occurred close to Noatak National Preserve. Both of these cumulative maximum impacts occurred far away from the Project area. Project impacts on nitrogen deposition and sulfur deposition are highest near the Willow MDP and decrease rapidly as we move away from the Project area.

Table 5.3-4 Alternative B (Proponent's Project) Nitrogen and Sulfur Deposition Cumulative Impacts: Spatial Maximum and Average

Assessment Area	Nitrogen (kg N/ha-yr)			Sulfur (kg S/ha-yr)	
	Maximum	Average	Below/Within/ Above Critical Load Range (1.0-3.0 kg/ha-yr)	Maximum	Average
Arctic National Wildlife Refuge	0.71	0.34	Below	0.71	0.31
Gates of the Arctic	0.59	0.38	Below	0.68	0.37
Noatak National Preserve	1.12	0.49	Within/Below	1.58	0.61

Table 5.3-5 Alternative B (Proponent's Project) Nitrogen and Sulfur Deposition Project Impacts: Spatial Maximum and Average

Assessment Area	Nitrogen (kg N/ha-yr)			Sulfur (kg S/ha-yr)		
	Maximum	Average	Below Deposition Analysis Threshold (0.005 kg/ha-yr)	Maximum	Average	Below Deposition Analysis Threshold (0.005 kg/ha-yr)
Arctic National Wildlife Refuge	3.6E-03	4.5E-04	Yes	1.50E-05	3.93E-05	Yes
Gates of the Arctic	8.7E-04	5.0E-04	Yes	1.40E-05	5.27E-05	Yes
Noatak National Preserve	3.2E-03	8.6E-04	Yes	4.09E-05	8.06E-05	Yes

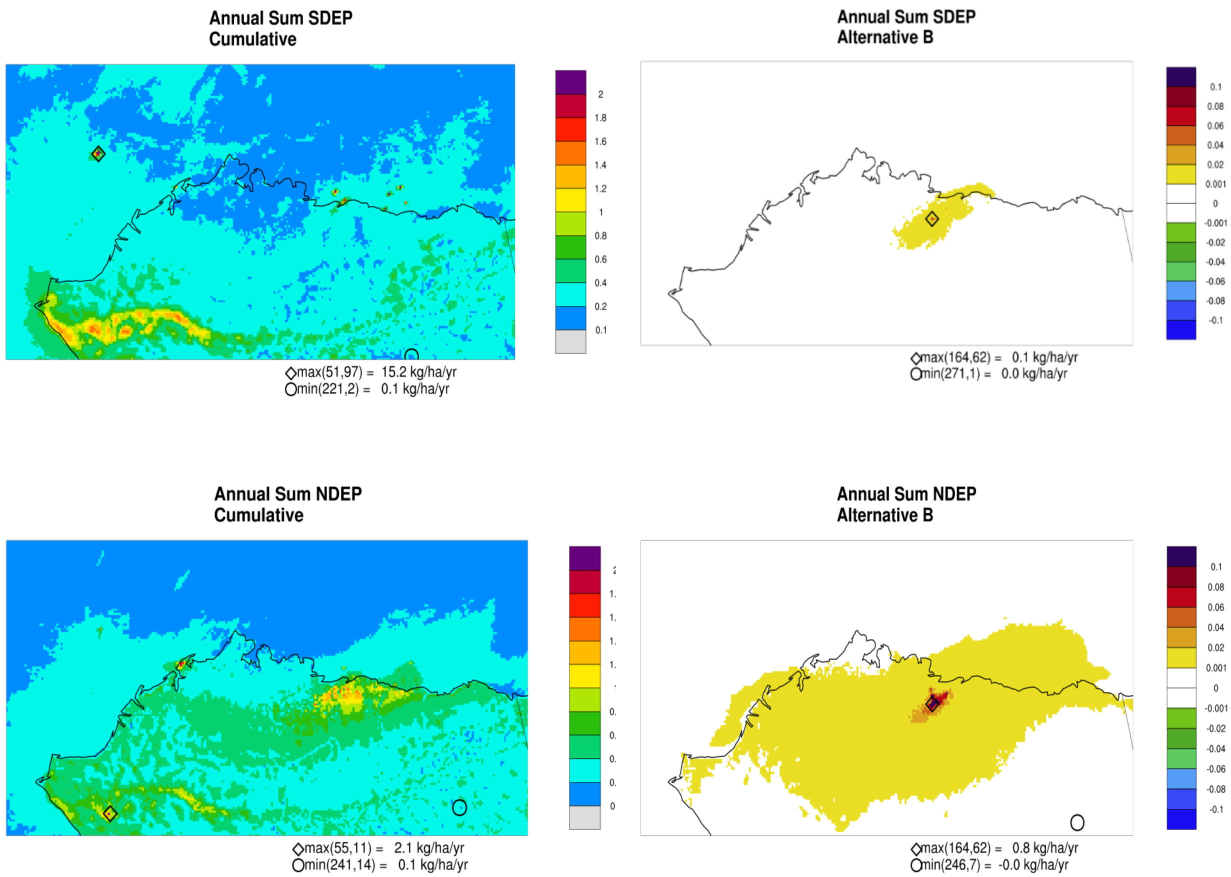


Figure 5.3.7 Alternative B (Proponent's Project): Annual Sum of Sulfur (S) (top) and Nitrogen (N) (bottom) Deposition Cumulative (left) and Project (right) Impacts

5.3.4 Visibility Analysis

The analysis of the effects on visibility from this Project follows the approach explained in detail in Chapter 4. The cumulative impacts on visibility were calculated using the SMAT-CE tool, while Project impacts are assessed following the FLAG (2010) screening method.

Table 5.3-6 shows the cumulative visibility design values estimated for Alternative B at each of the three assessment areas. As described in Chapter 4, these values are derived from the monitoring data at Denali NP and therefore the Base Year design value is unchanged among all the areas. For both the 20 percent best and the 20 percent most impaired days the projected visibility will slightly degrade from current values at all three assessment areas. The area with the worst cumulative visibility during the 20 percent best days is Noatak National Preserve, while Gates of the Arctic has the worst cumulative visibility during the 20 percent most impaired days. The design values account for the cumulative visibility changes in the whole domain between the base and future year and thus reflects not only the Project contributions but also the contributions from all other sources.

Table 5.3-6 Alternative B (Proponent's Project): Base (2012) and Future (2025) Cumulative Visibility Impacts for the 20 Best and Most Impaired Days

Assessment Area	20 Percent Best Days (dv)		20 Percent Most Impaired Days (dv)	
	Base Year	Future Year	Base Year	Future Year
Arctic National Wildlife Refuge	2.671	2.682	7.245	7.248
Gates of the Arctic		2.684		7.279
Noatak National Preserve		2.739		7.249

Table 5.3-7 shows the Willow MDP impacts on visibility when compared to natural background conditions under the Alternative B. These estimates indicate that the direct visibility impacts under Alternative B are all small and would not significantly degrade visibility at any of the three assessment areas. None of the three assessment areas exceeds either the 1 and 0.5 delta deciview thresholds, furthermore the largest impacts observed at Arctic National Wildlife Refuge are only half of the 0.5 delta deciview threshold. Modeling results indicate that the impacts are more likely to be observed during the spring as both Arctic National Wildlife Refuge and the Noatak National Preserve experience the peak delta deciview values in April. The visibility impacts during the 20 percent worst days are generally an order of magnitude lower than the maximum values.

Table 5.3-7 Alternative B (Proponent's Project): Project Visibility Impacts

Assessment Area	Δdv (Max)	Δdv (98th percentile)	Δdv (W20)	Δdv (B20)	Number of Days	
					Δdv > 1	Δdv > 0.5
Arctic National Wildlife Refuge	0.36026	0.11401	0.03110	0.00009	0	0
Gates of the Arctic	0.17987	0.05501	0.01170	0.00001	0	0
Noatak National Preserve	0.08118	0.04246	0.01074	0.00001	0	0

5.4 Alternative C (Disconnected Infield Roads)

This section presents the Project and cumulative impacts for Alternative C. The model outputs are processed following the methodology discussed in Chapter 4. The concentrations are compared with NAAQS and AAAQS standards, PSD increments and deposition thresholds for the full domain and at the three assessment areas.

5.4.1 NAAQS Analysis

Table 5.4-1 provides a summary of maximum ambient air quality concentrations from the cumulative Alternative C scenario for all criteria pollutants at the assessment areas. Air concentrations for all criteria pollutants are below the NAAQS and AAAQS anywhere in the modeling domain.

Table 5.4-2 shows the maximum Project impacts for all criteria pollutants in terms of the standards. For all pollutants, the Project impacts are well below the NAAQS and AAAQS and show negligible contribution to the cumulative air quality concentrations.

Table 5.4-1 Comparison of Modeled Cumulative Concentrations under Alternative C (Disconnected Infield Roads) with AAQS

	CO		NO_2		O_3	$PM_{2.5}$		PM_{10}	SO_2			
	8 hours	1 hour	1 hour	Annual	8 hours	Annual	24 hours	24 hours	1 hour	3 hours	24 hours	Annual
	ppm	ppm	ppb	ppb	ppb	μg/m³	μg/m³	μg/m³	ppb	ppm	ppm	ppm
Primary NAAQS and AAAQS[a, b]	9	35	100	53	70	12	35	150	75	0.5	0.14	0.03
Secondary NAAQS[b]	NA	NA	NA	53	70	15	35	150	NA	0.5	NA	NA
	Modeled Concentrations											
Full Domain[1]	3.1	0.9	72.4	22.0	55.5	10.1	31.4	121.3	58.1	0.1	0.0	0.0
Arctic National Wildlife Refuge	0.6	0.4	21.0	1.6	55.5	2.5	7.3	30.5	0.74	0.002	0.001	0.000
Gates of the Arctic	0.2	0.2	1.2	0.2	53.4	1.4	3.9	9.9	0.68	0.001	0.001	0.000
Noatak National Preserve	3.1	0.9	13.0	0.5	46.8	2.6	8.8	105.6	3.17	0.010	0.002	0.000

NA indicates "not applicable"
[1] Full Domain values represent the maximum modeled concentration seen in the entire domain.
[a] AAAQS are presented in units consistent with the Primary NAAQS to assist with comparison to modeled impacts.
[b] The methods to prepare model results for comparison to the primary and secondary NAAQS and AAAQS are described in Chapter 4.

Table 5.4-2 Comparison of Modeled Project Concentrations under Alternative C (Disconnected Infield Roads) with AAQS

	CO		NO_2		O_3	$PM_{2.5}$		PM_{10}	SO_2			
	8 hours	1 hour	1 hour	Annual	8 hours	Annual	24 hours	24 hours	1 hour	3 hours	24 hours	Annual
	ppm	ppm	ppb	ppb	ppb	µg/m³	µg/m³	µg/m³	ppb	ppm	ppm	ppm
Primary NAAQS and AAAQS[a, b]	9	35	100	53	70	12	35	150	75	0.5	0.14	0.03
Secondary NAAQS[b]	NA	NA	NA	53	70	15	35	150	NA	0.5	NA	NA
	Modeled Concentrations											
Full Domain[1]	0.0	0.0	11.0	4.4	1.4	0.9	0.6	2.1	0.1	0.0	0.0	0.0
Arctic National Wildlife Refuge	0.0000	0.0000	0.0000	0.0004	0.0000	0.0008	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Gates of the Arctic	0.0000	0.0000	0.0001	0.0004	0.0011	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Noatak National Preserve	0.0000	0.0000	0.0001	0.0003	0.0000	0.0002	0.0000	0.0033	0.0000	0.0000	0.0000	0.0000

[1] Full Domain values represent the maximum modeled concentration in the numerical form of the air quality standard in the entire domain.

Figure 5.4-1 through Figure 5.4-6 show the spatial distribution of cumulative and Project impacts for all O_3, NO_2, $PM_{2.5}$, PM_{10}, SO_2 and CO respectively.

The 4th highest 8-hour cumulative O3 impacts (Figure 5.4-1 (left)) are below the NAAQS throughout the domain and the maximum of 55.5 ppb is modeled to occur near the Arctic National Wildlife Refuge. The Project contribution to this maximum is negligible at this location. The maximum Project impact anywhere in the analysis area is 1.4 ppb (Figure 5.4-1 (right)) and is modeled near the Willow MDP area. Some of the Project impacts ranging from 0.1-1 ppb occurred further downwind south of the Project area. The Project has little to no impact on O3 concentrations for the vast majority of the modeling domain, including within the three assessment areas.

The spatial maximum of annual average and 8^{th} highest daily average $PM_{2.5}$ cumulative impacts (Figure 5.4-2, left) are 10.1 and 31.4 $\mu g/m^3$ respectively. Both these maximum impacts are below the NAAQS and occurred near the northern coastline near Wainwright. The annual $PM_{2.5}$ cumulative concentrations are less than 2 $\mu g/m^3$ for the vast majority of the modeling domain, including the three assessment areas, although certain areas near the coast and along roadways show concentrations ranging from 2 to 4 $\mu g/m^3$. The cumulative 8^{th} highest daily average $PM_{2.5}$ near the Project area falls in the range of 4 to 6 $\mu g/m^3$. Overall the Project area and all three assessment areas are well below the NAAQS. The maximum Project impacts (Figure 5.4-2, top-right) on annual $PM_{2.5}$ concentrations ranges between 0.1 and 0.7 $\mu g/m^3$. The annual average and 8^{th} highest daily average $PM_{2.5}$ Project impacts show spatial maxima of 0.9 $\mu g/m^3$ and 0.6 $\mu g/m^3$ respectively. The Project impacts are the highest within the Willow MDP area and decrease in magnitude rapidly with distance. Project impacts in the rest of the modeling domain, including the three assessment areas, range from extremely small to negligible.

The maximum second-highest daily cumulative PM_{10} of 121.3 $\mu g/m^3$ is modeled near the Noatak National Preserve as shown in Figure 5.4-3; this is below the NAAQS of 150 $\mu g/m^3$. The high PM_{10} concentrations modeled near Noatak are due to the emissions from wildland fires as modeled in the BOEM base case 2012 regional inventory. The maximum Project impact of 2.3 $\mu g/m^3$ is modeled near the Project area and impacts appear to be less in the vicinity of the Project area.

The modeled maximum cumulative concentrations of the annual average NO_2 and 8^{th} highest (98^{th} percentile) daily maximum NO_2 are 22 ppb and 72.4 ppb respectively and are near coastline and off the coast as shown in Figure 5.4-4. These high values are mainly due to the offshore oil and gas emissions sources and shipping activity in the Chukchi Sea. Near the Project area the cumulative concentrations for annual average NO_2 and 8^{th} highest daily max NO_2 are in the range of 2-5 ppb and 5-20 ppb and the Project impacts from Alternative C shows a spatial maxima of 4.4 ppb and 11.0 ppb respectively. The Project impacts maximum occurred mainly near the Project area and decreases moving away from the Project area. The 8^{th} highest 1-hour NO_2 shows some Project impacts offshore in the Beaufort Sea (up to approximately 0.8 ppb) and south-west of the Project area (up to approximately 11 ppb).

The cumulative impact spatial maxima of the annual average SO_2 (9.1 ppb), second-highest 24-hour SO_2 (34.6 ppb), second-highest 3-hour SO_2 (57.4 ppb) and fourth-highest daily maximum 1-hour SO_2 (58.1 ppb) are modeled off the coast and away from the Project area as shown in Figure 5.4-5. Cumulative SO_2 concentrations in the inland portion of the modeling domain, including near the Project area and the three assessment areas, are generally less than 2 ppb. The maximum Project impacts of SO_2 occur southwest of the Willow MDP area and the maximum increases are less than 0.2 ppb.

The spatial distributions of cumulative impacts on 1-hour and 8-hour CO concentrations are shown in Figure 5.4-6**.** The spatial maxima of the second-highest 1-hour and 8-hour CO are 3.1 ppm and 0.9 ppm, both are well below the corresponding NAAQS (35 ppm for 1-hour and 9 ppm for 8-hour). The high PM_{10} concentrations modeled near Noatak are due to the emissions from wildland fires as modeled in the BOEM base case 2012 regional inventory. The Project impacts from Alternative C are extremely small away from the Project area.

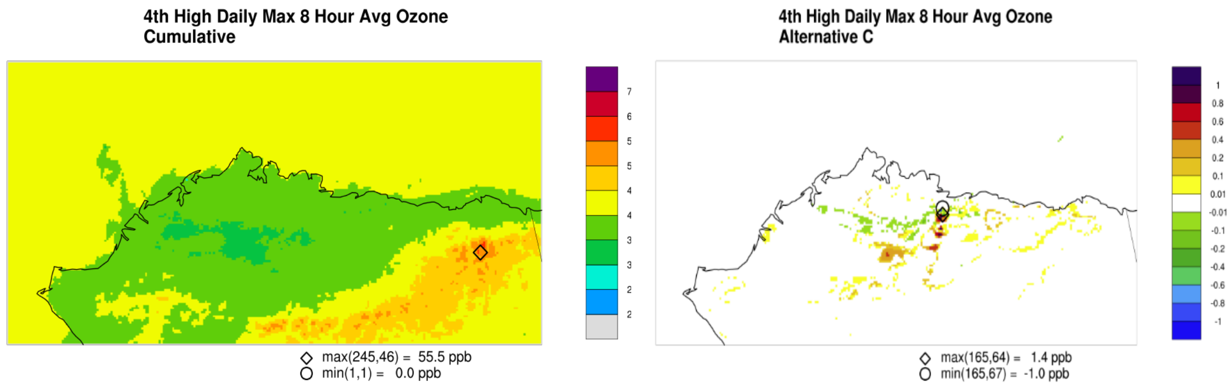


Figure 5.4.1 Alternative C (Disconnected Infield Roads): Fourth-Highest Daily Maximum 8-hour Ozone Cumulative (left) and Project Impacts (right)

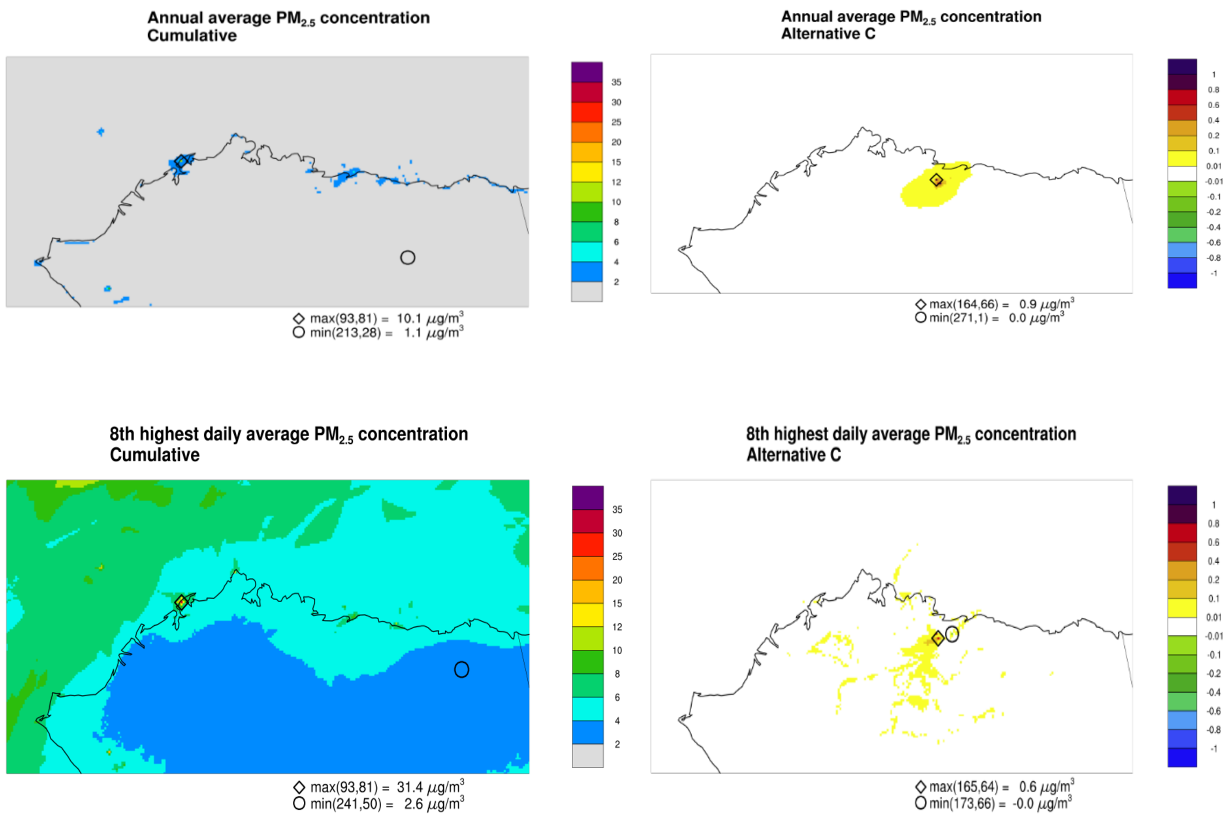


Figure 5.4.2 Alternative C (Disconnected Infield Roads): Annual Average (top) and 8th Highest Daily Average (bottom) $PM_{2.5}$ Cumulative (left) and Project (right) Impacts

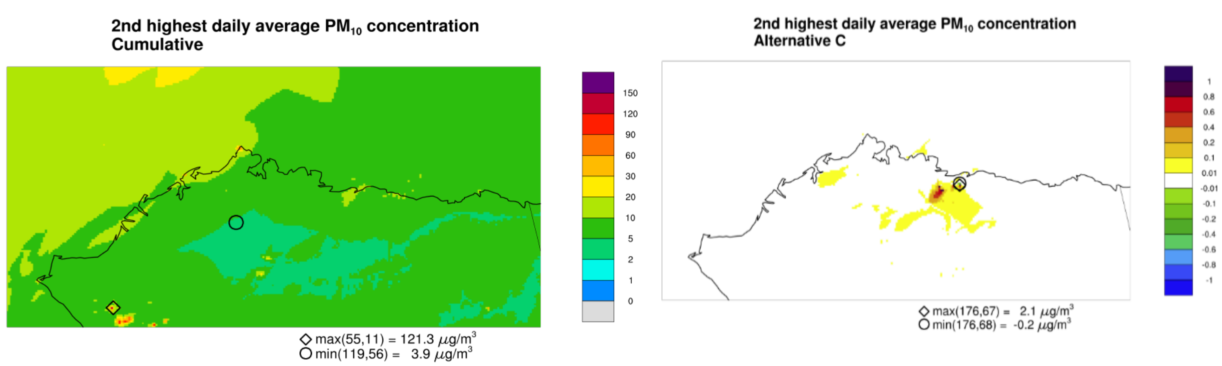


Figure 5.4.3 Alternative C (Disconnected Infield Roads): 2nd Highest Daily Average PM_{10} Cumulative (left) and Project (right) Impacts

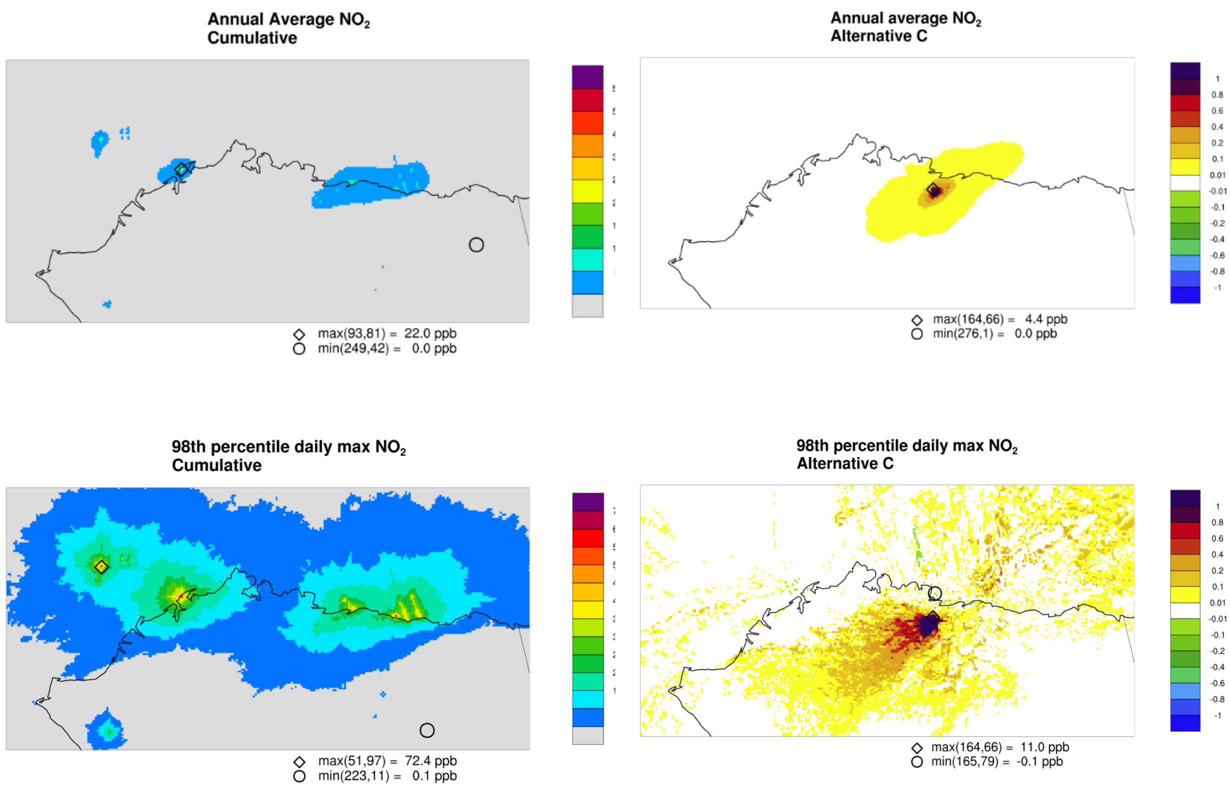


Figure 5.4.4 Alternative C (Disconnected Infield Roads): Annual Average (top) and 8th Highest 1-hr Daily Maximum (bottom) NO_2 Cumulative (left) and Project (right) Impacts

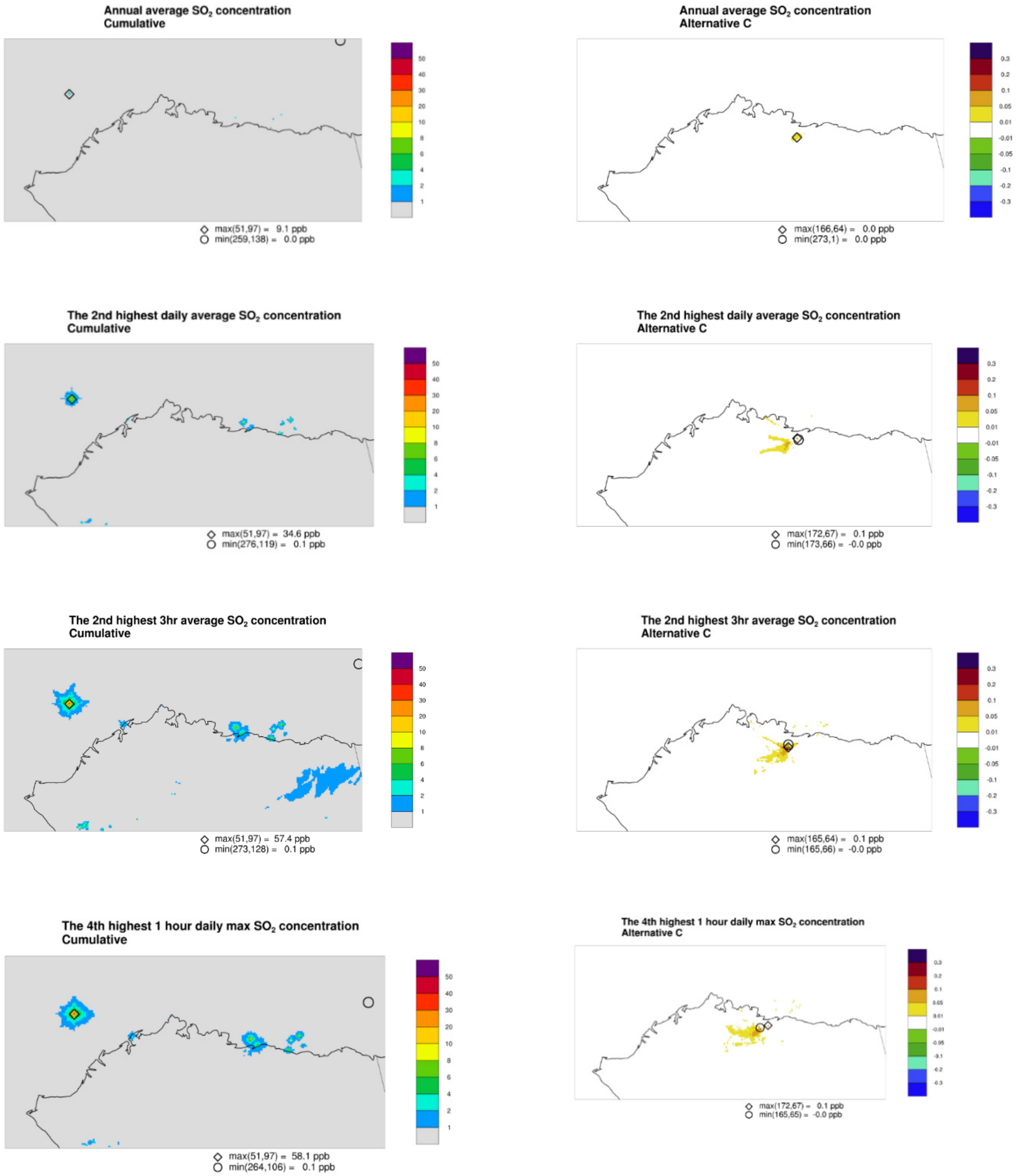


Figure 5.4.5 Alternative C (Disconnected Infield Roads): Annual average, 2nd Highest Daily Average, 2nd highest 3-hr Average and 4th Highest 1-hr Daily Maximum SO_2 Cumulative (left) and Project (right) Impacts

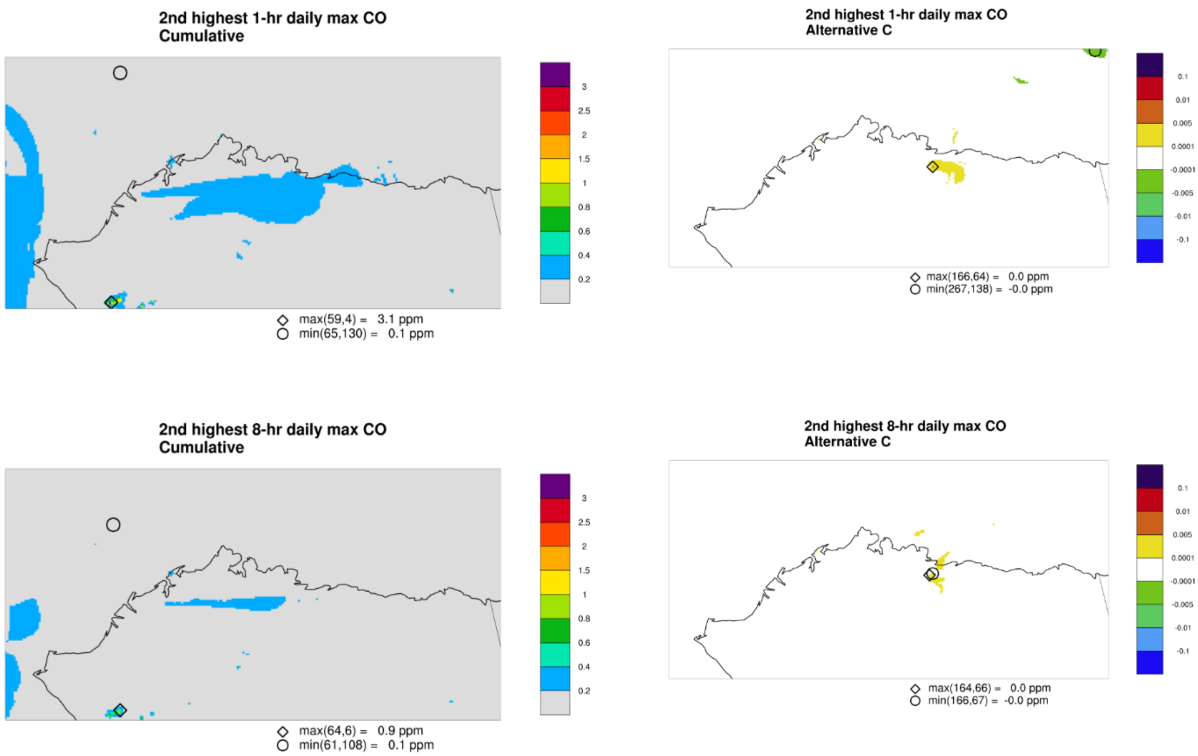


Figure 5.4.6 Alternative C (Disconnected Infield Roads): 2nd Highest 1-hr and 8-hr Average Daily Maximum CO Cumulative (left) and Project (right) Impacts

5.4.2 PSD Increments

The Alternative C Project modeled impacts at the three assessment areas and in the whole domain were compared with the respective Class II area PSD increments. As shown in Table 5.4-3 throughout the modeling domain and three assessment areas, the Alternative C maximum Project increments for all pollutants (NO_2, PM_{10}, $PM_{2.5}$, SO_2) are well below the PSD increments. Near the three assessment areas the impacts range from 0.0001 to 0.03 micrograms per cubic meter (µg/m^3). Overall the PSD increments indicate that the Project impacts are very small and are unlikely to deteriorate the air quality values at the three assessment areas.

Table 5.4-3 Alternative C (Disconnected Infield Roads) Modeled Project Impacts Compared with Class II Area PSD Increments

	NO_2		PM_{10}		PM_{25}		SO_2	
	Annual	24-hour	Annual	24-hour	Annual	3-hour	24-hour	Annual
	PSD Class II Increment (µg/m³)							
Standard	25	30	17	9	4	512	91	20
	Modeled Concentrations							
Full Domain[1]	8.25	3.50	1.12	3.27	0.89	1.31	0.65	0.12
Arctic National Wildlife Refuge	0.0065	0.0299	0.0018	0.0298	0.0016	0.0126	0.0041	0.0003
Gates of the Arctic	0.0026	0.0210	0.0011	0.0198	0.0010	0.0065	0.0042	0.0001
Noatak National Preserve	0.0033	0.0123	0.0009	0.0122	0.0008	0.0090	0.0039	0.0002

1 Full Domain values represent the maximum modeled concentration in the numerical form of the air quality standard in the entire domain.

5.4.3 Deposition Analysis

Table 5.4-4 and Table 5.4-5 provide a summary of maximum and average cumulative impacts and Project impacts at the three assessment areas. As shown in Table 5.4-4 the nitrogen deposition cumulative impacts are below or within the critical load range at all three assessment areas. The annual cumulative nitrogen deposition varies from 0.59 – 1.12 kg/ha-yr across these three assessment areas when considering the spatial maximum and from 0.34 – 0.49 kg/ha-yr when considering the average for each area. Annual cumulative sulfur deposition varies from 0.7 – 1.6 kg/ha-yr across these three assessment areas when considering the spatial maximum and from 0.3 – 0.6 kg/ha-yr when considering the average of each area. Among the three assessment areas, Noatak National Preserve is modeled to experience the highest nitrogen deposition and sulfur deposition due to cumulative impacts.

Table 5.4-5 shows the maximum and average nitrogen and sulfur Project impacts for Alternative C. These Project impacts are below the DAT of 0.005 kg/ha-yr. In general, the Project impacts at all three assessment areas have a very small contribution to the total cumulative deposition values.

Figure 5.4-7 shows the spatial extent of the sulfur and nitrogen deposition cumulative and Project impacts. The Alternative C cumulative sulfur deposition (Figure 5.4-7, top-left) maximum impact of 15.2 kg/ha-yr occurs in the ocean and is related to offshore oil and gas activities in the Chukchi Sea region; for the rest of the domain cumulative impacts range between 0.2 and 1.8 kg/ha-yr (Figure 5.4-7). The maximum cumulative nitrogen deposition maximum of 2.1 kg/ha-yr occurs at the location of maximum impacts from the Project area. The Project contributes to almost 50 percent of the cumulative nitrogen deposition, but this effect decreases substantially with distance with impacts of less than 0.02 kg/ha-yr beyond the 300 km radius around the Project. Maximum sulfur impacts for 0.01 kg/ha-yr occur within the Project area and substantially decrease to values in the range of 0.001 – 0.02 kg/ha-yr.

Table 5.4-4 Alternative C (Disconnected Infield Roads): Nitrogen and Sulfur Deposition Cumulative Impacts – Spatial Maximum and Average

Assessment Area	Nitrogen (kg N/ha-yr)			Sulfur (kg S/ha-yr)	
	Maximum	Average	Below/Within/ Above Critical Load Range (1.0-3.0 kg/ha-yr)	Maximum	Average
Arctic National Wildlife Refuge	0.71	0.34	Below	0.71	0.31
Gates of the Arctic	0.59	0.38	Below	0.68	0.37
Noatak National Preserve	1.12	0.49	Within/Below	1.58	0.61

Table 5.4-5 Alternative C (Disconnected Infield Roads): Nitrogen and Sulfur Deposition Project Impacts – Spatial Maximum and Average

Assessment Area	Nitrogen (kg N/ha-yr)			Sulfur (kg S/ha-yr)		
	Maximum	Average	Below Deposition Analysis Threshold (0.005 kg/ha-yr)	Maximum	Average	Below Deposition Analysis Threshold (0.005 kg/ha-yr)
Arctic National Wildlife Refuge	4.7E-03	5.8E-04	Yes	1.4E-05	3.8E-05	Yes
Gates of the Arctic	1.1E-03	6.4E-04	Yes	1.4E-05	5.0E-05	Yes
Noatak National Preserve	3.9E-03	1.1E-03	Yes	3.9E-05	7.6E-05	Yes

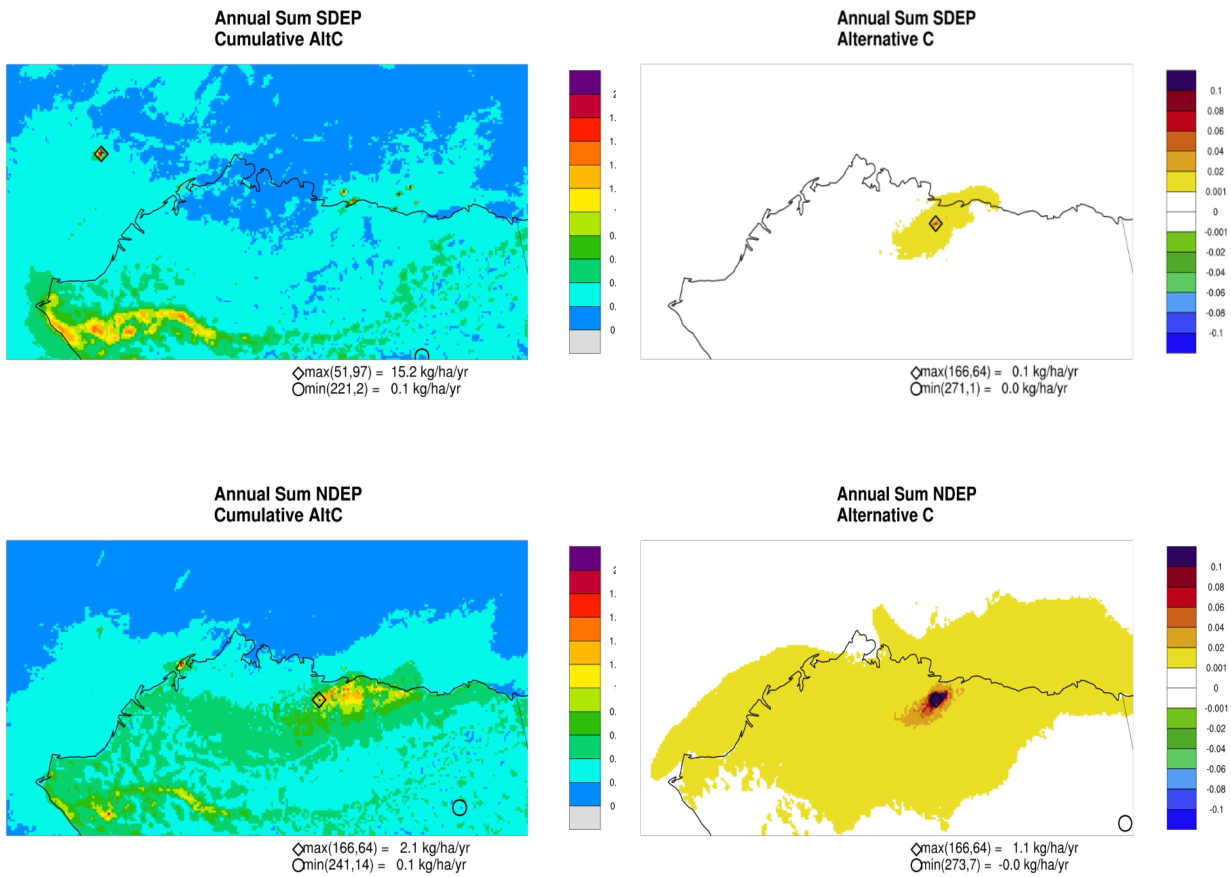


Figure 5.4.7 Alternative C (Disconnected Infield Roads): Annual Sum of Sulfur (S) (top) and Nitrogen (N) (bottom) Deposition: Cumulative (left) and Project (right) Impacts

5.4.4 Visibility Analysis

The analysis of the effects on visibility from Alternative C is similar to that of Alternative B and follows the approach explained in detail in Chapter 4. The cumulative impacts on visibility were calculated using the SMAT-CE tool, while Project impacts are assessed following the FLAG (2010) screening method.

Table 5.4-6 shows the cumulative visibility design values estimated for Alternative C at the three assessment areas. As described in Chapter 4, these values are derived from the monitoring data at Denali NP and therefore the Base Year design value is unchanged among all the areas. For both 20 percent best and 20 percent most impaired days the cumulative visibility will slightly degrade from current values at all three assessment areas. The area with the worst cumulative visibility during the 20 percent best days is Noatak National Preserve, while Gates of the Arctic has the worst cumulative visibility during the 20 percent most impaired days. As in the case of Alternative B, the design values account for the cumulative visibility changes in the whole domain between the base and future year and reflect the contributions from all sources.

Table 5.4-6 Alternative C (Disconnected Infield Roads): Base (2012) and Future (2025) Cumulative Visibility Impacts for the 20 Best and Most Impaired Days

Assessment Area	20 Percent Best Days (dv)		20 Percent Most Impaired Days (dv)	
	Base Year	Future Year	Base Year	Future Year
Arctic National Wildlife Refuge	2.671	2.682	7.245	7.248
Gates of the Arctic		2.684		7.281
Noatak National Preserve		2.741		7.253

Table 5.4-7 shows the Project specific impacts on visibility when compared to natural background conditions under Alternative C. These estimates indicate that the direct visibility impacts under Alternative C are all small and would have little contribution to visibility degradation at the three assessment areas. None of the three assessment areas exceeds either the 1 and 0.5 delta deciview thresholds. The largest impacts are modeled at the Arctic National Wildlife Refuge; these impacts are 60 percent of the 0.5 delta deciview threshold. Modeling results indicate that the higher impacts are more likely during the spring as both Arctic National Wildlife Refuge and Noatak show maximum delta deciview values in April. The delta deciview impacts during the 20 percent worst days are generally an order of magnitude lower than the maximum values.

Table 5.4-7 Alternative C (Disconnected Infield Roads): Project Visibility Impacts

Assessment Area	Δdv (Max)	Δdv (98th percentile)	Δdv (W20)	Δdv (B20)	Number of Days	
					Δdv > 1	Δdv > 0.5
Arctic National Wildlife Refuge	0.30573	0.11276	0.03223	0.00009	0	0
Gates of the Arctic	0.23194	0.06161	0.01126	0.00001	0	0
Noatak National Preserve	0.08033	0.04192	0.01016	0.00001	0	0

5.5 Comparison between Alternative B (Proponent's Project) and C (Disconnected Infield Roads)

In general, the direct impacts to AQ and AQRV from both alternatives are very small and therefore the comparison of cumulative concentrations and other AQRVs shows very little difference between Alternative B and C. A comparison of Project specific impacts between Alternative B and C for pollutants subject to the NAAQS indicates in general that Alternative C has larger domain-wide impacts than Alternative B but these large impacts occur in the immediate vicinity of the Project area. The most noticeable difference can be observed for NO_2 and $PM_{2.5}$ as the larger total annual NOx emissions for Alternative C lead to larger impacts to both NO_2 and particulate nitrate. For ozone the domain-wide maximum is larger for Alternative C compared to Alternative B but the difference is small (0.3 ppb). The spatial distribution of ozone due to either alternatives is very similar and the effect on ozone from both alternatives is same. The main driver of PM_{10} impacts is related to primary particulates. In case of PM_{10}, the emissions for Alternative C are smaller than Alternative B and therefore the impacts are also smaller for Alternative C. The impacts at the three assessment areas from both alternatives are extremely low for all pollutants with no noticeable differences modeled between the two alternatives.

Regarding PSD increments, a similar conclusion to NAAQS is observed in that increased NO_2 emissions in Alternative C lead to higher impact for both NO_2 and $PM_{2.5}$. The lower emission of PM_{10} in Alternative C lead to lower PM_{10} impacts compared to Alternative B. SO_2 impacts are similar in both alternatives as the emissions are similar in both.

Nitrogen deposition related impacts for Alternative C are slightly larger compared to those for Alternative B. However, the main impacts occur within the Project area for both alternatives. Sulfur deposition impacts for both alternatives are very similar and show no distinct differences with the largest impacts occurring within the Project area for both.

The location of the three assessment areas is far from the Project and therefore Project specific maximum deposition impacts are very similar between the two alternatives. In both cases, no alternative will exceed the 0.5 Δdv threshold on any day. The cumulative visibility impacts are very similar between these two alternatives. However, Alternative C shows slightly higher impacts during the 20% most impaired days at Gates of the Arctic and the Noatak National Preserve. The key differences between Alternative B and C that were discussed above are tabulated in Table 5.5-1.

Table 5.5-1 Comparison of Regional Modeling Impacts Across Alternatives

Metric	Impact
NAAQS and AAAQS	Domain-wide impacts for $PM_{2.5}$ and NO_2 are higher for Alternative C compared to Alternative B. Both alternatives show similar impacts for ozone. All pollutants analyzed are below the NAAQS and AAAQS for both alternatives. Alternative D is also anticipated to be below all standards because its emissions are between Alternatives B and C or lower than both of them.
PSD Increment	Domain-wide impacts for $PM_{2.5}$ and NO_2 are higher for Alternative C compared to Alternative B. All pollutants analyzed are below the PSD increment thresholds for both alternatives. Alternative D is also anticipated to be below all PSD increments because its emissions are between Alternatives B and C or lower than both of them.
Deposition	Nitrogen deposition is larger for Alternative C relative to Alternative B. Sulfur deposition for both alternatives is similar. The nitrogen and sulfur deposition for both alternatives are below the Deposition Analysis Thresholds. Alternative D is also anticipated to be below the DATs because its emissions are between Alternatives B and C or lower than both of them.
Visibility	Impacts for both alternatives are similar. Both are well below 0.5 delta dv threshold, so they do not contribute to visibility impairment. Alternative D is also anticipated to be below visibility thresholdsbecause its emissions are between Alternatives B and C or lower than both of them.

5.6 Comparison between Alternative B (Proponent's Project) and Alternative D (Disconnected Access)*

Alternative D was not assessed with the regional model because its CAP emissions (and therefore regional air quality impacts) would be typically lower than Alternative C and higher than Alternative B, or lower than both Alternative B and C in the case of PM_{10}. Therefore, all CAPs would be below the AAQS under Alternative D. The Project impacts related to PSD increments for Alternative D would be higher than Alternative B but lower than Alternative C, or lower than both alternatives in the case of PM_{10}. The Project impacts would be below the PSD increment thresholds for all CAPs in all three assessment areas. Visibility impacts would be between those for Alternatives B and C and would be well below the

0.5 dv threshold based on the emissions, so Alternative D would not contribute to or cause visibility impairment in the three assessment areas. Nitrogen deposition for Alternative D is anticipated to be lower than Alternative C and higher than Alternative B based on the projected emissions. Sulfur deposition for Alternative D would be similar to the other action alternatives. The Project-specific nitrogen and sulfur deposition under Alternative D would be below the DATs and the cumulative nitrogen deposition would be below or within the critical loads for nitrogen deposition. The location of the three assessment areas is far from the Project and therefore Project specific maximum visibility impacts are very similar between the two alternatives. Neither alternative will exceed the 0.5 Δdv threshold on any day. The cumulative visibility impacts are expected to be very similar between these two alternatives.

5.7 Comparison between Alternative B (Proponent's Project) and E (Three-Pad Alternative)*

Alternative E far-field modeling was not performed because the changes in the emissions inventory between Alternative B and Alternative E are minor and impacts to AQ and AQRV can be assessed instead by comparison to modeled impacts disclosed for Alternative B. Table 5.7-1 shows a subset of the emissions presented in Chapter 2 of this AQTSD and shows the maximum year emissions for each criteria pollutant for all Project activities for both Alternatives. As shown, Alternative E maximum year emissions are lower than Alternative B.

Table 5.7-1 Alternative E Maximum Year Emissions from All Project Activities Compared to Alternative B*

Alternative	Peak Annual Emissions (tons per year [tpy])					
	Criteria Pollutants					
	NO_x	CO	SO_2	PM_{10}	$PM_{2.5}$	VOC
Alternative B	903.8	893.9	56.2	554.3	128.1	666.7
Alternative E	838.6	839.9	54.9	545.7	126.9	641.8
Percent Difference (Alt E – Alt B)	-7.2%	-6.0%	-2.3%	-1.6%	-0.9%	-3.7%

Table 5.7-1 shows that the total project emissions for all criteria pollutants and VOCs are lower under Alternative E compared with Alternative B, therefore it is expected the direct impacts to AQ and AQRV for Alternative E would be less or about the same as those of Alternative B, which are already very small. Cumulative concentrations and other AQRVs under both alternatives are expected to show very little differences. Project specific impacts for Alternative E are expected to be similar or lower than the impacts under Alternative B. In general, it is expected that Alternative B shows larger domain-wide impacts than Alternative E and that these impacts will occur in the vicinity of the Project area.

The largest difference in emissions from Table 5.7-1 is in the annual NOx emissions that for Alternative E are 7% smaller than in Alternative B and this will lead to smaller impacts to both NO_2 and particulate nitrate, thus reducing the expected impacts to $PM_{2.5}$. For ozone the domain-wide maximum is expected to be larger for Alternative B compared to Alternative E since the VOC and NOx precursor emissions are both smaller under Alternative E. The spatial distribution of ozone due to either alternative will be similar and the effect on ozone from both alternatives about the same. The main driver of PM_{10} impacts is related to primary particulates. In the case of PM_{10}, the emissions for Alternative E are 1.6% smaller than Alternative B and therefore the impacts are expected to be smaller for Alternative E. The impacts at the three assessment areas for Alternative E are likely to be extremely low for all pollutants since the modeled impacts on Alternative B are shown to be low as well.

Regarding PSD increments[11], a similar conclusion to NAAQS is observed in that decreased NO_2 emissions in Alternative E will lead to smaller impacts for both NO_2 and $PM_{2.5}$. The lower emissions of PM_{10} in Alternative E will lead to lower PM_{10} impacts compared to Alternative B. SO_2 impacts are expected to be smaller for Alternative E given that the SO_2 emissions are 2.3% smaller than Alternative B.

Nitrogen deposition related impacts for Alternative E are expected to be smaller compared to those for Alternative B. However, the main impacts will still occur within the Project area for both alternatives. Sulfur deposition impacts for both alternatives are likely to be similar and show no distinct differences with the largest impacts occurring within the Project area for both.

The location of the three assessment areas is far from the Project and therefore Project specific maximum visibility impacts are expected to be very similar between the two alternatives. Neither alternative will exceed the 0.5 Δdv threshold on any day. The cumulative visibility impacts are expected to be very similar between these two alternatives.

[11] As indicated previously, this is not a formal PSD increment consumption analysis and is presented only for background information

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Appendix E.4
Soils, Permafrost, and Gravel Resources
Technical Appendix

There is no technical appendix for this resource

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Appendix E.5
Contaminated Sites Technical Appendix

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List of Acronyms

Project Willow Master Development Plan Project

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1.0 CONTAMINATED SITES TECHNICAL INFORMATION

1.1 Assessment Criteria and Methodology

The potential for the Willow Master Development Plan Project (Project) to encounter contamination from existing sites was evaluated using records of existing contaminated sites and spills within 0.5 mile of the Project to identify the locations, characteristics, and quantities of existing contamination. The locations of existing contamination were evaluated against the Project activities to assess the likelihood of encountering contamination. The likelihood of encountering contamination during Project construction was assessed using a rating system of very low to high. Ratings are a function of spill status (cleanup complete or active) and distance of the site from the Project footprint. Table E.5.1 presents the assessment criteria for contaminated sites.

Table E.5.1. Contaminated Sites Assessment Criteria

Location	Active Status	Cleanup Complete or Cleanup Complete with Institutional Controls Status
Within 100 feet of Project activity	Moderate	Low
Between 100 and 500 feet of Project activity	Low	Very low
Greater than 500 feet from Project activity	Very low	Very low

1.2 Contaminated Site Details

Table E.5.2 provides a summary of contaminated sites within 0.5 mile of the Project (Figure 3.5.1).

Table E.5.2. Contaminated Sites within 0.5 mile of the Project*

ADEC Hazard ID	Site Name	Event Year	Status	Distance to Project Activity (miles)	Likelihood of Encountering
2654	Oliktok DEW Diesel Tanks SS009a	2004	Cleanup complete	0.2	Very low
1446	Kuparuk Construction Service (KCS)	1992	Cleanup complete – institutional controls	0.3	Very low
2923	Lonely AFS Dewline - Diesel Tank SS10	1995	Cleanup complete	0.0	Low
2924	Lonely AFS Dewline - Beach Diesel SS003	1995	Cleanup complete	0.2	Very low
2925	Lonely AFS Dewline - Hangar Pad SS13	1995	Cleanup complete	0.0	Very low
2926	Lonely AFS Dewline - Landfill LF007	1995	Cleanup complete	0.0	Low
2927	Lonely AFS Dewline - Diesel Spills SS05	1995	Cleanup complete	0.0	Moderate
2928	Lonely AFS Dewline - POL Storage SS04	1995	Cleanup complete	0.0	Low
2932	Lonely AFS Dewline - Garage SS09	1995	Cleanup complete	0.0	Very low
2933	Lonely AFS Dewline - Landfill LF011/SS006	1995	Cleanup complete	0.1	Very low
2934	Lonely AFS Dewline - Sewage Disposal SS01	1995	Cleanup complete	0.2	None[a]
2935	Lonely AFS Dewline - Drum Storage SS02	1995	Cleanup complete	0.1	None[b]
2936	Lonely AFS Dewline - Module Train SS012	1995	Cleanup complete	0.0	Low
4223	Lonely AFS Dewline - AOC 1, 2, & 3	2005	Cleanup complete	0.0	Very low

Source: (ADEC 2022a)

Note: ADEC (Alaska Department of Environmental Conservation); AFS (Air Force site); AOC (area of concern); DEW (Distant Early Warning); POL (petroleum, oil, and lubricant).

[a] Site 2934 was noted by the Alaska Department of Environmental Conservation as having eroded into the Beaufort Sea in August 2008.

[b] Site 2935 was noted by the Alaska Department of Environmental Conservation as having eroded into the Beaufort Sea in April 2015.

1.3 Registered Facilities*

Table E.5.3 provides a summary of U.S. Environmental Protection Agency–regulated facilities within 0.5 mile of the Project that may be affected by the release, or threat of release, of hazardous substances, pollutants, or contaminants from Project activities (Figure 3.5.1).

Table E.5.3. U.S. Environmental Protection Agency–Regulated Facilities within 0.5 mile of the Project*

EPA Registry ID	Facility Name	Description	Release of Hazardous Substance, Pollutants, or Contaminant (yes/no)	Number of Releases (size/type)	Distance from Project Activity
110056899281	Alpine oil field	Crude petroleum and natural gas extraction, drilling oil and gas wells, and support activities for oil and gas operations	Yes	6 (266 gallons/ non-crude oil; 248.5 gallons/hazardous substance)	0.0
110041479030	Alpine airstrip	Airport operations	No	0	0.0
110022527121	Camp Lonely	Airport operations and crude petroleum and natural gas extraction	Yes	3 (10 gallons/ non-crude oil) (3 gallons/hazardous substance)	0.0

Source: (ADEC 2022b; EPA 2022)
Note: EPA (U.S. Environmental Protection Agency).

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Appendix E.6
Noise Technical Appendix

There is no technical appendix for this resource

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Appendix E.7
Visual Resources Technical Appendix

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Appendix E.7A
Visual Resources Technical Appendix

Appendix E.7B
Visual Contrast Ratings Worksheets

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Appendix E.7A
Visual Resources Technical Appendix

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List of Acronyms

BLM	Bureau of Land Management
NPR-A	National Petroleum Reserve in Alaska
Project	Willow Master Development Plan Project
VCRW	Visual contrast rating worksheets
VRI	Visual Resource Inventory
VRM	Visual Resources Management

Glossary Terms

Background zone: Areas visible within 5 to 15 miles from viewer locations.

Distance zones: The level of visibility and distances from important viewer locations, including travel routes, human use areas, and observation points. Distance zones consist of foreground-middleground (0 miles to 5 miles), background (5 to 15 miles), and seldom-seen (not visible or beyond 15 miles). The Willow Master Development Plan Project's (Project's) estimated nighttime lighting conditions are determined by the heights of drill rigs and communications towers. The Project would be visible out to 30 miles, based on the direct line-of-sight limits due to the curvature of the earth and regional atmospheric conditions.

Foreground-middleground distance zone: Areas visible within less than 5 miles from key observation points.

Scenic quality: The relative worth of a landscape from a visual perception point of view expressed as a quantitative measure of qualitative criteria associated with landform, vegetation, water, color, adjacent scenery, scarcity, and cultural modifications (BLM 2020).

Seldom seen areas: Areas within the foreground-middleground and background zones that are not visible, or areas that are visible but are beyond the background zone (more than 15 miles from key observation points).

Sensitivity level: The measure of public concern for scenic quality (as determined through the Visual Resource Inventory process).

Viewshed: The total landscape seen from a point, or from all or a logical part of a travel route, use area, or waterbody.

Visual resources: Visible physical features on a landscape, including land, water, vegetation, animals, structures, and other features.

Visual Resource Inventory: The process of determining the visual value of BLM-managed lands through the assessment of the scenic quality rating, sensitivity level, and distance zones of visual resources within those lands.

Visual Resource Inventory classes: Four visual resource inventory classes into which all BLM-managed lands are placed based on scenic quality, sensitivity levels, and distance zones, as determined through the Visual Resource Inventory process.

Visual Resources Management classes: Categories assigned to public lands based on scenic quality, sensitivity level, and distance zones with consideration for multiple-use management objectives. There are four classes; each class has an objective that prescribes the amount of change allowed in the characteristic landscape. Visual resource management classes are assigned through BLM Resource Management Plans (in this case, the IAP for the NPR-A).

Visual Resources Management: The system used by BLM to manage visual resources (including in the NPR-A). It includes inventory and planning actions to identify visual values and to establish objectives for managing those values.

1.0 VISUAL RESOURCES

1.1 Visual Resources Management in the National Petroleum Reserve in Alaska

The following descriptions, worksheets, and tables support the analysis in the Willow Master Development Plan Environmental Impact Statement Section 3.7, *Visual Resources*, and tier to previous Bureau of Land Management (BLM) studies. Section 3.7 discusses existing conditions in Section 3.7.1, *Affected Environment*, and discloses impacts to scenery and people, and conformance with **BLM Visual Resources Management** (VRM) objectives (BLM 2022)in Section 3.7.2, *Environmental Consequences*. The BLM **Visual Resource Inventory** (VRI) (BLM 2012) provides the visual baseline conditions using the indicators of scenic quality, sensitivity, and distance zones. The BLM scenic quality rating is the basis for determining impacts to scenery in the analysis area. The BLM sensitivity levels and distance zones are the basis for determining impacts to people (human environment) in the analysis area.

The referenced figures and tables in this appendix contain quantitative and qualitative information for:

1. **Scenic quality** is the relative worth of a landscape from a visual perception point of view expressed as a quantitative measure of qualitative criteria associated with landform, vegetation, water, color, adjacent scenery, scarcity, and cultural modifications.
2. **Sensitivity level** is the measure of public concern for scenic quality (as determined through the VRI process).
3. **Distance zones** are the level of visibility and distances from important viewer locations, including travel routes, human use areas, and observation points. Distance zones consist of the foreground-middleground (0 miles to 5 miles), background (5 to 15 miles), and seldom-seen (not visible or beyond 15 miles) zones. The Willow Master Development Plan Project's (Project's) estimated nighttime lighting conditions are determined by the heights of drill rigs and communications towers which would be visible out to 30 miles, based on the direct line-of-sight limits due to the curvature of the earth and regional atmospheric conditions.
4. **VRI classes** are four visual resource inventory classes which all BLM-administered lands are placed into based on scenic quality, sensitivity levels, and distance zones, as determined through the VRI process.
5. **VRM classes** are categories assigned to public lands based on scenic quality, sensitivity level, and distance zones with consideration for multiple-use management objectives. There are four classes. Each class has an objective that prescribes the amount of change allowed in the characteristic landscape. VRM classes are assigned through BLM Resource Management Plans, which for the National Petroleum Reserve in Alaska (NPR-A) is the Integrated Activity Plan (BLM 2022).

The BLM's VRM class objectives are defined in Table E.7.1.

Visual contrast rating worksheets (VCRW), located in Appendix E.7B, *Visual Contrast Rating Worksheets*, document:

1. The forms, lines, colors, and textures of landforms/water, vegetation, and structures in the characteristic landscape.
2. The forms, lines, colors, and textures of landforms/water, vegetation, and structures of the project.
3. The visual contrasts in the categories are strong, moderate, weak, and none; conformance with VRM objectives; and recommended mitigations, if any.

Table E.7.1. Bureau of Land Management Visual Resources Management Class Objectives

Class	Management Objective
I	The objective of this class is to preserve the existing character of the landscape. This class provides for natural ecological changes; however, it does not preclude very limited management activity. The level of change to the characteristic landscape should be very low and must not attract attention.
II	The objective of this class is to retain the existing character of the landscape. The level of change to the characteristic landscape should be low. Management activities may be seen but should not attract the attention of the casual observer. Any changes must repeat the basic (design) elements of form, line, color, and texture found in the predominant natural features of the characteristic landscape.
III	The objective of this class is to partially retain the existing character of the landscape. The level of change to the characteristic landscape should be moderate. Management activities may attract attention but should not dominate the view of the casual observer. Changes should repeat the basic elements found in the predominant natural features of the characteristic landscape.
IV	The objective of Class IV is to provide for management activities that require major modifications to the existing character of the landscape. The level of change to the landscape can be high. The management activities may dominate the view and may be the major focus of viewer attention. However, every attempt should be made to minimize the impact of these activities through careful location, minimal disturbance, and repetition of the basic visual elements of form, line, color, and texture.

Source: BLM 1986

The Project's VCRWs are included in Appendix E.7B and include:

- VCRW-1: Contrast Ratings and Conformance for Foreground-Middleground Viewing Situations in VRM Class IV Areas
- VCRW-2: Contrast Ratings and Conformance for Background and Seldom-Seen Viewing Situations in VRM Class IV Areas
- VCRW-3: Contrast Ratings and Conformance in VRM Class II Areas
- VCRW-4: Contrast Ratings and Conformance for Foreground-Middleground Viewing Situations in VRM Class III Areas (Option 3)
- VCRW-5: Contrast Ratings for Foreground-Middleground Viewing Situations (Non-BLM lands)
- VCRW-6: Contrast Ratings for Background and Seldom-Seen Viewing Situations (Non-BLM lands)

1.2 The Willow Project and Visual Resources Analysis Area

The analysis area for visual resources is the area within line-of-sight from ground-eye-level to the tallest components of the Project (drill rig and communications tower lighting). For this Project, that area (also known as the **viewshed**) is 30 miles, with the exception of the diesel and seawater pipelines from near Nuiqsut to Kuparuk, which would be colocated with existing pipeline infrastructure and has a viewshed of 15 miles (Figure 3.7.1).The Project viewshed includes all areas from which the proposed facilities would be visible based on topographical obstruction and viewer distance from the Project (0- to 5-miles **foreground-middleground zone** and the 5- to 15-miles **background zone**.

1.2.1 State Lands

State lands that occur within the analysis area are not subject to known visual management standards. The BLM visual contrast rating process has been applied to non-BLM lands to provide a qualitative analysis of the potential degree of contrast of Project facilities when viewed from 0- to 5-miles foreground-middleground zone and the 5- to 15-miles background zone.

1.3 Bureau of Land Management Scenic Quality in the Project Viewshed

The BLM scenic quality classes are the basis for determining impacts to scenery in the analysis area. Due to the natural character of existing conditions in the viewshed, the Project would be strongly contrasting with scenery due to the broad, panoramic landscape where few human-made or built features occur. The Project's impacts to scenery are determined by comparing the view characteristics of the action alternatives with views of the characteristic landscape. The relative scenic quality (Class A, B, or C) is assigned to a landscape by applying the VRI scenic quality evaluation factors with scenic quality A having the highest rating and scenic quality C having the lowest. The Project would result in substantial changes in the visual landscape for public land users and viewers in the foreground-middleground and background distance zones and the level of change and scenic quality would reduce the inventoried scenery class designations in the viewshed based on the introduction of Project components that are not common in the landscape. Table E.7.2 shows the acreages and percentages of scenic quality classes where viewers would have visibility toward the Project. The scenic quality classes are shown in Figure 3.7.2, and the Project's viewshed is shown in Figure 3.7.1.

Table E.7.2. Scenic Quality Classes in the Analysis Area and Viewshed

Area	Class A Acres (%)	Class B Acres (%)	Class C Acres (%)	No Data Acres (%)	Unclassified, Not in NPR-A Acres (%)	Total Acres (%)
In analysis area	180,538.9 (3.0%)	28,979.4 (0.5%)	2,399,945.0 (39.9%)	1,777.6 (less than 0.1%)	3,411,329.1 (56.7%)	**6,020,792.4 (100%)**
In Project viewshed	161,764.8 (3.3%)	20,508.4 (0.4%)	1,720,473.0 (35.4 %)	1,481.2 (less than 0.1%)	2,954,376.6 (60.8%)	**4,857,122.8 (100%)**

Note: NPR-A (National Petroleum Reserve in Alaska). Areas outside of NPR-A are not managed by the Bureau of Land Management and thus do not have scenic quality classifications.

1.4 Bureau of Land Management Sensitivity Levels and Distance Zones in the Project Viewshed

The BLM sensitivity level and distance zones are the basis for determining impacts to people/viewers in the analysis area. Higher user concern for scenery would be more susceptible to visual impacts than lower concern and near distance zones would be more susceptible to visual impacts than far distance zones. Visual contrasts for viewers are determined by comparison of the view characteristics of the Project with views of the characteristic landscape. The Project would result in strong visual contrasts and viewer impacts that are strong in comparison with existing conditions, including visually dominant forms, lines, colors, and textures of landforms, water, vegetation, and structures. The Project would result in strong contrasts to scenic quality for viewers in the foreground-middleground, and background distance zones, and the level of contrast likely would reduce the inventoried sensitivity level designations in the analysis area. Table E.7.3 shows the acreages and percentages of BLM sensitivity classes where viewers would have visibility toward the Project. Table E.7.4 summarizes BLM distance zones where viewers would have visibility toward the Project. The Project's viewshed is shown in Figure 3.7.1, BLM sensitivity levels are shown in Figure 3.7.3, and the distance zones are shown in Figure 3.7.4.

Table E.7.3. Sensitivity Classes in the Analysis Area and Viewshed

Area	High Acres (%)	Medium Acres (%)	Low Acres (%)	No Data Acres (%)	Unclassified, Not in NPR-A Acres (%)	Total Acres (%)
In analysis area	2,611,241.0 (43.4%)	0.0 (0.0%)	0.0 (0.0%)	0.9 (less than 0.1%)	3,409,551.4 (56.6%)	**6,020,792.4 (100%)**
In Project viewshed	1,904,227.5 (42.4%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	2,952,894.9 (60.8%)	**4,857,122.4 (100%)**

Note: NPR-A (National Petroleum Reserve in Alaska). Areas outside of NPR-A are not managed by the Bureau of Land Management and thus do not have sensitivity classifications.

Table E.7.4. Distance Zones in the Analysis Area and Viewshed

Area	Foreground-Middleground Acres (%)	Background Acres (%)	Seldom Seen Acres (%)	Unclassified, Not in NPR-A Acres (%)	Total Acres (%)
In analysis area	2,169,481.5 (36.0%)	441,759.4 (7.3%)	0.0 (0.0%)	3,409,551.4 (56.6%)	**6,020,792.4 (100%)**
In Project viewshed	1,560,104.2 (32.1%)	344,123.3 (7.1%)	0.0 (0.0%)	2,952,894.9 (60.8%)	**4,857,122.4 (100%)**

Note: NPR-A (National Petroleum Reserve in Alaska). Areas outside of NPR-A are not managed by the Bureau of Land Management and thus do not have distance zone classifications.

1.4.1 <u>State Lands</u>

Similar to BLM lands, Project facilities and lighting would affect scenery and people by impacting the undisturbed characteristic landscape (including night skies). State lands in the area of Project activity for the action alternatives would be in areas of existing activity (e.g., Oliktok Dock, Alpine Annual Resupply ice road), while state lands along the Module Delivery Option 3 ice road route from Kuparuk DS2P to the Colville River ice bridge would follow a route without permanent infrastructure, though there are other temporary winter activities that occur in the area (e.g., North Slope Borough's Community Winter Access Trail).

Along the Option 3 ice road route, visual contrast from Project facilities and activity (including light sources during operations) would cause the greatest visual impacts in foreground-middleground views due to the broad, panoramic landscape and lack of intervening land features. Overall contrasts would diminish based on viewer location and proximity to existing oil and gas infrastructure in the Kuparuk area. In viewing areas distant from the developed Kuparuk area, moderate to weak construction-related contrasts in the background and **seldom seen areas** (5-15 and greater miles) would occur.

1.5 Bureau of Land Management Visual Resource Inventory Classes in the Project Viewshed

The BLM VRI classes indicate the overall value of landscape on BLM lands. Views to the action alternatives from more valued landscapes have greater potential for impacts than do views from less valued landscapes. Table E.7.5 shows the acreages and percentages of existing BLM VRI classes in the analysis area and the Project's viewshed. Construction, operations, and reclamation activities would result in overall landscape values that strongly contrast with existing conditions. The Project would result in strong contrasts to the landscape for viewers in the foreground, middleground, and background distance zones, and the level of impact would likely reduce the inventoried BLM VRI class designations in the analysis area. The VRI classes are shown in Figure 3.7.5, and the Project's viewshed is shown in Figure 3.7.1.

Table E.7.5. Visual Resource Inventory Classes in the Analysis Area and Viewshed

Area	Class I Acres (%)	Class II Acres (%)	Class III Acres (%)	Class IV Acres (%)	Unclassified, Not in NPR-A Acres (%)	Total Acres (%)
In analysis area	0.0 (0.0%)	209,518.3 (3.5%)	1,959,963.2 (32.6%)	441,759.4 (7.3%)	3,409,551.5 (56.6%)	**6,020,792.4 (100%)**
In Project viewshed	0.0 (0.0%)	182,273.1 (4.1%)	1,377,831.0 (30.7%)	344,123.3 (7.7%)	2,952,894.9 (60.8%)	**4,857,122.3 (100%)**

Note: NPR-A (National Petroleum Reserve in Alaska). Areas outside of NPR-A are not managed by the Bureau of Land Management and thus do not have Visual Resource Inventory classifications.

1.6 Bureau of Land Management Visual Resources Management Classes Within the Analysis Area*

Conformance with VRM management classes is based on the characteristics of Project facilities that are physically located within the VRM classified lands. The VRM classes were assigned to these lands by the NPR-A IAP/EIS Record of Decision (BLM 2022). The VRM Class objectives for each alternative (BLM 2022) takes into consideration VRI information and overall BLM land management objectives for each resource managed within the NPR-A.

VRM Class objectives (BLM 2022) identify 1,179,885.4 acres of VRM Class II within the analysis area (19.6% of the analysis area) and 1,335,405.2 acres of VRM Class IV (22.2% of the analysis area). There are no VRM Class I or III objectives identified within the analysis area (Figure 3.7.6). The acres of each VRM class within the Project viewshed provides a summary of the amount of those areas from which a viewer could see the Project facilities (Table E.7.6).

Table E.7.6. Visual Resources Management Classes in the Analysis Area and Viewshed Objectives*

Area	Class I Acres (%)	Class II Acres (%)	Class III Acres (%)	Class IV Acres (%)	In NPR-A, No BLM Surface Authority Acres (%)	Unclassified, Not in NPR-A Acres (%)	Total Acres (%)
In analysis area	0.0 (0.0%)	1,179,572.5 (19.6%)	0.0 (0.0%)	1,335,404.1 (22.2%)	96,264.3 (1.6%)	3,409,551.4 (56.6%)	**6,020,792.3 (100.0%)**
In Project viewshed	0.0 (0.0%)	907,300.4 (29.8%)	0.0 (0.0%)	905,215.8 (18.6%)	89,130.4 (1.8%)	2,995,476.1 (61.7%)	**4,857,122.4 (100.0%)**

Note: NPR-A (National Petroleum Reserve in Alaska). Areas outside of NPR-A are not managed by the Bureau of Land Management and thus do not have Visual Resources Management classifications.

Conformance with the VRM objectives is determined by comparison of the forms, lines, colors, and textures of view characteristics of the Project with forms, lines, colors, and textures of views of the existing characteristic landscape where they are physically located. Within the analysis area, the Project would not conform with VRM Class II objectives but would conform with VRM Class III and IV objectives as allocated for each VRM Class Alternative described above.

2.0 REFERENCES

BLM. 1986. *BLM Manual H-8410-1: Visual Resource Inventory*. Washington, D.C.

-----. 2012. *National Petroleum Reserve-Alaska Final Integrated Activity Plan/Environmental Impact Statement*. Anchorage, AK.

-----. 2020. *National Petroleum Reserve-Alaska Integrated Activity Plan/Record of Decision*. Anchorage, AK.

Willow Master Development Plan

Appendix E.7B
Visual Contrast Rating Worksheets

June 2022

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Form 8400-4
(June 2018)

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT
VISUAL CONTRAST RATING WORKSHEET

Date: 03/08/2019
District Office: Arctic
Field Office:
Land Use Planning Area:

SECTION A. PROJECT INFORMATION

1. Project Name Willow	4. KOP Location (T.R.S) Varies	5. Location Sketch See 2020 FEIS - Appendix A: Figure 3.7.6 Visual Resource Management Classes
2. Key Observation Point (KOP) Name Foreground-MiddlegroundViews		
3. VRM Class at Project Location Class IV	(Lat. Long) Varies	

SECTION B. CHARACTERISTIC LANDSCAPE DESCRIPTION

	1. LAND/WATER	2. VEGETATION	3. STRUCTURES
FORM	Planar horizontal land, lakes and ponds.	Planar horizontal surface of grasses in summer turning to snow cover for 9-10 months..	None
LINE	Strongly horizontal land, lakes, and ponds..	Horizontal surface of grasses in summer turning to snow cover for 9-10 months.	None
COLOR	Very light to medium tan earth. Water reflecting colors of sky in summer turning to snow cover for 9-10 mo	Light to medium green turning to tan to brown grasses in summer and uniform snow cover for 9-10 months	None
TEX-TURE	Smooth land, lakes, and ponds	Smooth grasses and snow cover	None

SECTION C. PROPOSED ACTIVITY DESCRIPTION

	1. LAND/WATER	2. VEGETATION	3. STRUCTURES
FORM	Flat, planar pads and roads	Geometric patterns of present and absent grasses.	Strongly planar vertical and horizontal drill and valve structures. Cylindrical tanks. Geometric roads, pads, vehicles.
LINE	Horizontal pads and curvilinear roads	Horizontal and angular lines at edges of geometric shapes.	Strongly vertical and horizontal lines. Vertical and horizontal lines at edges of geometric shapes
COLOR	Tans and greys	Greens, tans, and greys.	Light to dark orange structures and multicolored equipment. White, blue, and red facility, vehicle lighting, sky glow.
TEX-TURE	Smooth.	Smooth to coarse at a distance.	Moderate to coarse.

SECTION D. CONTRAST RATING __SHORT TERM ✓ LONG TERM

1. DEGREE OF CONTRAST		FEATURES: LAND/WATER BODY (1)				VEGETATION (2)				STRUCTURES (3)			
		STRONG	MODERATE	WEAK	NONE	STRONG	MODERATE	WEAK	NONE	STRONG	MODERATE	WEAK	NONE
ELEMENTS	FORM		✓				✓			✓			
	LINE		✓				✓			✓			
	COLOR		✓				✓			✓			
	TEXTURE			✓				✓			✓		

2. Does project design meet visual resource management objectives? ✓ Yes ___No
(Explain on reverses side)

3. Additional mitigating measures recommended
✓ Yes ___No (Explain on reverses side)

Evaluator's Names: Chris Bockey
Date: 12/31/2019

(Continued on Page 2)

SECTION D. (Continued)

Comments from item 2.

Strong construction-related contrasts in the foreground and middleground seen areas (0-5 miles) would occur for the 10-11-year time period specified (Chapter 2.4.6.10.2) for drilling and from the presence of drill rigs and construction equipment. Strong contrasts would be caused by the structural forms, lines, and colors and colors of lighting for facilities, equipment, and vehicles. These contrasts would conform with Visual Resource Management Class IV management objectives (see following table). These noticeable forms and lines are required for function and the highly contrasting colors are needed for safety in the region's extreme weather conditions. Thus, they would cause strong contrasts in the characteristic landscape and mitigations of color would not be feasible.

Dark Sky BMP Re: down-shielded lighting – This BMP would limit direct (line-of-sight) visibility of the standard Osha-mandated lighting at facilities. However, down-shielding in snow cover conditions is known to increase reflectiveness toward the sky and the resultant sky glow and light dome would cause problematic navigation issues for humans and fauna.

Strong contrasts would be reduced to moderate and then weak during the operations, maintenance, and reclamation phases of the project. These phases would be portrayed by pads, roads, pipelines, and vehicles, and, eventually, less-noticeable forms, lines, and colors in the landscape.

BLM Visual Resource Management Class Objectives

Class I Objective The objective of this class is to preserve the existing character of the landscape. This class provides for natural ecological changes; however, it does not preclude very limited management activity. The level of change to the characteristic landscape should be very low and must not attract attention.

Class II Objective The objective of this class is to retain the existing character of the landscape. The level of change to the characteristic landscape should be low. Management activities may be seen, but should not attract the attention of the casual observer. Any changes must repeat the basic (design) elements of form, line, color, and texture found in the predominant natural features of the characteristic landscape.

Class III Objective The objective of this class is to partially retain the existing character of the landscape. The level of change to the characteristic landscape should be moderate. Management activities may attract attention, but should not dominate the view of the casual observer. Changes should repeat the basic elements found in the predominant natural features of the characteristic landscape.

Class IV Objective The objective Class IV is to provide for management activities that require major modifications to the existing character of the landscape. The level of change to the landscape can be high. The management activities may dominate the view and may be the major focus of viewer attention. However, every attempt should be made to minimize the impact of these activities through careful location, minimal disturbance, and repetition of the basic visual elements of form, line, color, and texture.

Source: BLM 1986, 2008b.

Additional Mitigating Measures (See item 3)

Form 8400-4
(June 2018)

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT
VISUAL CONTRAST RATING WORKSHEET

Date: 03/08/2019
District Office: Arctic
Field Office:
Land Use Planning Area:

SECTION A. PROJECT INFORMATION

1. Project Name Willow	4. KOP Location (T.R.S) Varies	5. Location Sketch See 2020 FEIS - Appendix A: Figure 3.7.6 Visual Resource Management Classes
2. Key Observation Point (KOP) Name Background-Seldom Seen Views		
3. VRM Class at Project Location Class IV	(Lat. Long) Varies	

SECTION B. CHARACTERISTIC LANDSCAPE DESCRIPTION

	1. LAND/WATER	2. VEGETATION	3. STRUCTURES
FORM	Planar horizontal land, lakes and ponds.	Planar horizontal surface of grasses in summer turning to snow cover for 9-10 months..	None
LINE	Strongly horizontal land, lakes, and ponds..	Horizontal surface of grasses in summer turning to snow cover for 9-10 months.	None
COLOR	Very light to medium tan earth. Water reflecting colors of sky in summer turning to snow cover for 9-10 mo	Light to medium green turning to tan to brown grasses in summer and uniform snow cover for 9-10 months	None
TEX-TURE	Smooth land, lakes, and ponds	Smooth grasses and snow cover	None

SECTION C. PROPOSED ACTIVITY DESCRIPTION

	1. LAND/WATER	2. VEGETATION	3. STRUCTURES
FORM	Flat, planar pads and roads	Geometric patterns of present and absent grasses.	Strongly planar vertical and horizontal drill and valve structures. Cylindrical tanks. Geometric roads, pads, vehicles.
LINE	Horizontal pads and curvilinear roads	Horizontal and angular lines at edges of geometric shapes.	Strongly vertical and horizontal lines. Vertical and horizontal lines at edges of geometric shapes
COLOR	Tans and greys	Greens, tans, and greys.	Light to dark orange structures and multicolored equipment. White, blue, and red facility, vehicle lighting, sky glow.
TEX-TURE	Smooth.	Smooth to coarse at a distance.	Moderate to coarse.

SECTION D. CONTRAST RATING __SHORT TERM ✓ LONG TERM

1.

DEGREE OF CONTRAST	FEATURES: LAND/WATER BODY (1)				VEGETATION (2)				STRUCTURES (3)			
ELEMENTS	STRONG	MODERATE	WEAK	NONE	STRONG	MODERATE	WEAK	NONE	STRONG	MODERATE	WEAK	NONE
FORM			✓				✓			✓		
LINE			✓				✓			✓		
COLOR			✓				✓			✓		
TEXTURE			✓				✓				✓	

2. Does project design meet visual resource management objectives? ✓ Yes ___No
(Explain on reverses side)

3. Additional mitigating measures recommended
✓ Yes ___No (Explain on reverses side)

Evaluator's Names: Chris Bockey
Date: 12/31/2019

(Continued on Page 2)

SECTION D. (Continued)

Comments from item 2.

Moderate to weak construction-related contrasts in the background and seldom seen areas (5-15 and greater miles) would occur for the 10-11-year time period specified (Chapter 2.4.6.10.2) for drilling and from the presence of drill rigs and construction equipment. Moderate contrasts would be caused by the structural forms, lines, and colors and colors of lighting for facilities and vehicles. These contrasts would conform with Visual Resource Management Class III and IV management objectives (see following table). These noticeable forms and lines are required for function and the highly contrasting colors are needed for safety in the region's extreme weather conditions. Thus, they would cause strong contrasts in the characteristic landscape and mitigations of color would not be feasible.
Dark Sky BMP Re: down-shielded lighting – This BMP would limit direct (line-of-sight) visibility of the standard Osha-mandated lighting at facilities. However, down-shielding in snow cover conditions is known to increase reflectiveness toward the sky and the resultant sky glow and light dome would cause problematic navigation issues with humans and fauna.
Moderate contrasts would be reduced to weak during the operations, maintenance, and reclamation phases of the project. These phases would be portrayed by pads, roads, pipelines, and vehicles, and, eventually, less-noticeable forms, lines, and colors in the landscape.

BLM Visual Resource Management Class Objectives
Class I Objective The objective of this class is to preserve the existing character of the landscape. This class provides for natural ecological changes; however, it does not preclude very limited management activity. The level of change to the characteristic landscape should be very low and must not attract attention.
Class II Objective The objective of this class is to retain the existing character of the landscape. The level of change to the characteristic landscape should be low. Management activities may be seen, but should not attract the attention of the casual observer. Any changes must repeat the basic (design) elements of form, line, color, and texture found in the predominant natural features of the characteristic landscape.
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Class IV Objective The objective Class IV is to provide for management activities that require major modifications to the existing character of the landscape. The level of change to the landscape can be high. The management activities may dominate the view and may be the major focus of viewer attention. However, every attempt should be made to minimize the impact of these activities through careful location, minimal disturbance, and repetition of the basic visual elements of form, line, color, and texture.
Source: BLM 1986, 2008b.

Additional Mitigating Measures (See item 3)

Form 8400-4
(June 2018)

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT
VISUAL CONTRAST RATING WORKSHEET

Date: 03/08/2019
District Office: Arctic
Field Office:
Land Use Planning Area:

SECTION A. PROJECT INFORMATION

1. Project Name Willow	4. KOP Location (T.R.S) Varies	5. Location Sketch See 2020 FEIS - Appendix A: Figure 3.7.6 Visual Resource Management Classes
2. Key Observation Point (KOP) Name Foreground-MiddlegroundViews		
3. VRM Class at Project Location Class II	(Lat. Long) Varies	

SECTION B. CHARACTERISTIC LANDSCAPE DESCRIPTION

	1. LAND/WATER	2. VEGETATION	3. STRUCTURES
FORM	Planar horizontal land, lakes and ponds.	Planar horizontal surface of grasses in summer turning to snow cover for 9-10 months..	None
LINE	Strongly horizontal land, lakes, and ponds..	Horizontal surface of grasses in summer turning to snow cover for 9-10 months.	None
COLOR	Very light to medium tan earth. Water reflecting colors of sky in summer turning to snow cover for 9-10 mo	Light to medium green turning to tan to brown grasses in summer and uniform snow cover for 9-10 months	None
TEX-TURE	Smooth land, lakes, and ponds	Smooth grasses and snow cover	None

SECTION C. PROPOSED ACTIVITY DESCRIPTION

	1. LAND/WATER	2. VEGETATION	3. STRUCTURES
FORM	Flat, planar pads and roads	Geometric patterns of present and absent grasses.	Strongly planar vertical and horizontal drill and valve structures. Cylindrical tanks. Geometric roads, pads, vehicles.
LINE	Horizontal pads and curvilinear roads	Horizontal and angular lines at edges of geometric shapes.	Strongly vertical and horizontal lines. Vertical and horizontal lines at edges of geometric shapes
COLOR	Tans and greys	Greens, tans, and greys.	Light to dark orange structures and multicolored equipment. White, blue, and red facility, vehicle lighting, sky glow.
TEX-TURE	Smooth.	Smooth to coarse at a distance.	Moderate to coarse.

SECTION D. CONTRAST RATING __SHORT TERM ✓ LONG TERM

1. DEGREE OF CONTRAST

	FEATURES											
	LAND/WATER BODY (1)				VEGETATION (2)				STRUCTURES (3)			
ELEMENTS	STRONG	MODERATE	WEAK	NONE	STRONG	MODERATE	WEAK	NONE	STRONG	MODERATE	WEAK	NONE
FORM		✓				✓			✓			
LINE		✓				✓			✓			
COLOR		✓				✓			✓			
TEXTURE			✓				✓			✓		

2. Does project design meet visual resource management objectives? ___Yes ✓ No
(Explain on reverses side)

3. Additional mitigating measures recommended
✓ Yes ___No (Explain on reverses side)

Evaluator's Names: Chris Bockey
Date: 12/31/2019

(Continued on Page 2)

Comments from item 2.

Strong construction-related contrasts in the foreground and middleground seen areas (0-5 miles) would occur for the 10-11-year time period specified (Chapter 2.4.6.10.2) for drilling and from the presence of drill rigs and construction equipment. Strong contrasts would be caused by the structural forms, lines, and colors and colors of lighting for facilities, equipment, and vehicles. These contrasts would not conform with Visual Resource Management Class II management objectives (see following table). These noticeable forms and lines are required for function and the highly contrasting colors are needed for safety in the region's extreme weather conditions. Thus, they would cause strong contrasts in the characteristic landscape and mitigations of color would not be feasible.

Dark Sky BMP Re: down-shielded lighting – This BMP would limit direct (line-of-sight) visibility of the standard Osha-mandated lighting at facilities. However, down-shielding in snow cover conditions is known to increase reflectiveness toward the sky and the resultant sky glow and light dome would cause problematic navigation issues for humans and fauna.
Strong contrasts would be reduced to moderate and then weak during the operations, maintenance, and reclamation phases of the project. These phases would be portrayed by pads, roads, pipelines, and vehicles, and, eventually, less-noticeable forms, lines, and colors in the landscape.

BLM Visual Resource Management Class Objectives
Class I Objective The objective of this class is to preserve the existing character of the landscape. This class provides for natural ecological changes; however, it does not preclude very limited management activity. The level of change to the characteristic landscape should be very low and must not attract attention.
Class II Objective The objective of this class is to retain the existing character of the landscape. The level of change to the characteristic landscape should be low. Management activities may be seen, but should not attract the attention of the casual observer. Any changes must repeat the basic (design) elements of form, line, color, and texture found in the predominant natural features of the characteristic landscape.

Class III Objective The objective of this class is to partially retain the existing character of the landscape. The level of change to the characteristic landscape should be moderate. Management activities may attract attention, but should not dominate the view of the casual observer. Changes should repeat the basic elements found in the predominant natural features of the characteristic landscape.
Class IV Objective The objective Class IV is to provide for management activities that require major modifications to the existing character of the landscape. The level of change to the landscape can be high. The management activities may dominate the view and may be the major focus of viewer attention. However, every attempt should be made to minimize the impact of these activities through careful location, minimal disturbance, and repetition of the basic visual elements of form, line, color, and texture.
Source: BLM 1986, 2008b.

Additional Mitigating Measures (See item 3)

Form 8400-4
(June 2018)

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT
VISUAL CONTRAST RATING WORKSHEET

Date: 12/31/2019
District Office: Arctic
Field Office:
Land Use Planning Area:

SECTION A. PROJECT INFORMATION

1. Project Name Willow EIS - Option 3	4. KOP Location (T.R.S) Varies	5. Location Sketch See 2020 FEIS - Appendix A: Figure 3.7.6 Visual Resource Management Classes
2. Key Observation Point (KOP) Name Foreground-Middleground Views		
3. VRM Class at Project Location Class III	(Lat. Long) Varies	

SECTION B. CHARACTERISTIC LANDSCAPE DESCRIPTION

	1. LAND/WATER	2. VEGETATION	3. STRUCTURES
FORM	Planar horizontal land, lakes and ponds.	Planar horizontal surface of grasses in summer turning to snow cover for 9-10 months..	Strongly planar vertical and horizontal drill and valve structures. Cylindrical tanks. Geometric roads, pads, vehicles.
LINE	Strongly horizontal land, lakes, and ponds.	Horizontal surface of grasses in summer turning to snow cover for 9-10 months.	Strongly vertical and horizontal lines. Vertical and horizontal lines at edges of geometric shapes
COLOR	Very light to medium tan earth. Water reflecting colors of sky in summer turning to snow cover for 9-10 mo	Light to medium green turning to tan to brown grasses in summer and uniform snow cover for 9-10 months	Light to dark orange structures and multicolored equipment. White, blue, and red facility, vehicle lighting, sky glow.
TEX-TURE	Smooth land, lakes, and ponds	Smooth grasses and snow cover	Moderate to coarse.

SECTION C. PROPOSED ACTIVITY DESCRIPTION

	1. LAND/WATER	2. VEGETATION	3. STRUCTURES
FORM	Flat, planar road	Indistinguishable	Geometric structures for construction camp at DS2P, vehicles.
LINE	Curvilinear road	Indistinguishable	Vertical and horizontal lines at edges of geometric shapes associated with construction camp.
COLOR	Tans and greys	Indistinguishable	Light to dark structures and multicolored equipment of construction camp, vehicle lighting, sky glow.
TEX-TURE	Smooth.	Indistinguishable	Moderate to coarse.

SECTION D. CONTRAST RATING ✓ SHORT TERM __LONG TERM

1.

DEGREE OF CONTRAST	FEATURES: LAND/WATER BODY (1)				VEGETATION (2)				STRUCTURES (3)			
ELEMENTS	STRONG	MODERATE	WEAK	NONE	STRONG	MODERATE	WEAK	NONE	STRONG	MODERATE	WEAK	NONE
FORM				✓				✓			✓	
LINE			✓					✓			✓	
COLOR			✓					✓			✓	
TEXTURE				✓				✓			✓	

2. Does project design meet visual resource management objectives? ___Yes ___No
(Explain on reverses side)

3. Additional mitigating measures recommended
___Yes ___No (Explain on reverses side)

Evaluator's Names: Chris Bockey
Date: 12/31/2019

(Continued on Page 2)

SECTION D. (Continued)

Comments from item 2.

Weak construction-related contrasts in the foreground and middleground seen areas (0-5 miles) would occur for the time period specified for delivery of drillsite modules. Due to the existing infrastructure in the foreground and middleground area associated with Oliktok and Kuparuk, generally weak contrast would be caused by the introduction of temporary structural forms, lines, and colors and colors of lighting for construction camp facilities, equipment,vehicles and ice road. Degree of contrast is identified below.

Degree of Contrast Criteria
None - The element contrast is not visible or perceived.
Weak - The element contrast can be seen but does not attract attention.
Moderate - The element contrast begins to attract attention and begins to dominate the characteristic landscape.
Strong - The element contrast demands attention, will not be overlooked, and is dominant in the landscape.

BLM 1986, 2008b.

Additional Mitigating Measures (See item 3)

Form 8400-4
(June 2018)

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT
VISUAL CONTRAST RATING WORKSHEET

Date: 01/09/2020
District Office: N/A
Field Office: N/A
Land Use Planning Area: N/A

SECTION A. PROJECT INFORMATION

1. Project Name Willow	4. KOP Location (T.R.S) Varies	5. Location Sketch See 2020 FEIS - Appendix A: Figure 3.7.1 Visual Resource Analysis Area
2. Key Observation Point (KOP) Name Foreground-MiddlegroundViews		
3. VRM Class at Project Location Non-BLM Managed Lands	(Lat. Long) Varies	

SECTION B. CHARACTERISTIC LANDSCAPE DESCRIPTION

	1. LAND/WATER	2. VEGETATION	3. STRUCTURES
FORM	Planar horizontal land, lakes and ponds.	Planar horizontal surface of grasses in summer turning to snow cover for 9-10 months..	None
LINE	Strongly horizontal land, lakes, and ponds..	Horizontal surface of grasses in summer turning to snow cover for 9-10 months.	None
COLOR	Very light to medium tan earth. Water reflecting colors of sky in summer turning to snow cover for 9-10 mo	Light to medium green turning to tan to brown grasses in summer and uniform snow cover for 9-10 months	None
TEX-TURE	Smooth land, lakes, and ponds	Smooth grasses and snow cover	None

SECTION C. PROPOSED ACTIVITY DESCRIPTION

	1. LAND/WATER	2. VEGETATION	3. STRUCTURES
FORM	Flat, planar pads and roads	Geometric patterns of present and absent grasses.	Strongly planar vertical and horizontal drill and valve structures. Cylindrical tanks. Geometric roads, pads, vehicles.
LINE	Horizontal pads and curvilinear roads	Horizontal and angular lines at edges of geometric shapes.	Strongly vertical and horizontal lines. Vertical and horizontal lines at edges of geometric shapes
COLOR	Tans and greys	Greens, tans, and greys.	Light to dark orange structures and multicolored equipment. White, blue, and red facility, vehicle lighting, sky glow.
TEX-TURE	Smooth.	Smooth to coarse at a distance.	Moderate to coarse.

SECTION D. CONTRAST RATING __SHORT TERM ✓ LONG TERM

1\. DEGREE OF CONTRAST

ELEMENTS	LAND/WATER BODY (1) STRONG	(1) MODERATE	(1) WEAK	(1) NONE	VEGETATION (2) STRONG	(2) MODERATE	(2) WEAK	(2) NONE	STRUCTURES (3) STRONG	(3) MODERATE	(3) WEAK	(3) NONE
FORM		✓				✓			✓			
LINE		✓				✓			✓			
COLOR		✓				✓			✓			
TEXTURE			✓				✓			✓		

2\. Does project design meet visual resource management objectives? ___Yes ___No (Explain on reverses side)

3\. Additional mitigating measures recommended ✓ Yes ___No (Explain on reverses side)

Evaluator's Names: Merlyn Paulson/ Chris Bockey
Date: 01/09/2020

(Continued on Page 2)

SECTION D. (Continued)

Comments from item 2.

Strong construction-related contrasts in the foreground and middleground seen areas (0-5 miles) would occur for the 10-11-year time period specified (Chapter 2.4.6.10.2) for drilling and from the presence of drill rigs and construction equipment. Strong contrasts would be caused by the structural forms, lines, and colors and colors of lighting for facilities, equipment, and vehicles.These noticeable forms and lines are required for function and the highly contrasting colors are needed for safety in the region's extreme weather conditions. Thus, they would cause strong contrasts in the characteristic landscape and mitigations of color would not be feasible.

Dark Sky BMP Re: down-shielded lighting – This BMP would limit direct (line-of-sight) visibility of the standard Osha-mandated lighting at facilities. However, down-shielding in snow cover conditions is known to increase reflectiveness toward the sky and the resultant sky glow and light dome would cause problematic navigation issues for humans and fauna.

Strong contrasts would be reduced to moderate and then weak during the operations, maintenance, and reclamation phases of the project. These phases would be portrayed by pads, roads, pipelines, and vehicles, and, eventually, less-noticeable forms, lines, and colors in the landscape.

Additional Mitigating Measures (See item 3)

Form 8400-4
(June 2018)

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT
VISUAL CONTRAST RATING WORKSHEET

Date: 03/08/2019
District Office: Arctic
Field Office:
Land Use Planning Area:

SECTION A. PROJECT INFORMATION

1. Project Name Willow	4. KOP Location (T.R.S) Varies	5. Location Sketch See 2020 FEIS - Appendix A: Figure 3.7.1 Visual Resource Analysis Area
2. Key Observation Point (KOP) Name Background-Seldom Seen Views		
3. VRM Class at Project Location Non-BLM Managed Lands	(Lat. Long) Varies	

SECTION B. CHARACTERISTIC LANDSCAPE DESCRIPTION

	1. LAND/WATER	2. VEGETATION	3. STRUCTURES
FORM	Planar horizontal land, lakes and ponds.	Planar horizontal surface of grasses in summer turning to snow cover for 9-10 months..	Strongly planar vertical and horizontal drill and valve structures. Cylindrical tanks. Geometric roads, pads, vehicles.
LINE	Strongly horizontal land, lakes, and ponds..	Horizontal surface of grasses in summer turning to snow cover for 9-10 months.	Strongly vertical and horizontal lines. Vertical and horizontal lines at edges of geometric shapes
COLOR	Very light to medium tan earth. Water reflecting colors of sky in summer turning to snow cover for 9-10 mo	Light to medium green turning to tan to brown grasses in summer and uniform snow cover for 9-10 months	Light to dark orange structures and multicolored equipment. White, blue, and red facility, vehicle lighting, sky glow.
TEX-TURE	Smooth land, lakes, and ponds	Smooth grasses and snow cover	Moderate to coarse.

SECTION C. PROPOSED ACTIVITY DESCRIPTION

	1. LAND/WATER	2. VEGETATION	3. STRUCTURES
FORM	Flat, planar pads and roads	Geometric patterns of present and absent grasses.	Strongly planar vertical and horizontal drill and valve structures. Cylindrical tanks. Geometric roads, pads, vehicles.
LINE	Horizontal pads and curvilinear roads	Horizontal and angular lines at edges of geometric shapes.	Strongly vertical and horizontal lines. Vertical and horizontal lines at edges of geometric shapes
COLOR	Tans and greys	Greens, tans, and greys.	Light to dark orange structures and multicolored equipment. White, blue, and red facility, vehicle lighting, sky glow.
TEX-TURE	Smooth.	Smooth to coarse at a distance.	Moderate to coarse.

SECTION D. CONTRAST RATING __SHORT TERM ✓ LONG TERM

1\.

DEGREE OF CONTRAST	LAND/WATER BODY (1)				VEGETATION (2)				STRUCTURES (3)			
ELEMENTS	STRONG	MODERATE	WEAK	NONE	STRONG	MODERATE	WEAK	NONE	STRONG	MODERATE	WEAK	NONE
FORM			✓				✓			✓		
LINE			✓				✓			✓		
COLOR			✓				✓			✓		
TEXTURE			✓				✓				✓	

2\. Does project design meet visual resource management objectives? ___Yes ___No
(Explain on reverses side)

3\. Additional mitigating measures recommended
✓ Yes ___No (Explain on reverses side)

Evaluator's Names: Merlyn Paulson/ Chris Bockey

Date: 01/09/2020

(Continued on Page 2)

SECTION D. (Continued)

Comments from item 2.

Overall contrast would diminish based on viewer location and proximity to existing drilling infrastructure in the area of Kuparuk.

In viewing areas distant from the area of Kuparuk, moderate to weak construction-related contrasts in the background and seldom seen areas (5-15 and greater miles) would occur for the 10-11-year time period specified (Chapter 2.4.6.10.2) for drilling and from the presence of drill rigs and construction equipment. Moderate contrasts would be caused by the structural forms, lines, and colors and colors of lighting for facilities and vehicles.
These noticeable forms and lines are required for function and the highly contrasting colors are needed for safety in the region's extreme weather conditions. Thus, they would cause moderate contrasts in the characteristic landscape and mitigations of color would not be feasible.
Dark Sky BMP Re: down-shielded lighting – This BMP would limit direct (line-of-sight) visibility of the standard Osha-mandated lighting at facilities. However, down-shielding in snow cover conditions is known to increase reflectiveness toward the sky and the resultant sky glow and light dome would cause problematic navigation issues with humans and fauna.

Moderate contrasts would be reduced to weak during the operations, maintenance, and reclamation phases of the project. These phases would be portrayed by pads, roads, pipelines, and vehicles, and, eventually, less-noticeable forms, lines, and colors in the landscape.

Additional Mitigating Measures (See item 3)

Willow Master Development Plan

Appendix E.8
Water Resources Technical Appendix

June 2022

Appendix E.8A
Water Resources Technical Appendix

Appendix E.8B
Ocean Point Technical Memorandums

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Willow Master Development Plan

Appendix E.8A
Water Resources Technical Appendix

June 2022

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List of Acronyms

cfs	cubic feet per second
CPAI	ConocoPhillips Alaska, Inc.
HDD	horizontal directional drilling
MBI	Michael Baker International
mm	millimeters
NAVD88	North American Vertical Datum of 1988
NWS	National Weather Service
Project	Willow Master Development Plan Project
RM	river mile
USGS	U.S. Geological Survey
VSM	vertical support member
WSE	water surface elevation

Glossary Terms

Bottom-fast ice – Ice that is attached to the waterbody or sea floor and is relatively uniform in composition and immobile during winter (also known as bedfast, ground-fast, fast, shorefast, or landfast ice).

Discharge – The rate at which a given volume of water passes a given location within a specific period of time (e.g., cubic feet per second or gallons per minute).

Rolligon – A type of wheeled, low-impact off-road vehicle frequently used on the North Slope for tundra or snow travel; it can be configured to suit a variety of industrial and construction needs.

Stage – The vertical height of the water above an established but usually arbitrary point. Sometimes zero stage corresponds to the riverbed but more often to just an arbitrary point.

Water surface elevation – The elevation of the water surface of a river, lake, or stream above an established reference or vertical datum.

1.0 WATER RESOURCES

1.1 General Flow Characteristics of Rivers and Streams in the Analysis Area

Freeze-up often begins with ice forming along the shoreline and ice pans floating down the river. As freeze-up continues, the ice cover spreads across the stream and in shallow locations the entire water column freezes. Stream flow during the winter on the North Slope is generally so low that it is not measurable and is often nonexistent. In late May or early June there is a rapid rise in **discharge** resulting from snowmelt runoff, a period generally referred to as spring breakup. More than half the annual discharge for a stream can occur during spring breakup, a period of several days to a few weeks. Extremely large areas can be inundated in a matter of days as a result of rapid snowmelt combined with ice- and snow-blocked channels. Most streams continue to flow through the summer but at substantially lower discharges. Rainstorms can increase streamflow temporarily, but they are seldom sufficient to produce a discharge comparable to that which occurs during the average spring breakup. Streamflow rapidly declines in most streams shortly after the onset of freeze-up in September and ceases in most streams by December.

1.1.1 Influence of Climate Change on Flow

Although climate change is occurring, it is unknown how it might impact flood-peak magnitude and frequency in the Arctic. The National Weather Service (NWS) evaluated the potential for statistically significant trends in the 1-day and 1-hour annual maximum daily precipitation data for Alaska (for stations that had at least 40 years of data), which are often used to predict flood-peak discharge (Perica, Kane et al. 2012). There was no trend in 1-hour annual maximum precipitation for the 12 stations with 40 years of record. Of the 154 stations with 40 years of 1-day annual maximum precipitation data, 85% had no statistically significant trends, 8% had a positive trend, and 7% had a negative trend. Spatial maps did not reveal any spatial cohesiveness in positive and negative trends.

U.S. Geological Survey (USGS) evaluated the flood-peak data set used to develop regression equations to predict flood-peak discharge throughout Alaska (Curran, Barth et al. 2016). Statistically significant trends were detected at 43 of the 387 stream gages evaluated. Of the 43 stream gages with significant trends, 22 had increasing trends and 21 had decreasing trends.

Although precipitation levels are projected to increase, the longer, warmer summers may increase evapotranspiration. An increase in evapotranspiration may result in a net loss in surface water by the end of the summer season, which could affect the size, depth, and areal extent of thaw lakes. Increases in winter precipitation may have some effect on lake recharge and peak snowmelt runoff in rivers and streams.

1.2 Hydrology of Rivers and Streams in the Willow Area

1.2.1 Colville River

The Colville River is the largest north-flowing river in the U.S. and drains an area of about 23,600 square miles. It originates in the DeLong Mountains of the Brooks Range and generally follows a west-east flow corridor until reaching Umiat, where it turns north and flows into Harrison Bay in the Beaufort Sea.

Discharge and **stage** data are available for several locations on the Colville River. The closest gaging stations to Ocean Point (approximately river mile [RM] 46.5) are at Umiat (RM 117) and Monument 1 (RM 26.5), Figure 3.8.2. Although neither of these existing gages measures winter flow at Ocean Point, Umiat is more closely representative of Ocean Point than Monument 1 because Umiat is upstream of the influence of saltwater intrusion and tidal backwatering from the Colville River Delta and Monument 1 is not. Seventeen years of stage and discharge have been measured at the USGS Umiat gaging station 15875000 (Tables E.8.1 and E.8.2). The average monthly mean discharge at Umiat in winter (December through April) ranged from 83 to 4.1 cubic feet per second (cfs) from 2002 to 2021 (USGS 2022), as shown in Table E.8.1. (The range of mean monthly discharge for December through April was 132.2 to 0.0 cfs; Table E.8.1.) During that time, the minimum recorded average daily winter discharge varied from 0.0 cfs (2003 through 2009) to 20.0 cfs (2019) (USGS 2022). The annual spring peak discharge occurred between May 22 and June 10, with a median date of June 1. The time from the last day of minimum flow to the annual spring discharge varied between 12 and 47 days, with a median time of 24 days. The annual spring peak discharge varied from 73,000 to 268,000 cfs, with a median of 177,800 cfs. Note that the Colville River is more than 2,000 feet wide at Umiat and that by late winter the flow is contained to a very small channel within that width. In other words, the ice across 99% of the channel is frozen to the bottom, but somewhere within that width there is a very small channel with flow.

Table E.8.1. Colville River Mean Monthly Discharge (cubic feet per second) at Umiat

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2002	ND	ND	ND	ND	ND	ND	ND	ND	21,030	7,221	844	100.1
2003	3.6	0	0	0	690	65,690	24,030	31,800	12,760	10,490	560	72.6
2004	6.9	2.2	0.2	0	40,890	24,940	15,310	24,870	12,060	557	142	56.6
2005	20.8	4.2	< 0.1	0	12,830	72,480	13,920	4,143	6,014	1,169	200	104.5
2006	18.4	0.1	0	0	22,010	37,120	21,940	33,560	6,229	2,667	325	80.0
2007	27.9	11.7	0.9	0	4,179	50,530	12,140	17,820	7,511	874	177	72.6
2008	21.1	0.7	0	0	17,260	46,530	12,900	10,770	1,867	560	207	72.9
2009	15.0	0	0	3.0	36,940	45,050	13,890	13,440	13,750	1,775	418	95.2
2010	36.5	13.9	1.7	0.5	17,280	48,760	10,370	15,720	6,213	1,248	454	132.2
2011	35.5	9.7	1.1	0.4	37,790	31,190	13,170	11,330	11,940	1,958	375	93.5
2012	29.2	11.0	1.9	0.5	16,680	41,910	16,970	14,860	27,440	3,678	145	45.9
2013	16.4	3.9	2.0	1.0	6,434	83,970	10,530	10,290	11,750	1,475	509	130.7
2014	25.9	9.3	6.0	6.0	33,290	72,180	29,820	10,130	16,140	1,215	217	89.9
2015	45.2	29.0	16.8	12.0	62,410	17,010	8,243	22,250	11,550	1,504	276	65.5
2016	24.4	10.1	5.7	2.8	47,460	32,660	14,540	27,290	15,310	4,868	405	64.4
2017	16.0	3.8	1.2	1.0	12,070	26,220	13,110	36,370	25,900	6,403	448	86.5
2018	24.9	11.9	7.1	6.0	12,220	47,610	26,970	30,330	23,280	3,122	343	67.1
2019	40.9	30.2	22.6	20.0	36,180	18,370	12,380	38,990	15,500	ND	ND	ND
2020	27.2	9.0	4.7	4.0	106,013	23,807	12,248	19,911	23,106	13,442.0	370.3	69.0
2021	21.7	7.8	2.6	2.1	9,792	34,387	24,607	21,238	27,565	ND	ND	ND
Average monthly mean discharge Sep 2002 to Sep 2021	**24.1**	**8.9**	**4.1**	**3.1**	**28,022.0**	**43,179.7**	**16,162.5**	**20,795.4**	**14,845.8**	**3,568.1**	**356.4**	**83.3**
Average monthly mean discharge Sep 2010 to Sep 2021	**27.9**	**12.3**	**6.5**	**5.1**	**34,576**	**39,029**	**16,599**	**22,090**	**17,975**	**3,891**	**354.2**	**84.5**

Source: USGS 2022

Note: ND (no data); < (less than); Sep (September). No incomplete data have been used for statistical calculations.

Table E.8.2. Summary of Annual Minimum and Spring Peak Discharge for the Colville River at Umiat

Year	First Date of Minimum Flow (month/day)	Last Date of Minimum Flow (month/day)	Minimum Flow Discharge (cfs)	Annual Spring Peak Stage Date (month/day)	Annual Spring Peak Discharge (cfs)	Minimum Flow to Spring Peak Discharge (days)
2003	1/19	5/08	0	6/10	213,000	33
2004	3/06	5/09	0	5/24	222,000	15
2005	3/02	5/04	0	6/08	161,000	35
2006	2/04	5/09	0	5/30	173,000	21
2007	3/11	5/17	0	6/05	183,000	19
2008	2/07	5/16	0	5/28	108,000	12
2009	1/29	4/21	0	6/07	152,000	47
2010	3/20	5/19	0.5	6/01	186,000	13
2011	3/21	4/23	0.3	5/29	230,000	36
2012	3/22	5/15	0.5	6/02	177,000	18
2013	4/04	5/22	1.0	6/04	243,000	13
2014	3/01	5/05	6.0	5/31	195,000	26
2015	3/31	5/08	12.0	5/21	268,000	13
2016	4/12	4/30	2.5	5/25	193,000	25
2017	3/06	5/09	1.0	6/02	73,000[a]	24
2018	3/30	5/04	6.0	6/01	112,000	28
2019	3/24	5/02	20.0	5/25	135,000	23
2020	4/03	5/08	4.0	5/27	149,000	19
2021	4/04	4/28	2.0	6/07	99,800	40

Source: USGS 2022

Note: cfs (cubic feet per second)

[a] The peak discharge of 82,000 cfs occurred on 8/19.

From January 2003 through January 2009, mean monthly minimum winter flows of 0.0 cfs were recorded. From March 2010 to the present, no flows of 0.0 cfs have been recorded in the gaging station record. However, the lack of recorded 0.0 cfs flows may be due to the 2010 change in the USGS offices responsible for the site, including a difference in procedures and more frequent late-winter site visits (M. Schellekens [USGS], personal communication to Ken Karle, Hydraulic Mapping and Modeling. January 31, 2020).

Direct stream discharge measurements are required to create a gaging station rating curve, which converts stage (water height) into discharge. The USGS maintains a database of 155 discharge measurements made at Colville River Gaging Station 15875000 at Umiat between March 1, 1953, and October 18, 2019. December through April winter measurements are provided in Table E.8.3 (USGS 2022).

Table E.8.3. Winter Field Discharge Measurements at Umiat, U.S. Geological Survey Gaging Station 15875000

Measurement Number	Date	Streamflow (cfs)	Ice Cover	Measurement Rating[a]
1	4/1/1953	0	Yes	Unspecified
15	12/2/2003	197	Yes	Poor
16	2/23/2004	2.2	Yes	Poor
26	12/1/2004	85.1	Yes	Poor
27	1/12/2005	23.4	Yes	Fair
44	12/4/2006	118	Yes	Fair
45	1/22/2007	22.4	Yes	Poor
46	3/27/2007	0	Yes	Good
52	12/12/2007	81.0	Yes	Fair
64	1/18/2009	12.3	Yes	Poor
71	2/11/2010	17.4	Yes	Poor
77	3/4/2011	2.6	Yes	Poor
78	3/30/2011	0.3	Yes	Poor
89	3/4/2012	3.8	Yes	Fair
97	1/8/2013	21.7	Yes	Poor
98	3/2/2013	2.6	Yes	Poor
106	1/21/2014	17.9	Yes	Poor
107	3/1/2014	4.4	Yes	Poor
108	3/31/2014	6.4	Yes	Poor
116	1/12/2015	46.0	Yes	Poor
117	4/15/2015	11.9	Yes	Poor
124	1/26/2016	16.2	Yes	Poor
125	3/14/2016	5.4	Yes	Poor
126	4/18/2016	2.3	Yes	Fair
134	3/14/2017	1.0	Yes	Poor
141	1/16/2018	24.0	Yes	Poor
142	4/16/2018	5.7	Yes	Poor
149	2/10/2019	31.4	Yes	Poor
150	3/27/2019	19.7	Yes	Poor

Source: USGS 2022
Notes: cfs (cubic feet per second). Table shows all the published data from December through April data for the time period listed for USGS Gaging Station 15875000.
[a] The measurement rating is used to describe the relationship between stage (water surface elevation) and discharge. An equation is used to describe the curve, since it changes constantly as the riverbed changes. Winter measurements are not used to help construct the measurement rating curve, as the stage measurements are unreliable due to the presence of ice. The measurement rating is not a rating of the accuracy of the data.

Downstream from Umiat, the probability of having flow in every month of the year increases as the drainage area increases. Similarly, the magnitude of the flow is likely to increase roughly proportional to the drainage area increase. Thus, when the average monthly mean April flow is 3.1 cfs at Umiat, where the drainage area is approximately 13,860 square miles, the average monthly mean April flow may be 1.5 times than that near Nuiqsut (4.7 cfs), where the drainage area is 20,670 square miles. Therefore, the flow at Ocean Point is likely higher than the flow at Umiat.

Ocean Point is located at a distinct transition of the Colville River channel pattern. Starting approximately 40 miles upriver from Ocean Point, the Colville, joined by several tributaries within the reach (Anaktuvuk River, Kogosukruk River, and Kikiakrorak River), flows north in a wide floodplain with two dissimilar side-by-side channel patterns. The main channel system on the west side includes interconnected distributary channels within a sparsely vegetated floodplain that includes depositional longitudinal and transverse bars. On the right side, multiple smaller channels take the form of serpentine (scroll) meanders, with extensively developed riparian vegetation. Five miles upstream from Ocean Point, the river enters a sweeping 180-degree right-hand bend. At Ocean Point, the river transitions to a single meandering channel, although remnant abandoned channels are readily apparent in aerial imagery. The river remains primarily in a single channel for another 20 miles to the east and northeast before entering the Colville River Delta.

Available data specific to the Colville River at Ocean Point are summarized in Table 3.8.4. Although the data are limited, Ocean Point has been used as a **rolligon** crossing for a number of years by various users (users are described in Section 3.14, *Land Ownership and Use*) because the area is shallow and has the potential for **bottom-fast ice**.

Table E.8.4. Water Data for the Colville River at Ocean Point

Date	Flow or Ice Conditions	Water Temperature (degrees C)	Salinity (ppt)	Source
December 10, 2007	Ice not grounded, approximately 2 to 3 feet water depth under the ice.	NC	NC	J. Winters [ADF&G], personal communication to DOWL. January 16, 2020.
April 4, 2019	Grounded ice to 0.7-foot water depth, 0.5 to 6.2 feet ice thickness.	NC	NC	CPAI 2019b
September 5, 2019	28,900 cubic feet per second. Open channel conditions. Average water depth 5.7 feet.	9.8 to 10.0	0.1	MBI 2019
December 31, 2019[a]	Ice grounded near both banks. Floating ice thickness is 2.8 feet. Approximately 1.2 to 2.2 feet of water under the ice. Velocity is 0.15 to 0.25 feet per second.	0.1	0.2	CPAI 2019b
February 25, 2020[a]	Ice grounded at both banks and in the middle of the channel. Water columns are less than 1.3 feet deep. Floating ice thickness is 4.6 feet.	0.4	0.26	CPAI 2020, MBI 2020a
March 10, 2021	Ice not grounded, approximately 4.6 feet water depth under the ice. Floating ice thickness is 5.5 feet. Velocity is 0 feet per second.	-0.1	0.47	CPAI 2022; MBI 2021

Note: ADF&G (Alaska Department of Fish and Game); C (Celsius); CPAI (ConocoPhillips Alaska, Inc.); NC (not collected); ppt (parts per thousand). Data collected at similar, but not the same, locations near Ocean Point.
[a] More data for this date are provided in Table E.8.5.

Michael Baker International (MBI) collected field data at two potential crossing locations on the Colville River near Ocean Point (Figure E.8.1). Data included cross-sectional river bottom profiles, discharge, velocity, water depth, **water surface elevation** (WSE), site conditions, and general in situ water quality parameters (Michael Baker International 2019). Soil active layer depths were also investigated for both banks of each crossing. Table E.8.5 summarizes the discharge measurements for Ocean Point at two locations and the coincident discharge at USGS Gaging Station 15875000 at Umiat.

Table E.8.5. Summary of Discharge Data Collected at Ocean Point in 2019, 2020, and 2021

Ocean Point Transect	Date	Time	Measured Width (feet)	Measured Area (square feet)	Average Velocity (feet/second)	Measured Discharge (cfs)	Coincident Discharge at USGS Gaging Station 15875000 (cfs)
1	September 5, 2019	2:50 p.m.	1,270	7,570	3.0	29,068	19,900
6 (8.5 miles downstream of Transect 1)	September 5, 2019	4:50 p.m.	1,803	6,189	2.83	28,874	19,600
1	December 31, 2019	12:00 p.m.	650	880	0.15	135	Unavailable
1	February 25, 2020	Unavailable	304	228	0.04	9	Unavailable
1	February 17, 2021	12:15 p.m.	450	495	0.03	13.8	Unavailable
1	March 10, 2021	11:17 a.m.	118	55	0.01	0.7	Unavailable

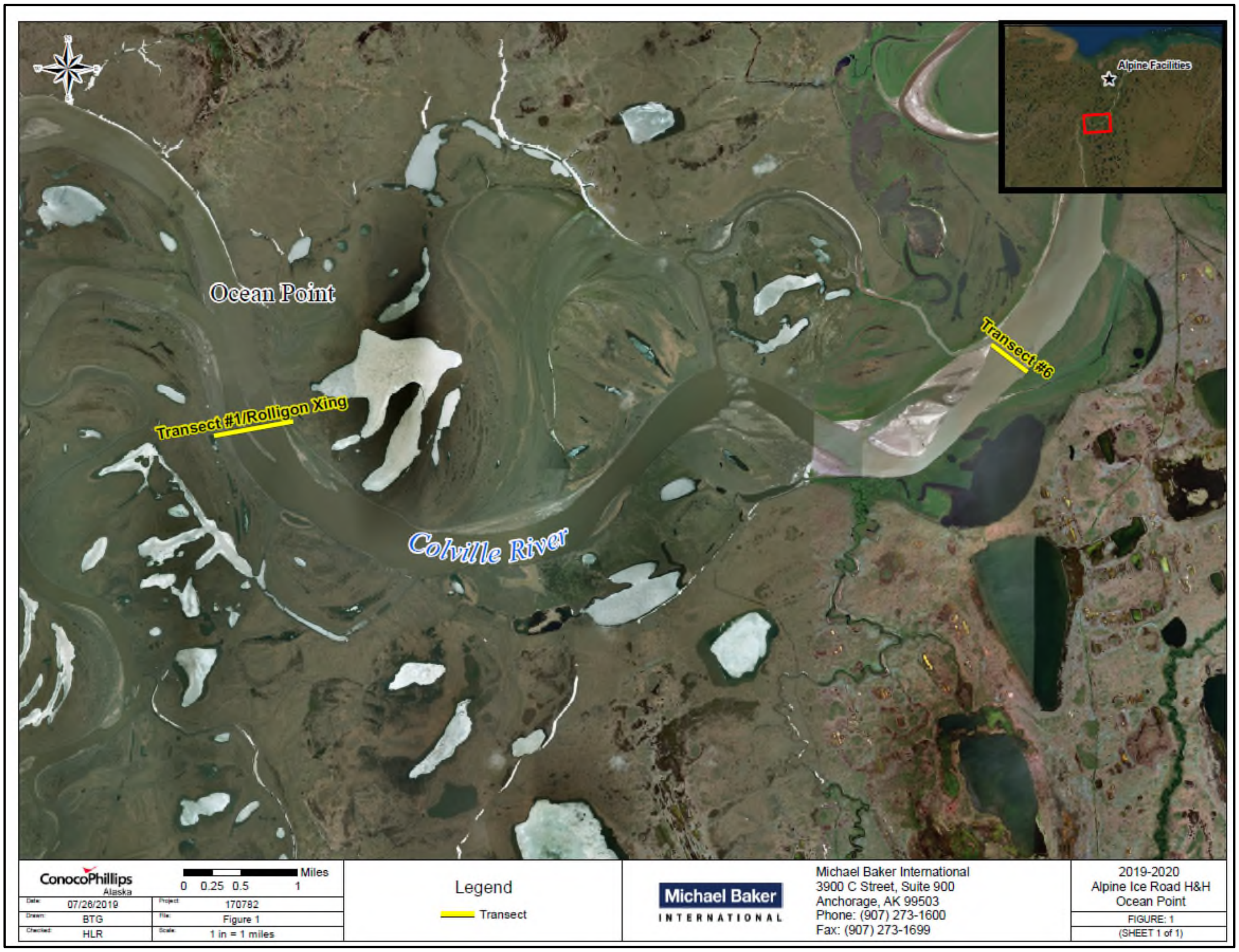
Source: CPAI 2022; MBI 2019, 2020b, 2021; USGS 2022
Note: cfs (cubic feet per second); USGS (U.S. Geological Survey).

Based on the data available for Ocean Point and Umiat, discharge at Ocean Point was estimated using the drainage-area ratio method (Emerson, Vecchia et al. 2005) commonly used to estimate individual streamflow discharges for sites where no streamflow data are available using data from one or more nearby gaging stations (Table E.8.6). More information on how this estimate was developed is in Karle (2020) and MacLeod (2022), provided as Appendix E.8B, *Ocean Point Technical Memorandums*.

Table E.8.6. Estimated Colville River Mean Monthly Discharge (cubic feet per second) at Ocean Point

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
41.3	18.3	9.7	7.5	51,173	57,762	24,566	32,693	26,602	5,759	524.3	125.0

Note: Estimate based on mean monthly discharge at Umiat, 2010–2021 (USGS 2020) using the drainage-area ratio method (Emerson, Vecchia et al. 2005).



Source: MBI 2019

Figure E.8.1. Ocean Point Data Collection Locations

1.2.2 Fish Creek (Uvlutuuq and Iqalliqpik Channels)

Fish Creek (Uvlutuuq and Iqalliqpik) has its headwater in the Arctic foothills and flows into Harrison Bay just east of the Colville River Delta. It has a drainage area of approximately 836 square miles, including its major tributaries: Judy (Kayyaaq) Creek, Judy (Iqalliqpik) Creek, and the Ublutuoch (Tiŋmiaqsiuġvik) River (Figure 3.8.1). The Willow Master Development Plan Project (Project) would cross or come near to all of these tributaries, which are described below. The Uvlutuuq channel of Fish Creek is upstream of the confluence with Judy (Iqalliqpik) Creek, and the Iqalliqpik channel of Fish Creek is downstream of the confluence.

The Project would cross Fish (Uvlutuuq) Creek at approximately RM 55.5, where the bankfull width is approximately 330 feet, the average bankfull depth is approximately 4.5 feet, and the depth to thalweg is approximately 6.4 feet (CPAI 2018b).

Spring breakup stage and discharge have been measured in Fish (Uvlutuuq) Creek for 17 years at RM 32.4 (Table E.8.7) (J. Aldrich [Arctic Hydrologic Consultants], personal communication to Richard Kemnitz [BLM]. September 11, 2018), about 22.8 RMs downstream from the proposed infrastructure. During that time, water began to flow between May 12 and June 5, with a median date of May 27. The annual peak discharge occurred between May 23 and June 18, with a median date of June 9. In 6 out of 17 years the peak stage occurred earlier and was higher than the stage at the time of the peak discharge. The largest difference between the peak stage and the stage at the peak discharge was 1.51 feet. The time from the beginning of flow to the peak discharge varied between 6 and 24 days, with a median time of 11 days. The annual peak discharge varied from 2,040 to 5,400 cfs, with a median of 3,370 cfs. Freeze-up data were collected in 14 of the 17 years. During that time, freeze-up occurred between October 4 and October 30, with a median date of October 17.

Table E.8.7. Summary of Annual Peak Stage and Annual Peak Discharge for Fish (Uvlutuuq) Creek at River Mile 32.4

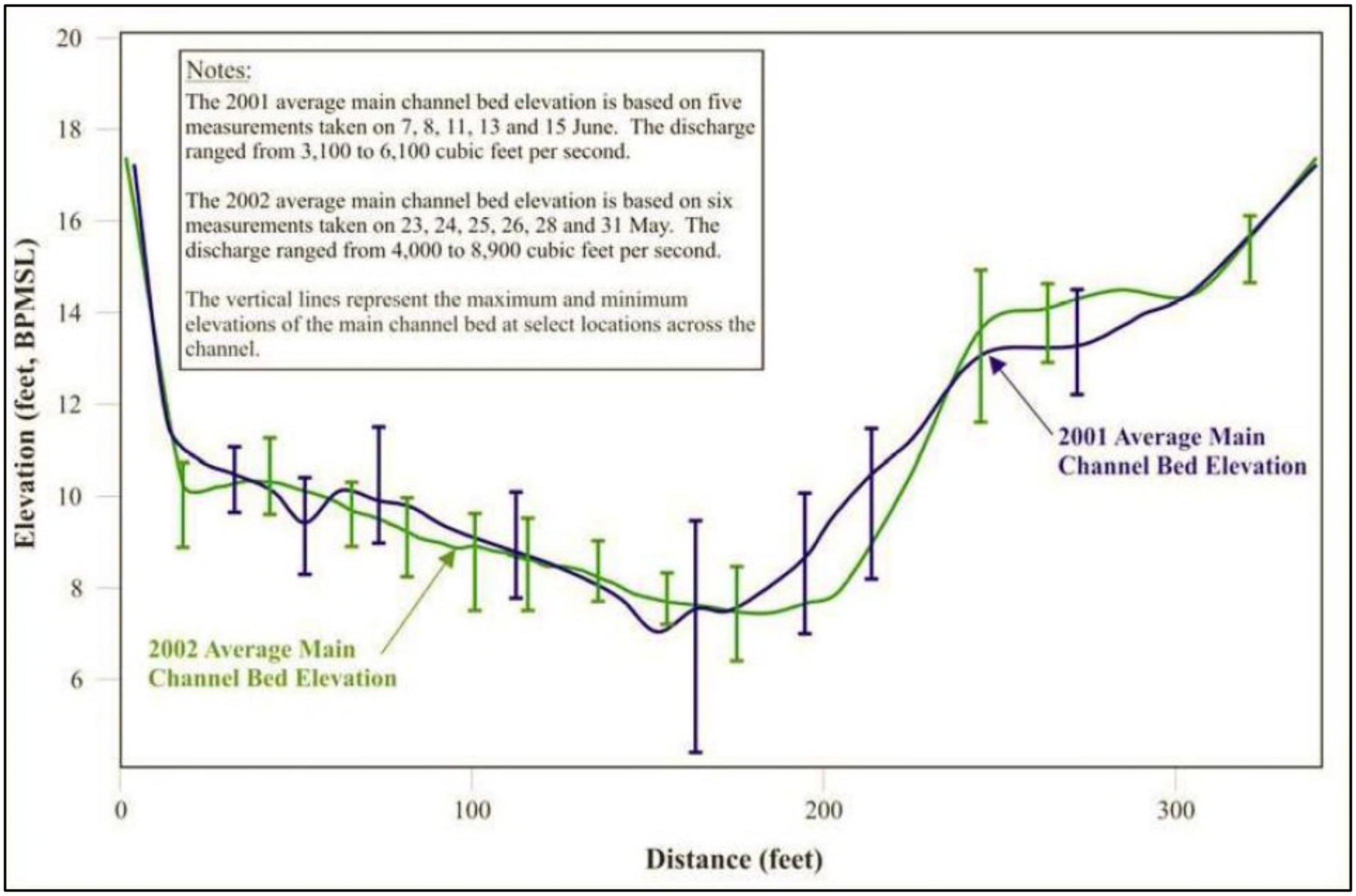
Year	Date Flow Begins (m/d)	Date of Freeze-Up (m/d)	Annual Peak Stage Date (m/d)	Annual Peak Stage (ft)	Annual Peak Stage Discharge (cfs)	Annual Peak Discharge Date (m/d)	Annual Peak Discharge Stage (ft)	Annual Peak Discharge (cfs)	Zero Flow to Peak Q (days)
2001	6/5	N/A	6/15	22.25	3,640	6/15	22.25	3,640	10
2002	5/17	N/A	5/27	22.42	3,685	5/27	22.42	3,685	10
2003	6/1	10/7 e	6/12	23.87	3,470	6/12	23.87	3,470	11
2004	6/2	10/30 e	6/9	23.48	4,410	6/9	23.48	4,410	7
2005	6/5	10/10 e	6/6	21.74	1,040	6/1	21.44	2,800	13
2006	5/27	10/16 e	6/12	21.72	3,170	6/12	21.72	3,170	16
2007	5/31	10/17 e	6/9	20.57	2,200	6/9	20.57	2,200	9
2008	5/23	10/4 e	6/6	20.12	2,270	6/6	20.12	2,270	14
2009	5/21	10/13	6/3	21.49	3,240	6/3	21.49	3,240	13
2010	6/1	10/8	6/9	23.50	3,730	6/9	23.50	3,730	8
2011	5/28	10/23	6/3	23.12	2,120	6/8	21.61	2,610	11
2012	5/25	10/20	6/6	22.25	2,720	6/11	21.93	3,510	17
2013	5/31	10/17	6/12	23.98	5,400	6/12	23.98	5,400	12
2014	5/15	10/17	5/20	22.35	2,290	6/8	21.77	3,370	24
2015	5/17	10/8	5/23	24.14	4,830	5/23	24.14	4,830	6
2016	5/12	10/21	5/27	20.10	1,470	5/31	20.08	2,040	19
2017	5/27	N/A	6/2	21.00	1,510	6/7	20.96	2,740	11

Source: J. Aldrich [Arctic Hydrologic Consultants], personal communication to Richard Kemnitz [BLM]. September 11, 2018
Note: cfs (cubic feet per second); d (day); e (estimate); ft (feet); m (month); N/A (not available); Q (discharge). Coordinates of the site (NAD27): 70.2706, -151.8692.

Both the Iqalliqpik and Uvlutuuq channels of Fish Creek are relatively low gradient and highly sinuous. Undercut stream banks and bank sloughing are common along the outside of meander bends (URS Corporation 2003). The riverbed appears to be very mobile. The river banks and bed of Fish Creek (both Iqalliqpik and Uvlutuuq channels) are composed of a mixture of sand and silt, with a median riverbed grain size of 0.13 millimeter (mm) at RM 25.1 and 0.037 mm at RM 32.4 (URS Corporation 2001). During the 2001 spring breakup, the maximum observed change in riverbed elevation was 5 feet at RM 25.1 and 7 feet at RM 32.4 (URS Corporation 2001). During the 2002 spring breakup, the maximum observed change in riverbed elevation was 3 feet at RM 25.1 and 1 foot at RM 32.4 (URS Corporation 2003). Figures E.8.2 and E.8.3 present the average riverbed elevation in 2001 and 2002 at RM 25.1 and RM 32.4, respectively. Also shown is the extent of the deviations from the average during those years.

On May 26, 2002, the discharge, suspended sediment load, and bedload were all measured at RM 25.1. The discharge was 8,900 cfs (the same as the annual peak discharge recorded the day before); the bedload was 423 tons per day; the suspended sediment load was 8,400 tons per day; and the total sediment load was computed to be 8,800 tons per day (URS Corporation 2003). The concentration of suspended sediment was 349 milligrams per liter. Approximately 6.1% of the bedload was composed of organic material (URS Corporation 2003). The median diameter of the mineral portion of the bedload was 0.12 mm and the specific gravity of the mineral portion of the bedload was 2.640 (URS Corporation 2003).

The daily changes in the channel bed that were recorded during the 2001 and 2002 breakups suggest that the bed is easily eroded, moved, and shaped by the flow (URS Corporation 2003). The interaction of the water-sediment mixture and the sand bed can create different bed configurations, such as ripples, dunes, transition, and antidunes. The type of bed form present affects both the hydraulic roughness and the rate of sediment transport, which affects the water velocity, the depth of the scour, and the WSE. At RM 25.1, dunes are probably present at discharges of 3,100 to 4,800 cfs (URS Corporation 2003). At discharges between 6,100 and 8,900 cfs, both dunes and antidunes are probably present (URS Corporation 2003). The antidunes are probably confined to the deepest and/or fastest portions of the channel (URS Corporation 2003). As the discharge increases beyond 6,100 cfs, the portion of the bed covered by antidunes is likely to increase (URS Corporation 2003). At RM 32.4, both ripples and dunes are probably present at discharges of 1,500 to 2,300 cfs (URS Corporation 2003). At discharges between 3,100 and 3,700 cfs, dunes are probably the predominant bed form.



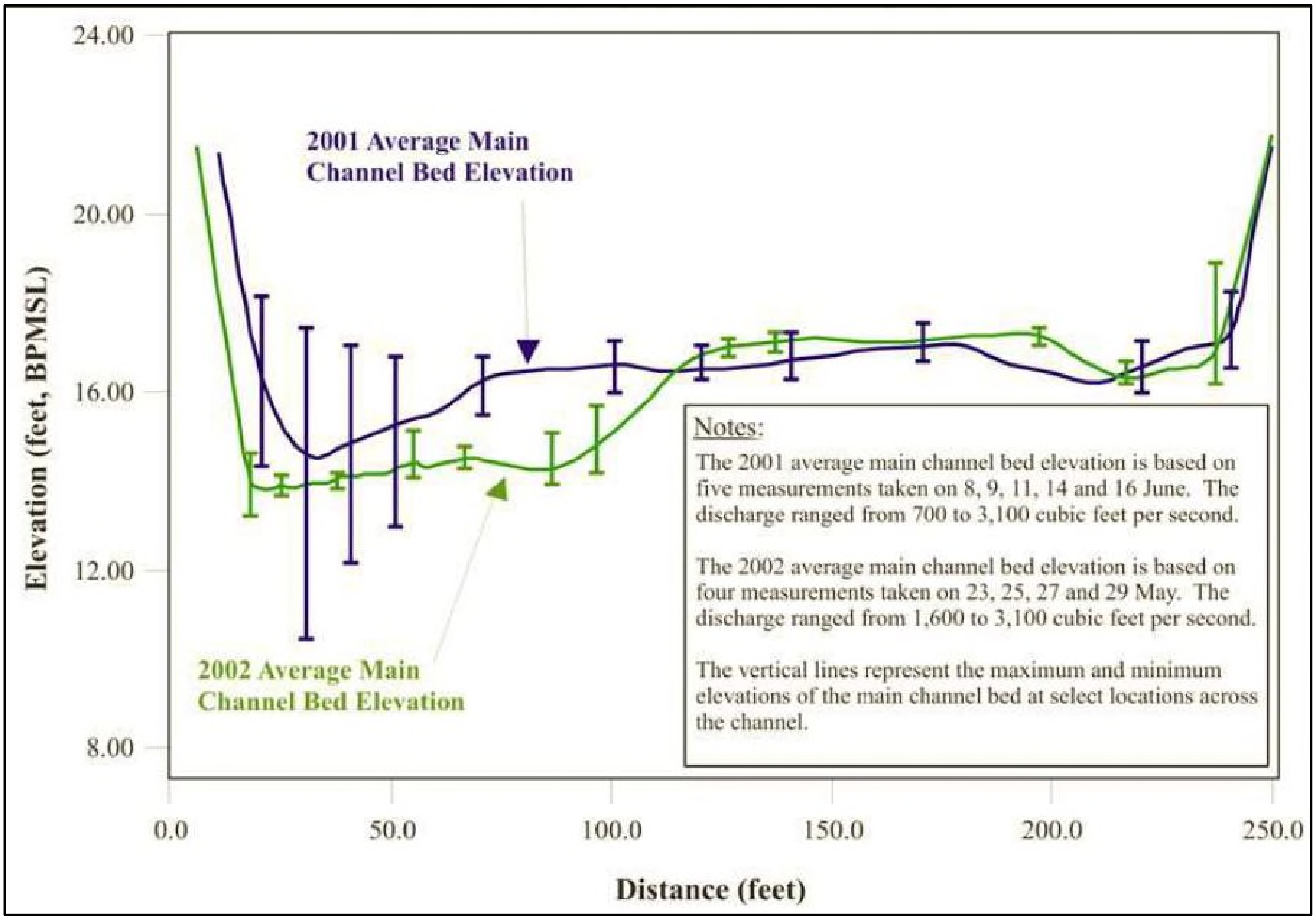
Source: URS Corporation 2003

Figure E.8.2. Average Riverbed Elevation in Fish (Iqalliqpik) Creek at River Mile 25.1, 2001 and 2002

Discharge and water surface slope measurements, along with surveyed cross-sections and a water surface profile model, were used to estimate hydraulic roughness in the channel on a particular day during spring breakup using data collected in both 2001 and 2002. At RM 25.1, the channel hydraulic roughness on the day of the measurements was 0.021 in both 2001 and 2002 (URS Corporation 2003). At RM 32.4, the channel hydraulic roughness on the day of the measurements was 0.028 in 2001 and 0.030 in 2002 (URS Corporation 2003). At RM 43.3, the channel hydraulic roughness on the day of the measurements was 0.027 in both 2001 and 2002. Although the values probably change from day to day during breakup and from year to year, the computed values are within the range of values one would expect when dunes and antidunes are present on the riverbed (0.014–0.035). Computations of hydraulic roughness based on measured discharge and water surface slope, and normal depth computations, on 5 to 6 days during breakup in both 2001 and 2002 suggested a slightly bigger range in hydraulic roughness values, but the values are still within the range one would expect when dunes and antidunes are present (URS Corporation 2003).

Seventeen years of summer flow data is available for Fish (Uvlutuuq) Creek at RM 32.4 (J. Aldrich [Arctic Hydrologic Consultants], personal communication to Richard Kemnitz [BLM]. September 11, 2018) . A summary of the available mean monthly discharge data is provided in Table E.8.8.

In 2018, a monitoring site was established at RM 55.5 (Michael Baker Jr. Inc. 2018). Observations during the 2018 spring breakup indicated the peak stage (46.25 feet [North American Vertical Datum of 1988]) occurred 0.5 hour after the peak discharge (4,400 cfs; WSE 46.03 feet NAVD88) and at a time when the channel was not impacted by snow or ice within the channel at the monitoring site (Michael Baker Jr. Inc. 2018). This suggests that the peak stage was due to backwater, possibly due to an ice jam downstream. Prior to the peak discharge, WSEs at the monitoring site had been impacted by snow and ice in the channel and an ice jam (Michael Baker Jr. Inc. 2018). It was also noted that the riverbed was mobile during spring breakup (Michael Baker Jr. Inc. 2018). Figure E.8.4 presents a cross-section of the channel showing the discharge measurement. In general, the WSE decreased throughout the summer but increased in early September in response to a rain event (Michael Baker Jr. Inc. 2018). Maximum and minimum summer WSEs were 43.17 feet NAVD88 (fall rainfall peak) and 40.74 feet NAVD88.



Source: URS Corporation 2003

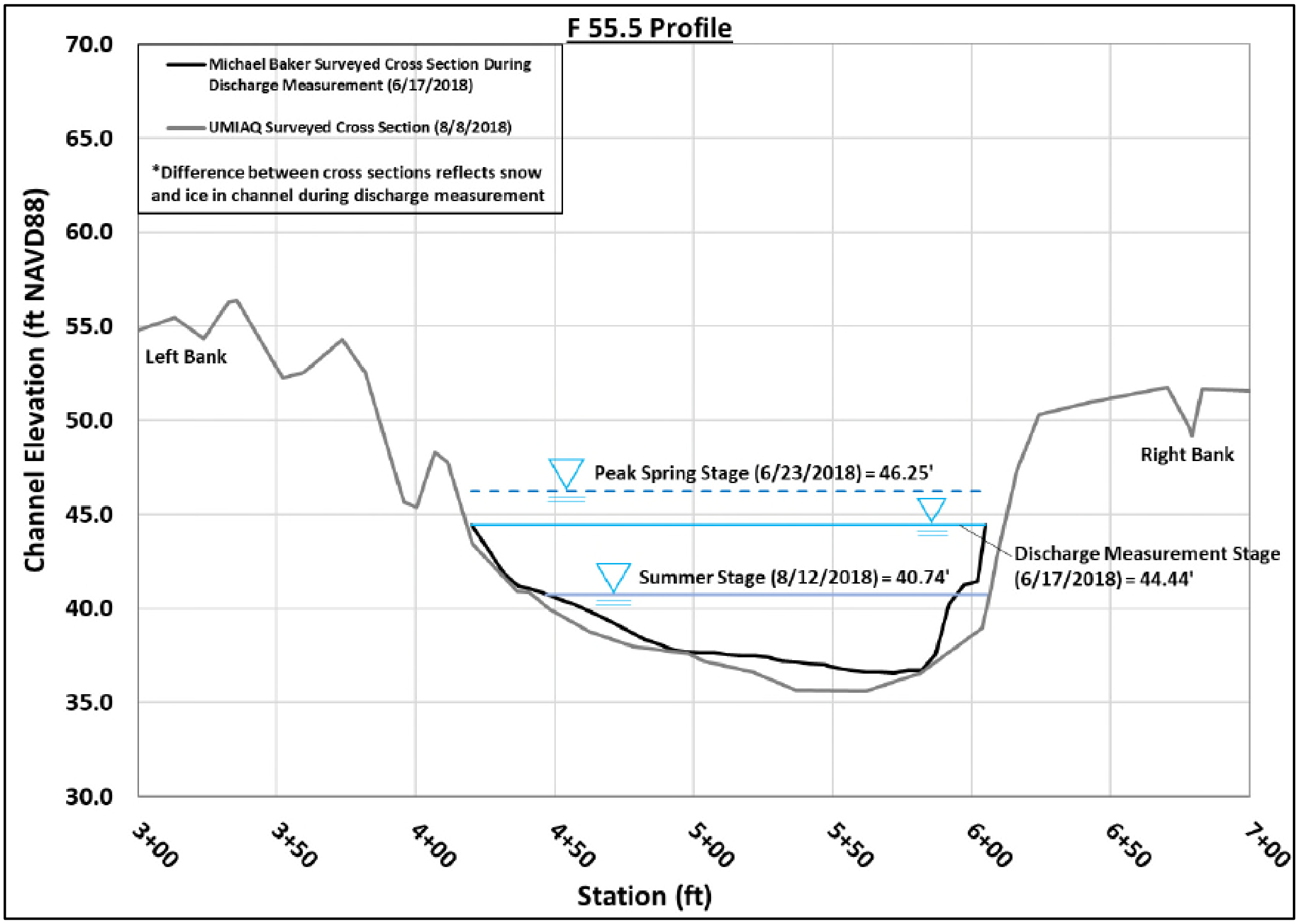
Figure E.8.3. Average Riverbed Elevation in Fish (Uvlutuuq) Creek at River Mile 32.4, 2001 and 2002

Table E.8.8. Mean Monthly Discharge (cubic feet per second) in Fish (Uvlutuuq) Creek at River Mile 32.4

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2001	–	–	–	–	–	1,761	697	412	298	242	208	173
2002	137	104	70	35	808	1,118	526	252	259	230	199	168
2003	137	107	77	47	16	1,620	633	391	341	173	25	0
2004	0	0	0	0	0	2,311	732	331	298	196	38	0
2005	0	0	0	0	0	1,484	750	282	171	44	6	0.2
2006	0	0	0	0	47	1,643	555	298	210	132	40	2
2007	0	0	0	0	0	10,004	259	66	37	12	0.1	0
2008	0	0	0	0	112	911	224	113	73	17	0	0
2009	0	0	0	0	432	1,684	405	179	196	63	5	0
2010	0	0	0	0	0	1,719	532	321	191	59	3	0
2011	0	0	0	0	37	1,600	437	206	185	120	28	2
2012	0	0	0	0	15	1,748	459	240	256	185	25	0
2013	0	0	0	0	0.6	2,617	803	439	386	293	27	0
2014	0	0	0	0	753	2,014	877	353	282	190	31	0.7
2015	0	0	0	0	1424	1,637	402	203	165	62	19	0.6
2016	0	0	0	0	325	1,085	372	245	518	352	45	1
2017	0	0	0	0	91	1,555	486	619	846	806	262	14

Source: J. Aldrich [Arctic Hydrologic Consultants], personal communication to Richard Kemnitz [BLM]. September 11, 2018
Note: "–" (no data).

Observations during the 2019 spring breakup indicated the peak stage of 44.71 feet NAVD88 and an estimated peak discharge of 5,100 cfs, both on May 28. Summer stage levels generally remained below peak spring stage. During a late summer precipitation event, stage crested at levels observed near the end of spring breakup. The minimum recorded summer stage was 40.08 feet NAVD88 on July 20, and the highest recorded summer stage was 42.59 feet NAVD88 on August 29 (Michael Baker International 2020b).



Source: Michael Baker Jr. Inc. 2018

Figure E.8.4. Cross-Section on Fish (Uvlutuuq) Creek at River Mile 55.5

Table E.8.9 presents flood-peak magnitude and frequency estimates for Fish (Uvlutuuq) Creek at RM 55.5 based on the Curran et al. (2003) USGS 2003 regression equations (Michael Baker Jr. Inc. 2018).

Table E.8.9. Flood Magnitude and Frequency in Fish (Uvlutuuq) Creek at River Mile 55.5

Percent Chance of Exceedance in Any Given Year (%)	Recurrence Interval (years)	Annual Peak Discharge (cfs)
50	2	10,400
20	5	15,200
10	10	18,200
4	25	21,800
2	50	24,400
1	100	26,900

Source: Michael Baker Jr. Inc. 2018

Spring breakup observations have also been made at the following sites:

- RM 0.7 in 2001 (URS Corporation 2001), 2002 (URS Corporation 2003), 2005 (Michael Baker International 2005), and 2006 (Michael Baker International 2007)
- RM 10.3 in 2005 (Michael Baker International 2005) and 2006 (Michael Baker International 2007)
- RM 11.7 in 2001 (URS Corporation 2001) and 2002 (URS Corporation 2003)
- RM 12.6 in 2001 (URS Corporation 2001) and 2002 (URS Corporation 2003)
- RM 18.4 in 2001 (URS Corporation 2001) and 2002 (URS Corporation 2003)
- RM 25.1 in 2005 (Michael Baker International 2005) and 2006 (Michael Baker International 2007)
- RM 32.4 in 2005 (Michael Baker International 2005) and 2006 (Michael Baker International 2007)
- RM 43.3 in 2001 (URS Corporation 2001) and 2002 (URS Corporation 2003)

Hydraulic designs on Fish (Uvlutuuq) Creek should consider the flood-peak data that have been collected on Fish (Uvlutuuq) Creek at RM 32.4, the highly mobile bed, the impact of ice and snow on annual peak WSEs, and the riverbed forms and hydraulic roughness likely to be present at the design discharge. In developing flood-peak magnitude and frequency estimates on streams in the Fish (Uvlutuuq) Creek basin, the 17 years of data collected at RM 32.4 should be considered. Single-station flood-peak magnitude and frequency analyses could be conducted with these data to estimate the flood-peak magnitude and frequencies at RM 32.4. A best estimate of the flood-peak magnitude and frequency at RM 32.4 could then be developed from a weighted average based on the uncertainty associated with estimates from each of two methods: the single-station frequency analysis and the Shell regression equations[1] (Arctic Hydrological Consultants and ERM 2015). The weighted average estimate would then be extrapolated to other locations within the basins as a proportion of the Shell regression equation estimate.

Since the hydraulic roughness is changing throughout spring breakup, when designing structures on this river it would be prudent to consider a range of hydraulic roughness values. Higher hydraulic roughness values will provide estimates with high WSEs and lower velocities. Lower hydraulic roughness values will provide estimates with lower WSEs and higher velocities. Both conditions are important when designing structures within the channel and floodplain.

1.2.2.1 Willow Creek 8

Willow Creek 8 is a tributary of Fish (Uvlutuuq) Creek. It has a meandering, incised channel with intermittent deep, beaded pools (Michael Baker Jr. Inc. 2018). The infield road for all action alternatives would cross Willow Creek 8 at the MBI TBD_6 and SW22 monitoring sites, about 1.7 and 3 RMs upstream of the Fish (Uvlutuuq) Creek confluence, respectively (Michael Baker Jr. Inc. 2018). At the SW22 crossing, Willow Creek 8 has a poorly defined channel in a low-lying area of polygon troughs connecting Lake M0305 to an unnamed lake to the south (Michael Baker Jr. Inc. 2018). At TBD_6, the Willow Creek 8 channel is incised and well defined. At TBD_6, the bankfull width is approximately 32 feet and the average bankfull depth is approximately 4.8 feet (CPAI 2018b). Monitoring sites TBD_6 and SW22 were established in 2018.

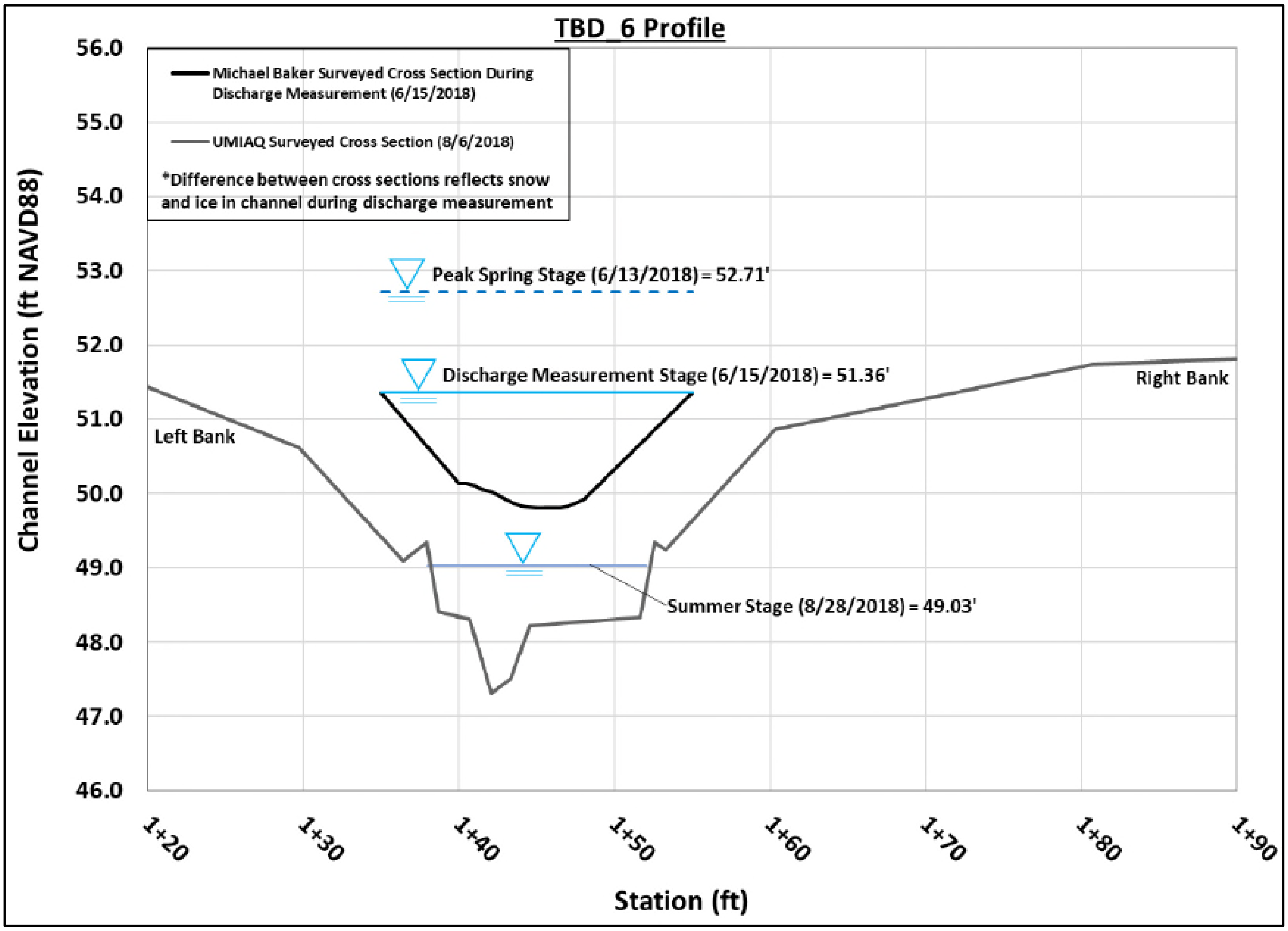
Due to low relief and the wide area of possible flow paths, the SW22 gage was not placed in the main flow path, and neither peak stage nor peak discharge information was collected during the 2018 spring breakup (Michael Baker Jr. Inc. 2018). At TBD_6, the peak stage was 52.71 feet NAVD88 and occurred on June 13. At the time of the peak stage there was snow and ice in the channel and overbank flooding (Michael Baker Jr. Inc. 2018). It is likely that the peak stage occurred prior to the peak discharge (Michael Baker Jr. Inc. 2018). The date and magnitude of the peak discharge were not recorded.

Figure E.8.5 shows a cross-section of the channel at TBD_6, including a cross-section from a June 15, 2018, discharge measurement, and the 2018 spring peak stage. The difference in the cross-sections, and the difference between the June 13 and 15 WSEs, is an indication of the magnitude of the impact of snow and ice on the peak stage and during the likely time of the peak discharge.

In general, the stage at TBD_6 fell throughout the summer except for fluctuations due to summer precipitation events (Michael Baker Jr. Inc. 2018). At the end of the summer monitoring season, the stage increased due to a late summer precipitation event (Michael Baker Jr. Inc. 2018). However, the stage remained well below the spring breakup peak stage throughout the summer (Michael Baker Jr. Inc. 2018). The maximum and minimum summer stages at TBD_6 were 50.18 feet and 49.03 feet NAVD88, respectively (Michael Baker Jr. Inc. 2018).

During the 2019 spring breakup, the TBD_6 peak stage was 53.72 feet NAVD88 on May 29. A discharge of 90 cfs was measured on May 30. The measured summer stage levels remained well below the spring breakup peak stage. The stage fluctuations reflected summer precipitation events. The minimum recorded summer stage was 49.07 feet NAVD88 on July 30 and the highest recorded summer stage was 50.96 feet NAVD88 on August 28 (Michael Baker International 2020b).

[1] The Shell regression equations are suggested rather than the 2003 USGS regression equations because considerably more North Slope river data were used to prepare the Shell regression equations than the USGS regression equations.



Source: Michael Baker Jr. Inc. 2018

Figure E.8.5. Cross-Section of Willow Creek 8 at Monitoring Site TBD_6

1.2.2.2 Judy (Iqalliqpik) Creek

Judy (Iqalliqpik) Creek has its headwater in the Arctic foothills and flows into Fish (Iqalliqpik) Creek at RM 26. Much of the Project infrastructure would be within the Judy (Iqalliqpik) Creek basin; Alternatives B (Proponent's Project) and D (Disconnected Access) would cross the main stem of Judy (Iqalliqpik) Creek at approximately RM 21.4 (Michael Baker Jr. Inc. 2018). At RM 21.4, the bankfull width is approximately 175 feet and the average bankfull depth is approximately 2.0 feet (CPAI 2018b). Several tributaries of Judy (Iqalliqpik) Creek are also crossed by the infrastructure: Judy (Kayyaaq) Creek, Willow Creek 1, Willow Creek 2, Willow Creek 3, Willow Creek 4, and Willow Creek 4A.

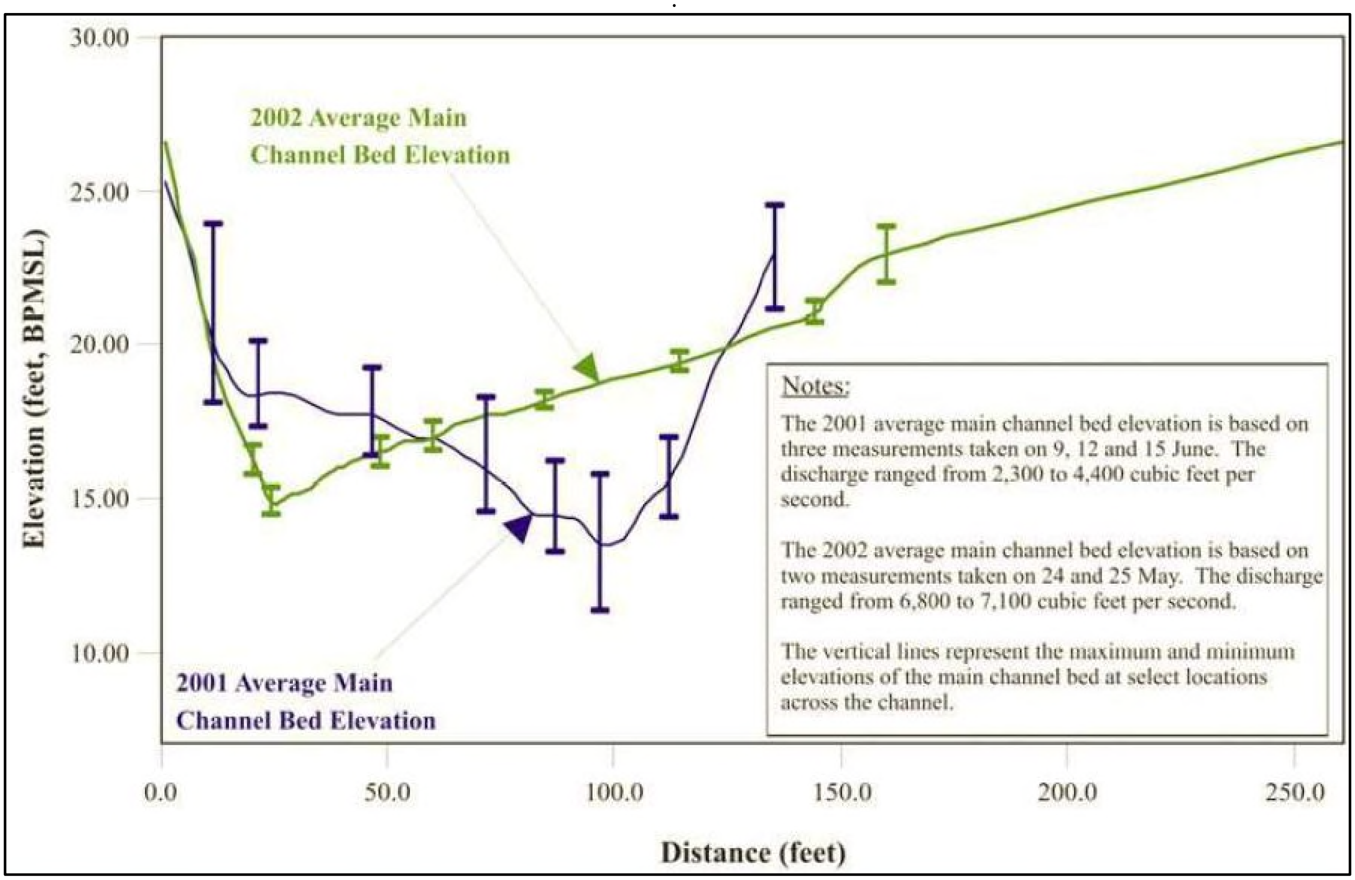
The spring breakup stage and discharge have been measured on the main stem of Judy (Iqalliqpik) Creek for 17 years at RM 7 (J. Aldrich [Arctic Hydrologic Consultants], personal communication to Richard Kemnitz [BLM]. September 11, 2018) , about 13.3 RMs downstream from the proposed infrastructure (Table E.8.10). The date on which water began to flow during that time was between May 11 and June 5, with a median date of May 26. The annual peak discharge occurred between May 18 and June 10, with a median date of June 5. In 6 out of 17 years the peak stage occurred earlier and was higher than the stage at the time of the peak discharge. The largest difference was 2.39 feet. The time from the beginning of flow to the peak discharge varied between 1 and 12 days, with a median time of 8 days. The annual peak discharge varied from 2,250 to 9,210 cfs, with a median of 4,770 cfs. Freeze-up data were collected in 14 of the 17 years. During that time, freeze-up occurred between September 20 and October 11, with a median date of September 26.

Judy (Iqalliqpik) Creek has a relatively low gradient and a highly sinuous channel. Undercut stream banks and bank sloughing are common along the outside of meander bends (URS Corporation 2003). The Judy (Iqalliqpik) Creek riverbed appears to be very mobile. The river banks and bed are composed of a mixture of sand and silt, with a median riverbed grain size of 0.17 mm at RM 7 (URS Corporation 2001). During the 2001 spring breakup, the maximum observed change in riverbed elevation at RM 7 was 5 feet (URS Corporation 2001). During the 2002 spring breakup, the maximum observed change in riverbed elevation at RM 7 was 2 feet (URS Corporation 2003). Figure E.8.6 presents the average riverbed elevation in 2001 and 2002 at RM 7 and the deviations from average during those years.

Table E.8.10. Summary of Annual Peak Stage and Discharge for Judy (Iqalliqpik) Creek at River Mile 7

Year	Date Flow Begins (m/d)	Date of Freeze-Up (m/d)	Annual Peak Stage Date (m/d)	Annual Peak Stage (ft)	Annual Peak Stage Discharge (cfs)	Annual Peak Discharge Date (m/d)	Annual Peak Discharge Stage (ft)	Annual Peak Discharge (cfs)	Zero Flow to Peak Q (days)
2001	6/5	N/A	6/10	27.11	N/A	6/10	27.11	5,590	5
2002	5/18	N/A	5/25	26.81	N/A	5/25	26.81	7,150	7
2003	5/31	9/25	6/6	28.00	N/A	6/6	25.61	4,720	7
2004	5/18	9/26	5/26	28.55	N/A	6/5	26.62	4,770	8
2005	6/2	9/26	6/6	27.47	N/A	6/10	25.99	4,400	8
2006	5/26	10/5	5/30	26.00	N/A	6/7	24.97	3,930	12
2007	5/26	9/23	6/5	25.40	N/A	6/5	25.40	4,560	10
2008	5/22	9/29	5/29	24.93	N/A	5/29	24.93	3,850	7
2009	5/18	9/23	5/27	25.16	N/A	5/28	24.78	2,250	10
2010	6/2	9/26	6/8	27.95	N/A	6/8	27.95	9,210	6
2011	5/30	10/1	5/31	30.05	N/A	5/31	29.66	5,480	1
2012	5/26	10/9	6/5	26.86	N/A	6/5	26.86	6,950	10
2013	5/31	9/26	6/9	26.86	N/A	6/9	26.86	6,300	10
2014	5/14	10/10	5/18	30.07	N/A	5/18	30.07	5,410	4
2015	5/18	9/20	5/22	29.21	N/A	5/22	29.21	5,990	4
2016	5/11	10/11	5/22	26.21	N/A	5/22	26.21	4,010	11
2017	5/26	N/A	6/3	25.85	N/A	6/3	25.85	4,070	8

Source: J. Aldrich (Arctic Hydrologic Consultants), personal communication to Richard Kemnitz (BLM). September 11, 2018
Note: cfs (cubic feet per second); d (day); e (estimate); ft (feet); m (month); N/A (not available); Q (discharge); RM (river mile). The coordinates of the site (NAD27): 70.2206, -151.8352).



Source: URS Corporation 2003

Figure E.8.6. Average Riverbed Elevation for Judy (Iqalliqpik) Creek at River Mile 7, 2001 and 2002

The daily changes in the channel bed that were recorded during the 2001 and 2002 breakups suggest that the bed is easily eroded, moved, and shaped by the flow (URS Corporation 2003). At RM 7, dunes are probably present at discharges on the order of 2,300 cfs (URS Corporation 2003). At discharges between 3,200 and 7,000 cfs, both dunes and antidunes are probably present (URS Corporation 2003). The antidunes are probably confined to the deepest and/or the fastest portions of the channel (URS Corporation 2003). At discharges above 7,000 cfs, it is likely that antidunes cover the bed (URS Corporation 2003).

Discharge and water surface slope measurements, along with surveyed cross-sections and a water surface profile model, were used to estimate hydraulic roughness in the channel on a particular day during spring breakup using data collected in both 2001 and 2002. At RM 7 the channel hydraulic roughness on the day of the measurements was 0.014 in 2001 and 0.024 in 2002 (URS Corporation 2003). At RM 13.8 the channel hydraulic roughness on the day of the measurements was 0.020 in 2001 and 0.024 in 2002 (URS Corporation 2003). Although the values probably change from day to day during breakup and from year to year, the computed values are within the range of values one would expect when dunes and antidunes are present on the riverbed (0.014–0.035). Computations of hydraulic roughness based on measured discharge and water surface slope, and normal depth computations, at RM 7 on several different days suggest that in 2001 the hydraulic roughness during ice- and snow-impacted conditions varied from 0.022 to 0.028 (URS Corporation 2003). Similar computations during open-water conditions in 2001 and 2002 suggest that the hydraulic roughness varies from 0.13 to 0.022.

Seventeen years of summer flow data is available for Judy (Iqalliqpik) Creek at RM 7 (J. Aldrich [Arctic Hydrologic Consultants], personal communication to Richard Kemnitz [BLM]. September 11, 2018) . A summary of the available mean monthly discharge data is provided in Table E.8.11.

Table E.8.11. Mean Monthly Discharge (cubic feet per second) in Judy (Iqalliqpik) Creek at River Mile 7

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2001	–	–	–	–	–	1,448	175	175	176	129	78	26
2002	0	0	0	0	1,273	492	285	166	155	110	66	22
2003	0	0	0	0	1	1,306	307	171	214	60	0.9	0
2004	0	0	0	0	493	1,786	263	155	221	51	3	0
2005	0	0	0	0	0	1,717	271	72	63	13	0	0
2006	0	0	0	0	93	1,559	164	133	85	38	4	0
2007	0	0	0	0	1	879	65	21	14	2	0	0
2008	0	0	0	0	334	775	91	65	42	4	0	0
2009	0	0	0	0	513	904	103	90	166	38	3	0
2010	0	0	0	0	0	1,718	149	220	113	18	1	0
2011	0	0	0	0	250	1,473	167	81	151	65	3	0
2012	0	0	0	0	64	1,785	132	82	161	86	3	0
2013	0	0	0	0	6	2,537	264	170	186	93	8	0
2014	0	0	0	0	1,044	1,469	310	134	166	85	8	0
2015	0	0	0	0	1,268	650	128	89	110	12	0	0
2016	0	0	0	0	977	570	106	139	358	308	41	0
2017	0	0	0	0	165	1,557	144	512	753	600	73	3

Source: J. Aldrich (Arctic Hydrologic Consultants), personal communication to Richard Kemnitz (BLM). September 11, 2018
Note: "–" (no data).

At RM 13.8, spring breakup peak WSEs have been measured periodically since 2001 (Table E.8.12).

Table E.8.12. Historical Peak Stage in Judy (Iqalliqpik) Creek at River Mile 13.8

Year	Peak Stage (feet BPMSL)	Date
2019	35.81	5/27
2018	37.09	6/6
2017	34.68	6/4
2006	35.56	5/30
2005	37.25	6/4
2004	–	–
2003	36.58	6/6
2002	35.86	5/25
2001	39.66	6/7

Note: "–" (no data); BPMSL (British Petroleum Mean Sea Level). Table adapted from Table 4.3 in Michael Baker Jr. Inc. (2018).

Observations made during the 2018 spring breakup at RM 13.8 indicated the peak stage (37.09 feet NAVD88) occurred prior to the peak discharge (4,100 cfs; WSE 36.37 feet NAVD88). On the day of the peak discharge, some intermittent ice floes were observed and considerable snow was present along each bank, but no bottom-fast ice was observed (Michael Baker Jr. Inc. 2018). It was also noted that the riverbed was mobile on both the day of the peak discharge and 10 days after the peak discharge, and that on the later date a moving bed velocity averaging 0.7 feet per second was observed (Michael Baker Jr. Inc. 2018). In 2019, recorded stage data revealed multiple spikes followed by declines in stage, indicating ice jams and associated backwater releases upstream of the J13.8 reach.

At RM 21.4, spring breakup monitoring was conducted in 2017, 2018, and 2019 (CPAI 2018a; Michael Baker International 2020a; Michael Baker Jr. Inc. 2018). In 2017, the peak stage was recorded as 90.2 feet (arbitrary datum; [CPAI 2018a]); in 2018, the peak stage was recorded as 51.24 feet NAVD88 (Michael Baker Jr. Inc. 2018); and in 2019, the peak stage was recorded as 49.80 feet NAVD88 (Michael Baker International 2020a). In 2018, it was noted that the channel bed was highly mobile during spring breakup (Michael Baker Jr. Inc. 2018). Summer stage was measured in 2018 and indicated that the stage fluctuated with precipitation, but water levels remained below the peak spring breakup stage (Michael Baker Jr. Inc. 2018). The stage increased at the end of the summer monitoring period due to a late summer precipitation event. Maximum and minimum summer WSEs in 2018 were 47.49 feet NAVD88 (fall rainfall peak) and 44.78 feet NAVD88. In 2019, a late summer precipitation event caused the stage to crest to levels observed near the end of spring breakup. The peak summer stage was 49.8 feet on May 27.

Table E.8.13 presents flood-peak magnitude and frequency estimates for Judy (Iqalliqpik) Creek at RM 13.8 based on the Curran et al. (2003) USGS 2003 regression equations (Michael Baker Jr. Inc. 2018).

Table E.8.13. Flood Magnitude and Frequency in Judy (Iqalliqpik) Creek at River Mile 13.8

Percent Chance of Exceedance in Any Given Year (%)	Recurrence Interval (years)	Annual Peak Discharge (cubic feet per second)
50	2	7,400
20	5	10,900
10	10	13,100
4	25	15,800
2	50	17,700
1	100	19,500

Source: Michael Baker Jr. Inc. 2018

Spring breakup observations have also been made at the following sites:

- RM 16.5 in 2017 (CPAI 2018a)
- RM 31.0 in 2001 (URS Corporation 2001)

Hydraulic designs on Judy (Iqalliqpik) Creek should consider the flood-peak data that have been collected on Judy (Iqalliqpik) Creek at RM 7, the highly mobile bed, the impact of ice and snow on annual peak WSEs, and the riverbed forms and hydraulic roughness likely to be present at the design discharge. In developing flood-peak magnitude and frequency estimates on streams in the Judy (Iqalliqpik) Creek basin, the 17 years of data collected at RM 7 should be considered. A single-station flood-peak magnitude and frequency analyses could be conducted with these data to estimate the flood-peak magnitude and frequencies at RM 7. A best estimate of the flood-peak magnitude and frequency at RM 7 could then be developed from a weighted average, based on the uncertainty associated with estimates from each of two methods: the single-station frequency analysis, and the Shell regression equations[2] (Arctic Hydrological Consultants and ERM 2015). The weighted average estimate would then be extrapolated to other locations within the basins as a proportion of the Shell regression equation estimate.

Since the hydraulic roughness is changing throughout spring breakup, when designing structures on this river it would be prudent to consider a range of hydraulic roughness values. Higher hydraulic roughness values would provide estimates with higher WSEs and lower velocities. Lower hydraulic roughness values would provide estimates with lower WSEs and higher velocities. Both conditions are important when designing structures within the channel and the floodplain.

1.2.2.2.1 Judy (Kayyaaq) Creek

Judy (Kayyaaq) Creek is a tributary to Judy (Iqalliqpik) Creek. It has a highly sinuous and incised channel: over 8 feet from the top of the bank to the streambed and typically about 30 feet wide (Michael Baker Jr. Inc. 2018).

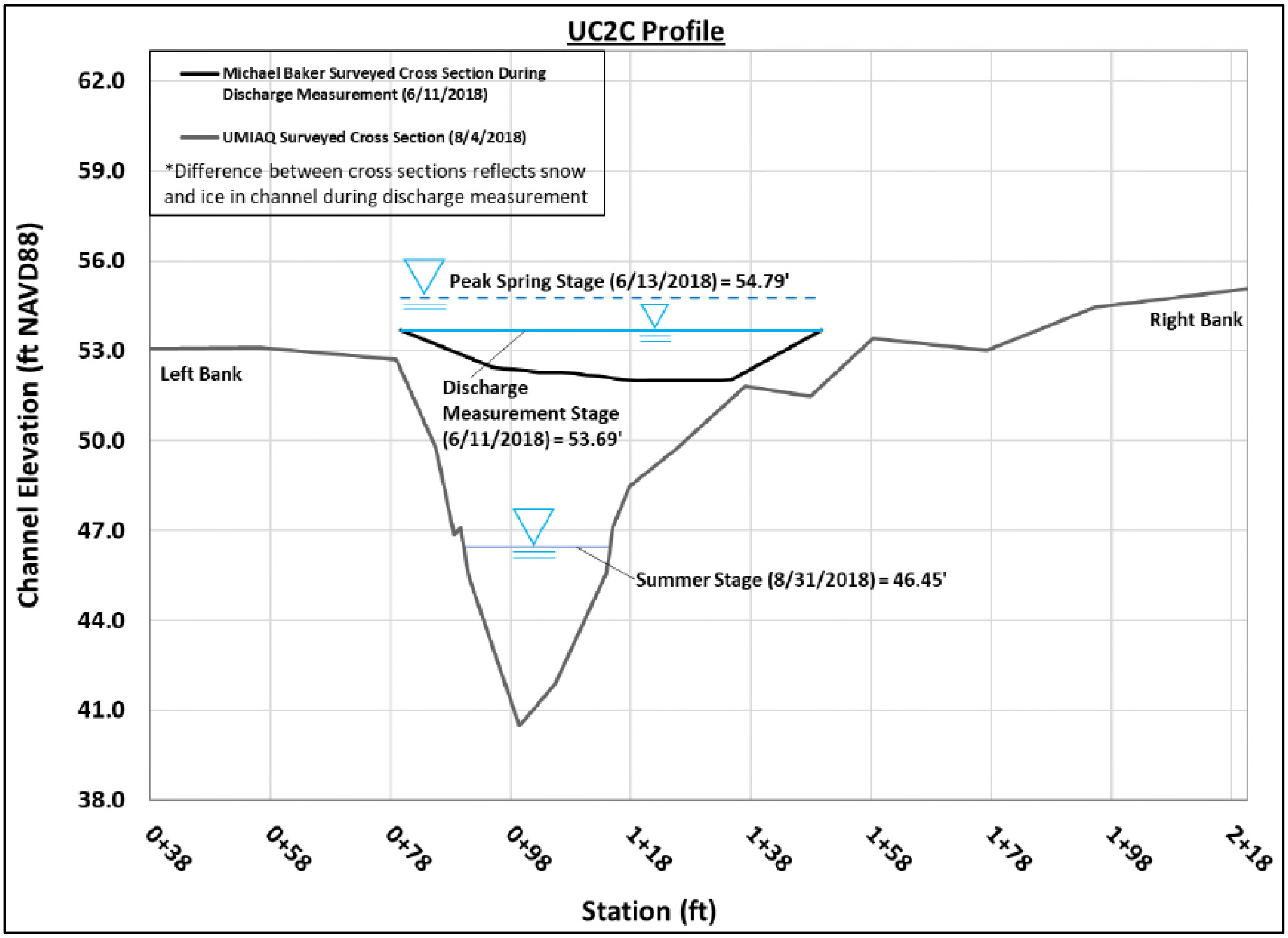
[2] The Shell regression equations are suggested rather than the 2003 USGS regression equations because considerably more North Slope river data was used to prepare the Shell regression equations than the USGS regression equations.

The UC2A, UC2B and UC2C gaging stations were established at approximately RM 8.4, 10.2, and 13.0, respectively (Michael Baker Jr. Inc. 2017). The UC2C gaging station is located where the infield road (for all action alternatives) would cross Judy (Kayyaaq) Creek (Michael Baker Jr. Inc. 2017), about 13 miles upstream from the confluence with Judy (Iqalliqpik) Creek. At RM 13.0 (UC2C gage) the bankfull width is approximately 20 feet and the average bankfull depth is approximately 5.5 feet (CPAI 2018b). Spring breakup and the summer stage have been monitored in both 2017 and 2018.

In both 2017 and 2018, the channel was full of wind-blown snow prior to the start of breakup (Michael Baker Jr. Inc. 2017, 2018). In 2017, it was reported that water began flowing on top of the drifted snow at all of the monitoring stations and then cut a channel down through the wind-blown snow (Michael Baker Jr. Inc. 2017). It was also stated that in 2017 the peak stage at all of the monitoring stations was elevated above bankfull by snow and ice in the channel and that the peak stage probably did not occur at the same time as the peak discharge (Michael Baker Jr. Inc. 2017). At UC2C the peak stage in 2017 was 99.88 feet (arbitrary datum) and occurred on May 30 (Michael Baker Jr. Inc. 2017). In 2018, the peak stage at UC2C was 54.78 feet NAVD88 and occurred on June 13 (Michael Baker Jr. Inc. 2018). In 2018, the peak stage was believed to have occurred at the same time as the peak discharge (Michael Baker Jr. Inc. 2018). At the time of the peak stage, "overbank flooding and minimal impedance from snow" was reported (Michael Baker Jr. Inc. 2018). However, since an observer could probably not have seen through 13-plus feet of water (Figure E.8.7), it seems unknown whether or not the peak stage and/or the stage at the peak discharge were impacted by snow and ice in the bottom of the channel. No estimate for the 2018 peak discharge was provided (Michael Baker Jr. Inc. 2018). Bankfull conditions with some overbank flooding in low-lying areas persisted through at least June 18.

Figure E.8.7 presents a surveyed cross-section at UC2C and a cross-section taken during a spring breakup discharge measurement (Michael Baker Jr. Inc. 2018). The difference between the cross-sections, and the difference between the WSE's on June 11 and 13, represents the impact of snow and ice in the channel on the WSE.

In both 2017 and 2018, the summer stage fluctuated with precipitation, but water levels remained below the spring breakup peak stage. The maximum and minimum stages recorded at UC2C during summer 2017 were 93.1 feet and 90.85 feet, respectively (both based on an arbitrary datum). The maximum and minimum stages recorded at UC2C during the summer of 2018 were 47.81 feet and 46.45 feet NAVD88, respectively. In both years, the stage increased in the beginning of September as a result of precipitation events.



Source: Michael Baker Jr. Inc. 2018

Figure E.8.7. Cross-Section of Judy (Kayyaaq) Creek at Gaging Station UC2C

1.2.2.2.2 Willow Creek 1

Willow Creek 1 is a tributary of Judy (Iqalliqpik) Creek. Alternatives B (Proponent's Proposal) and C (Disconnected Infield Roads) would cross Willow Creek 1 between Lake R0060 and Lake M0016, which is also where the W1S monitoring site is located in a poorly defined, low-lying area (Michael Baker Jr. Inc. 2018).

The 2018 spring breakup peak stage at W1S was 79.16 feet NAVD88 and occurred on June 6 (Michael Baker Jr. Inc. 2018). The 2019 spring breakup peak stage was 79.25 feet NAVD88 and occurred on May 28 (Michael Baker International 2020a). Throughout the entire breakup monitoring periods for both 2019 and 2020, no distinguishable channel or discernible flow was identified near W1S, and the peak stage was probably the result of ponded local melt (Michael Baker International 2020a; Michael Baker Jr. Inc. 2018). During the summer, small stage fluctuations associated with summer precipitation were recorded, but water levels remained below the spring breakup peak stage (Michael Baker Jr. Inc. 2018). The 2018 maximum and minimum summer stages at W1S were 78.59 feet NAVD88 and 78.39 feet NAVD88, respectively (Michael Baker Jr. Inc. 2018). During summer 2018, no defined channel or flow was observed, only standing water (Michael Baker Jr. Inc. 2018).

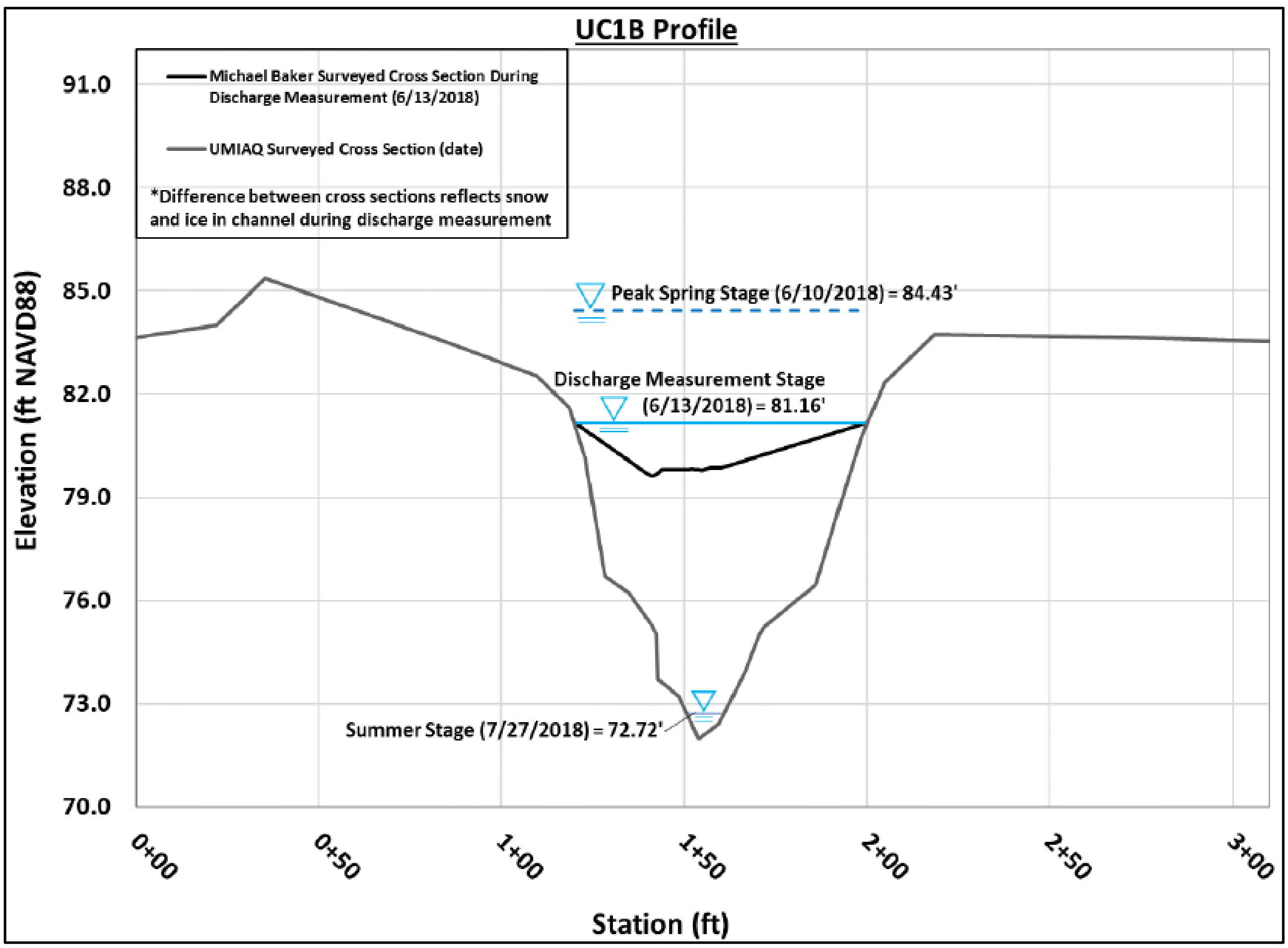
1.2.2.2.3 Willow Creek 2

Willow Creek 2 is a tributary of Judy (Iqalliqpik) Creek. Willow Creek 2 has a highly sinuous, deeply incised, beaded channel (Michael Baker Jr. Inc. 2018). It is over 10 feet from the top of the bank to the streambed and has a typical channel width of 20 feet (Michael Baker Jr. Inc. 2017). Alternatives B (Proponent's Proposal) and C (Disconnected Infield Roads) would cross Willow Creek 2 at RM 4.5, and the UC1B monitoring site is located on Willow Creek 2 at the proposed crossing (Michael Baker Jr. Inc. 2018). At RM 4.5, the bankfull width is approximately 4.5 feet and the average bankfull depth is approximately 2.5 feet (CPAI 2018b). Spring breakup and summer stage were monitored at UC1B in 2017, 2018, and 2019.

In 2017, 2018, and 2019, the channel was full of wind-blown snow prior to the start of breakup (Michael Baker International 2020a; Michael Baker Jr. Inc. 2017, 2018). In all 3 years, it was reported that water began flowing on top of the drifted snow and then cut a channel down through the wind-blown snow (Michael Baker International 2020a; Michael Baker Jr. Inc. 2017, 2018). In all 3 years, peak stage was reportedly affected by snow and ice in the channel, and peak stage did not coincide with the peak discharge (Michael Baker International 2020a; Michael Baker Jr. Inc. 2017, 2018). In 2017, the peak stage at UC1B occurred on May 30 at 96.87 feet (arbitrary datum) (Michael Baker Jr. Inc. 2017). In 2018, the peak stage at UC1B occurred on June 10 at 84.42 feet NAVD88 (Michael Baker Jr. Inc. 2018). A spring peak discharge was not recorded in either year. In 2019, the peak stage at CU1B occurred on May 26. The measured discharge on June 1 was 110 cfs (Michael Baker International 2020a).

Figure E.8.8 presents a surveyed cross-section at UC1B and a cross-section taken during a spring breakup discharge measurement (Michael Baker Jr. Inc. 2018). The difference between the cross-sections, and the difference between the WSEs on June 11 and 13, represents the impact of snow and ice in the channel on the WSE.

In all 3 years, the summer stage fluctuated with precipitation, but water levels remained below the spring breakup peak stage. The maximum and minimum stages recorded at UC1B during summer 2017 were 84.63 feet and 83.01 feet, respectively (both based on an arbitrary datum) (Michael Baker Jr. Inc. 2017). The maximum and minimum stages recorded at UC1B during summer 2018 were 74.43 feet and 72.72 feet NAVD88, respectively (Michael Baker Jr. Inc. 2018). The maximum and minimum stages recorded at UC1B during summer 2019 were 75.2 feet and 72.83 feet NAVD88, respectively (Michael Baker International 2020a).



Source: Michael Baker Jr. Inc. 2018

Figure E.8.8. Cross-Section of Willow Creek 2 at Monitoring Site UC1B

1.2.2.2.4 Willow Creek 3

Willow Creek 3 is a tributary of Judy (Iqalliqpik) Creek. The infield road for all action alternatives would cross Willow Creek 3 between Lake M0015 and Lake R0055, which is also where the W3S monitoring site is located in a poorly defined, low-lying area (Michael Baker Jr. Inc. 2018). At W3S, the bankfull width is approximately 18 feet and the average bankfull depth is approximately 2.0 feet (CPAI 2018b). The Willow Creek 3 basin is also where the constructed freshwater reservoir would be located for all action alternatives. The constructed freshwater reservoir would divert water from Lake M0015.

The 2018 spring breakup peak stage at W3S was 84.13 feet NAVD88 and occurred on June 4 (Michael Baker Jr. Inc. 2018). The peak stage was affected by ice and snow but may have been the result of pooled local melt rather than flowing water (Michael Baker Jr. Inc. 2018). Eight days later (stage about 83.65 feet NAVD88), areas inundated by snowmelt and low-velocity flow were observed (Michael Baker Jr. Inc. 2018). During summer, small stage fluctuations associated with summer precipitation were recorded, but water levels remained below the spring breakup peak stage (Michael Baker Jr. Inc. 2018). The maximum and minimum summer stages at W3S were 83.40 feet and 82.86 feet NAVD88, respectively (Michael Baker Jr. Inc. 2018). Low-velocity flow through a poorly defined, ephemeral channel was observed on July 9 (Michael Baker Jr. Inc. 2018).

The 2019 spring breakup peak stage at WS3 was 88.49 feet NAVD88 and occurred on June 2 (Michael Baker International 2020a). Aerial observations at the time showed widespread meltwater and saturated snow across the Willow Creek 3 drainage, with no defined drainage channel (Michael Baker International 2020a). Discharge during spring breakup was measured twice. The May 30 discharge measurement of 5 cfs was classified as poor based on the influence of ice and snow in the channel. The June 2 discharge measurement of 16 cfs was classified as fair after water had receded from the peak stage and multiple flow paths had been established in the snow (Michael Baker International 2020a). During summer, water levels remained below the spring breakup stage and minimal stage fluctuations with summer precipitation events were recorded. The maximum and minimum summer stages at W3S were 87.78 feet and 87.24 feet NAVD88, respectively (Michael Baker International 2020a).

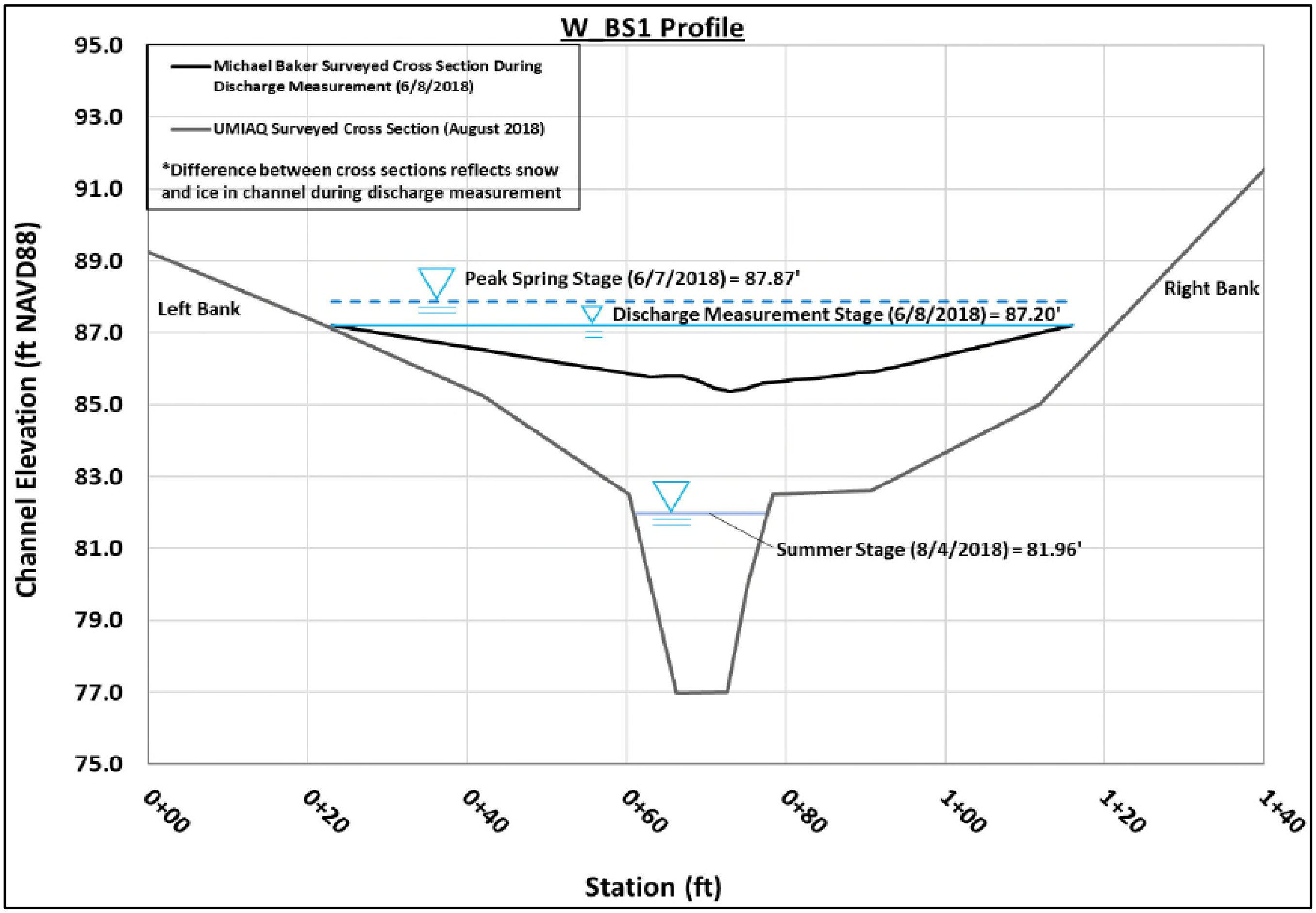
1.2.2.2.5 Willow Creek 4

Willow Creek 4 is a tributary of Judy (Iqalliqpik) Creek. It has an incised channel with intermittent, deep, beaded pools (Michael Baker Jr. Inc. 2018). The infield road for all action alternatives would cross Willow Creek 4 at RM 9, which is also the location of the W_BS1 monitoring site. At RM 9, the bankfull width is approximately 26 feet and the average bankfull depth is approximately 2.7 feet (CPAI 2018b). The W4 monitoring site is located at RM 5.2, adjacent to the Bear Tooth drill site 3/Willow Processing Facility pad.

The 2018 spring breakup peak stage at W_BS1 was 87.87 feet NAVD88 and occurred on June 7 (Michael Baker Jr. Inc. 2018). The 2018 spring breakup peak stage at W4 was 96.38 feet (arbitrary datum) and also occurred on June 7 (Michael Baker Jr. Inc. 2018). Both peaks occurred after a short, rapid rise in the WSE of 1.5 to 2 feet, and snow and ice within the channel affected the peak WSE at both sites. The timing and magnitude of the peak discharge were not recorded.

The 2019 spring breakup peak stage at W_BS1 was 87.38 feet NAVD88 and occurred on May 26 (Michael Baker International 2020a). The 2019 spring breakup peak stage at W4 was 94.21 feet (arbitrary datum) and occurred on May 26. The upstream gage, W_BS1, recorded the peak stage about 3 hours prior to the peak stage at the downstream gage, W4 (Michael Baker International 2020a).

Figure E.8.9 presents a surveyed cross-section at W_BS1 and a cross-section taken during a spring breakup discharge measurement (Michael Baker Jr. Inc. 2018). The difference between the cross-sections, and the difference between the WSE’s on June 11 and 13, represents the impact of snow and ice in the channel on the WSE.



Source: Michael Baker Jr. Inc. 2018

Figure E.8.9. Cross-Section of Willow Creek 4 at Monitoring Site W_BS1

During the summers of both 2018 and 2019, the stage fluctuated with summer precipitation at both monitoring sites, but the water levels remained well below the spring breakup peak stage (Michael Baker International 2020a; Michael Baker Jr. Inc. 2018). The stage at the end of the summer monitoring season for both years increased due to late summer precipitation. The maximum and minimum summer stages at W4 for 2018 were 87.96 feet (arbitrary datum) and 85.11 feet (arbitrary datum), respectively (Michael Baker Jr. Inc. 2018), and for 2019 were 86.47 feet and 84.99 feet (arbitrary datum), respectively (Michael Baker International 2020a). The maximum and minimum summer stages at W_BS1 for 2018 were 83.79 feet and 81.96 feet NAVD88, respectively (Michael Baker Jr. Inc. 2018), and for 2019 were 85.46 feet and 82.29 feet (arbitrary datum), respectively (Michael Baker International 2020a).

1.2.2.2.6 Willow Creek 4A

Willow Creek 4A is a tributary of Willow Creek 4. The infield road for all action alternatives would cross Willow Creek 4A at MBI Monitoring Site W_S1, established in 2018. The channel near W_S1 is beaded and has defined banks. It has a bankfull width of approximately 24 feet and an average bankfull depth of approximately 4.5 feet (CPAI 2018b).

The 2018 spring breakup peak stage at W_S1 was 101.93 feet NAVD88 and occurred on June 8 (Michael Baker Jr. Inc. 2018). It was affected by snow and ice in the channel (Michael Baker Jr. Inc. 2018). At the time of the peak stage, the meltwater was confined by saturated snow, and the stage rose 1.5 feet in about 3 hours (Michael Baker Jr. Inc. 2018). The timing and magnitude of the peak discharge were not recorded.

In general, the stage fell throughout the summer except for fluctuations due to summer precipitation events (Michael Baker Jr. Inc. 2018). At the end of the summer monitoring season, the stage increased due to a late summer precipitation event (Michael Baker Jr. Inc. 2018). However, the stage remained well below the spring breakup peak stage throughout the summer (Michael Baker Jr. Inc. 2018). The maximum and minimum summer stages at W_S1 were 98.67 feet and 98.22 feet NAVD88, respectively (Michael Baker Jr. Inc. 2018).

The 2019 spring breakup peak stage at W_S1 was 101.89 feet NAVD88 on May 27 (Michael Baker International 2020a). Minor overbank flooding was noted in low-lying areas and adjacent polygon troughs, with stranded ice above the reach of the bank.

Summer stage levels fell except for fluctuations due to summer precipitation events. The stage increased to a maximum level of 99.68 feet on August 29 due to a notable precipitation event and the minimum stage was 98.77 feet on July 18 (Michael Baker International 2020a).

1.2.2.3 Ublutuoch (Tiŋmiaqsiuġvik) River

The Ublutuoch (Tiŋmiaqsiuġvik) River has its entire drainage basin on the Arctic Coastal Plain and flows into Fish (Iqalliqpik) Creek at RM 10. It has a drainage area of approximately 248 square miles, of which approximately 15% is covered by lakes (URS Corporation 2003). Two gravel mine site options are located in the Ublutuoch (Tiŋmiaqsiuġvik) River drainage basin, one on each side of the Ublutuoch (Tiŋmiaqsiuġvik) River. The downstream boundary of the gravel mine site analysis area would cross the Ublutuoch (Tiŋmiaqsiuġvik) River at approximately RM 13.9.

Spring breakup stage and discharge have been measured on the main stem of the Ublutuoch (Tiŋmiaqsiuġvik) River for 17 years at RM 13.7, about 0.2 RM downstream from the downstream boundary of the gravel mine site study area (Table E.8.14). During that time, water began to flow between May 17 and June 8, with a median date of May 30. The annual peak discharge occurred between May 19 and June 9, with a median date of June 5. In 9 out of 17 years the peak stage occurred earlier and was higher than the stage at the time of the peak discharge. The largest difference was 1.82 feet in 2005. The time from the beginning of flow to the peak discharge varied between 1 and 7 days, with a median time of 3 days. The annual peak discharge varied from 55 to 3,200 cfs, with a median of 1,700 cfs. Freeze-up data were collected in 7 of the 17 years. During that time, freeze-up occurred between September 26 and October 21, with a median date of October 8.

The Ublutuoch (Tiŋmiaqsiuġvik) River has a relatively low gradient and highly sinuous channel. In the vicinity of RM 13.7 the channel is incised within relatively steep upper banks that are vegetated with dense brush (URS Corporation 2003). The lower portion of the channel consists of a relatively flat bench located approximately 10 to 15 feet below the top of the upper banks (URS Corporation 2003). A 2- to 3-foot-deep × 15- to 20-foot-wide low-water channel is located in the bottom of the otherwise vegetated channel (URS Corporation 2003). The riverbed is composed of sand and gravel, with a median diameter of 7.0 mm (URS Corporation 2003).

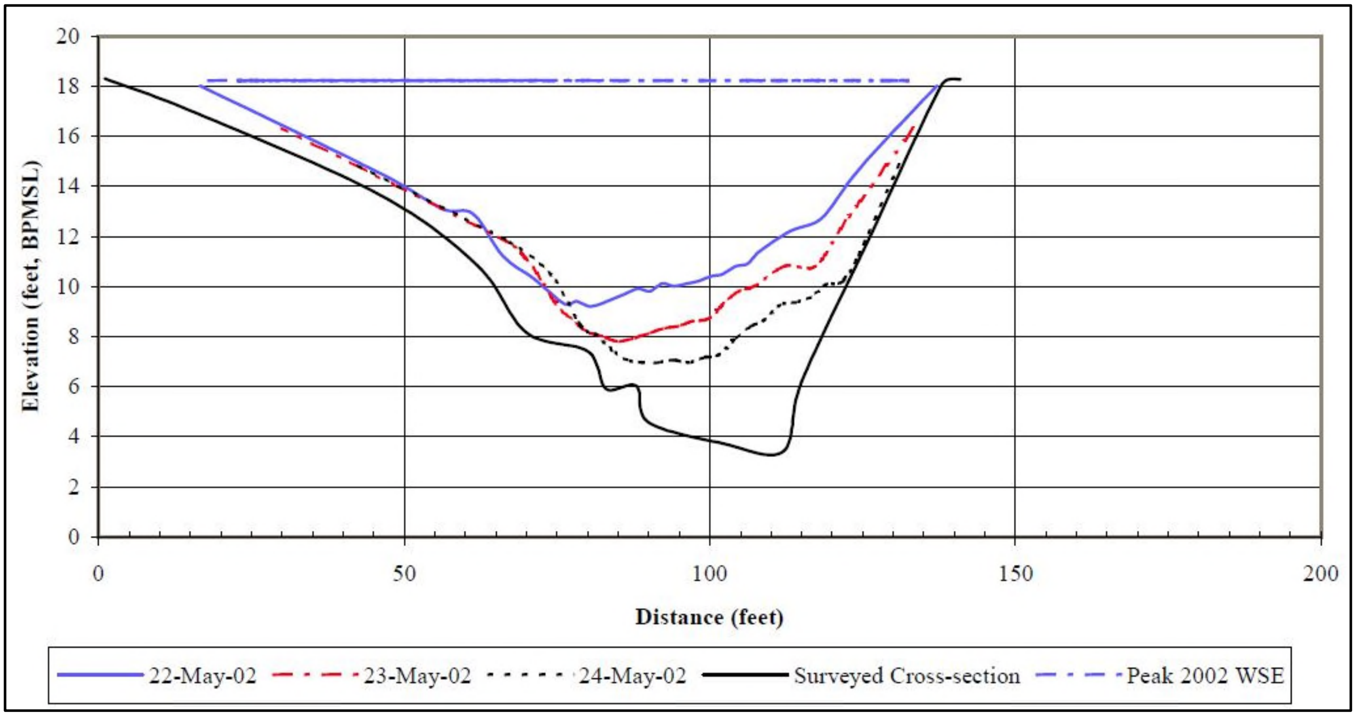
At the time of the 2001 and 2002 spring peak WSE and discharge, the water was flowing on snow within the channel. A comparison of riverbed elevation on various dates during the 2002 breakup at RM 13.7 is shown in Figure E.8.10, and 2001 and 2002 riverbed elevations at the time of the peak discharge are presented in Figure E.8.11.

Table E.8.14. Summary of Annual Peak Stage and Discharge for the Ublutuoch (Tiŋmiaqsiuġvik) River at River Mile 13.7

Year	Date Flow Begins (m/d)	Date of Freeze-Up (m/d)	Annual Peak Stage Date (m/d)	Annual Peak Stage (ft)	Annual Peak Stage Discharge (cfs)	Annual Peak Discharge Date (m/d)	Annual Peak Discharge Stage (ft)	Annual Peak Discharge (cfs)	Zero Flow to Peak Q (days)
2001	6/8	N/A	6/9	18.09	N/A	6/9	18.09	2,200	1
2002	5/19 e	N/A	5/22	18.22	N/A	5/22	18.22	2,000	3
2003	6/5	N/A	6/6	19.30	N/A	6/7	18.34	1,600	2
2004	6/1	N/A	6/5	19.55	N/A	6/5	19.55	2,400	4
2005	6/5	N/A	6/6	19.23	N/A	6/9	17.41	1,520	4
2006	6/1 e	N/A	6/4	16.67	N/A	6/6	15.04	1,250	5
2007	6/3	N/A	6/5	17.35	N/A	6/5	16.84	1,520	2
2008	5/27	N/A	5/29	17.42	N/A	5/29	16.85	955	2
2009	5/25	10/8	5/28	18.90	N/A	5/28	18.34	1,700	3
2010	6/5	9/27	6/7	19.68	N/A	6/7	19.68	3,200	2
2011	5/30	N/A	6/1	19.17	N/A	6/3	17.91	1,960	4
2012	5/30	10/11	6/5	18.33	N/A	6/5	18.33	2,130	6
2013	6/2	10/4	6/5	19.29	N/A	6/9	18.47	2,440	7
2014	5/17	10/11	5/19	18.61	N/A	5/19	18.61	1,270	2

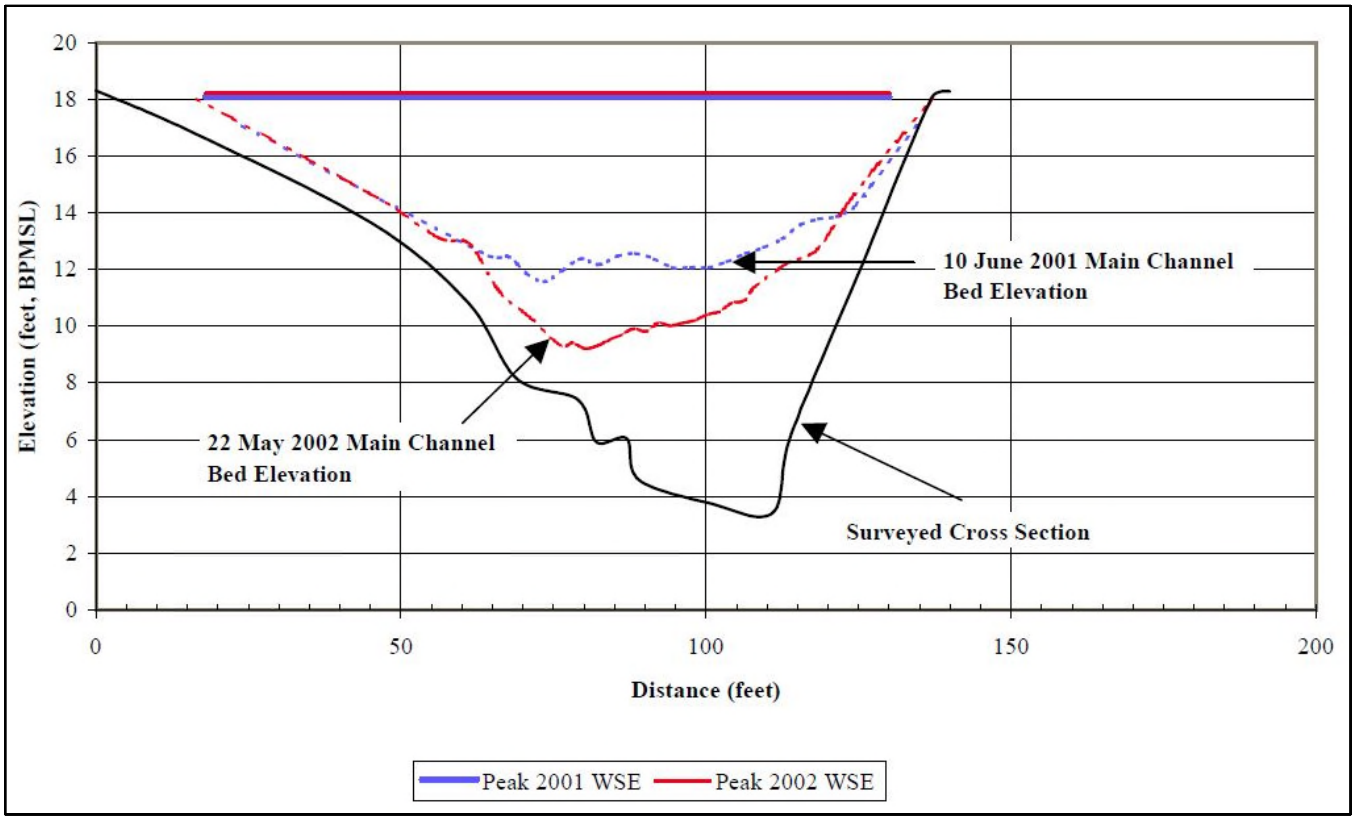
Year	Date Flow Begins (m/d)	Date of Freeze-Up (m/d)	Annual Peak Stage Date (m/d)	Annual Peak Stage (ft)	Annual Peak Stage Discharge (cfs)	Annual Peak Discharge Date (m/d)	Annual Peak Discharge Stage (ft)	Annual Peak Discharge (cfs)	Zero Flow to Peak Q (days)
2015	5/20	9/26	5/22	19.91	N/A	5/23	19.26	2,440	3
2016	5/22	10/21	5/24	17.76	N/A	5/24	17.76	1,150	2
2017	5/28	N/A	5/31	16.69	N/A	5/31	16.69	1,380	3

Source: J. Aldrich (Arctic Hydrologic Consultants), personal communication to Richard Kemnitz (BLM). September 11, 2018
Note: cfs (cubic feet per second); d (day); e (estimate); ft (feet); m (month); N/A (not available); Q (discharge); RM (river mile). The coordinates of the site (NAD83): 70.24316, -151.29693.



Source: URS Corporation 2003

Figure E.8.10. Effect of Snow and Ice in 2002 on Channel Cross-Section at River Mile 13.7



Source: URS Corporation 2003

Figure E.8.11. Comparison of 2001 and 2002 Cross-Sections at Peak Discharge at River Mile 13.7

Discharge and water surface slope measurements, along with surveyed cross-sections and a water surface profile model, were used to estimate hydraulic roughness in the channel on a particular day during the 2002 spring breakup. At RM 8 and RM 13.7, the channel hydraulic roughness on the day of the measurements, when ice and snow were impacting the hydraulic conditions, was 0.012 and 0.021, respectively (URS Corporation 2003). Computations of hydraulic roughness based on measured discharge and water surface slope and normal depth computations at RM 13.7 on each of 3 days in 2001 and 2002 during ice- and snow-impacted conditions varied from 0.019 to 0.025, with a median of 0.023 (URS Corporation 2001, 2003).

Seventeen years of summer flow data is available for the Ublutuoch (Tiŋmiaqsiuġvik) River at RM 13.7 (J. Aldrich [Arctic Hydrologic Consultants], personal communication to Richard Kemnitz [BLM]. September 11, 2018) . A summary of the available mean monthly discharge data is provided in Table E.8.15.

Table E.8.15. Mean Monthly Discharge (cubic feet per second) in the Ublutuoch (Tiŋmiaqsiuġvik) River at River Mile 13.7

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2001	0	0	0	0	0	435	47	45	38	27	16	5
2002	0	0	0	0	377	133	80	24	24	17	10	3
2003	0	0	0	0	0	389	112	57	52	6	0.5	0
2004	0	0	0	0	0	827	69	21	32	6	0.3	0
2005	0	0	0	0	0	467	78	13	7	2	0	0
2006	0	0	0	0	0	434	36	25	16	9	1	0
2007	0	0	0	0	0	283	18	2	0.5	0	0	0
2008	0	0	0	0	101	223	15	7	3	0.6	0	0
2009	0	0	0	0	241	456	27	12	31	15	4	0.6
2010	0	0	0	0	0	596	54	54	25	7	0.5	0
2011	0	0	0	0	11	628	33	10	12	7	0.8	0
2012	0	0	0	0	0.2	535	37	10	12	9	5	0.3
2013	0	0	0	0	0	857	72	26	30	8	2	0.1
2014	0	0	0	0	359	441	84	25	38	38	6	0.6
2015	0	0	0	0	438	208	18	14	16	2	0.2	0
2016	0	0	0	0	184	181	24	22	91	87	10	3

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2017	0	0	0	0	92	367	18	78	200	150	23	0.1

Source: J. Aldrich (Arctic Hydrologic Consultants), personal communication to Richard Kemnitz (BLM). September 11, 2018

At RM 14.5 (MBI Monitoring Site UB14.5) and RM 15.5 (MBI Monitoring Site UB15.5), the spring breakup stage and the extent of flooding was monitored in 2018 and 2019 (Michael Baker International 2020a; Michael Baker Jr. Inc. 2018). RM 14.5 is just downstream of the mouth of Bill's Creek, and RM 15.5 is just upstream. MBI (2018) also monitored the stage and extent of flooding on Bill's Creek, at Monitoring Site BC1. All of these sites are within the gravel mine site analysis area.

At UB14.5, the channel is incised and deep and fills with wind-blown snow during winter (Michael Baker Jr. Inc. 2018). During the 2018 spring breakup, the peak stage was 20.20 feet (adjusted for NAVD88 in 2020) and occurred on June 9. Pictures of the monitoring site on the day of the peak stage suggest that the peak stage was affected by snow and ice. During the 2019 spring breakup, the peak stage was 19.23 feet NAVD88 and occurred on May 29 (Michael Baker International 2020a).

At UB15.5, the channel is incised and deep and fills with wind-blown snow during the winter (Michael Baker Jr. Inc. 2018). During the 2018 spring breakup, the peak stage was 23.49 feet (adjusted for NAVD88 in 2020) and occurred on June 8. Pictures of the monitoring site on the day of the peak stage suggest that the peak stage was affected by snow and ice. During the 2019 spring breakup, the peak stage was 22.46 feet NAVD88 and occurred on May 26 (Michael Baker International 2020a).

Bill's Creek is a beaded channel consisting of large beads connected by deeply incised, narrow grass-lined channels with its headwaters in an area of small lakes (Michael Baker Jr. Inc. 2018). Wind-blown snow fills much of the drainage during the winter (Michael Baker Jr. Inc. 2018). During the 2018 spring breakup, the peak stage at BC1 was 41.85 feet (adjusted to NAVD88) and occurred on June 11. Based on the description of the conditions at the time of the peak stage (Michael Baker Jr. Inc. 2018), the peak stage was affected by snow and ice in the channel. The summer stage fluctuated with precipitation events but remained below the peak breakup stage (Michael Baker Jr. Inc. 2018). The stage increased at the end of the summer monitoring period as a result of late summer precipitation (Michael Baker Jr. Inc. 2018). The maximum and minimum summer stages were 88.67 feet and 87.01 feet (arbitrary datum), respectively (Michael Baker Jr. Inc. 2018).

During the 2019 spring breakup, the peak stage at BC1 was 39.78 feet NAVD88 and occurred on May 23. The peak stage was affected by snow and ice in the channel (Michael Baker International 2020a).

Spring breakup observations have also been made at the following sites:

- RM 6.8 in 2003, 2004, 2005, 2006, 2009, 2010, 2011, and 2013 (CPAI 2018a)
- RM 8.0 in 2002 (URS Corporation 2003)
- RM 13.5 in 2001 (URS Corporation 2001) and 2002 (URS Corporation 2003)

Hydraulic designs on the Ublutuoch (Tiŋmiaqsiuġvik) River should consider the flood-peak data that have been collected at RM 13.7, the impact of snow and ice at the time of the annual peak discharge, the impact of snow and ice on the annual peak WSE, and the hydraulic roughness likely to be present at the time of the design discharge. In developing flood-peak magnitude and frequency estimates on streams in the Ublutuoch (Tiŋmiaqsiuġvik) River basin, the 17 years of data collected at RM 13.7 should be considered. A single-station flood-peak magnitude and frequency analyses could be conducted with these data to estimate the flood-peak magnitude and frequencies at RM 13.7. A best estimate of the flood-peak magnitude and frequency at RM 13.7 could then be developed from a weighted average, based on the uncertainty associated with estimates from each of two methods: the single-station frequency analysis and the Shell regression equations[3] (Arctic Hydrological Consultants and ERM 2015). The weighted average estimate would then be extrapolated to other locations within the basin as a proportion of the Shell regression equation estimate.

Since the hydraulic roughness is changing throughout spring breakup, when designing structures on this river it would be prudent to consider a range of hydraulic roughness values. Higher hydraulic roughness values will provide estimates with higher WSEs and lower velocities. Lower hydraulic roughness values will provide estimates with lower WSEs and higher velocities. Both conditions are important when designing structures within

[3] The Shell regression equations are suggested rather than the 2003 USGS regression equations because considerably more North Slope river data was used to prepare the Shell regression equations than the USGS regression equations.

the channel and the floodplain. Additionally, snow blockage at the time of the peak discharge seems to be an annual occurrence and should be considered when estimating design WSEs.

1.2.3 Kalikpik River

The Kalikpik River originates in a complex network of lakes, approximately 15 miles south of Teshekpuk Lake, and flows into Harrison Bay northwest of Fish (Iqalliqpik) Creek (Michael Baker Jr. Inc. 2018). The river has a relatively low gradient, a highly sinuous channel, and the channel bed and banks consist predominantly of silt and sand (Michael Baker Jr. Inc. 2018). The most downstream end of the proposed infrastructure comes close to the Kalikpik River, about 17.5 RMs upstream from the coast (RM 17.5).

In 2018 and 2019, the stage was monitored during spring breakup at Kal 1 (Michael Baker Jr. Inc. 2018), about 21.8 RMs upstream from the coast. In 2018, the channel was full of windblown snow prior to the start of breakup (Michael Baker Jr. Inc. 2018). The peak stage occurred on June 11 at an elevation of 50.30 feet NAVD88 and was affected by snow and ice conditions (Michael Baker Jr. Inc. 2018). Snow remained along the banks and large ice floes were present in the channel for a couple of days following the peak stage (Michael Baker Jr. Inc. 2018). A second, smaller rise in the stage was observed on June 16 and may have been coincident with the peak discharge (Michael Baker Jr. Inc. 2018). A discharge of 320 cfs was measured at a stage of 48.18 feet NAVD88 on June 16 at 4:00 p.m. The stage was just below bankfull (Michael Baker Jr. Inc. 2018). No ice or snow was observed in the channel, but saturated snow remained along the south bank just above the water surface (Michael Baker Jr. Inc. 2018).

In 2019, the peak stage of 49.44 feet NAVD88 occurred on May 26, and was likely elevated by large quantities of saturated snow and bottom-fast channel ice (Michael Baker International 2020a). A discharge of 245 cfs was measured at a stage of 48.94 feet NAVD88 on May 30 (Michael Baker International 2020a).

For 2018 and 2019, MBI continued to monitor the stage during summers. The stage fluctuated throughout summer as a result of precipitation events but remained below the spring breakup peak stage (Michael Baker Jr. Inc. 2018). For both summers, later summer precipitation events led to increased stage levels that were slightly higher than the stage during the discharge measurement near the end of the summer monitoring period (Michael Baker International 2020a; Michael Baker Jr. Inc. 2018). The highest summer stage levels were 47.10 feet in 2018 and 47.91 feet in 2019 (Michael Baker International 2020a; Michael Baker Jr. Inc. 2018).

At Kal 1, the bankfull width is approximately 140 feet, the average bankfull depth is approximately 3 feet, and the thalweg depth is approximately 8 feet (CPAI 2018b).

1.3 Environmental Consequences

1.3.1 In-Water Structures

1.3.1.1 Bridge Crossings

The potential impacts to streams crossed by bridges during the life of the structure include the following:

- Increased backwater on the upstream side of the bridge
- Increased riverbed erosion within the bridge opening
- Increased riverbed and bank erosion downstream from the bridge
- Increased sediment deposition downstream from the bridge
- Increased sediment transport within and downstream from the bridge
- A change in channel morphology downstream from the bridge

The impact of a bridge on the stream being crossed is directly related to the criteria used to design the bridge and the extent to which the bridge is constructed according to the design. Some of the most important factors related to the hydraulic design of bridges on the North Slope include 1) the frequency of the design event in relation to the anticipated life of the structure; 2) the reliability of the computed magnitude and frequency of the design event; 3) the impact of snow and ice (including ice floes) at the time of the design event and during events with a smaller discharge than the design event; and 4) the reliability of the hydraulic computations used to estimate WSE and velocity, riverbed scour, and bank erosion. With regard to the frequency of the design event, the probability that the design event will not be exceeded during the life of the structure should be considered.

All bridges would be designed to maintain bottom chord clearance of 4 feet above the 100-year base flood elevation and at least 3 feet above the highest documented flood elevation. Table E.8.16 presents the relationship between the average return period of the design event and the probability that the design event will not be exceeded during various lengths of time. Note that the probability that the design event will not be exceeded decreases as the life of the structure increases. Based on the life of past structures on the North Slope, it seems very likely that the life of the structures could be greater than 40 or 50 years. A culvert or bridge based on a 100-year flood design that is likely to be in place for 50 years before removal or replacement would have a 61% chance that the design flood would not be exceeded one or more times during the life of the structure (i.e., 39% chance that design flood would be exceeded). As shown, although it is more likely that the design life will not be exceeded during the life of the Project, there is still a 39% chance it could be. This section describes the potential effects of bridges.

Table E.8.16. Theoretical Probability That the Design Event Will Not Be Exceeded in a Specified Number of Years

Design Event (average return period in years)	10 years	20 years	30 years	40 year	50 years	60 years	70 years
25	66%	44%	29%	20%	13%	8%	6%
50	82%	67%	55%	45%	36%	30%	24%
100	**90%**	**82%**	**74%**	**67%**	**61%**	**55%**	**49%**
200	95%	90%	86%	82%	78%	74%	70%
500	98%	96%	94%	92%	90%	89%	87%

Note: **Bold** denotes the design life of bridges for the Project. The difference between the theoretical probability and the actual probability is the accuracy of the design events' predicted probability of occurrence. For instance, if the design discharge is supposed to be a 100-year event but actually has an average return period of 90 years, the theoretical probability that the design event will not be exceeded will be higher than what is experienced.

During floods in which the cross-sectional area of the flow is restricted by the bridge, water would back up behind the bridge. The difference between the unrestricted WSE and the restricted WSE on the upstream side of the bridge is called backwater. The magnitude of the backwater would depend upon the amount of constriction presented by bridge or road embankments and would usually become larger with larger flood events.
The maximum increase in WSE generally occurs at a location upstream from the bridge, about equal in distance to about one-half the total length of the embankment obstructing the flow of water. The upstream extent of the backwater is a function of both the magnitude of the constriction and the slope of the stream. The duration of the backwater would be somewhat less than the duration of the flood. Backwater is generally a concern if it causes a structure (such as an upstream pipeline) or another resource to be damaged by the inundation created as a result of the backwater.

The more a bridge restricts the flow (i.e., the greater the backwater), the higher the velocity through the bridge. At a particular discharge, if the velocity through the bridge exceeds the velocity that would have occurred prior to construction of the bridge, and the bed material is mobile at that velocity, it is likely that the depth of the scour would be greater than would have occurred prior to bridge construction. Similarly, if the velocity downstream from the bridge is greater than the velocity that would have occurred prior to bridge construction, it is possible that bank erosion would be more severe than would have occurred. With increased erosion comes increased sediment transport and increased sediment deposition. An increase in erosion and deposition can lead to a change in channel morphology. If the bridge abutments or pier piles are undermined by scour, the bridge may collapse. Scour is historically one of the most common causes of bridge failure in North America (Cook 2014). However, scour is not a problem if it is correctly addressed during the design of the bridge.

1.3.1.2 Culverts

The potential impacts to streams crossed by culverts during the life of the structure include the following:

- Increased backwater on the upstream side of the culvert
- Increased riverbed and bank erosion downstream from the culvert
- Increased sediment deposition downstream from the culvert
- Increased sediment transport downstream from the culvert
- A change in channel morphology downstream from the culvert

The impact of the culvert on the stream being crossed is directly related to the criteria used to design the culvert and the extent to which the culvert is constructed according to the design. The size, layout, and quantity of Project culverts would be based on site-specific conditions in order to pass the 50-year flood event with a headwater elevation not exceeding the top of the culvert (headwater to diameter ratio of 1 or less). Some of the most important factors related to the hydraulic design of culverts on the North Slope include 1) the frequency of the design event in relation to the anticipated life of the structure; 2) the reliability of the computed magnitude and frequency of the design event; 3) the impact of snow and ice (including ice floes) at the time of the design event and during events with a smaller discharge than the design event; 4) the reliability of the hydraulic computations used to estimate WSE and velocity, riverbed scour, and bank erosion; and 5) the reliability of the topographic and flow information used to located the culvert. With regard to the frequency of the design event, see the discussion in Section 2.5.3.2.1, *Bridges*. A culvert based on a 50-year flood design that is likely to be in place for 50 years before removal or replacement would have a 36% chance that the design flood would not be exceeded one or more times during the life of the structure (i.e., 64% chance that design flood would be exceeded).

During floods in which the cross-sectional area of the flow is restricted by the culvert, water would back up behind the culvert. The magnitude of the backwater would depend upon the amount of constriction presented by the culvert. See discussion in Section 2.5.3.2.1 for additional information.

The more the culvert restricts streamflow (i.e., the greater the backwater), the higher the velocity through the culvert. The higher the velocity through the culvert, the more likely it is that riverbed erosion (scour) and bank erosion would occur at the culvert outlet and downstream from the culvert. With increased erosion comes increased sediment transport and increased sediment deposition. An increase in erosion and deposition can lead to a change in channel morphology.

1.3.2 <u>Pipelines</u>

All of the pipeline waterbody crossings would be aboveground on vertical support members (VSMs) except for the Colville River crossing, which would be installed 70 feet below the river channel using horizontal directional drilling (HDD).

1.3.2.1 Aboveground Crossings

As water passes around VSMs, at an aboveground crossing there is the potential for an increase in velocity and scour. This may result in erosion at the VSM and sediment deposition downstream from the VSM. If ice floes or debris build up on a VSM, the scour at the VSM could be greater than anticipated and could compromise the integrity of the VSM and thus the pipeline.

If water, floating ice, or debris comes in contact with the aboveground pipeline, the pipeline could be ruptured. It is unknown to what flood event or ice condition the pipeline crossings would be designed.

Where an aboveground pipeline crossing is immediately upstream from a road crossing (either a bridge or a culvert), backwater from the road during the pipeline design event should be considered when setting the bottom of the pipe elevation. Additionally, if the road is designed for a smaller flood than the pipeline, the changes in hydraulic conditions at the pipeline as a result of the road wash-out should be considered (i.e., changes in location of the concentrated flow and the impact on erosion at the VSM).

Where an aboveground pipeline crossing is immediately downstream from a road crossing (either a bridge or a culvert), the impact of the road on where water will be flowing and the velocity of the water at the pipeline VSM should be considered. Additionally, if the road is designed for a smaller flood than the pipeline, the changes in hydraulic conditions at the pipeline as a result of the road wash-out should be considered (i.e., changes in the location of the concentrated flow and the impact on erosion at the VSM).

1.3.2.2 Belowground Crossings

Design of the HDD crossing should consider the likely scour depth during all floods up to and including the design flood and the likely channel migration over the life of the crossing. It is unknown to what flood event the HDD crossing would be designed.

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Willow Master Development Plan

Appendix E.8B
Ocean Point Technical Memorandums

June 2022

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HYDRAULIC MAPPING AND MODELING
Kenneth F. Karle, P.E.
1091 West Chena Hills Drive, Fairbanks, AK 99709

May 26, 2020

Ocean Point Technical Memorandum

To: E. Leyla Arsan, DOWL

From: Kenneth Karle, P.E.

Subject: Ocean Point Monthly Mean Discharge

An EPA SDEIS reviewer recommended that, as there are no flow data available for the Colville River at Ocean Point, a representative 'synthetic dataset' could be developed for the Ocean Point crossing, using discharge data from the Umiat gaging station. This memo describes the methodology for conducting such an analysis, and includes a table listing average monthly discharge estimates for the Ocean Point crossing.

The drainage-area ratio method suggested by EPA to develop an Ocean Point discharge dataset is indeed commonly used to estimate both flood frequency magnitudes, and individual streamflow discharges, for sites where no streamflow data are available using data from one or more nearby gaging stations (Emerson et al., 2005). The method is intuitive and straightforward to implement and is in widespread use by analysts and managers of surface-water resources. It's often used for locations where no supporting discharge data are available to confirm the validity or develop some type of bias correction to account for differences in watershed characteristics.

A simple ratio of watershed areas upstream of the point of interest is used to estimate flood magnitudes of ungaged sites on gaged streams. The drainage area ratio equation is:

$$Q_u = \frac{Q_g \times A_u}{A_g}$$

Where
- Q_u = ungaged area flow statistic
- Q_g = gaged area flow statistic
- A_u = ungaged area
- A_g = gaged area

In a memo dated November 16, 2018, Jim Aldrich (Arctic Hydrologic Consultants) compiled a table of Colville River Mean Monthly Flow at Umiat, AK, using data from the USGS gaging station 15875000. I updated the table in February 2020; see Table 1.

Note that in every year from 2002 to 2009, there was at least one month from February to April with an average discharge of 0 cfs. Starting in 2010, there were no more '0 cfs' months, and average winter monthly discharge values increased significantly for the period from 2010 to 2019. There are several possible explanations for this. Ongoing climate change on the Alaskan North Slope, with drastically increased temperatures, is well documented. Warmer winters will result in increased winter discharge. Matt Schellekens, the chief hydrologist of the USGS Fairbanks office, noted that prior to the mid-1990s, winter flow was never observed in the Sagavanirktok River. Now, flow is almost always observed and often it is quite a bit (M. Schellekens, personal communication, January 31, 2020).

A second explanation is that slight differences in procedures were used for two different periods. From 2003 to 2009, the site was operated from the USGS Anchorage field office. During that time, there were not many late winter visits, and flow was assumed to go to zero. Since 2010 the gage has been operated from the USGS Fairbanks field office. The Fairbanks hydrographers “usually spent a lot of time in late March or April hunting around the river reach near the gage and almost always found/find at least one or two very small open leads of water seeping out of the downstream end of a gravel bar or two” (M. Schellekens, personal communication, January 31, 2020).

The EPA reviewer noted the increase in winter flows and recommended that only the last 10 years of the Umiat discharge data should be used for the area-ratio analysis, as using mean discharges from the entire period of record “will likely underestimate the discharge at Ocean Point…”

The drainage area for USGS Umiat gaging station 15875000 is 13,860 mi^2. The drainage area upstream of the proposed Ocean Point ice bridge crossing is estimated at 20,580 mi^2. The drainage area ratio (Ocean Point/Umiat) is 1.48.

As a check on the validity of using the drainage area ratio method, I compared a discharge measurement made at Ocean Point to gaged flow at Umiat. CPAI measured a discharge flow rate of 29,000 cfs at Ocean Point on 9/5/2019 at 250 pm. The average flow velocity was 3 ft/sec. Accounting for travel time downstream, the related upstream discharge at Umiat on 9/4/2019 at 1050 am was 23,000 cfs. The Ocean Point flow was approximately 1.3 times greater than the Umiat flow. One data-pair point set is not statistically significant. However, it does imply some reassurance for using the drainage-are method for flow estimates.

Table 1 includes the mean value of the mean monthly discharge values at Umiat for two periods: 2003-2019, and 2010-2019.

I conducted an area ratio analysis to estimate flows at Ocean Point using the mean value of the mean monthly flows for the period 2010-2019, and a drainage area ratio (ungaged/gage) of 1.48. See Table 2.

Table 1. Colville River mean monthly discharge (cfs) at Umiat.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2002									21,030	7,221	844.3	100.1
2003	3.55	0	0	0	690	65,690	24,030	31,800	12,760	10,490	560	72.6
2004	6.87	2.17	0.161	0	40,890	24,940	15,310	24,870	12,060	556.5	142.3	56.6
2005	20.8	4.23	0.016	0	12,830	72,480	13,920	4,143	6,014	1,169	200	104.5
2006	18.4	0.107	0	0	22,010	37,120	21,940	33,560	6,229	2,667	324.7	80
2007	27.9	11.7	0.887	0	4,179	50,530	12,140	17,820	7,511	873.5	177	72.6
2008	21.1	0.724	0	0	17,260	46,530	12,900	10,770	1,867	560	207	72.9
2009	15	0	0	3.03	36,940	45,050	13,890	13,440	13,750	1,775	418	95.2
2010	36.5	13.9	1.65	0.5	17,280	48,760	10,370	15,720	6,213	1,248	454	132.2
2011	35.5	9.66	1.07	0.37	37,790	31,190	13,170	11,330	11,940	1,958	375	93.5
2012	29.2	11	1.92	0.5	16,680	41,910	16,970	14,860	27,440	3,678	145.3	45.9
2013	16.4	3.93	2	1.02	6,434	83,970	10,530	10,290	11,750	1,475	509.3	130.7
2014	25.9	9.25	6	6	33,290	72,180	29,820	10,130	16,140	1,215	216.7	89.9
2015	45.2	29	16.8	12	62,410	17,010	8,243	22,250	11,550	1,504	275.7	65.5
2016	24.4	10.1	5.71	2.75	47,460	32,660	14,540	27,290	15,310	4,868	404.7	64.4
2017	16	3.79	1.16	1	12,070	26,220	13,110	36,370	25,900	6,403	447.9	86.5
2018	24.9	11.9	7.14	6.00	12,220	47,610	26,970	30,330	23,280	3,122	342.9	67.1
2019	40.9	30.2	22.6	20.0	36,180	18,370	12,380	38,990	15,500			
Mean of Monthly Discharge- Sept 2002-Sept 2019	24.0	8.9	3.9	3.1	24,500	44,800	15,900	20,800	13,700	2,990	356.0	84.0
Mean of Monthly Discharge- Jan 2010- Sept 2019	29.5	13.3	6.6	5.0	28,181	41,988	15,610	21,756	16,502	2,830	352.4	86.2

Table 2. Estimated Colville River mean monthly discharge (cfs) at Ocean Point, based on mean monthly discharge at Umiat 2010-2019.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Estimated Mean Monthly Discharge	43.7	19.7	9.8	7.4	41,710	62,140	23,100	32,200	24,420	4190	521.6	127.6

Numerous factors will affect the relationship between discharge and drainage area. For example, if the watershed characteristics of the upper watershed, such as the ratio of mountainous area to lowlands, were significantly different than those of the additional downstream drainage area, then the flow relationship may not be linear. Such a relationship could potentially be improved by investigating regional statistics, regression, and rainfall-runoff modeling (bias correction). That type of additional analysis generally leads to the development of an exponent for the drainage area ratio. But that type of data is obviously scarce and probably not worth pursuing.

Another consideration is that this analysis does not account for other conditions that may affect flow rates at Ocean Point. For example, surface flow passing Umiat may be forced downstream into a gravel bed flow condition due to a blocked channel. Surface flow may also end up in storage as ice until warming temperatures occur. Conversely, groundwater seeps between Umiat and Ocean Point may lead to larger flows downstream than predicted by the drainage area ratio. The consensus of opinion from Jim Aldrich, Matt Schellekens (USGS), and Richard Kemnitz (BLM retired) is that there is probably surface flow in the Colville River downstream of Umiat in every month of the year.

As noted elsewhere, the best course of action to characterize winter flows at Ocean Point will be to conduct field observations and measurements during the winter months at the Ocean Point crossing for the next several years. However, until such field measurements are made, the flow statistics in Table 2 can be used, with caution, to provide an estimate of the magnitude of winter flows for the Ocean Point crossing.

Please let me know if you have additional questions or need more information.

Ken

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MEMORANDUM

TO:	Zach Huff, E.I.
FROM:	Euan-Angus MacLeod, P.E.
DATE:	January 31, 2022
SUBJECT:	Ocean Point Monthly Mean Discharge - Update

This memorandum provides an update to average monthly discharge estimates for the Ocean Point crossing of the Colville River originally presented in the May 26, 2020, Ocean Point Technical Memorandum prepared by Kenneth Karle, P.E. (2020 Memo). This memorandum includes updates to Table 1 and Table 2 from the 2020 Memo using additional flow data available for USGS gaging station 15875000 at Umiat from January 2020 through September 2021. The same drainage-area ratio methodology described in the 2020 Memo was used to update Table 2, which provides estimated mean monthly discharge for the Coville River at Ocean Point.

Table 1. Colville River mean monthly discharge (cfs) at Umiat.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2002	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	21,030	7,221	844.3	100.1
2003	3.55	0	0	0	690	65,690	24,030	31,800	12,760	10,490	560	72.6
2004	6.87	2.17	0.161	0	40,890	24,940	15,310	24,870	12,060	556.5	142.3	56.6
2005	20.8	4.23	0.016	0	12,830	72,480	13,920	4,143	6,014	1,169	200	104.5
2006	18.4	0.107	0	0	22,010	37,120	21,940	33,560	6,229	2,667	324.7	80
2007	27.9	11.7	0.887	0	4,179	50,530	12,140	17,820	7,511	873.5	177	72.6
2008	21.1	0.724	0	0	17,260	46,530	12,900	10,770	1,867	560	207	72.9
2009	15	0	0	3.03	36,940	45,050	13,890	13,440	13,750	1,775	418	95.2
2010	36.5	13.9	1.65	0.5	17,280	48,760	10,370	15,720	6,213	1,248	454	132.2
2011	35.5	9.66	1.07	0.37	37,790	31,190	13,170	11,330	11,940	1,958	375	93.5
2012	29.2	11	1.92	0.5	16,680	41,910	16,970	14,860	27,440	3,678	145.3	45.9
2013	16.4	3.93	2	1.02	6,434	83,970	10,530	10,290	11,750	1,475	509.3	130.7
2014	25.9	9.25	6	6	33,290	72,180	29,820	10,130	16,140	1,215	216.7	89.9
2015	45.2	29	16.8	12	62,410	17,010	8,243	22,250	11,550	1,504	275.7	65.5
2016	24.4	10.1	5.71	2.75	47,460	32,660	14,540	27,290	15,310	4,868	404.7	64.4
2017	16	3.79	1.16	1	12,070	26,220	13,110	36,370	25,900	6,403	447.9	86.5
2018	24.9	11.9	7.14	6.00	12,220	47,610	26,970	30,330	23,280	3,122	342.9	67.1
2019	40.9	30.2	22.6	20.0	36,180	18,370	12,380	38,990	15,500	0	0	0
2020	27.2	9.0	4.7	4.0	106,013	23,807	12,248	19,911	23,106	13,442	370.3	69.0
2021	21.7	7.8	2.6	2.1	9,792	34,387	24,607	21,238	27,565	No Data	No Data	No Data
Mean of Monthly Discharge- Sept 2002- Sept 2021	24.1	8.9	4.1	3.1	28,022	43,180	16,163	20,795	14,846	3,568	356.4	83.3
Mean of Monthly Discharge- Sep 2010- Sept 2021	27.9	12.3	6.5	5.1	34,576	39,029	16,599	22,090	17,975	3,891	354.2	84.5

Table 2. Estimated Colville River mean monthly discharge (cfs) at Ocean Point, based on mean monthly discharge at Umiat 2010-2021.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Estimated Mean Monthly Discharge	41.3	18.3	9.7	7.5	51,173	57,762	24,566	32,693	26,602	5,759	524.3	125.0

Willow Master Development Plan

Appendix E.9
Vegetation and Wetlands Technical Appendix

June 2022

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List of Acronyms

Project area	Willow Master Development Plan Project area

Glossary Terms

Emergent – Of or denoting a plant which is taller than the surrounding vegetation.

Lacustrine – Produced or originating from or within a lake.

Marine – Produced or originating from or within the sea.

Palustrine – Produced or originating from or within a marsh.

Riverine – Relating or situated on a river or riverbank.

Unconsolidated – Sediment that is loosely arranged or unstratified, or whose particles are not cemented together.

Upland – Land area that under normal circumstances does not satisfy the three required wetland factors (i.e., hydrology hydrophytic vegetation, hydric soils), and does not lie below the ordinary high water mark or high tide line of a jurisdictional water.

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1.0 VEGETATION AND WETLANDS

1.1 Affected Environment

Table E.9.1 details the wetland types in the Willow Master Development Plan Project area (Project area; field-verified area) and the analysis area. Wetland types in the Willow area are not unique and occur throughout the analysis area and the Arctic Coastal Plain. Table E.9.1 also shows the Cowardin code for each wetland type; the Cowardin system (1979) is a national classification system based on wetland characteristics. Figure 3.9.3 in Appendix A, *Figures*, in the Final Environmental Impact Statement shows land cover classes in the analysis area (using data from the North Slope Science Initiative).

Table E.9.1. Vegetation by Wetland Type in the Analysis Area

Wetland Type	Cowardin Code[a]	Acres in Analysis Area[b]	Acres in Field-Verified Portion of Analysis Area[c]
Estuarine Subtidal **Unconsolidated** Bottom	E1UBL	64,512.9	0.0
Estuarine Intertidal **Emergent** Persistent/Unconsolidated Shore Irregularly Flooded	E2EM1/USP	14,258.4	0.0
Estuarine Intertidal Emergent Persistent Regularly Flooded	E2EM1N	9.3	0.0
Estuarine Intertidal Emergent Persistent Irregularly Flooded	E2EM1P	16,110.0	0.0
Estuarine Intertidal Emergent Nonpersistent/Unconsolidated Shore Irregularly Flooded	E2EM2/USP	5,161.8	0.0
Estuarine Intertidal Unconsolidated Shore/Emergent Persistent Irregularly Flooded	E2US/EM1P	11,405.4	0.0
Estuarine Intertidal Unconsolidated Shore/Emergent Nonpersistent Irregularly Flooded	E2US/EM2P	60.9	0.0
Estuarine Intertidal Unconsolidated Shore Regularly Flooded	E2USN	136.3	0.0
Estuarine Intertidal Unconsolidated Shore Irregularly Flooded	E2USP	30,799.8	0.0
Lacustrine Limnetic Unconsolidated Bottom Permanently Flooded	L1UBH	580,199.4	365.7
Lacustrine Limnetic Unconsolidated Bottom Permanently Flooded Diked/Impounded	L1UBHh	2,681.7	0.0
Lacustrine Limnetic Unconsolidated Bottom Permanently Flooded Excavated	L1UBHx	0.0	<0.1
Lacustrine Littoral Aquatic Bed Aquatic Moss Permanently Flooded	L2AB2H	3.9	0.0
Lacustrine Littoral Emergent Nonpersistent/Unconsolidated Bottom Semi-Permanently Flooded	L2EM2/UBF	153.3	0.0
Lacustrine Littoral Emergent Nonpersistent/Unconsolidated Bottom Permanently Flooded	L2EM2/UBH	3,501.2	0.0
Lacustrine Littoral Emergent Nonpersistent Semi-Permanently Flooded	L2EM2F	1,512.4	0.0
Lacustrine Littoral Emergent Nonpersistent Permanently Flooded	L2EM2H	5,832.8	4.1
Lacustrine Littoral Unconsolidated Bottom/Emergent Nonpersistent Permanently Flooded	L2UB/EM2H	1,229.2	0.0
Lacustrine Littoral Unconsolidated Bottom Semi-Permanently Flooded	L2UBF	34.9	0.0
Lacustrine Littoral Unconsolidated Bottom Permanently Flooded	L2UBH	1,362.2	0.0
Lacustrine Littoral Unconsolidated Shore Temporarily Flooded	L2USA	4,169.0	0.0
Lacustrine Littoral Unconsolidated Shore Seasonally Flooded	L2USC	5,158.9	0.0
Marine Subtidal Unconsolidated Bottom[c]	M1UBL	35,795.1	76.7
Marine Intertidal Unconsolidated Shore Sand Regularly Flooded	M2US2N	1.6	1.6
Marine Intertidal Unconsolidated Shore Regularly Flooded	M2USN	4.6	0.0
Marine Intertidal Unconsolidated Shore Irregularly Flooded	M2USP	275.0	0.0
Palustrine Emergent Persistent/Nonpersistent Semi-Permanently Flooded	PEM1/2F	4,477.2	0.0
Palustrine Emergent Persistent/Moss-Lichen Moss Seasonally Saturated	PEM1/ML1B	300.8	0.0
Palustrine Emergent Persistent/Scrub-Shrub Broad-Leaved Deciduous Temporarily Flooded	PEM1/SS1A	68.1	0.0
Palustrine Emergent Persistent/Scrub-Shrub Broad-Leaved Deciduous Seasonally Saturated	PEM1/SS1B	907,301.3	4,027.6
Palustrine Emergent Persistent/Scrub-Shrub Broad-Leaved Deciduous Continuously Saturated[d]	PEM1/SS1D	2,677.6	2,677.6
Palustrine Emergent Persistent/Scrub-Shrub Broad-Leaved Deciduous Continuously Seasonally Flooded/Saturated	PEM1/SS1E	420,546.6	312.1
Palustrine Emergent Persistent/Scrub-Shrub Broad-Leaved Deciduous Semi-Permanently Flooded	PEM1/SS1F	38,157.7	431.6

Wetland Type	Cowardin Code[a]	Acres in Analysis Area[b]	Acres in Field-Verified Portion of Analysis Area[c]
Palustrine Emergent Persistent/Scrub-Shrub Broad-Leaved Evergreen Saturated	PEM1/SS3B	7.1	7.1
Palustrine Emergent Persistent/Unconsolidated Bottom Semi-Permanently Flooded	PEM1/UBF	41,116.2	0.0
Palustrine Emergent Persistent/Unconsolidated Bottom Semi-Permanently Flooded Diked/Impounded	PEM1/UBFh	5.3	0.0
Palustrine Emergent Persistent/Unconsolidated Shore Temporarily Flooded	PEM1/USA	1,273.0	0.0
Palustrine Emergent Persistent/Unconsolidated Shore Seasonally Flooded	PEM1/USC	677.8	0.0
Palustrine Emergent Persistent/Unconsolidated Shore Seasonally Flooded/Saturated	PEM1/USE	2,913.7	0.0
Palustrine Emergent Persistent Seasonally Saturated	PEM1B	23,883.0	1.6
Palustrine Emergent Persistent Seasonally Flooded	PEM1C	567.2	0.0
Palustrine Emergent Persistent Continuously Saturated	PEM1D	17.6	17.6
Palustrine Emergent Persistent Seasonally Flooded/Saturated	PEM1E	287,035.6	9.5
Palustrine Emergent Persistent Semi-Permanently Flooded	PEM1F	167,131.5	2,608.0
Palustrine Emergent Persistent Semi-Permanently Flooded Diked/Impounded	PEM1Fh	12.8	0.0
Palustrine Emergent Persistent Permanently Flooded[d]	PEM1H	372.3	372.3
Palustrine Emergent Nonpersistent/Persistent Semi-Permanently Flooded	PEM2/1F	5,044.4	0.0
Palustrine Emergent Nonpersistent/Unconsolidated Bottom Semi-Permanently Flooded	PEM2/UBF	64.3	0.0
Palustrine Emergent Nonpersistent/Unconsolidated Bottom Permanently Flooded	PEM2/UBH	781.0	0.0
Palustrine Emergent Nonpersistent Semi-Permanently Flooded	PEM2F	178.8	0.0
Palustrine Emergent Nonpersistent Permanently Flooded	PEM2H	2,408.1	21.2
Palustrine Scrub-Shrub/Emergent Persistent Temporarily Flooded	PSS/EM1A	489.0	0.0
Palustrine Scrub-Shrub/Emergent Persistent Seasonally Saturated	PSS/EM1B	15,969.0	0.0
Palustrine Scrub-Shrub/Emergent Persistent Seasonally Flooded/Saturated	PSS/EM1E	27,599.1	0.0
Palustrine Scrub-Shrub/Emergent Persistent Semi-Permanently Flooded	PSS/EM1F	50.9	0.0
Palustrine Scrub-Shrub Broad-Leaved Deciduous/Emergent Persistent Temporarily Flooded	PSS1/EM1A	1,348.5	0.0
Palustrine Scrub-Shrub Broad-Leaved Deciduous/Emergent Persistent Seasonally Saturated	PSS1/EM1B	9,850.8	94.0
Palustrine Scrub-Shrub Broad-Leaved Deciduous/Emergent Persistent Seasonally Flooded	PSS1/EM1C	167.5	0.0
Palustrine Scrub-Shrub Broad-Leaved Deciduous/Emergent Persistent Continuously Saturated	PSS1/EM1D	23.5	23.5
Palustrine Scrub-Shrub Broad-Leaved Deciduous/Emergent Persistent Seasonally Flooded/Saturated	PSS1/EM1E	11,783.9	0.0
Palustrine Scrub-Shrub Broad-Leaved Deciduous/Emergent Persistent Semi-Permanently Flooded	PSS1/EM1F	751.6	0.0
Palustrine Scrub-Shrub Broad-Leaved Deciduous/Unconsolidated Shore Temporarily Flooded	PSS1/USA	747.5	0.0
Palustrine Scrub-Shrub Broad-Leaved Deciduous/Unconsolidated Shore Seasonally Saturated[d]	PSS1/USB	18.0	18.0
Palustrine Scrub-Shrub Broad-Leaved Deciduous/Unconsolidated Shore Seasonally Flooded	PSS1/USC	13.9	0.0
Palustrine Scrub-Shrub Broad-Leaved Deciduous Temporarily Flooded	PSS1A	4,449.0	0.0
Palustrine Scrub-Shrub Broad-Leaved Deciduous Seasonally Saturated	PSS1B	2,697.6	374.8
Palustrine Scrub-Shrub Broad-Leaved Deciduous Seasonally Flooded	PSS1C	132.0	105.2
Palustrine Shrub-Scrub Broad-Leaved Deciduous Continuously Saturated[d]	PSS1D	123.1	123.1
Palustrine Shrub-Scrub Broad-Leaved Deciduous Seasonally Flooded/Saturated	PSS1E	117.6	0.0
Palustrine Scrub-Shrub Broad-Leaved Evergreen/Emergent Persistent Seasonally Saturated	PSS3/EM1B	6.4	6.4
Palustrine Scrub-Shrub Broad-Leaved Evergreen/Emergent Persistent Continuously Saturated	PSS3/EM1D	22.0	22.0
Palustrine Scrub-Shrub Broad-Leaved Evergreen Seasonally Saturated[d]	PSS3B	133.1	133.1
Palustrine Unconsolidated Bottom/Emergent Persistent Semi-Permanently Flooded	PUB/EM1F	9,139.7	0.0

Wetland Type	Cowardin Code[a]	Acres in Analysis Area[b]	Acres in Field-Verified Portion of Analysis Area[c]
Palustrine Unconsolidated Bottom/Emergent Nonpersistent Semi-Permanently Flooded	PUB/EM2F	45.0	0.0
Palustrine Unconsolidated Bottom/Emergent Nonpersistent Permanently Flooded	PUB/EM2H	734.1	0.0
Palustrine Unconsolidated Bottom Semi-Permanently Flooded	PUBF	155.8	0.0
Palustrine Unconsolidated Bottom Semi-Permanently Flooded Diked/Impounded	PUBFh	5.9	0.0
Palustrine Unconsolidated Bottom Permanently Flooded	PUBH	61,283.2	285.0
Palustrine Unconsolidated Bottom Permanently Flooded Diked/Impounded	PUBHh	42.9	0.0
Palustrine Unconsolidated Bottom Permanently Flooded Excavated	PUBHx	26.7	1.0
Palustrine Unconsolidated Shore/Emergent Persistent Temporarily Flooded	PUS/EM1A	483.2	0.0
Palustrine Unconsolidated Shore/Emergent Persistent Seasonally Flooded	PUS/EM1C	69.3	0.0
Palustrine Unconsolidated Shore/Emergent Persistent Seasonally Flooded/Saturated	PUS/EM1E	309.1	0.0
Palustrine Unconsolidated Shore/Scrub-Shrub Broad-Leaved Deciduous Temporarily Flooded	PUS/SS1A	53.5	0.0
Palustrine Unconsolidated Shore Temporarily Flooded	PUSA	265.6	0.0
Palustrine Unconsolidated Shore Seasonally Flooded	PUSC	165.7	0.3
Riverine Tidal Unconsolidated Bottom Permanently Flooded[d]	R1UBV	43.0	16.8
Riverine Tidal Unconsolidated Shore Regularly Flooded	R1USQ	7.3	6.2
Riverine Low Perennial Emergent Nonpersistent/Unconsolidated Bottom Permanently Flooded	R2EM2/UBH	578.3	0.0
Riverine Low Perennial Emergent Nonpersistent Semi-Permanently Flooded	R2EM2F	4.5	0.0
Riverine Low Perennial Unconsolidated Bottom/Emergent Nonpersistent Permanently Flooded	R2UB/EM2H	435.4	0.0
Riverine Low Perennial Unconsolidated Bottom Semi-Permanently Flooded	R2UBF	5,790.8	0.0
Riverine Low Perennial Unconsolidated Bottom Permanently Flooded	R2UBH	19,648.2	37.9
Riverine Low Perennial Unconsolidated Shore Temporarily Flooded	R2USA	1,717.4	0.0
Riverine Low Perennial Unconsolidated Shore Seasonally Flooded	R2USC	14,640.3	20.4
Riverine Upper Perennial Unconsolidated Bottom Permanently Flooded	R3UBH	6,342.7	0.0
Riverine Upper Perennial Unconsolidated Shore Temporarily Flooded	R3USA	186.8	0.0
Riverine Upper Perennial Unconsolidated Shore Seasonally Flooded	R3USC	512.3	0.0
Riverine Intermittent Streambed Temporarily Flooded	R4SBA	22.1	0.0
Riverine Intermittent Streambed Seasonally Flooded	R4SBC	10.7	0.0
Riverine Unknown Perennial Unconsolidated Bed Permanently Flooded	R5UBH	70.1	0.0
Upland	U[e]	129.7	129.7
Upland	Upland[e]	12,324.2	0.0
Upland (fill)	Us[e]	582.7	582.7
Total	**N/A**	**2,903,709.2**	**12,914.5**

Note: N/A (not applicable); USFWS (U.S. Fish and Wildlife Service). Bold terms (excluding "total") are defined in the glossary.
[a] Cowardin 1979 (codes defined therein)
[b] Wells et al. 2018 and USFWS 2016
[c] Wells et al. 2018
[d] Wetland type uses a higher-resolution classification than that in the USFWS inventory (2016) and would only be documented through field verification. The lack of this wetland type in the rest of the analysis area is due to mapping methods and to the USFWS inventory (2016) covering a broad area that did not receive the same level of field verification as the Project area.
[e] Cowardin code of "U" was field verified; Cowardin code of "Upland" included all areas in National Wetlands Inventory mapping that were not identified as wetlands; Cowardin code for 'Us' was field verified to distinguish between vegetated uplands and developed uplands.

1.2 Comparison of Alternatives: Wetlands and Vegetation

Tables E.9.2 and E.9.3 detail the acres of direct and temporary fill in wetlands by wetland type and action alternative or module delivery option. Table E.9.4. summarizes direct wetland loss by watershed and action alternative. Table E.9.5 summarizes acres of vegetation damage from ice infrastructure by action alternative or module delivery option. Table E.9.6 summarizes acres of indirect dust shadow on wetlands and vegetation by wetland type and action alternative or module delivery option. Table E.9.7 summarizes indirect effects (dust shadow and vegetation damage) in wetlands and waterbodies by watershed and action alternative.

Table E.9.2. Acres of Wetland Loss Due to Direct Fill or Excavation by Wetland Type and Action Alternative or Module Delivery Option*

Cowardin Code	Alternative B: Proponent's Project	Alternative C: Disconnected Infield Roads	Alternative D: Disconnected Access	Alternative E: Three-Pad Alternative	Option 1: Atigaru Point Module Transfer Island	Option 2: Point Lonely Module Transfer Island	Option 3: Colville River Crossing
L1UBH	1.5	1.5	1.5	<0.1	0.0	0.0	0.0
PEM1/SS1B	290.1	379.1	342.5	258.1	0.0	0.0	2.5
PEM1/SS1D	154.4	168.4	150.9	148.0	0.0	0.0	0.9
PEM1/SS1E	1.8	1.8	1.7	0.3	0.0	0.0	0.0
PEM1/SS1F	8.7	11.3	8.0	2.9	0.0	0.0	0.0
PEM1D	0.0	0.0	0.0	0.0	0.0	0.0	0.2
PEM1E	1.0	0.0	1.0	1.7	0.0	0.0	0.0
PEM1F	105.3	131.4	101.7	88.2	0.0	0.0	0.8
PEM1H	8.3	13.3	14.7	6.2	0.0	0.0	0.1
PEM2H	0.6	0.8	0.0	0.6	0.0	0.0	0.0
PSS1/EM1B	8.9	8.5	9.6	8.3	0.0	0.0	0.1
PSS1/EM1D	0.6	0.8	0.6	0.3	0.0	0.0	0.0
PSS1/USB	1.3	1.0	1.0	1.4	0.0	0.0	0.0
PSS1B	10.3	11.2	31.2	8.1	0.0	0.0	0.0
PSS1C	1.6	1.4	1.5	1.3	0.0	0.0	0.0
PSS1D	1.8	1.0	2.2	4.3	0.0	0.0	0.0
PSS3/EM1B	1.1	1.1	0.0	1.1	0.0	0.0	0.0
PSS3/EM1D	1.6	1.6	0.0	1.6	0.0	0.0	0.0
PSS3B	7.5	6.3	7.6	4.4	0.0	0.0	0.0
PUBH	4.4	7.5	7.7	3.9	0.0	0.0	<0.1
R2UBH	0.6	0.4	0.6	0.6	0.0	0.0	<0.1
R2USC	0.5	0.1	0.3	0.5	0.0	0.0	0.0
U	7.8	3.2	4.6	6.2	0.0	0.0	0.0
Us	0.3	0.3	0.3	0.3	0.0	0.0	0.4
Total	**619.8**	**752.0**	**689.1**	**548.4**	**0**	**0**	**5.0**
Total in Wetlands[a]	**604.8**	**739.1**	**674.2**	**536.9**	**0**	**0**	**4.6**
Total in Freshwater WOUS	**7.0**	**9.5**	**10.0**	**5.0**	**0**	**0**	**<0.1**
Total in Uplands	**8.1**	**3.5**	**4.9**	**6.5**	**0**	**0**	**0.4**

Note: < (less than); WOUS (Waters of the United States). Cowardin codes are defined in Table E.9.1. Numbers may differ slightly with other reported values in the Environmental Impact Statement due to rounding.

[a] Fill that is not in wetlands would be in uplands or freshwater WOUS (lakes, ponds, or rivers).

Table E.9.3. Acres of Temporary Fill from Multi-Season Ice Pads by Wetland and Waterbody Type and Action Alternative or Module Delivery Option*

Cowardin Code	Alternative B: Proponent's Project	Alternative C: Disconnected Infield Roads	Alternative D: Disconnected Access	Alternative E: Three-Pad Alternative	Option 1: Atigaru Point Module Transfer Island	Option 2: Point Lonely Module Transfer Island	Option 3: Colville River Crossing
PEM1/SS1B	1.7	4.4	12.1	1.7	18.2	17.9	0.0
PEM1/SS1D	9.7	11.1	4.7	9.7	8.8	9.4	0.0
PEM1/SS1E	0.0	0.0	2.4	0.0	0.0	0.0	0.0
PEM1/SS3B	0.0	0.0	0.0	0.0	1.6	0.0	0.0
PEM1F	16.5	10.0	6.9	16.5	15.2	12.6	0.0
PEM1H	2.0	0.7	0.7	2.0	5.0	8.8	0.0
PSS1B	0.0	3.5	3.2	0.0	0.0	0.0	0.0
PUBH	0.2	0.4	0.0	0.2	1.3	1.3	0.0
Total	**30.0**	**30.0**	**30.0**	**30.0**	**50.0**	**50.0**	**0.0**

Note: Cowardin codes are defined in Table E.9.1. Multi-season ice pads (lasting more than 1 full year in a single location) are considered temporary fill and are subject to U.S. Army Corps of Engineers jurisdiction. Therefore, they are included in the Willow Master Development Plan Project's Clean Water Act 404 permit as temporary fill.

Table E.9.4. Direct Wetland Loss by Watershed and Action Alternative*

Watershed (acres)	Alternative B: Proponent's Project (acres)	Alternative B: Proponent's Project (% of watershed)	Alternative C: Disconnected Infield Roads (acres)	Alternative C: Disconnected Infield Roads (% of watershed)	Alternative D: Disconnected Access (acres)	Alternative D: Disconnected Access (% of watershed)	Alternative E: Three-Pad Alternative Access (acres)	Alternative E: Three-Pad Alternative (% of watershed)
Colville River Delta-Frontal Harrison Bay (303,614.3)	2.2	< 0.1	2.2	< 0.1	3.5	< 0.1	2.2	<0.1
Kalikpik River (233,090.1)	28.0	< 0.1	29.1	< 0.1	28.0	< 0.1	0.0	0.0
Outlet Fish Creek (137,576.9)	60.8	< 0.1	111.8	0.1	65.9	< 0.1	54.3	<0.1
Outlet Judy Creek (246,274.6)	358.0	0.1	361.8	0.1	346.1	0.1	324.7	0.1
Ublutuoch River (150,954.4)	155.0	0.1	233.5	0.2	230.0	0.2	155.0	0.1
Ugnuravik River (77,253.8)	0.7	< 0.1	0.7	< 0.1	0.7	< 0.1	0.7	<0.1
Total Fill and Excavation in Wetlands	**604.8**	**N/A**	**739.1**	**N/A**	**674.2**	**N/A**	**536.9**	**N/A**
Fill and Excavation in Waters of the U.S.	**7.0**	**N/A**	**9.5**	**N/A**	**10.0**	**N/A**	**5.0**	**N/A**
Fill and Excavation in Uplands	**8.1**	**N/A**	**3.5**	**N/A**	**4.9**	**N/A**	**6.5**	**N/A**
Total	**619.8**	**N/A**	**752.0**	**N/A**	**689.1**	**N/A**	**548.4**	**N/A**

Note: < (less than); N/A (not applicable). The total acres for each watershed were assumed to be equal to the total wetland acres since uplands compose less than 1% of the analysis area. Direct wetland loss would come from either the placement of gravel fill or excavation (e.g., gravel mine site, constructed freshwater reservoir). Total acres of direct fill and excavation may vary slightly from other resource sections in the Environmental Impact Statement because those sections include fill in uplands and this section does not. Wetland loss for Option 3 would be less than 5 acres and thus is not included in the table.

Table E.9.5. Acres of Vegetation Damage from Ice Infrastructure by Action Alternative or Module Delivery Option*

Ice Infrastructure	Alternative B: Proponent's Project	Alternative C: Disconnected Infield Roads	Alternative D: Disconnected Access	Alternative E: Three-Pad Alternative	Option 1: Atigaru Point Module Transfer Island	Option 2: Point Lonely Module Transfer Island	Option 3: Colville River Crossing
Single-season ice pads	936.6	1,166.4	1,241.4	830.6	118.9	195.2	83.4
Multi-season ice pads	30.0	30.0	30.0	30.0	30.0	30.0	0.0
Freshwater ice roads	3,590.7	4,411.6	5,893.4	3,166.2	710.7	1,530.9	583.2
Total	4,557.3	5,608.0	7,164.8	**4,026.8**	**859.6**	**1,756.1**	**666.6**

Note: The total acres indirectly impacted by ice infrastructure were assumed to be equal to wetland acres, since uplands compose less than 1% of the analysis area.

Table E.9.6. Acres of Indirect Dust Shadow on Wetlands and Vegetation by Wetland Type and Action Alternative or Module Delivery Option*

Cowardin Code	Alternative B: Proponent's Project	Alternative C: Disconnected Infield Roads	Alternative D: Disconnected Access	Alternative E: Three-Pad Alternative	Option 1: Atigaru Point Module Transfer Island	Option 2: Point Lonely Module Transfer Island	Option 3: Colville River Crossing
L1UBH	17.0	16.8	17.2	26.3	0	0	<0.1
L2EM2H	0.1	0.1	0.1	1.4	0	0	0
PEM1/SS1B	1225.0	1272.2	931.5	1016.0	0	0	8.5
PEM1/SS1D	723.4	781.5	584.7	664.2	0	0	2.5
PEM1/SS1E	31.2	34.9	31.5	10.2	0	0	4.6
PEM1/SS1F	83.1	95.7	69.2	44.6	0	0	0
PEM1B	1.6	1.6	1.6	1.4	0	0	0
PEM1D	0	0	0	0	0	0	0.3
PEM1E	6.3	0	6.3	7.8	0	0	0
PEM1F	779.9	731.5	539.9	628.4	0	0	2.2
PEM1H	117.2	119.1	98.9	79.9	0	0	0
PEM2H	6.3	5.9	2.4	4.9	0	0	0
PSS1/EM1B	54.5	54.7	45.9	51.8	0	0	0.1
PSS1/EM1D	12.7	13.0	15.2	4.0	0	0	0
PSS1/USB	12.2	9.1	9.1	12.1	0	0	0
PSS1B	107.1	113.7	110.0	70.6	0	0	<0.1
PSS1C	26.1	24.7	26.8	22.7	0	0	0
PSS1D	22.1	14.4	26.2	31.2	0	0	0
PSS3/EM1B	5.3	5.3	0	5.3	0	0	0
PSS3/EM1D	20.3	20.0	0	20.3	0	0	0
PSS3B	42.4	28.7	45.1	46.2	0	0	0
PUBH	66.9	70.7	58.3	52.2	0	0	0.1
R1UBV	0.2	0.2	0.2	0.2	0	0	0
R2UBH	14.5	10.0	11.3	13.7	0	0	0
R2USC	7.1	1.9	4.0	7.1	0	0	0
U	64.6	39.8	54.1	39.1	0	0	0
Us	0.2	0.2	0.2	0.2	0	0	10.1
Total	**3,447.4**	**3,465.7**	**2,689.7**	**2,862.3**	**0**	**0**	**28.2**
Total in Wetlandsa	**3,276.9**	**3,326.1**	**2,544.4**	**2,722.0**	**0**	**0**	**18.0**
Total in Freshwater WOUS	**105.7**	**99.7**	**91.1**	**100.9**	**0**	**0**	**0.1**
Total in Uplands	**64.8**	**40.0**	**54.3**	**39.3**	**0**	**0**	**10.1**

Note: < (less than); WOUS (Waters of the United States). Cowardin codes are defined in Table E.9.1. Dust shadow is calculated from all gravel infrastructure. Numbers may differ slightly from other reported values in the Environmental Impact Statement due to rounding.
[a] Fill that is not in wetlands would be in uplands or freshwater WOUS (lakes, ponds, or rivers).

Table E.9.7. Indirect Dust Shadow in Wetlands and Waterbodies by Watershed and Action Alternative*

Watershed (acres)	Alternative B: Proponent's Project (acres)	Alternative B: Proponent's Project (% of watershed)	Alternative C: Disconnected Infield Roads (acres)	Alternative C: Disconnected Infield Roads (% of watershed)	Alternative D: Disconnected Access (acres)	Alternative D: Disconnected Access (% of watershed)	Alternative E: Three-Pad Alternative	Alternative E: Three-Pad Alternative
Colville River Delta-Frontal Harrison Bay (224,452.3)	27.6	<0.1	27.6	<0.1	31.0	<0.1	27.6	<0.1
Kalikpik River (233,088.3)	193.1	0.1	193.7	0.1	193.1	0.1	0.0	0.0
Outlet Fish Creek (137,576.9)	563.7	0.4	751.7	0.5	566.7	0.4	402.1	0.3
Outlet Judy Creek (246,274.6)	2,416.5	1.0	2,244.3	0.9	1,679.3	0.7	2,211.6	0.9
Ublutuoch (Tiŋmiaqsiuġvik) River (150,954.4)	180.7	0.1	207.6	0.1	164.5	0.1	180.7	0.1
Ugnuravik River (77,253.8)	0.9	<0.1	0.9	<0.1	0.9	<0.1	0.9	<0.1
Total	**3,382.5**	**N/A**	**3,425.8**	**N/A**	**2,635.5**	**N/A**	**2,822.9**	**N/A**

Note: < (less than); N/A (not applicable). The total acres for each watershed were assumed to be equal to the total wetland acres since uplands compose less than 1% of the analysis area. However, numbers may vary slightly from other resource sections in the Environmental Impact Statement because those sections include fill to uplands and this section does not. Dust shadow is calculated from all gravel infrastructure. Dust shadow for Option 3 would be less than 28 acres and thus is not included in the table.

2.0 REFERENCES

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Willow Master Development Plan

Appendix E.10
Fish Technical Appendix

June 2022

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1.0 Fish 1

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List of Species

Alaska blackfish (*Dallia pectoralis*)
Arctic grayling (*Thymallus arcticus*)
Broad whitefish (*Coregonus nasus*)
Humpback whitefish (*Coregonus pidschian*)
Least cisco (*Coregonus sardinella*)
Ninespine stickleback (*Pungitius pungitius*)
Round whitefish (*Prosopium cylindraceum*)
Slimy sculpin (*Cottus cognatus*)

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1.0 FISH

Tables E.10.1 through E.10.4 summarize Willow project area lakes and the fish species that are present in the analysis area by action alternative.

Table E.10.1. Willow Project Area Lakes and Fish Species that Occur in the Alternative B Analysis Area

Lake	Species	Winter Water Status	Latitude	Longitude
MM1818	No fish captured	Unfrozen	70.29404	-152.225
Small lake	Not sampled; Nearby larger and similar sized lakes do not contain fish	Unfrozen	70.29929	-152.204
Small lake	Not sampled; NSSB possible	Unfrozen	70.03551	-152.195
M1523	NSSB	Unfrozen	70.15469	-152.113
M8104	No fish captured	Unfrozen	70.28623	-149.866
M9525	BDWF, BKFH, HBWF, LSCS, NSSB, RDWF, SLSC	Unfrozen	70.32266	-150.98
L9824	BKFH, GRAY, NSSB	Unfrozen	70.28425	-151.271
M0015	NSSB, GRAY	Unfrozen	70.10824	-152.058
L9911	NSSB	Unfrozen	70.17073	-151.79
M8103	NSSB	Unfrozen	70.29131	-149.916
M8103	NSSB	Unfrozen	70.28761	-149.894
Wetland ponds	None	Frozen	70.27549	-152.195
Small lake	No fish captured	Frozen	70.31457	-152.193
Small lake	Not sampled; Nearby larger and similar sized lakes do not contain fish	Frozen	70.30939	-152.196
Small lake	Not sampled; Nearby larger and similar sized lakes do not contain fish	Frozen	70.32664	-152.221
Wetland ponds	None	Frozen	70.28688	-152.222
Small lake	Not sampled; Nearby larger and similar sized lakes do not contain fish	Frozen	70.32082	-152.211
Wetland ponds	None	Frozen	70.20368	-152.105
Wetland ponds	None	Frozen	70.27688	-152.199
Wetland ponds	None	Frozen	70.21493	-152.105
M1522	NSSB	Frozen	70.15288	-152.086
Small pond	NSSB inferred, connected to Lake M1523	Frozen	70.15742	-152.088
M2108	BDWF, NSSB	Frozen	70.2494	-152.179
Wetland ponds	None	Frozen	70.17279	-152.121
Wetland ponds	None	Frozen	70.17713	-152.11
Wetland ponds	None	Frozen	70.25424	-152.186
M0017	NSSB	Frozen	70.10085	-152.133
Wetland ponds	None	Frozen	70.17217	-152.113
Small lake	Not Sampled; NSSB possible	Frozen	70.13882	-152.014
Wetland ponds	None	Frozen	70.15845	-151.774
Wetland ponds	None	Frozen	70.15558	-151.81
Wetland ponds	None	Frozen	70.14726	-151.867
Wetland ponds	None	Frozen	70.16142	-151.762
Wetland ponds	NSSB	Frozen	70.12428	-152.078
Wetland ponds	None	Frozen	70.12781	-152.08
Small lake	Not sampled; NSSB possible	Frozen	70.1131	-152.102
Wetland ponds	None	Frozen	70.14187	-151.888
Mine Site	Not sampled; Isolated (fish unlikely)	Frozen	70.28641	-149.887
Wetland ponds	None	Frozen	70.28466	-149.898
Wetland ponds	None	Frozen	70.2754	-150.062
Wetland pond/impoundment	None	Frozen	70.33655	-149.728
Mine Site	Not sampled; Isolated (fish unlikely)	Frozen	70.28669	-149.883
Wetland ponds	None	Frozen	70.27822	-149.911

Note: BDWF (broad whitefish); BKFH (Alaska blackfish); GRAY (Arctic grayling); HBWF (humpback whitefish); LSCS (least cisco); NSSB (ninespine stickleback); RDWF (round whitefish); SLSC (slimy sculpin).

Table E.10.2. Willow Project Area Lakes and Fish Species that Occur in the Alternative C Analysis Area*

Lake	Species	Winter Water Status	Latitude	Longitude
M8103	NSSB	Unfrozen	70.29131	-149.916
M8103	NSSB	Unfrozen	70.28761	-149.894
M0235	No fish captured	Unfrozen	70.23704	-152.188
MM1818	No fish captured	Unfrozen	70.29404	-152.225
Small lake	Not sampled; Nearby larger and similar sized lakes do not contain fish	Unfrozen	70.29929	-152.204
Small lake	Not sampled; NSSB possible	Unfrozen	70.03551	-152.195
M1523	NSSB	Unfrozen	70.15469	-152.113
M8104	No fish captured	Unfrozen	70.28623	-149.866
M9525	BDWF, BKFH, HBWF, LSCS, NSSB, RDWF, SLSC	Unfrozen	70.32266	-150.98
L9824	BKFH, GRAY, NSSB	Unfrozen	70.28425	-151.271
M0015	NSSB, GRAY	Unfrozen	70.10824	-152.058
L9911	NSSB	Unfrozen	70.17073	-151.79
Mine Site	Not sampled; Isolated (fish unlikely)	Frozen	70.28641	-149.887
Wetland ponds	None	Frozen	70.28466	-149.898
Wetland ponds	None	Frozen	70.2754	-150.062
Wetland pond/impoundment	None	Frozen	70.33655	-149.728
Mine Site	Not sampled; Isolated (fish unlikely)	Frozen	70.28669	-149.883
Wetland ponds	None	Frozen	70.27822	-149.911
Wetland ponds	None	Frozen	70.22333	-152.203
Wetland ponds	None	Frozen	70.22217	-152.196
Small pond	Not Sampled; NSSB likely	Frozen	70.13415	-152.01
Wetland ponds	None	Frozen	70.15032	-151.957
Wetland ponds	None	Frozen	70.24239	-152.172
Wetland ponds	None	Frozen	70.27549	-152.195
Small lake	No fish captured	Frozen	70.31457	-152.193
Small lake	Not sampled; Nearby larger and similar sized lakes do not contain fish	Frozen	70.30939	-152.196
Small lake	Not sampled; Nearby larger and similar sized lakes do not contain fish	Frozen	70.32664	-152.221
Wetland ponds	None	Frozen	70.28688	-152.222
Small lake	Not sampled; Nearby larger and similar sized lakes do not contain fish	Frozen	70.32082	-152.211
Wetland ponds	None	Frozen	70.20368	-152.105
Wetland ponds	None	Frozen	70.27688	-152.199
Wetland ponds	None	Frozen	70.21493	-152.105
M1522	NSSB	Frozen	70.15288	-152.086
M2108	BDWF, NSSB	Frozen	70.2494	-152.179
Wetland ponds	None	Frozen	70.17279	-152.121
Wetland ponds	None	Frozen	70.17713	-152.11
Wetland ponds	None	Frozen	70.25424	-152.186
M0017	NSSB	Frozen	70.10085	-152.133
Wetland ponds	None	Frozen	70.17217	-152.113
Wetland ponds	None	Frozen	70.15845	-151.774
Wetland ponds	None	Frozen	70.15558	-151.81
Wetland ponds	None	Frozen	70.14726	-151.867
Wetland ponds	None	Frozen	70.16142	-151.762
Wetland ponds	NSSB	Frozen	70.12428	-152.078
Wetland ponds	None	Frozen	70.12781	-152.08
Small lake	Not sampled; NSSB possible	Frozen	70.1131	-152.102
Wetland ponds	None	Frozen	70.14187	-151.888

Note: BDWF (broad whitefish); BKFH (Alaska blackfish); GRAY (Arctic grayling); HBWF (humpback whitefish); LSCS (least cisco); NSSB (ninespine stickleback); RDWF (round whitefish); SLSC (slimy sculpin).

Table E.10.3. Willow Project Area Lakes and Fish Species that Occur in the Alternative D Analysis Area*

Lake	Species	Winter Water Status	Latitude	Longitude
M8103	NSSB	Unfrozen	70.29131	-149.916
M8103	NSSB	Unfrozen	70.28761	-149.894
M0235	No fish captured	Unfrozen	70.23704	-152.188
MM1818	No fish captured	Unfrozen	70.29404	-152.225
Small lake	Not sampled; Nearby larger and similar sized lakes do not contain fish	Unfrozen	70.29929	-152.204
Small lake	Not sampled; NSSB possible	Unfrozen	70.03551	-152.195
M1523	NSSB	Unfrozen	70.15469	-152.113
M8104	No fish captured	Unfrozen	70.28623	-149.866
M9525	BDWF, BKFH, HBWF, LSCS, NSSB, RDWF, SLSC	Unfrozen	70.32266	-150.98
L9824	BKFH, GRAY, NSSB	Unfrozen	70.28425	-151.271
M0015	NSSB, GRAY	Unfrozen	70.10824	-152.058
Mine Site	Not sampled; Isolated (fish unlikely)	Frozen	70.28641	-149.887
Wetland ponds	None	Frozen	70.28466	-149.898
Wetland ponds	None	Frozen	70.2754	-150.062
Wetland pond/impoundment	None	Frozen	70.33655	-149.728
Mine Site	Not sampled; Isolated (fish unlikely)	Frozen	70.28669	-149.883
Wetland ponds	None	Frozen	70.27822	-149.911
Wetland ponds	None	Frozen	70.10958	-152.135
N77084	None	Frozen	70.10867	-152.154
Wetland ponds	None	Frozen	70.10967	-152.15
Wetland ponds	None	Frozen	70.11185	-152.15
Wetland ponds	None	Frozen	70.111	-152.139
Wetland ponds	None	Frozen	70.24239	-152.172
Wetland ponds	None	Frozen	70.27549	-152.195
Small lake	No fish captured	Frozen	70.31457	-152.193
Small lake	Not sampled; Nearby larger and similar sized lakes do not contain fish	Frozen	70.30939	-152.196
Small lake	Not sampled; Nearby larger and similar sized lakes do not contain fish	Frozen	70.32664	-152.221
Wetland ponds	None	Frozen	70.28688	-152.222
Small lake	Not sampled; Nearby larger and similar sized lakes do not contain fish	Frozen	70.32082	-152.211
Wetland ponds	None	Frozen	70.20368	-152.105
Wetland ponds	None	Frozen	70.27688	-152.199
Wetland ponds	None	Frozen	70.21493	-152.105
M1522	NSSB	Frozen	70.15288	-152.086
Small pond	NSSB inferred, connected to Lake M1523	Frozen	70.15742	-152.088
M2108	BDWF, NSSB	Frozen	70.2494	-152.179
Wetland ponds	None	Frozen	70.17279	-152.121
Wetland ponds	None	Frozen	70.17713	-152.11
Wetland ponds	None	Frozen	70.25424	-152.186
M0017	NSSB	Frozen	70.10085	-152.133
Wetland ponds	None	Frozen	70.17217	-152.113
Wetland ponds	NSSB	Frozen	70.12428	-152.078
Wetland ponds	None	Frozen	70.12781	-152.08
Small lake	Not sampled; NSSB possible	Frozen	70.1131	-152.102

Note: BDWF (broad whitefish); BKFH (Alaska blackfish); GRAY (Arctic grayling); HBWF (humpback whitefish); LSCS (least cisco); NSSB (ninespine stickleback); RDWF (round whitefish); SLSC (slimy sculpin).

Table E.10.4. Willow Project Area Lakes and Fish Species that Occur in the Alternative E Analysis Area*

Lake	Species	Winter Water Status	Latitude	Longitude
M8103	NSSB	Unfrozen	70.29131	-149.916
M8103	NSSB	Unfrozen	70.28761	-149.894
M0014	No fish captured	Unfrozen	70.11906	-152.063
M0110	No fish captured	Unfrozen	70.20167	-152.118
M0112	NSSB	Unfrozen	70.24747	-152.151
L9911	NSSB	Unfrozen	70.17073	-151.79
M0235	No fish captured	Unfrozen	70.23704	-152.188
M1523	NSSB	Unfrozen	70.15469	-152.113
M8104	No fish captured	Unfrozen	70.28623	-149.866
M9525	BDWF, BKFH, HBWF, LSCS, NSSB, RDWF, SLSC	Unfrozen	70.32266	-150.98
L9824	BKFH, GRAY, NSSB	Unfrozen	70.28425	-151.271
M0015	NSSB, GRAY	Unfrozen	70.10824	-152.058
Mine Site	Not sampled; Isolated (fish unlikely)	Frozen	70.28641	-149.887
Wetland ponds	None	Frozen	70.28466	-149.898
Wetland ponds	None	Frozen	70.2754	-150.062
Wetland pond/impoundment	None	Frozen	70.33655	-149.728
Mine Site	Not sampled; Isolated (fish unlikely)	Frozen	70.28669	-149.883
Wetland ponds	None	Frozen	70.27822	-149.911
Wetland ponds	NSSB, GRAY	Frozen	70.11387	-152.079
Small lake	Not Sampled; NSSB possible	Frozen	70.13882	-152.014
Wetland ponds	None	Frozen	70.15845	-151.774
Wetland ponds	None	Frozen	70.15558	-151.81
Wetland ponds	None	Frozen	70.14726	-151.867
Wetland ponds	None	Frozen	70.16142	-151.762
Wetland ponds	None	Frozen	70.14187	-151.888
Wetland ponds	None	Frozen	70.24239	-152.172
M1522	NSSB	Frozen	70.15288	-152.086
Small pond	NSSB inferred, connected to Lake M1523	Frozen	70.15742	-152.088
M2108	BDWF, NSSB	Frozen	70.2494	-152.179
Wetland ponds	None	Frozen	70.17279	-152.121
Wetland ponds	None	Frozen	70.17713	-152.11
Wetland ponds	None	Frozen	70.25424	-152.186
M0017	NSSB	Frozen	70.10085	-152.133
Wetland ponds	None	Frozen	70.17217	-152.113
Wetland ponds	NSSB	Frozen	70.12428	-152.078
Wetland ponds	None	Frozen	70.12781	-152.08
Small lake	Not sampled; NSSB possible	Frozen	70.1131	-152.102

Note: BDWF (broad whitefish); BKFH (Alaska blackfish); GRAY (Arctic grayling); HBWF (humpback whitefish); LSCS (least cisco); NSSB (ninespine stickleback); RDWF (round whitefish); SLSC (slimy sculpin).

Willow Master Development Plan

Appendix E.11
Birds Technical Appendix

June 2022

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List of Acronyms

ACP	Arctic Coastal Plain
BLM	Bureau of Land Management
DEW	Distant Early Warning
NPR-A	National Petroleum Reserve in Alaska
Project	Willow Master Development Plan Project
USFWS	U.S. Fish and Wildlife Service

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1.0 BIRDS

1.1 Bird Species and Habitats

Table E.11.1 summarizes bird species and habitat use in the analysis area.

Table E.11.1. Bird Species that may Occur in the Analysis Area

Group	English Name	Scientific Name	Relative Abundance[a]	Status	Habitats Used[b]	References
Waterfowl	Greater white-fronted goose	*Anser albifrons*	Common	Breeder	SAMA, TLHC, DOWIP, SOW, SOWIP, SEMA, DPC, YBWC, OBWC, NPWM, PWM, MSSM, MTT, TLDS	Burgess, Johnson et al. 2003; Burgess, Johnson et al. 2013; Johnson, Burgess, Lawhead, Neville et al. 2003; Johnson, Burgess et al. 2004, 2005; Johnson, Parrett et al. 2014; Rozell and Johnson 2016
Waterfowl	Snow goose[c]	*Anser caerulescens*	Common	Breeder	ONW, BRWA, SAMA, TFB, TLLC, TLHC, DOW, DOWIP, SOW, SEMA, DPC, GRMA, OBWC, NPWM, PWM, MSSM, MTT, TLDS, BAR[b]	Burgess, Johnson et al. 2013; Johnson, Burgess et al. 2004; Johnson, Parrett et al. 2015; Johnson, Parrett et al. 2014; Johnson, Wildman et al. 2012, 2013; Mowbray, Cooke et al. 2000
Waterfowl	Brant	*Branta bernicla*	Common	Breeder	ONW, BRWA, SAMA, TFB, TLLC, TLHC, DOWIP, SOW, SOWIP, RS, DPC, YBWC, OBWC, NPWM, PWM, BAR	Burgess, Johnson et al. 2013; Day, Prichard et al. 2005; Johnson, Burgess, Lawhead, Neville et al. 2003; Johnson, Burgess et al. 2004; Johnson, Parrett et al. 2015; Johnson, Parrett et al. 2014; Johnson, Wildman et al. 2012, 2013
Waterfowl	Canada goose	*Branta canadensis*	Common	Breeder	DOW, DOWIP, SOW, SOWIP, SEMA, YBWC, OBWC, NPWM, PWM	Burgess, Johnson et al. 2013; Johnson, Burgess et al. 2004, 2005; Johnson, Parrett et al. 2015; Johnson, Parrett et al. 2014; Rozell and Johnson 2016
Waterfowl	Tundra swan	*Cygnus columbianus*	Common	Breeder	BRWA, SAMA, TFB, TLLC, TLHC, DOW, DOWIP, SOW, RS, SEMA, DPC, GRMA, YBWC, OBWC, NPWM, PWM, MSSM, MTT, TLDS, BAR	Johnson, Burgess, Lawhead, Neville et al. 2003; Johnson, Burgess et al. 2005; Johnson, Parrett et al. 2015; Johnson, Parrett et al. 2016; Jorgenson 2004; Rothe, Markon et al. 1983
Waterfowl	Gadwall	*Mareca strepera*	Casual	Visitor	NA[d]	Johnson and Herter 1989
Waterfowl	American wigeon	*Mareca americana*	Uncommon	Breeder	SEMA, PWM	Rothe, Markon et al. 1983
Waterfowl	Mallard	*Anas platyrhynchos*	Uncommon	Breeder	YBWC, PWM	Burgess, Johnson et al. 2003; Johnson, Burgess et al. 2005
Waterfowl	Northern shoveler	*Spatula clypeata*	Uncommon	Breeder	SEMA, GRMA, NPWM, PWM, MSSM	Burgess, Johnson et al. 2003; Johnson, Burgess, Lawhead, Neville et al. 2003; Rothe, Markon et al. 1983
Waterfowl	Northern pintail	*Anas acuta*	Common	Breeder	SEMA, DPC, NPWM, PWM, MSSM, MTT, TLDS, BAR	Burgess, Johnson et al. 2003; Johnson, Burgess et al. 2004, 2005; Johnson, Burgess, Lawhead, Neville et al. 2003; Johnson, Parrett et al. 2014; Johnson, Parrett et al. 2015; Rothe, Markon et al. 1983; Rozell and Johnson 2016
Waterfowl	Green-winged teal	*Anas crecca*	Uncommon	Breeder	SEMA, DPC, PWM, MSSM, MTT, TLDS	Burgess, Johnson et al. 2003; Johnson, Burgess et al. 2004, 2005; Johnson, Burgess, Lawhead, Neville et al. 2003; Johnson, Parrett et al. 2014; Rothe, Markon et al. 1983; Rozell and Johnson 2016

Group	English Name	Scientific Name	Relative Abundance[a]	Status	Habitats Used[b]	References
Waterfowl	Canvasback	*Aythya valisineria*	Casual	Visitor	NA[d]	Johnson and Herter 1989
Waterfowl	Greater scaup	*Aythya marila*	Uncommon	Breeder	ONW, SEMA, DPC, GRMA, YBWC, NPWM, PWM, MSSM	Burgess, Johnson et al. 2003; Johnson, Burgess et al. 2004, 2005; Johnson, Burgess, Lawhead, Neville et al. 2003; Lysne, Mallek et al. 2004
Waterfowl	Lesser scaup	*Aythya affinis*	Rare	Breeder	ONW, NPWM	Johnson, Burgess et al. 2004; Lysne, Mallek et al. 2004
Waterfowl	**Steller's eider**	***Polysticta stelleri***	**Casual**	**Visitor**	**SOWIP, SEMA, YBWC, OBWC, GRMA, NPWM, PWM, MSSM**	**Graff 2016; Quakenbush, Suydam et al. 2000; Safine 2013, 2015**
Waterfowl	**Spectacled eider**	***Somateria fischeri***	**Uncommon**	**Breeder**	**ONW, BRWA, SAMA, SKT, TLHC, DOW, DOWIP, SOW, SOWIP, DPC, GRMA, YBWC, OBWC, NPWM, PWM**	**Johnson, Burgess, Lawhead, Neville et al. 2003; Johnson, Parrett et al. 2014; Johnson, Parrett et al. 2015; Johnson, Parrett et al. 2016; Anderson, Ritchie et al. 1999; Johnson, Parrett et al. 2008; Fischer and Larned 2004; Johnson, Burgess et al. 2005; Burgess, Johnson et al. 2003**
Waterfowl	King eider	*Somateria spectabilis*	Common	Breeder	ONW, BRWA, SAMA, TLLC, DOW, DOWIP, SOW, SOWIP, RS, SEMA, DPC, GRMA, YBWC, OBWC, NPWM, PWM, MSSM	Burgess, Johnson et al. 2013; Fischer and Larned 2004; Johnson, Burgess et al. 2004, 2005; Johnson, Burgess, Lawhead, Neville et al. 2003; Johnson, Parrett et al. 2014; Johnson, Parrett et al. 2015; Johnson, Parrett et al. 2016; Rozell and Johnson 2016
Waterfowl	Common eider[e]	*Somateria mollissima*	Uncommon	Breeder	ONW, BAR[e]	Fischer and Larned 2004; Johnson 2000; LGL Alaska Research Associates Inc. 2002
Waterfowl	Surf scoter	*Melanitta perspicillata*	Common	Breeder	ONW	Johnson and Herter 1989; Lysne, Mallek et al. 2004
Waterfowl	White-winged scoter	*Melanitta deglandi*	Common	Breeder	ONW	Johnson and Herter 1989; Lysne, Mallek et al. 2004
Waterfowl	Black scoter	*Melanitta americana*	Casual	Visitor	ONW	Johnson and Herter 1989; Lysne, Mallek et al. 2004
Waterfowl	Long-tailed duck	*Clangula hyemalis*	Common	Breeder	ONW, BRWA, DOW, DOWIP, SOW, SOWIP, SEMA, DPC, GRMA, YBWC, OBWC, NPWM, PWM, MSSM, MTT, TLDS, RS	Johnson, Burgess, Lawhead, Neville et al. 2003; Johnson, Parrett et al. 2014; Johnson, Parrett et al. 2015; Johnson, Parrett et al. 2016; Fischer and Larned 2004; Rothe, Markon et al. 1983; Johnson, Burgess et al. 2004, 2005; Burgess, Johnson et al. 2013; Burgess, Johnson et al. 2003
Waterfowl	Red-breasted merganser	*Mergus serrator*	Rare	Breeder	DOW, DOWIP, SOWIP	Johnson, Burgess et al. 2004; ABR unpublished data
Loons and grebes	Red-necked grebe	*Podiceps grisegena*	Rare	Breeder	TLHC, DOW, SEMA, GRMA[f]	Johnson, Burgess, Lawhead, Neville et al. 2003; Rothe, Markon et al. 1983
Loons and grebes	**Red-throated loon**	***Gavia stellata***	**Common**	**Breeder**	**ONW, BRWA, SAMA, SOWIP, DPC, OBWC, RICO, NPWM, PWM[f]**	**Burgess, Johnson et al. 2013; Burgess, Johnson et al. 2003; Day, Prichard et al. 2005; Fischer and Larned 2004; Johnson, Burgess et al. 2004; Johnson, Burgess, Lawhead, Neville et al. 2003; Rothe, Markon et al. 1983**
Loons and grebes	Pacific loon	*Gavia pacifica*	Common	Breeder	ONW, BRWA, SAMA, TLHC, DOW, DOWIP, SOW, SOWIP, SEMA, DPC, GRMA, OBWC, RICO, NPWM, PWM, MSSM, HUMO[f]	Burgess, Johnson et al. 2013; Burgess, Johnson et al. 2003; Day, Prichard et al. 2005; Fischer and Larned 2004; Johnson, Burgess, Lawhead, Neville et al. 2003; Kertell 1996; Rothe, Markon et al. 1983; Rozell and Johnson 2016

Group	English Name	Scientific Name	Relative Abundance[a]	Status	Habitats Used[b]	References
Loons and grebes	Common loon	*Gavia immer*	Casual/Accidental	Visitor	NA[d]	–
Loons and grebes	**Yellow-billed loon**	***Gavia adamsii***	**Common**	**Breeder**	**ONW, TLHC, DOW, DOWIP, SOWIP, SEMA, DPC, GRMA, NPWM, PWM, MSSM[f]**	**Day, Prichard et al. 2005; Fischer and Larned 2004; Johnson, Burgess et al. 2004; Johnson, Burgess, Lawhead, Neville et al. 2003; Johnson, Parrett et al. 2015; Johnson, Parrett et al. 2016; Rothe, Markon et al. 1983**
Seabirds	Pomarine jaeger	*Stercorarius pomarinus*	Uncommon	Visitor	NA[d]	Johnson and Herter 1989
Seabirds	Parasitic jaeger	*Stercorarius parasiticus*	Uncommon	Breeder	SEMA, YBWC, OBWC, DPC, NPWM, PWM, MSSM, RICO	Burgess, Johnson et al. 2003; Burgess, Johnson et al. 2013; Day, Prichard et al. 2005; Johnson, Burgess, Lawhead, Neville et al. 2003; Johnson, Parrett et al. 2014; Jorgenson 2004; Rozell and Johnson 2016
Seabirds	Long-tailed jaeger	*Stercorarius longicaudus*	Uncommon	Breeder	OBWC, NPWM, PWM, MSSM, MTT	Anderson, Lawhead et al. 2001; Burgess, Johnson et al. 2003; Day, Prichard et al. 2005; Johnson, Burgess et al. 2004; Johnson, Burgess, Lawhead, Neville et al. 2003
Seabirds	Black guillemot	*Cepphus grylle*	Rare	Visitor	ONW	Johnson and Herter 1989
Seabirds	Black-legged kittiwake	*Rissa tridactyla*	Rare	Visitor	ONW	Johnson and Herter 1989
Seabirds	Sabine's gull	*Xema sabini*	Uncommon	Breeder	ONW, BRWA, SAMA, DOW, DOWIP, SOWIP, SEMA, DPC, OBWC, NPWM, MSSM, SKT, BAR	Day, Prichard et al. 2005; Day, Stenhouse et al. 2001; Johnson, Burgess et al. 2004; Johnson, Burgess, Lawhead, Neville et al. 2003; Johnson, Parrett et al. 2015; Rozell and Johnson 2016
Seabirds	Herring gull	*Larus argentatus*	Casual/ Accidental	Visitor	NA[d]	Johnson and Herter 1989
Seabirds	Thayer's gull	*Larus thayeri*	Casual/ Accidental	Visitor	NA[d]	Johnson and Herter 1989
Seabirds	Glaucous-winged gull	*Larus glaucescens*	Casual/ Accidental	Visitor	NA[d]	Johnson and Herter 1989
Seabirds	Glaucous gull	*Larus hyperboreus*	Common	Breeder	ONW, BRWA, TFB, TLLC, TLHC, DOWIP, SOW, SOWIP, SEMA, YBWC, OBWC, BAR, DPC	Burgess, Johnson et al. 2003; Burgess, Johnson et al. 2013; Day, Prichard et al. 2005; Fischer and Larned 2004; Johnson, Burgess et al. 2004; Johnson, Burgess, Lawhead, Neville et al. 2003; Johnson, Parrett et al. 2014
Seabirds	**Arctic tern**	***Sterna paradisaea***	**Common**	**Breeder**	**ONW, SKT, SAMA, TLHC, DOW, DOWIP, SOWIP, SOW, SEMA, DPC, YBWC, OBWC, NPWM, PWM, MSSM**	**Day, Prichard et al. 2005; Fischer and Larned 2004; Johnson, Burgess, Lawhead, Neville et al. 2003; Johnson, Burgess et al. 2002; Johnson, Burgess et al. 2004; Johnson, Parrett et al. 2015; Johnson, Parrett et al. 2014**
Shorebirds	Black-bellied plover	*Pluvialis squatarola*	Common	Breeder	OBWC, DUCO, PWM, MSSM	Andres 1989; Rothe, Markon et al. 1983
Shorebirds	American golden-plover	*Pluvialis dominica*	Common	Breeder	SAMA, DPC, PWM, MSSM, MTT, TLDS	Andres 1989; Brown, Bart et al. 2007; Meehan 1986; Rothe, Markon et al. 1983; Taylor, Lanctot et al. 2010
Shorebirds	Semipalmated plover	*Charadrius semipalmatus*	Uncommon	Breeder	BAR, HUMO	Johnson and Herter 1989

Group	English Name	Scientific Name	Relative Abundance[a]	Status	Habitats Used[b]	References
Shorebirds	Upland sandpiper	*Bartramia longicauda*	Casual/ Accidental	Visitor	NA[d]	Johnson and Herter 1989
Shorebirds	**Whimbrel**	***Numenius phaeopus***	**Rare**	**Breeder**	**PWM**	**Burgess, Johnson et al. 2003**
Shorebirds	**Bar-tailed godwit**	***Limosa lapponica***	**Uncommon**	**Breeder**	**NPWM, PWM, MSSM, MTT, TLDS**	**Burgess, Johnson et al. 2003; Day, Prichard et al. 2005; Johnson, Burgess, Lawhead, Neville et al. 2003; Johnson, Burgess et al. 2004; Johnson, Parrett et al. 2015; Johnson, Parrett et al. 2016; McCaffery and Gill 2001**
Shorebirds	Ruddy turnstone	*Arenaria interpres*	Uncommon	Breeder	SKT, DPC, NPWM, PWM	Andres 1989; Johnson and Herter 1989
Shorebirds	**Red knot**	***Calidris canutus***	**Rare**	**Visitor**	**NA[d]**	**Johnson and Herter 1989**
Shorebirds	Stilt sandpiper	*Calidris himantopus*	Common	Breeder	YBWC, OBWC, PWM, NPWM	Andres 1989, 1994; LGL Alaska Research Associates Inc. 1988
Shorebirds	Sanderling	*Calidris alba*	Rare	Visitor	TFB[d]	Johnson and Herter 1989
Shorebirds	**Dunlin**	***Calidris alpina***	**Common**	**Breeder**	**SAMA, TFB, SEMA, YBWC, OBWC, NPWM, PWM, MSSM**	**Andres 1989; LGL Alaska Research Associates Inc. 1988; Taylor, Lanctot et al. 2010**
Shorebirds	Baird's sandpiper	*Calidris bairdii*	Rare	Breeder	MSSM, TLDS, BAR, MTT	Moskoff and Montgomerie 2002
Shorebirds	Least sandpiper	*Calidris minutilla*	Casual/ Accidental	Visitor	NA[d]	Johnson and Herter 1989
Shorebirds	White-rumped sandpiper	*Calidris fuscicollis*	Rare	Breeder	NPWM, PWM, MSSM, TLDS	Parmelee 1992
Shorebirds	**Buff-breasted sandpiper**	***Calidris subruficollis***	**Rare**	**Breeder**	**DUCO, NPWM, MSSM, MTT, TLDS, BAR**	**McCarty, Wolfenbarger et al. 2017**
Shorebirds	Pectoral sandpiper	*Calidris melanotos*	Common	Breeder	SAMA, SEMA, GRMA, DPC, YBWC, OBWC, NPWM, PWM, MSSM, BAR	Andres 1989; Brown, Bart et al. 2007; LGL Alaska Research Associates Inc. 1988; Taylor, Lanctot et al. 2010
Shorebirds	Semipalmated sandpiper	*Calidris pusilla*	Common	Breeder	SAMA, TFB, DPC, YBWC, OBWC, NPWM, PWM, MSSM	Andres 1989; LGL Alaska Research Associates Inc. 1988; Rothe, Markon et al. 1983; Taylor, Lanctot et al. 2010
Shorebirds	Western sandpiper	*Calidris mauri*	Casual/ Accidental	Visitor	SAMA, PWM	Andres 1989; Taylor, Lanctot et al. 2010
Shorebirds	Long-billed dowitcher	*Limnodromus scolopaceus*	Common	Breeder	SAMA, SEMA, YBWC, OBWC, NPWM, PWM	Andres 1989; Takekawa and Warnock 2000; Taylor, Lanctot et al. 2010
Shorebirds	Wilson's snipe	*Gallinago delicata*	Uncommon	Breeder	YBWC, OBWC, NPWM, PWM, MSSM	Johnson, Burgess, Lawhead, Neville et al. 2003
Shorebirds	Lesser yellowlegs	*Tringa flavipes*	Rare	Breeder	NA[d]	Johnson and Herter 1989
Shorebirds	Red-necked phalarope	*Phalaropus lobatus*	Common	Breeder	ONW, SAMA, SEMA, DPC, GRMA, YBWC, OBWC, NPWM, PWM, MSSM, HUMO	Andres 1989; Brown, Bart et al. 2007; LGL Alaska Research Associates Inc. 1988; Rothe, Markon et al. 1983; Rubega, Schamel et al. 2000

Group	English Name	Scientific Name	Relative Abundance[a]	Status	Habitats Used[b]	References
Shorebirds	Red phalarope	*Phalaropus fulicarius*	Common	Breeder	ONW, SAMA, SEMA, DPC, GRMA, YBWC, OBWC, NPWM, PWM	Andres 1989; Brown, Bart et al. 2007; LGL Alaska Research Associates Inc. 1988; Tracy, Schamel et al. 2002
Cranes	Sandhill crane	*Mareca americana*	Uncommon	Breeder	SEMA, GRMA, NPWM, PWM	Gerber, Dwyer et al. 2014; Johnson, Parrett et al. 2014; Johnson, Lawhead et al. 1998
Raptors	Bald eagle	*Haliaeetus leucocephalus*	Rare	Visitor	NA[d]	Johnson and Herter 1989
Raptors	Northern harrier	*Circus hudsonius*	Rare	Breeder	NPWM, PWM, MSSM, TLDS	Smith, Wittenberg et al. 2011; Burgess, Johnson et al. 2003
Raptors	Rough-legged hawk	*Buteo lagopus*	Uncommon	Breeder	MSSM, MTT, HUMO	Johnson and Herter 1989; Ritchie 1991
Raptors	Golden eagle	*Aquila chrysaetos*	Uncommon	Visitor	NA[d]	Johnson and Herter 1989
Raptors	Snowy owl	*Bubo scandiacus*	Uncommon	Breeder	OBWC, PWM, NPWM, MSSM, MTT, TLDS	Holt, Larson et al. 2015; Burgess, Johnson et al. 2013
Raptors	Short-eared owl	*Asio flammeus*	Uncommon	Rare breeder	NPWM, PWM, MSSM, MTT, TLDS	Johnson, Burgess et al. 2001; Johnson, Burgess et al. 2002; Johnson, Burgess, Lawhead, Parrett et al. 2003
Raptors	Merlin	*Falco columbarius*	Rare	Visitor	NA[d]	Johnson and Herter 1989
Raptors	Gyrfalcon	*Falco rusticolus*	Rare	Visitor	NA[d]	Johnson, Parrett et al. 2014
Raptors	**Arctic peregrine falcon**	***Falco peregrinus tundrius***	**Uncommon**	**Rare Breeder**	**TLDS, HUMO**	**Frost, Ritchie et al. 2007; Ritchie 2014; White, Clum et al. 2002**
Ptarmigan	Willow ptarmigan	*Lagopus lagopus*	Common	Breeder	DPC, OBWC, NPWM, PWM, MSSM, MTT, TLDS	Johnson, Burgess, Lawhead, Neville et al. 2003; Johnson, Parrett et al. 2014; Johnson, Parrett et al. 2015; Johnson, Burgess et al. 2004; Rothe, Markon et al. 1983; Johnson, Burgess et al. 2005; Burgess, Johnson et al. 2013; Burgess, Johnson et al. 2003
Ptarmigan	Rock ptarmigan	*Lagopus muta*	Uncommon	Breeder	PWM, MSSM, MTT, TLDS	Johnson, Burgess, Lawhead, Neville et al. 2003; Rothe, Markon et al. 1983; Burgess, Johnson et al. 2003
Passerines	Common raven	*Corvus corax*	Uncommon (except common around infrastructure)	Breeder	TLDS, HUMO	Johnson, Lawhead et al. 1998; Powell and Backensto 2009
Passerines	Arctic warbler	*Phylloscopus borealis*	Rare	Breeder	TLDS	Johnson and Herter 1989; Lowther and Sharbaugh 2014
Passerines	Bluethroat	*Luscinia svecica*	Casual/ Accidental	Visitor	TLDS	Guzy and McCaffery 2002; Johnson and Herter 1989
Passerines	Gray-cheeked thrush	*Catharus minimus*	Casual/ Accidental	Visitor	TLDS	Johnson and Herter 1989; Lowther, Rimmer et al. 2001
Passerines	Eastern yellow wagtail	*Motacilla tschutschensis*	Uncommon	Breeder	MSSM, MTT, TLDS	Badyaev, Kessel et al. 1998; Johnson and Herter 1989

Group	English Name	Scientific Name	Relative Abundance[a]	Status	Habitats Used[b]	References
Passerines	Redpoll	*Acanthis flammea* and *A. hornemanni*	Uncommon	Breeder	MSSM, TLDS	Johnson and Herter 1989; Knox and Lowther 2000a, 2000b
Passerines	Lapland longspur	*Calcarius lapponicus*	Common	Breeder	NPWM, PWM, MSSM, MTT	Hussell and Montgomerie 2002
Passerines	Snow bunting	*Plectrophenax nivalis*	Uncommon (except common around infrastructure)	Breeder	BAR, HUMO	Montgomerie and Lyon 2011
Passerines	American tree sparrow	*Spizelloides arborea*	Uncommon	Breeder	TLDS	Johnson and Herter 1989; Naugler, Pyle et al. 2017
Passerines	Savannah sparrow	*Passerculus sandwichensis*	Common	Breeder	DPC, NPWM, PWM, MSSM, MTT	Johnson and Herter 1989; Wheelwright and Rising 2008
Passerines	Fox sparrow	*Passerella iliaca*	Casual/ Accidental	Visitor	TLDS	Weckstein, Kroodsma, and Faucett 2002
Passerines	Lincoln's sparrow	*Melospiza lincolnii*	Casual/ Accidental	Visitor	TLDS	Ammon 1995
Passerines	White-crowned sparrow	*Zonotrichia leucophrys*	Rare	Breeder	TLDS	Chilton, Baker et al. 1995; Johnson and Herter 1989

Note: Shading denotes species that may use the analysis area year-round. Bolding denotes Special Status Species.
BAR (Barren); BRWA (Brackish Water); DOW (Deep Open Water without Islands); DOWIP (Deep Open Water with Islands or Polygonized Margins); DPC (Deep Polygon Complex); DUCO (Dune Complex); GRMA (Grass Marsh); HUMO (Human Modified); MSSM (Moist Sedge-Shrub Meadow); MTT (Moist Tussock Tundra); NPWM (Nonpatterned Wet Meadow); NA (not applicable); OBWC (Old Basin Wetland Complex); ONW (Open Nearshore Water); PWM (Patterned Wet Meadow); RICO (Riverine Complex); RS (River or Stream); SAMA (Salt Marsh); SEMA (Sedge Marsh); SKT (Salt-Killed Tundra); SOW (Shallow Open Water without Islands); SOWIP (Shallow Open Water with Islands or Polygonized Margins); TFB (Tidal Flat Barrens); TLDS (Tall, Low, or Dwarf Shrub); TLHC (Tapped Lake with High-Water Connection); TLLC (Tapped Lake with Low-water Connection); YBWC (Young Basin Wetland Complex). Habitats are defined in Willow Master Development Plan Environmental Impact Statement, Section 3.9, *Wetlands and Vegetation*, and Table E.11.2.

[a] Common—occurs in all or nearly all proper habitats, but some areas are occupied sparsely or not at all; uncommon—occurs regularly but uses little of the suitable habitat or occurs regularly in relatively small numbers; rare—occurs within normal range, regularly, in very small numbers; casual—beyond its normal range, but irregular observations are likely over years; accidental—so far beyond its normal range that future observations are unlikely (Johnson and Herter 1989).

[b] Primarily nesting habitats but includes pre-breeding, brood-rearing, and post-breeding habitats for species whose preference or use varies markedly between these periods (e.g., brant, snow goose, and shorebirds). Preference based on selection analyses, where available; in absence of selection analyses, based on use of nesting, brood-rearing, and post-breeding habitat from literature. Habitats that occur in the Project vicinity are listed in the table.

[c] Snow goose colonies tend to be on the coast; they initially colonized river deltas on the Arctic Coastal Plain. They have been expanding inland across a variety of habitats. Initially found on raised areas, where snow melts early but is not subject to flooding; thus, unvegetated and partially vegetated BAR, TLDS, NPWM, PWM, and DPC.

[d] No records of nesting or no nesting habitat are described for the central Beaufort Sea coast.

[e] Common eiders nest on coastal barrier islands, sandspits, and partially vegetated beaches along the Beaufort Sea coast.

[f] Pacific, red-throated, and yellow-billed loons and red-necked grebes nest on the shorelines of waterbodies; terrestrial habitats in the table refer to the shoreline habitat bordering a waterbody.

1.1.1 Special Status Species

Nine bird species listed as sensitive species by the Bureau of Land Management (BLM) may occur in the analysis area: spectacled eider, Steller's eider, yellow-billed loon, red-throated loon, dunlin (*arcticola* subspecies), bar-tailed godwit, whimbrel, buff-breasted sandpiper, and red knot (BLM 2019). The U.S. Fish and Wildlife Service (USFWS) list of species of conservation concern includes seven species on the BLM list above (spectacled and Steller's eiders are not included as they are listed as threatened under the Endangered Species Act), plus Arctic peregrine falcon and Arctic tern. Of the Special Status Species, Steller's eider is a casual visitor whose former breeding range extended across the Artic Coastal Plain (ACP), until its range contracted with a population-wide decline (Quakenbush, Day et al. 2002). Red knot is a rare to casual visitor. Buff-breasted sandpiper, whimbrel, and peregrine falcon are rare breeders. The remaining species are common to uncommon breeders in the analysis area. Red-throated loons are common breeders in some areas that use polygonal ponds, shallow lakes, brackish water, and wetland complexes for nesting and raising broods (Johnson, Burgess et al. 2004, 2005) and marine waters for feeding (Barr, Eberl et al. 2000). Dunlin is among the top six most common nesting shorebirds in the National Petroleum Reserve in Alaska (NPR-A) (Bart, Brown et al. 2012), and one of the top three migrating along the coast (Taylor, Lanctot et al. 2010). It nests primarily in wet and moist sites in wetlands with ponds and drained lake basins (Bart, Brown et al. 2012; Warnock and Gill 1996) and uses silt barrens during post-breeding (Andres 1994). Bar-tailed godwits are widely distributed but uncommon breeders that nest in lowlands and uplands, in wet to moist sedge or tussock meadows, often in association with dwarf or low shrubs; they use a wide range of habitats (Bart, Brown et al. 2012; McCaffery and Gill 2001). Whimbrels nest in low wetlands and dwarf shrubs from flat to low center or high center polygons (Skeel and Mallory 1996). Whimbrel is a rare breeder, found in low numbers (on 21 of 637 plots) in moist and wet habitats on the ACP (Bart, Brown et al. 2012), and only one was recorded during post-breeding on the Colville River Delta (Andres 1994). Another rare breeder in NPR-A, buff-breasted sandpiper (21 birds recorded on 357 plots; Bart, Brown et al. 2012) is considered an "upland" shorebird and is unique among the shorebirds in this area for its use of dry ridges, stream banks, and dwarf shrub and partially vegetated areas for breeding displays; it nests in drier sloping tundra with tussocks and in moist and wet sedge meadows with nonpatterned or polygonal surface forms (McCarty, Wolfenbarger et al. 2017). Red knots are not known to breed east of Point Barrow on the ACP but can occur along the Beaufort Sea coast during migration (Baker, Gonzalez et al. 2013). Peregrine falcon is a rare breeder on the ACP but will nest on bluffs along streams and lakes in the NPR-A (Ritchie 2014) and uses bridges (J. Parrett, Research Biologist, ABR, to C. Johnson. 2018) and elevated structures (White, Clum et al. 2002), such as the Distant Early Warning (DEW) Line site at Oliktok Point (Frost, Ritchie et al. 2007), for nest sites. Arctic terns are common nesters, are not evenly distributed, and are often found in complex fresh and salt marshes and wetlands or emergent vegetation and islands in deep and shallow lakes (Johnson, Burgess, Lawhead, Neville et al. 2003; Johnson, Burgess et al. 2004, 2005); they use marine waters for feeding and migration (Fischer and Larned 2004). Table E.11.2 shows habitat types used by Special Status Species on the ACP from spring arrival to fall staging. All but three habitat types in the analysis area are used by one or more Special Status Species.

Spectacled eiders occur in the analysis area during pre-breeding in a non-uniform distribution (Figure 3.11.2) and nest in some parts of the analysis area in low densities (Johnson, Shook et al. 2019; Morgan and Attanas 2018). Spectacled eiders are more abundant in coastal areas, where the module delivery facilities are located, than they are in the Willow area. Surveys conducted at 50% coverage for the Willow Master Development Plan Project (Project) detected two groups of spectacled eiders in 2017, five groups in 2018, and five groups in 2019 (Figure 3.11.2), resulting in indicated total densities of 0.015, 0.035, and 0.035 birds per square mile, respectively (0.006, 0.014, and 0.014 birds per square kilometer) (Shook, Parrett et al. 2020), which are within the range of densities recorded on USFWS aerial surveys (Figure 3.11.2). The density of spectacled eiders from those Project surveys is approximately 10% to 30% of densities found on the Colville River Delta and the entire ACP (Figure 4 in Johnson, Parrett et al. 2018a). Densities of pre-breeding spectacled eiders from USFWS surveys of the ACP (USFWS unpublished data) vary from 0 to 0.26 birds per square mile in the area of permanent roads and pads, whereas the module delivery options contain higher densities, ranging from 0 to 0.87 birds per square mile (Figure 3.11.2). Spectacled eiders nest in the Kuparuk Oilfield along the Oliktok Road, near Option 3 (Morgan and

Attanas 2018), near Point Lonely (Frost, Ritchie et al. 2007), and probably nest in appropriate habitat at Atigaru Point. Three spectacled eider nests were found in a wetland about 7 miles east of the Bear Tooth drill site 4 (BT4) in 2001 and no spectacled eider nests have been found in the Willow area over the past two years of nest searches focused on king eiders and shorebirds (Rozell, Shook et al. 2021). Whereas the 656-foot (200 meters [m]) disturbance zone is intended to protect spectacled eiders from various types of human disturbance, there is some research that suggests this zone may be larger than necessary to protect nesting eiders. Data collected on spectacled eiders on the Colville River during nesting found that nesting spectacled eiders rarely (7% or 6 of 84 hens on nests) flush at distances greater than 82 feet (> 25 m) from people on foot; the greatest distance at which flushing occurred was 131 feet (40 m) (ABR unpublished data). There are several examples of spectacled eider nests that have hatched and some that have failed < 656 feet (200 m) from active roads and airstrips (Attanas and Shook 2020; Johnson, Parrett et al. 2008; Morgan and Attanas 2018; Seiser and Johnson 2018). An analysis of variance of distance to active infrastructure at Alpine CD3 on the Colville Delta found no significant effects of year, construction phase, or nest fate ($P \geq 0.36$), even though on average, successful nests were closer than failed nests to a road, drill pad, or airstrip (Johnson, Parrett et al. 2008). There was no evidence of displacement or decreased nesting success from before construction to the operation phase of the development.

In addition to being a Bird of Conservation Concern, the yellow-billed loon was a candidate for listing under the Endangered Species Act because of its small population size, patchy breeding distribution, and possible threats to its population viability in Alaska (USFWS 2014b) until listing of the species was ruled unwarranted in 2014 (USFWS 2014a). A conservation plan for yellow-billed loons was adopted by federal, state, and local governments (USFWS 2006), but it lapsed 10 years after adoption. The yellow-billed loon is distributed unevenly on the ACP, occurring in the NPR-A east to approximately the Colville River Delta (Earnst 2004; Earnst, Stehn et al. 2005). The NPR-A supports > 75% of the U.S. breeding population (Schmutz, Wright et al. 2014). Yellow-billed loons are territorial breeders, excluding conspecifics from nesting lakes or portions of very large lakes that are shared by two to four pairs (Johnson, Wildman et al. 2019). They are common breeders in the analysis area; surveys conducted since 2001 have detected 67 breeding territories encompassing 71 lakes in the portion of the analysis area within the NPR-A (Johnson, Parrett et al. 2018b, 2019; Parrett and Shook 2021). Yellow-billed loons maintain territories on the same lakes for several decades (Johnson, Parrett et al. 2019) and are habitat specialists, preferring deep, clear, open lakes and deep lakes with emergent vegetation containing fish (Earnst, Platte et al. 2006; Haynes, Schmutz et al. 2014); they nest most often on islands, peninsulas, and shorelines protected from wave action (Haynes, Schmutz et al. 2014; North and Ryan 1989). Citing a lack of population growth, a patchy breeding distribution, specific habitat requirements for breeding lakes, high fidelity to and retention rates of breeding territories, and low rates of colonization of unoccupied lakes in their range, several studies have suggested that yellow-billed loons are habitat limited (Haynes, Schmutz et al. 2014; Johnson, Wildman et al. 2019; Schmutz, Wright et al. 2014).

1.1.2 Bird Habitats

Bird habitat types and use in the analysis area is detailed in Table E.11.1. Table E.11.2 ranks habitat types in order of number of species reported to use them (i.e., species richness) from literature and reports. Table E.11.3 summarizes preferred pre-breeding and all nesting habitat types documented for spectacled eiders in the NPR-A and the adjacent Colville River Delta. The ranking is an index of the importance of the various habitat types to the avian community as a whole, although not all the species on the list may occur in the analysis area, or some may occur sporadically. While species richness can be related to abundance (i.e., the habitat types with more species also tend to support higher numbers, particularly for nesting), species richness is not equivalent to abundance or density. Some habitat types with low species richness may be crucial to some species for important facets of life history. For example, tidal flat barrens on the ACP are important feeding areas for post-breeding and pre-migratory shorebirds that support thousands to tens of thousands of shorebirds during late summer (Andres 1994; Taylor, Lanctot et al. 2010). Another habitat type used by two species, Dune Complex, is one of several habitat types that can include stream banks, barren or partially vegetated ridges and dunes, and uplands, which are used by male buff-breasted sandpipers for leks (i.e., breeding display areas). All but two habitat types in the analysis area are used by one or more Special Status Species.

Table E.11.2. Descriptions and Use of Bird Habitats in the Analysis Area

Habitat[a]	Description	Special Status Species Use	No. of Species Using	Acres in Analysis Area
Dune Complex	Mosaic of swale and ridge features on inactive sand dunes, supporting wet to flooded sedge and moist shrub types in swales and moist to dry dwarf and low shrub types on ridges	Yes	2	1,838.6
Riverine Complex	Mosaic of moist to wet sedge and shrub types, water, and barrens along flooded streams and associated floodplains	Yes	3	1,701.4
River or Stream	Permanently flooded channels large enough to be mapped as separate units	No	4	8,199.3
Salt-Killed Tundra	Coastal low-lying areas where salt water from storm surges has killed the original vegetation and is being colonized by salt-tolerant vegetation	Yes	4	434.4
Tapped Lake with Low-Water Connection	Same as Tapped Lake with High-Water Connection except connected to adjoining surface waters even at low water	No	5	2,234.2
Human Modified[b]	Area with vegetation, soil, or water significantly disturbed by human activity	Yes	7	4,103.9
Tidal Flat Barrens	Nearly flat, barren mud or sand periodically inundated by tidal waters; may include small areas of partially vegetated mud or sand	Yes	7	131.8
Brackish Water	Coastal ponds and lakes that are flooded periodically by salt water during storm surges	Yes	10	205.8
Tapped Lake with High-Water Connection	Lakes that were breached and drained by a migrating river channel and permafrost thaw; tapped lakes are subject to river stages and discharge and are connected only during flood or high-water events	Yes	10	4,547.7
Shallow Open Water without Islands	Waterbody lacking emergent vegetation with depths less than 6.6 feet (2 m)	Yes	11	10,609.2
Barren	Area without vegetation and not normally inundated	Yes	12	10,255.1
Deep Open Water without Islands	Waterbody lacking emergent vegetation with a depth of at least 6.6 feet (2 m) and lacking islands or polygonized margins	Yes	12	34,753.6
Deep Open Water with Islands or Polygonized Margins	Waterbody with depths of at least 6.6 feet (2 m) with islands or with polygonized wetlands forming a complex shoreline	Yes	14	25,351.9
Shallow Open Water with Islands or Polygonized Margins	Waterbody lacking emergent vegetation with depths less than 6.6 feet (2 m) with islands or polygonized wetlands forming a complex shoreline (Willow Master Development Plan Environmental Impact Statement, Section 3.9, *Wetlands and Vegetation*)	Yes	14	7,482.2
Grass Marsh	Ponds and lake margins with the emergent grass *Arctophila fulva* (pendant grass); shallow water depths (less than 3.3 feet [1 m]); tends to have abundant invertebrates, good escape cover for birds, and is of high importance to many waterbirds	Yes	15	1,919.0
Moist Tussock Tundra	Gentle slopes and ridges of coastal deposits and terraces, pingos, and the uplifted centers of older drained lake basins; vegetation is dominated by tussock-forming plants, most commonly *Eriophorum vaginatum*; associated with high-centered polygons of low or high relief	Yes	19	134,620.5
Salt Marsh	Complex assemblage of small brackish ponds, halophytic sedges and willows, and barren patches on stable mudflats usually associated with river deltas	Yes	21	1,280.5
Young Basin Wetland Complex	Complex ice-poor, drained lake thaw basins characterized by a complex mosaic of vegetation classes that, in general, have surface water with a high percentage of Sedge Marsh and Grass Marsh	Yes	21	4,606.2
Open Nearshore Water	Shallow estuaries, lagoons, and embayments along the Beaufort Sea coast	Yes	22	1,786.5
Deep Polygon Complex	Area permanently flooded with water more than 1.6 feet (0.5 m) deep, frequently with emergent sedge in margins, deep polygon centers, and well-developed polygon rims	Yes	25	1,317.9
Sedge Marsh	Permanently flooded waterbodies dominated by the emergent sedge *Carex aquatilis*; typically, emergent sedges occur in water < 1.6 feet (0.5 m) deep	Yes	25	9,177.3

Habitat[a]	Description	Special Status Species Use	No. of Species Using	Acres in Analysis Area
Old Basin Wetland Complex	Complex ice-rich habitat in older drained lake basins with well-developed low- and high-centered polygons resulting from ice-wedge development and aggradation of segregated ice	Yes	27	35,899.6
Tall, Low, or Dwarf Shrub	Both open and closed stands of low (≤4.9 feet [1.5 m] high) and tall (>4.9 feet [1.5 m] high) willows along riverbanks and *Dryas* tundra on upland ridges and stabilized sand dunes	Yes	27	26,802.2
Moist Sedge-Shrub Meadow	High-centered, low-relief polygons and mixed high- and low-centered polygons on gentle slopes of lowland, riverine, drained basin, and deposits formed by the movement of soil and other material; soils saturated at intermediate depths (>0.5 feet [> 0.15 m]) but generally free of surface water during summer	Yes	37	104,498.2
Nonpatterned Wet Meadow	Analogous to Sedge Meadow or Shrub Meadow; lowland areas, typically flooded in spring but lacking polygons or other terrain relief features	Yes	39	30,076.9
Patterned Wet Meadow	Lowland areas with low-centered polygons that are flooded in spring and centers flooded or with water remaining close to the surface throughout the growing season; vegetation growth typically is more robust in polygon troughs than in centers	Yes	44	68,927.1
Unmapped	Unknown	Unknown	Unknown	642,071.6
Total	**NA**	NA	**NA**	**1,174,832.6**

Source: See sources for Table E.11.1.

Note: As described in Section 3.11.1.2, *Bird Habitats*, habitats were ranked by the number of species using them to portray areas with the highest potential for avian occurrence. Actual scores ranged from 1 (one species used the habitat) to 44 (44 species used the habitat). Shading denotes high-use habitats (at least 20 species use the habitat). See Table E.11.1 for more details on habitat values.

m (meters); NA (not applicable).

[a] More information on these habitat types is provided in Willow Master Development Plan Environmental Impact Statement, Section 3.9.

[b] Used by one Special Status Species, peregrine falcon, and several species of passerines, raptors, and shorebirds that nest on structures or gravel.

Table E.11.3. Spectacled Eider Habitat Preference and Use

Habitat	NE NPR-A Pre-breeding Use (%)[a]	NE NPR-A Pre-breeding Availability (%)	NE NPR-A Pre-breeding Preference[b]	Colville Pre-breeding Use (%)[a]	Colville Pre-breeding Availability (%)	Colville Pre-breeding Preference[b]	NE NPR-A Nesting[c] Use (%)	Colville Nesting[c] Use (%)
Open Nearshore Water[d]	**1.7**	**0.3**	**ns**	**0.2**	**1.6**	**avoid**	**–**	**–**
Brackish Water	**11.7**	**0.3**	**prefer**	**6.7**	**1.3**	**prefer**	–	**4.0**
Tapped Lake with Low-Water Connection	0	0.2	ns	2.9	4.5	avoid	–	–
Tapped Lake with High-Water Connection	**0**	**< 0.1**	**ns**	**2.2**	**3.7**	**ns**	**–**	**1.2**
Salt Marsh	**3.3**	**0.7**	**ns**	**6.7**	**3.2**	**prefer**	**9.1**	**1.7**
Tidal Flat Barrens	0	0.3	ns	0.2	7.0	avoid	-	–
Salt-Killed Tundra	**0**	**< 0.1**	**ns**	**9.3**	**5.1**	**prefer**	**–**	**12.7**
Deep Open Water without Islands	**3.3**	**8.0**	**ns**	**4.3**	**3.4**	**ns**	**–**	**0.6**
Deep Open Water with Islands or Polygonized Margins	**13.3**	**4.9**	**prefer**	**3.8**	**2.1**	**prefer**	**–**	**6.4**
Shallow Open Water without Islands	**11.7**	**1.2**	**prefer**	**0.7**	**0.4**	**ns**	**–**	**–**
Shallow Open Water with Islands or Polygonized Margins	**10.0**	**1.4**	**prefer**	**1.4**	**0.1**	**prefer**	**9.1**	**1.2**
River or Stream	1.7	0.9	ns	3.1	14.4	avoid	–	–
Sedge Marsh	1.7	2.2	ns	0.2	< 0.1	ns	–	–
Deep Polygon Complex	**0**	**< 0.1**	**ns**	**27.6**	**2.7**	**prefer**	**–**	**24.9**
Grass Marsh	**5.0**	**0.4**	**prefer**	**1.0**	**0.2**	**prefer**	**9.1**	**–**
Young Basin Wetland Complex	**0**	**0.3**	**ns**	**0**	**< 0.1**	**ns**	**9.1**	**–**
Old Basin Wetland Complex	**18.3**	**8.0**	**prefer**	**0**	**< 0.1**	**ns**	**45.5**	**–**
Riverine Complex	0	0.4	ns	–	–	–	–	–
Dune Complex	1.7	0.9	ns	–	–	–	–	–
Nonpatterned Wet Meadow	**3.3**	**3.9**	**ns**	**8.3**	**8.2**	**ns**	**9.1**	**12.1**
Patterned Wet Meadow	**11.7**	**12.2**	**ns**	**20.7**	**19.3**	**ns**	**9.1**	**35.3**
Moist Sedge-Shrub Meadow	1.7	19.2	avoid	0	2.3	avoid	–	–
Moist Tussock Tundra	0	28.7	avoid	0.2	0.6	ns	–	–
Tall, Low, or Dwarf Shrub	0	4.7	ns	0	4.9	avoid	–	–
Barrens	0	1.1	ns	0.3	14.8	avoid	–	–
Human Modified	0	0	ns	0	0.1	ns	–	–
Total	**100**	**100**	**NA**	**100**	**100**	**NA**	**100**	**100**
Number of groups/nests	**60**	**NA**	**NA**	**579**	**NA**	**NA**	**11**	**173**

Note: Bolding denotes preference during pre-breeding or use during nesting. "–" (no data); NA (not applicable); NE NPR-A (northeast National Petroleum Reserve in Alaska); ns (not significant). Totals may be up to 0.2 due greater or less due to rounding.

[a] Use = (groups / total groups) × 100.

[b] Significance calculated from 1,000 simulations at α = 0.05; avoid = significantly less use than availability, ns = not significant (use proportional to availability), prefer = significantly greater use than availability for pre-breeding eider groups recorded on aerial surveys (Johnson, Parrett et al. 2018a, 2019).

[c] Not all habitats were available in nest search areas; different areas were searched in different years; therefore, total availability of habitat is not presented. Habitats used by nesting spectacled eiders (n = 173 nests) on the Colville River Delta and in the NE NPR-A (n = 11 nests) were collected across multiple study sites (Johnson, Burgess et al. 2014).

[d] Post-breeding habitat is included because it is essential during post-fledging, pre-molting, and migration.

1.2 Comparison of Alternatives: Birds

Effects to birds are detailed by habitat type and action alternative in Tables E.11.4 through E.11.11.

Table E.11.4. Acres of Bird Habitats Permanently Lost by Action Alternative*

Habitat	Habitat Use (1 to 44 species)[a]	Alternative B: Proponent's Project	Alternative C: Disconnected Infield Road	Alternative D: Disconnected Access	Alternative E: Four-Pad Alternative
Unmapped Area	NA	0	0	0	0
Dune Complex	2	0.9	0.7	0.7	1.0
Riverine Complex	3	0.9	0.9	0.8	0.5
River or Stream	4	0.6	0.3	0.5	0.6
Salt-Killed Tundra	4	0	0	0	0
Tapped Lake with Low-Water Connection	5	0	0	0	0
Human Modified	7[b]	0.4	0.4	0.4	0.3
Tidal Flat Barrens	7	0	0	0	0
Brackish Water	10	0	0	0	0
Tapped Lake with High-Water Connection	10	0	0	0	0
Shallow Open Water without Islands	11	2.7	2.5	3.1	2.4
Barren	12	0.8	0.1	0.5	0.8
Deep Open Water without Islands	12	0	0.3	0	0
Deep Open Water with Islands or Polygonized Margins	14	0	0	0	0
Shallow Open Water with Islands or Polygonized Margins	14	0.3	1.0	2.7	0.2
Grass Marsh	15	0	0.5	0	0
Moist Tussock Tundra	19	278.2	287.1	282.8	255.2
Salt Marsh	21	0	0	0	0
Young Basin Wetland Complex	21	0.1	0	0.1	0.1
Open Nearshore Water	22	0	0	0	0
Deep Polygon Complex	25	0	0	0	0
Sedge Marsh	25	3.7	11.5	8.1	3.2
Old Basin Wetland Complex	27	26.5	39.9	23.9	18.9
Tall, Low, or Dwarf Shrub	27	26.2	23.1	43.2	23.5
Moist Sedge-Shrub Meadow	37	61.4	71.2	52.9	46.5
Nonpatterned Wet Meadow	39	16.0	31.1	19.2	11.1
Patterned Wet Meadow	44	65.6	75.2	62.1	64.7
Total high-use acres (> 20 species)	**NA**	**199.4**	**252.1**	**209.4**	**168.0**
Total acres	**NA**	**484.0**	**545.9**	**500.8**	**429.0**

Note: NA (not applicable). Numbers may differ slightly with other reported values in the Willow Master Development Plan Environmental Impact Statement due to rounding. Acres of habitat lost is presented for bird habitats only; thus, the total gravel footprint may differ from the total direct habitat loss, as some areas in the gravel footprint may not be bird habitat.

[a] As described in Section 3.11.1.2, *Bird Habitats*, habitats were ranked by the number of species using them to portray areas with the highest potential for avian occurrence. Actual scores ranged from 1 (one species used the habitat) to 44 (44 species used the habitat). Shading denotes high-use habitats (at least 20 species use the habitat). See Table E.11.1 for more details on habitat values.

[b] Impoundments caused (in part) by dust shadows and early thaw on roadsides provide the earliest water available and attract considerable bird use (by spectacled eiders) before other areas are snow free (possible positive effect). Attraction to roadsides may also increase the risk of collisions with vehicles (possible negative effect).

Table E.11.5. Acres of Bird Habitats Permanently Altered by Excavation*

Habitat	Habitat Use (1 to 44 species)[a]	Constructed Freshwater Reservoir[b]	Tiŋmiaqsiuġvik Mine Site (Alternatives B and E)	Tiŋmiaqsiuġvik Mine Site (Alternatives C and D)
Deep Open Water without Islands	12	1.5	0	0
Moist Tussock Tundra	19	0	72.4	119.1
Sedge Marsh	25	0	1.4	1.8
Tall, Low, or Dwarf Shrub	27	1.6	0	1.9
Moist Sedge-Shrub Meadow	37	4.6	40.9	62.1
Nonpatterned Wet Meadow	39	7.0	0	0
Patterned Wet Meadow	44	1.7	4.8	0
Total high-use acres (> 20 species)	**NA**	**14.9**	**47.1**	**70.7**
Total acres	**NA**	**16.4**	**119.4**	**189.8**

Note: NA (not applicable). Acres apply to all action alternatives; habitat would be altered to become water habitat. Acres of habitat altered is presented for bird habitats only; thus, the total excavation footprint may differ from the total direct habitat alteration, as some areas may not be bird habitat. Numbers may differ slightly with other reported values in the Willow Master Development Plan Environmental Impact Statement due to rounding.

[a] As described in Section 3.11.1.2, *Bird Habitats*, habitats were ranked by the number of species using them to portray areas with the highest potential for avian occurrence. Actual scores ranged from 1 (one species used the habitat) to 44 (44 species used the habitat). Shading denotes high-use habitats (at least 20 species use the habitat). See Table E.11.1 for more details on habitat values.

[b] Alternatives B, C, and D only; there would be no constructed freshwater reservoir under Alternative E.

Table E.11.6. Acres of Bird Habitats Altered by Dust, Gravel Spray, Thermokarsting, or Impoundments by Alternative*

Habitat	Habitat Use (1 to 44 species)[a]	Alternative B: Proponent's Project	Alternative C: Disconnected Infield Road	Alternative D: Disconnected Access	Alternative E: Four-Pad Alternative
Unmapped Area	NA	0	0	0	0
Dune Complex	2	11.4	8.3	8.3	11.4
Riverine Complex	3	16.6	20.5	15.5	12.1
River or Stream	4	13.9	8.5	10.5	13.1
Salt-Killed Tundra	4	0	0	0	0
Tapped Lake with Low-Water Connection	5	0	0	0	0
Human Modified	7[b]	1.1	1.1	1.1	0.2
Tidal Flat Barrens	7	0	0	0	0
Brackish Water	10	0	0	0	0
Tapped Lake with High-Water Connection	10	0	0	0	0
Shallow Open Water without Islands	11	35.1	32.6	23.1	28.3
Barren	12	10.3	2.5	6.8	9.8
Deep Open Water without Islands	12	11.8	17.8	11.5	15.1
Deep Open Water with Islands or Polygonized Margins	14	7.2	4.4	7.2	11.0
Shallow Open Water with Islands or Polygonized Margins	14	18.3	16.9	20.9	13.7
Grass Marsh	15	0.1	0.8	0.1	2.1
Moist Tussock Tundra	19	1,581.5	1,715.4	1,269.9	1,406.5
Salt Marsh	21	0	0	0	0
Young Basin Wetland Complex	21	1.3	1.8	1.3	1.0
Open Nearshore Water	22	0	0	0	0
Deep Polygon Complex	25	0	0	0	0
Sedge Marsh	25	62.5	69.4	38.4	59.9
Old Basin Wetland Complex	27	262.8	293.3	175.7	173.8
Tall, Low, or Dwarf Shrub	27	277.4	235.2	277.4	210.9
Moist Sedge-Shrub Meadow	37	405.0	363.7	264.3	312.2
Nonpatterned Wet Meadow	39	165.1	168.7	154.5	111.7

Habitat	Habitat Use (1 to 44 species)[a]	Alternative B: Proponent's Project	Alternative C: Disconnected Infield Road	Alternative D: Disconnected Access	Alternative E: Four-Pad Alternative
Patterned Wet Meadow	44	567.0	505.8	404.3	469.7
Total high-use acres (> 20 species)	**NA**	**1,741.1**	**1,637.9**	**1,316.0**	**1,339.2**
Total acres	**NA**	**3,448.5**	**3,466.8**	**2,690.8**	**2,862.4**

Note: NA (not applicable). Acres of habitat altered is presented for bird habitats only; thus, the total dust shadow may differ from the total indirect habitat alteration, as some areas may not be bird habitat. Acreage is located within 100 meters of gravel infrastructure.

[a] As described in Section 3.11.1.2, *Bird Habitats*, habitats were ranked by the number of species using them to portray areas with the highest potential for avian occurrence. Actual scores ranged from 1 (one species used the habitat) to 44 (44 species used the habitat). Shading denotes high-use habitats (at least 20 species use the habitat). See Table E.11.1 for more details on habitat values.

[b] Impoundments caused (in part) by dust shadows and early thaw on roadsides provide the earliest water available and attract considerable bird use (by spectacled eiders) before other areas are snow free (possible positive effect). Attraction to roadsides may also increase risk of collisions with vehicles (possible negative effect).

Table E.11.7. Acres of Bird Disturbance and Displacement by Habitat Type within 656 feet (200 meters) of Gravel Infrastructure and Pipelines by Alternative*

Habitat	Habitat Use (1 to 44 species)[a]	Alternative B: Proponent's Project	Alternative C: Disconnected Infield Road	Alternative D: Disconnected Access	Alternative E: Four-Pad Alternative
Unmapped Area	NA	0	0	0	0
Dune Complex	2	16.8	12.5	12.5	16.8
Riverine Complex	3	61.2	68.9	50.9	49.1
River or Stream	4	170.7	167.2	169.1	165.2
Salt-Killed Tundra	4	0	0	0	0
Tapped Lake with Low-Water Connection	5	1.2	1.2	1.2	1.2
Human Modified	7[b]	167.5	167.5	172.4	170.2
Tidal Flat Barrens	7	0	0	0	0
Brackish Water	10	0	0	0	0
Tapped Lake with High-Water Connection	10	32.6	32.6	32.6	32.6
Shallow Open Water without Islands	11	326.1	330.6	325.5	290.6
Barren	12	181.4	172.2	173.7	179.4
Deep Open Water without Islands	12	332.2	355.8	351.2	434.8
Deep Open Water with Islands or Polygonized Margins	14	158.4	151.4	169.1	132.2
Shallow Open Water with Islands or Polygonized Margins	14	141.8	143.7	156.0	131.1
Grass Marsh	15	39.5	40.3	37.0	41.6
Moist Tussock Tundra	19	6,561.2	7,011.4	6,418.2	5,972.9
Salt Marsh	21	44.4	44.4	44.4	44.4
Young Basin Wetland Complex	21	144.6	145.1	142.9	143.1
Open Nearshore Water	22	0	0	0	0
Deep Polygon Complex	25	79.5	79.5	79.5	79.5
Sedge Marsh	25	392.2	401.8	325.8	335.2
Old Basin Wetland Complex	27	1,487.6	1,569.5	1,419.3	1,295.1
Tall, Low, or Dwarf Shrub	27	1,042.0	987.0	992.3	848.5
Moist Sedge-Shrub Meadow	37	3,521.2	3,483.0	3,129.4	3,294.2
Nonpatterned Wet Meadow	39	1,195.2	1,217.1	1,199.3	1,112.2
Patterned Wet Meadow	44	2,959.0	2,995.3	2,834.0	2,648.1
Total high-use acres (by >20 species)	**NA**	**10,865.6**	**10,922.5**	**10,167.0**	**9,800.4**
Total acres	**NA**	**19,056.2**	**19,578.3**	**18,236.5**	**17,418.1**

Note: NA (not applicable). Disturbance zone estimated as 656 feet (200 meters) beyond the perimeter of gravel infrastructure, pipelines, Oliktok Dock improvements, and screeding (summer disturbance), where disturbance would alter behavior or displace birds, as indicated by the U.S. Fish and Wildlife Service disturbance and displacement buffer for spectacled eiders (USFWS 2015). Table does not include the gravel mine site since activity there would occur only in winter.

[a] As described in Section 3.11.1.2, *Bird Habitats*, habitats were ranked by the number of species using them to portray areas with the highest potential for avian occurrence. Actual scores ranged from 1 (one species used the habitat) to 44 (44 species used the habitat). Shading denotes high-use habitats (at least 20 species use the habitat). See Table E.11.1 for more details on habitat values.

[b] Impoundments caused (in part) by dust shadows and early thaw on roadsides provide the earliest water available and attract considerable bird use (by spectacled eiders) before other areas are snow free (possible positive effect). Attraction to roadsides may also increase the risk of collisions with vehicles (possible negative effect).

Table E.11.8. Comparison of Acres of Vegetation Damage from Ice Infrastructure and Volume of Water Withdrawn from Lakes by Alternative*

Ice Infrastructure	Alternative B: Proponent's Project	Alternative C: Disconnected Infield Road	Alternative D: Disconnected Access	Alternative E: Four-Pad Alternative	Option 1: Atigaru Point Module Transfer Island	Option 2: Point Lonely Module Transfer Island	Option 3: Colville River Crossing
Freshwater ice infrastructure (vegetation damage and soil compaction) (acres)	4,557.3	5,608.0	7,164.8	4,026.8	859.6	1,756.1	666.6
Multi-season ice pads (acres)[a]	30.0	30.0	30.0	30.0	0	0	0
Freshwater use (millions of gallons)	1,662.4	1,914.3	2,286.3	1,478.7	307.9	572.0	257.2

[a] Acres of multi-season ice pads are also included in the total ice infrastructure in row 1.

Table E.11.9. Estimated Numbers of Focal Bird Species in the 656-Foot (200-meter) Disturbance Zone around Project Infrastructure*

Species	Alternative B: Proponent's Project	Alternative C: Disconnected Infield Road	Alternative D: Disconnected Access Road	Alternative E: Four-Pad Alternative	Option 1: Atigaru Point Module Transfer Island	Option 2: Point Lonely Module Transfer Island	Option 3: Colville River Crossing
Spectacled eider	2.2	2.3	2.2	2.2	NA	NA	< 0.1
Yellow-billed loon	6.3	6.5	6.0	5.8	NA	NA	< 0.1

Note: NA (not applicable, disturbance zone is in marine waters). Eider calculations in the Willow area are based on average density (0.028 eiders per square mile) / detection error (0.75) × total area (square miles) from Table E.11.6. Eider calculations in the Kuparuk area are based on the average density (0.165 eiders per square mile) with the same detection error (0.75). Average densities in the Willow area are from Shook, Parrett et al. 2020 and in Kuparuk from Attanas and Shook 2020; detection error is from Wilson, Stehn et al. 2017. Yellow-billed loon calculations are based on average density (0.21 loons per square mile) × total area (square miles) from Table E.11.6. Detection error is unavailable for yellow-billed loons. The average density in the analysis area is from Shook, Parrett et al. 2020.

Table E.11.10. Estimated Numbers of Yellow-Billed Loon Breeding Sites near Project Facilities*

Breeding Sites	Alternative B: Proponent's Project	Alternative C: Disconnected Infield Road	Alternative D: Disconnected Access	Alternative E: Four-Pad Alternative	Option 1: Atigaru Point Module Transfer Island	Option 2: Point Lonely Module Transfer Island	Option 3: Colville River Crossing
Nests (unique sites) within 1 mile of infrastructure	22	21	21	16	ND	ND	ND
Number of lakes with nests within 1 mile of infrastructure	11	10	10	8	ND	ND	ND
Number of breeding lakes (with nests or broods) within 1,640 feet (500 m) of infrastructure	6	6	5	4	ND	ND	ND

Sources: Johnson, Parrett et al. (2019), Shook, Parrett et al. (2020); additional data on nests from Bureau of Land Management and U.S. Fish and Wildlife Service registry.
Note: m (meters); ND (no data). Distances of 1 mile from a nest and 1,640 feet from a breeding lake are stipulated as no development areas in required operating procedure E-9. Multiple unique nest sites may occur, usually in different years, on any one lake within 1 mile of proposed infrastructure.

Table E.11.11. Acres of Spectacled Eider Preferred Habitat Affected by Action Alternative and Module Delivery Option*

Effect	Alternative B: Proponent's Project	Alternative C: Disconnected Infield Road	Alternative D: Disconnected Access	Alternative E: Four-Pad Alternative	Option 1: Atigaru Point Module Transfer Island	Option 2: Point Lonely Module Transfer Island	Option 3: Colville River Crossing
Direct habitat loss	111.1	150.6	111.0	97.3	0	0	1.2
Direct habitat alteration (excavation)	15.2	15.2	15.2	4.8	0	0	0
Indirect habitat alteration (dust shadow)	1,068.7	1,042.1	794.7	826.4	0	0	4.8[a]
Disturbance zone[b]	6,940.8	7,105.6	6,791.0	6,385.3	0	0	2.0

Note: Preferred habitats are described in Table E.11.3.

[a] For areas where existing roads would be widened, calculations did not include the existing road's dust shadow.

[b] Disturbance zone estimated as 656 feet (200 meters) beyond the perimeter of gravel, where disturbance would alter behavior or displace birds, as indicated by the U.S. Fish and Wildlife Service disturbance and displacement buffer for spectacled eiders (USFWS 2015). Acres of disturbance is presented for bird habitats only; thus, the total disturbance may not be proportional to the total direct habitat loss, as some areas in the behavioral disturbance footprint may not be bird habitat.

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Willow Master Development Plan

Appendix E.12
Terrestrial Mammals Technical Appendix

June 2022

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List of Acronyms

ACP	Arctic Coastal Plain
BLM	Bureau of Land Management
CAH	Central Artic Herd
EIS	Environmental Impact Statement
GMT	Greater Mooses Tooth
GMT-1	Greater Mooses Tooth 1
IAP	Integrated Activity Plan
km^2	square kilometers
LS	lease stipulations
m	meters
NPR-A	National Petroleum Reserve in Alaska
Project	Willow Master Development Plan Project
ROP	required operating procedure
TCH	Teshekpuk Caribou Herd

Glossary Terms

Subnivean – Occurring beneath a layer of snow.

Ungulate – A hoofed mammal.

1.0 TERRESTRIAL MAMMALS

1.1 Species

At least 20 species of terrestrial mammals use the analysis area, and most remain in the analysis area year-round. Relative abundance and habitat use for mammals likely to be affected by the Willow Master Development Plan Project (Project) are summarized in Table E.12.1. Habitat use is depicted in Figure E.12.1. Habitat types and habitat use are described in more detail below in Section 1.2, *Habitats*.

1.1.1 Foxes

Arctic foxes and red foxes occur in the analysis area year-round, although arctic foxes are more abundant (Johnson, Burgess et al. 2003). Both species use similar denning habitats, which include well-drained soils such as riverbanks, lake basins, and pingos. Red foxes are aggressive toward arctic foxes and will displace them from feeding areas and den sites (Johnson, Burgess et al. 2005; Stickney, Obritschkewitsch et al. 2014). In the Prudhoe Bay oil fields, red foxes have increased in abundance at a faster pace than arctic foxes, possibly due to warmer winters or the availability of anthropogenic food (Stickney, Obritschkewitsch et al. 2014). Foxes in the oilfields are highly tolerant of humans and are often attracted to areas of human activities (Burgess 2000).

Arctic foxes range from the Brooks Range to the Beaufort Sea coast, but the highest abundance is on the ACP. Red foxes range throughout most of Alaska (MacDonald and Cook 2009). Arctic and red foxes prey on small mammals, such as lemmings, ground squirrels, and voles. Fluctuations in lemming abundance are often followed by fluctuations in the arctic fox population (Angerbjorn, Arvidson et al. 1991). Red foxes are omnivorous and opportunistic, eating a variety of items, including insects, small mammals, berries, and carrion. Both species will also scavenge eggs from ground-nesting birds (Hull 1994).

1.1.2 Grizzly Bears

Grizzly bears occur throughout the ACP in low densities (0.5–2.0 bears per 1,000 square kilometers [km^2]) compared to the mountains and foothills of the Brooks Range (10–30 bears per 1,000 km^2) (Carroll 1998). The lower density on the ACP is likely due to marginal habitat because of severe climate, a short growing season, and limited food resources. Grizzly bears of all ages and both sexes den during winter in pingos, river and lake banks, sand dunes, and steep gullies in uplands (Shideler and Hechtel 2000) that accumulate large snowdrifts for insulation. The Willow area contains some of these features and generally has more topography than areas further east on the central ACP. As a result, the area likely has suitable denning habitat for grizzly bears. Grizzly bears are opportunistic omnivores that rely on food sources that vary with the season. Small mammals, such as ground squirrels, are a common prey source in the National Petroleum Reserve in Alaska (NPR-A) as are eggs of ground-nesting birds. In June, caribou calves are an important seasonal food source. Since 2001, incidental observations of grizzly bears and their dens have been recorded during aerial surveys for caribou and other wildlife throughout the analysis area (Johnson, Burgess et al. 2005; Lawhead, Prichard, and Welch 2014; Welch, Prichard et al. 2021). Moderate numbers of grizzly bears have used the North Slope oilfields in the last few decades (Shideler and Hechtel 2000), and can be attracted to areas of human activity, or garbage storage.

1.1.3 Moose

Moose occur in low densities on the ACP and their population has fluctuated substantially since 1992. Moose occur in a wide variety of habitat types during the summer, but generally prefer areas with tall shrub vegetation. In the analysis area, tall shrubs are generally associated with riverine drainages. During fall and winter, moose aggregate along riparian corridors of large river systems where they rely on tall willows for browse. The largest winter concentrations of moose on the western North Slope occur in the inland portions of the Colville River drainage (Carroll 2005) and regularly occur as far downstream as Ocean Point, south of Nuiqsut (Zhou, Tape et al. 2020). In late spring, parturient cows often disperse into smaller drainages of the Colville, Chandler, Itkillik, and Anaktuvuk rivers to calve. A portion of the moose population may disperse short distances away from the primary river drainages onto the tundra to utilize the beaded streams and shallow lakes during summer (Klimstra and Daggett 2020). Moose have been recorded sporadically near Fish (Uvlutuuq and Iqalliqpik) Creek and Judy (Kayyaaq and Iqalliqpik) Creek in the Willow area (Lawhead, Prichard et al. 2009; Lawhead, Prichard, Macander et al. 2014; Welch, Prichard et al. 2021).

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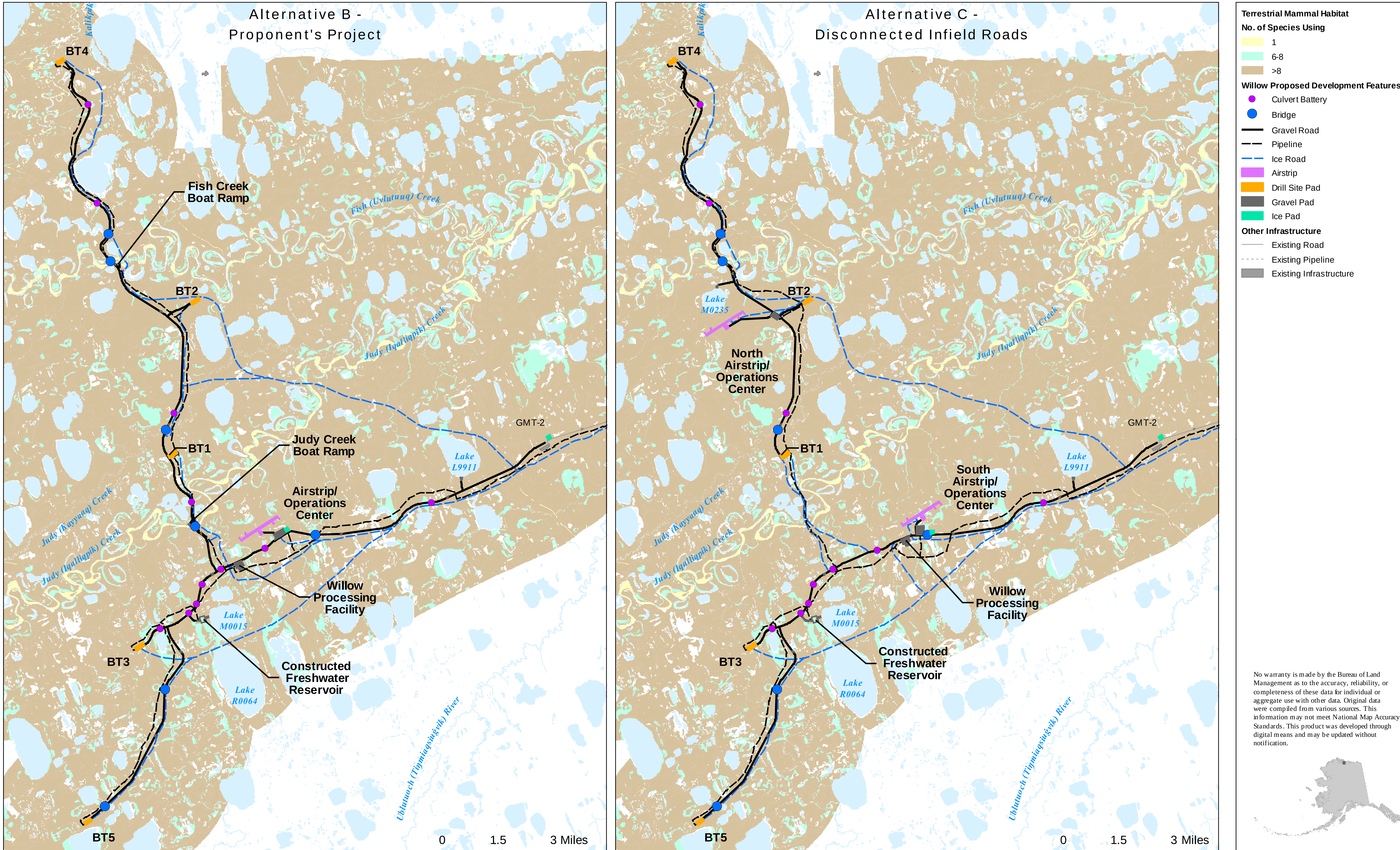

Figure E.12.1A

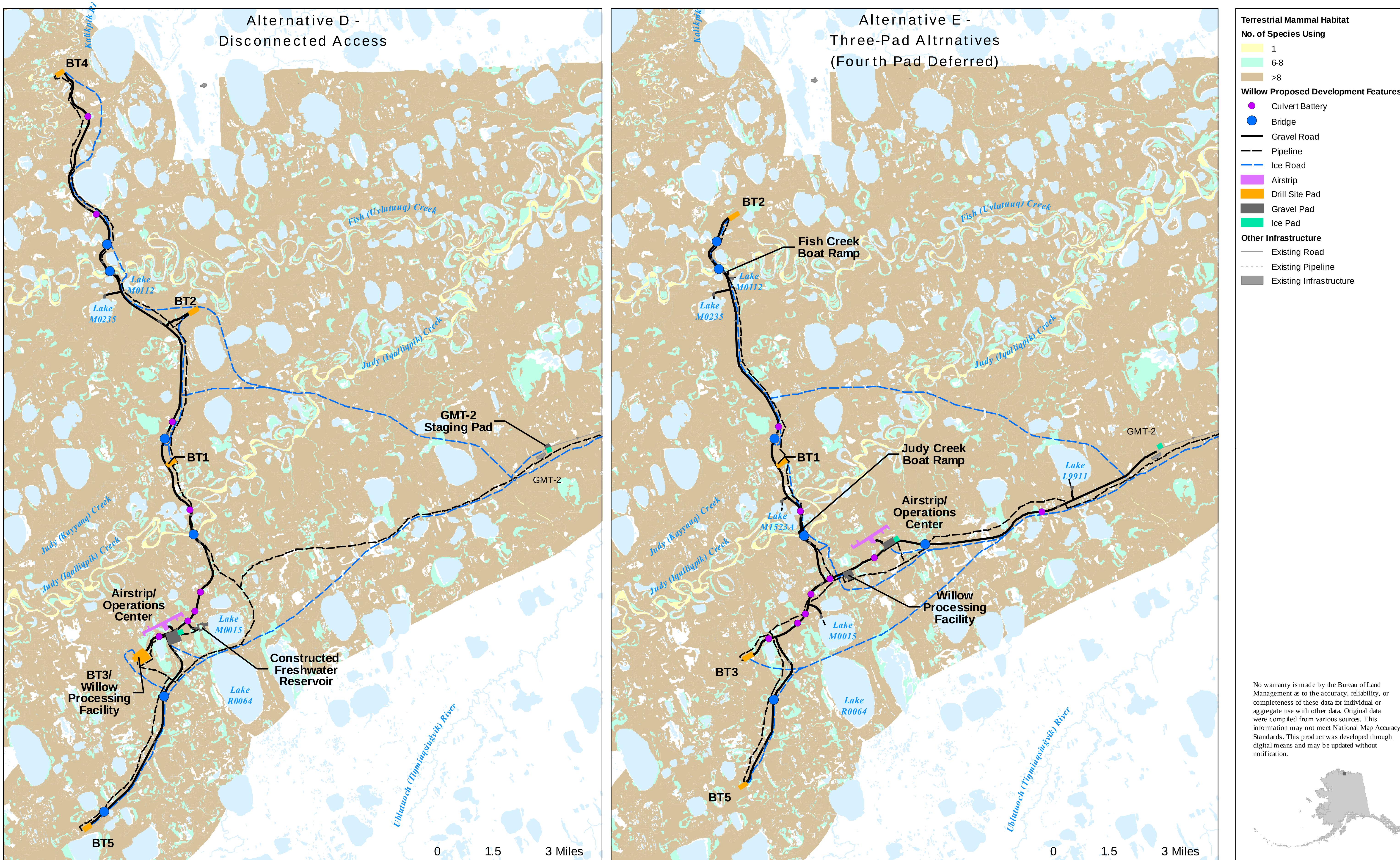

Figure E.12.1B

Table E.12.1. Terrestrial Mammal Species Likely to Use the Analysis Area

Common Name	Scientific Name	Habitat Use	Relative Abundance in Analysis Area	References
Arctic fox, red fox	*Vulpes lagopus, Vulpes vulpes*	Natal dens (summer): pingos, mounds, banks of streams and lakes; mainly in TLDS but also microsites in MSSM and PWM, SAMA Foraging: broad use, depending on prey habitat use	Arctic fox: Common; moderate density, varying annually. Red fox: Low density; population increasing near oil fields	Arctic fox: Burgess 2000; Chesemore 1968; Eberhardt, Hanson et al. 1982; Red fox: Eberhardt 1977; Savory, Hunter et al. 2014; Stickney, Obritschkewitsch et al. 2014
Arctic ground squirrel	*Urocitellus parryii*	River terraces, banks, pingos, dunes, and mounds; mostly in TLDS but occasionally in other habitat types, depending on microsite suitability	Abundant; highest densities along river corridors	Barker and Derocher 2010; Batzli and Sobaski 1980; MacDonald and Cook 2009
Barren ground shrew	*Sorex ugyunak*	OBWC, YBWC, PWM, NPWM, MSSM, MTT, RICO, DUCO	Poorly known; probably low density	Bee and Hall 1956; MacDonald and Cook 2009
Brown lemming	*Lemmus trimucronatus*	Wetter habitats than collared lemming: PWM, NPWM, OBWC, YBWC, MTT, RICO, SEMA, SAMA	Less common than collared lemming; population fluctuates cyclically (often 3 to 4 years)	MacDonald and Cook 2009; Batzli and Lesieutre 1995; Garrott, Eberhardt et al. 1983
Canada lynx	*Lynx canadensis*	TLDS, especially along riverine corridors	Very rare, recent sightings near Willow Project, increasing abundance along Colville River, cyclical population.	Tape, Christie et al. 2016; Welch, Prichard et al. 2022
Caribou	*Rangifer tarandus*	Foraging: MSSM, MTT, TLDS, OBWC, YBWC, PWM, RICO Insect relief: BAR, HUMO, SKT, RICO, DUCO, TFB, SAMA	Abundant	Kuropat 1984; Murphy and Lawhead 2000; Parrett 2007; Parrett 2015; Person, Prichard et al. 2007; Prichard, Welch et al. 2018; Wilson, Prichard et al. 2012
Collared lemming	*Dicrostonyx groenlandicus*	Drier habitats than brown lemming: TLDS, MSSM, DUCO	Common; population fluctuates cyclically (less frequently than brown lemming)	Batzli and Hentonnen 1990; Pitelka and Batzli 1993; Bee and Hall 1956; Batzli and Lesieutre 1995; MacDonald and Cook 2009
Ermine	*Mustela erminea*	OBWC, YBWC, PWM, NPWM, MSSM, MTT, TLDS, RICO, SEMA, SAMA	Uncommon; in habitats supporting lemmings and voles but fluctuating in abundance with those species	Bee and Hall 1956; MacDonald and Cook 2009
Grizzly (brown) bear	*Ursus arctos*	MSSM, TLDS, MTT, OBWC, YBWC, RICO, DUCO, SAMA	Low density: 1.8 bears per 100 square miles in GMU 26B (lower density on coastal plain than in foothills and mountains)	Carroll 1995, 2013a; Lenart 2015a 2015c; Young and McCabe 1997; Shideler and Hechtel 2000
Least weasel	*Mustela nivalis*	OBWC, YBWC, PWM, NPWM, MSSM, MTT, TLDS, SEMA, SAMA	Uncommon; in habitats supporting lemmings and voles but fluctuating in abundance with those species	Bee and Hall 1956; MacDonald and Cook 2009
Moose	*Alces americanus*	TLDS	Rare; generally restricted to riverine areas with tall shrubs; range expanding	Tape, Gustine et al. 2016; Carroll 2014; Mould 1977; Lawhead, Prichard, and Welch 2014; Lenart 2014
Muskox	*Ovibos moschatus*	TLDS, OBWC, PWM, MSSM, MTT, RICO	Rare; groups rarely observed near the Project area	Arthur and Del Vecchio 2009, 2013b; Danks and Klein 2002; Gustine, Barboza et al. 2011; Wilson and Klein 1991; Lenart 2015c
Muskrat	*Ondatra zibethicus*	RS, GRMA, SAMA	Unknown distribution or abundance, multiple sightings near Nuiqsut	BLM 2019; MacDonald and Cook 2009
Root/tundra vole	*Microtus oeconomus*	Wetter habitats than singing vole: OBWC, YBWC, PWM, NPWM, MTT, RICO, SEMA, SAMA	Patchily distributed; populations fluctuate markedly between years	Batzli and Hentonnen 1990; Bee and Hall 1956; MacDonald and Cook 2009; Pruitt 1968
Singing vole	*Microtus miurus*	Drier habitats than root vole: TLDS, MSSM, DUCO	Uncommon; less common than farther inland (foothills)	MacDonald and Cook 2009; Batzli and Lesieutre 1995; Garrott, Eberhardt et al. 1983

Common Name	Scientific Name	Habitat Use	Relative Abundance in Analysis Area	References
Snowshoe hare	*Lepus americanus*	TLDS, especially along riverine corridors	Rare; restricted to areas of tall shrubs; population fluctuates cyclically	MacDonald and Cook 2009; Tape, Christie et al. 2016
Tundra shrew	*Sorex tundrensis*	Broad habitat use, especially drier terrestrial habitats, SEMA, SAMA	Poorly known; probably lower density than barren ground shrew	Bee and Hall 1956; MacDonald and Cook 2009
Wolf	*Canis lupus*	All terrestrial habitats, depending on prey habitat use	Rare; very low density: 1.8–2.9 wolves per 100 square miles in GMU 26A but lower on Arctic Coastal Plain	Caikoski 2012; Lawhead, Prichard, and Welch 2014; Harper 2012
Wolverine	*Gulo gulo*	All terrestrial habitats, depending on prey habitat use	Uncommon; low density	Carroll 2013b; Magoun 1979, 1985, 1987; Poley, Magoun et al. 2018; Delerum, Kunkel et al. 2009; Caikoski 2013

Source: Common and scientific names follow MacDonald and Cook's (2009) list, except that Bradley, Ammerman et al.'s (2014) list was used for taxonomic changes since 2009.
Note: BAR (Barren); DUCO (Dune Complex); GMU (Game Management Unit); GRMA (Grass Marsh); HUMO (Human Modified); MSSM (Moist Sedge-Shrub Meadow); MTT (Moist Tussock Tundra); NPWM (Nonpatterned Wet Meadow); OBWC (Old Basin Wetland Complex); PWM (Patterned Wet Meadow); RICO (Riverine Complex); RS (River or Stream); SAMA (Salt Marsh); SEMA (Sedge Marsh); SKT (Salt-Killed Tundra); TFB (Tidal Flat Barrens); TLDS (Tall, Low, or Dwarf Shrub); YBWC (Young Basin Wetland Complex). Habitats are defined in Section 3.9, *Wetlands and Vegetation*, and Table E.12.2 below. Habitat use is depicted in Figure E.12.1.

1.1.4 Muskoxen

Muskoxen historically occurred throughout northern Alaska, but over-harvesting led to their extirpation in the late 1800s or early 1900s (Hone 2013 [1934]; Smith 1989). Their population in northeastern Alaska was reestablished by translocation to Barter Island and the Kavik River in 1969 and 1970. As their numbers on the ACP increased, their range expanded westward to the Colville River and eastward to Babbage River in the Yukon (Lenart 2007; Reynolds 1998).

Although small numbers of muskoxen have occasionally been observed west of the Colville River, they are not considered common in the NPR-A (BLM 2012). Between 2001 and 2012, muskoxen herds as large as 25 individuals were occasionally recorded incidentally in the NPR-A near the Beaufort Sea coast along Harrison Bay. A group of six was recorded near Greater Mooses Tooth 2 in June 2001 (Lawhead and Prichard 2002). Nuiqsut residents report muskox using the Fish (Uvlutuuq and Iqalliqpik) Creek drainage (Jonah Nukapigak, Nuiqsut resident, personal communication to CPAI. June 6, 2018). Two groups were observed west of the Colville River in 2021 (Welch, Prichard et al. 2022). The current population is reportedly stable or slowly increasing (Arthur and Del Vecchio 2013a; Lenart 2021) and the population on the central North Slope could potentially expand into the analysis area. Suitable habitat, which generally consists of riparian, upland shrub, and moist sedge shrub meadows, exists throughout the NPR-A (Danks 2000; Johnson, Burgess et al. 1996).

1.1.5 Wolves

Gray wolves occur throughout Alaska, occupy large home ranges, and travel maximum distances of 28 to 60 miles per day (Stephenson 1979). On the ACP, the highest wolf densities are near the Colville River and its tributaries, where winter moose densities are highest. Populations fluctuate substantially due to variability in prey availability and the severity of winters. Wolf abundance on the ACP is low relative to the foothills and mountains of the Brooks Range. This is thought to be due to the seasonal scarcity of caribou on the ACP, and poorer quality denning habitat than in the foothills and mountains. In addition to moose and caribou, wolves also prey on voles, lemmings, ground squirrels, and snowshoe hares (Hull 1994; Stephenson 1979). At last estimate, approximately 240 to 390 wolves in 32 to 53 packs were present on the western North Slope (Carroll 1998, 2006).

1.1.6 Wolverines

Wolverines are uncommon in the analysis area (BLM 2012; Johnson, Burgess et al. 2005; Lawhead, Prichard, and Welch 2014). On the North Slope, wolverines are closely associated with caribou, especially during calving and post-calving. They also rely heavily on caribou carcasses in the winter (BLM 1978; Magoun 1979). Two wolverines were seen incidentally during other surveys in the analysis area in 2013 (Lawhead, Prichard, and Welch 2014) as well as one each in 2001 and 2002 (ABR 2017, unpublished data). Wolverines occur across the ACP but are more common in the mountains and foothills of the Brooks Range (Bee and Hall 1956; BLM 1998; Poley, Magoun et al. 2018). In 1984, the Bureau of Land Management (2004) estimated a density of one wolverine per 140 km^2; however, Poley et al. (2018) found that the area southeast of Teshekpuk Lake had a higher probability of occupancy that most of the ACP in the NPR-A. Wolverines require large territories and use a broad range of habitats, frequently occurring in well-drained, drier areas such as tussock meadow, riparian willow, and alpine tundra habitats (BLM 1998; Poley, Magoun et al. 2018). Wolverines may avoid areas near human activity (May, Landa et al. 2006).

1.1.7 Small Mammals

Small mammals, including shrews, lemmings, voles, ground squirrels, and weasels, are important prey for predatory birds and carnivorous mammals on the ACP. Many small mammal species have cyclical population fluctuations that are often reflected, with a short temporal lag, in the population fluctuations of their predators. For example, snowy owl populations in northern Alaska are highly volatile and are closely associated with lemming abundance. Arctic ground squirrels hibernate during winter, whereas lemmings, voles, weasels, and shrews are active year-round, often underneath the snow.

1.1.8 Canada Lynx*

Lynx were first observed during Alaska Department of Fish and Game moose surveys along the Colville River in 1998 (Tape, Christie et al. 2016). This and subsequent observations document the northern range expansion of lynx as a result of the range expansion of snowshoe hare (*Lepus americanus*), the principal prey of lynx (Tape, Christie et al. 2016). Multiple lynx were observed in the oilfields east of the Project or along the lower Colville River during 2021 (Welch, Prichard et al. 2022). These sightings included a lynx crossing the Ublutuoch

(Tiŋmiaqsiuġvik) River north of the GMT-1 road in late June 2021 (J. McFarland, Owl Ridge Inc., pers. comm., Welch, Prichard et al. 2022). On the ACP, lynx are most likely to use areas with tall shrubs where snowshoe hares are more likely to be present, but lynx have cyclical populations and individual lynx will disperse long distances across many types of habitats (Vanbianchi, Gaines et al. 2018). Snowshoe hares require a mean riparian shrub height of at least 4.1–4.5 feet (1.24–1.36 meters [m]) to provide adequate browse (Tape, Christie et al. 2016), so the recent climate-related increase in shrubs in the Arctic has allowed snowshoe hare to expand its range north. Snowshoe hare observations occurred as far north as the Colville River Delta by 1993.

1.2 Habitats

Habitats used by terrestrial mammals are summarized in Table E.12.2. The number of species that use each habitat type (as listed in Table E.12.1) are tallied in Tables E.12.2 and E.12.3.

Table E.12.2. Terrestrial Mammal Habitat Types

Habitat[a]	Description	Species Use[b]
Barren	Area without vegetation and not normally inundated.	1
Grass Marsh	Ponds and lake margins with the emergent grass *Arctophila fulva* (pendant grass). Shallow water depths (less than 3.3 feet).	1
Rivers and Streams	Permanently flooded channels large enough to be mapped as separate units.	1
Tidal Flat Barrens	Nearly flat, barren mud or sand periodically inundated by tidal waters; may include small areas of partially vegetated mud or sand	1
Salt-Killed Tundra	Coastal low-lying areas where saltwater from storm surges has killed the original vegetation and colonization is occurring by salt-tolerant vegetation.	1
Human Modified	Area with vegetation or soil significantly disturbed by human activity.	3
Nonpatterned Wet Meadow	Analogous to sedge meadow or shrub meadow.	6
Sedge Marsh	Permanently flooded waterbodies dominated by the emergent sedge *Carex aquatilis*. Typically, emergent sedges occur in water < 1.6 feet deep.	6
Dune Complex	Mosaic of swale and ridge features on inactive sand dunes, supporting wet to flooded sedge and moist shrub types in swales and moist to dry dwarf and low shrub types on ridges.	7
Riverine Complex	Mosaic of moist to wet sedge and shrub types, water, and barrens along flooded streams and associated floodplains.	8
Young Basin Wetland Complex	Complex ice-poor, drained-lake thaw basins characterized by a complex mosaic of vegetation classes and by surface water with a high percentage of Fresh Sedge Marsh and Fresh Grass Marsh.	9
Moist Tussock Tundra	Gentle slopes and ridges of coastal deposits and terraces, pingos, and the uplifted centers of older drained lake basins. Vegetation dominated by tussock-forming plants, most commonly tussock cottongrass (*Eriophorum vaginatum*). Associated with high-centered polygons of low or high relief.	10
Old Basin Wetland Complex	Complex ice-rich habitat in older drained lake basins with well-developed low- and high-centered polygons resulting from ice-wedge development and aggradation of segregated ice.	10
Patterned Wet Meadow	Lowland areas with low-centered polygons that are flooded in spring, with water remaining close to the surface throughout the growing season. Vegetation growth typically is more robust in polygon troughs than in centers. (See also Wet Sedge Meadow description in the Willow MDP EIS, Section 3.9, *Wetlands and Vegetation*.)	10
Salt Marsh	Complex assemblage of small brackish ponds, halophytic sedges and willows, and barren patches on stable mudflats usually associated with river deltas.	10
Moist Sedge-Shrub Meadow	High-centered, low-relief polygons and mixed high- and low-centered polygons on gentle slopes of lowland, riverine, drained basin, and deposits formed by the movement of soil and other material. Soils saturated at intermediate depths (> 0.5 feet) but generally free of surface water during summer.	12
Tall, Low, or Dwarf Shrub	Woody plants that are smaller than trees and have several main stems arising at or near the ground.	13

Note: EIS (Environmental Impact Statement). Habitat use is depicted in Figure E.12.1. Shading depicts high habitat use (by nine or more species). Habitats described in other sections of the EIS are not used by terrestrial mammals and thus not included in the table.
[a] More information on these habitat types is in the Willow Master Development Plan EIS, Section 3.9, *Wetlands and Vegetation*.
[b] Indicates the number of species that typically use the habitat.

Table E.12.3. Habitat Use by Terrestrial Mammals*

Habitat Type	Caribou	Muskox	Moose	Grizzly (brown) Bear	Foxes (2 species)	Arctic Ground Squirrel	Collared Lemming	Brown Lemming	Singing Vole	Snowshoe Hare	Root Vole	Weasels (2 species)	Shrews (2 species)	Muskrat	Canada Lynx	No. Species Using Habitat
Barren	IR	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Grass Marsh	–	–	–	–	–	–	–	–	–	–	–	–	–	U	–	1
Rivers and Streams	–	–	–	–	–	–	–	–	–	–	–	–	–	U	–	1
Salt-Killed Tundra	IR	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Tidal Flat Barrens	IR	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Human Modified	IR	–	–	F, D	F, D	–	–	–	–	–	–	–	–	–	–	3
Nonpatterned Wet Meadow	–	–	–	–	–	–	–	U	–	–	U	U	U	–	–	6
Sedge Marsh	–	–	–	–	–	–	–	U	–	–	U	U	U	–	–	6
Dune Complex	IR	–	–	F, D	D	U	U	–	U	–	–	–	U	–	–	7
Riverine Complex	F	F	–	F	F	–	–	U	–	–	U	U	U	–	–	8
Young Basin Wetland Complex	F	–	–	F	F	–	–	U	–	–	U	U	U	–	–	9
Patterned Wet Meadow	F	F	–	–	F, D	–	–	U	–	–	U	U	U	–	–	10
Moist Tussock Tundra	F	F	–	F	F	–	–	U	–	–	U	U	U	–	–	10
Old Basin Wetland Complex	F	F	–	F	–	U	–	U	–	–	U	U	U	–	–	10
Salt Marsh	IR	–	–	F	F	–	–	U	–	–	U	U	U	U	–	10
Tall, Low, or Dwarf Shrub	F	F	F	F, D	F, D	U	U	–	U	U	–	U	–	–	U	13
Moist Sedge-Shrub Meadow	F	F	–	F, D	F, D	U	U	–	U	–	–	U	U	–	–	12

Note: – (not used); D (denning); F (foraging); IR (insect relief); No. (number); U (general use). Shading indicates high habitat use (nine or more species use the habitat).

1.3 Environmental Consequences to Species Other Than Caribou

1.3.1 Applicable Lease Stipulations and Required Operating Procedures*

All the existing lease stipulations (LS) and required operating procedures (ROPs) for caribou in Table 3.12.1 (in the Willow MDP Environmental Impact Statement [EIS], Section 3.12, *Terrestrial Mammals*) would also apply to other terrestrial mammals. Table E.12.4 summarizes other LS and ROPs that would apply to Project actions on Bureau of Land Management (BLM) managed lands and are intended to mitigate impacts to terrestrial mammals from development activity (BLM 2022). The LS and ROPs would reduce impacts to terrestrial mammal habitat, subsistence hunting areas, and the environment that are associated with the construction, drilling, and operation of oil and gas facilities. In 2021, BLM was directed to re-evaluate the 2020 NPR-A Integrated Activity Plan (IAP). The NPR-A IAP re-evaluation resulted in the issuance of a new NPR-A IAP Record of Decision. Full text of the requirements is provided in BLM (2022).

Table E.12.4. Summary of Required Operating Procedures Intended to Mitigate Impacts to Terrestrial Mammals*

ROP	Description or Objective	Requirement/Objective
ROP A-1	Protect the health and safety of oil and gas field workers and the general public by disposing of solid waste and garbage in accordance with applicable federal, State, and local law and regulations.	Areas of operation shall be left clean of all debris.
ROP A-2	Minimize impacts on the environment from non-hazardous and hazardous waste generation. Encourage continuous environmental improvement. Protect the health and safety of oil field workers and the general public. Avoid human-caused changes in predator populations.	Lessees/permittees shall prepare and implement a comprehensive waste management plan for all phases of exploration and development, including seismic activities. The plan shall be submitted to the AO for approval, as part of a plan of operations or other similar permit application. Waste generation shall be addressed in the following order of priority: 1) prevention and reduction, 2) recycling, 3) treatment, and 4) disposal. The plan shall consider the following requirements: a. The plan shall identify precautions that are to be taken to avoid attracting wildlife to food and garbage. b. Requirements prohibit the burial of garbage. Users shall have a written procedure to ensure that the handling and disposal of putrescible waste will be accomplished in a manner that prevents the attraction of wildlife. All putrescible waste shall be incinerated, backhauled, or composted in a manner approved by the AO. All solid waste, including incinerator ash, shall be disposed of in an approved waste-disposal facility. The burial of human waste is prohibited. c. BLM requires all pumpable solid, liquid, and sludge waste be disposed of by injection in accordance with EPA, DEC, and AOGCC regulations and procedures. d. BLM prohibits wastewater discharges or disposal of domestic wastewater into bodies of water, including wetlands, unless authorized by a National Pollutant Discharge Elimination System or State permit.
ROP A-8	Minimize conflicts resulting from interaction between humans and bears during oil and gas activities.	Lessees will prepare and implement bear-interaction plans to minimize conflicts between bears and humans. These plans shall include measures to: a. Minimize attraction of bears to the drill sites. b. Organize layout of buildings and work sites to minimize human-bear interactions. c. Warn personnel of bears near or on work sites and identify proper procedures to be followed. d. Establish procedures, if authorized, to discourage bears from approaching the work site. e. Provide contingencies in the event bears do not leave the site or cannot be discouraged by authorized personnel. f. Discuss proper storage and disposal of materials that may be toxic to bears. g. Provide a systematic record of bears on the work site and in the immediate area.

ROP	Description or Objective	Requirement/Objective
ROP C-1	Protect grizzly bear, polar bear, and marine mammal denning and/or birthing locations.	a. Grizzly bear dens: Cross-country use of vehicles, equipment, and oil and gas activity is prohibited within 0.5 mile of occupied grizzly bear dens, unless protective measures are approved by BLM. b. Polar bear dens: Cross-country use of vehicles, equipment, and oil and gas activity is prohibited within 1 mile of known or observed polar bear dens, unless alternative protective measures are approved by BLM. c. To limit disturbance around known polar bear dens, implement the following: 1. Onshore activities in known or suspected polar bear denning habitat during the denning season (approximately November to April) must make efforts to locate occupied polar bear dens. All observed or suspected polar bear dens must be reported to USFWS prior to the initiation of activities. 2. Permittees must observe a 1-mile operational exclusion zone around all known polar bear dens during the denning season (or until the female and cubs leave the areas). Should previously unknown occupied dens be discovered, work must cease and USFWS must be contacted for guidance. Potential actions may range from cessation or modification of work to conducting additional monitoring. 3. Use the den habitat map developed by USGS. 4. Restrict activity timing to limit disturbance around dens. d. To limit disturbance of activities to seal lairs in the nearshore area (< 9.8-foot water depth): 1. Prior to the initiation of winter seismic surveys on marine ice, the permittee will conduct a sound source verification test approved by BLM and NMFS. 2. For all activities: i. Maintain airborne sound levels of equipment below 100 db re 20 µPa at 66 feet. ii. On-ice operations after May 1 will employ a full-time protected species observer on vehicles to ensure that all basking seals are avoided by vehicles by at least 500 feet and will ensure that all equipment with airborne noise levels are operating at distances from observed seals that allow for the attenuation of noise to levels below 100 decibels. iii. Sea ice trails must not be greater than 12 feet wide. iv. No unnecessary equipment or operations will be placed or used on sea ice.
ROP E-8	Minimize the impact of mineral materials mining activities on air, land, water, fish, and wildlife resources.	Gravel mine site design and reclamation will be in accordance with a plan approved by the AO. The plan shall consider: a. Locations outside the active flood plain. b. Design of gravel mine sites within active flood plains to serve as water reservoirs for future use. c. Potential use of the site for enhancing fish and wildlife habitat. d. Potential storage and reuse of sod/overburden for the mine site or at other disturbed sites on the North Slope.
ROP E-9	Avoidance of human-caused increases in populations of predators of ground nesting birds.	a. Lessee shall use best available technology to prevent facilities from providing nesting, denning, or shelter sites for ravens, raptors, and foxes. The lessee shall provide the AO with an annual report on the use of facilities by ravens, raptors, and foxes as nesting, denning, and shelter sites. b. Feeding wildlife is prohibited.
ROP M-4	Minimize loss of individuals of, and habitat for, mammalian species designated as Sensitive by BLM in Alaska.	If a development is proposed in an area that provides potential habitat for the Alaska tiny shrew, the development proponent would conduct surveys at appropriate times of the year and in appropriate habitats in an effort to detect the presence of the shrew. The results of these surveys will be submitted to BLM with the application for development.

Source: BLM 2022
Note: AO (authorized officer); AOGCC (Alaska Oil and Gas Conservation Commission); BLM (Bureau of Land Management); DEC (Alaska Department of Environmental Conservation); EPA (U.S. Environmental Protection Agency); ROP (required operating procedure); USGS (U.S. Geological Survey).

Similar types of effects as described for caribou under Alternative B (Proponent's Project) would also occur for other species. Effects unique to other species are described below.

1.3.2 Habitat Loss or Alteration

Alternative B would permanently remove 619.8 acres of terrestrial mammal habitat due to gravel fill or gravel mining. Tables E.12.5 and E.12.6 summarize habitat loss or alteration by habitat type. The largest amount of habitat loss would occur in moist tussock tundra, which is used by 10 species. The mine site pit and CFWR (Alternatives B, C, and D) would be transformed into permanent open water habitat unsuitable for terrestrial mammals. Because the habitats lost are not unique and occur throughout the analysis area and ACP, caribou and other species would likely move to similar habitats nearby.

Use of gravel infrastructure would result in gravel spray and dust deposition, which would alter 3,448.4 acres of terrestrial mammal habitats within 328 feet (100 m) of gravel infrastructure (3,120.5 acres in high use habitats). Dust can change plant community composition or structure, and is discussed in detail in the Willow MDP EIS, Section 3.9, *Wetlands and Vegetation*.

Arctic ground squirrels and other small mammals would lose foraging and burrow habitat and grizzly bears could lose minor amounts of foraging. Impacts would be at an individual level and likely would not affect the population.

Compressed snow and ice from ice infrastructure and from snow-removal on gravel roads would temporarily alter habitats by delaying snow melt and compacting vegetation. Ermine, short-tailed weasel, least weasel, collared lemming, brown lemming, singing vole, root and tundra mole, barren ground shrew, and tundra shrew remain active all winter and thus their winter habitats are vulnerable to crushing from placement of ice, snow, and gravel for road and pad construction. These mammals may relocate to avoid impacts of winter construction. Arctic ground squirrels hibernate in winter and are unable to relocate in response to winter construction activities.

1.3.3 Disturbance or Displacement

Disturbance of grizzly bears during winter denning has the potential to displace bears from their dens, imposing large energetic costs on adults and risking mortality of cubs (Amstrup 1993; Clough, Patton et al. 1987; Linnell, Swenson et al. 2000; Reynolds 1986). Snow cover greatly attenuates sounds, and Project activities would not likely disturb bears in dens at distances greater than 328 feet (100 m) (Blix and Lentfer 1992), although activities may be detectable above background levels at 0.3 to 1.25 miles (0.5 to 2 kilometers), depending on the stimulus (LGL Limited Environmental Research Associates and JASCO Research Ltd. 2003). The most audible disturbance stimuli inside bear dens would be an underground blast (gravel mining) or airborne helicopters directly overhead. Studies have noted high variability in the tolerance of bears to noise and disturbance (LGL Limited Environmental Research Associates and JASCO Research Ltd. 2003).

Existing ROP C-1 for the NPR-A stipulate that occupied grizzly bear dens must be avoided by a distance of 0.5 mile. Grizzly bears may abandon dens because of disturbance (Clough, Patton et al. 1987; Swenson, Sandegren et al. 1997). Although the analysis area likely provides suitable denning habitat, the number of bears denning near Project facilities in a single year would be low, thus reducing the risk of disturbance; however, females denning with cubs would be of most concern. Because bank habitats along Fish (Uvlutuuq and Iqalliqpik) Creek and Judy (Kayyaaq and Iqalliqpik) Creek are suitable for bear dens in the analysis area. Ongoing coordination with agency biologists monitoring radio-collared bears in the region would provide precise location information to avoid the dens of marked individuals, although uncollared bears also occur in the area.

Wolverines could be displaced from areas of increased human activity and could experience higher risk of human-caused mortality (May, Landa et al. 2006). Wolves are also likely to avoid areas of human activity. Changes in wolf and wolverine distribution as well as the presence of development, could alter harvest effort and locations for these species. Changes in caribou distribution could have indirect effects of wolf and wolverine distribution.

1.3.4 Injury or Mortality

Foxes are present and active year-round in the analysis area and would be subject to vehicle strikes during all seasons. Collision rates for terrestrial mammals in the Alpine and GMT developments from 2015 to June 2021 ranged from one to seven collisions per year with a total of 25 reported collisions. Collisions were mostly with foxes (16 red foxes, 3 arctic foxes, and 3 unknown species of fox), but collisions with one wolverine, one muskrat, and one caribou were also reported. In general, however, the scheduling of the heaviest construction-related traffic during the winter would help to reduce the potential for vehicles to strike terrestrial mammals.

Small terrestrial mammals with limited mobility and small home ranges could be directly killed within the footprints of ice road construction, gravel excavation, and gravel placement. In addition, individual lemmings, voles, and shrews may experience indirect mortality due to habitat disruption and fragmentation from the compaction of **subnivean** spaces by ice road construction and from construction of gravel roads and pads, which would pose barriers to small-mammal movement.

1.3.5 Attraction to Human Activities and Facilities

Foxes and grizzly bears are attracted to areas of human activity, where they feed on garbage and handouts (Eberhardt, Hanson et al. 1982; Follmann 1989; Follmann and Hechtel 1990; LGL Ecological Research Associates 1993; Shideler and Hechtel 2000). Their presence near human activity increases the potential for animals to be struck by vehicles, ingest toxic substances, or be killed by humans in defense of life or property. Foxes and, to a lesser extent, grizzly bears, may use human structures, such as gravel embankments and empty pipes, for denning (Burgess, Rose et al. 1993; Shideler and Hechtel 2000).

Increased predator populations around oil field developments may increase predation on prey populations (Day 1998; Martin 1997). This impact is inferred from the higher number of foxes, increased density of fox dens (Burgess 2000; Burgess, Rose et al. 1993; Eberhardt, Hanson et al. 1982), and higher numbers of bears (Shideler and Hechtel 2000) in the North Slope oil fields and near Deadhorse. Foxes prey on birds and small terrestrial mammals, and bears prey on caribou, muskoxen, ground squirrels, and bird nests. Red fox may displace Arctic fox and kill pups; therefore, if red foxes have access to anthropogenic food, it could result in an increase in red fox numbers and a decline of Arctic fox numbers. Increases in mortality of **ungulate** calves by bear may affect populations locally, although there is little information to suggest population-level effects occur with any regularity. Grizzly bear predation of muskoxen is difficult to quantify. It is unlikely that bear predation depresses the caribou population substantially, although the muskox population appears to be more affected.

Human-animal interactions would occur during all seasons and all phases of the Project but would be likely to occur most frequently during construction when human activity would be most intensive and widespread. Lower levels of human activity during drilling and operations would result in correspondingly lower rates of human-animal interactions.

Control of food waste and other garbage would help minimize predators and scavengers being attracted to facilities. Existing ROPs and company policies against feeding animals would be strictly enforced. Proper containment and removal of garbage and hazardous waste at camps and drill sites would minimize the attraction of predators and the risks to animals. A Wildlife Avoidance and Interaction Plan and environmental awareness program for all Project employees would be required to address waste-handling practices and bear interactions. Even with effective enforcement of these policies, attraction of predators and scavengers would be likely.

1.4 Alternatives Comparison Tables: All Species

Habitat loss and alteration is summarized by land-based alternative in Tables E.12.5 and E.12.6. Table E.12.7 summarizes the proportion of the TCH seasonal range within 2.5 miles of new gravel infrastructure by action alternative and module delivery option.

Table E.12.5 Acres of Terrestrial Mammal Habitats Permanently Lost by Action Alternative or Option*

Habitat	Habitat Value (1 to 13)[a]	Acres in the Analysis Area	Alternative B: Proponent's Project	Alternative C: Disconnected Infield Road	Alternative D: Disconnected Access	Alternative E: Three-Pad Alternative	Option 3: Colville River Crossing
Unmapped Area	NA	620,107.1	0	0	0	0	0
Barren	1	9,717.9	0.8	0.1	0.5	0.8	0
Grass Marsh	1	1,817.2	0	0.5	0	0	0
Rivers and Streams	1	7,490.5	0.6	0.3	0.5	0.6	0
Tidal Flat Barrens	1	131.3	0	0	0	0	0
Salt-Killed Tundra	1	362.7	0	0	0	0	0
Human Modified	3[b]	4,037.3	0.4	0.4	0.4	0.3	1.0
Nonpatterned Wet Meadow	6	26,723.0	16.0	31.1	19.2	11.1	0.4
Sedge Marsh	6	8,933.6	5.1	13.3	9.9	4.6	0
Dune Complex	7	1,771.9	0.9	0.7	0.7	1.0	0
Riverine Complex	8	1,694.1	0.9	0.9	0.8	0.5	0
Young Basin Wetland Complex	9	2,849.4	0.1	0	0.1	0.1	0
Moist Tussock Tundra	10	119,866.9	350.6	406.2	401.9	327.6	0.8
Old Basin Wetland Complex	10	31,429.6	26.5	39.9	23.9	18.9	0.4
Patterned Wet Meadow	10	65,951.9	72.1	81.8	68.7	70	0.5
Salt Marsh	10	1,133.1	0	0	0	0	0
Tall, Low, or Dwarf Shrub	11	25,708.4	27.8	26.6	46.7	23.5	0
Moist Sedge-Shrub Meadow	12	94,568.5	106.9	137.9	119.6	87.4	1.9
Total high-use habitat acres	**NA**	**340,374.7**	**614.3**	**692.4**	**660.9**	**527.0**	**3.6**
Total acres	**NA**	**1,022,744.6**	**615.7**	**746.7**	**699.9**	**545.9**	**5.0**

Note: NA (not applicable). All action alternatives include acres lost from the mine site. Options 1 and 2 would not result in habitat loss for terrestrial mammals and are not included in this table. Total acres of terrestrial mammal habitat loss may differ from total gravel footprint because not all areas that would be filled are used by terrestrial wildlife.
[a] As described above in Section 1.2, *Habitats*, habitats were ranked by the number of species using them to portray areas with the highest potential for species occurrence. Shading denotes high-use habitats (use by nine or more species). See Tables E.12.2 and E.12.3 for more details on habitat use.
[b] Seasonal use of areas with fewer insects (possible positive effect). Attraction to roads may also increase risk of collisions with vehicles (possible negative effect).

Table E.12.6. Acres of Terrestrial Mammal Habitats Altered by Dust, Gravel Spray, Thermokarsting, or Impoundments by Action Alternative or Option*

Habitat	Habitat Value (1 to 13)[a]	Alternative B: Proponent's Project	Alternative C: Disconnected Infield Road	Alternative D: Disconnected Access	Alternative E: Three-Pad Alternative	Option 3: Colville River Crossing
Unmapped Area	NA	0	0	0	0	2.2
Barren	1	10.3	2.5	6.8	9.8	0
Grass Marsh	1	0.1	0.8	0.1	2.1	0
Rivers and Streams	1	13.9	8.5	10.5	13.1	0
Human Modified	3[b]	1.1	1.1	1.1	0.2	0
Nonpatterned Wet Meadow	6	165.1	168.7	154.5	11.7	1.0
Sedge Marsh	6	62.5	69.4	38.4	59.9	0
Dune Complex	7	11.4	8.3	8.3	11.4	0
Riverine Complex	8	16.6	20.5	15.5	12.1	0.1
Young Basin Wetland Complex	9	1.3	1.8	1.3	1.0	0
Moist Tussock Tundra	10	1,581.5	1,715.4	1,269.9	1,406.5	6.4
Old Basin Wetland Complex	10	262.8	293.3	175.7	173.8	0.7

Habitat	Habitat Value (1 to 13)[a]	Alternative B: Proponent's Project	Alternative C: Disconnected Infield Road	Alternative D: Disconnected Access	Alternative E: Three-Pad Alternative	Option 3: Colville River Crossing
Patterned Wet Meadow	10	567.0	505.9	404.3	469.7	3.0
Salt Marsh	10	0	0	0	0	<0.1
Tall, Low, or Dwarf Shrub	11	277.4	235.2	277.4	210.9	0.4
Moist Sedge-Shrub Meadow	12	405.0	363.7	264.3	312.2	13.6
Total high-use habitat acres	**NA**	**3,095.0**	**3,115.3**	**2,392.9**	**2,574.1**	**24.1**
Total acres	**NA**	**3,376.0**	**3,395.1**	**2,628.1**	**2,794.4**	**27.4**

Note: NA (not applicable). Table depicts area potentially altered by dust generated from vehicles or wind on gravel fill (328-foot [100-meter] radius from gravel infrastructure). Options 1 and 2 would not result in habitat alteration by dust, gravel spray, thermokarsting, or impoundments for terrestrial mammals and are not included in this table. Total acres altered by dust may differ among resources because not all habitats are used by all resources (e.g., birds use different habitats than terrestrial mammals, and thus the total acres affected would be different).

[a] As described in F.12.2, *Habitats*, habitats were ranked by the number of species using them to portray areas with the highest potential for species occurrence. Shading denotes high-use habitats (use by nine or more species). See Tables E.12.2 and E.12.3 for more details on habitat use.

[b] Seasonal use of areas with fewer insects (possible positive effect). Attraction to roadsides may also increase risk of collisions with vehicles (possible negative effect).

Table E.12.7. Percent of the Teshekpuk Caribou Herd Seasonal Range within 2.5 Miles of New Gravel Infrastructure by Action Alternative and Module Delivery Option*

Percentage of Seasonal Range	Alternative B: Proponent's Project	Alternative C: Disconnected Infield Road	Alternative D: Disconnected Access	Alternative E: Three-Pad Alternative	Option 1: Proponent's Module Transfer Island	Option 2: Point Lonely Module Transfer Island[a]	Option 3: Colville River Crossing	Analysis Area
Spring migration	1.13	1.17	1.03	0.88	<0.01	<0.01	<0.01	6.01
Calving	0.66	0.69	0.61	0.48	<0.01	<0.01	<0.01	9.87
Calving (maternal females only)	0.60	0.61	0.54	0.42	<0.01	<0.01	<0.01	11.87
Post-calving	0.48	0.50	0.43	0.31	<0.01	<0.01	<0.01	13.07
Mosquito season	0.20	0.20	0.19	0.09	0.01	<0.01	<0.01	15.36
Oestrid fly season	0.86	0.89	0.79	0.61	0.01	<0.01	<0.01	10.26
Late summer	1.48	1.53	1.36	1.12	0.01	<0.01	<0.01	8.07
Fall migration	1.48	1.52	1.32	1.18	<0.01	<0.01	<0.01	6.88
Winter	1.12	1.16	1.00	0.92	<0.01	<0.01	<0.01	5.27

Source: ABR Inc. 2022

Note: < (less than). Percentages based on the proportion of use distribution calculated using kernel density estimation for each season.

[a] Percent of caribou herd within 2.5 miles (4 kilometers) of new and existing gravel infrastructure at Point Lonely.

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Willow Master Development Plan

Appendix E.13
Marine Mammals Technical Appendix

June 2022

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List of Acronyms

CRD	Colville River Delta
dB	decibels
dBA	A-weighted decibels
dB re 1 μPa	decibels referenced to 1 microPascal
CBS	Chukchi/Bering Sea
DPS	distinct population segment
EIS	Environmental Impact Statement
Hz	hertz
kHz	kilohertz
m	meter
MMPA	Marine Mammal Protection Act
NMFS	National Marine Fisheries Service
NPRW	North Pacific right whale
Project	Willow Master Development Plan Project
rms	root-mean-square
SBS	Southern Beaufort Sea
TL	transmission loss
USDOT	U.S. Department of Transportation
USFWS	U.S. Fish and Wildlife Service

1.0 MARINE MAMMALS

This appendix contains additional information on species and applicable underwater noise concepts and methodologies used in the development of the Willow Master Development Plan Project (Project) Environmental Impact Statement (EIS), Section 3.13, *Marine Mammals*.

1.1 Marine Mammals and Critical Habitats Protected under the Endangered Species Act

Descriptions of marine mammals that may be affected by the Project are summarized below, full descriptions are in BLM (2019b, 2020) and BOEM (2018).

1.1.1 Baleen Whales

1.1.1.1 Blue Whale

There are two stocks of blue whales (*Balaenoptera musculus*) in the North Pacific: the Eastern North Pacific stock and the Western/Central North Pacific stock. Individuals from both stocks may be found in Alaska. Blue whales primarily eat krill and generally occur in areas with high concentrations of krill. Blue whales feed at the surface and at depths over 328.1 feet (100 meters [m]). This may be tied to coastal upwelling that creates high concentrations of phytoplankton (Bailey, Mate et al. 2009) or because of vertical movements of prey through the water column (NMFS 2018a). Foraging habitat for the Western/Central North Pacific stock includes areas southwest of Kamchatka, south of the Aleutians, and in the Gulf of Alaska during the summer months (Stafford 2003). For the Eastern North Pacific stock, the U.S. west coast is one of the most important feeding areas in summer and fall; feeding to the north and south of this area has increased in recent years (Carretta, Forney et al. 2018). Blue whales could be encountered along the barge transit route in the Gulf of Alaska and the southern Bering Sea. They have not been reported in the Chukchi or Beaufort seas and thus would not occur near Oliktok Dock.

There is no critical habitat designated for blue whales.

1.1.1.2 Bowhead Whales

There are four stocks of bowhead whale (*Balaena mysticetus*) recognized globally by the International Whaling Commission, but only the Western Arctic stock, also referred to as the Bering-Chukchi-Beaufort stock or the Bering Sea stock, is found in Alaskan waters (Muto, Helker et al. 2021). Bowhead whales could be encountered along the barge transit route in fall as they migrate west across the Beaufort and Chukchi seas (Muto, Helker et al. 2021). They migrate to the east in spring, generally prior to when barges would be transiting the analysis area. Bowhead whales have been reported all summer in Harrison Bay, although they generally remain outside of the barrier islands in waters over 65 feet (20 m) in depth. They are not expected to be near Oliktok Dock due to the area’s shallow waters.

There is no critical habitat designated for bowhead whales.

1.1.1.3 Fin Whale

Fin whales (*Balaenoptera physalus*) of the Northeast Pacific stock can be found in the Chukchi Sea, in the Sea of Okhotsk, around the Aleutian Islands, and in the Gulf of Alaska (Muto, Helker et al. 2021). Surveys conducted along the Bering Sea shelf indicated fin whales were the most common large whale sighted, with whales distributed in an area of high productivity along the edge of the eastern Bering Sea continental shelf and in the middle shelf area (Friday, Waite et al. 2012; Friday, Zerbini et al. 2013; Springer, McRoy et al. 1996). Fin whales feed on krill, small schooling fish (e.g., herring, capelin, sand lance), and squid in summer. The whales fast in the winter while they migrate to warmer waters. Fin whales could be encountered along the barge transit route in the Gulf of Alaska and the Bering and Chukchi seas. Fin whales have not been reported in the Beaufort Sea, and thus would not occur near Oliktok Dock.

There is no critical habitat designated for fin whales.

1.1.1.4 Humpback Whale*

Three distinct population segments (DPSs) of humpback whale (*Megaptera novaeangliae*) occur in Alaska: the Western North Pacific DPS, the Mexico DPS, and the Hawaii DPS. Research indicates movement between winter and spring locations off Asia, including several island chains in the western North Pacific, primarily to Russia, as well as the Bering Sea and the Aleutian Islands during the summer months (Muto, Helker et al. 2021). The Mexico DPS of humpback whale winters in Mexico and migrates to diverse feeding areas. Summer feeding areas for this DPS include the Aleutian Islands; the Bering, Chukchi, and Beaufort seas; the Gulf of Alaska; southeast Alaska and northern British Columbia; southern British Columbia and Washington; and Oregon and California. Humpback whales could be encountered along the barge transit route in the Bering and Chukchi seas; there is a very low potential for encounters in the Beaufort Sea as there are only a few sightings of humpback whales east of Point Barrow. Humpback whales are not expected to occur near Oliktok Dock.

The National Marine Fisheries Service (NMFS) issued a final rule designating critical habitat for the endangered Western North Pacific DPS and the Mexico DPS in Alaska waters in 2021, partially encompassing the southernmost extent of the barge transit route near Dutch Harbor (86 FR 21082). Threats and vulnerabilities identified for this stock of humpback whales include natural and anthropogenic factors such as shipping traffic, military sonars, harmful algal blooms (Geraci, Anderson et al. 1989), climate change–related changes in prey distribution, fishing equipment entanglements, vessel strikes, and oil and gas–related activities (Muto, Helker et al. 2021).

1.1.1.5 North Pacific Right Whale

Historically, and prior to commercial whaling activities, North Pacific right whales (NPRWs) (*Eubalaena japonica*) were found in the Gulf of Alaska, the eastern Aleutian Islands, the south-central Bering Sea, the Sea of Okhotsk, and the Sea of Japan (Muto, Helker et al. 2021). The majority of NPRW sightings have occurred from approximately 40 degrees north to 60 degrees north latitude. Most sightings of right whales in the past 20 years have been in the southeastern Bering Sea, with a few in the Gulf of Alaska (Muto, Helker et al. 2021). NPRWs could be encountered along the barge transit route in the Bering Sea. There is critical habitat for NPRW in the barge transit route, but the route will be designed to avoid critical habitat. NPRWs have not been reported in the Beaufort Sea and thus will not occur near Oliktok Dock.

Critical habitat for NPRWs was designated in 2006 and is located in the Gulf of Alaska and the Bering Sea (NMFS 2006). Principal habitat requirements for right whales are areas of dense concentrations of prey, such as large species of zooplankton (Clapham, Shelden et al. 2006). Potential threats to right whale habitat are linked to commercial shipping and fishing vessel activity. Fishing activity increases the risk of entanglement, while shipping activities increase the risk of vessel strikes and oil spills in right whale habitat.

1.1.1.6 Gray Whale

Two stocks of gray whale (*Eschrichtius robustus*) occur in Alaska—the Western North Pacific stock and the Eastern North Pacific stock. They feed during the summer and fall in the Okhotsk Sea off northeastern Sakhalin Island, Russia, and southeastern Kamchatka in the Bering Sea (Muto, Helker et al. 2021). Some gray whales observed feeding off Sakhalin and Kamchatka migrate during winter to the west coast of North America in the eastern North Pacific while others migrate to areas off Asia in the western North Pacific (Muto, Helker et al. 2021). The western stock of gray whale could be encountered along the barge transit route in the Bering and Chukchi seas. The gray whales reported in the Beaufort Sea are likely from the eastern stock of gray whale, which are not listed. Therefore, the western stock will not occur near Oliktok Dock.

There is no critical habitat designated for gray whales.

1.1.2 Toothed Whales

1.1.2.1 Sperm Whale

Sperm whales (*Physeter macrocephalus*) are one of the most widely distributed marine mammal species; however, their population was depleted by commercial whaling over a period of more than 100 years. The North Pacific stock of sperm whales is widely distributed in the North Pacific, generally south of latitude 62 degrees north (Muto, Helker et al. 2021). Extensive numbers of female sperm whales have been documented in the western Bering Sea and the Aleutian Islands (Ivashchenko, Brownell Jr et al. 2014; Mizroch and Rice 2006). Males have been found in the Gulf of Alaska, the Bering Sea, and the waters around the Aleutian Islands in summer (Ivashchenko, Brownell Jr et al. 2014; Mizroch and Rice 2013). Sperm whales could be encountered along the barge transit route in the Gulf of Alaska and Bering Sea. They have not been reported in the Chukchi or Beaufort seas, so they will not occur near Oliktok Dock.

There is no critical habitat designated for sperm whales.

1.1.3 Pinnipeds

1.1.3.1 Bearded Seal

The Bering Sea stock of bearded seals (*Erignathus barbatus*) (Muto, Helker et al. 2021) are benthic feeders, preferring relatively shallow waters with drifting pack ice, where they feed on clams, shrimp, crabs, squid, and fish (Kovacs 2009). Hence, bearded seals typically prefer water depths of 80 to 250 feet (24 to 76 m) in the Beaufort Sea (Stirling, Kingsley et al. 1982). Bearded seals are closely associated with sea ice, and they prefer ice that is constantly in motion, which naturally creates open areas of water. They prefer broken, drifting pack ice but also use bottom-fast ice (Burns 1983; Kelly 1988).

During winter, bearded seals sometimes concentrate around consistently open leads in the ice and near the edge of pack ice (Kovacs 2009). Sea ice is important for reproduction, molting, and breeding (Cameron, Bengtson et al. 2010). Bearded seals pup on ice in late April or early May, mate after pups are weaned two to three weeks later, and molt in May and June (Kelly 1988). The primary predator of bearded seals is the polar bear.

As seasonal sea-ice cover retreats in the spring, bearded seals travel northward from the Bering Sea to the Chukchi and Beaufort seas and then back to the Bering Sea in fall and winter, when the ice begins to form again (Cameron, Bengtson et al. 2010). Bearded seals are less common in the Beaufort Sea, where only a few overwinter (Burns 1983; MacIntyre, Stafford et al. 2013). Most of the population disperses widely throughout northern Alaska waters in the open-water season, when some move into the Beaufort Sea (Burns 1983). Suitable habitat in the Beaufort Sea appears to be more limited than in the Chukchi Sea, which supports a higher rate of productivity than the Beaufort Sea (Bengston, Hiruki-Raring et al. 2005).

During the open-water season, bearded seals have been documented in Harrison Bay offshore from the Project, albeit in much lower numbers than ringed seals (LGL Alaska Research Associates Inc. 2008, 2011; Tetra Tech EC Inc. 2005, 2006, 2007); and a few bearded seals have been documented in the waters near Oliktok Point (LGL Alaska Research Associates Inc. 2008, 2011). Bearded seals are uncommon in the shallow waters near the Colville River Delta (CRD) because they tend to prefer drifting ice offshore (Seaman 1981).

There is no critical habitat designated for bearded seals.

1.1.3.2 Ringed Seal

The Arctic stock of ringed seals (*Pusa hispida*) (Muto, Helker et al. 2021) typically inhabit waters greater than 16 feet (4.9 m) deep. Thus, they are not abundant in the nearshore waters immediately off the CRD and barrier islands but are more common farther offshore in Harrison Bay (Seaman 1981). Ringed seals can winter on bottom-fast ice (Kelly, Bengtson et al. 2010), a habitat not used by other seal species. Ringed seals are strongly associated with sea ice; thus, changes in ice conditions influence their movements, foraging, reproductive behavior, and vulnerability to predation (Kelly, Bengtson et al. 2010). Arctic ringed seals use sea ice for resting, pupping, and molting; they rarely come ashore (Kelly, Badajos et al. 2010; Kelly, Bengtson et al. 2010).

Ringed seals move northward as ice cover recedes, spend summer far offshore (over 100 miles in some years), and return southward as ice advances in fall (Seaman 1981). Ringed seals forage in the open sea on fish, crustaceans, zooplankton, and invertebrates (Harwood, Smith et al. 2012; Kovacs 2007). The ringed seal is the primary prey species for polar bears and also is preyed on by Arctic foxes.

In 2014, NMFS published a proposed rule to designate critical habitat for the Arctic subspecies of ringed seal in the northern Bering, Chukchi, and Beaufort seas (NMFS 2014). In 2021, NMFS issued a revision to the proposed designation (86 FR 1452). Proposed critical habitat includes waters of the Bering, Chukchi, and Beaufort seas of the coast of Alaska within the geographical area presently occupied by the Arctic ringed seal (south past Nunivak Island). Primary constituent elements include sea ice habitat and prey resources such as Arctic cod, saffron cod, shrimp, and amphipods.

1.1.3.3 Steller Sea Lion

Steller sea lion (*Eumetopias jubatus*) habitat extends around the North Pacific Ocean rim from northern Japan, the Kuril Islands and the Okhotsk Sea, through the Aleutian Islands and the Bering Sea, along Alaska's southern coast, and south to California (Figure 16; Muto, Helker et al. 2021). The western DPS breeds on rookeries in Alaska, from Prince William Sound west through the Aleutian Islands. There are more than 100 haulout and rookery sites within the Steller sea lion range in western Alaska, with centers of abundance and distribution in the Gulf of Alaska and Aleutian Islands. Outside of the breeding season, during late May to early July, large numbers of individuals, both male and female, disperse widely. Steller sea lions are commonly found from nearshore habitats to the continental shelf and slope (Muto, Helker et al. 2018). Steller sea lions will be encountered in the southern part of the barge transit route along the Aleutian Islands and the Bering Sea. They do not inhabit the Chukchi or Beaufort seas, so they will not occur near Oliktok Dock.

Designated critical habitat includes all of the major Steller sea lion rookeries and major haulouts identified in the listing notice (NMFS 1993) and associated terrestrial, air, and aquatic zones. Critical habitat includes a terrestrial zone that extends 3,000 feet (0.9 kilometers [km]) landward from each major rookery and major haulout and an air zone that extends 3,000 feet (0.9 km) above the terrestrial zone of each major rookery and major haulout. For each major rookery and major haulout located west of 144 degrees west, critical habitat includes an aquatic zone (or buffer) that extends 20 nautical miles (37 km) seaward in all directions. Critical habitat also includes three large offshore foraging areas: the Shelikof Strait area, the Bogoslof area, and the Seguam Pass area (NMFS 1993). NMFS has also prohibited vessel entry within 3 nautical miles (6.5 km) of all Steller sea lion rookeries west of 150 degrees west. At the time of preparation of the Supplemental EIS, NMFS was reviewing existing Steller sea lion critical habitat to consider any new and pertinent sources of information since the 1993 designation.

The portion of the barge transit route near Dutch Harbor is located within designated critical habitat.

1.1.4 Other Marine Mammals

1.1.4.1 Northern Sea Otter

The southern barge transit route near Dutch Harbor, Unalaska, is within the range of the Southwest Alaska DPS (Southwest DPS) of northern sea otter (*Enhydra lutris kenyoni*). Northern sea otters occur in nearshore coastal waters along the U.S. north Pacific Rim, from the Aleutian Islands to California (USFWS 2014b). The Southwest DPS occurs along the western shore of lower Cook Inlet; throughout the Alaska Peninsula and Bristol Bay coasts; and along the Aleutian, Barren, Kodiak, and Pribilof islands (USFWS 2014b). Northern sea otters are non-migratory and occur year-round in nearshore coastal waters, typically within 131.2 feet (40 m) of depth to maintain consistent access to benthic foraging habitat

(Riedman and Estes 1990). Although individuals can cover long distances, greater than (>) 160 miles (> 100 km), movement is generally restricted by geography, energy requirements, and social behavior, and individuals tend to remain within a home range of less than (<) 11.6 square miles (<30 square km; Riedman and Estes 1990; Garshelis and Garshelis 1984).

The Eastern Aleutian critical habitat unit also occurs in the southern barge transit route near Dutch Harbor. The critical habitat is characterized as all the nearshore marine environment, ranging from the mean high tide line to the 65.6-foot (20-m) depth contour as well as waters occurring within 328.1 feet (100 m) of the mean high tide line (74 FR 51988).

1.1.4.2 Polar Bear

Denning habitat is an important factor for success of polar bears (*Ursus maritimus*), and it is a parameter often used to describe effects to the species. Polar bears may den on land or on ice. Only pregnant females den during the winter, typically entering the den in October or November and leaving in late March or April (Lentfer and Hensel 1980). Males and nonbreeding females remain active through the winter. Terrestrial dens are excavated in compacted snowdrifts adjacent to coastal banks of barrier islands and mainland bluffs, river or stream banks, and other areas with steep topographic relief to catch drifting snow (Durner, Amstrup et al. 2003). Between Utqiaġvik (Barrow) and the Kavik River (east of Prudhoe Bay), 95% of dens occupied by radio-collared bears were located within 5 miles (8 km) of the coast (Durner, Douglas et al. 2009); historical reports of dens found by other methods demonstrate some females den farther inland (Durner, Fischbach et al. 2010; Seaman 1981).

Polar bear critical habitat was designated by the U.S. Fish and Wildlife Service (USFWS) in 2011 (75 FR 76086). The three units of critical habitat in the analysis area (Figure 3.13.1) are as follows:

- **Sea-Ice Critical Habitat:** Used for feeding, breeding, denning, and movements; comprises U.S. territorial waters extending from the mean high-tide line seaward over the continental shelf to the 984-foot (300-m) depth contour.
- **Terrestrial Denning Critical Habitat:** Occurs along the northern coast of Alaska, where there are coastal bluffs or riverbanks suitable for capturing and retaining snowdrifts of sufficient depth to sustain maternal dens through winter, as described by Durner et al. (2001). Between the Kavik River and Utqiaġvik, terrestrial denning critical habitat occurs within 5 miles (8 km) of the mainland coast.
- **Barrier Island Critical Habitat:** Used for denning, refuge from human disturbance, and movements along the coast; comprises barrier islands and associated mainland spits, includes a “no disturbance zone” extending 1 mile (1.6 km) around all designated barrier-island habitat. (The no disturbance zone does not automatically preclude Project activities from occurring within it.)

Existing human-made structures and the land on which they were located on the effective date of the final critical habitat designation (75 FR 76086) are excluded from critical habitat. In addition, seven specific areas were excluded: the communities of Utqiaġvik and Kaktovik and five U.S. Air Force radar sites—Point Barrow, Point Lonely, Oliktok Point, Bullen Point, and Barter Island.

Because of topography and the distribution of suitable habitat characteristics across the landscape, not all portions of terrestrial denning critical habitat are suitable for denning. Thus, the U.S. Geological Survey mapped common denning habitat characteristics to describe suitable potential terrestrial denning habitat (Blank 2012; Durner, Amstrup et al. 2001; Durner, Simac et al. 2013) along the Beaufort Sea coast, as shown in Figures 3.13.1 and 3.13.2.

The analysis area is populated by the Southern Beaufort Sea (SBS) and Chukchi/Bering Sea (CBS) stocks of polar bears, which are classified as depleted under the Marine Mammal Protection Act (MMPA) and listed as threatened under the ESA (USFWS 2021a, 2021b). Polar bears occur in low densities throughout their range, and life-history characteristics including high longevity, late maturity, and few offspring, as well as remote habitat, contribute to difficulty in obtaining accurate abundance estimates (USFWS 2019a, 2019b).

The SBS and CBS populations have experienced substantial depletion because of overharvest in the 1960s, and have since undergone periodic cycles of growth and decline. Bromaghin, McDonald et al. (2015) estimated the SBS stock to be composed of 907 animals in 2010, based on consistent population declines since 1986 (USFWS 2017). In 2010, the USFWS reported a CBS stock population estimate of 2,000 individuals based on extrapolation of aerial survey and den detection data collected during the late 1990s; however, updated population modeling performed by Regehr et al. (2018) estimated an abundance of 2,937 bears (95% confidence interval [CI] = 1,552–5,944).

The SBS stock abundance is believed to be steadily declining because of negative impacts of sea ice loss on habitat availability and body condition (USFWS 2017). Although the CBS stock has experienced additional pressure from high harvest rates in Russia (Regehr, Hostetter et al. 2018; USFWS 2010), recent work by Regehr, Hostetter et al. (2018) demonstrates average-to-high reproductive parameters for the CBS stock since 1986, which suggests the population may be experiencing a productive trend.

1.2 Marine Mammals Protected under the Marine Mammal Protection Act

1.2.1 <u>Baleen Whales</u>

1.2.1.1 Minke whale

There are two stocks of minke whale (*Balaenoptera acutorostrata*) in U.S. waters: the Alaska stock and the California/Oregon/Washington stock. The Alaska stock is relatively common in the Bering and Chukchi seas through fall and in the inshore waters of the Gulf of Alaska (Muto, Helker et al. 2019). They are scattered throughout coastal, middle shelf, and outer shelf/slope oceanographic domains and appear to be migratory in the northern regions. No human mortality or serious injury of minke whales was reported to NMFS and a population estimate is not available for the stock. Minke whales feed by side-lunging into schools of prey (plankton, krill, small schooling fish). Minke whales could be encountered along the barge transit route in the Gulf of Alaska, and the Bering and Chukchi seas. They have not been reported in the Beaufort Sea, so they will not occur near Oliktok Dock.

1.2.2 <u>Toothed Whales</u>

1.2.2.1 Baird's beaked whale

Baird's beaked whales (*Berardius bairdii*) are the largest members of the beaked whale family and are found throughout the North Pacific Ocean. There are two stocks defined in the U.S.: the California/Oregon/Washington stock and the Alaska stock. In the Bering Sea and the Okhotsk Sea, Baird's beaked whales arrive in April–May, are observed throughout the summer, and decrease by October (Muto, Helker et al. 2019). Their winter distribution is unknown, although they have been acoustically detected from November through January in the northern Gulf of Alaska. They prefer cold, deep oceanic waters but may also be found nearshore along continental shelves. They make long, deep dives lasting from 11 to 30 minutes, diving to depths of 2,500 to 4,000 feet (762 to 1,219 m), feeding on deep sea fish, crustaceans, and cephalopods. Baird's beaked whales could be encountered along the barge transit route in the Gulf of Alaska and the Bering Sea. They have not been reported in the Chukchi or Beaufort seas, so they will not occur near Oliktok Dock.

1.2.2.2 Beluga Whale

Beluga whales (*Delphinapterus leucas*) in Arctic Alaska belong to the Beaufort Sea stock or the Eastern Chukchi Sea stock (Muto, Helker et al. 2021). They use waters in the eastern Beaufort Sea but stay farther offshore than bowhead whales, typically beyond the shelf break (Hauser, Laidre et al. 2014). Spring migration eastward through the Beaufort Sea is stock specific, with the Beaufort Sea stock migrating in spring (April and May) and Eastern Chukchi Sea stock migrating in summer (June and July; Suydam, Lowry et al. 2001). The Beaufort Sea stock continues on to Canadian waters, spending the summer in the eastern Beaufort Sea, the Mackenzie River Estuary, Amundsen Gulf, M'Clure Strait, and Viscount Melville Sound (Hauser, Laidre et al. 2017; Hauser, Laidre et al. 2014). The Eastern Chukchi Sea stock

spends the summer primarily restricted to the continental shelf and slope north of Alaska in the northeastern Chukchi and western Beaufort seas (Hauser, Laidre et al. 2014; Stafford, Ferguson et al. 2018; Suydam 2009). The Beaufort Sea stock starts moving west and south in September, leading to an overlap of ranges for the two stocks that extends from Prince of Wales Strait in Canada westward to Herald Shoal in the Chukchi Sea (Stafford, Ferguson et al. 2018; Stafford, Nieukirk et al. 1999).
The main fall migration corridor of beluga whales is over 54 nautical miles (100 km) north of the coast; however, they do occasionally approach shallow water in coastal areas, such as lagoons and river deltas, to molt or feed (Suydam 2009). Beluga whales could be encountered along the barge transit route in the Beaufort and Chukchi seas. They have been reported in Harrison Bay but typically travel outside of the barrier islands and are not expected occur near Oliktok Dock.

1.2.2.3 Cuvier's beaked whale

Cuvier's beaked whales (*Ziphius cavirostris*) have the most extensive range of all beaked whales, except in high polar waters (Muto, Helker et al. 2019). There are three recognized stocks: the Alaska stock, the California/Oregon/Washington stock, and the Hawaii stock. They range north to the northern Gulf of Alaska, the Aleutian Islands, and the Commander Islands. They prefer deep pelagic oceanic waters but may also be found nearer shore along the continental slope. They make long, deep dives lasting from 20 to 40 minutes or longer, diving at least 3,300 feet (1,006 m), feeding on cephalopods, deep sea fish, and crustaceans. Cuvier's beaked whales could be encountered along the barge transit route in the Gulf of Alaska and the Bering Sea. They have not been reported in the Chukchi or Beaufort seas, so they will not occur near Oliktok Dock.

1.2.2.4 Dall's porpoise

Dall's porpoises (*Phocoenoides dalli*) are common in the North Pacific and have been divided into two stocks: the California/Oregon/Washington stock and the Alaska stock. Dall's porpoises are widely distributed in deep oceanic water over 8,000 feet (2,500 m) and over the continental slope of the Bering Sea (Muto, Helker et al. 2019) during all months. They feed on small school fish, mid- and deep-water fish, cephalopods, and crustaceans. Dall's porpoises could be encountered along the barge transit route in the Gulf of Alaska and the Bering Sea. They have not been reported in the Chukchi or Beaufort seas, so they will not occur near Oliktok Dock.

1.2.2.5 Harbor porpoise

Harbor porpoises (*Phocoena phocoena*) are the smallest cetacean in the Arctic. The Bering Sea stock comprises 48,215 individuals that occur from the Aleutian Islands north to Point Barrow. They rarely occur near Point Barrow, although the increase in their frequency of occurrence over the past 20 years may represent a range expansion (Funk, Ireland et al. 2010; Hamilton and Derocher 2019; Whiting, Griffith et al. 2011). Harbor porpoises could be encountered along the barge transit route in the Gulf of Alaska and the Bering and Chukchi seas. They have not been reported in the Beaufort Sea, so they will not occur near Oliktok Dock.

1.2.2.6 Killer Whale

Two stocks of killer whale (*Orcinus orca*) may occur in the analysis area: the Alaska Resident stock that occurs from southeastern Alaska to the Bering Sea, and the Eastern North Pacific, Gulf of Alaska, Aleutian Islands, and Bering Sea Transient stock that can occur in the Chukchi and Beaufort seas (Muto, Helker et al. 2021). NMFS is currently evaluating new genetic information on killer whales in Alaska that indicates the current stock structure needs to be reassessed (Muto, Helker et al. 2021). Killer whales are occasionally reported in the northeastern Chukchi Sea attacking gray and beluga whales and bearded seals, and possibly foraging on fish. They have rarely been recorded in the Beaufort Sea east of Utqiaġvik (Clarke, Brower et al. 2015; Clarke, Christman et al. 2013; Lowry, Nelson et al. 1987). Killer whales could be encountered along the barge transit route in the Bering and Chukchi seas. They have not been reported in the Beaufort Sea, so they will not occur near Oliktok Dock.

1.2.2.7 Pacific white-sided dolphin

The Pacific-white sided dolphin (*Lagenorhynchus obliquidens*) is found throughout the North Pacific, north to the Gulf of Alaska, west to Amchitka in the Aleutian Islands, and sometimes in the southern Bering Sea (Muto, Helker et al. 2019). There are three stocks; the stock that uses Alaska waters is the North Pacific stock, whose population estimate is 26,880 animals. Pacific white-sided dolphins could be encountered along the barge transit route in the Gulf of Alaska and the Bering Sea. They have not been reported in the Chukchi or Beaufort seas, so they will not occur near Oliktok Dock.

1.2.2.8 Stejneger's beaked whale

Stejneger's beaked whales (*Mesoplodon stejnegeri*) are rarely seen at sea, and the distribution is generally inferred from stranded carcasses. The species is endemic to the cold, deep waters of the southwestern Bering Sea and Gulf of Alaska (Muto, Helker et al. 2019) and is not known to enter Arctic waters. They are deep divers, feeding on deep-water fish, tunicates, and cephalopods. Stejneger's beaked whales could be encountered along the barge transit route in the Gulf of Alaska and the Bering Sea. They have not been reported in the Chukchi or Beaufort seas, so they will not occur near Oliktok Dock.

1.2.3 Pinnipeds

1.2.3.1 Pacific walrus

Pacific walruses (*Odobenus rosmarus*) are listed as a Special Status Species by BLM (2019a). They occur throughout the continental shelves of the Bering and Chukchi seas and occasionally in the East Siberian and Beaufort seas (USFWS 2014a). Aerial surveys conducted in 2006 estimated 129,000 individuals (95% confidence interval: 55,000–507,000) within the survey area (Speckman, Chernook et al. 2011). This estimate is considered to be biased low because not all areas important to walruses were surveyed (USFWS 2014a). During the winter breeding season, walruses occur in the Bering Sea in areas with thin ice, open leads, and polynyas (Fay, Kelly et al. 1984; Garlich-Miller, MacCracken et al. 2011). Most of the population of Pacific walruses summers in the Chukchi Sea, although several thousand individuals, primarily adult males, congregate at coastal haulouts in the Gulf of Anadyr, Russia; both sides of the Bering Strait; and Bristol Bay, Alaska. Historically, walruses spent the summer on sea ice cover in the Chukchi Sea, with large numbers found over Hanna Shoal in U.S. waters and near Wrangel Island in Russia (USFWS 2014a). Over the past decade, the number of walruses hauling out on land along the Alaska and Chukotka coastlines of the Chukchi Sea has increased from hundreds to > 100,000 (Garlich-Miller, MacCracken et al. 2011; Jay, Marcot et al. 2011; Kavry, Boltunov et al. 2008). Within the National Petroleum Reserve in Alaska, walruses regularly haul out on the barrier islands of Kasegaluk Lagoon and coastline in and near Peard Bay (Fischbach, Kochnev et al. 2016; Jay, Fischbach et al. 2012) (BLM 2019b, Appendix A, Map 3-24). This change in distribution within the Chukchi Sea is coincident with the accelerating loss of summer sea ice over the continental shelf (NSIDC 2012). As more walruses haul out in coastal areas, they may deplete prey resources that are readily accessible near the haulouts. Walruses rely primarily on bivalves as prey but also eat a wide variety of other benthic prey items (Sheffield and Grebmeier 2009).

Walruses could be encountered along the barge transit route in the Bering and Chukchi seas. Very few individuals have been reported in the Beaufort Sea, so they are not expected to occur near Oliktok Dock.

1.2.3.2 Ribbon Seal

Ribbon seals (*Histriophoca fasciata*) inhabit the Bering, Chukchi, and western Beaufort seas. They are relatively solitary, except when they form loose aggregations on pack ice during spring to give birth, nurse, and molt. They are rarely seen on shorefast ice or land. The estimated abundance is approximately 163,086 seals (Muto, Helker et al. 2021). Ribbon seals are an important resource for Alaska Native subsistence hunters. Ribbon seals could be encountered along the barge transit route in the Bering, Chukchi, and Beaufort seas. They are rarely found on land or in shallow waters, so they are not expected to occur near Oliktok Dock.

1.2.3.3 Spotted Seal

The Bering Sea stock of spotted seals (*Phoca largha*) may be seasonally present in the analysis area along the coast of Harrison Bay and in the CRD (BLM 2012) during winter and spring near sea ice (Quakenbush 1988) using terrestrial haulouts on mud, sand, or gravel beaches, and on sea ice in spring where, water depth does not exceed 650 feet (Muto, Helker et al. 2021). Numerous haulout sites have been identified in the CRD (USACE 2018). During winter and spring, this species is strongly associated with the presence of sea ice (Quakenbush 1988).

1.3 Noise and Marine Mammals

This section summarizes the properties of underwater noise, which are relevant to understanding the effects of noise produced by construction and operations activities on the underwater marine environment in the analysis area. This document does not provide a detailed calculation to acoustical thresholds of specific Project components proposed under the action alternatives. This detailed information would be analyzed further in a MMPA authorization request and associated Endangered Species Act Section 7 consultation.

1.3.1 Overview of Acoustics

Sound is a physical phenomenon consisting of minute vibrations that travel through a medium, such as air or water. The disturbed particles of the medium move against undisturbed particles, causing an increase in pressure. This increase in pressure causes adjacent undisturbed particles to move away, spreading the disturbance away from its origin. This combination of pressure and particle motion makes up an acoustic wave.

The intensity of sound is characterized by decibels (dB). The mathematical definition of a decibel is the base 10 logarithmic function of the ratio of the pressure fluctuation to a reference pressure. Decibels are measured using a logarithmic scale, so sound levels cannot be added or subtracted directly. For example, if a sound's intensity is doubled, the sound level increases by 3 dB, regardless of the initial sound level. Thus, 60 dB + 60 dB = 63 dB, and 80 dB + 80 dB = 83 dB. The decibel measures the difference in orders of magnitude (× 10), so 10 dB means 10 times the power; 20 dB means 100 times the power; 30 dB means 1,000 times the power; and so on.

Because the decibel is a relative measure, any absolute value expressed in dB is meaningless without the appropriate reference. The metric that describes the change in pressure (amplitude) is the pascal (Pa), approximately equivalent to 0.0001465 pounds per square inch. In this document, all underwater sound levels are expressed in decibels referenced to 1 microPascal (dB re 1 μPa) and all airborne sound levels are expressed in dB re 20 μPa. It is possible to convert between the reference pressures—in this instance, 26 dB. However, the efficiencies of sound generation and reception in air and water differ greatly, so simply adding a constant to the underwater sound pressure level will not allow a reasonable assessment of how the sound is perceived by the receiver. Table E.13.1 summarizes terms commonly used to describe sounds.

The method commonly used to quantify airborne sounds consists of evaluating all frequencies of a sound according to a weighting system that reflects that human hearing is less sensitive at low frequencies and extremely high frequencies than at mid-range frequencies. This is called A-weighting, and the measured level is called the A-weighted decibel (dBA). Sound levels to assess potential noise impacts on terrestrial wildlife, airborne or underwater, are not weighted and measure the entire frequency range of interest, unless specified by an agency.

Hertz (Hz) is a measure of how many times each second the crest of a sound pressure wave passes a fixed point. For example, when a drummer beats a drum, the skin of the drum vibrates a number of times per second. When the drum skin vibrates 100 times per second, it generates a sound pressure wave that is oscillating at 100 Hz, and this pressure oscillation is perceived by the ear/brain as a tonal pitch of 100 Hz. Sound frequencies between 20 and 20,000 Hz (or 20 kilohertz) are within the range of sensitivity of the best human ear. The hearing sensitivities of the animals of interest in this document will be discussed for each species below.

As sound propagates out from the source, there are many factors that change the amplitude. These include the spreading of sound over a wide area (spreading loss), the loss to friction between particles that vibrate (absorption), and the scattering and reflections from objects in the path (including surface or seafloor). The total propagation, including these factors, is called the transmission loss (TL). In air, TL parameters vary with frequency and type of source, temperature, wind, source and receiver height, and ground type. Underwater, TL parameters vary with frequency and type of source, temperature, wind, sea conditions, source and receiver depth, water chemistry, and bottom composition and topography. For ease in estimating distances to agency thresholds, simple TL can be calculated using logarithmic spreading loss with the following formula:

$$TL = B * log10(R)$$

TL is transmission loss, B is logarithmic loss, and R is radius to the threshold

In air, the standard value of B is 20 (or reported as 20 log(R)), resulting in a reduction of 6 dB for every doubling of distance. For underwater TL, there are three common spreading models used by agencies: 1) cylindrical spreading for shallow water, or 10 log(R), resulting in a reduction of 3 dB for every doubling of distance; 2) spherical spreading for deeper water, or 20 log(R), resulting in a reduction of 3 dB for every doubling of distance; and 3) practical spreading, which is used when agencies have not defined the depth for the other models, or 15 log(R), resulting in a reduction of 4.5 dB for every doubling of distance.

Table E.13.1. Definition of Acoustical Terms

Term	Definition
Decibel (dB)	A unit describing the amplitude of sound, equal to 20 times the logarithm to the base 10 of the ratio of the pressure of the sound measured to the reference pressure. The reference pressure for water is 1 microPascal (µPa) and for air is 20 µPa (approximate threshold of human audibility).
Sound exposure level (SEL)	The SEL is the total noise energy produced from a single noise event and is the integration of all the acoustic energy contained within the event. SEL incorporates both the intensity and duration of a noise event. SEL is expressed in dB re 1 μPa^2-sec.
Sound pressure level (SPL)	Sound pressure is the force per unit area, usually expressed in µPa (or 20 micro newtons per square meter), where 1 Pascal is the pressure resulting from a force of 1 Newton exerted over an area of 1 m^2. The SPL is expressed in decibels as 20 times the logarithm to the base 10 of the ratio between the pressure exerted by the sound to a reference sound pressure. SPL is the quantity that is directly measured by a sound level meter.
Frequency, hertz (Hz) or kilohertz (kHz)	Frequency is expressed in terms of oscillations, or cycles, per second. Cycles per second are commonly referred to as Hz. Typical human hearing ranges from 20 Hz to 20,000 Hz (or 20 kHz).
Peak sound pressure (unweighted)	The peak sound pressure level is based on the largest absolute value of the instantaneous sound pressure over the measured frequency range, reported as dB re 1 µPa for underwater or dB re 20 µPa for airborne.
Root-mean-square (rms)	The rms level is the square root of the energy divided by a defined time period. For pulses, the rms has been defined as the average of the squared pressures over the time that comprises that portion of the waveform containing 90% of the sound energy for one impulse.
Ambient noise level	The ambient noise level is the background sound level, which is a composite of noise from all sources near and far. The normal or existing level of environmental noise at a given location.

1.3.2 Applicable Noise Criteria

Under the MMPA, NMFS and USFWS have defined levels of harassment for marine mammals. Level A harassment is defined as the potential to injure and Level B harassment is defined as the potential to disturb. Table E.13.2 summarizes the thresholds for assessing potential impacts on marine mammals from underwater and airborne sound.

Table E.13.2. Marine Mammal Injury and Disturbance Thresholds for Underwater and Airborne Sound

Marine Mammals	Underwater Injury Threshold (Level A) Impulsive	Underwater Injury Threshold (Level A) Non-Impulsive	Underwater Disturbance Threshold (Level B) Impulsive	Underwater Disturbance Threshold (Level B) Non-Impulsive	Airborne Threshold (Level B)
Low-frequency cetaceans	219 dB L_{pk} 183 dB SEL	199 dB SEL	160 dB rms	120 dB rms	NA
Mid-frequency cetaceans	*230 dB L_{pk}* 185 dB SEL	198 dB SEL	160 dB rms	120 dB rms	NA
High-frequency cetaceans	202 dB L_{pk} 155 dB SEL	173 dB SEL	160 dB rms	120 dB rms	NA
Phocid pinnipeds[a]	218 dB L_{pk} 185 dB SEL	201 dB SEL	160 dB rms	120 dB rms	100 dB rms
Otariid pinnipeds	232 dB L_{pk} 203 dB SEL	219 dB SEL	160 dB rms	120 dB rms	100 dB rms
Polar bears, walrus, sea otters	190 dB rms	180 dB rms	160 dB rms	160 dB rms	NA

Source: NMFS 2018

Note: All underwater sound levels are reported as decibels (dB) referenced to 1 microPascal (dB re 1 µPa) and all airborne sound levels are reported as dB re 20 µPa. Peak (L_{pk}) is the instantaneous maximum sound level; sound exposure level (SEL) is the accumulative sound energy over a 24-hour period; root-mean-square (rms) is the arithmetic mean of the squares of the measured pressure of the sound. NA (not applicable).

[a] The airborne threshold for harbor seals is 90 dB rms. The airborne threshold for all other phocid pinnipeds is 100 dB rms.

1.3.3 Airborne Acoustic Environment of the Beaufort Sea

The airborne acoustic environment is characterized in the Willow Master Development Plan Supplemental EIS, Section 3.6, *Noise*.

1.3.4 Underwater Acoustic Environment of the Beaufort Sea

The underwater acoustic environment consists of sounds from natural, biologic, and anthropogenic sources. Underwater sound levels in the ocean vary over time, as these sources fluctuate on daily, seasonal, and annual scales. Natural sources include geologic processes, earthquakes, wind, thunder, rain, waves, ice, etc. Biologic sources include marine mammals and fish. Anthropogenic sounds are those generated by humans, including vessels, scientific research equipment, aircraft, and offshore industrial activities.

The Beaufort Sea has a narrow continental shelf that drops off to the north into the Beaufort Sea Plateau, a deep basin with depths of 6,500 to 10,000 feet, allowing for the long-range propagation of high-amplitude, low-frequency sounds. All of the module delivery options are in the very shallow waters of Harrison Bay. Generally, underwater sound levels in shallow waters increase with increasing wind speed (Wenz 1962). Marine mammal vocalizations and anthropogenic sounds have been measured using seafloor-mounted passive acoustic monitoring devices since the late 1970s. The typical reported ambient levels range from 77 to 135 dB re 1 µPa (Greene Jr., Blackwell et al. 2008; LGL Alaska Research Associates Inc., Greenridge Sciences et al. 2013), with general ambient conditions at approximately 120 dB re 1 µPa. For consideration of underwater noise effects from Project-related noise sources, the analysis assessed the distance needed for a noise source to attenuate to the underwater background sound level of 120 dB re 1 µPa.

1.3.5 Description of Underwater Sound Sources

The acoustic characteristics of each of the Project activities are described in the following section and are summarized in Table E.13.3. Aspects of module transfer island construction that have the potential to incidentally harass marine mammals are the airborne noise generated by vibratory and impact pile driving or removal during winter (through bottom-fast ice), some construction activities through ice, screeding, and vessel traffic. Inland pile driving may result in airborne disturbance to polar bears.

Table E.13.3. Summary of Noise Sources

Activity	Airborne Sound Level (dBA re 20 µPa)	Underwater Sound Level (dB re 1 µPa)	Frequency	Reference
Impact driving of pipe piles	101 dBA at 50 feet	None proposed in-water for the Project	Range: 100–4,000 Hz Concentration: 125 Hz	Airborne: USDOT 2006 Underwater: Illingworth and Rodkin 2007
Vibratory driving of pipe piles	101 dBA at 50 feet	None proposed in-water for the Project	Range: 100–4,000 Hz Concentration: 125 Hz	Airborne: USDOT 2006 Underwater: Illingworth and Rodkin 2007
Vibratory pile removal	101 dBA at 50 feet	None proposed in-water for the Project	Range: 10–10,000 Hz	Airborne: USDOT 2006 Underwater: Pangerc et al. 2017
Vibratory driving of sheet piles	81 dBA at 328 feet	None proposed in-water for the Project	Range: 10–10,000 Hz Concentration: 24–25 Hz	Greene et al. 2008
Screeding (tugboat and barge)	NA	164–179 dB rms at 3.28 feet	Range: 10–10,000 Hz Concentration: 10–2,000 Hz	Blackwell and Greene 2003
Ice trenchers (bulldozer)	64.7 dBA at 328 feet	114 dB rms at 328 feet	Range: 10–8,000 Hz Concentration: 31–400 Hz	Greene et al. 2008
Grading excavators (backhoe)	78 dBA at 50 feet	125 dB rms at 328 feet	Range: 10–8,000 Hz Concentration: 31–400 Hz	Airborne: USDOT 2006 Underwater: Greene et al. 2008
Ditch Witch	76.3 dBA at 328 feet	122 dB rms at 328 feet	Range: 10-8,000 Hz Concentration: 20–400 Hz	Greene et al. 2008
General vessel operations	40 at 1,000 feet	145–175 dB rms at 3.28 feet	10–1,500 Hz	Blackwell and Greene 2003; Richardson et al. 1995; TORP Terminal LP 2009

Note: dB (decibels); dB re 1 µPa (decibels referenced to 1 microPascal); dBA (A-weighted decibels); Hz (hertz); NA (not applicable); rms (root-mean-square); USDOT (U.S. Department of Transportation).

1.3.5.1 Impact Pile Driving

The U.S. Department of Transportation (USDOT) *Construction Noise Handbook* provides a summary of equipment with measured maximum airborne sound levels at 50 feet (15 m). The handbook reports an airborne level of 101 dBA at 50 feet (15 m) for impact pile driving.

1.3.5.2 Vibratory Pile Driving and Removal

Greene et al. (2008) measured underwater sound, airborne sound, and iceborne vibrations associated with the construction of Northstar Island (~39 feet depth). For vibratory pile driving of sheet piles, they reported airborne levels of 81 dB at 328 feet (100 m), with the energy between 10 and 10,000 Hz and concentrated at 50 Hz. Airborne sound levels associated with pile removal is the same as installation.

1.3.5.3 Underwater Construction

Seabed preparation may use a barge with a screeding device. Blackwell and Greene (2003) reported a source level of 164 dB re 1 µPa rms at 3.28 (1 m) feet for the tugboat *Leo* pushing a full barge near the Port of Anchorage. The source level increased to 179 dB re 1 µPa rms at 3.28 feet (1 m) when the tugboat was using its thrusters to maneuver the barge during docking. Most of the sound energy is in the band of 100 to 2,000 Hz, with a large peak at 50 Hz. There are no measurements available in Alaska of screeding, so these levels are used as a proxy for a characterization of these activities.

In their analysis of Northstar Island, Greene et al. (2008) measured an underwater sound level of a bulldozer at 114.2 dB re 1 µPa rms at 328 feet (100 m), a backhoe at 124.8 dB re 1 µPa rms at 328 feet (100 m), and a Ditch Witch at 122 dB re 1 µPa rms at 328 feet (100 m), with the center frequency between 10 and 63 Hz. They reported that broadband sounds from these activities diminished to the median background level of 77 to 116 dB re 1 µPa rms (10 to 10,000 Hz range) at distances between 0.62 and 3.1 miles (1 and 5 km).

The measured airborne level of the bulldozer and Ditch Witch were 64.7 dB and 76.3 re 20 µPa rms at 328 feet (100 m), respectively; and airborne sound associated with the backhoe was not measured (Greene et al. (2008). The USDOT *Construction Noise Handbook* provides a summary of equipment with measured maximum levels at 50 feet. The handbook reports an airborne level of 78 dBA at 50 feet.

1.3.5.4 Vessels

Some vessels such as tugboats and cargo ships can under some circumstances generate underwater sound exceeding the non-impulsive threshold of 120 dB due largely to the continuous cavitation sound produced from the propeller arrangement of both drive propellers and thrusters. Large ships produce broadband sound pressure levels of about 170 dB re 1 µPa rms at 3.28 feet (1 m) (Blackwell and Greene 2003; Richardson, Greene et al. 1995). Thrusters have generally smaller blade arrangements operating at higher rotations per minute and therefore largely produce more cavitation sound than drive propellers.

1.3.6 Calculation of Distances to Thresholds

A detailed analysis of impacts to marine mammals would be included in the MMPA authorization request, if required. For purposes of the EIS, distances from construction activities were estimated to the 120 dB underwater and 100 dB airborne thresholds. Assuming a TL of 20 log(R) for airborne sound and 15 log(R) for underwater sound, the estimated distances to the underwater and airborne thresholds are summarized in Table E.13.4. Airborne noise from construction activities would be below the 100-dB airborne threshold within 55 feet for all activities and less than 21 feet for non–pile driving activities. Underwater noise from construction activities such as use of a backhoe, bulldozer, or Ditch Witch would be below the 120-dB threshold between 131 and 707 feet from the source. Underwater noise from vessels would be below the 120-dB threshold at 7,067 feet.

Table E.13.4. Estimates of Noise Levels to Thresholds by Activity

Activity	Distance to 100 dB airborne threshold (feet)	Distance to 120 dB underwater threshold (feet)
Impact pipe pile driving	55	None proposed in-water for the Project
Vibratory pipe pile driving	55	None proposed in-water for the Project
Vibratory sheet pile driving	37	None proposed in-water for the Project
Bulldozer	6	131
Backhoe	4	707
Ditch Witch	21	446
Vessel	NA	7,067

Note: dB (decibels); NA (not applicable).

1.4 Required Measures to Avoid and Minimize Effects to Marine Mammals

The following measures were identified during ESA consultation with NMFS to avoid or minimize the effects of the Project on species and habitats protected by the ESA.

1.4.1 General Measures

1. The applicant will notify NMFS 7 days prior to the start of in-water activity.
    a. If there is a delay in activity, the applicant will notify NMFS as soon as possible.

1.4.2 Measures for Transiting Vessels

1. Crew members on barges and support vessels will be trained on basic marine mammal identification and vessel disturbance guidelines.
2. When weather conditions require, such as when visibility drops, vessel operators must reduce speed and change direction, as necessary (and as operationally practicable), to avoid the likelihood of injuring marine mammals.
3. The transit of vessels is not authorized before July 1. This operating condition is intended to allow marine mammals the opportunity to disperse from the confines of spring leads in sea ice and minimize interactions with subsistence hunters. The return transit is dependent on completion of project work and presence of near shore ice that precludes safe operations. The typical timeframe for returning vessels is mid-to late October or early November, depending on ice conditions. Transit will be prior to formation of shore or bottom-fast ice.
4. The marine vessel route will avoid North Pacific right whale (NPRW)designated critical habitat. Should crew members identify NPRW outside of critical habitat, a sighting report will be reported to NMFS within 24 hours with the following information:
    a. Date, time, and geographic coordinates of the sighting(s);
    b. Species observed, number of animals observed per sighting event; and number of adults/juveniles/calves per sighting event (if determinable); and
    c. Because sightings of NPRWs are uncommon, and photographs that allow for identification of individual whales from markings are extremely valuable, photographs will be taken if feasible, but in a way that does not involve disturbing the animal (e.g., if vessel speed and course changes are not otherwise warranted, they will not take place for the purpose of positioning a photographer to take better photographs). Photographs taken of NPRWs will be submitted to NMFS.
5. Vessels may not be operated in such a way as to separate members of a group of marine mammals from other members of the group.
6. Operators should take reasonable steps to alert other vessel operators in the vicinity of marine mammals.
7. Vessels will not allow tow lines to remain in the water, and no trash or other debris will be thrown overboard, thereby reducing the potential for marine mammal entanglement.
   All personnel will be responsible for cutting all unused packing straps, plastic rings, and other synthetic loops that have the potential to become entangled around fish or wildlife.
8. Vessels will implement measures to minimize risk of spilling hazardous substances. These measures will include avoiding operation of watercraft in the presence of sea ice to the extent practicable and using fully operational vessel navigation systems composed of radar, chart plotter, sonar, marine communication systems, and satellite navigation receivers, as well as the Automatic Identification System (AIS) for vessel tracking.
9. Vessel operators will avoid groups of 3 or more whales. A group is defined as being 3 or more whales observed within a 500 m (1,645 ft) area and displaying behaviors of directed or coordinated activity (e.g., group feeding).
10. All nonessential boat and barge traffic will be scheduled to avoid periods when bowhead whales are migrating through the area to where they may be affected by sound from the project. Any non-essential boat, barge, or aircraft will be scheduled to avoid approaching the harvest area around Cross Island during the bowhead whale subsistence hunting season consistent with the Conflict Avoidance Agreement.
11. If a vessel approaches within1.6 km (1 mi) of observed whales, except when providing emergency assistance to whalers or in other emergency situations, the operator will take reasonable precautions to avoid potential interaction with the whales by taking one or more of the following actions, as appropriate:
    a. Reducing vessel speed to less than 5 knots (5.8 miles per hour [mph]) within 274m (900 ft) of the whale.

   b. Steering around the whale, if possible.
   c. Operating the vessel to avoid causing a whale to make multiple changes indirection.
   d. Checking the waters around the vessel to ensure that no whales will be injured when the propellers are engaged.
   e. Vessels will not exceed speeds of 10 knots (11.5 mph) in order to reduce potential whale strikes.
   f. If a whale approaches the vessel and if maritime conditions safely allow, the engine will be put in neutral and the whale will be allowed to pass beyond the vessel. If the vessel is taken out of gear, vessel crew will ensure that no whales are within 50 m (164 ft) of the vessel when propellers are re-engaged, thus minimizing risk of marine mammal injury.
   g. Vessels will stay at least 300 m (984 ft) away from cow-calf pairs, feeding aggregations, or whales that are engaged in breeding behavior.
12. Consistent with NMFS marine mammal viewing guidelines(https://alaskafisheries.noaa.gov/pr/mm-viewing-guide), vessel operators will, at all times, avoid approaching within 91 m (300 ft) of marine mammals. Operators will observe direction of travel and attempt to maintain a distance of 91 m (300 ft) or greater between the animal and the vessel by working to alter course or slowing the vessel.
13. If a listed marine mammal is struck by a vessel, it must be reported to NMFS within 24 hours. The following will be included when reporting vessel collisions with marine mammals:
   a. Information that will otherwise be listed in the PSO Observation Record.
   b. Number and species of marine mammals involved in the collision.
   c. The date, time, and location of the collision.
   d. The cause of the take (e.g., vessel strike).
   e. The time the animal(s) was first observed and last seen.
   f. Mitigation measures implemented prior to and after the animal was taken.
   g. Contact information for PSO on duty at the time of the collision, vessel's pilot at the time of the collision, or ship's captain.
14. Vessel transit through Steller sea lion critical habitat or near major rookeries and haulouts:
   a. The vessel operator will not purposely approach within 3 nautical miles (5.5 km) of major Steller sea lion rookeries or haulouts where vessel safety requirements allow and/or where practicable. Vessels will remain 3 nautical miles (5.5 km) from all Steller sealion rookery sites listed at 50 CFR 224.103(d)(1)(iii).

1.4.3 Measures for screeding at Oliktok Dock

1. During screeding, a trained PSO will be stationed on the tug or barge.
2. Screeding will stop if a marine mammal is observed within a 215 m (707 ft) radius of the screeding equipment. Screeding will recommence when the marine mammal has moved outside of that radius or has not been observed for 15 minutes (for seals) or 30 minutes (for cetaceans).
3. PSOs will record observations on data forms or electronic data sheets to be submitted to NMFS in a digital spreadsheet in monthly, annual, and final reports. PSOs will record the following:
   a. Date and time that in-water activity and observation efforts begin and end;
   b. Weather parameters (e.g., percent cloud cover, percent glare, visibility) and sea state where the Beaufort Wind Force Scale will be used to determine sea-state(https://www.weather.gov/mfl/beaufort);
   c. Species, numbers, and, if possible, sex and age class (or color) of observed marine mammals, along with the date, time, and location of the observation;
   d. The predominant sound-producing activities occurring during each marine mammal sighting;

e. Description of any marine mammal behavior patterns during observation, including direction of travel and estimated time spent within the shutdown zone while screeding was active. Behavioral reactions of marine mammals observed just prior to, and during, screeding;
f. Location of marine mammals (geographic coordinates), distance from observer to the marine mammal, and distance from the predominant sound-producing activity or activities to marine mammals;
g. Whether the presence of marine mammals necessitated the implementation of mitigation measures to avoid acoustic impact, and the duration of time that operations were affected by the presence of marine mammals.

1.4.4 Reporting

1. Operators should report any dead or injured listed marine mammals to NMFS.
2. Monthly reports will be submitted to NMFS for all months with project activities by the15th of each month following the monthly reporting period. The monthly report will contain and summarize the following information:
    a. Dates, times, locations, heading, speed, weather, sea conditions (including Beaufort state and wind force), and a list of all in-water sound-producing activities occurring concurrent with marine mammal observations.
    b. Species, number, location, distance from the vessel, and behavior of all observed marine mammals, as well as associated project activity (e.g., number of power-downs and shutdowns), observed throughout all monitoring activities.
    c. Observation data will be provided in digital spreadsheet format that can be queried.
    d. An estimate of the number of animals (by species) exposed to sound at received levels greater than or equal to Level B harassment thresholds, with a discussion of any specific behaviors those individuals exhibited.
    e. The report will confirm the implementation of each mitigation measure, and describe their effectiveness for minimizing the adverse effects of the action on ESA-listed marine mammals.
3. Within 90 calendar days of the cessation of in-water work each year, a comprehensive annual report will be submitted to NMFS for review. The report will synthesize all sighting data and effort during each activity for each year. NMFS will provide comments within 30 days after receiving annual reports, and the action agency or its non-federal designee will address the comments and submit revisions within 30 days after receiving NMFS comments. If no comments are received from the NMFS within 30 days, the annual report is considered completed. The report will include the following information:
    a. Summaries of monitoring effort including total hours, observation rate by species and marine mammal distribution through the study period, accounting for sea state and other factors affecting visibility and detectability of marine mammals.
    b. Analyses of the effects of various factors that may have influenced detectability of marine mammals (e.g., sea state, number of observers, fog/glare, and other factors as determined by the PSOs).
    c. Species composition, occurrence, and distribution of marine mammal sightings, including date, water depth, numbers, age/size/gender categories (if determinable), group sizes, and ice cover.
    d. Marine mammal observation data with a digital record of observation data provided in digital spreadsheet format that can be queried.
    e. Summary of implemented mitigation measures (i.e., shutdowns and delays).
    f. Number of marine mammals during periods with and without project activities(and other variables that could affect detectability), such as: (i) initial sighting distances versus project activity at the time of sighting; (ii) closest point of approach versus

project activity; (iii) observed behaviors and types of movements versus project activity; (iv) numbers of sightings/individuals seen versus project activity; (v) distribution around the source vessels versus project activity; and (vi) numbers of animals detected in the Shutdown Zone.

g. Analyses of the effects of project activities on listed marine mammals

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Willow Master Development Plan

Appendix E.14
Land Ownership and Use Technical Appendix

June 2022

North Slope Borough Ordinance
Serial No. 75-06-75

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Willow Master Development Plan

Appendix E.15
Economics Technical Appendix

June 2022

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Memorandum

Date: April 20, 2022

To: Kristen Hansen, DOWL

From: Patrick Burden and Leah Cuyno

Re: Updated Economic Analysis of Proposed Alternatives for the Willow Master Development Plan SEIS

DOWL requested Northern Economics to quantify the potential economic impacts of the proposed alternatives being considered for the Supplement to the Willow Master Development Plan (MDP) EIS. The supplemental analysis addresses deficiencies identified in the August 2021 U.S. District Court of Alaska decision to vacate the earlier Record of Decision and Final EIS by including an additional alternative that would provide 'maximum protection' to surface values in the Teshekpuk Lake Special Area (TLSA). This new action alternative would result in less infrastructure in the TLSA. The results of this updated economic impact analysis will be used to inform the environmental consequences section of the Supplemental EIS (SEIS).

This memorandum transmits the results of the updated economic impact analysis and describes the approach, assumptions, and data used in the analysis.

Scope of Analysis

Project Alternatives

For the purpose of this quantitative analysis, the following action alternatives are analyzed-- Alternatives B, C, D, and E. Note that Alternative A, is the No Project alternative; no development will occur under this alternative and the existing or baseline economic conditions will continue.

Alternative B is the *Proponent's Project* alternative. The alternative provides the shortest road access from the GMT Unit to the proposed Willow facilities.

Alternative C is described as the '*disconnected infield roads*' alternative.

Alternative D is described as the '*disconnected access*' alternative.

Alternative E is described as the '*Three-Pad Alternative*'.

The proposed development scenarios for Alternatives B, C, and D include 5 drill sites, and construction of processing facilities at the Willow Central Processing Facility (WCF), a Willow Operations Center (WOC), access roads, pipelines, an airstrip, and a gravel mine. However, certain features, particularly with respect to location and access vary depending on the alternative. For example, Alternative C would not include a gravel road connection between the WCF and the three northern drill sites, BT1, BT2, and BT4. There would be no road bridge across Judy Creek. Instead, an annually- constructed ice road would provide seasonal ground access to these drill sites. Alternative C would require two WOCs and airstrips: a South WOC and airstrip near the WCF, and a North WOC and airstrip, near BT2.

Alternative D, on the other hand, considers a development in which the Plan Area does not have year-round gravel road access to GMTU and Alpine. Instead, the Plan Area would be accessible only by air, ice road, and limited low ground-pressure vehicle. Alternative D includes construction of an annual ice road from GMTU to the Plan Area. Alternative D retains gravel roads between Plan Area facilities for safety and spill response. Alternative D would require a new diesel pipeline to the WOC from the Kuparuk CPF2 and approximately 25 acres of additional gravel pad footprint at the WCF. The lack of flexibility to use existing North Slope infrastructure and associated constraints on construction and logistics would extend the construction phase, delay the first oil date, and affect operational efficiency and emergency response for the life of the development.

Alternative E is the additional alternative identified by the BLM and cooperating agencies to address the Alaska District Court's remand. Under this alternative, drill site BT4 will be eliminated, resulting in only 4 drill sites and a WCF to support the Willow Project. Additional features of this alternative include moving drill site BT2 to a location north of Fish Creek (BT2 North), expanding drill sites BT1 and BT2 to accommodate more wells, relocating drill site BT5 to the northeast location just outside of yellow-billed loon setback buffer, and eliminating the constructed freshwater reservoir.

More details on these different alternatives are provided in Chapter 2 of the SEIS document.

Economic Indicators

This analysis quantifies the potential economic effects or consequences of the Project alternatives with respect to the following economic indicators:

1. **Potential Revenues.** This analysis provides estimates of the following potential government revenue streams:
    - State of Alaska: Royalty Revenue, Property Tax, Production Tax, Oil Surcharge, Corporate Income Tax.
    - Federal Government: Royalty Revenue, Corporate Income Tax, Gravel sales
    - North Slope Borough: Property Tax
2. **Potential Employment.** This analysis provides estimates of the direct, indirect, and induced employment effects associated with the construction phase and operations phase of the proposed Project alternatives. Employment effects reflect the total number of average part-time and full-time jobs resulting from the proposed construction and production (operations) activities.
3. **Potential Labor Income.** This analysis provides estimates of the potential labor income effects associated with the construction phase and operations phase of the proposed Project alternatives.

Approach, Assumptions, and Data

Estimating Potential Revenues

To quantify the potential streams of government revenues, the cash-flow model originally developed by the Alaska Department of Natural Resources (DNR) for evaluation of oil and gas projects in the Alaska North Slope was adapted and modified to reflect the Willow MDP SEIS project alternatives. The DNR model is based on the current fiscal regime and contains input cells that are fixed due to statutes or regulations; the major fiscal model parameters are shown in the table below.

Table 1. Alaska Fiscal Model Parameters

Category	Definition (Alaska Statute)	Value
Conservation Surcharges ($/barrel)	*43.55.201, 43.55.300*	$0.05
North Slope Oil Tax	–	–
Production Tax Rate on PTV	*43.55.011 (e)*	35%
$/BOE QCE exclusion ($/barrel)	*43.55.165 (e)(18)*	$0.30
Overhead allowance for lease expenditures	*43.55.165 (a)(2), 15 AAC 55.271*	4.5%
Minimum tax	–	–
Minimum Gross Tax (applied on GVPP)	*43.55.011 (f)*	4.0%
Oil and Gas Property Tax	–	–
Property Tax Rate	*43.56.010*	2.0%
Gross Value Reduction on "New Oil"	–	–
GVR %	43.55.160 (f)	20.0%
Additional GVR % (New field, ROY>12.5%)	43.55.160 (f &g)	30.0%
GVR Year Limit	*43.55.160 (f)*	7
GVR Oil Price limit: 3 years with ANS price above	*43.55.160 (f)*	$70.00
State and Federal Income Tax	–	–
State Income Tax	–	9.40%
Federal Income Tax	–	21.00%

The major inputs and assumptions used in the model to reflect the proposed project include:

1. Capital Expenditures (CAPEX)

Over the last 10 years Northern Economics, Inc. (NEI) has been working on various development projects in the North Slope, to estimate the effects of oil and gas development on local communities, regional entities, and the State of Alaska. As part of these projects, NEI has obtained cost information from company specific projects as well as from surveys of operating companies and businesses in the oil and gas support services sector.

The facility CAPEX estimates presented in this memorandum are based on data from five proprietary project CAPEX estimates that had central processing facilities. The CAPEX estimates were adjusted to fit the specification required by the DNR cash-flow model, and a linear regression equation for CAPEX was developed based on total volume of oil and natural gas liquids (NGLs) produced over the life of the field, and whether the project had seasonal access. The regression equation has the form of Seasonal Access (1 if seasonal access, 0 if year-round access) * 1015.96 + million barrels of oil and NGLs produced (MMBO) * 0.656946 + 4306.702. The equation has a coefficient of determination (r^2) of 0.60.

Drilling CAPEX was estimated using the same variables as the facility CAPEX. The drilling regression equation has the form of Seasonal Access (0,1) * 152.8 + MMBO * 1.30049 + 2875.411. The equation has a coefficient of determination (r^2) of 0.72.

The estimated drilling and facilities capital expenditures are shown in the table below.

Table 2. Estimated Capital Expenditures by Alternative, in millions of 2021 $

Capital Expenditure Item:	Alternatives B	Alternative C	Alternative D	Alternative E
Drilling	$3,914	$4,270	$4,331	$3,893
Facilities	$4,832	$5,847	$5,935	$4,821
Total:	$8,746	$10,118	$10,267	$8,714

Source: Northern Economics estimates.

2. Operating Expenditures (OPEX)

The OPEX regression equation has the form of MMBO * 0.039407392 + 4515.887379. Alternatives C and D have higher operating costs than Alternative B and E due to the additional costs of providing seasonal access and operating additional facilities.

The estimated total cumulative operating expenditures amount to $4.547 billion for Alternative B, $4.774 billion for Alternative C, $4.843 billion for Alternative D, and $4.546 billion for Alternative E.

3. Crude Oil Price Forecasts

Two oil price projections were used in this analysis to provide a range of estimates for the potential revenue effects— 1) the latest U.S. Energy Information Administration (EIA) oil price projections published in the *Annual Energy Outlook 2021* on February 3, 2021, and 2) the latest Alaska Department of Revenue (ADOR) oil price projections published in the *Revenue Sources Book Fall 2021* on December 24, 2021.

The ADOR oil price forecast (for ANS West Coast) reflects a more conservative price forecast (at $60.66 per barrel in real 2021$, average over 2022 to 2031 period) while the EIA price forecast reflects a higher oil price scenario (at $80.33 per barrel in real 2021$, average over 2022 to 2050). The ADOR forecast is a 10-year forecast through 2029 and the EIA forecast is through year 2050. Prices beyond the timeframe published were extrapolated using the cumulative annual growth rate provided in the 10-year forecast.

4. Netback Costs: Tariffs/Transportation Costs

For royalty calculations, oil is valued at the wellhead, hence, netback costs which include marine transportation cost, quality adjustment, TAPS tariff, and pipeline and feeder line tariffs, are deducted from the projected market price. Estimates of netback costs used in this analysis are from the Alaska Department of Revenue's *Revenue Sources Book Fall 2021*; except for the feeder line tariff data which was obtained from the Alaska Department of Natural Resources, Division of Oil and Gas.

5. Projected Annual Production Volumes

The table below shows the total projected oil production under each alternative. All Alternatives have a 25-year production life. Oil production for Alternatives B, C, and E begin in Year 6 of the project life, while first oil production for Alternative D starts in Year 7.

Table 3. Annual Production Volumes in millions of barrels of oil (MMBO)

Year	Alternative B	Alternative C	Alternative D	Alternative E
6	60.39	60.39	0.00	60.31
7	66.48	66.48	60.39	66.88
8	59.30	59.30	66.48	60.18
9	52.58	52.58	59.30	51.74
10	46.40	46.40	52.58	45.67
11	41.10	41.10	46.40	39.43
12	36.92	36.92	41.10	35.38
13	33.28	33.28	36.92	31.20
14	29.85	29.85	33.28	27.83
15	26.74	26.74	29.85	25.24
16	24.21	24.21	26.74	23.06
17	21.50	21.50	24.21	20.93
18	19.07	19.07	21.50	18.62
19	16.23	16.23	19.07	15.96
20	14.19	14.19	16.23	13.93
21	12.32	12.32	14.19	11.98
22	10.93	10.93	12.32	10.47
23	9.68	9.68	10.93	9.27
24	8.77	8.77	9.68	8.31
25	8.07	8.07	8.77	7.57
26	7.46	7.46	8.07	6.94
27	6.32	6.32	7.46	5.87
28	6.19	6.19	6.32	5.82
29	5.66	5.66	6.19	5.22
30	5.23	5.23	5.66	4.84
31	0.0	0.0	5.23	0.0

Source: CPAI, 2022.

Estimating Employment and Income Effects

Direct manpower requirements for the Willow MDP were estimated by CPAI and presented in the results section below. The potential indirect and induced employment and income effects for this analysis were estimated using the IMPLAN model of the Alaska economy. The IMPLAN model is an input-output model that is commonly used in economic impact studies to measure the multiplier effects/stimulus effects of an economic development project.

The estimates of industry spending on capital expenditures (CAPEX; construction costs) and on operating expenditures (OPEX) for each of the project alternatives, as described above, were used as inputs for the model. The IMPLAN model provides estimates of the number of part-time and full-time indirect and induced jobs required to meet the increase in demand for goods, materials, and services during the construction and the operations phases of the proposed project. These indirect and induced jobs (and associated income) are considered the multiplier effects or stimulus effects that result from the increase in demand in various industries/sectors in the Alaska economy, particularly those that support the construction sector, and the oil and gas extraction/production sector (indirect effects), as well as all the other sectors that provide goods and services to the industry workers (induced effects).

The IMPLAN model provides estimates of indirect and induced labor income based on information on average Alaska wages and salaries in the various sectors of the economy. Prevailing annual average wages for oil and gas jobs are presented below.

Results

Projected Government Revenues

The Willow MDP is projected to generate revenues to the federal government, the State of Alaska, and the North Slope Borough from royalties, taxes, and other fees. The projected revenues by revenue stream and by Alternative are presented in the table below. The values shown in the table reflect the estimated total cumulative revenues through the end of the production life of the field.

Table 4. Estimated Potential Revenues of the Willow MDP SEIS Alternatives

Revenue Category	Alternative B		Alternative C		Alternative D		Alternative E	
	DOR Price	EIA Price	DOR Price	EIA Price	DOR Price	EIA Price	DOR Price	EIA Price
State of Alaska								
Royalty Revenue	$2,329.9	$3,662.3	$2,329.9	$3,662.3	$2,301.5	$3,701.2	$2,270.0	$3,560.1
Property Tax	$103.7	$103.7	$124.3	$124.3	$133.7	$133.7	$101.4	$101.4
Production Tax	$393.0	$3,622.9	$404.1	$3,273.5	$385.4	$3,593.2	$374.3	$3,399.1
Oil Surcharge	$26.2	$26.2	$26.2	$26.2	$26.2	$26.2	$25.5	$25.5
Corporate Income Tax	$833.2	$1,781.8	$677.3	$1,659.7	$630.1	$1,644.0	$783.0	$1,711.1
Total:	**$3,686.0**	**$9,196.9**	**$3,561.8**	**$8,746.1**	**$3,477.0**	**$9,098.4**	**$3,554.2**	**$8,797.3**
Federal Government								
Royalty Revenue	$2,329.9	$3,662.3	$2,329.9	$3,662.3	$2,301.5	$3,701.2	$2,270.0	$3,560.1
Corporate Income Tax	$1,726.9	$3,646.8	$1,411.3	$3,399.8	$1,315.8	$3,368.0	$1,625.3	$3,503.8
Gravel sales	$9.9	$9.9	$9.9	$9.9	$9.9	$9.9	$9.9	$9.9
Total:	**$4,066.7**	**$7,319.0**	**$3,751.1**	**$7,072.0**	**$3,627.2**	**$7,079.1**	**$3,905.2**	**$7,073.8**
North Slope Borough								
Property Tax	$1,278.6	$1,278.6	$1,533.2	$1,533.2	$1,649.3	$1,649.3	$1,250.1	$1,250.1

Source: Northern Economics estimates.

At the State level, there are several potential sources of revenues that would be generated from the proposed development. Production from the Willow development would result in royalties paid to the federal government, and State of Alaska would receive 50 percent of those royalties. The federal royalty rate is 16.67 percent of the wellhead value. Total estimated cumulative state royalties range from $2.27 billion to $3.70 billion.

The state would receive property tax payments on onsite facilities and these revenues would start accruing during the construction phase. Total State property tax revenues are projected to range between $101 million and $134 million, depending on the Alternative.

Oil produced and sold from lands within Alaska are subject to a severance tax as the resources leave the land. This severance tax is commonly referred to as the “production tax.” The production tax applies to oil produced from any area within the boundaries of the state, including lands that are owned by the state, the federal government (like NPR-A), or private parties, such as Native corporations. Severance tax or production tax payments are based on the current tax rate of 35 percent of the production value, which is the value at the point of production, less all qualified lease expenditures (net value). Qualified lease expenditures include certain qualified capital and operating expenditures. Total production taxes are estimated to range from $374 million to over $3.6 billion, depending on the oil price assumption and the Alternative.

An oil and gas corporation’s Alaska income tax liability depends on the relative size of its Alaska and worldwide activities and the corporation’s total worldwide net earnings. State corporate income tax is calculated as 9.4 percent of the Alaska share of worldwide income for each corporation. The ADNR model, however, does not take into consideration corporate worldwide income (which is unknown at this time) but simply evaluates all the costs and revenues and the resulting state income tax given the 9.4 percent income tax rate. Total estimated state corporate income tax payments could range between $630 million and $1.78 billion, depending on the Alternative and oil price assumption. In addition, the state would also receive oil surcharge revenues estimated to amount to about $26 million. Conservation surcharges apply to all oil production in Alaska and are in addition to oil and gas production taxes. Revenues derived from these surcharges are intended to be used for oil and hazardous substance release prevention and response

At the Federal level, projected federal royalty revenue, corporate income taxes, and gravel royalties could amount to between $3.63 billion and $7.3 billion (total through the entire economic life of the field).

At the regional level, the NSB government is anticipated to benefit from property tax revenues. The property tax would be based on the assessed valuation of the facilities developed onsite. The annual levy is based on the full and true value of property taxable under AS 43.56. For production property, the full and true value is based on the replacement cost of a new facility, less depreciation. The depreciation rate is based on the economic life of proven reserves. Pipeline property is treated differently; it is valued on the economic value of the property over the life of the proven reserves. The State property tax rate is 20 mills. A local tax is levied on the state's assessed valued for oil and gas property within a city or borough and is subject to local property tax limitations. The current tax rate for the NSB is 18.5 mills (hence, the state portion of the property tax is 1.5 mills). Property tax payments would start to accrue during the construction phase. Total cumulative NSB property tax revenues are estimated to amount to between $1.25 billion and $1.65 billion, depending on the Alternative.

The City of Nuiqsut could also potentially benefit from higher bed tax revenues from higher hotel occupancy during the initial construction years while mobilization of construction equipment is occurring and even during operations. The City of Nuiqsut currently has a 12 percent bed tax. The change in the level of hotel occupancy however is difficult to quantify at this point because the timing and level of activities are uncertain and may vary. The City also has a tobacco tax that could generate additional revenues for the City. Furthermore, the City of Nuiqsut would be eligible to receive funds through the NPR-A Impact Mitigation Grant Program, which is funded by royalty and other revenues from leases in the NPR-A. As noted above, production from the Willow development is anticipated to generate royalties that would significantly increase funds for the NPR-A Impact Mitigation Grant Program.

Projected Employment and Income Effects

Table 5 presents the estimated direct manpower requirements during the construction phase for both the Proponent's Proposed Alternative (Alternative B) and Alternative E (the additional alternative being considered in the SEIS). These jobs will be required on the project site in the North Slope. Peak construction employment for both Alternatives is anticipated to occur in Year 4 of the project schedule with about 1,650 jobs (seasonal peak) jobs under Alternative B and about 1,700 jobs (seasonal peak) under Alternative E. The jobs created during the construction phase would be temporary, with some activities only occurring over several months (i.e., ice road construction). Given Alternative E's reduced infrastructure, the construction phase is expected to be shorter, lasting 8 years compared to 10 years under Alternative B.

Drilling activities are planned to occur over a period of 7 years starting in Year 5. Under Alternative E, drilling activities would require 390 annual average jobs in the North Slope from Year 5 through Year 8, and reduced to 195 jobs for the remaining 3 years of drilling (Year 9 to 11). Under Alternative B, 390 annual average jobs would be required from Year 5 through Year 10, then reduced to 99 jobs on the last year of drilling (Year 11). North-Slope based workers would be on a 2-week rotation so the number of workers on-site would be half of the numbers noted above. Drilling activities would also require 10 year-round jobs based in Anchorage.

Direct construction and drilling activities would also support on average about 3,000 indirect and induced part-time and full-time jobs per year in other sectors of the state's economy over the construction phase (under Alternatives B). Alternatives C and D would result in slightly higher indirect and induced jobs (about

3,500 and 3,900, respectively), mainly due to the higher estimated construction spending on additional facilities and logistics, while Alternative E is projected to result in about 2,900 indirect and induced jobs.

Table 5. Estimated Number of Direct Construction Jobs

Year	Proponent's Proposed Alternative		Alternative E	
	Seasonal Peak	Annual Average	Seasonal Peak	Annual Average
1	40	26	40	26
2	200	130	200	130
3	750	488	750	488
4	1,650	1,073	1,733	1,127
5	1,500	975	1,650	1,073
6	950	618	950	618
7	350	228	350	228
8	100	65	100	65
9	100	65	–	–
10	100	65	–	–

Source: CPAI, 2022.

During the operations phase, Alternative E is projected to generate the same number of direct O&M jobs as the Project Proponent's Alternative as shown in Table 6. The project is estimated to support 25 year-round jobs based in Anchorage during the operations phase of the project. The North Slope based job numbers shown in the table are the estimated number of workers required for O&M activities assuming a 2-week rotation. The number of workers onsite at any given time would be half of the number shown in each year in the table above (CPAI, 2022). These operations and maintenance jobs would mostly be year-round but there will be some jobs associated with production activities that will also be seasonal in nature.

Table 6. Estimated Number of Direct O&M Jobs: Proponent's Project Alternative and Alternative E

Year	Slope Based	Anchorage Based
6	100	25
7	275	25
8	400	25
9+	425	25

Source: CPAI, 2022.

In addition to the direct jobs, annual operations and maintenance activities are estimated to create an additional 360 to 400 indirect and induced jobs per year.

These estimated jobs are available for workers residing in the North Slope, other areas of Alaska, and outside Alaska. It is unknown at this time how many workers from North Slope communities and other Alaska communities would participate in the direct oil and gas activities. According to the Alaska Department of Labor and Workforce Development, over the past decade, the share of oil industry workers who are not Alaska residents has grown, ranging from 31 percent nonresident in 2010 to 35 percent in 2020. This percentage of non-resident workers could change in the future, depending on availability of training programs and labor supply.

Oil field development projects in the North Slope typically require specialty tradesmen and construction workers with the skills and experience in ice roads, pipeline construction, facilities construction, and drilling; and these jobs are typically held by non-local workers. However, opportunities do exist for North Slope residents that live near existing oil developments. Local residents have participated in oil and gas jobs such as ice road monitors, camp security and facilities operators, and subsistence representatives. The Alaska Department of Labor and Workforce Development and the oil and gas industry have training programs geared towards developing special skills required in oilfield services. This is expected to create more employment opportunities for local residents.

Table 7 shows the prevailing average yearly earnings of workers in various industries in Alaska that are associated with the direct construction and operations jobs described above. The table shows that direct oil and gas industry jobs currently pay about $170,000 per year; and the oil and gas extraction sector paying even more at approximately $242,000 per year.

Note that a direct oil and gas industry worker either works for an oil producer or an oilfield service company. Thousands of other jobs that directly serve the oil and gas industry but are not categorized under this sector are generally included in the Support Activities for Mining sector; some of these jobs are in security, catering, accommodations, transportation, and logistics services.

Indirect and induced jobs, on the other hand, would be jobs in a variety of other sectors of the Alaska economy that provide goods and services to the oil and gas industry and its direct workers. The projected annual average earnings associated with these indirect and induced jobs are estimated to be about $60,500.

Table 7. Prevailing Statewide Average Annual Earnings by Selected Industries associated with the Direct Construction and Operations Jobs

Industry	Average Annual Earnings
Oil and Gas Industry	$169,632
Oil and Gas Extraction	$242,160
Support Activities for Mining	$119,268
Construction (industry-wide average)	$82,356
Construction of Buildings	$76,428
Heavy Construction	$110,748
Specialty Trade Contractors	$71,052

Source: QCEW 2020 data, ADOLWD,2022.

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