National Science Foundation
Office of Polar Programs
Alexandria, Virginia

ENVIRONMENTAL DOCUMENT CONCURRENCE

Activity:
Center for Oldest Ice Exploration (COLDEX) Project

[PGAN2301.IEE]

I have read the attached document and concur with the findings and recommendation. I concur that the proposed activity can commence.

PAUL R SHEPPARD

Digitally signed by PAUL R SHEPPARD
Date: 2022.11.18 15:27:37 -05'00'

Paul R. Sheppard
Executive Officer
Office of Polar Programs

Date

National Science Foundation
Office of Polar Programs
Alexandria, Virginia

ENVIRONMENTAL DOCUMENT AND
FINDING OF NO MORE THAN
MINOR OR TRANSITORY ENVIRONMENTAL IMPACT

Center for Oldest Ice Exploration (COLDEX) Project

[PGAN2301.IEE]

FINDING

The National Science Foundation (NSF) has prepared an Initial Environmental Evaluation/Environmental Assessment to evaluate the environmental impacts of the Center for Oldest Ice Exploration (COLDEX) project. Two project alternatives were evaluated:

Alternative A: Proposed COLDEX Project

No Action Alternative

Alternative A would conduct the proposed COLDEX project. The project's field components would: 1) explore locations in the interior East Antarctic Plateau with the goal of identifying a site for a deep ice core to be drilled during a later phase of the project; and 2) collect and analyze ice from sites along the eastern margin of the East Antarctic Ice Sheet. The project would consist of the following five major elements:

- Airborne Survey
- Combined Surface Geophysics and Ice Diver
- Shallow Coring
- Surface Geophysics
- Intermediate Depth Drilling

Under the No Action Alternative, the COLDEX project would not be conducted.

Based on the analyses in the environmental document (Initial Environmental Evaluation), NSF Office of Polar Programs (OPP) has determined that implementation of Alternative A would have no more than a minor or transitory effect on the Antarctic environment, within the meaning of NSF's implementing regulations for the Protocol on Environmental Protection to the Antarctic Treaty. Therefore, a comprehensive environmental evaluation will not be prepared.

I recommend this activity proceed based on the implementation of Alternative A.

Paul Cutler 11/18/22

Recommending Official **Date**
Paul M. Cutler
Program Director
Glaciology, Ice Core Science & Geophysics
Office of Polar Programs

Andrew J. Titmus 11/18/22

Recommending Official **Date**
Andrew Titmus
Environmental Program Manager
Office of Polar Programs

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1.0 INTRODUCTION

In support of the United States (U.S.) Antarctic Program (USAP) and scientific research, the National Science Foundation (NSF) proposes to conduct the Center for Oldest Ice Exploration (COLDEX) project (hereinafter referred to as COLDEX). COLDEX would address fundamental questions critical to understanding past and future climate change, including sensitivity to higher levels of greenhouse gases, the role of greenhouse gases in the evolution of ice age cycles, and the behavior of the Antarctic Ice Sheet in warmer climates. COLDEX is funded by the NSF Science and Technology Center (STC) Program, under the NSF Office of Integrative Activities, and is a collaborative effort involving multiple U.S. institutions working together to support the central focus of the effort, which is to find, drill, and process oldest ice. The current funding is for five years, and all STC projects are able to submit one five-year renewal proposal for a maximum duration of 10 years of support.

This Initial Environmental Evaluation (IEE) evaluates the potential environmental impacts of conducting the first five years of COLDEX. The IEE is prepared in accordance with applicable provisions of Annex I, Article 3 of the *Protocol on Environmental Protection to the Antarctic Treaty* (the Protocol); the *Guidelines for Environmental Impact Assessment in Antarctica* (Antarctic Treaty Secretariat [ATS] 2016); the Antarctic Conservation Act, as amended by the *Antarctic Science Tourism and Conservation Act of 1996*, 16 U.S. Code (U.S.C.) § 2401 et seq. (ACA); and implementing regulations set forth in *Environmental Assessment Procedures for National Science Foundation Actions in Antarctica*, 45 Code of Federal Regulations (C.F.R.) § 641.

COLDEX would involve several types of complex field activities conducted over four Antarctic field seasons (austral summers) from 2022 through 2026. The project's field components would: 1) explore locations in the interior East Antarctic Plateau (EAP) using both established and novel radar and rapid access techniques with the goal of identifying a site for a deep ice core to be drilled during a later phase of the project; and 2) collect and analyze ice from sites along the eastern margin of the East Antarctic Ice Sheet (Ice Margin) where old ice occurs near the surface. COLDEX would culminate, in a later phase, in the collection of an ice core that extends the continuous ice core record to at least 1.5 million years before present.

The COLDEX field program would consist of the following five major elements, shown schematically in Figure 1-1. The general region of COLDEX field activities is shown in Figure 1-2.

- **Airborne Survey:** two seasons (2022–2023 and 2023–2024) of airborne radar echo sounding, gravity, and magnetic surveys of the EAP between USAP's Amundsen-Scott South Pole Station and Dome A to locate and characterize potential deep ice sites for later ground-based investigation.
- **Combined Surface Geophysics and Ice Diver:** two seasons (2024–2025 and 2025–2026) of surface geophysical surveys and Ice Diver (thermal probe that measures ice geochronologies without the need for a borehole) and dust logger investigations at two locations on the EAP, identified using airborne survey data, to characterize modern ice sheet behavior and ice dynamic history as part of the site selection for collection of a long, continuous core.
- **Shallow Coring:** three seasons (2023–2024, 2024–2025, and 2025–2026) of shallow ice core collection (to 200-m [660-ft] depths) at Allan Hills and Elephant Moraine on the Ice

Margin to expand the existing record of ice in the 1-to-2-million-year age range and to collect older ice to extend the discontinuous climate record further back in time.

- **Surface Geophysics:** one season (2022–2023) of surface geophysical surveys to confirm a site for drilling a 1250-m (4100-ft) ice core at Allan Hills and to conduct radar surveys and collect short cores (to 10-m [33-ft] depths) at Elephant Moraine to determine sites for shallow coring. Geophysical surveys also would be conducted in 2023–2024, with repeat radar measurements in 2024–2025 at a third site on the EAP to assist with site selection for drilling a long, continuous core of 1.5-million-year-old ice.
- **Intermediate Depth Drilling:** three seasons (2023–2024, 2024–2025, and 2025–2026) for setup, staging, and extraction of a 1250-m (4100-ft) continuous core of 1-million-year-old ice from Allan Hills.

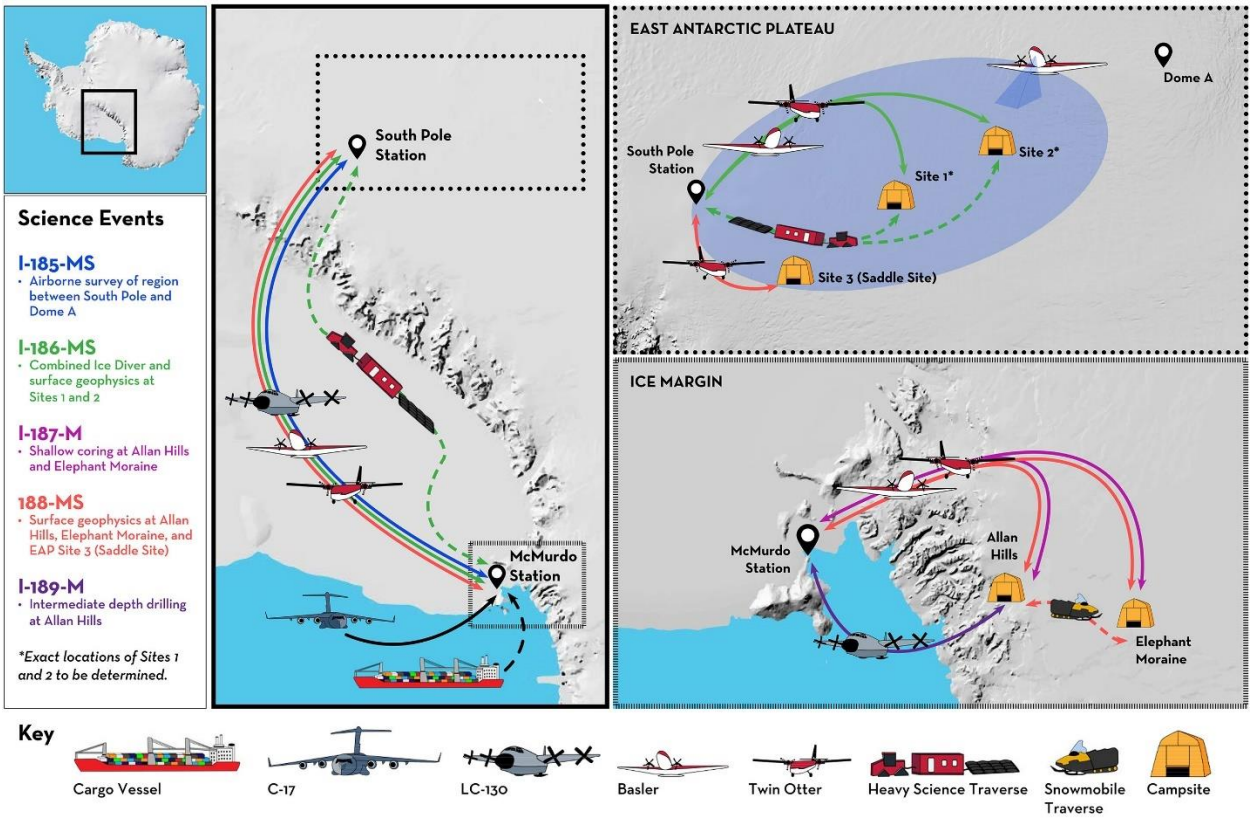

Figure 1-1. COLDEX: Logistics Overview

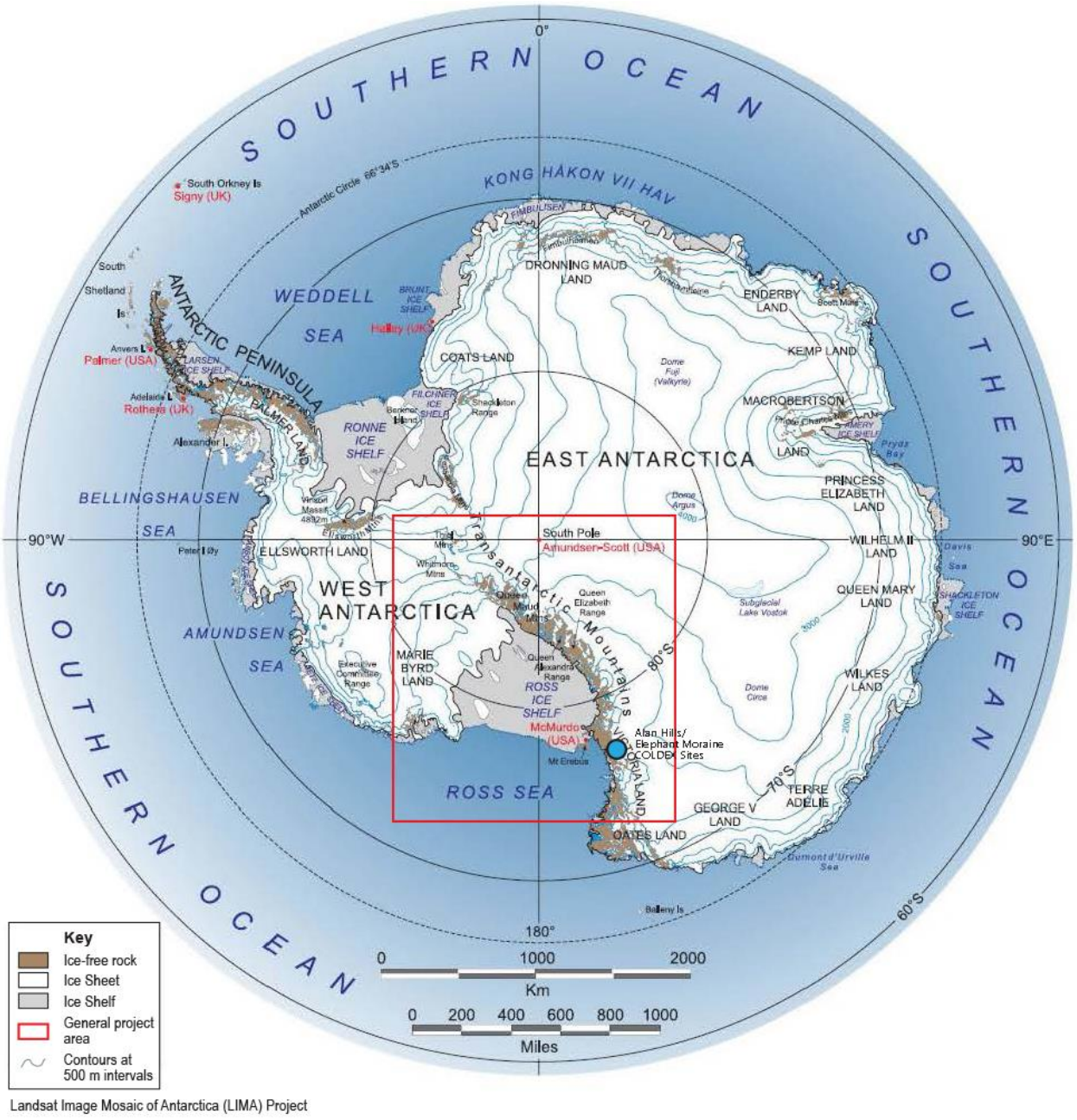

Figure 1-2. Map of Antarctica Showing the COLDEX Region

The COLDEX field program would focus on two general areas within East Antarctica: the Ice Margin and the interior EAP between Amundsen-Scott South Pole Station and Dome A. The general locations of the Ice Margin and EAP sites are shown in Figure 1-3 and Figure 1-4, respectively. Specific locations for EAP sites #1 and #2 would be determined based on the results of the airborne surveys. EAP site #3 (Saddle Site) would be located about 245 km (152 mi) from Amundsen-Scott South Pole Station in the general direction of Dome A; however, specific site coordinates have not yet been determined.

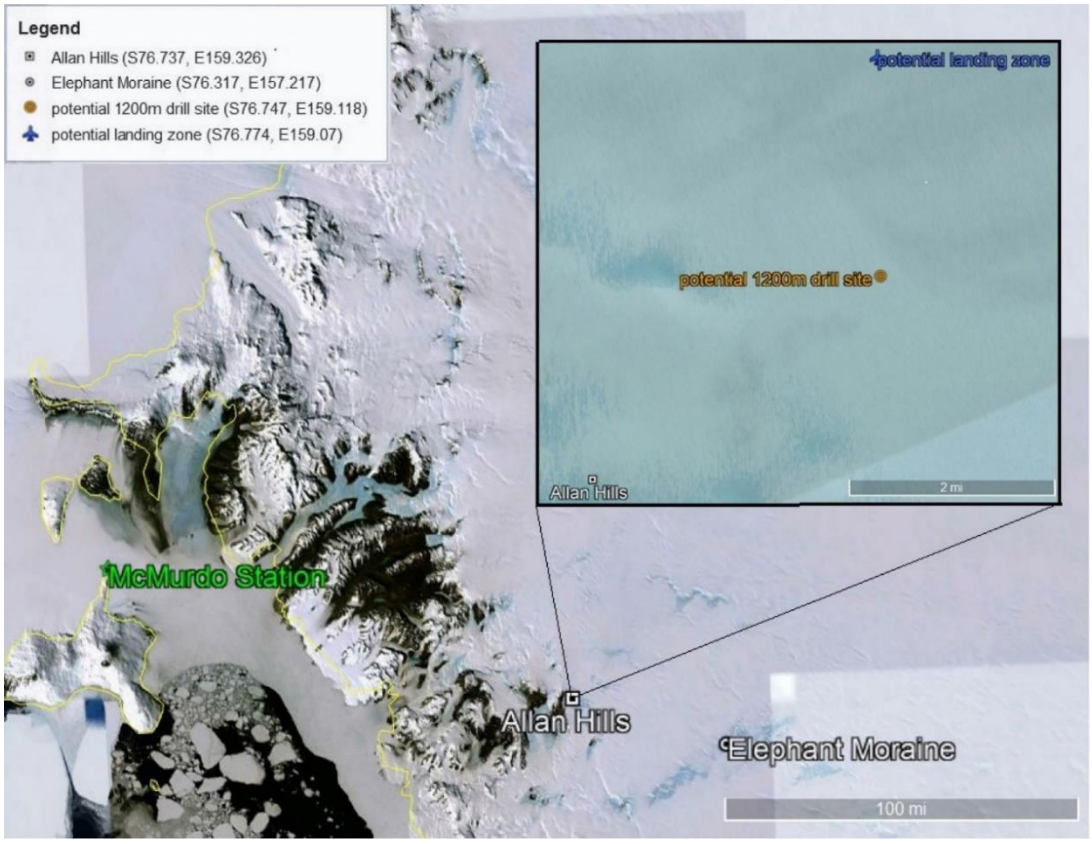

Figure 1-3. Map of COLDEX Allan Hills and Elephant Moraine Ice Margin Sites

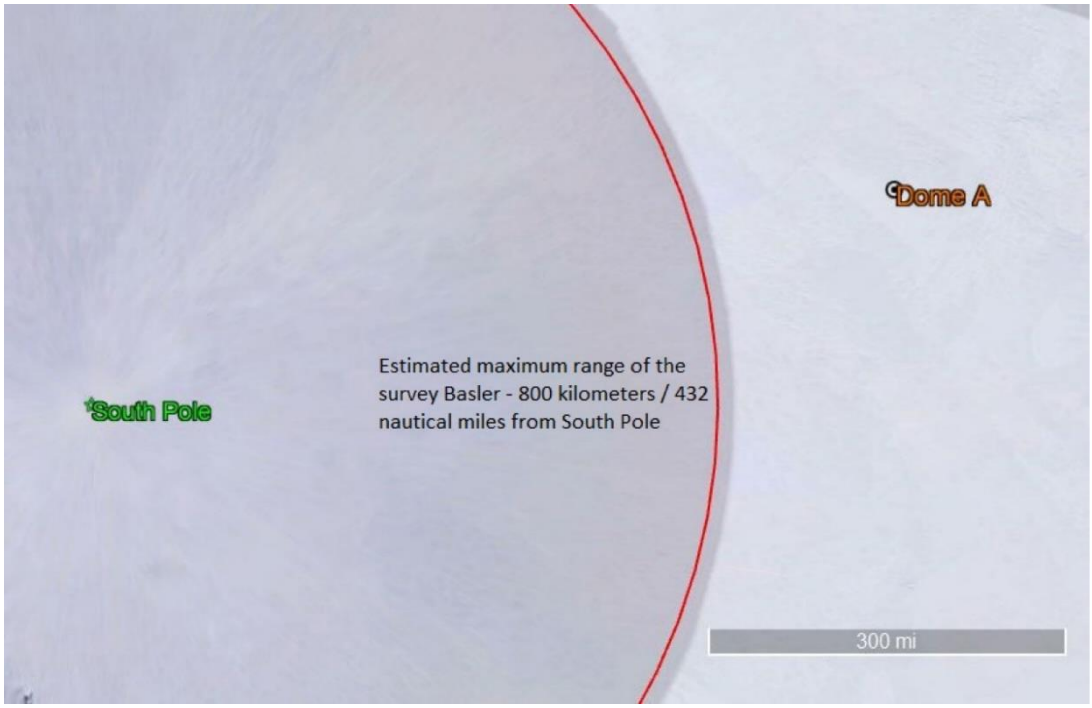

Figure 1-4. Map of COLDEX East Antarctic Plateau Area of Interest between Amundsen-Scott South Pole Station and Dome A

Table 1-1 shows a potential timeline to implement the COLDEX field components.

Table 1-1. COLDEX Field Timeline

Activity	2022–2023	2023–2024	2024–2025	2025–2026
Airborne Surveys	Broad survey of the EAP	Detailed survey of the EAP		
Combined Surface Geophysics and Ice Diver/Dust Logger			Surveys and Ice Diver/dust logger deployments at EAP site #1; autonomous repeat phase-sensitive radar (ApRES) measurements at EAP site #2	Surveys and Ice Diver/dust logger deployments at EAP site #2; ApRES measurements at EAP site #1
Shallow Coring at Ice Margin		Coring and repeat ApRES measurements at Allan Hills	Coring and repeat ApRES measurements at Elephant Moraine	Coring at Elephant Moraine or Allan Hills
Surface Geophysics	Surveys and ApRES measurements at Allan Hills and Elephant Moraine and near-surface coring at Elephant Moraine	Surveys and ApRES measurements at EAP site #3	Repeat ApRES measurements at EAP site #3	
Intermediate Depth Drilling		Staging at Allan Hills	Drilling at Allan Hills	Drilling at Allan Hills and retrograde (complete site demobilization)

Key: ApRES = autonomous repeat phase-sensitive radar; EAP = East Antarctic Plateau

Note: Ice Diver testing in Greenland would occur in approximately June/July 2023; however, this is not included within the scope of COLDEX addressed in this IEE.

Table 1-2 provides a summary of environmental impact assessment documents that previously evaluated research projects with technical scopes and logistical support requirements comparable to those for COLDEX. These documents are incorporated herein by reference.

Table 1-2. Summary of Related Environmental Impact Assessments for Ice Sheet Geophysical Studies in Antarctica Relevant to COLDEX

Title	Document Number	Scope of Analysis	Comments
USAP Activity: Construct and Operate New or Modified USAP Field Camps (NSF 2008)	PGAN0901.IEE	This IEE evaluates programmatically the environmental effects resulting from the construction and operation of conventional USAP field camps under different environmental settings (e.g., snow/ice covered, dry land, sea ice).	NSF determined that implementation of the project is an action that would have no more than a minor or transitory effect on the Antarctic environment, within the meaning of the Protocol on Environmental Protection to the Antarctic Treaty.

Table 1-2. Summary of Related Environmental Impact Assessments for Ice Sheet Geophysical Studies in Antarctica Relevant to COLDEX

Title	Document Number	Scope of Analysis	Comments
USAP Activity: Conduct Rock, Soil, Ice, or Sediment Drilling, Coring, and Select Excavation Activities to Support USAP Scientific Research and Logistical Operations (NSF 2009)	PGAN1001.IEE	This IEE evaluates programmatically the environmental effects resulting from typical USAP rock, soil, ice, and sediment drilling and coring operations related to scientific research as well as logistical drilling for construction of new structures or maintenance of existing resources.	NSF determined that implementation of the project is an action that would have no more than a minor or transitory effect on the Antarctic environment, within the meaning of the Protocol on Environmental Protection to the Antarctic Treaty.
USAP Activity: Characterize the West Antarctic Ice Sheet Using Multi-Disciplined Geophysical Survey Techniques to Support the Center for Remote Sensing of Ice Sheets (NSF 2007a)	PGAN0703.IEE	This IEE evaluates the effects of the proposed Center for Remote Sensing of Ice Sheets (CReSIS) project that would involve three main research efforts: 1) reconnaissance seismic surveying using explosives as the seismic source, 2) airborne radar surveys using crewed and autonomously flown aircraft, and 3) shallow (less than 100 m [330 ft] deep) ice coring. The reconnaissance survey activities are designed to • inventory all major ice sheet drainage basins (area, extent, surface and bed elevations, velocity fields, snow accumulation and melting, and basal conditions); • identify drainage basins undergoing significant change; and • partition these changing drainage basins into those caused by perturbations in snow accumulation/ablation and those caused by changes in ice motion.	NSF determined that implementation of the project is an action that would have no more than a minor or transitory effect on the Antarctic environment, within the meaning of the Protocol on Environmental Protection to the Antarctic Treaty.
USAP Activity: Characterize the West Antarctic Ice Sheet Using Multi-Disciplined	PGAN0703.IEE.AMI	This IEE amendment evaluates environmental effects of aerial and ground-based surveys, using radar, seismic, geophysical, and	NSF determined that implementation of the project is an action that would have no more than a minor or

Table 1-2. Summary of Related Environmental Impact Assessments for Ice Sheet Geophysical Studies in Antarctica Relevant to COLDEX

Title	Document Number	Scope of Analysis	Comments
Geophysical Techniques to Support the Center for Remote Sensing of Ice Sheets. IEE Amendment 1 (NSF 2011a)		radio-echo sounding techniques, to characterize the West Antarctic Ice Sheet.	transitory effect on the Antarctic environment, within the meaning of the Protocol on Environmental Protection to the Antarctic Treaty.
USAP Activity: Characterize the West Antarctic Ice Sheet Using Multi-Disciplined Geophysical Techniques to Support the Center for Remote Sensing of Ice Sheets. IEE Amendment 2 (NSF 2013)	PGAN0703.IEE.AM2	This IEE amendment evaluates environmental effects under the second season of CReSIS Phase II aerial and ground-based surveys to characterize the Whillans and Bindschadler ice streams on the Siple Coast of West Antarctica.	NSF determined that implementation of the project is an action that would have no more than a minor or transitory effect on the Antarctic environment, within the meaning of the Protocol on Environmental Protection to the Antarctic Treaty.
USAP Activity: Recovery of a Deep Ice Core from the West Antarctic Ice Sheet Ice Flow Divide (WAIS Divide; NSF 2005)	PGFC0501.IEE	This IEE evaluates the environmental effects from collection of an ice core up to a depth of 3540 m (11,600 ft) from an inland location in West Antarctica's Polar Plateau beginning in the 2005–2006 field season. An additional 800-m (2600-ft) replicate ice core would be collected from a branch borehole, and a chemical drilling fluid would be used to provide long-term stability for the borehole.	NSF determined that implementation of the project is an action that would have no more than a minor or transitory effect on the Antarctic environment, within the meaning of the Protocol on Environmental Protection to the Antarctic Treaty.
USAP Activity: Recovery of a Deep Ice Core from the WAIS Divide. IEE Amendment 1 (NSF 2007b)	PGFC0501.AM1	The first IEE amendment updates the description of the WAIS Divide Camp and identifies drilling or coring activities and related conditions that changed from those assessed in the original IEE. The amendment evaluates the potential environmental impacts related to the research aspects of the WAIS Divide Ice Core project, the camp infrastructure needed to support the ice coring project, and the camp resources needed to support	NSF determined that implementation of the project is an action that would have no more than a minor or transitory effect on the Antarctic environment, within the meaning of the Protocol on Environmental Protection to the Antarctic Treaty.

Table 1-2. Summary of Related Environmental Impact Assessments for Ice Sheet Geophysical Studies in Antarctica Relevant to COLDEX

Title	Document Number	Scope of Analysis	Comments
		other science projects in West Antarctica.	
USAP Activity: Recovery of a Deep Ice Core from the WAIS Divide. IEE Amendment 2 (NSF 2010)	PGFC0501.AM2	The second amendment to the IEE updates the description of the WAIS Divide Camp and identifies drilling or coring activities and related conditions that changed from those assessed in the original IEE and Amendment 1. Amendment 2 evaluates the potential environmental impacts related to the research aspects of the WAIS Divide Ice Core project, the camp infrastructure needed to support the ice coring project, and the camp resources needed to support other science projects in West Antarctica. Changes were primarily related to use of drilling fluids, camp use by other projects, and wastewater generation and disposal.	NSF determined that implementation of the project is an action that would have no more than a minor or transitory effect on the Antarctic environment, within the meaning of the Protocol on Environmental Protection to the Antarctic Treaty.
USAP Activity: Recovery of a Deep Ice Core from the WAIS Divide. IEE Amendment 3 (NSF 2011b)	PGFC0501.AM3	The third amendment to the IEE identifies drilling, coring, well logging, and seismic activities that changed from those assessed in the original IEE and Amendments 1 and 2. Amendment 3 evaluates the potential environmental impacts related to the research aspects of the WAIS Divide Ice Core project, the camp infrastructure needed to support the ice coring project, and the camp resources needed to support other science projects in West Antarctica. Changes were primarily related to use of drilling fluids, use of explosives, camp use, and wastewater generation and disposal.	NSF determined that implementation of the project is an action that would have no more than a minor or transitory effect on the Antarctic environment, within the meaning of the Protocol on Environmental Protection to the Antarctic Treaty.
Aircraft Over-Flights of the Antarctic Sea Ice of the Weddell,		This document evaluated the environmental effects of the Operation Ice Bridge project to study and monitor the	NASA determined that the environmental impacts of the Operation Ice Bridge project would

Table 1-2. Summary of Related Environmental Impact Assessments for Ice Sheet Geophysical Studies in Antarctica Relevant to COLDEX

Title	Document Number	Scope of Analysis	Comments
Bellingshausen, and Amundsen Seas and Land-Ice of the Antarctic Peninsula and the Thwaites, Pine Island, and Abbot Glaciers (NASA 2009)		changing areas of the cryosphere including Earth's ice sheets, sea ice, and glaciers. Operation Ice Bridge will use airborne platforms to maintain altimetry time series and monitor important areas of land ice and sea ice until the launch of the National Aeronautics and Space Administration's (NASA's) next satellite-lidar mission. Operation Ice Bridge will monitor the sea ice extent, snow cover on sea ice, ice sheet elevation, ice sheet near-surface firn (snow that has persisted through one melt season), ice sheet mass balance, and the bed topography of the ice sheet.	be minor and transient, and that the project qualifies for a categorical exclusion in accordance with 14 C.F.R. § 1216.305 (d)(2) – *Research and Development Activities in Space and Terrestrial Applications*.

Key: C.F.R. = Code of Federal Regulations; CReSIS = Center for Remote Sensing of Ice Sheets; ft = feet; IEE = Initial Environmental Evaluation; m = meter; NASA = National Aeronautics and Space Administration; NSF = National Science Foundation; USAP = United States Antarctic Program; WAIS = West Antarctic Ice Sheet

2.0 PURPOSE AND NEED

The purpose of the proposed action is to conduct COLDEX as detailed in Section 3.0 (Proposed Activity). COLDEX would find, drill, and process oldest ice, culminating in the collection of a continuous ice core that extends the ice core record to at least 1.5 million years before present. The need for COLDEX is to increase the understanding of past and future climate change, including sensitivity to higher levels of greenhouse gases, the role of greenhouse gases in the evolution of ice age cycles, and the behavior of the Antarctic Ice Sheet in warmer climates.

Information preserved in the Antarctic Ice Sheet plays a critical role in understanding past natural climate change, including past temperatures, snowfall, and many other properties of the environment. Ice traps small samples of the atmosphere, preserving a unique and highly accurate record of greenhouse and other gases, and providing the best evidence for a strong link between atmospheric carbon dioxide (CO_2) and Earth's climate on geologic timescales (https://coldex.org/research).

The oldest ice cores are from East Antarctica, the largest and most stable of the polar ice sheets. Existing ice core data do not extend back far enough to provide information from periods when Earth's climate was significantly warmer and/or greenhouse gas levels were higher than present. Such information is vital for understanding how climate will evolve as greenhouse levels rise and for developing a deeper understanding of long-term trends in Earth history (https://coldex.org/research).

3.0 PROPOSED ACTIVITY

3.1 Project Description

COLDEX would include several complex field activities that would: 1) explore locations in the interior EAP with the goal of identifying a site for a deep ice core to be drilled during a later phase of the project; and 2) collect and analyze ice from sites along the Ice Margin where ice flow brings old ice near the surface.

Starting in October 2022, COLDEX would deploy up to 12 science teams to multiple sites within two regions of East Antarctica over a four-year period (through February 2026) to meet the science goals. Research would be focused on Allan Hills and Elephant Moraine within the Ice Margin and three locations within the EAP between Amundsen-Scott South Pole Station and Dome A (Figure 1-3 and Figure 1-4). Concurrent COLDEX field activities identified in Table 1-1 would occur during austral summer (generally November through February) within the EAP and Ice Margin project areas.

The COLDEX teams must complete their investigations in a particular sequence to meet the Phase 1 research goals. Each region presents challenges with access related to weather, elevation, surface conditions at the study sites, and distance from the supporting station(s). Specific combinations of aircraft and traverse resources have been identified in the support plans for each activity (NSF 2022a, 2022b) to address these challenges in the most efficient manner possible (shown schematically in Figure 1-1).

Additional schedule constraints associated with methods of transport also would dictate many of the timelines required for COLDEX procurements, team deployments, retrograde (final, complete, site demobilization) efforts, and return sample shipments. Because of these interdependencies, significant station support, resource management, and interagency coordination would be required to ensure that all resources critical to achieving the research goals would be available when needed.

High-level support planned for activities based out of Amundsen-Scott South Pole Station would include specialized aircraft (Lockheed LC-130, De Havilland Twin Otter, and Basler) missions and Heavy Science Traverse (HST) support to move people, cargo, and bulk fuel between McMurdo Station and Amundsen-Scott South Pole Station (see Section 3.2, Major Resource Requirements). Light aircraft and traverse support also would be needed to accommodate travel requirements from Amundsen-Scott South Pole Station to the three field sites on the EAP. Additional critical resources provided by Amundsen-Scott South Pole Station would include bed space, vehicle maintenance space, and office and airfield space and power. High-level support planned for activities based out of McMurdo Station would include light aircraft to support surface geophysics and shallow core collection at Allan Hills and Elephant Moraine in the Ice Margin and, pending confirmation of an approved LC-130 landing area, LC-130 and light aircraft to support intermediate depth drilling operations at Allan Hills.

Descriptions of each of the five project elements and required logistics support are provided in Sections 3.1.1 (Airborne Survey) through 3.1.5 (Intermediate Depth Drilling).

3.1.1 Airborne Survey

This project element would consist of airborne (Basler-supported) radar echo sounding and gravity and magnetic surveys of the EAP between Amundsen-Scott South Pole Station and Dome

A. The airborne surveys would collect radar, magnetic, and gravimetric data using the University of Texas Institute for Geophysics (UTIG) and Center for Remote Sensing of Ice Sheets (CReSIS) instrument packages to generate fine-resolution maps of internal-ice stratigraphy (layers). Results from the airborne surveys would also be used to locate and characterize potential deep ice sites for later ground-based investigations.

The airborne surveys would span two deployment seasons (2022–2023 and 2023–2024). The first season would conduct a broad survey (15-km [9.3-mi] line spacing) from the South Pole region to approximately 800 km (500 mi) toward Dome A, requiring an estimated 15 flights. The second season would involve a more detailed survey of two or three smaller regions selected from the broad survey area. The airborne surveys would provide the information needed to identify two locations for follow-on surface geophysics investigations (Section 3.1.2, Combined Surface Geophysics and Ice Diver).

In 2022–2023, prior to the initial airborne survey, science personnel would set up the survey equipment on the Basler (utility aircraft that can make open field landings) and conduct three test flights in the McMurdo area. Following the McMurdo-area test flights, personnel would deploy for four weeks to conduct the 15 survey missions between Amundsen-Scott South Pole Station and Dome A.

Flight paths for the first season (2022–2023) of airborne surveys are shown in Figure 3-1; the flight paths include CORE, TRANSVERSE, EAST, WEST, and TABLE MOUNTAIN. Pending NSF approval, and in consultation with the National Program(s) operating within the area of the Amundsen-Scott South Pole Station, a limited number of the planned flights would cross the Clean Air Sector (CAS) and Dark Sector of the Scientific Zone within the Amundsen-Scott South Pole Station Antarctic Specially Managed Area (ASMA). The *Management Plan for Antarctic Specially Managed Area No. 5 Amundsen-Scott South Pole Station, South Pole* (CEP 2017) prohibits overflights below 2000 m (6000 ft) above ground level (AGL) while in the CAS, except for essential scientific, operational, or management purposes, and recommends aircraft remain above the boundary layer air (2000 m [6000 ft] AGL) to limit the potential for deposition of particles and gas at the snow surface. The *Management Plan* (CEP 2017) also restricts active radio frequency emissions and use of light-emitting instruments with the potential for causing electromagnetic interference of other, ongoing scientific investigations within the Dark Sector. Seven low-altitude (i.e., 660 m [2000 ft] AGL) flights within the CAS and a portion of the Dark Sector are considered essential for achieving specific scientific objectives of the COLDEX airborne surveys, namely providing continuity of radar measurements between the South Pole Ice Core project (hereinafter referred to as SPICEcore) site (located in the Dark Sector), where the age-depth structure of the ice sheet was previously determined, and the COLDEX regional survey grid in order to understand the internal structure of the ice sheet.

To minimize the potential for the airborne survey flights to interfere with ongoing scientific investigations in the CAS and Dark Sector, flights for the first season would follow the following procedures:

1. The CORE and TRANSVERSE flights that must cross the CAS would initially ascend to 660 m (2000 ft) AGL outside the CAS. The flight paths would turn toward the COLDEX survey grid and cross the CAS at 660 m (2000 ft) AGL. The flights would remain at 660 m (2000 ft) AGL for the entirety of the survey. The return flights would cross the CAS at an altitude of 660 m (2000 ft) AGL and fly over the SPICEcore site (in the Dark Sector) at 660 m (2000 ft) AGL. Once past the SPICEcore site, the radar would be shut down and the aircraft would return to the skiway.

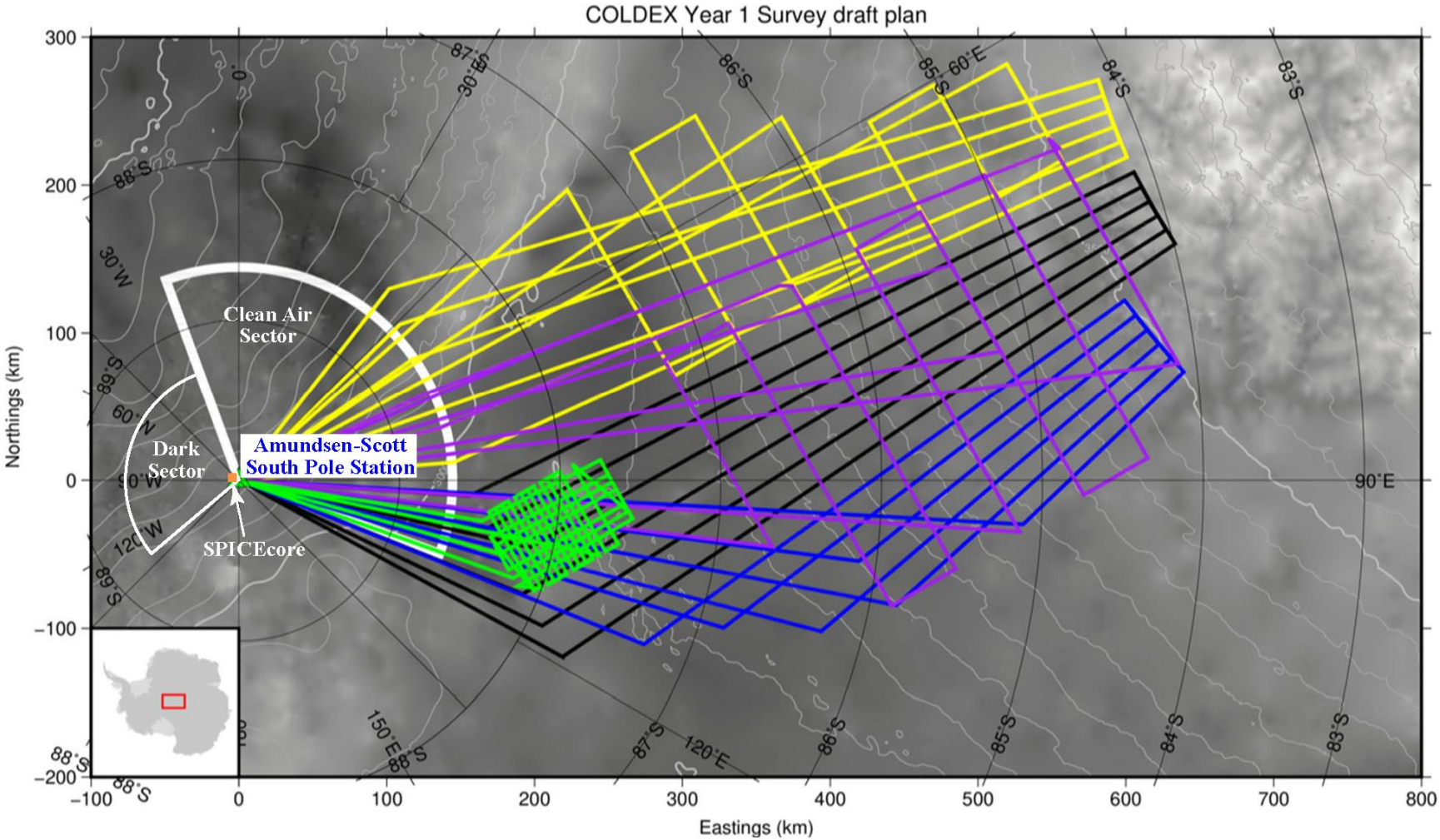

Figure 3-1. Flight Paths for the 2022–2023 Airborne Surveys

For purposes of achieving the scientific objectives of the airborne surveys, the highest to lowest priority is as follows: Black (CORE: three flights); Purple (TRANSVERSE: four flights); Blue (EAST: three flights); Yellow (WEST: five flights); and Green (TABLE MOUNTAIN: two flights).

2. The seven low-altitude CORE and TRANSVERSE flights would spend approximately 20 to 30 minutes in the CAS at an altitude of 600 m (2000 ft) during both the outgoing and return legs of the flights.
3. Outgoing WEST, EAST, and TABLE MOUNTAIN flights from the Amundsen-Scott South Pole Station would ascend to an altitude of 2000 m (6000 ft) AGL outside of the CAS. Once the plane reaches an altitude of 2000 m (6000 ft) AGL, it would turn toward the survey region and cross the CAS at the same altitude. Once in the survey region, the aircraft would descend to an altitude of 660 m (2000 ft) AGL. The return flights would cross the CAS at 2000 m (6000 ft) AGL and then descend outside of the CAS to the skiway at the Amundsen-Scott South Pole Station with the radar off.
4. Apart from the passes over the SPICEcore site during the CORE and TRANSVERSE flights, the radars typical would not be operating within about 50 km (30 mi) of the Amundsen-Scott South Pole Station.

All other first-season flights crossing the CAS would be at altitudes above 2000 m (6000 ft), whereas flight altitudes outside of the CAS would be approximately 660 m (2000 ft). The first-season flights are expected to occur in early December 2022. Outgoing and incoming flights typically would begin at around 0700 and conclude around 1200 New Zealand Daylight Time. The second season (2023–2024) flights would remain above the boundary layer air while crossing the CAS and avoid crossing into the Dark Sector. Logistics support for this project element would include

- LC-130 (four-engine turboprop transport airplane) to transport up to five science personnel and 1360 kg (3000 lb) of cargo between McMurdo Station and Amundsen-Scott South Pole Station, including 61,000 L (16,000 U.S. gal) of bulk fuel (six missions, six-hour duration each season);
- workspace and power for up to nine science personnel in McMurdo Station and airfield, and up to five science personnel at Amundsen-Scott South Pole Station;
- beds at Amundsen-Scott South Pole Station for a maximum of eight personnel (five science personnel and three aviation service provider [ASP] personnel) for four weeks in December 2022; and
- Basler support for seven weeks, including two weeks in McMurdo Station for setup and three survey test flights; four weeks at Amundsen-Scott South Pole Station to reposition and fly approximately 15 survey missions; and one week in McMurdo Station to deconfigure the aircraft.

3.1.2 Combined Surface Geophysics and Ice Diver

This project element would consist of surface geophysical surveys and Ice Diver/dust logger deployments at EAP site #1 and site #2 over two seasons (2024–2025 and 2025–2026). The specific locations of these sites would be identified from results of the airborne geophysical surveys (Section 3.1.1, Airborne Survey). Activities would include surface-based, high frequency and shallow impulse radar (glacier structure), deployment of global positioning system (GPS) receivers (glacier flow dynamics), radio-echo-sounding techniques (englacial structure and bed properties), and geophysical characterizations (water layer thickness and bed roughness).

An Ice Diver is a thermal probe that melts through ice using electrical heating in order to penetrate to the bottom of large ice sheets. The Ice Diver is about 2 m (6 ft) long, and the nose cone is heated using power from small generators on the surface and a conducting wire that unspools from the probe as it descends through the ice. A dust logger that uses optical backscatter from a laser light source to measure the amount of windblown dust in ice would be integrated with the

Ice Diver. Ice Diver and dust logger deployments would be conducted to age-date ice, obtain basal ice temperatures, and characterize modern ice sheet behavior and ice dynamic history, with a goal of identifying a site for collection of a long continuous ice core. Two Ice Divers/dust loggers would be deployed simultaneously at separate sites within 5 km (3.1 mi) of the central camp. An estimated 21 days (at 24 hours per day) would be required for the Ice Divers/dust loggers to reach the planned ice layer depths of up to 3000 m (9800 ft). Ice melted by the Ice Diver would refreeze behind the probe, such that the Ice Diver/dust logger instruments and wire would not be retrieved following the deployments but would remain in the environment indefinitely. At end of the period, the science team would box up the surface equipment for retrograde with generators and empty fuel drums.

Autonomous repeat phase-sensitive radar (ApRES), which is a low-power, lightweight instrument, would be used to collect time series of ice shelf thickness changes with a precision of approximately 1 mm (0.04 in). The instrument uses a 200 to 400 megahertz (MHz), frequency-modulated continuous wave radar, with a one-second tone sweep (chirp), run by controller and a battery that is buried in a shallow hole. The radar's transmit and receive aerials (antennas) are spaced 5 m (16 ft) on each side of the controller and are also buried. Each system records for a nominal 12 months and has the ability to process and send, via satellite link, melt-rate data (https://www.bas.ac.uk/polar-operations/sites-and-facilities/facility/phase-sensitive-radar-apres/). Up to three ApRES systems would be installed for a full year at EAP site #2 during 2024–2025 and at EAP site #1 during 2025–2026 at locations within a 50 x 50 km (31 x 31 mi) area around the central camp. Three snowmobile-towed radars would be run simultaneously by three two-person teams, separated by some distance.

The team of nine scientists plus a field guide would be deployed for six weeks field time during each of the two seasons. The HST would move camp and science equipment between Amundsen-Scott South Pole Station and the research location each season and provide camp support. HST transit routes between Amundsen-Scott South Pole Station and the remote sites would circumnavigate the CAS sector perimeter to avoid the potential for interferences with other, ongoing investigations in the Scientific Zone. Light aircraft would provide transportation for the scientists and sensitive instruments between Amundsen-Scott South Pole Station and the camp.

Logistics support would include

- LC-130 to transport 10 science personnel and up to six Antarctic Support Contract (ASC) personnel plus 25,000 kg (55,000 lb) of cargo between McMurdo Station and Amundsen-Scott South Pole Station in both seasons (five missions of six-hour duration each season);
- beds at Amundsen-Scott South Pole Station for a maximum of 17 personnel (10 science personnel and seven ASP personnel) for one week in December and one week in January each season, and beds at Amundsen-Scott South Pole Station for a maximum of six ASC personnel for three weeks in November and five ASC personnel for two weeks in January in 2024–2025 and 2025–2026;
- light aircraft (Twin Otter and Basler) transport of science personnel and critical cargo between Amundsen-Scott South Pole Station and the remote site each season;
- Twin Otter (turboprop airplane that can land on snow and ice) day trips for two personnel to collect ApRES data at one site at the start of each season (four missions of six flight hours each, for a total of six Twin Otter days);
- Basler aircraft for 13 missions of 5.5 flight hours each, for 13 days each season; and
- HST support for delivery and return of materials and bulk fuel between McMurdo Station and Amundsen-Scott South Pole Station, and between Amundsen-Scott South Pole

Station and the remote sites. A minimum of 45 days of support would be required in 2022–2023 to prepare the HST vehicles.

3.1.3 Shallow Coring

This project element would conduct shallow coring in blue ice areas (BIAs) near the Transantarctic Mountains, including Allan Hills and Elephant Moraine, that are expected to preserve very old (more than 2 million years) ice (https://coldex.org/research). Shallow cores (up to 200-m [660-ft] depth each) would be collected at Allan Hills in 2023–2024 and at Elephant Moraine in 2024–2025 to expand the existing record of ice in the 1-to-2-million-year age range and to extend the discontinuous climate record further back in time. Shallow cores also would be collected at one of these two locations in 2025–2026. Repeat ApRES measurements at the Allan Hills and Elephant Moraine sites would be performed in conjunction with shallow coring during 2023–2024 and 2024–2025, respectively.

Cores would be collected using two drill systems – the blue ice drill (https://icedrill.org/equipment/blue-ice-drill) that is capable of retrieving cores of approximately 24 cm (9.4 in) in diameter and the Foro 400 drill (https://icedrill.org/equipment/foro-400-drill) that collects 9.8-cm (3.8-in) diameter cores. The estimated drilling time to collect a 200-m (660-ft) core would be approximately 60 hours using the blue ice drill and approximately 75 hours using the Foro 400 drill. Drilling fluid would not be used for collection of the shallow cores because neither of these drill systems require drilling fluid or other bore lubrication for normal operation. A maximum of four cores, representing 8900 kg (19,600 lb) of ice core samples requiring 140 large ice core boxes, would be collected each season.

The shallow ice coring team would deploy for three seasons: first to Allan Hills in 2023–2024; second to Elephant Moraine in 2024–2025; and third to one or the other of these two locations in 2025–2026. Eleven personnel, including scientists and drillers, would deploy for 10 weeks each season. Ten personnel would spend eight weeks in the field. Twin Otter and Basler aircraft would support drill camp put-in/take-out, passenger transport, and ice core retrograde from the field camp to McMurdo Station each season.

Logistics would include

- light aircraft transport for a 10-person field team including science personnel and drillers, plus ASC camp support and approximately 22,700 kg (48,000 lb) of cargo between McMurdo Station and the drilling location each season;
- Twin Otter:
  - 2023–2024 and 2024–2025: 28 missions of two flight hours each, for a total of 14 Twin Otter days each season;
  - 2025–2026: 32 missions of two flight hours each, for a total of 16 Twin Otter days;
- Basler aircraft for four missions of 1.5 flight hours each, for a total of two Basler days each season (assumes two missions per day); and
- eight weeks of field time to complete put-in and take-out via light aircraft and to collect a maximum of four cores each season.

3.1.4 Surface Geophysics

This project element would consist of surface geophysical surveys, including ApRES measurements, in the Ice Margin at Allan Hills and at Elephant Moraine in 2022–2023. Surveys would be conducted to map internal structures in the ice to guide site selection for shallow coring.

Additionally, at Elephant Moraine only, near-surface (5 to 10 m [16 to 32 ft]) ice cores (requiring one core box) would be collected by hand auger for preliminary dating. The goal for surveys at Allan Hills would be to collect additional high-resolution geophysical data (with GPS and new radars) in the vicinity of the potential 1250-m (4100-ft) core site that would be used to determine the optimal drilling location for the intermediate depth drilling element (Section 3.1.5, Intermediate Depth Drilling). The goal for surveys at Elephant Moraine would be to investigate potential sites for shallow core collection where ice older than 1 million years can be recovered.

Six weeks of field time would be required to confirm a site for intermediate depth drilling at Allan Hills and to confirm multiple sites for shallow coring at Elephant Moraine. Camp put-in to Allan Hills and take-out from Elephant Moraine would be supported by a Twin Otter. Camp moves between sites, a distance of about 70 km (43 mi), would be done by snowmobile traverse. Repeat ApRES measurements at the Allan Hills and Elephant Moraine sites would be performed as part of the shallow coring element (Section 3.1.3, Shallow Coring) during 2023–2024 and 2024–2025, respectively.

A similar deployment to conduct geophysical surveys and collect ApRES measurements at EAP site #3 would occur in 2023–2024. Five personnel, including one field safety coordinator, would deploy through Amundsen-Scott South Pole Station and camp for six weeks at EAP site #3. Two two-person teams would conduct the radar surveys within a 50 x 50 km (31 x 31 mi) area around the camp. Repeat ApRES measurements at EAP site #3 in 2024–2025 would be accomplished by personnel operating out of Amundsen-Scott South Pole Station as part of the combined surface geophysics and Ice Diver element (Section 3.1.2, Combined Surface Geophysics and Ice Diver). Results from these surveys would be used for selecting a site for future collection (i.e., during a subsequent COLDEX phase) of a long, continuous core of ice older than one million years.

Logistics support would include

- Twin Otter flight days to transport a six-person team, including five science personnel and one field safety guide, and approximately 6600 kg (14,500 lb) of science equipment and camp gear between McMurdo Station, Allan Hills, and Elephant Moraine (18 missions of two flight hours each, for a total of nine Twin Otter days [assumes two missions per Twin Otter day]) in 2022–2023;
- LC-130 missions to transport a four-person surface geophysics team, including three science personnel and one field safety guide, and approximately 6400 kg (14,000 lb) of cargo between McMurdo Station and Amundsen-Scott South Pole Station in 2023–2024;
- beds at Amundsen-Scott South Pole Station for seven people (four team members and three ASP crew) for one week in late December 2023 and one week in January 2024;
- Twin Otter flights to transport a four-person team, including three science personnel and one field safety guide, and approximately 7348 kg (16,200 lb) of science equipment and camp gear between Amundsen-Scott South Pole Station and EAP site #3 (17 missions of two flight hours each, for a total of six Twin Otter days [assumes up to three missions per Twin Otter day]) in 2023–2024;
- beds at Amundsen-Scott South Pole Station for up to two science personnel and three ASP crew for one week in January 2024; and
- Twin Otter flights to transport two personnel and approximately 91 kg (200 lb) of cargo on two day trips from Amundsen-Scott South Pole Station.

3.1.5 Intermediate Depth Drilling

This project element would collect one 1250-m (4100-ft) core at Allan Hills for the purpose of developing a continuous geochronology of 1-million-year-old ice. The core would be collected using the Foro 1650 drill system (https://icedrill.org/equipment/foro-1650-drill) that consists of a core processing system (core barrel puller, trays, vacuum, saw, and tables), chip melter to recover drilling fluid from ice chips (cuttings) created by drilling the core, drilling fluid handling system, vacuum to clean the drill cable and the core, pilot hole system, and a 4.9 m (16 ft) x 19.5 m (64 ft) x 2.8 m (9 ft) uninsulated tent structure for housing the drilling and core processing operations. This drill system can collect 10-cm (3.85-in) diameter cores in approximately 2-m (6.6-ft) long sections. The estimated time required to collect a 1250-m (4100-ft) core is 10 weeks, assuming 24-hour operations. An estimated 18,363 L (4851 gal) of the drilling fluid ESTISOL™ 140 would be used for the intermediate depth drilling operation. To the maximum extent practicable, drilling fluid would be recovered at the completion of COLDEX (discussed further in Section 6.3 [Release of Materials to the Antarctic Environment]).

This project element would require three field seasons, including a staging season in 2023–2024 and two drilling seasons (2024–2025 and 2025–2026) that include setup and retrograde. Nine personnel, including scientists and drillers, would deploy for the two drilling seasons and spend approximately 12 weeks in the field each year.

NSF cannot determine the supportability of this project element until an LC-130 landing zone has been identified near the drill site and the availability of the heavy equipment required to support drilling operations at this location has been confirmed. The New York Air National Guard unit must complete a Ski Landing Area Control Officer (SLACO) reconnaissance flight to confirm a potential LC-130 landing zone near the drill site during the same season prior to when the actual planned LC-130 mission would occur (i.e., 2023–2024) to ensure that the most accurate field conditions are being assessed. If possible, an initial SLACO reconnaissance flight would be conducted in 2022–2023 for preliminary evaluation of an LC-130 landing zone near the drill site, prior to when the actual suitability determination would be made in the 2023–2024 season. If NSF determines these tasks are supportable, logistics support would include

- a Twin Otter SLACO reconnaissance flight to be conducted in 2022–2023;
- a Twin Otter SLACO site suitability determination flight to be conducted in 2023–2024;
- Twin Otter and LC-130 flights for staging and setup for the drilling equipment and camp in 2023–2024. This would include transport for science, drilling, and ASC personnel between McMurdo Station and Allan Hills, and delivery of approximately 91,000 kg (200,000 lb) of materials and heavy equipment;
- Twin Otter and LC-130 flights to support 12 weeks of drilling operations in 2024–2025, including transport for a 10-person team (six drillers and four science personnel) and ASC staff and approximately 16,000 kg (35,000 lb) of seasonal cargo between McMurdo Station and Allan Hills, and one LC-130 cold deck to return 300 m (1000 ft)/4500 kg (10,000 lb) of ice cores; and
- Twin Otter and LC-130 flights to support 12 weeks of drilling operations and the full retrograde of the camp in 2025–2026, including transport for 10 personnel (six drillers and four science personnel) and ASC staff between McMurdo Station and Allan Hills, and for the return of approximately 91,000 kg (200,000 lb) of materials and heavy equipment including 900 m (3000 ft)/14,000 kg (30,000 lb) of ice cores transported on two LC-130 cold decks.

3.2 Major Resource Requirements

COLDEX would require significant resources to support the proposed science activities, including aircraft and the HST, fuel, cargo movements, field camps, and field equipment. These resources are described below.

3.2.1 Aircraft and Heavy Science Traverse

LC-130: LC-130s would be required to support both regions of activities with flight operations between McMurdo Station and Amundsen-Scott South Pole Station for EAP support and between McMurdo Station and Allan Hills to support intermediate depth drilling in the Ice Margin, pending confirmation of a suitable landing area at Allan Hills. An evaluation of the area by a SLACO, using a Twin Otter, would be completed in the 2023–2024 season prior to staging activities.

Twin Otter: Twin Otters would be required for the SLACO reconnaissance flight in 2022–2023, the SLACO site suitability determination flight in 2023–2024, support with field team deployments to sites on the EAP, and day trips from Amundsen-Scott South Pole Station. Twin Otter support would also be required for moving teams to the Ice Margin. Flights would be required to support passenger and cargo movements, and sample shipments across all field seasons.

Basler: Two types of Basler support would be required to support the project. A dedicated, specially equipped survey Basler would be required to conduct two seasons of airborne radar surveys from Amundsen-Scott South Pole Station. The airborne survey Basler would require aircraft instrumentation setup and testing prior to deploying to the Antarctic in each season. Seven weeks of dedicated Basler support would be required to complete the survey, including two weeks in McMurdo Station for setup, four weeks at Amundsen-Scott South Pole Station, and one week in McMurdo Station to reconfigure the aircraft. A shared utility Basler would be required to transport people and equipment between Amundsen-Scott South Pole Station and remote study sites on the EAP, and to assist with cargo movements between McMurdo Station, Allan Hills, and Elephant Moraine for shallow coring in the Ice Margin.

Heavy Science Traverse: The HST would be required to support the combined Ice Diver and surface geophysics deployments from Amundsen-Scott South Pole Station to a selected field site on the EAP for each season in 2024–2025 and 2025–2026. HST activities would require annual start-up/takedown, traverse time between McMurdo Station and Amundsen-Scott South Pole Station, traverse time to/from Amundsen-Scott South Pole Station and the remote site (unknown distance), and on-site operational window for the science teams to accomplish their field objectives. A minimum of 45 days in 2022–2023 would be required to prepare the HST vehicles and infrastructure. The HST would depart McMurdo Station in 2023–2024 to transport materials and bulk fuel between McMurdo Station and Amundsen-Scott South Pole Station. Once fieldwork is completed, the HST would return to McMurdo Station at the end of each field season.

All HST assets would be integrated in each site's operations where feasible. This includes the traverse's PistenBully 100 (ground-penetrating radar vehicle) that would also serve to transport personnel between Ice Diver/dust logger sites when available.

3.2.2 Fuel

Fuel deliveries to Amundsen-Scott South Pole Station would be required for all project seasons and would be accomplished in the most efficient manner possible based on the planned logistics and timing requirements. The majority of fuel delivered by LC-130 or HST would be bulk AN-8

fuel for aircraft and equipment uses. Basler operations would require 61,000 L (16,000 gal) of AN-8 fuel in 2022–2023 and 2023–2024. Delivery of bulk AN-8 fuel would be based on four primary tankers at 11,000 L (3000 gal) each, with the remaining balance distributed amongst other passenger/cargo missions. Slightly less total volumes would be required to conduct small fixed-wing operations in 2024–2025 and 2025–2026.

The HST would deliver field operations fuel to Amundsen-Scott South Pole Station in 2023–2024, 2024–2025, and possibly 2025–2026. Preliminary HST fuel delivery amounts are dependent on many variables, such as the traverse configuration (fuel versus cargo), trail conditions, and equipment performance. Depending on final cargo requirements, a maximum of approximately 230,000 L (60,000 gal; sixteen 11,000-L [3000-gal] fuel bladders) would be delivered from McMurdo Station by the HST. Traverse fuel consumption to Amundsen-Scott South Pole Station, roundtrips to field sites, and return to McMurdo Station would consume around 170,000 L (45,000 gal). AN-8 fuel requirements for Ice Diver generator operations at two sites is expected to be 19,000 L (5000 gal) per season for a total of 38,000 L (10,000 gal).

Fuel storage at Amundsen-Scott South Pole Station would be further analyzed with station management based on the above bulk AN-8 fuel deliveries and timelines. All project AN-8 fuel delivered via LC-130 would be transferred and stored in the station fuel arch per standard operating procedure. Bulk AN-8 fuel delivered by the HST at the start of the project would be stored in the station's outside fuel tanks if capacity allows. As a backup plan, the HST would set up standard field camp 38,000-L (10,000-gal) bladders and secondary containment systems for all of the remaining balance. Any AN-8 fuel required to support traverse travel in subsequent seasons would then be transferred from these storage bladders back into traverse bladders each year. For the return traverse to McMurdo Station in 2026, the HST would require approximately 48,000 L (12,750 gal) of AN-8 fuel.

An estimated 95,000 L (25,000 gal) of AN-8 fuel for drill generators and camp operations needed for the Allan Hills drill seasons would be delivered by LC-130. Fuel would be stored in standard deep field fuel bladders and secondary containment systems.

Ice Margin science events for shallow coring, snowmobile traversing between sites, and intermediate depth drilling would all require additional fuel types for small equipment (MOGAS) and snowmobile two-stroke engines (premix). LC-130 delivery of these additional fuel types would be in 210-L (55-gal) steel drums.

3.2.3 Cargo Movements

Cargo movements into field locations by project element are noted below. Estimated weights for science cargo and camp gear required for field deployments for each team, for each year include the following:

- Airborne Survey (EAP): 4100 kg (9000 lb)
- Combined Surface Geophysics and Ice Diver (EAP site #1 and site #2): 25,000 kg (55,000 lb)
- Surface Geophysics (EAP site #3): 7348 kg (16,200 lb)
- Surface Geophysics (Ice Margin): 6600 kg (14,500 lb)
- Shallow Coring (Ice Margin): 22,000 kg (48,000 lb)
- Intermediate Depth Drilling at Allan Hills (Ice Margin): approximately 107,000 kg (235,000 lb)

Ice core shipments would be a major component of the project. Shipments of packaged ice cores would be regularly returned to McMurdo Station via fixed-wing aircraft based on a project tempo and timelines for proper staging in refrigerated containers. Sample shipments would be loaded on the northbound resupply vessel for a final destination at the NSF Ice Core Facility in Denver, Colorado. Up to four, 12-m (40-ft), International Organization for Standardization refrigerated containers would be in constant rotation between McMurdo Station and the NSF Ice Core Facility each season. Two containers would likely be in transit each way to ensure that empty, available containers would be pre-staged in McMurdo Station each season upon station closing. The NSF Ice Core Facility would provide all core shipment materials including core tubes and insulated boxes.

The intermediate depth drill component of the project would require 18 1040-L (275-gal) intermediate bulk carrier totes (18,740 L [4950 gal] total) of ESTISOL™ 140 drilling fluid that must be procured from Denmark in 2022 in order to be available for staging at Allan Hills in 2023–2024. This material would be shipped via resupply vessel or C-17 aircraft.

3.2.4 Field Camps

Several minor- to major-sized temporary field camps, as defined in the NSF (2008) IEE titled *Construct and Operate New or Modified USAP Field Camps*, would be established on the EAP and Ice Margin during all field seasons to provide housing for the field teams and support for research and logistical activities. The sizes of individual camps, including numbers of tents, temporary structures, and camp equipment, would vary depending on the number of personnel and specific sampling objectives. Temporary mobile camps would also be required during transits of the HST between McMurdo Station and Amundsen-Scott South Pole Station. Standard USAP camp equipment (e.g., tents, heaters, cooking items, and small portable generators) would be used to accommodate the smaller field teams and temporary mobile camps.

Per 45 C.F.R. § 671.2 (*Waste Disposal*), release of human waste and greywater would not be permitted at field camps in the Ice Margin at Allan Hills and Elephant Moraine because these sites would be located on BIAs on the boundary of the McMurdo Dry Valleys ASMA and not located in a snow accumulation zone. Therefore, all human waste and greywater generated at these sites would be containerized and returned to McMurdo Station for disposal.

Wastewater generated at field camps in snow accumulation areas and not in an ASMA, including the three EAP sites and mobile traverse camps, would be discharged below the surface of the ice sheet. The discharge of wastewater in snow accumulation areas is consistent with normal field operations as described in the USAP Master Permit.

3.2.5 Field Equipment

Large equipment, such as power generation for equipment and instruments greater than portable units, would be needed for the two EAP sites and the Ice Margin drill site to adequately provide support for science, cargo, and camp operations. This equipment would include two 50-kilowatt generators for intermediate depth drilling, four 30-kilowatt generators for the Ice Diver deployments, and several smaller generators for drilling and camp operations.

The Ice Margin drill site would require use of a Caterpillar 297C multi-track loader to assist in camp, cargo, and drilling operations. However, depending on the location of the LC-130 ski landing zone relative to camp locations, additional large equipment also may be required to transport LC-130 cargo between sites if a Caterpillar 297C would be unsuitable in terms of tractor

capabilities and other priorities. Other required field equipment would include snowmobiles, chain saws, snow blowers, and solar panel systems.

3.3 Best Management Practices

Best management practices (BMPs) represent routine actions that would be performed during project activities, when applicable, to minimize potential adverse effects of the proposed action on the Antarctic environment. Throughout the planning and review process, BMPs applicable to COLDEX, such as those listed in Table 3-1, would be considered and recommended as appropriate to minimize adverse impacts.

Table 3-1. Best Management Practices Applicable to COLDEX Field Activities

Action	Best Management Practices
All Scientific Operations	Define clearly the scope and minimal requirements necessary to achieve scientific goals.
	Follow to the maximum extent practicable BMPs for avoiding the introduction or spread of non-native species. Equipment and boots will be cleaned in accordance with the *Non-Native Species Manual* (CEP 2019), and clothing will be inspected and brushed, before going into the field and between each sampling location to limit the potential for spread of non-native species.
Camp Construction and Operation	Minimize the size and number of camp facilities (structures) and equipment to those needed to support the research and operate the camp.
	Minimize the camp footprint (disturbed area) to designated areas.
	Design, select, and position camp facilities to minimize the effects of snow accumulation and prevent structures or materials from becoming buried and potentially irretrievable.
	Use secondary containment for all fueling operations and fuel-operated equipment.
	Develop and implement a consistent approach for the transfer of liquids that incorporates spill prevention techniques and use of containment devices.
	Clean any accidental releases during construction or operation of the camps to the maximum extent practicable using spill kits and absorbent materials.
	Report any releases from equipment and/or scientific investigations, planned or unplanned, as well as all materials and equipment remaining in the ice, per the USAP Master Permit reporting requirements in the Environmental End of Season (EOS) report.
Camp Closeout and Decommissioning	Remove all camp structures and materials containing designated pollutants when no longer needed to support COLDEX and restore (e.g., regrade) disturbed areas to their original condition to the maximum extent practical.
	Inspect camp for signs of accidental releases, remediate, and report as necessary.
	Record and report the coordinates of the camp, boreholes, and waste disposal area(s); report the condition of any materials remaining at the camp.
Release of Materials to Antarctic Environment –	Containerize wastes from Ice Margin sites for transport back to and disposal at McMurdo Station.
	Provide adequate wastewater disposal facilities to accommodate the volume of waste expected and, to the maximum extent practical, minimize the quantity of wastewater released and limit the number of individual discharge points.

Table 3-1. Best Management Practices Applicable to COLDEX Field Activities

Action	Best Management Practices
Wastewater Discharges	When reoccupying the camp each year, position discharge points (outhouses) at the same location or near previous discharge locations. Avoid creating new areas for the disposal of sanitary wastewater.
	Install wastewater discharge outlets as deep as practical to effectively isolate the waste from the surrounding environment.
	Provide storage vessels or facilities sufficient to contain all wastes, segregate incompatible wastes, and secure wastes stored for subsequent removal.
	During camp winterization, remove all nonhazardous wastes, to the maximum extent practical, and secure remaining wastes for storage.
	Document all USAP Master Permit-related activities each year including: • type, quantity, and disposition of materials containing designated pollutants that were used at the camp; • quantity and disposition of wastes generated; • characteristics (composition, quantity, and location) of substances intentionally and accidentally released to the Antarctic environment; and • inventory of materials containing designated pollutants that were stored on-site during the austral winter.
Release of Materials to Antarctic Environment – Solid and Hazardous Wastes	Adequately mark locations where materials containing designated pollutants are stored to prevent loss or damage by vehicles.
	Label all Antarctic hazardous waste containers to identify contents and initial date of accumulation.
	Inspect the following at least weekly to detect leaks or damage: • Bulk fuel storage tanks, pipelines, valves, distribution pumps, and hoses • Storage containers (e.g., drums or totes containing fuel, oil, glycol, drilling fluid) • Equipment (generator, heater) tanks, fuel lines • Vehicles (e.g., fuel tanks, oil pans, hydraulic lines, coolant systems) • Drilling fluid mixing basins, chip melter, or other equipment and vessels
	Containerize human wastes from Ice Margin sites for transport back to and disposal at McMurdo Station.
	During camp winterization, secure all materials containing designated pollutants for storage in a manner which prevents the items from becoming encrusted in snow and ice and possibly damaged upon retrieval.
	Use secondary containment for all fueling operations and fuel-operated equipment.
	Develop and implement a consistent approach for the transfer of liquids that incorporates spill prevention techniques and use of containment devices.
	Provide adequate redundant storage to enable transfer of a liquid from damaged or leaking containers (e.g., fuel tank, bladder, drum).
	Provide spill response materials (e.g., absorbents, waste drums) and train camp personnel in their proper and immediate use following a spill.
	Recover and containerize for disposal snow affected by leaks or spills immediately after detection to the maximum extent practical. Manage resulting contaminated materials as Antarctic hazardous waste; when feasible, recover spilled drilling fluid from snow. Report all spills and remedial actions, as required by 45 C.F.R. § 671.
	Prohibit the discharge of materials containing designated pollutants (e.g., drilling fluid rinsates, fuel wastes).

Table 3-1. Best Management Practices Applicable to COLDEX Field Activities

Action	Best Management Practices
	Report any releases of designated pollutants from equipment and/or scientific investigations, planned or unplanned, as per the USAP Master Permit reporting requirements in the EOS report.
Release of Materials to Antarctic Environment – Drilling/Coring	Limit the extent of drilling or coring activities (e.g., number of boreholes, depth, use of drilling fluid, disturbance to subglacial environments) to the minimum necessary to achieve the scientific goals.
	Incorporate drilling techniques that minimize the amount of time required to complete drilling or coring and achieve the scientific objectives.
	Modify (in consultation with NSF Office of Polar Programs [OPP] Environmental) or cease drilling or coring activities if environmental conditions (e.g., substrate characteristics) are encountered that are significantly different from those expected and there is a potential for adverse environmental impacts.
	Install casing pipe through the porous firn to minimize the migration of drilling fluid from the borehole.
	Prevent the introduction of foreign substances to the subsurface by using methods to close the borehole such as installing a riser or a hole plug.
	Utilize closed circuit drilling fluid systems where practical to minimize the potential for the release of drilling fluid to the environment.
	Prevent releases of drilling fluid by using containment or absorbent material to capture and remove fluid expelled from the borehole.
	Provide secondary containment for all drilling fluid mixing, transfer, or recycling activities.
	Minimize the evaporative loss of drilling fluid by keeping containers (e.g., drums, totes, mixing basin) sealed when not in use.
	Operate the drilling facility to provide adequate ventilation to reduce personnel exposure to drilling fluid vapors.
	Fit fuel-powered equipment with appropriately sized spill kits prior to deployment.
	Process ice chips containing drilling fluid using chip melter to remove and recover excess drilling fluid; reuse recovered drilling fluid to the extent practicable.
	Remove drilling fluid from the borehole to the maximum extent practicable at the end of COLDEX.
	Recover drilling fluid, contain, and process accordingly as a solid or Antarctic hazardous waste.
	Remove all casing and packers from the boreholes where possible.
	Clean the drill string and associated equipment between sites to the maximum extent practicable to prevent cross-contamination or transport of organic material.
	Record the coordinates of the waste disposal areas and include in the EOS report.
Health and Safety	Develop and comply with written operating procedures, job hazard analyses, and memoranda of understanding to address health and safety aspects of proposed activities. Where applicable, obtain input from other drilling projects (e.g., Project IceCube, South Pole Ice Core project [SPICEcore], Higgins I-165-M) and provide review of emergency procedures by appropriate USAP operating groups (e.g., Field Support and Training Program, Medical).

Key: BMP = best management practice; C.F.R. = Code of Federal Regulations; COLDEX = Center for Oldest Ice Exploration; EOS = end of season; NSF = National Science Foundation; OPP = Office of Polar Programs; USAP = United States Antarctic Program

4.0 ALTERNATIVES TO THE PROPOSED ACTIVITY

Alternatives considered in this IEE include conducting COLDEX as described herein (Alternative A) and No Action.

4.1 Alternative A

Under Alternative A, COLDEX would be conducted per the *Antarctic Infrastructure and Logistics Operational Memorandum for the STC Integrative Partnership: The Center for Oldest Ice Exploration (COLDEX;* NSF 2021), the *Science Logistics Plan for COLDEX* (NSF 2022a), and the *Operational Notice for COLDEX* (NSF 2022b) as described in Section 3.1 (Project Description). COLDEX would involve multiple U.S. institutions working together to address fundamental questions critical to understanding past and future climate change, including sensitivity to higher levels of greenhouse gases, the role of greenhouse gases in the evolution of ice age cycles, and the behavior of the Antarctic Ice Sheet in warmer climates. The central focus of the effort is to find, drill, and process oldest ice, culminating in the collection, during a subsequent phase, of a continuous ice core that extends the ice core record to at least 1.5 million years before present.

4.2 No Action Alternative

Under the No Action Alternative, COLDEX would not be performed. USAP resources not needed for COLDEX would be allocated to other scientific investigations in Antarctica. The international scientific community would not have access to the data otherwise generated by COLDEX and considered necessary to address fundamental questions critical to understanding past and future climate change. While the No Action Alternative would not meet the purpose and need (Section 2.0, Purpose and Need), it is included in this IEE to provide a comparative baseline against which to analyze the effects of the action alternative (Alternative A).

4.3 Alternatives Considered but Not Further Evaluated

Other possible alternatives that were considered, but subsequently dismissed and not evaluated further, were related to a possible reduced scope of research activities, using alternative locations for sampling and data collection, and using alternative research methods. These alternatives would not meet the scientific objectives (see Section 2.0, Purpose and Need) of COLDEX and, therefore, were eliminated from further consideration.

5.0 INITIAL ENVIRONMENTAL REFERENCE STATE

The COLDEX field activities would focus on two general areas within East Antarctica: the Ross Sea Ice Margin and the interior EAP between Amundsen-Scott South Pole Station and Dome A (see Figure 1-1, Figure 1-3, and Figure 1-4). The Ice Margin is a region of Victoria Land that fronts the western side of the Ross Sea and Ross Ice Shelf and includes ranges of the Transantarctic Mountains and the McMurdo Dry Valleys, as well as the Allan Hills and Elephant Moraine research sites. The region consists largely of snow-covered mountains and a network of outlet glaciers draining the adjacent East Antarctic Ice Shelf (EAIS).

Nunataks (exposed mountain peaks or ridges) with irregular surface topography can induce a microclimate where precipitation is low and the annual mean wind speeds are relatively high. Such settings are favorable for the formation of BIAs, which are outcrops of glacial ice brought to the surface by ice flow guided by bedrock topography. Ice flowing from the accumulation zone to

the barrier nunatak becomes virtually stagnant in the ablation area (net loss over time of surface ice due to sublimation [phase change from ice to vapor], erosion, calving, or melting) where the ice flows in an upward direction, such that the vertical ice velocity equals the ablation rate (Bintanja 1999). As a result, ice associated with BIAs can be very old. The upward ice flow trajectories, enhanced by high sublimation rates, also allows for the formation of blue ice moraines as rocks and till accumulate at the ice surface (Dadic et al. 2017). BIAs cover an estimated 1 to 2 percent of Antarctica (Kassab et al. 2019).

The Allan Hills and Elephant Moraine BIAs are located near the Transantarctic Mountain Range. This range is a barrier to ice flow that drains the EAIS into the Mawson and Mackay outlet glaciers. The altitudes/elevations of the main ice fields are 2010 m (6600 ft) and 2001 m (6565 ft), respectively, and the sizes of the associated ice fields are 88.7 sq km (34 sq mi) and 74.4 sq km (29 sq mi), respectively (Evatt et al. 2020).

The Allan Hills BIA is located near the northwest corner of the McMurdo Dry Valleys in South Victoria Land, approximately 200 km (120 mi) from McMurdo Station. The BIA comprises four ice fields separated by snow plains; snow cover is known to change seasonally and annually (Spaulding et al. 2012). The Allan Hills region is characterized by high katabatic (dense, cold air blowing down from ice sheets toward lower elevations along the coast) wind speeds and very low or negative average snow accumulation that are typical of BIAs. However, snow patches, which represent accumulation areas, occur within topographic depressions at Allan Hills. Snow accumulates if it is deposited at high wind speed and with a viscosity that is so high that, at the prevailing low temperatures, the erosion and compaction rates are slow (Dadic et al. 2017).

Ice flowing into the Allan Hills BIA at the present time has an accumulation area located only about 20 km (12 mi) upstream (Faure et al. 1992). As such, it is ideally located to capture climatic changes within the Ross Embayment and the Transantarctic Mountains. As in most BIAs, ice flow through and within the main ice field of the Allan Hills BIA is controlled by complex sub-ice topography and the presence of outcropping nunataks. Ice enters the main ice field from the south/southwest with a horizontal velocity of 50 cm (20 in) per year and then follows the north/northeasterly path. Horizontal ice velocities decrease to 1.5 cm (0.6 in) per year near the base of the Allan Hills nunatak. The low horizontal velocities, combined with vertical velocities of 1 cm (0.4 in) to 3 cm (1.2 in) per year and net ice loss through ablation (about 2 cm [0.8 in] per year), bring older ice to the surface and maintain its exposure over long periods of time. As ice flows through the main ice field, small-scale compression and extension forces reshape the appearance of the present-day surface, creating the cracking, ridging, and sharp changes in surface slope (Spaulding et al. 2013). Due to the sub-ice topography, the thickness of the ice sheet within the Allan Hills BIA varies from less than 200 m (660 ft) to over 1000 m (3280 ft) within horizontal distances of a few kilometers (Higgins et al. 2015). Thicker ice (greater than 1000 m [3280 ft] to 1200 m [3940 ft]) with snow cover is prevalent in the subglacial troughs between the BIAs (Spaulding et al. 2012). The age of shallow ice is documented by ages of meteorites exposed on the surface by ablation that mostly range from between 100,000 to 400,000 years, with a small number that extend to 1 million years, and one with an age of 2.2 million years (Higgins et al. 2015).

Elephant Moraine is on the EAIS about 70 km (43 mi) northwest of Allan Hills. The moraine itself is a deposit of glacially derived clasts and fine-grained sediment. Unlike the Allan Hills area, there are no exposed mountain peaks at Elephant Moraine. The apparent recent age of the moraine combined with the local topography of the ice sheet suggest that the Elephant Moraine may be forming because a significant decrease in the ice thickness allowed irregularities of the bedrock surface to interfere with the normal flow pattern of the EAIS in this area. The sediment laden ice

that underlies the moraine is interpreted as basal ice, suggesting that the BIA surrounding the moraine may expose a cross-section of the EAIS (Faure and Taylor 1985).

The second general area that would be investigated for COLDEX is located between Amundsen-Scott South Pole Station and Dome A, which is on the summit of the EAIS on top of the Gamburtsey Mountain Range. Dome A is the highest ice feature of Antarctica and is one of the driest and coldest locations on Earth, with snow accumulation rates from 1 cm (0.4 in) to 3 cm (1.2 in) per year that are variable at decadal time scales. Annual ice layers are potentially thinner than at other sites on the EAP, such that a longer paleoclimate record is preserved in a given ice thickness. Due to the potential for providing a very long and undisturbed ice core, as well as calm weather, this area is considered a candidate site to obtain ice core samples for paleoclimate research (Xiao et al. 2008).

6.0 ENVIRONMENTAL IMPACTS, MITIGATION MEASURES, AND MONITORING PROCEDURES

6.1 Introduction

This section discusses the potential environmental impacts resulting from the proposed action to conduct COLDEX. The discussion focuses on potential adverse effects to the EAIS environment. Impacts to the following resources were initially evaluated but not carried forward for detailed analysis for the reasons provided:

- **Visual Resources:** Research/sampling activities would be temporary, occurring during the austral summer over four seasons, would be confined to the interior portions of the continent, and would not result in permanent alterations or obstructions of scenic vistas or viewsheds.
- **Transportation:** Research activities would not result in increased vessel, car, or truck trips that would interfere with or restrict land, air, or marine traffic.
- **Cultural Resources:** There are no indigenous people of Antarctica and no cultural resources that would be threatened by COLDEX research activities.
- **Noise:** An increase in short-term, local noise levels produced by project activities (at ground level) would occur with varying intensity and duration. Most activities would occur in interior portions of the continent and would not be audible to humans other than the research and drilling teams associated with project activities.
- **Biological Resources:** The proposed research sites are in the interior portion of Antarctica and generally devoid of any flora or fauna. Aircraft providing support from McMurdo Sound to field stations may fly over wildlife in coastal areas, such as penguin and seal colonies; however, flight altitudes in these areas would be greater than 610 m (2000 ft) AGL, which is the minimum recommended vertical separation distance that would avoid aircraft noise impacts to penguin, albatross, and other bird colonies, per the *Guidelines for the Operation of Aircraft Near Concentrations of Birds in Antarctica* (Antarctic Treaty Consultative Meeting Resolution 2 [2004]). Thus, COLDEX would not affect wildlife.
- **Health and Safety:** For COLDEX, all possible health and safety requirements for field camp safety and procedures unique to the project would be developed and adhered to. These procedures would include strict personal protective equipment (PPE) adherence, materials handling, vehicle operation zones, and chemical hygiene/handling plan. NSF requires that field personnel be familiar and comply with applicable requirements of the

latest version of the NSF Office of Polar Programs (OPP) Safety and Occupational Health Policy (PESH-POL_2000.10).

6.2 Physical Disturbance

6.2.1 Alternative A

COLDEX field activities would disturb snow and ice surfaces, resulting in possible terrain alterations, from placement of camp structures, preparation and grooming of skiways, storage of materials, vehicle use, collection of ice cores, and deployment of scientific instrumentation. In general, airborne and surface geophysical surveys using passive, remote-sensing instrumentation would result in physical disturbances to the Antarctic environment that would be considered no more than minor or transitory.

Field activities would require construction and operation of temporary camps at Allan Hills, Elephant Moraine, and each of the three EAP study sites. Camps would be classified as major or minor field camps, as defined in the NSF (2008) IEE titled *Construct and Operate New or Modified USAP Field Camps*. Temporary mobile camps would also be required during transits of the HST between McMurdo Station and Amundsen-Scott South Pole Station. Physical disturbances associated with mobile camps would depend on the types and number of traverse vehicles used and the number of camps required. The potential impacts from physical disturbances associated with traverse mobile camps were evaluated in NSF's (2004) comprehensive environmental evaluation titled *Development and Implementation of Surface Traverse Capabilities in Antarctica* and were determined to be no more than minor or transitory.

Camps at Allan Hills and Elephant Moraine would be constructed within snow-covered areas adjacent to the BIAs. The three EAP sites would also be constructed within snow-covered areas. According to NSF (2008), the placement/construction of structures, storage of materials, and vehicle use, including aircraft, would result in minor disturbances to snow-covered surfaces. The typical aerial extent of disturbance would be less than or equal to 0.25 sq km (0.1 sq mi) for a major camp and less than or equal to 0.1 sq km (0.04 sq mi) for a minor camp (NSF 2008). The extent of disturbance associated with a typical mobile camp would be less than or equal to 1000 sq m (11,000 sq ft) per camp.

Intermediate depth drilling at Allan Hills would require grooming a skiway for LC-130 aircraft (assuming an LC-130 landing zone can be identified near the drill site and the availability of the heavy equipment required to support drilling operations at this location can be confirmed; see Section 3.1.5, Intermediate Depth Drilling). Skiways prepared for other Antarctic coring projects (e.g., West Antarctic Ice Sheet [WAIS] Divide; NSF 2005) were approximately 3 km (1.9 mi) in length to accommodate Basler and Twin Otter aircraft (Slawny et al. 2014). A 3-km (1.9-mi) skiway would disturb an area of approximately 0.4 sq km (0.15 sq mi). Assuming skiways for the five COLDEX sites (three EAP sites and the Allan Hills and Elephant Moraine sites) would disturb comparable areas, a combined area of about 2 sq km (0.8 sq mi) could be disturbed. Additional physical disturbances to surface snow and ice layers would be associated with tracks from HST, snowmobiles, sled/skid transits, track loaders, and other machinery required for moving supplies, including collected ice cores.

Other potential physical disturbances related to COLDEX field activities would be associated with coring, hand augering, and Ice Diver/dust logger and other instrument deployments. Drilling for ice cores as part of the shallow and intermediate depth drilling elements of COLDEX would result in multiple boreholes that penetrate the ice sheet to varying depths at the Allan Hills and Elephant

Moraine sites. Boreholes would result from collection of 5-m (16-ft) to 10-m (33-ft) surface cores, up to twelve 200-m (660-ft) shallow cores, and one 1250-m (4100-ft) intermediate depth core in BIAs. Following core collection, boreholes would either be covered with snow during camp retrograde or, for the one intermediate depth borehole, potentially capped and left open for future sampling. If left open, the borehole would remain visible, but it would deform over time due to the slow movement of the ice sheet. The displacement and deformation rates of the intermediate depth borehole due to ice flow would be small, such that after an estimated period of eight years the upper 850 m (2800 ft) of the borehole would be near vertical but displaced about 3.5 m (11 ft) downslope (Brook 2022, personal communication). Ice Diver/dust logger deployments would also produce temporary holes through the ice sheet that would extend to the underlying bedrock. Following passage of the thermal probe, ice would refreeze and seal the hole. Consequently, the hole produced by the probe would not be visible. However, the probe and trailing wire would not be retrieved and would remain in the environment.

For shallow coring at Allan Hills, the field team would reoccupy a previously used site (the Higgins I-165-M site [NSF 2019]). The ice core storage trench at this location is still open and would be reused, thus eliminating the need to construct a new trench and resulting physical disturbances of the surface snow layer. Shallow coring at Elephant Moraine would require excavation of an ice core storage trench at this site.

Based on experiences from SPICEcore (Johnson et al. 2020), the COLDEX intermediate depth drilling at Allan Hills would require excavating a trench and compacting a pad centered on the borehole location with an approximate area of 91 m (300 ft) by 91 m (300 ft) and depth of 1.5 m (5 ft). The pad would be needed to reduce the potential for the drill system to settle in the snow layer and to increase the strength of the drill trench walls. The trench may be extended as needed for storage of cores and related utilities and supplies, such as drilling fluid totes. Camp facilities would be secured at the end of each season over the austral winter, but the trench would remain open and used for storage of food, equipment, and brittle ice cores. At the conclusion of drilling, the drill trench and the ice core storage trench would be backfilled with snow, and the terrain would be returned to the pre-camp conditions to the extent possible as part of retrograde.

The areal extent of these physical disturbances would be surficial, localized, and temporary, with the exception that the intermediate depth borehole would result in a long-term physical disturbance to the BIA. Once the camps are dismantled and removed, the snow-covered terrain is expected to quickly return to its natural condition.

BMPs would be implemented to address potential impacts from constructing and operating field camps (Table 3-1):

- Minimize the size and number of camp facilities (structures) and equipment to those needed to support the research and operate the camp.
- Minimize the camp footprint (disturbed area) to designated areas.
- Design, select, and position camp facilities to minimize the effects of snow accumulation and prevent structures or materials from becoming buried and potentially irretrievable.
- Use secondary containment for all fueling operations and fuel-operated equipment.
- Develop and implement a consistent approach for the transfer of liquids that incorporates spill prevention techniques and use of containment devices.
- Clean any accidental releases during construction or operation of the camps to the maximum extent practicable using spill kits and absorbent materials.

- Remove all camp structures and materials containing designated pollutants when no longer needed to support COLDEX and restore (e.g., regrade) disturbed areas to their original condition to the maximum extent practical.
- Inspect camp for signs of accidental releases, remediate, and report as necessary.
- Record and report the coordinates of the camp, boreholes, and waste disposal area(s).
- Report any releases from equipment and/or scientific investigations, planned or unplanned, and all materials and equipment remaining in the ice per the USAP Master Permit and include in the Environmental End of Season (EOS) report.

With incorporation of these BMPs, impacts associated with physical disturbances from construction and operation of the COLDEX field camps would be no more than minor or transitory.

6.2.2 No Action Alternative

Under the No Action Alternative, no impacts associated with physical disturbances would occur.

6.3 Release of Materials to the Antarctic Environment

6.3.1 Alternative A

Various substances released to the environment during COLDEX field activities would include air emissions consisting of fuel combustion byproducts from aircraft and diesel- and gasoline-powered equipment (e.g., vehicles, generators, heaters); wastewater, consisting of sewage and domestic liquid wastes; and drilling fluid (both in liquid and vapor states). Other minor releases would include unrecoverable materials, such as wood, metal supports, anchor pins, cables, other building materials, and possibly borehole casing materials, which become frozen in the ice and irretrievable. In general, airborne and surface geophysical surveys using passive, remote-sensing instrumentation would not result in any releases to the Antarctic, other than the Ice Diver/dust logger instruments and associated wiring.

Air Emissions

COLDEX-related air emissions would result from aircraft and from operation of diesel- and gasoline-powered equipment, and the quantity of emissions would be directly related to the quantity of fuel used. Fuel combustion byproducts from aircraft operated by USAP are a typical component of normal logistical support operations and have already been characterized in the USAP Master Permit. Because a finite number of aircraft and flight hours are available to USAP each year, the air support resources used by COLDEX would be a part of the general annual support and would not increase the total number of aircraft hours flown annually by USAP or the resulting air emissions.

As noted in Section 3.1.1 (Airborne Surveys), seven of the 15 flights planned for the first season (2022–2023) would cross the CAS at an altitude of approximately 660 m (2000 ft). Overflights within the CAS below 2000 m (6000 ft) are prohibited, except for essential scientific, operational, or management purposes, and require prior approval by NSF, as well as consultation with other National Program(s) operating within the area of the Amundsen-Scott South Pole Station. Low-altitude overflights (i.e., 660 m [2000 ft]) within the CAS are considered essential for achieving the COLDEX scientific objectives. Specifically, low-altitude overflights are needed to provide the resolution required to connect the internal structure of the ice sheet in the regional grid to the ice age/depth scale at the SPICEcore site, which represents the single source for ground-truthing the age-depth structure of the ice sheet. By contrast, the quality of the data would

be significantly degraded, and observations of the internal structure of the ice sheet would be potentially compromised, if overflights occurred at an altitude of 2000 m (6000 ft) (Young 2022, personal communication). Low-altitude overflights within the CAS would only be needed for seven of the flights because the flight patterns converge in the CAS (see Figure 3-1) and would provide adequate spatial coverage and resolution. The Basler aircraft does not have sufficient range to divert flight paths around the CAS and still reach the northern extent of the flight grid (84° S), which is another important science goal for COLDEX.

The rationale for designating the CAS was to ensure a near-pristine air- and snow-sampling environment for atmospheric and climate systems research (CEP 2017). Low-altitude overflights within the CAS would result in air emissions consisting of fuel combustion byproducts from aircraft engines. The magnitude of these emissions can be estimated by multiplying the total number of flight hours within the CAS by the hourly aircraft engine emission factors, in kilograms pollutant per hour, for the Basler. The flight hours are based on a total of seven flights, and each flight will spend one hour within the CAS for each landing/take-off cycle. Table 6-1 provides the calculated total emissions from the proposed flights within the CAS.

Table 6-1. Air Pollutant Emissions from Airborne Survey Flights within the CAS

Emission Source	Air Pollutant Emissions					
	CO	NO_x	PM	SO_x	EH	CO_2
Emission Rate (kg/hr Flight)[1]	5.49	2.426	6.2	0.35	3.214	2.4909855[2]
Daily Emissions (kg)[3]	5.49	2.426	6.2	0.35	3.214	693.85
Total Emissions (kg)[4]	38.4	16.98	43	2.4	22.50	4856.95

Key: CAS = Clean Air Sector; CO = carbon monoxide; CO_2 = carbon dioxide; EH = exhaust hydrocarbons; hr = hour; kg = kilograms; NO_x = nitrogen oxides; PM = particulate matter; SO_x = sulfur oxides

Notes:

[1] Emissions based on seven flights of an estimated one hour each within the CAS
[2] Estimated as 2.4909855 kg of CO_2 per liter of fuel consumed (rather than kg per hr)
[3] Assumes one flight per day and both the outgoing and return flight paths cross the CAS for a period of 30 minutes
[4] Assumes a total of seven flights, and both the outgoing and return flight paths for each flight cross the CAS for a period of 30 minutes

Air pollutants would be quickly dispersed over the approximately 26,000-sq-km (10,000-sq-mi) area of the CAS due to the predominant meteorological conditions (e.g., wind speeds, direction, etc.). Further, pollutants would be altered, broken down, or removed from the air by a number of physical and chemical processes over time. Because these emissions would be transitory in nature (i.e., dispersed over a larger area and, thus, diluted), temporally spaced (i.e., all flights would not occur on the same day), and minor in total magnitude, it is unlikely that these emissions would adversely affect air quality within the CAS and/or unduly interfere with other ongoing scientific research in the area.

On a cumulative basis, all USAP outlying facilities and field camps consume approximately 2 million L (530,000 gal) of diesel fuel and gasoline annually. In general, the amounts of fuel consumed by typical field operations are negligible in comparison to consumption associated with major facilities such as McMurdo Station and Amundsen-Scott South Pole Station (NSF 2005). COLDEX field activities would consume an estimated 1660 L (440 gal) to 9000 L (2400 gal) of fuel (MOGAS and premix) per year (NSF 2022b). Thus, the maximum amount of fuel that would be consumed by COLDEX and the resulting air emissions are expected to be 1 percent or less of all USAP outlying facilities in an average year. The persistent and relatively strong katabatic winds on the Polar Plateau would rapidly disperse fuel combustion and evaporative emissions from drilling, camp operations, and aircraft flight activities. Emissions would not accumulate to levels

that would alter the physical and chemical properties of the terrain or adversely affect local air quality.

Wastewater Discharges

Sanitary wastewater generated by COLDEX field personnel would originate from domestic sources and consist of blackwater (urine) and greywater (used washwater containing freshwater and trace residues of soap, food particles, and personal care products). The discharge of non-domestic substances or hazardous materials with the wastewater would be avoided through the implementation of waste management practices that are already in place at USAP facilities. None of the COLDEX field sites would be in locations, such as ice shelves, sea ice, or coastal areas, that would specifically prohibit the discharge of avian (chicken/poultry) cooking wastes. However, per 45 C.F.R. § 671.2 (*Waste Disposal*), release of human waste and greywater would not be permitted at the Allan Hills and Elephant Moraine field sites because they are located on or near BIAs on the boundary of the McMurdo Dry Valleys ASMA and not within a snow accumulation zone. Liquid wastes, including avian cooking wastes, generated at these field sites would be containerized and returned to McMurdo Station for disposal. Wastewaters generated at field camps in snow accumulation areas and not in an ASMA, including the three EAP sites and mobile traverse camps, would be discharged below the surface of the ice sheet in deep ice pits. The discharge of wastewater in snow accumulation areas is consistent with normal field operations as described in the USAP Master Permit, and the impacts would be no more than minor or transitory.

The quantity of wastewater generated at the COLDEX EAP camps can be estimated using an average generation rate for large USAP field camps of 5.6 L (1.5 gal) per person per day. Based on the personnel requirements identified in the Operations Notice (NSF 2022b), not including personnel for airborne surveys, the COLDEX EAP camps, including traverse operations, would generate volumes of sanitary wastewater for disposal up to 4234 L (1118 gal) per year depending on personnel requirements for the different, concurrent field activities. Wastewater would be discharged to the maximum depth practical and would become frozen in the ice sheet and isolated, thereby minimizing possible future exposure. Activities at Allan Hills and Elephant Moraine would generate up to 9644 L (2548 gal) per year of wastewaters, all of which would be containerized and transported to McMurdo Station for disposal, and none would be discharged to the environment.

BMPs would be implemented to address potential impacts from wastewater releases (Table 3-1):

- Containerize wastes from Ice Margin sites for transport back to and disposal at McMurdo Station.
- Provide appropriate wastewater disposal facilities to accommodate the volume of waste expected and, to the maximum extent practical, minimize the quantity of wastewater released and limit the number of individual discharge points.
- When reoccupying the camp each year, position discharge points (outhouses) at the same location or near previous discharge locations. Avoid creating new areas for the disposal of sanitary wastewater.
- Install wastewater discharge outlets as deep as practical to effectively isolate the waste from the surrounding environment.
- Provide storage vessels or facilities sufficient to contain all wastes, segregate incompatible wastes, and secure wastes stored for subsequent removal.
- During camp winterization, remove all nonhazardous wastes, to the maximum extent practical, and secure remaining wastes for storage.

- Document all USAP Master Permit-related activities each year including
    - type, quantity, and disposition of materials containing designated pollutants that were used at the camp;
    - quantity and disposition of wastes generated;
    - characteristics (composition, quantity, and location) of substances intentionally and accidentally released to the Antarctic environment; and
    - inventory of materials containing designated pollutants that were stored on-site during the austral winter.

Solid and Hazardous Wastes

Solid and hazardous wastes would be generated as a result of research and field camp construction, operation, and decommissioning/retrograde activities. Consistent with current waste management practices at field camps, adequate resources would be provided to containerize wastes generated at the camp and transport the wastes to McMurdo Station, where they would be processed for retrograde to the United States.

Various products and materials containing designated pollutant constituents, such as fuels, glycol, oils and lubricants, propane, and compressed gases, would be stored and used to support COLDEX camp operations. Fuel would be stored on-site in bulk containers consisting of fuel bladders, tanks, and/or drums. Each bladder would be contained in a liner and placed in a lined berm of snow/ice. Steel tanks would be double-walled and placed in berms to provide overfill protection. Drums and other containers would be stored in portable containment berms. A spare bladder would be kept on-site to provide redundant storage capacity in case a slow leak develops in the primary bladder and it must be emptied. Thorough planning would ensure that the quantity of designated pollutants transported and stored in the field would be limited to the amount needed to support research and camp operations for a particular operating season. Secondary containment would be used with all fueling operations and with handling of hazardous materials.

Nevertheless, accidental releases of designated pollutants may occur as a result of spills, leaks, or the unexpected loss of equipment. Since accidental releases are not planned, their frequency, magnitude, composition, and resulting environmental effects cannot be projected. In accordance with the *Environmental Standards for Field Camp Construction, Operation and Decommissioning* (NSF 2008; Attachment 1), mitigating measures currently in use by USAP would be implemented to prevent accidental releases of designated pollutants to the environment. In the event that an accidental release occurs, resources, such as spill kits and absorbent materials, would be readily available to facilitate recovery, cleanup, and removal of contaminated media (e.g., snow, ice) to the maximum extent practical. All spills would be documented and reported consistent with the requirements of 45 C.F.R. § 671 and the USAP Master Permit.

BMPs would be implemented to address potential impacts from handling and storing solid and hazardous wastes (Table 3-1):

- Adequately mark locations where materials containing designated pollutants are stored to prevent loss or damage by vehicles.
- Label all Antarctic hazardous waste containers to identify contents and initial date of accumulation.
- Prohibit the discharge of materials containing designated pollutants (e.g., drilling fluid rinsates, fuel wastes).
- Inspect the following at least weekly to detect leaks or damage:
    - Bulk fuel storage tanks, pipelines, valves, distribution pumps, and hoses

    - Storage containers (e.g., drums or totes containing fuel, oil, glycol, drilling fluid)
    - Equipment (e.g., generator, heater) tanks, fuel lines
    - Vehicles (e.g., fuel tanks, oil pans, hydraulic lines, coolant systems)
    - Drilling fluid mixing basins, chip melter, or other equipment and vessels
- During camp winterization, secure all materials containing designated pollutants for storage in a manner that prevents the items from becoming encrusted in snow and ice and possibly damaged upon retrieval.
- Use secondary containment for all fueling operations and fuel-operated equipment.
- Develop and implement a consistent approach for the transfer of liquids that incorporates spill prevention techniques and use of containment devices.
- Provide adequate redundant storage to enable transfer of a liquid from damaged or leaking containers (e.g., fuel tank, bladder, drum, tote).
- Provide spill response materials (e.g., absorbents, waste drums) and train camp personnel in their proper and immediate use following a spill.
- Recover and containerize for disposal snow affected by leaks or spills immediately after detection to the maximum extent practical. Manage resulting contaminated materials as Antarctic hazardous waste; when feasible, recover spilled drilling fluid from snow. Report all spills and remedial actions, as required by 45 C.F.R. § 671.
- Report any releases of designated pollutants from equipment and/or scientific investigations, planned or unplanned, as per the USAP Master Permit reporting requirements in the EOS report.

Operational Materials

Materials used in the construction of field camps that become frozen in place and irretrievable and/or construction debris, such as sawdust, could be inadvertently released to the environment. Use to the extent possible of prefabricated structures would minimize the potential for releases of construction debris. For intermediate depth drilling, steel or plastic casing would be used in the upper portions of the boreholes to physically reinforce the hole and prevent losses of drilling fluids. Although standard procedures and BMPs require removal of all materials to the maximum extent practicable, the casing could become frozen in place and irretrievable. Casings are made of inert materials that would not readily degrade in the Antarctic environment. There is also a risk of irretrievably sticking a drill in a borehole and abandoning it; however, based on past experience the risk is very low. If either the blue ice drill or Foro 400 drill was to become stuck, approximately 4 to 19 L (1 to 5 gal) of ethanol or propylene glycol would be added to the borehole to free the drill. Similarly, there is a small risk that the Foro 1650 drill could become stuck. The recovery procedure would involve putting frozen glycol/water pellets in the borehole. The pellets would descend down to the drill before melting, at which point the glycol would flow around the drill and melt the drill free. Typically, a few liters of glycol would be required to free a drill using this method (Johnson 2022a, personal communication).

In compliance with the USAP Master Permit, all materials introduced to a camp site would be removed to the maximum extent practical as part of project retrograde (NSF 2008). Materials and equipment remaining in the ice would be reported as required by the USAP Master Permit and included in the EOS report.

Drilling Fluid

Ice coring for the intermediate depth drilling element of COLDEX would require use of drilling fluid, whereas drilling fluid would not be needed for collection of shallow cores or near-surface ice cores collected using a hand auger at Elephant Moraine (NSF 2022b). Drilling fluids are low freezing point liquids with a density approximately equal to that of ice and are used to lubricate the drill

cutting head, maintain borehole pressures, and facilitate recovery of ice chips (cuttings). The specific drilling fluid formulation selected must meet several requirements, such as: the fluid density must be approximately 935 kg per cu m (58 lb per cu ft; slightly greater than the ice density); the melting point must be lower than the temperature of the borehole (-50°C [-58°F]); and the fluid must not present unacceptable hazards to human health (toxic or explosive) or to the natural environment (Sheldon et al. 2014). The environmental effects of using drilling fluid for ice coring in Antarctica have been evaluated previously in the NSF (2009) programmatic IEE titled *Conduct Rock, Soil, Ice and Sediment Coring, and Select Excavation Activities to Support USAP Scientific Research and Logistical Operations*.

For COLDEX, the drilling fluid ESTISOL™ 140 would be used for intermediate depth drilling to collect a single 1250-m (4100-ft) core at Allan Hills. ESTISOL™ 140 is an aliphatic synthetic ester that is nonvolatile, biodegradable, and nonflammable with low toxicity, high solvency, high boiling point, high flash point, and low vapor pressure. ESTISOL™ 140 has a typical density of 870 kg per cu m (54 lb per cu ft) at 20°C (68°F). At -50°C (-58°F), the density of ESTISOL™ 140 should be 935 kg per cu m (58.4 lb per cu ft) and, therefore, sufficiently dense to compensate for ice-overburden pressure (Talalay 2011). ESTISOL™ 140 was selected for coring operations during SPICEcore because it was considered a nearly ideal single component fluid to pressure balance the SPICEcore borehole (Johnson et al. 2020). ESTISOL™ 140 was also selected as the drilling fluid for the Rapid Access Ice Drilling (RAID) test project because it satisfied the needs for low viscosity at low temperature, drill lubrication, ice-chip flotation, borehole pressure stabilization, optical quality, safety, modest cost, and environmental suitability (Goodge and Severinghaus 2016). ESTISOL™ 140 is not classified as a hazardous or toxic material, which minimizes shipping and handling restrictions (Johnson et al. 2020).

Johnson (2022b, personal communication) estimated that 18,363 L (4851 gal) of ESTISOL™ 140 would be required for intermediate depth drilling. During coring, drilling fluid would be pumped into the borehole to facilitate the coring process. The drill and portions of the cable that contact drilling fluid would become coated. To reclaim drilling fluid that coated the cable and drill, SPICEcore employed a cable vacuum device. Drilling fluid recovered using the vacuum device was recirculated into the borehole, reducing potentials for losses of drilling fluid to the environment (Johnson et al. 2020). COLDEX would use a similar system to recover drilling fluid from the cable and drill. Drilling fluid also would coat ice chips (cuttings) generated during intermediate depth drilling. Ice chips would be collected when the core is retrieved from the borehole, and the chips would be transferred to a chip melter to recover the drilling fluid. The chip melter uses an electric heating element to melt ice cuttings saturated with drilling fluid. The denser water from the melted ice sinks while the drilling fluid floats to the top in the tank. Drains on the side of the tank remove the separated drilling fluid and water. The drilling fluid would then be cooled and reused, and the water would be retained for transport back to McMurdo Station. Small amounts of drilling fluid coating the outside of the ice core would be removed and/or evaporate during processing and storage.

To the maximum extent practicable, drilling fluid would be recovered from the intermediate depth borehole at the completion of COLDEX. While standard procedure is to recover as much of the deployed drilling fluid from the borehole as possible at the end of coring, it may not be feasible or practical to recover all of the drilling fluid from the intermediate depth borehole. Furthermore, from a scientific perspective, it may be deemed useful to leave drilling fluid in the borehole to maintain stability in the event future research projects could benefit from additional downhole measurements, such as measurements of borehole temperature or dust logging. For example, the RAID test project left drilling fluid (ESTISOL™ 140) in the boreholes following core extraction to maintain borehole stability for five years to accommodate follow-up wireline logging (Goodge

et al. 2021). If the initial phase of COLDEX determines a need to maintain the intermediate depth borehole for future measurements, an estimated 15,800 L (4170 gal) of drilling fluid may be left in the intermediate depth borehole if plans are in place for a subsequent phase of COLDEX. As part of a subsequent, approved, and funded phase of COLDEX, an amendment to this IEE would be prepared that would present plans for the continued use of the intermediate depth borehole and eventual removal of the drilling fluid, and evaluate the environmental impacts of the plans. In addition to unrecoverable drilling fluid that remains in the borehole, losses of drilling fluid associated with ice chips, and evaporative losses from ice cores, drilling fluid may be lost to the environment via seepage from the borehole, from the joint at the casing-to-ice transition, and from casing joints. However, ice beneath the firn layer and cased section of the borehole is expected to be impermeable (NSF 2005). Thus, losses due to seepage from the borehole would be negligible. The intermediate depth borehole could potentially penetrate the ice sheet and reach the underlying bedrock. Based on existing information (Kehrl et al. 2018), temperatures within the bed at the Allan Hills BIA are expected to be -10°C (14°F). Consequently, the bed layer would be frozen, and the potential release of drilling fluid to a basal water system is considered an unlikely possibility.

For COLDEX, Johnson (2022b, personal communication) estimated that 5 percent of the drilling fluid deployed (790 L or 210 gal) would be unrecoverable and potentially lost to the environment due to losses from drilling operations, including chip melting, fluid remaining on the cores, and evaporation. By comparison, SPICEcore estimated that 15 percent of the drilling fluid deployed was unrecoverable, the majority of which was due to the inefficiency of the centrifuge process used to recover drilling fluid from ice chips, with the remainder due to fluid left on the cores, loss during drilling operations, and evaporation (Johnson et al. 2020). Use of a chip melter instead of a centrifuge for intermediate depth drilling during COLDEX is expected to reduce the loss of drilling fluid to around 5 percent (Johnson 2022b, personal communication). Upon completion of drilling activities, all recovered and unused drilling fluid would be returned to McMurdo Station and either be used on another project or retrograded from Antarctica.

Drilling Fluid Evaporative Emissions

Although ESTISOL™ 140 is considered a nonvolatile material, some amount would be released to the atmosphere when the material is handled, when cores and ice chips are removed from the borehole, and during core processing and storage (NSF 2009). The quantity of drilling fluid that would be lost to the environment through evaporation during drilling and coring handling activities would be influenced by a variety of physical and environmental factors, such as air temperature and airflow rates (McLain 2015). Residual drilling fluid remaining in the intermediate depth borehole would be expected to experience minimal fluid losses via evaporation due to the limited surface exposed to the ambient air. As noted previously, the expected total volume of unrecoverable drilling fluid during COLDEX is estimated at five percent (Johnson 2022b, personal communication). Because evaporation would account for only a portion of this loss, the volume lost to the environment due to evaporation is expected to be only a few percent (i.e., less than five percent) of the total volume used.

ESTISOL™ 140 is also not classified as a hazardous or toxic material, which minimizes handling restrictions. Per the safety data sheet (Appendix B), ESTISOL™ 140 does not have any harmful effects when used and handled according to specification. There are no skin or eye irritant effects. However, ESTISOL™ 140 has a strong odor, particularly at room temperature, from which some people experience negative side effects. Johnson et al. (2020) noted that during SPICEcore, the only symptoms experienced from direct skin contact with ESTISOL™ 140 were dryness and mild irritation in isolated cases. However, the larger issues experienced with using ESTISOL™ 140

were drillers reporting having headaches, light-headedness, appetite changes, loss of sense of smell, and irritation of the nose and eyes. Their symptoms persisted despite the ventilation in the drill tent providing 22 air exchanges per hour and a downdraft ventilation system in the heated control room providing 53 air exchanges per hour. Also, ESTISOL™ 140 reacts with many elastomers and plastic materials, limiting the types of seals, wire jacket materials, equipment containing plastic parts, and selection of PPE that can be used in and around it (Johnson et al. 2020).

During SPICEcore, a variety of PPE and operational mitigations were implemented to minimize operator exposure to ESTISOL™ 140 and to keep insulating layers dry (Johnson et al. 2020). When handling the drill and working directly with the drilling fluid, aprons with arms (DuPont™ Tychem® 5000 CPF 3) were worn over one-piece insulated waterproof coveralls. This was one of the few materials found that was completely unaffected by ESTISOL™ 140 and maintained decent flexibility at -40°C (-40°F). The SPICEcore drilling team also used Dailove 102 series thermal gloves for general work because they deteriorated much slower than other glove options. If a task required finer dexterity, polyethylene food service gloves or nitrile gloves were worn under fabric mechanics gloves. The SPICEcore drilling team also wore Baffin Derrick-model safety toe boots because they performed well in both the cold and in contact with the drilling fluid. Safety glasses or goggles were worn at all times when working with the drilling fluid. Results from air monitoring conducted with a handheld photoionization detector in both the drill tent and control room showed that concentrations did not exceed 7.0 parts per million (ppm) for 15-minute measurements and 1.8 ppm for an 8-hour measurement, which was well below the published Derived No Effect Level of 20.4 ppm for acute exposure and 10.2 ppm for long-term exposure. All outer layers of clothing worn while working, including boots, were kept at the drill site and dried and stored in a heated changing building next to the drill tent. This was effective at minimizing the amount of contaminated clothing brought back to common areas and berthing spaces (Johnson et al. 2020).

The COLDEX intermediate depth drilling element would use similar procedures to minimize potentials for health and safety risks to the drilling and core processing teams. Ventilation and vapor pressures, based on environmental conditions expected at the site, would be calculated and used for refining the facility design to ensure health and safety issues are minimized. Overall mechanical ventilation rates would be developed, along with finalization of the drill tent specifications. Air changes sufficient to keep a fresh airflow and exposure limit concentrations would be determined. Totes containing drilling fluid would be stored outside, and drilling fluid would be pumped in as needed. Totes would be kept sealed when not in use to minimize evaporation and exposures of personnel to vapors and odors.

Slawny et al. (2014) also noted that for WAIS Divide drill operators received basic first-aid, cardiopulmonary resuscitation, and automatic external defibrillator training, as well as several safety trainings, including back safety, confined space, drill safety, and fall protection. Season start-up, daily, and weekly safety checks of all equipment were performed. The drill system was well-equipped with signage and PPE, including eye and ear protection, a variety of gloves, chemical spill kits and sorbent pads, lighting, fire extinguishers and basic first-aid equipment. The drill arch was also equipped with an emergency alarm system to notify occupants to evacuate in the event of an emergency. A four-channel air monitoring system continuously monitored fluid vapor levels in the drill arch in the recessed winch pit, the drill slot, the drill control room, and near the screen cleaning system. A supplementary handheld oxygen monitor was also utilized when entering the slot, which was considered a permit-required confined space. The COLDEX drilling elements would use similar procedures to minimize potential health and safety issues.

Other Drilling Wastes – Ice Chips

Ice coring at Allan Hill and Elephant Moraine would generate ice chips as a result of drilling though the ice layers. A 12-cm (4.7-in) diameter borehole generates an estimated 2.3 cu m (81 cu ft) of ice chips per 100 m (330 ft) of core length (NSF 2009). Thus, collection of a single 10-cm (3.85-in) diameter, 1250-m (4100-ft) long intermediate depth core would generate approximately 19 cu m (670 cu ft) of ice chips, whereas collection of 200-m (660-ft) shallow cores using the 24-cm (9.4-in) diameter blue ice drill or the Foro 400 (9.8-cm [3.8-in] diameter) drill would generate approximately 18 cu m (636 cu ft) and 3.1 cu m (109 cu ft), respectively, of ice chips per core. Ice chips from shallow and surface boreholes generated without using drilling fluid (i.e., dry drilling), and therefore not chemically altered, would be disposed of on-site. Ice chips generated from the intermediate depth borehole using drilling fluid (i.e., wet drilling) would be recovered and transferred to a chip melter to remove the drilling fluid. Drilling fluid would be reused, while melt water would be containerized for transport back to McMurdo Station. BMPs would be implemented to address potential impacts from ice coring and processing (Table 3-1):

- Limit the extent of drilling or coring activities (e.g., number of boreholes, depth, use of drilling fluid, disturbance to subglacial environments) to the minimum necessary to achieve the scientific goals.
- Incorporate drilling techniques that minimize the amount of time required to complete drilling or coring and achieve the scientific objectives.
- Modify (in consultation with NSF OPP Environmental) or cease drilling or coring activities if environmental conditions (e.g., substrate characteristics) are encountered that are significantly different from those expected and there is a potential for adverse environmental impacts.
- Install casing pipe through the porous firn to minimize the migration of drilling fluid from the borehole.
- Prevent the introduction of foreign substances to the subsurface by using methods to close the borehole such as installing a riser or a hole plug.
- Utilize closed circuit drilling fluid systems where practical to minimize the potential for the release of drilling fluid to the environment.
- Prevent releases of drilling fluid by using containment or absorbent material to capture and remove fluid expelled from the borehole.
- Provide secondary containment for all drilling fluid mixing, transfer, or recycling activities.
- Minimize the evaporative loss of drilling fluid by keeping containers (e.g., drums and totes) sealed when not in use.
- Operate the drilling facility to provide adequate ventilation to reduce personnel exposure to drilling fluid vapors.
- Fit fuel-powered equipment with appropriately sized spill kits prior to deployment.
- Process ice chips containing drilling fluid using a chip melter to remove and recover excess drilling fluid; reuse recovered drilling fluid to the extent practicable.
- Remove drilling fluid from the borehole to the maximum extent practicable at the end of COLDEX.
- Recover drilling fluid, contain, and process accordingly as a solid or Antarctic hazardous waste.
- Remove all casing and packers from the boreholes where possible.
- Clean the drill string and associated equipment between sites to the maximum extent practicable to prevent cross-contamination or transport of organic material.
- Record the coordinates of the waste disposal areas and include in the EOS report.
- Develop and comply with written operating procedures, job hazard analyses, and memoranda of understanding to address health and safety aspects of proposed activities.

Where applicable, obtain input from other drilling projects (e.g., Project IceCube, SPICEcore, Higgins I-165-M) and provide review of emergency procedures by appropriate USAP operating groups (e.g., Field Support and Training Program, Medical).

With incorporation of these BMPs, impacts associated with releases of drilling- and operations-related materials to the environment from COLDEX field activities would be no more than minor or transitory.

6.3.2 No Action Alternative

Under the No Action Alternative, no impacts associated with releases of drilling- and operations-related materials to the environment would occur.

6.4 Short-Term Effects

As detailed previously in Sections 6.2 (Physical Disturbance) and 6.3 (Release of Materials to the Antarctic Environment), short-term effects for Alternative A would include physical disturbances and releases of materials to the environment. These effects would persist on a seasonal basis, through the life of the project, after which the camp and drilling facilities would be disassembled and removed, allowing the area to return to its initial environmental state. Due to the lack of environmental receptors on the EAP and Ice Margin, impacts resulting from the release of wastewater would be minor. Within several years or less, snow accumulation would return the physical surface of the EAP and Ice Margin sites to its natural condition, thereby preserving the wilderness value of the region.

Pending NSF approval, a portion of the 2022–2023 aircraft flights would cross the CAS at altitudes below the recommended guidelines, resulting in air emissions within an area designated specifically for maintaining near-pristine air and snow conditions. The aircraft emissions would be minimal, and the environmental impacts are expected to be no more than minor or transitory due to the limited number of flights, short flight duration within the CAS, and short survey period.

The design for the proposed action includes a series of BMPs (Table 3-1) intended to eliminate or minimize potential effects to the Antarctic environment. These measures include features routinely applied to the construction and operation of Antarctic field camps as well as measures specific to the drilling and coring applications. With implementation of BMPs, short-term impacts expected under Alternative A would be no more than minor or transitory.

6.5 Long-Term and Cumulative Effects

NSF (2009) concluded that the nature and extent of long-term impacts associated with drilling to collect ice cores would vary depending on the environmental setting. As discussed previously, boreholes generated by shallow and intermediate depth drilling would persist for a period of several years but would eventually deform due to ice movement. Any residual drilling fluid or casing remaining in the boreholes would also persist but would be isolated from the surface environment. Holes in the ice created by the Ice Diver/dust logger deployment would refreeze with minimal evidence of long-term physical disturbance, although the probe itself and associated wiring would remain in the borehole indefinitely.

Deep ice cores have been recovered from multiple sites in East Antarctica (e.g., South Pole, Dronning Maud Land, Vostok, Law Dome, Taylor Dome, Dome C, Dome F, and Talos Dome) and in West Antarctica (e.g., Byrd Station, Siple Dome, WAIS Divide, Roosevelt Island, Berkner Island, and Fletcher Promontory; Casey et al. 2014; Goodge and Severinghaus 2016; Figure 6-1).

KEY

- Ice Core
- Ice-free Rock
- Ice Sheet
- Ice Shelf
- General Project Area
- Contours at 500 m intervals

A	Dome A
AH/EM	Allan Hills/Elephant Moraine COLDEX
BI	Berkner Island
BY	Byrd
C	Dome C
DC	EPICA Dome C
DF	Dome Fuji
DML	Dronning Maud Land
FP	Fletcher Promontory
LD	Law Dome
R	RAID/Minna Bluff
RI	Roosevelt Island
S	SPICECore
SD	Siple Dome A
TA	Talos Dome
TR	Taylor Dome
V	Vostok
WAIS	WAIS Divide

Figure 6-1. Locations of Deep Ice Cores in Antarctica

Plans for collecting deep cores at other locations in Antarctica (e.g., Dome A, Dome B, Dome C, and Dome Fuji) are currently in process. All of these research projects have or will result in environmental impacts related to camp operations, logistics, and drilling/ice coring that are similar to those for COLDEX. In each case, impacts are localized to the area of the drill site, and the project locations associated with the individual research efforts are spread across large areas of the Antarctic continent. Given the small number of ice cores extracted from boreholes across the expansive EAIS, potentials for cumulative impacts resulting from geographically overlapping projects are considered negligible. The likelihood of follow-on phases to COLDEX presently is undetermined. If an additional phase of the project is funded, it is possible that future fieldwork could revisit some of the same sampling locations, such as one or more of the EAP sites, for collection of a long, continuous core. Regardless, the potential for cumulative impacts would also be no more than minor or transitory.

The probability of an accidental release of materials containing designated pollutants from COLDEX would be low due to standard practices and implementation of BMPs. However, if a release occurs, it could result in substances migrating into the underlying snow and ice and becoming unrecoverable, representing a potential long-term impact in the vicinity of the spill site.

The overall severity of the long-term and cumulative impacts would be minimal because of measures to immediately contain and clean up the spill, as well as the isolation of the spill site, large distance between other past, present, and future research sites, and absence of sensitive receptors (e.g., wildlife).

6.6 Summary of Effects

Table 6-2 summarizes the magnitude of expected impacts that would result from COLDEX (Alternative A). The No Action Alternative would not result in environmental impacts.

As previously stated, the environmental effects of the proposed action would be consistent in scope and nature with those previously evaluated by NSF in the programmatic IEE titled *Construct and Operate New or Modified USAP Field Camps* (NSF 2008) and the IEE titled *Conduct Rock, Soil, Ice and Sediment Coring, and Select Excavation Activities to Support USAP Scientific Research and Logistical Operations* (NSF 2009). These effects were determined to be no more than minor or transitory.

The proposed action has identified BMPs designed to minimize the potential environmental effects from proposed drilling activities and camp operations. Drilling/coring activities would result in some physical disturbances and releases of materials to the environment, including some drill casings and drilling fluid that would not be completely recovered. Although these impacts would be irreversible, they would be localized in the slowly moving ice sheet and would not be expected to affect any environmental receptors. Ice diver/dust logger deployments would result in minor, localized, physical disturbances to the ice sheet and releases of unrecoverable, inert materials (probe and wire). The environmental impacts resulting from the camp operations and logistical support aircraft would be within the typical range of USAP activities conducted each year and would not add significantly to the impacts already being realized at field sites, such as physical disturbances, fuel combustion air emissions, and wastewater releases to the environment.

Overall, the projected impacts associated with COLDEX would be no more than minor or transitory, and localized, and would not contribute cumulatively to adverse impacts to the EAP, Ice Margin, or other locations in Antarctica. The potential scientific benefits of the proposed action are significant and outweigh the potential impacts that may result.

Table 6-2. Summary of Impacts Resulting from COLDEX

Activity	Output	Environmental and Operational Impacts					
		Affected Environment	***Duration***	***Extent***	***Intensity***	***Impact Probability***	***Overall Rating (see note)***
Ice Coring at Allan Hills and Elephant Moraine • Operate drill facility and deploy drilling fluid • Collect 12 shallow (200-m [660-ft]) cores • Collect one intermediate depth (1250-m [4100-ft]) core • Collect several surface (5-m [16-ft] to 10-m [33-ft]) cores	Physical Disturbance (ice sheet coring)	Snow and Ice; Ice Margin sites only	Long-term	Up to 12 shallow (to 200-m [660-ft]) cores, one intermediate (1250-m [4100-ft]) core, and several surface (5-m [16-ft] to 10-m [33-ft]) cores	Low	Certain	3
	Borehole Casing (unrecoverable, inert materials)	Snow and Ice; Ice Margin site (Allan Hills) only	Long-term	Estimated 100-m (330-ft) casing, if needed, at Allan Hills	Low	Unlikely	3
	Drilling Fluid Releases						
	• evaporation	Air; Ice Margin sites only	Short-term	Localized	Low	Low	1
	• handling losses	Snow and Ice; Ice Margin sites only	Short-term	Localized	Low	Low	3
	• unrecovered from borehole	Snow and Ice; Ice Margin sites only	Long-term	Localized[1]	Low	Low	3
	Ice-Chip Disposal	Ice Margin sites only	None	Ice chips from intermediate depth drilling would be melted and melt water would be retained for disposal at McMurdo Station. Ice chips from surface and shallow cores would be disposed on-site.[2]	None	None	0
	Accidental Releases (liquid spills)	Snow and Ice	Long-term	Localized	Low	Unlikely	2
Ice Diver/Dust Logger Deployments at EAP Site #1 and Site #2	Physical Disturbance and Material Release (unrecoverable, inert materials)	Snow and Ice; EAP sites	Long-term	Localized	Low	Unlikely	3

Table 6-2. Summary of Impacts Resulting from COLDEX

Activity	Output	Environmental and Operational Impacts					
		Affected Environment	***Duration***	***Extent***	***Intensity***	***Impact Probability***	***Overall Rating (see note)***
Construct and Operate COLDEX Camps and Skiways	Physical Disturbance (terrain alteration)	Snow and Ice; EAP and Ice Margin sites	Medium-term (4 years)	Multiple 0.1 sq km (0.04 sq mi) to 0.25 sq km (0.1 sq mi) camps; 5 skiways: 2 sq km (0.8 sq mi)	Low	Certain (reversible)	2
	Material Releases (unrecoverable materials)	Snow and Ice	Long-term	Localized	Low	Unlikely	3
	Waste Discharge	Snow and Ice EAP sites only	Medium-term (4 years)	Localized (multiple locations)	Low	Certain	2
	Accidental Releases (liquid spills)	Snow and Ice	Long-term	Localized	Low	Unlikely	2
Airborne Surveys	Air Emissions	Air and Snow within the CAS	Short-term	Localized	Low	Low	3

Key: + = environmental improvement; 0 = no substantial effect or highly unlikely; 1 = minor, short-term effect; 2 = minor effect that continues for a limited period of time after the activity is completed; 3 = minor, localized long-term effect; 4 = environmental effects may be substantial or long-term; COLDEX = Center for Oldest Ice Exploration; EAP = East Antarctic Plateau; CAS = Clean Air Sector

Notes:

[1] The total volume of unrecovered drilling fluid is estimated to be 790 L (210 gal) assuming a 5-percent loss rate due to a combination of evaporation, handling losses, and incomplete recovery from the borehole. In the event COLDEX determines a need to keep the intermediate depth borehole open, an estimated 15,800 L (4170 gal) of drilling fluid could remain in the borehole until it is removed during a subsequent phase of COLDEX.

[2] Assumes all surface and shallow cores would be collected using dry drilling (i.e., no drilling fluid)

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APPENDIX A: ACRONYMS, ABBREVIATIONS, AND UNITS OF MEASURE

Units of Measure

°C	degrees Celsius	L	liter(s)
°F	degrees Fahrenheit	lb	pound(s)
cm	centimeter(s)	m	meter(s)
cu ft	cubic foot (feet)	MHz	megahertz
cu m	cubic meter(s)	mi	mile(s)
ft	foot (feet)	mm	millimeter(s)
gal	gallon(s)	sq ft	square foot (feet)
in	inch(es)	sq km	square kilometer(s)
kg	kilogram(s)	sq m	square meter(s)
km	kilometer(s)	sq mi	square mile(s)

Abbreviations and Acronyms

ACA	Antarctic Conservation Act
AGL	above ground level
ApRES	autonomous repeat phase-sensitive radar
ASC	Antarctic Support Contract
ASMA	Antarctic Specially Managed Area
ASP	aviation service provider
ATS	Antarctic Treaty Secretariat
BIA	blue ice area
BMP	best management practice
CAS	Clean Air Sector
C.F.R.	Code of Federal Regulations
CO_2	carbon dioxide
COLDEX	Center for Oldest Ice Exploration
CReSIS	Center for Remote Sensing of Ice Sheets
E	East
EAIS	East Antarctic Ice Shelf
EAP	East Antarctic Plateau
EOS	End of Season
GPS	global positioning system
HST	Heavy Science Traverse
Ice Margin	western margin of the East Antarctic Ice Sheet
IEE	Initial Environmental Evaluation
NASA	National Aeronautics and Space Administration
NSF	National Science Foundation
OPP	Office of Polar Programs
PPE	personal protective equipment
ppm	parts per million
Protocol	Protocol on Environmental Protection to the Antarctic Treaty
RAID	Rapid Access Ice Drilling
S	South
SLACO	Ski Landing Area Control Officer
SPICEcore	South Pole Ice Core

Abbreviations and Acronyms continued

STC	Science and Technology Center
U.S.	United States
U.S.C.	United States Code
USAP	United States Antarctic Program
UTIG	University of Texas Institute for Geophysics
WAIS	West Antarctic Ice Sheet

APPENDIX B: SAFETY DATA SHEET: ESTISOL™ 140

Safety data sheet
according to 1907/2006/EC, Article 31

Printing date 14.01.2013 Revision: 14.01.2013

1 Identification of the substance/mixture and of the company/undertaking

· **Product identifier**

· **Trade name: ESTISOL 140**
· **Application of the substance / the preparation** Solvents

· **Details of the supplier of the safety data sheet**
· **Manufacturer/Supplier:**
Esti Chem A/S
Erhvervsparken 16
DK - 4621 Gadstrup
Tel.: +45-56-65 33 72
Fax.:+45-56-65 33 75

· **Further information obtainable from:**
product safety department
birgit.pape@additiv-chemie.de
· **Emergency telephone number:**
+45-56653372 - Office hours (Mo.-Fr. 8:00 - 16.00)
+45-40113372 - Outside office hours

2 Hazards identification

· **Classification of the substance or mixture**
· **Classification according to Regulation (EC) No 1272/2008**
The product is not classified according to the CLP regulation.

· **Classification according to Directive 67/548/EEC or Directive 1999/45/EC** Not applicable.
· **Information concerning particular hazards for human and environment:**
The product does not have to be labelled due to the calculation procedure of the "General Classification guideline for preparations of the EU" in the latest valid version.
· **Classification system:**
The classification is according to the latest editions of the EU-lists, and extended by company and literature data.

· **Label elements**
· **Labelling according to Regulation (EC) No 1272/2008** Void
· **Hazard pictograms** Void
· **Signal word** Void
· **Hazard statements** Void
· **Other hazards**
· **Results of PBT and vPvB assessment**
· **PBT:** Not applicable.
· **vPvB:** Not applicable.

3 Composition/information on ingredients

· **Chemical characterization: Mixtures**
· **Description:** Mixture of substances listed below with non hazardous additions.

· **Dangerous components:** Void
· **Additional information:** For the wording of the listed risk phrases refer to section 16.

4 First aid measures

· **Description of first aid measures**
· **General information:** No special measures required.
· **After inhalation:** Supply fresh air; consult doctor in case of complaints.
· **After skin contact:** Immediately wash with water and soap and rinse thoroughly.
· **After eye contact:** Rinse opened eye for several minutes under running water.
· **After swallowing:** If symptoms persist consult doctor.

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Safety data sheet
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Trade name: ESTISOL 140

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· **Information for doctor:**
· **Most important symptoms and effects, both acute and delayed** No further relevant information available.
· **Indication of any immediate medical attention and special treatment needed**
No further relevant information available.

5 Firefighting measures

· **Extinguishing media**
· **Suitable extinguishing agents:**
CO2, powder or water spray. Fight larger fires with water spray or alcohol resistant foam.
· **Special hazards arising from the substance or mixture** No further relevant information available.
· **Advice for firefighters**
· **Protective equipment:** Wear self-contained respiratory protective device.

6 Accidental release measures

· **Personal precautions, protective equipment and emergency procedures** Wear protective clothing.
· **Environmental precautions:** Do not allow to enter sewers/ surface or ground water.
· **Methods and material for containment and cleaning up:**
Absorb with liquid-binding material (sand, diatomite, acid binders, universal binders, sawdust).
· **Reference to other sections** No dangerous substances are released.

7 Handling and storage

· **Handling:**
· **Precautions for safe handling** No special measures required.
· **Information about fire - and explosion protection:** No special measures required.

· **Conditions for safe storage, including any incompatibilities**
· **Storage:**
· **Requirements to be met by storerooms and receptacles:** Provide solvent resistant, sealed floor.
· **Information about storage in one common storage facility:** Store away from foodstuffs.
· **Further information about storage conditions:** None.
· **Specific end use(s)** No further relevant information available.

8 Exposure controls/personal protection

· **Additional information about design of technical facilities:** No further data; see item 7.

· **Control parameters**
· **Ingredients with limit values that require monitoring at the workplace:**
The product does not contain any relevant quantities of materials with critical values that have to be monitored at the workplace.
· **Additional information:** The lists valid during the making were used as basis.

· **Exposure controls**
· **Personal protective equipment:**
· **General protective and hygienic measures:**
The usual precautionary measures are to be adhered to when handling chemicals.
· **Respiratory protection:** Not required.
· **Protection of hands:**
Only use chemical-protective gloves with CE-labelling of category III.
To minimize the wetness in the glove due to perspiration changing of gloves during a shift is required.
For the protection against chemicals in areas with heightened risk of injury (mechanical hazard) no recommendation for a suitable glove material can be given.

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The glove material has to be impermeable and resistant to the product/ the substance/ the preparation.
Selection of the glove material on consideration of the penetration times, rates of diffusion and the degradation

· ***Material of gloves***
The selection of the suitable gloves does not only depend on the material, but also on further marks of quality and varies from manufacturer to manufacturer.
Butyl rubber, BR
Natural rubber, NR

· ***Penetration time of glove material***
For the mixture of chemicals mentioned below the penetration time has to be at least > 60 minutes (Permeation according to EN 374 Part 3: Level 1).
The determined penetration times according to EN 374 part III are not performed under practical conditions. Therefore a maximum wearing time, which corresponds to 50% of the penetration time, is recommended.
Value for the permeation: Level ≥ 1
The exact break trough time has to be found out by the manufacturer of the protective gloves and has to be observed.

· ***Eye protection:*** *Goggles recommended during refilling*

9 Physical and chemical properties

· ***Information on basic physical and chemical properties***	
· ***General Information***	
· ***Appearance:***	
Form:	*Fluid*
Colour:	*Clear*
· ***Odour:***	*Fruit-like*
· ***Change in condition***	
Melting point/Melting range:	*-93°C*
Boiling point/Boiling range:	*199°C*
· ***Flash point:***	*75°C*
· ***Ignition temperature:***	*270°C*
· ***Danger of explosion:***	*Product does not present an explosion hazard.*
· ***Explosion limits:***	
Lower:	*1.1 Vol %*
Upper:	*7.5 Vol %*
· ***Density at 20°C:***	*0.865 g/cm³*
· ***Solubility in / Miscibility with water:***	*Not miscible*
· ***Other information***	*No further relevant information available.*

10 Stability and reactivity

· ***Reactivity***
· ***Chemical stability***
· ***Thermal decomposition / conditions to be avoided:*** *No decomposition if used according to specifications.*
· ***Possibility of hazardous reactions*** *No dangerous reactions known.*
· ***Conditions to avoid*** *No further relevant information available.*
· ***Incompatible materials:*** *No further relevant information available.*
· ***Hazardous decomposition products:*** *No dangerous decomposition products known.*

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11 Toxicological information

· **Information on toxicological effects**
· **Acute toxicity:**

· **LD/LC50 values relevant for classification:**		
Oral	LD50	3000 mg/kg (rat)

· **Primary irritant effect:**
· **on the skin:** No irritant effect.
· **on the eye:** No irritating effect.
· **Sensitization:** No sensitizing effects known.
· **Additional toxicological information:**
The product is not subject to classification according to the calculation method of the General EU Classification Guidelines for Preparations as issued in the latest version.
When used and handled according to specifications, the product does not have any harmful effects to our experience and the information provided to us.

12 Ecological information

· **Toxicity**
· **Aquatic toxicity:** No further relevant information available.
· **Persistence and degradability** No further relevant information available.
· **Behaviour in environmental systems:**
· **Bioaccumulative potential** No further relevant information available.
· **Mobility in soil** No further relevant information available.
· **Additional ecological information:**
· **General notes:**
Water hazard class 1 (German Regulation) (Self-assessment): slightly hazardous for water
Do not allow undiluted product or large quantities of it to reach ground water, water course or sewage system.
· **Results of PBT and vPvB assessment**
· **PBT:** Not applicable.
· **vPvB:** Not applicable.
· **Other adverse effects** No further relevant information available.

13 Disposal considerations

· **Waste treatment methods**
· **Recommendation**
Must not be disposed together with household garbage. Do not allow product to reach sewage system.

· **Uncleaned packaging:**
· **Recommendation:** Disposal must be made according to official regulations.

14 Transport information

· **UN-Number**	
· **ADR, ADN, IMDG, IATA**	Void
· **UN proper shipping name**	
· **ADR, ADN, IMDG, IATA**	Void
· **Transport hazard class(es)**	
· **ADR, ADN, IMDG, IATA**	
· **Class**	Void

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Trade name: ESTISOL 140

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· **Packing group** · **ADR, IMDG, IATA**	Void
· **Environmental hazards:** · **Marine pollutant:**	No
· **Special precautions for user**	Not applicable.
· **Transport in bulk according to Annex II of MARPOL73/78 and the IBC Code**	Not applicable.
· **UN "Model Regulation":**	-

15 Regulatory information

· **Chemical safety assessment:** A Chemical Safety Assessment has not been carried out.

16 Other information

This information is based on our present knowledge. However, this shall not constitute a guarantee for any specific product features and shall not establish a legally valid contractual relationship.

· **Department issuing MSDS:** product safety department
· **Contact:** Mrs. Birgit Pape

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