SOUTH POLE STATION

MASTER PLAN DRAFT

— 2024 —

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* Cover photo: Sunrise beyond IceCUBE. Source: NSF, Johannes Werthebach, 2018.

Skiway grooming. Source: NSF, Johannes Werthebach, 2018.

Geographic South Pole Flag Station. Source: NSF, 2018.

Executive Summary

The U.S. Antarctic Program (USAP) research campus at the South Pole provides a platform for climate research, Earth observation, astrophysics, and polar field work that is unparalleled anywhere else on the planet. Science conducted from the Amundsen-Scott South Pole Station (referred to as “SPS” in this document) provides valuable insights into the past and future of our climate and the origins of the universe. This South Pole Station Master Plan (referred to as “SPS Master Plan”) establishes the National Science Foundation’s (NSF) long-range vision for ensuring SPS infrastructure can continue to support a world-leading science program.

Complex logistics support and smart programmatic decisions are required to operate a permanent USAP research station at such a remote location. In preparation for the SPS Master Plan, the planning team conducted an analysis of several SPS population and energy growth scenarios. As stewards of this national program, the NSF then weighed the estimated total cost of ownership of each scenario against Antarctic Treaty and USAP requirements and national research priorities. After completing this review, the NSF concluded that it is in the nation’s best interest to modernize SPS infrastructure and operations while maintaining the 150-bed capacity. While this will limit the overall volume of individuals the SPS can support at any one time, implementation of the recommendations of this SPS Master Plan can reduce operational demands and maximize future scientific support at SPS.

Large-scale infrastructure recapitalization will be necessary at SPS over the coming decades to prevent critical primary infrastructure and service failures. Several currently funded, USAP resource-dependent scientific research projects are also approved for completion at SPS during this same period. The NSF will continue to act as good stewards of federal research dollars for these projects while balancing necessary SPS infrastructure and operations modernizations to maintain a safe environment for all visitors, grantees, and personnel.

This SPS Master Plan presents a summary of current conditions, constraints, and opportunities for the SPS area. It identifies projects that will require capital-funding levels for completion, presents a site plan for redevelopment of infrastructure in need of replacement, considers conceptual building forms and design considerations for those replacement structures, and establishes a phasing plan for accomplishing these improvements.

As demands for research based out of SPS are growing, the master planning process is critical to maintaining a functional and safe station at the South Pole over the next 30-50 years. The SPS Master Plan is the first such plan developed for SPS. This plan, like all other USAP station master plans, will be routinely reviewed and updated as infrastructure conditions, USAP requirements, and national priorities warrant.

This SPS Master Plan is a Draft. In the Draft Master Plan, three concept plans are presented in Section 7 looking at different development scenarios for the SP over the coming decades. The Final Master Plan will only provide one scenario which best achieves the Vision established for the SPS.

SECTION 1

Summer Camp. Source: NSF, 2018 - 2019.

Purpose of the Master Plan

The purpose of the SPS Master Plan is to establish an actionable recapitalization plan in support of the NSF vision to modernize infrastructure and operations to continue scientific support at the South Pole, maintaining the 150-bed capacity of the station for the next 35-50 years. The SPS Master Plan will serve as a guide for future development at the South Pole.

A scientific community engagement charrette was conducted prior to the development of this master plan to identify the broad needs and future priorities of the scientific research community across all major South Pole-based scientific fields. NSF then compared the information gathered through this outreach to the impact and feasibility of any additions or major renovations to primary infrastructure required to support those future priorities while maintaining operations at the station. The result of these efforts is a SPS Master Plan presenting a cohesive, integrated approach to future redevelopment of the South Pole area based on current (2024) supportable levels of scientific activity and support operations.

This SPS Master Plan provides an overview of existing station conditions and phasing for completing the large infrastructure projects necessary to continue supporting scientific research at SPS. However, this SPS Master Plan does not include structural or architectural designs, energy modeling and design, snowdrift modeling, or project initiation schedules or pricing. These project activities require additional resources beyond the scope of this SPS Master Plan.

Methodology

The SPS Master Plan has been developed through a process of discovery, assessment, validation, planning, and projections. Figure 2.1 illustrates the master planning process.

The first step in the planning process is discovery. During this phase, all available existing infrastructure assessments and historical data was collected to understand the baseline conditions at the South Pole. From the baseline, an integrated needs assessment was undertaken to ascertain existing deficiencies and identify improvements that can be made to maintain the SPS science research capabilities over the next 35-50 years. A primary focus of the assessment step in the master planning process was understanding the concerns of the science community who conduct research at the South Pole. A four-day virtual charrette was conducted with all science disciplines with an interest in the South Pole area. Participants were given time to express their concerns with the existing station, share their desired future projects, and discuss preferred solutions for the station area. This information was documented using an interactive whiteboard tool.

Validation is the process of confirming information and collecting supporting documentation and empirical data. During the planning process, focus groups were conducted with subject matter experts (SMEs), SPS personnel, Antarctic Support Contractor (ASC) personnel, and NSF personnel. The focus groups were opportunities for the SMEs to verify information, ask exploratory questions, and identify best practices for specialty areas. As the SPS Master Plan was drafted, iterations of the document were submitted to the focus groups for review and comment. The review comments were used to further refine the contents of the master plan.

Equipped with the information gathered from the assessment and validation processes, the SPS Master Plan was developed. Maps were created in Arc GIS, proposed sizing of replacement infrastructure was determined, and building structural types were assessed for their compatibility with the South Pole environment. A Regulating Plan was created to establish land use districts, overlay districts, and easements to guide the placement of future large structures and facilities based on the impacts created by their associated uses. Sub Areas were established for focused Sub Areas plans, and three overall master plan concepts were developed. Validation of supporting information and identification of the potential benefits and impacts of these three concepts was ongoing throughout the drafting process.

The final master plan concept presented in the SPS Master Plan was selected in accordance with the NSF vision for the future of SPS and the goals and objectives of the SPS Master Plan. Capital projects required to support this master plan were assigned to one of four phases to maximize efficiencies in construction processes and reduce risk and impact to life safety and science activity at SPS. Rough Order of Magnitude (ROM) costs for projects anticipated to occur in the next 20 years were also established to support NSF resource planning during each phase.

MASTER PLANNING PROCESS FLOW

FACTS

- The South Pole is a harsh environment to live and work. The physical elements impose environmental strains on buildings and equipment, limiting the lifespan of infrastructure at SPS.
- The Sectors are managed by the Antarctic Specially Managed Area Number 5 (ASMA), and any proposed edit to the ASMA will require approval by the Antarctic Treaty Consultative Meeting (ATCM) before formal adoption and implementation.
- The SPS Operations Zone provides support facilities and sustaining environmental systems for scientific research.
- New infrastructure or substantial upgrades for scientific research projects is funded independently. Shared infrastructure and support systems are funded by NSF Office of Polar Programs (OPP).
- The SPS Master Plan is a 35–50-year horizon.
- The SPS will continue to support a 150-bed capacity for the next 35-50 years.

The following baseline planning assumptions form the foundation of this SPS Master Plan:

- New support facilities will be programmed and right-sized to maintain current operations.
- The consolidation of facilities to centralize logistics and storage of existing capacity is supported by NSF.
- Changes in operations to improve efficiencies and save costs is supported by NSF.
- Final design and snow drift modeling of any replacement structures will follow this master plan.

Aurora Australis blends into Milky Way over South Pole Station. Source: NSF, Martin Wolf, 2017.

Vision

VISION STATEMENT

The NSF vision is to modernize infrastructure and operations to continue scientific support at the South Pole.

MISSION

The greater SPS Master Plan will ensure SPS remains a viable platform for supporting Antarctic science for the next 35-50 years by:

- supporting future redevelopment of SPS that is optimized for support of local and deep field science;
- supporting predictable operational costs, personnel requirements, and improved operational efficiency;
- supporting improved energy efficiency for facilities and operational support;
- providing a reliable, safe, and healthy working environment for USAP personnel, researchers, and visitors;
- providing the flexibility to adapt to the evolving needs of U.S. scientific research in Antarctica over a 35-50-year planning horizon;
- ensuring an "active and influential presence" in Antarctica in a manner consistent with U.S. stature in the international research community; and
- ensuring the professional nature of the NSF and of the scientific activities carried out at the station.

GOALS

The primary goals of the SPS Master Plan are to:

- guide future development decisions by documenting existing and projected conditions, infrastructure needs, and science support requirements;
- create a conceptual site design and station layout by identifying land use designations and general building placement for future scientific and support requirements;
- integrate the planning of future national science priorities; and
- provide a general sequence for identified work to facilitate the efficient and effective use of resources.

OBJECTIVES

The primary objectives of the SPS Master Plan are to:

- identify gaps in services, facilities, and information at SPS;
- articulate goals for future SPS operations to support research;
- identify efficiencies for the long-term sustainability of SPS;
- determine priorities for the long-term viability of SPS; and
- identify phasing for the long-term viability of SPS.

History & Background

DISCOVERY AND DEVELOPMENT OF THE SOUTH POLE

The Amundsen and Scott expeditions of 1911-1912 marked the first known human activity at the Geographic South Pole. In 1956, in preparation for the 1957-1958 International Geophysical Year (IGY), the U.S. established SPS as the first permanent Antarctic scientific research station located near the Geographic South Pole. The IGY was an intensive, multi-national, multi-disciplinary, global research effort designed to study a wide range of geophysical processes. The IGY led to the Antarctic Treaty, which the 12 original signatory nations, including the U.S., signed in 1961. The treaty reserves the area south of 60 degrees south latitude as a zone of peace and prohibits measures of a military nature (including fortifications), nuclear explosions, and the disposal of radioactive waste. It gives international treaty parties the right to inspect all areas of Antarctica, including the stations, installations, equipment, ships, and airplanes of other member states to ensure adherence to the treaty.

The U.S. has maintained a permanent presence at the Geographic South Pole continuously since the IGY. Since 1982, Presidential Memorandum 6646 has directed the NSF to:

“Maintain the United States Antarctic Program (USAP) program at a level providing an active and influential presence in Antarctica designed to support the range of U.S. Antarctic interests. This presence shall include the conduct of scientific activities in major disciplines; year-round occupation of the South Pole and two coastal stations; and availability of related necessary logistics support.”

The treaty nations have since agreed to several addenda, including the 1991 Environmental Protocol to the Antarctic Treaty (referred to as “the Protocol”), which reserves Antarctica for peace and science purposes, designates Antarctica as a natural preserve, sets forth principles regarding human activities, and restricts activities related to mineral resources. The Protocol was ratified and went into effect in 1998 and may not be modified before 2048 without unanimous agreement of all Consultative Parties of the Antarctic Treaty.

The first station, known as “Old Pole”, was created for the IGY by the U.S. Navy and was later abandoned due to structural failure caused by snow and ice accumulation and differential movement of the ice sheet. Old Pole is now irretrievably buried beneath the ice sheet surface and is considered a restricted zone in the greater station area. It was replaced in 1974 by a geodesic dome main station structure with supporting fuel and logistic arches. Additional garage shop and power plant arches were added in 1998 and 1999, respectively, in advance of construction of a new station. The dome was removed after completion of the current “Elevated Station” in 2010.

In July 2012, the report of the U.S. Antarctic Program Blue Ribbon Panel, More and Better Science in Antarctica Through Increased Logistical Effectiveness was completed at the request of the White House Office of Science and Technology Policy and the National Science Foundation. The report identified demands placed on the logistical enterprise to support future scientific efforts at all USAP locations and the Antarctic region, discerned any mismatches with currently projected capabilities, and proposed opportunities and corrective actions for exploration. Although the report included many logistics, operations, and facility recommendations for SPS, creation of a master plan for the future of SPS was beyond the scope of the document.

The USAP SPS is supported by McMurdo Station. 100% of the logistical support runs through McMurdo Station. All people, material, equipment, and waste transit through McMurdo to/from SPS.

The Elevated Station was uniquely designed to provide clearance beneath the structure to reduce the rate of annual wind-driven snowdrift accumulation. The 65,000 square foot structure was built on a network of columns as two connected pods, and it was designed to be lifted incrementally over time to prevent burial beneath the ice and extend the structure’s lifespan. The Elevated Station currently provides housing, dining, recreation, and medical services for approximately 150 scientific research and support personnel in the austral summer and approximately 50 scientific research and support personnel in the austral winter. The structure also contains mission support offices, a computer laboratory, and a hydroponic greenhouse. The Elevated Station is connected to the previously constructed fuel, power plant, garage shop, and logistics arches for primary power, heat, and additional support services.

During construction and following completion of the Elevated Station in 2008, the footprint of the SPS campus also continued to grow. Remote science facilities and freestanding storage solutions transformed the station campus into a large assembly of structures; the current configuration does not reflect optimized placement for efficient, long-term sustainability of science-supporting operations. A wide range of integrated, large-scale recapitalization projects are now required to address normal wear and tear, environmental challenges (such as snow accumulation and plateau movement), aging infrastructure, and evolving scientific research interests. As SPS is directly supported by McMurdo Station, all people, material, equipment, and waste must transit through McMurdo to/from SPS.

The Elevated Station and current SPS infrastructure were designed to provide mission support to world-class U.S. scientific and international collaborations at the South Pole and surrounding field areas under the leadership of the USAP, which is managed as a national program by the NSF on behalf of the U.S. Inter-agency collaborations for scientific activities involve a variety of U.S. Federal agencies, such as:

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- Department of the Interior, United States Geological Survey (DOI—USGS)
- National Oceanic and Atmospheric Administration (NOAA)
- National Aeronautics and Space Administration (NASA)
- United States Space Force (USSF)
- Department of Energy/Office of Science (DOE-Science)
- Joint Task Force—Support Forces Antarctica (JTF—SFA)
- Cold Regions Research and Engineering Laboratory (CRREL)
- New York Air National Guard (NYANG)
- Naval Information Warfare Center (NIWC)
- U.S. Army Corps of Engineers (USACE)
- United States Air Force (USAF) Reserve Command

ASMA NO.5: AMUNDSEN-SCOTT SOUTH POLE STATION, SOUTH POLE

The 1991 Protocol on Environmental Protection to the Antarctic Treaty (Environmental Protocol) established rules and procedures specifically designed to protect the Antarctic environment across the continent and created the Committee for Environmental Protection (CEP). The CEP is comprised of representatives of the countries who are party to the Environment Protocol and is tasked “to provide advice and formulate recommendations to the Parties in connection with the implementation of this Protocol, including the operation of its Annexes, for consideration at Antarctic Treaty Consultative Meetings [ATCM]” (Environmental Protocol Article 12). The CEP generally convenes alongside the ATCM once a year. Since the adoption of the Environmental Protocol in 1998, additional Antarctic Specially Managed Areas (ASMAs) and Antarctic Specially Protected Areas (ASPAs) were established to further define standards, protections, and restrictions specific to various geographical areas of the continent. The Management Plan for Antarctic Specially Managed Area (ASMA) No.5: Amundsen-Scott South Pole Station, South Pole (2017) (referred to as “the ASMA” in this document) -conserves and protects the environment surrounding the South Pole by managing and coordinating human activities in the area. The ASMA is reviewed by the CEP every five years, or when circumstances warrant a change in the ASMA. ATCM consensus is required for the formal adoption of any proposed changes to the ASMA.

The ASMA divides the greater South Pole area into three management zones: Scientific, Operations, and Restricted. The established objectives and allowed activities for each management zone are described in the ASMA.

The ASMA describes the Operations Zone as the area containing the “primary human activity in the Area, including science support activities, main station services (e.g. living facilities), skiway operations, and on-ground support facilities for non-governmental visitors (NGVs).” The Downwind Sector of the Scientific Zone “was established to provide an area free from obstructions for balloon launches, aircraft operations, and other activities. Scientific and Operations Zone activities are allowed in the Downwind Sector.” In practice, the Downwind Sector has been used for aircraft operations and overland transportation activities that support the station. Balloon launches currently occur in the Operations Zone and not the Downwind Sector.

DARK SECTOR
The Dark Sector was established to preserve the conditions of low light pollution and low electromagnetic interference (EMI) at SPS that are important to facilitate many types of astrophysical, astronomical, and aeronautical research.

CLEAN AIR SECTOR
The Clean Air Sector (CAS) is established to preserve the unique conditions that are required for atmospheric research at the SPS.

QUIET SECTOR
Sound noise and mechanical equipment activities are limited within the Quiet Sector to minimize vibration effects on seismological and other vibration-sensitive research.

DOWNWIND SECTOR
The Downwind Sector was established to provide an area free from obstructions for balloon launches, aircraft operations, and other activities. Both scientific and operations activities are allowed in the Downwind Sector.

OPERATIONS ZONE
The Operations Zone contains the science support facilities and human activity areas.

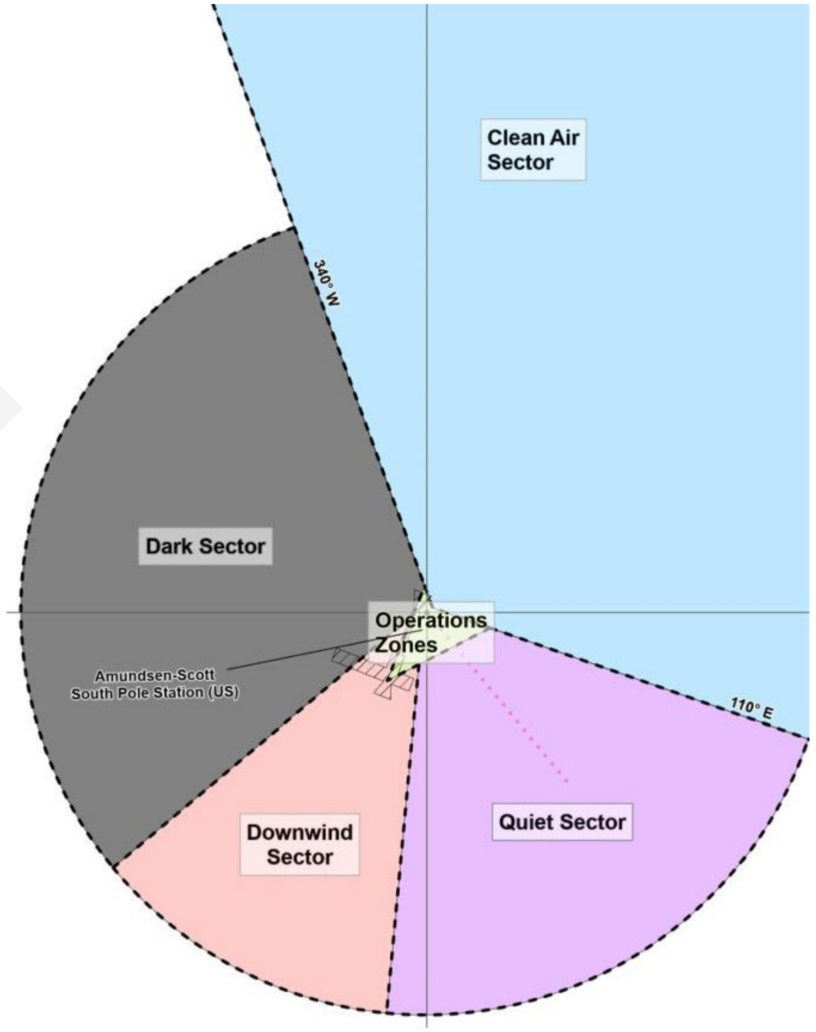
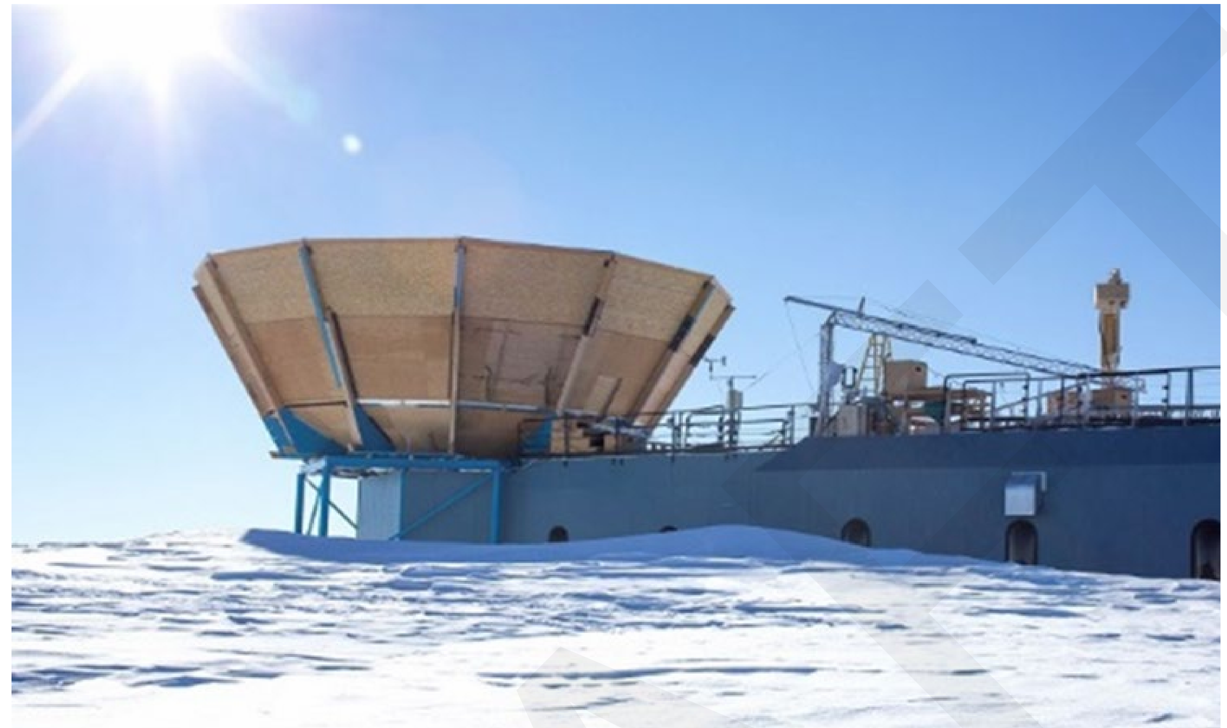


Figure 4.1 ASMA No. 5 Sectors.

ASMA No. 5 Zone	Zone Objectives	Interior Zones or Sections
Operations Zone	To ensure that science support facilities and related human activities within the Area are contained and managed within a designated area.	None
Scientific Zone	To ensure those planning science or logistics within the Area, and all visitors to the Area, are aware of sites of current or long-term scientific investigation that may be sensitive to disturbance or have sensitive scientific equipment installed, so these may be taken into account during the planning and conduct of activities within the Area. A particular objective of the Scientific Zone is to minimize conflicts between different types of use.	Clean Air Sector (CAS); Quiet Sector; Dark Sector; Downwind Sector
Restricted Zone	To restrict access into a particular part of the Area and/or activities within it for a range of reasons, e.g., owing to special scientific values because of sensitivity, presence of hazards, or to restrict emissions or constructions at a particular site. Access into Restricted Zones should normally be for compelling reasons that cannot be served elsewhere within the Area.	Aircraft Operations Zone; Old Pole Station Zone; ARO “No Vehicle” Zone; ARO “Meteorological Tower” Zone; Antenna Field Zone; Communications Zone

MAPO buried by snowdrift. Source: NSF, Robert Schwarz, 2018.



MMAPO buried by snow drift. Source: NSF, Andrea Dixon, 2018.

South Pole Station Aerial.Source: Andrew V Williams, Undated.

LANDSCAPE AND CLIMATE

The South Pole occupies a gently sloping and relatively featureless ice sheet approximately 9,300 feet above sea level. The ice sheet under the South Pole is approximately 8,850 feet thick and rests on the bedrock of the underlying Antarctic continental mass. The surface of the ice sheet is characterized by sastrugi (windblown snow), which is compacted to form building foundation pads and the skiway for the station. The area is not crevassed.

The ice sheet and all infrastructure upon or buried within the ice sheet move at a rate of approximately ten meters per year. As such, Global Positioning System (GPS) coordinates for all infrastructure change over time, complicating traditional mapping efforts. To help alleviate this issue, a local grid system is used to define boundaries and building locations.

The South Pole is also a bitterly cold, dry, and windy polar desert. The average annual temperature is recorded has varied between minus (-) 13.6 degrees (°) Celsius (C) (-7.5° F) and -82.8° C (-117.0° F). Annual mean is -49° C (-56.2° F), and the air holds little to no humidity (average relative humidity is less than 10 percent [%]. Snowfall is minimal, and persistent winds averaging between 5-15 knots cut across the area, primarily from Grid northeast/east. The winds create deep drifts and wells around anything protruding from the flat surface of the ice, burying structures over time. Snowdrift mitigation is a continual maintenance activity at the station, which currently requires hundreds of labor hours and more than 25,000 gallons of AN8 fuel to complete each year. Over time, nature prevails and structures throughout the South Pole area must be lifted or relocated to prevent complete burial beneath the ice surface (as was the fate of the Old Pole station).

The altitude of the South Pole, combined with the snowy surfaces reflecting sunlight, creates a blindingly bright environment in the austral summer. During this time, the South Pole experiences 24 hours of sunlight, with the sun peaking at a maximum elevation of 23.5° above the horizon. The station is generally isolated during the austral winter (mid-February to late-October) due to extreme weather conditions that prevent air and overland travel to the South Pole. Although the winter months bring 24 hours of darkness, the austral winter also brings the dazzling aurora australis (or southern lights), which shimmers across the sky as charged particles from the sun, channeled by Earth's magnetic field, bombard the atmosphere.

Satcom Construction. Source: NSF, Jack Corbin, Undated.

SCIENCE ACTIVITIES AT THE SOUTH POLE

Under the U.S. presidential mandate to occupy the South Pole, the current Elevated Station primarily exists and was designed to maintain the influential U.S. scientific presence in the international community. The South Pole is uniquely defined by its level of isolation and environmental constraints that are only common to the east Antarctic plateau. High, dry, cold, and clean desert characteristics coupled with nearly two miles of ice depth provide some of the best field science conditions in the world for supporting a wide variety of sciences.

The station supports the operation of world class science experiments on the cutting edge of discovery in their respective fields. Due to its isolation, the South Pole is relatively free from anthropogenic inputs that could compromise the integrity of data in other locations on the planet. Support for remote science field camps only occurs during the austral summer months because harsh weather conditions prevent access to those camps in the austral winter, but the presence of modern laboratory facilities at SPS allows observations in the station area to continue year-round. Simply put, SPS is internationally renowned as one of the premiere field laboratory sites on the planet and supports areas of scientific exploration.

According to the ASMA, the major areas of scientific exploration in the South Pole ASMA Zones and Sectors are listed below:

ATMOSPHERIC SCIENCES

Atmospheric science activity occurs primarily in the Clean Air Sector and Operations Zone. Scientists conduct research from the Atmospheric Research Observatory (ARO) and Meteorological Tower along the Clean Air Sector boundary, and they measure stratospheric ozone depletion via scientific and operational balloon launches from the Balloon Inflation Facility (BIF) in the Operations Zone.

ASTROPHYSICS AND COSMOLOGY SCIENCES

Astrophysics and Cosmology research primarily occur in the Dark Sector, where light and electromagnetic interference are reduced.

GEOSPACE SCIENCE

Geospace research occurs in a restricted area within the Operations Zone.

GLACIOLOGY

The properties of the Antarctic ice sheet are studied via ice core drilling focus from a science perspective.

SEISMOLOGY

Seismometers at the South Pole measure and record energy created by seismic events elsewhere on earth. The primary science facility associated with seismology is the South Pole Remote Earth Science and Seismological Observatory (SPRESSO), which is in the Quiet Sector and can detect vibrations up to four times quieter than other seismic observatories on the earth.

MEDICAL RESEARCH

Social behavior, human physiology, psychology, and medical illnesses related to isolated settings, high altitude, and sleep pattern disruption are periodically performed at SPS because of the uniquely isolated environment.

South Pole Station Aerial. Source: NSF, Undated.

Existing Conditions

EXISTING SOUTH POLE STATION

To establish a baseline for conditions at the SPS, this section describes the existing conditions within each of the management zones. Figure 5.1 shows the existing Site Plan and identifies the airfield, restricted areas, and primary buildings. Each ASMA Sector contains either science specific facilities or operational facilities and infrastructure. A summary of the existing conditions for each Sector and the primary components in the Sector are described below.

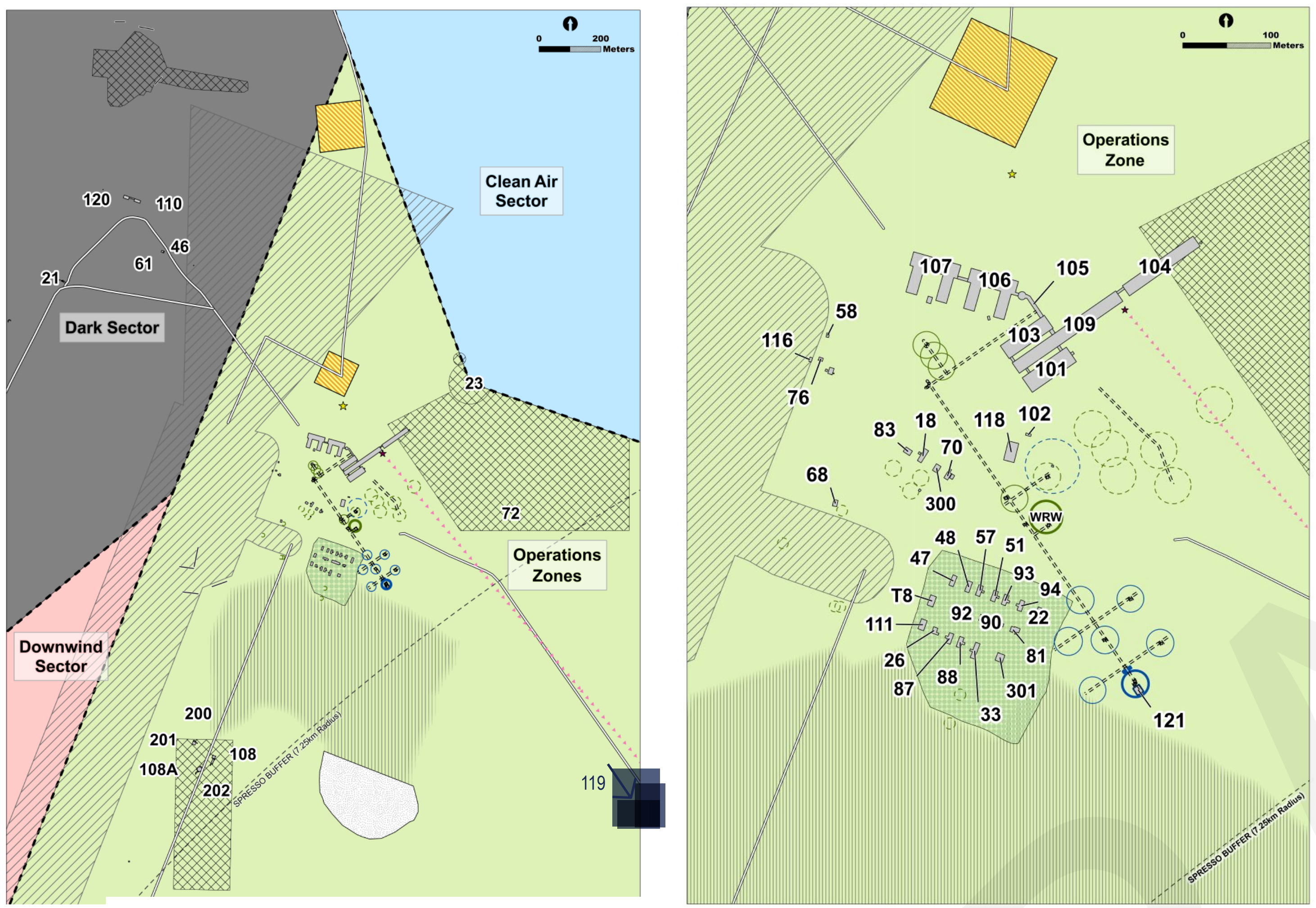


Figure 5.1 Existing Conditions

Legend

			ASMA Zone	ASMA Sector
Ceremonial South Pole	ASMA Sector Edge	NGO Area	Restricted	Downwind Sector
Geographic South Pole	SPRESSO Buffer 7.25km	Snow Storage	Operations Zone	Clean Air Sector
South Pole Trajectory	Structure	Berm Area		Dark Sector
Route	Airfield			Quiet Sector
Tunnel	Summer Camp			

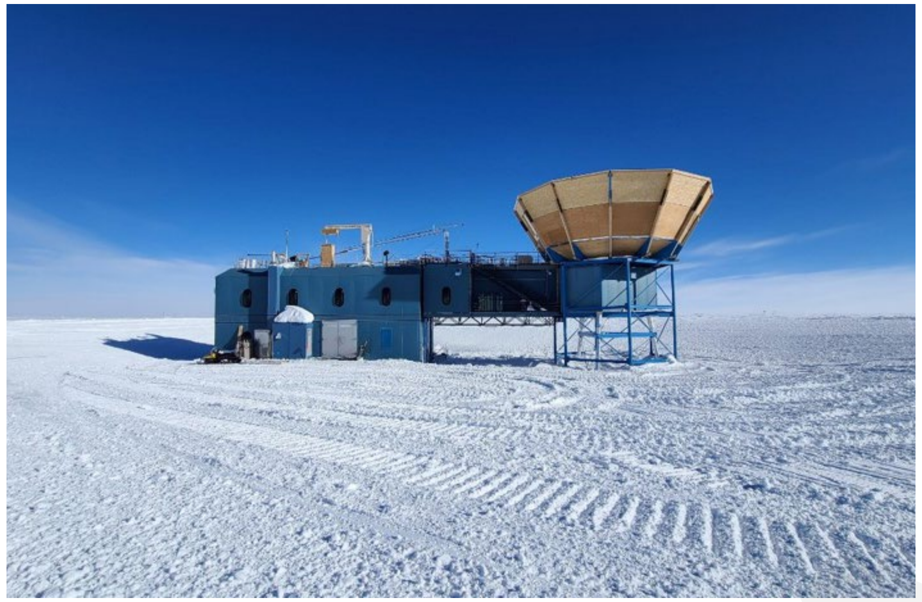
List of Primary Buildings

#*	BUILDING NAME	INTENDED USE	CURRENT USE
18	Storage Tent	Do Not Freeze Storage	Do Not Freeze Storage
22	Summer Camp Hazardous Waste	Temp. Hazardous Materials Storage	Storage
21	IceCube Laboratory	Science	Science
23	Atmospheric Research Observatory (ARO)	Science	Science
26	Summer Camp Smoking Lounge	“Temporary (Temp.) Housing Support	Storage
33	Summer Camp Berthing Tent J-9	Temp. Housing Support	Storage
47	Summer Camp Hypertat No.1	Temp. Support	Storage
46	Martin A. Pomerantz Observatory (MAPO)	Science	Science
48	Summer Camp Hypertat No. 2	Temp. Support	Storage

#*	BUILDING NAME	INTENDED USE	CURRENT USE
51	Summer Camp Hypertat No.3	Temp. Support	Surge Housing
57	Summer Camp Hypertat No.4	Temp. Support	Surge Housing
58	Passenger Terminal	Transportation	Transportation
61	Dark Sector Electrical Substation	Utility	Utility
68	Summer Camp Electrical Substation	Utility	Utility
70	Hazardous Materials Van	Hazardous Materials Storage	Hazardous Materials Storage
72	SuperDARN (Dual Auroral Radar Network)	Science	Science
81	Summer Camp Climbing Wall/Gym	Temp. Recreation	Recreation
83	Cargo Facility	Storage	Storage
87	Summer Camp Berthing Tent J-11	Temp.Housing Support	Storage
88	Summer Camp Berthing Tent J-10	Temp. Housing Support	Storage
90	Summer Camp Restroom	Temp. Housing Support	Decommissioned
92	Summer Camp Carpentry Shop	Temp. Logistics & Operations	Logistics & Operations
93	Summer Camp Berthing Tent J-12	Temp. Housing Support	Storage
94	Summer Camp Berthing Tent J-13	Temp. Housing Support	Storage
101	Garage Shops and Arch	Mixed Use	Mixed Use
102	Vehicle Fueling Module Mobile	Fuel	Fuel
103	Power Plant Arch	Utility	Utility
104	Fuel Pumphouse and Arch	Utility	Utility
105	Vertical Tower	Passenger Elevator	Cargo Elevator
106	Elevated Station Pod A	Mixed Use	Mixed Use
107	Elevated Station Pod B	Mixed Use & Emergency Pod	Mixed Use & Emergency Pod
108	RF Facility	Comms	Comms
108A	Radome - SPMGT	Comms	Comms
108C	South Pole TDRS Relay (SPTR)	Comms	Comms
109	Logistics Cargo Facility and Arch	Logistics & Operations	Storage
110	Dark Sector Laboratory	Science	Science
116	Aircraft Fuel Module	Fuel	Fuel
118	Cryogen Facility	Science	Science & Aviation Support
119	SPRESSO	Science	Science
120	10 Meter Telescope	Science	Science
121	Rodwell No.3 (Water Supply)	Utility	Utility
201	Radome - SPTR	Comms	Comms
300	Beverage Barn (Do Not Freeze)	Do Not Freeze Storage	Do Not Freeze Storage
301	Solar Garage	Temp. Transportation	Storage
POD	Rodwell No.2 Building	Temp. Utility	Decommissioned
T8	Summer Camp Electrical Warehouse	Utility	Storage
R1	Rodwell No.1 Building	Utility	Decommissioned
R2	Rodwell No.2 (Wastewater)	Utility	Utility
WRW	Waste Rodwell	Utility	Utility

SECTOR AND ZONE CONDITIONS

NSF maintains existing science facilities to continue support of the research hosted at SPS. Known structural deficiencies of buried vaults, the snow burial of five remote scientific structures, and the stretching of critical utility cabling between core infrastructure and existing scientific facilities due to the movement of the ice are current risks to research at SPS.



MAPO. Source: NSF, Gabe Nerf, 2021.

Scientific activities in the SP area are primarily housed in blue-colored, remote Science Research Facilities, which provide laboratory and shelter space for researchers in the Operations Zone and the Dark and Clean Air Sectors. The first Science Research Facility constructed was used as a dormitory and was later relocated for its current use as a Science Facility. The insulated, metal-panel-clad buildings were assembled from expanded polystyrene panels and placed on steel-constructed elevated substructures. The Science Research Facilities were originally designed to have skids so they could be dragged to new locations to stay above the ice, but the skid system was never completed. Instead, these structures were expected to be lifted at regular intervals to maintain their positions above the ice, but these lifts have not occurred.

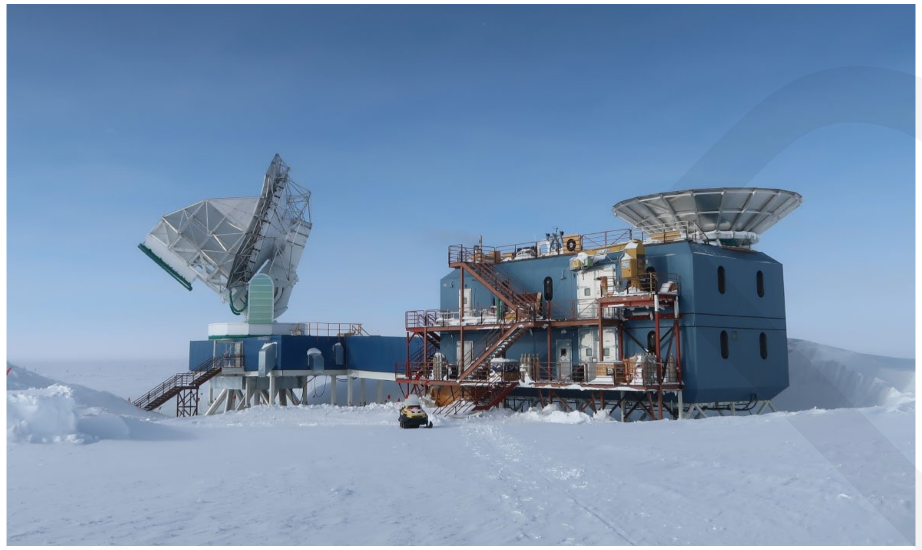
The Science Research Facilities include the Martin A. Pomerantz Observatory (MAPO, built in 1994), IceCube Laboratory (ICL, built in 1993 as a dormitory and repurposed and relocated in 2004), and Dark Sector Laboratory/South Pole Telescope (DSL/SPT, built in 2005 and 2006, respectively) in the Dark Sector; the Super Dual Auroral Radar Network (SuperDARN, placed in its location in 2010) and the modular cryogen building (built in 2005, then relocated and remodeled in 2015) in the Operations Zone; the Atmospheric Research Observatory (ARO, built in 1996) in the Clean Air sector, and the SPRESSO (built in 2003) in the Quiet Sector

DARK AND CLEAN AIR SECTOR

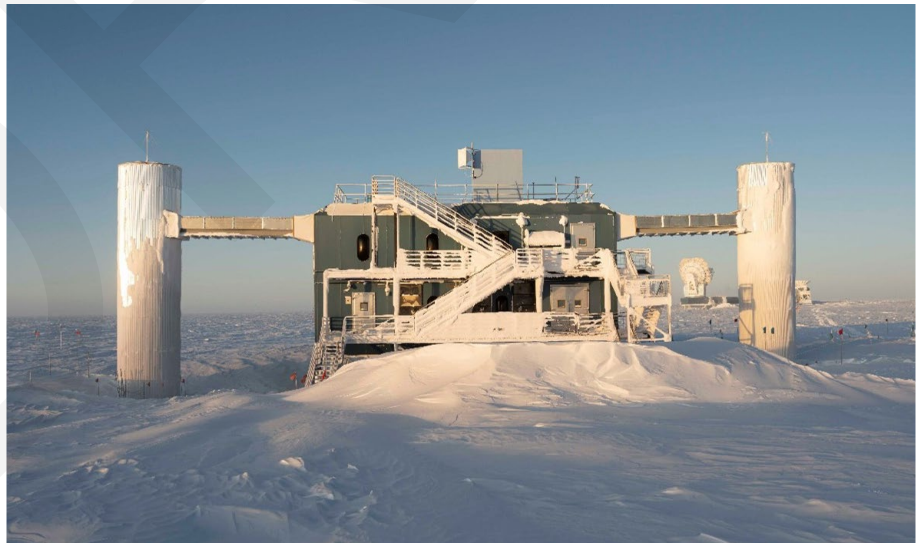
The structures within the Dark and Clean Air Sectors are in extreme need of lifting or relocation due to ice accumulation and burial in snowdrifts. MAPO currently has the deepest level of burial. The immediate concern of the MAPO burial is the potential loss of egress of the first story doors, difficulty servicing with fuel and cargo, and increased maintenance costs of snow removal. In the near future, there is also a high potential of structural damage due to the snow loading on the roof. ARO is also substantially buried and at high risk for similar issues as MAPO, but it is currently being planned for a lift in an upcoming season. Based on current snow levels, DSL/SPT would be the next in line for lifting after MAPO and ARO, and they would be followed by ICL.

QUIET SECTOR

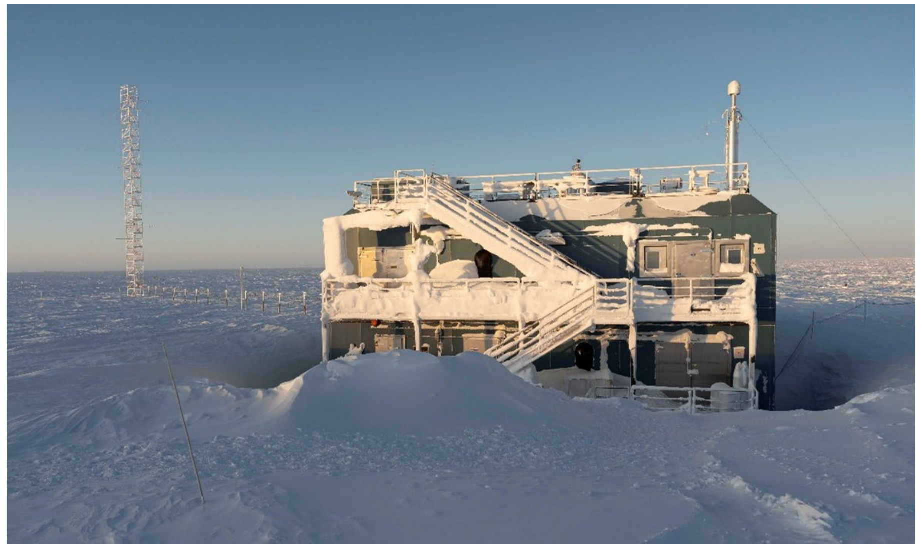
In the Quiet Sector, SPRESSO sustains large forces from the ice sheet due to its depth 20 feet beneath the surface. The structure was only designed for 15 years of use and is now 20 years old. The SPRESSO vault is encased in a crush wall exterior frame. SPRESSO is approximately 5.0 miles (8 kilometers [km]) from the Elevated Station, and its associated utility cabling now strains under the pressure and differential movement of the ice sheet, which moves the facility farther from the station each year causing additional cabling strain. Fiber-optic cabling and other utilities need to be comprehensively evaluated for replacement, as the annual movement of the ice sheet is stretching the cabling beyond its specified limit. As the current structure exists only to meet the needs of one specific research project, any future modifications or rebuilds of the structure is dependent on the continuation and infrastructure needs of that project. The remaining lifespan of the structure has not been confirmed, and a future plan for the research occurring in the SPRESSO structure is not yet in place.



DLS. Source: NSF, Troftgruben, Undated.



ICL. Source: NSF, 2023.



ARO. Source: NSF, 2023.

OPERATIONS ZONE

The Operations Zone of the South Pole houses all primary support structures (the Elevated Station, the arches, and the primary utility infrastructure). All permanent facilities at SPS were constructed by USAP. For a multitude of reasons, many auxiliary structures exist outside of the main Elevated Station structure and the support arches. Many of these structures, such as the “Summer Camp” buildings, were intended to be temporary and removed from the station following the completion of the Elevated Station construction. As indicated by name, these structures were only intended for seasonal summer use. However, each structure has been repurposed over time to serve needs that the Elevated Station is unable to accommodate, such as adequate warehousing, surge housing space, and field science staging.

ELEVATED STATION

The Elevated Station was designed as a liftable megaplex comprised of two pods (Station Pod A / Building (Bldg.) No. 106, and Pod B / Bldg. No. 107) containing primary lodging, dining services, recreation and social spaces, a hydroponic greenhouse, limited warehousing, and emergency services for approximately 150 science and support personnel in the austral summer and approximately 50 science and support personnel in the austral winter. The Elevated Station is connected to a network of arches that contain support infrastructure and warehousing for station operations via a vertical tower / Bldg. 105. The vertical tower holds all the utility connections between the Elevated Station and the arches. In the event of a critical power failure in the winter, Pod B can be sealed off from the rest of the structure until evacuation is possible. Pod B contains an emergency power generator, lodging, dining, and service spaces to support a winter population until rescue.

Elevated Station Entrance. Source: NSF, 2023

SOUTH POLE SOUTH POLE POPULATION: BY THE NUMBERS

The SPS population falls into two distinct categories: support staff (personnel responsible for station logistics, safety, and operation) and science staff (all scientific research team staff whose presence is associated with specific science initiatives).

ELEVATED STATION BASIS OF DESIGN (BOD):

- Population: 150 maximum and 0 surge
- Population Ratio: 1-1 support staff to science staff
- Support Services: All sized for 150 people maximum.

ELEVATED STATION ACTUAL PERFORMANCE:

- Baseline summer population: 150 permanent and 18 surge.
- Average summer population (past 5 years, excluding FY21 COVID response): 128
- Median summer population (past 5 years, excluding FY21 COVID response): 147
- Average summer population ratio: 2-1 support staff to science staff
- Average winter population: 42
- Average winter population ratio: 4-1 support staff to science staff

CHANGES IMPACTING THE 1-1 BOD RATIO:

Assumptions made within the BOD for the Elevated Station were based on the function of the previous dome station and existing technology and regulations available in the 1990s. Since the 1990s design phase of the Elevated Station, significant advancements in technological and scientific research capabilities have occurred, creating a higher demand for data, energy, and field research staging at SPS. Large, long-standing science projects, such as IceCube and SPT, did not exist before the design of the Elevated Station, and their associated staffing, power, and ifnormation technology (IT) support needs were not anticipated. As a result, higher levels of support services at the station are required, including, but not limited to, IT and power generation technicians, fuel and cargo staff, and dining and emergency service personnel. Regulations and contractual requirements have also changed during this time, including the requirement for additional on-site Aircraft Rescue Fire Fighting (ARFF) and waste management personnel. Due to the evolution of support requirements, the ratio of support staff to science personnel has never aligned with the BOD 1-1 ratio following completion of the Elevated Station in 2008.

STRUCTURAL DESIGN

The current Elevated Station was designed to provide clearance beneath the structure to reduce the rate of annual wind-driven snow drifting and accumulation. The 65,000 square foot structure was built on a network of columns as two connected pods (A and B) and designed to be lifted twice during its lifetime to prevent burial beneath the ice and extend the structure’s lifespan. Each raise is designed to lift the station 13 feet (approximately one story). However, the structure has not been lifted since initial construction was completed in 2008. A survey is completed every 1-2 years to assess the rate of settlement between the 32 columns supporting the station, and the structure is incrementally levelled and shimmed based on the movements recorded. The ability to shim the facility is nearing capacity in some areas and a major building lift event must be completed in the future to keep it above the snow surface.

All structures in the SP area rely on the previously constructed fuel, power plant, logistics, and garage shop arches for primary power generation and critical station support services. All surface-built arches containing these critical services are now completely buried in the ice, complicating structural repairs to the buildings within them and increasing maintenance requirements. Although the engineering design for the Elevated Station included proposed plans to lift one pod at a time during lift events, a complete analysis of BOD lift process and the project plan is needed before the proposed lift can be confirmed as feasible or practical. The study of the associated project demands is also necessary to determine several key impacts on station activities and amenities, including the impact on connections to utilities in the arch structures, and if the full station can be safely occupied during the lift process.

ARCHES

Since 1974, corrugated metal arches at SPS have provided a protective covering from snowdrift and wind for the buildings under the arch structures. Over time, arches are subject to deformation as snow accumulates and they become buried. Ice-floor surfaces are subject to gradual upward deflection (or “doming”), arch footings settle as snow load exerts more downward pressure, arch ceilings press downward and arch sidewalls begin to deform by crumpling near the footings. Arch floors are also subject to the differential movement of the ice sheet. These foundational settlements and movements result in the gradual elimination of clearance space between the arch ceiling and the internal building roofs. Buildings within the arches were originally constructed with approximately three feet of clearance between the arch ceiling and the interior building roofs. Arches were constructed with three feet of clearance between the arch underside and the building exterior corners. Arches are subject to gradual crushing due to the enormous weight of ice accumulation, and the clearance space will decrease to the point where Arches press on building structures. Arches last for decades when installed on the ice surface, then slowly begin to fail as they are buried in the ice. The fuel and logistics arches were originally built in 1974 as supporting structures for the dome station and are now nearly 50 years old, which is beyond the service life precedent for any arch on moving ice, in either the Arctic or Antarctic. These arches were retained from the previous station due to their serviceable condition at the time of the Elevated Station construction. However, they are now at the end of their service life and need replacement.

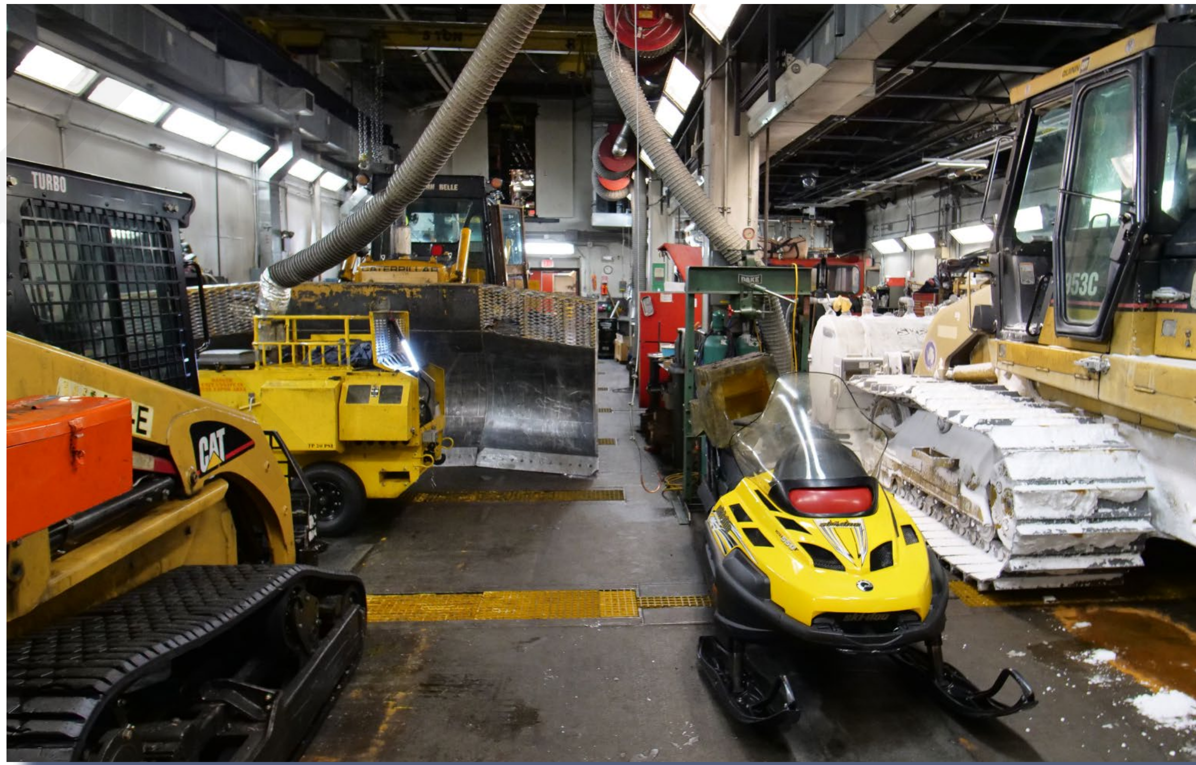
When the garage shop (also known as the Vehicle Maintenance Facility, or “VMF”) and power plant arches were built along the sides of the existing fuel and logistics arches in 1998 and 1999, respectively, their foundation planes were excavated to match that of the existing arches. This pre-burial of the newer arches has significantly reduced their lifespans compared to the original fuel and logistics arches.

Excavated Covered Arch Entries. Source: NSF, 2023.

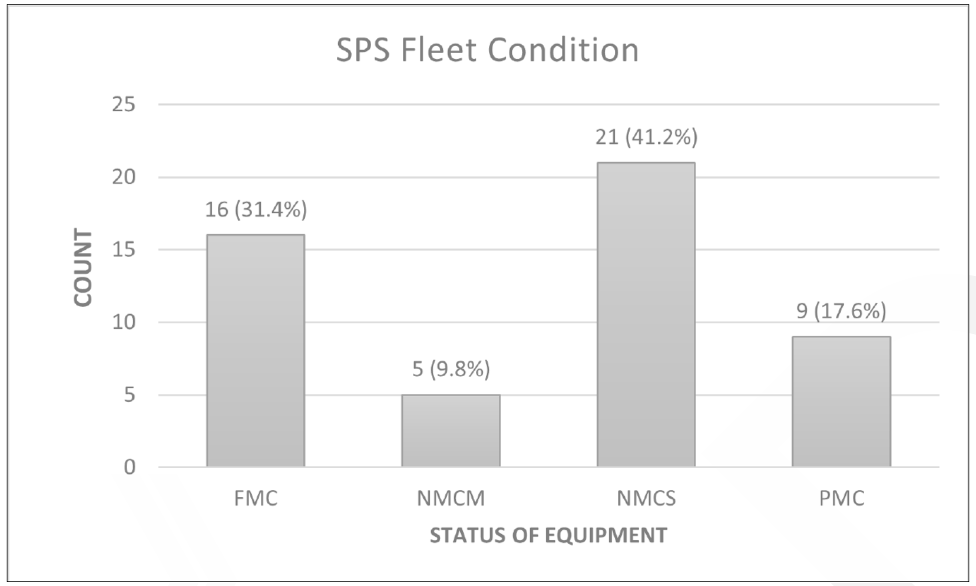
GARAGE AND SHOPS / BLDG. NO. 101

The garage shop arch was built in 1999 and is the arch most immediately at risk for contact between the arch ceiling and the buildings inside. The garage shop arch houses the VMF, which services vehicles and heavy equipment for SPS and contains a small facilities maintenance workshop. The VMF now services more fleet vehicles than it was designed to accommodate. The need to keep large vehicles heated over the winter was not included in the low-bay and high-bay design of the arch or VMF, causing winter vehicle storage and maintenance activity constraints. The garage shop building is also significantly in need of leveling. However, due to the proximity of the arch ceiling to the building roof, raising, jacking, and shimming are no longer possible without arch ceiling contact. According to an engineering analysis completed in 2020 by DH Glabe & Associates, the VMF was projected to make contact with the arch ceiling as early as 2025, based on the current average linear encroachment rate of approximately 1.3 inches a year. The original three-foot “crush zone” space has been reduced to only six inches. An interim mitigation effort to remove a corner of the VMF building and relocate roof-based heating, ventilation and air conditioning (HVAC) systems is currently underway to prevent imminent building failure. However, this is only a temporary solution and the VMF structure and contents must be wholly replaced to maintain vehicle and facilities maintenance capabilities at SPS.

The SPS relies on a fleet of vehicles and equipment. The following graph chart the condition of all inventoried fleet vehicles as of December 2023. Vehicles and equipment need to be maintained and winterized. Currently there is not enough interior heated space to winterize all the equipment. One constraint on operations is that several items of equipment have reached their life expectancy and need to be replace. The graph shows that 65% of the fleet is beyond its service life.



WINTER VEHICLE STORAGE. More vehicles and a greater variety of vehicles are stored in the garage shop over the winter than the original station design had anticipated. Source: NSF, Josiah Horneman, 2021.



Fleet equipment conditions as of February 2024.

SPS Fleet Condition Key

FMC	Fully Mission Capable
NMCM	Not Mission Capable (McMurdo)
NMCS	Not Mission Capable (SPS)
PMC	Partially Mission Capable

Winterized Pisten Bully. Source: NSF, 2023.

Snowmobile Spool Storage. Source: NSF, 2023.

POWER PLANT ARCH / BLDG. NO. 103

The power plant arch, built in 1998, contains the primary power generators, waste heat recovery equipment, electrical switchgear, and associated power and hot water distribution lines. Snow is currently removed annually with a snow blower to maintain a snow overburden no greater than five feet. This approach will continue to extend the arch's lifespan for a limited time, as the natural grade is rising at roughly eight inches per year. The current placement of exhaust stacks creates a safety risk, as escaping heat creates wells (or deep voids) in the snow. Infrastructure in the power plant arch is projected to make contact with the arch ceiling in less than 10 years. The power plant arch and associated infrastructure must be replaced in advance of this structural failure to prevent critical loss of power and heat that would impact all buildings serviced by the power plant, including the Elevated Station itself. The reciprocating internal combustion engine (RICE) generators (originally installed in 1999) have been recently overhauled and will continue functioning dependably beyond the life of the arch that contains them. It is currently estimated that the engines themselves are approximately halfway through their service life assuming continued maintenance in accordance with the manufacturer's requirements.

FUEL ARCH / BLDG. NO.104

The fuel arch, built in 1974, is one of the oldest arches at SPS. The tank infrastructure within the arch was refit in 1999, although the original fuel arch remains without modification since its original 1974 construction for the dome station. The arch has traveled 1640.42 feet (500 meters) horizontally with the movement of the ice cap since its construction and is now completely buried. The fuel arch contains 45 fuel-storage tanks, secondary tank containment, piping, and primary pumping infrastructure. The snow floor currently exhibits significant doming due to the heavy ice load and associated pressures along the wall footings, as well as 50 years of differential movement. These movements negatively affect the alignment and fixed-point connections of the tanks, structures, and piping systems comprising the SPS fuel delivery system. Tank leveling and shoring and pipe system adjustments or replacements are typically performed as annual maintenance efforts. The remaining leveling and adjustment capacity of the system components and remaining fuel delivery system lifespan is currently unknown. However, fuel tank safety relief valves are estimated to make contact with the arch ceiling in less than 10 years. Safety railings on top of fuel storage tanks are also a contact risk, and the tank maintenance access area above the tanks is quickly diminishing. The fuel arch and associated infrastructure must be replaced in advance of this structural failure to prevent critical power failure at the station.

LOGISTICS CARGO BUILDING / BLDG. NO. 109

Like the fuel arch, the logistics arch was built in 1974, has provided extended effective service, and is nearing its end of life.

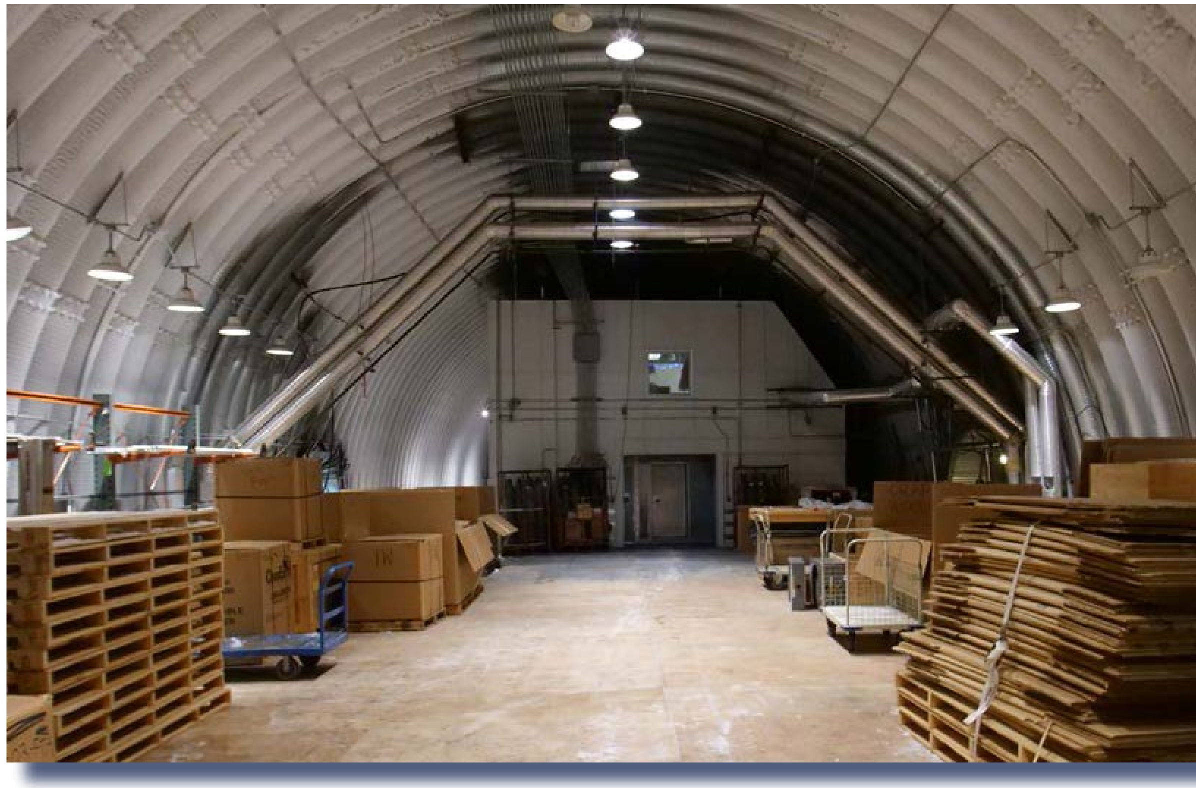
The logistics arch contains a single heated warehouse/logistics building and open cold storage areas with vertical pallet racks for bulk box storage on a structural floor. The warehouse was inadequately sized to house the entire stock of supplies and materials now needed to maintain the technologies and infrastructure of the Elevated Station and Science Research Facilities. As a result, more than half of the station's supplies are stored outside on snow berms and across a slew of disparate auxiliary structures in the immediate station area.

A vertical tower containing a service elevator connects the Elevated Station to the arch system and warehouse via an under-snow tunnel. The existing elevator fails to serve as a cargo movement device because it is improperly sized to handle the standard cargo packaging delivered to the station. It is also unable to move people due to the inability to annually obtain recertification to meet occupancy code standards.

The plywood floor of the cold storage area rests on a floating steel frame that is subject to the doming of the ice surface beneath it. In 2023, the centerline of the floor was nearly ten inches higher than the outer edges. The smooth plywood finish and the slightly uneven slope of the floor has created a slip risk for personnel and forklift operation. The shelving racks also begin to tilt as the floor buckles.

The buildings in the logistics arch are projected to make contact with the arch ceiling in less than 10 years, as the original three-foot "crush zone" space has been reduced to approximately 18 inches. The infrastructure inside the logistics arch must be replaced in advance of structural failure or floor buckling.

POWER PLANT GENERATORS. The power plant arch connects to the Elevated Station tower and to the logistics arch via interior arch system corridors. Source: NSF, Josiah Horneman, 2021.



WAREHOUSING IN THE LOGISTICS ARCH. The logistics arch and heated warehouse building have a structural steel and plywood floor to allow the forklift use and pallet storage; the floor is beginning to dome. Source: NSF, Josiah Horneman, 2021.

SNOW BERM STORAGE

Most of the station's supplies that are not considered "Do Not Freeze" (DNF) are stored in a complex of snow berms adjacent to the airfield and cargo staging areas due to the lack of adequate indoor storage space. This manner of storage significantly complicates inventory efforts due to the level of manual labor required to confirm inventory across all the disparate locations. Storage in berms and has also resulted in lower inventory condition accuracy; new projects are unable to rely on the materials stored outside the logistics arch to be in suitable condition for project and construction use. Outdoor snow berm storage is also particularly inefficient and costly because mission support personnel must dig for buried materials in a given area to confirm the status of the inventory items, which introduces the risk of damage to those items during the excavation.

As of 2024, spare and remnant construction materials from the Elevated Station, IceCube, and SPT construction projects from the early 2000s remains buried in the snow berms. The removal of these materials is a yearly summer effort. Progress has been incremental due to the volume of the materials and the labor hours associated with their retrieval from the berms. As of 2023, the projected timeline for completing removal of the material in the berms at the current rate was at least seven years.

The berms have limited lifespan and must be rebuilt every four years to prevent complete burial of berm under snowdrift. Maintaining the sprawling snow berm complex is an annual, inefficient summer task, as the berms are reburied every winter. Snowdrift snow is relocated as berms and structures are unburied each summer and moved to a snow disposal area located grid-south of the berms.

SNOW STORAGE. Snow pile scale - flat edge is approximately 4 feet tall. Source: NSF, 2023.

AUXILIARY STRUCTURES

More than 20 auxiliary buildings, tents, and huts are scattered outside the Elevated Station, providing storage and staging areas for uses that have insufficient allocated space within the Elevated Station and arches. These uses include, but are not limited to, storing cargo, DNF supplies, waste, fuel, summer trade shops, snowmobile parking, and Dark Sector and field science staging.

"Summer Camp," which was originally created to support the construction of the Elevated Station and was intended to be removed upon station completion, has remained in its location since construction ended in 2008. Most of the structures in the Summer Camp area are now used for storage. These structures were generally built on-site and not equipped with skis, which reduces the ability to move them to new locations without structural damage. Two of the four "Hypertats" originally created for worker housing were converted into storage structures and are now being renovated to restore their use for worker housing. A single Hypertats can provide nine (9) beds. Two Hypertats are also equipped with solar panels that produce enough energy to support themselves and add a small amount of energy to the power grid.

Hypertat bedspace is not accounted for in annual bedspace planning, as these beds exist to provide necessary redundancy during weather or other event-related flight groundings during periods of peak population.

Although many of the auxiliary structures outside the Elevated Station have experienced structural decay and serviceability issues, the Hypertats and the cryogen modular building have provided an acceptable level of continued service.

AUXILIARY STRUCTURES. The area surrounding the Elevated Station is occupied by a variety of auxiliary structures serving a wide variety of storage and operational needs. Source: NSF, Ian McEwan, 2016.

INFRASTRUCTURE

ENERGY

POWER GENERATION

The SPS power plant is housed in an arch that is now below the surface of the snow. Fuel to support station operations is located in the nearby sub-surface fuel arch, and an emergency power plant is located in Pod B of the Elevated Station to provide emergency power in the event of a power failure.

Waste oil produced by station activities is currently filtered and used as fuel for power production. Expanding the use of waste for energy and heating is a desirable direction for the future energy production portfolio at SPS. Existing waste-to-energy and micro gasification systems, such as those used by U.S. Navy ships and commercial cruise liners could drastically reduce the amount of waste that must be removed from the continent via existing waste retrograde procedures or deposited into the sewer outfalls (decommissioned Rodriguez Well [Rodwell]), where it will remain beneath the ice surface for thousands of years. A Rodwell is a well drilled into the ice sheet for water and used as an outfall for human waste when water wells are decommissioned.

The two Hypertat structures currently used for surge housing have solar panels. Although the South Pole is subject to 24-hours of continuous sunlight in the austral summer, the angle of the sun is not ideal for the solar technology currently present at SPS. Production levels are low, though the panels do provide energy to the structures they rest upon and contribute a small amount of additional energy into the electrical grid. Expanding solar power production at SPS may be feasible, but it requires additional research on currently available technologies.

Wind energy also has a small presence at SPS, at one point, one wind turbine generator was positioned near the Rodwell. That turbine no longer works, but was an example of one application for wind energy. There is no shortage of wind at the South Pole, although the speeds are typically less than ideal for extended periods. Storm winds can exceed the turbine limitations. Wind gusts can over-torque the blades, which triggers a mechanism that prevents the blades from spinning. The static blades are then subject to icing that often requires manual removal before energy production can resume. Expanding wind power production at SPS may be feasible with current available technologies, but additional research is needed before these technologies can be incorporated.

FUEL TRANSPORT AND STORAGE

Approximately 300,000 gallons of fuel is transported to SPS by three overland traverses each year. The remaining annual fuel (approximately 150,000 gallons) is delivered by LC-130 airframe. While fuel transport capacity is a factor to the amount of existing fuel storage at SPS, it is not the only limiting factor. Fuel capacity in the arch is 405,000 gallons of fuel in tanks, with a safe fill of 90%. The actual amount of volume available is less, as the pick-up lines do not extend to the bottom of the tanks and thus cannot utilize that fuel. Additionally, 68,000 gallons of emergency reserve fuel is kept in surface tanks separately from the Fuel Arch.

The station must be able to sustain itself without fuel resupply between February 15 and November 15 (roughly 274 days). Approximately 425,000 gallons of fuel must be on station at the close of summer operations to sustain winter operations and maintain a contingency buffer for emergencies and for station reopening for the next summer. This amount is subject to change, based on summer and winter power consumption. Increases in power demand increase fuel consumption and thus the amount of fuel that must be delivered each summer. The price for combined air and overland delivered fuel varies year over year. The following list are estimated fuel cost in the coming years:

Projected Costs/gal for AN8 (LC, SPoT, powerplants):

- FY25: $22.51
- FY26: $22.96
- FY27: $23.42
- FY28: $23.89
- FY29: $24.37
- FY30: $24.85

Power Plant Generators. Source: NSF, Josiah Horneman, 2021 .

POWER PLANT CAPACITY AND INFRASTRUCTURE

The current power plant was designed for a maximum capacity of approximately one megawatt (MW). It consists of three CAT 3512B diesel fired RICE generators, each with an on-site prime power rating of 750 kilowatts (kW), and a CAT 3406C peaking unit with an on-site prime rating of 239 kW (all engines are de-rated due to high altitude). The normal power consumption target is no more than 680 kW for the 3512Bs. 600 kW is the "prime power," i.e., the maximum power accessible for an unlimited number of hours per year in the variable load setting (80% of the generator capacity). Prime power assumes an average load under 80% of prime capacity to maintain the lifespan of the system and the ability to operate at a higher level in an emergency. Power usage above prime power decreases generator efficiency. 680 kW is considered the high end of the range for acceptable continuous operation. If the power consumption reaches 712kW, the peaking unit activates to carry the additional load. Generally, only one 3512B runs at a time, except during transfer operations.

AVERAGE CURRENT POWER CONSUMPTION

Current power consumption ranges have been compliant with energy consumption targets, with an average of 600 kW from 2013-2019. As the prime power is 600 kW for each generator and running the peaking generator continuously is not necessary. If the peaking generator were needed the maximum additional capacity would be 30kW to 50kW.

Current SPS power consumption level is maintained at the optimal capacity of the existing power plant. Power consumption rates would be expected to rise with any facility expansions beyond the current footprint of the station and existing science facilities, which would exceed the optimal capacity of the current power plant. Gradual increases in fuel demands have also been recorded in recent years as aging infrastructure requires more maintenance to remain functional, and as the volume of snowdrift that must be relocated increases.

POWER PLANT EFFICIENCY

Average power plant fuel efficiency is approximately 14 kW-hour (hr.)/gallon (gal) (per data from June 2023). The current cost of energy at SPS, based on the current plant and fuel cost is $1.80/kW-hr.

(Cost ($/1kW-hr) = $25.45 ($/gal) /14 (kW-hr/gal) = $1.8/kW-hr

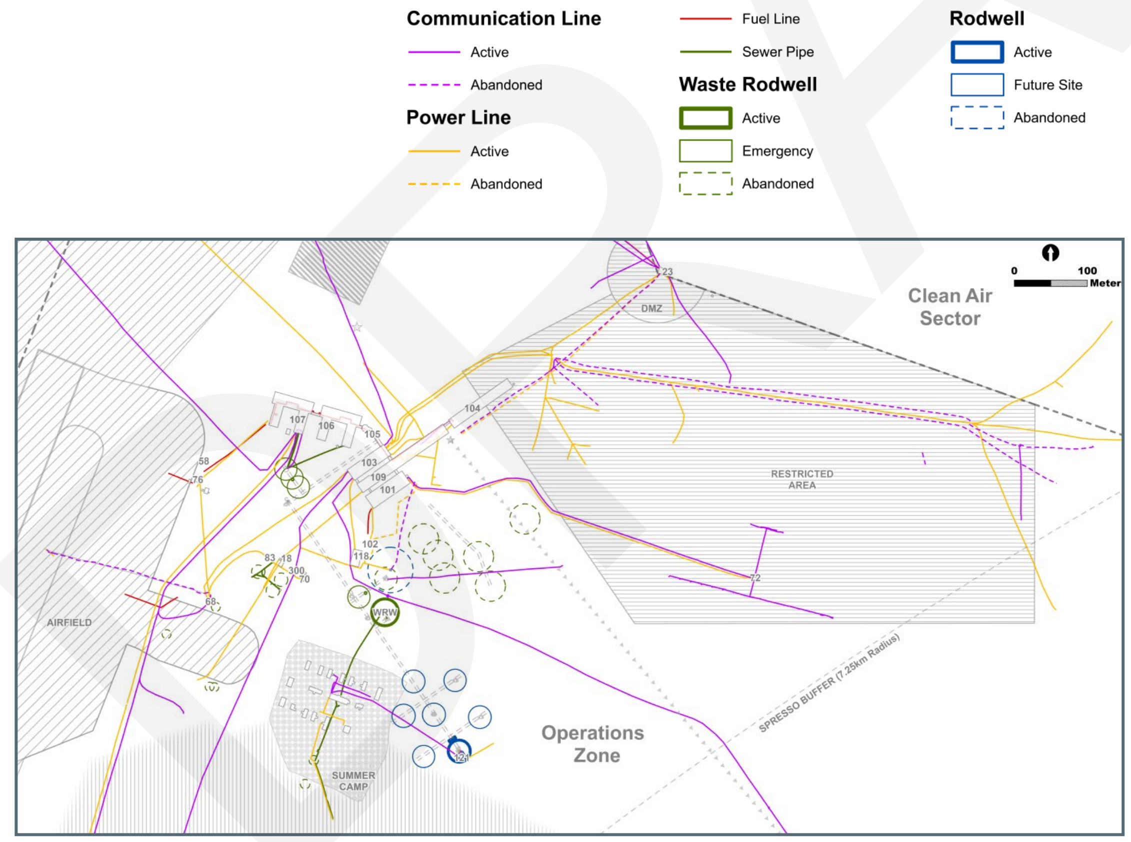
UTILITY CABLING

The subsurface utility cabling running throughout the SPS forms a sprawling network of cables that were placed from utility source to end on a project-to-project basis without a comprehensive utility plan or a detailed record of placement. As a result, many utility lines are difficult to locate, and the Operations Zone area immediately adjacent to the Elevated Station has become a crowded subsurface network. A substantial portion of the existing SPS immediate area also contains scattered subsurface vaults, decommissioned Rodwells, and antennas, further complicating future structural placements within the area.

Exact locations of utility lines are unknown in many areas, and locations are not surveyed annually. Buried utility cable locations shift within the ice sheet over time, complicating utility location efforts. Cabling repairs and location is typically accomplished via hot water trenching.

Of particular concern is the stretching that occurs throughout a cable line due to the annual, uneven, differential movement of the ice sheet. The power and data cables running to SPRESSO, for example, are currently stretched nearly to capacity in several areas. A coordinated trenching and cabling effort may be combined with the SPRESSO vault replacement, as the vault itself has also reached the end of its designed lifespan.
Critical cabling in the immediate station area also runs through abandoned building sites, buried vaults that get increasingly deeper, and structures that are approaching the end of their service lives due to structural strain or burial. The airfield beacon lights, for example, are currently fed via cabling through an abandoned building site.

Building 61 houses the electrical distribution module and primary cabling hub for the Dark Sector. The structure is becoming increasingly buried and in need of lifting or replacement to ensure uninterrupted power to Dark Sector science.



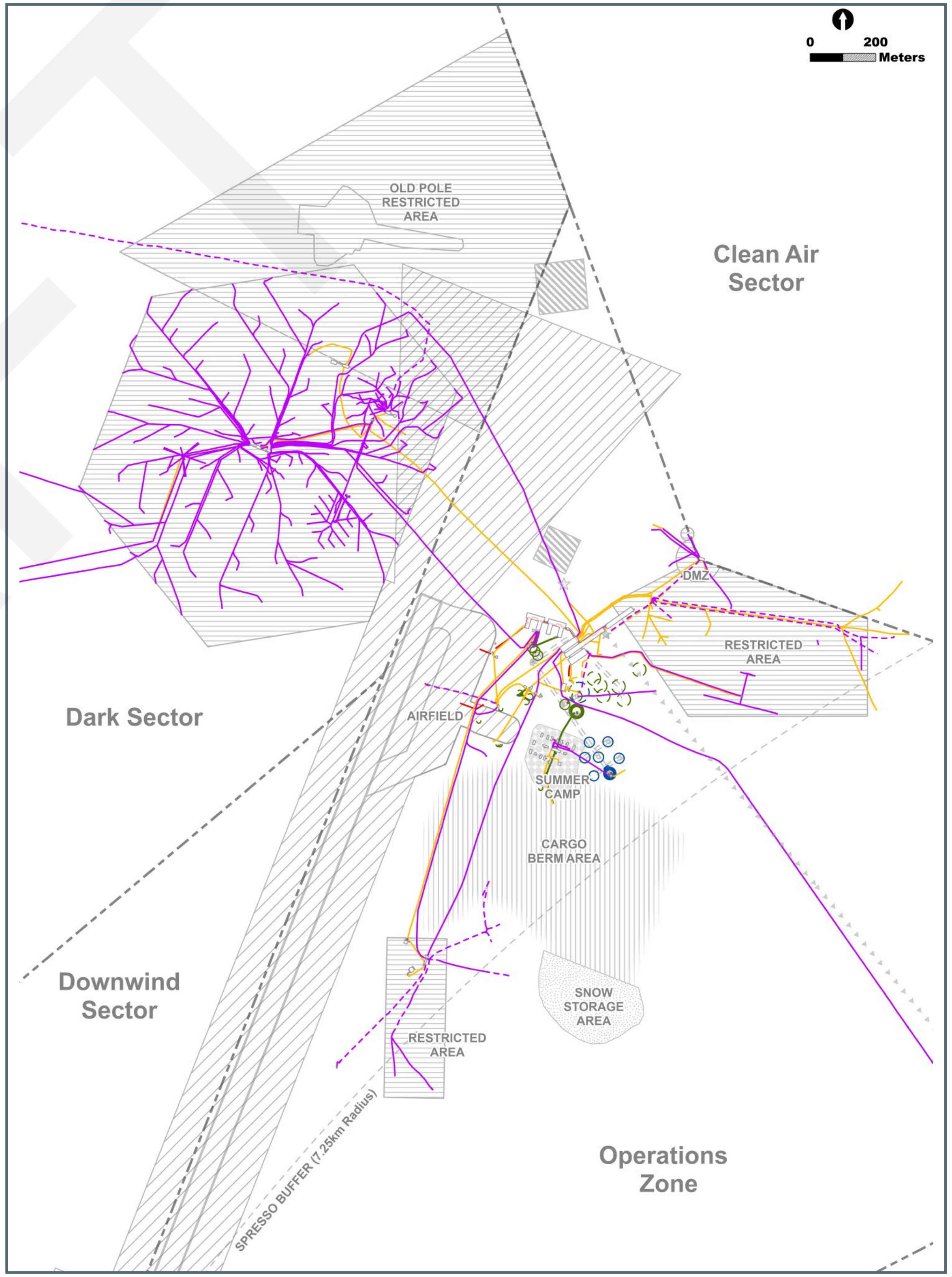


Figure 5.2 APPROXIMATE CABLING MAP. The station area has an overlapping network of cables running under the ice. In this graphic, yellow indicates power lines, blue indicates water lines, green indicates waste piping, purple indicates communications and data cabling. Source, NSF, Undated. Not to scale.

INFORMATION TECHNOLOGY (IT) & TELECOMMUNICATIONS

Communications and science demands are currently subject to the following data/IT bandwidth and restrictions at SPS:

- There are two available satellite constellations used by USAP for communication: the National Aeronautics and Space Administration (NASA) Tracking and Data Relay Satellite System (TDRS), and Defense Satellite Communications System (DSCS). DSCS is owned and operated by the U.S. military. The USAP does not currently have a written commitment for continued service from this satellite constellation, and its availability is subject to change at any time. TDRS is not expected to be available in the future.
- The two satellite constellations combined provide approximately 16 hours of coverage each day. Adding another DSCS satellite would allow almost 20 hours of satellite connectivity. DSCS is expected to be available to South Pole until the year 2043.
- The daily allowable science data load is 450 gigabytes within four hours dedicated to scientific data transfers. Business, personal, and aviation uses are allocated outside of the science data use.
- Wi-Fi is currently available in the Elevated Station. However, there are concerns that Wi-Fi could interfere with Dark Sector research.
- Emergency Medical Services relies on the Land Mobile Radio system, while aviation communicates with standard vehicle high frequency Air/Ground aeronautical communications, SPS via a Iridium Mobile Satellite System and very high frequency radio. The current very high frequency radio system for aircraft communications will need replacement.

The satellite constellation services employed by USAP may expand in future years, but new downlinks will be necessary off-continent. Multiple private entities are soon launching low-Earth and polar orbiting systems that may support improved communication availability, increased capacities, and better capabilities at SPS. However, SPS communications and data connectivity efforts are becoming less focused on available satellites and more focused on new communication and data technologies.

WASTE

Current solid waste management practices at SPS involve on-site packaging and shipping to McMurdo via traverse or LC-130 and then onward shipment to the continental U.S. via refrigerated vessel to Port Hueneme, California. This process is referred to as “waste retrograde.” Waste material removed through this process must remain refrigerated on site and during transit until it reaches its final destination to minimize mold and bacteria growth. Once the waste reaches the continental U.S., it is incinerated or otherwise disposed of by fee-based private companies and fee-based public systems that have contractual agreements with the USAP. The required infrastructure for moving refrigerated cargo and the number of transfers currently involved in the process restricts the speed and efficiency of waste removal from the station. Investment in a modernized process would alleviate multiple logistical challenges and reduce supply, transportation, and labor costs.

Human waste is handled via a sewer outfall system that repurposes decommissioned Rodwells. A Rodwell is a well drilled into the ice sheet. It’s original purpose is for water collection. When a water Rodwell is decommissioned it is repurposed to store human waste. When the sewage outfall reaches capacity, waste deposits are redirected to another decommissioned Rodwell and the timeline for its lifecycle begins again. The current sewer outfall has approximately 2.8 million gallons of capacity remaining and is expected to reach that capacity by 2027. A new waste Rodwell must be established before 2028 to enable a sewage management transition before overflow occurs. An intermediate sewer outfall is being constructed to collect human waste until water production can be transitioned to a new Rodwell and the decommissioned Rodwell can become the new waste outfall.

DSCS. USAP satellite infrastructure provides approximately 9.5 hours of communications coverage per day.
Source: NSF, Gabe Nerf, 2020.

WASTE RETROGRADE. Packaged retrograde materials are set outside over winter and staged along the SPoT route and airfield to be loaded onto the SPoT platform or an LC-130 in the austral summer.
Source: NSF, Austin Danicic, Undated.

WATER

Approximately 650,000 gallons of fresh water is provided to the station each year via a Rodwell and water treatment system. A well pump is lowered into the Rodwell and runs continuously. When the water well gets too deep (approximately 500 feet to water's surface), the Rodwell is decommissioned and water sourcing moves to a new Rodwell. A set of future Rodwell locations has already been planned in the immediate station area and organized in a honeycomb pattern adjacent to the ice tunnel system to minimize relocation impacts on the Elevated Station's water supply infrastructure. To maintain operation of the Rodwell, the pump must be pulled and the access hole re-bored annually.

The ice tunnel system has functioned well for a utilidor. Ongoing maintenance is required to keep the tunnels from closing in. Ice tunnels work well and can be utilized in the future as utility locations move and new buildings are added. Complete installation of a new Rodwell typically spans as many as six years, including component delivery and installation. Design generally requires pre-fabrication before shipment to Antarctica. Engineering and conceptual review require specialized expertise and the participation of subject matter experts in polar well construction. The next water Rodwell is expected to be ready for use between 2028 and 2030.

Back-up water supply is provided for the population via a portable, glycol-heated snow melter that is staged outside of the existing power plant arch. Snow must be manually loaded into the system and melted before being treated in the water treatment plant. The back-up snow melter is adequately sized for winter populations but would be under-sized for supporting summer season populations. The plans for the Elevated Station initially included a plan for a wastewater treatment plant to reduce demand on water supply and sewage outfall Rodwells, but the plant was removed from the project scope before construction.

SCIENCE STRUCTURES IN THE OPERATIONS ZONE

A variety of scientific research projects are also located within the Operations Zone, grid-east and grid-northeast of the Elevated Station. These projects, although long standing, create potential for conflict between operational activities and machine operation and scientific instrument sensitivity. However, proximity to the Elevated Station is also important for these projects due to their pedestrian winter servicing requirements.

The positioning of scientific research facilities and vaults in the Operations Zone has created the need for Restricted Zones in operational space, which limits the area within the Operations Zone where support operations may occur without conflicting with scientific measurement and communications tools. Although these science projects may change over the years, the vaults that may be left behind also create potential building hazards in the Operations Zone.

Ice Tunnel Utilidor. Source: NSF, 2023.

FIELD SCIENCE

Support services for field science is centered and currently supported by McMurdo Station, which allows continuity in mobilization and demobilization and a central location in which returned equipment can be prepared for reissuance. SPS was not originally designed to sure as a support hub for field science. Due to the absence of adequate supply storage space at SPS and the changing locations of scientific interest that may exclude SPS as a support hub, this has been the most efficient model for maximizing field support and Search and Rescue assets thus far. However, this model of field science deployment also currently requires shipping supplies for each project to and from SPS via LC-130 aircraft, South Pole Traverse (SPoT), or science traverse which creates logistical challenges when field equipment competes with other equipment and supplies for delivery space on the LC-130s, and traverses.

SPS currently operates as a staging base for field science expeditions to eastern Antarctica. Existing field science staging space is located in the Cryogen/Balloon Inflation Facility (BIF) building, B2 laboratory, and in a Jamesway hut in the old summer camp area. However, field science staging areas are not adequately sized to stage the volume of deep field science gear that moves through SPS. In the Elevated Station, there is no indoor space dedicated for field gear storage or for briefing field teams. Due to the short nature of planned stays, temporary lodging for transient field science teams is often provided in the Hypertat structures located in the Summer Camp area. However, not all field science teams depart from the station to field camps for the entirety of the summer, and there are frequent weather-related delays due to reliance on aircraft transportation. To account for these delays, bedspace occupancy periods must be reserved for field science visitors beyond the proposed official dates of each field science expedition. These teams compete for bed space with other SPS-based researchers and operational and infrastructure-project personnel.

A recent summer projects used polar equipped wheeled vehicles and proved out a concept of using the technology for future field teams based out of SPS.

FIELD CAMP PLANNING. Field camps vary in size, based on the scale of the research support requirements. Each camp must plan for limited supplies and transportation options.
Source: NSF, Howard Conway, Undated.

Emergency Services. Source: NSF, Undated.

EMERGENCY SERVICES

On-site emergency response capability consists of a medical clinic with two qualified medical staff, a gymnasium space for mass casualty and emergency response staging and treatment, and a brigade-based response to emergencies. Aircraft Rescue Fire Fighters (ARFF) are required per U.S. Air Force Aircraft Fire Protection for Exercises and Contingency Response Operations (Air Force Pamphlet 32-2004) for military LC-130 aircraft operations during the austral summer.

The SPS emergency services brigade that operates in the summer is staffed by the winter-over team. This provides year-round consistency for primary response to all manner of emergency situations, with the exception of Air Force aircraft under ARFF jurisdiction. The brigade responsibility turns over once each year in November, when the previous team departs the station at the end of the winter and is replaced by the next year’s group. The presence of the professional ARFF contingent during the short summer allows the new brigade to train and drill for readiness to cover station needs through the long austral winter.

Search and Rescue capability is managed from McMurdo Station to provide continuity and centralized command and control, and it is reliant on airlift availability (currently provided via LC-130, Basler, and Twin Otter). Primary emergency response resources for field or remote response are sent from McMurdo via airlift. SPS houses a limited cache of emergency equipment and supplies in the Elevated Station to be used for off-station emergency response. If future Search and Rescue responses are to be coordinated and staged out of SPS for near-field science, additional dedicated storage space and personnel will be necessary.

For significant events, emergencies are managed at a program level by the McMurdo Emergency Operations Center, which makes resource distribution decisions. Incident command of the SPS brigade remains local. Examples of large events include aircraft emergencies, Search and Rescue operations for field groups, aid to other nationality programs or private expeditions, humanitarian aid, international diplomacy, and medical evacuations.

Medical facilities at SPS are in the Elevated Station for on-station medical needs, but the location of emergency service equipment, supplies, and servicing areas does not provide ease of access. Medical supply storage, for example, is located on the lower level of the station, while the substantially undersized medical center is located on the upper level. Storage for emergency response team gear was also not included in the Elevated Station plans. The gymnasium provides adequate space for staging and response in the event of a mass-casualty or large-scale emergency response. However, none of the medical servicing areas are located for ease of access during patient transport.

The Elevated Station and facilities within arches primarily employ a water sprinkler fire suppression system. Auxiliary structures outside of the Elevated Station employ localized fire suppression systems that are meant to protect only specific high-value equipment. Arches are ambient or colder, so no fire suppression is provided under arches. The under arch Power Plant, and the Emergency Power Plant in the elevated have CO2 Suppression, and the under arch VMF is sprinklered. These systems are subject to annual maintenance and testing to ensure code compliance and reliability.

Emergency service personnel rely on the Land Mobile Radio system for communication of emergency events and needs, while aviation-related coordination relies on the existing Iridium and high frequency radio systems. The Iridium system currently relies on the short-text-message interface called InReach™, which is currently unable to communicate through the walls and windows of the Elevated Station. New technologies may resolve this issue, but there is an overall lack of variation in the existing systems to prevent multiple failures. All emergency communications systems require periodic upgrades, based on military requirements, equipment condition, obsolescence, and technological capabilities, and all systems are currently in need of system updates.

TRAVERSES

Overland traverse platforms are a well-established technology in Antarctica and are used by many other nationality programs with a permanent presence on the continent, such as Australia, France, and Russia. A South Pole Traverse (SPoT) platform was established between McMurdo and SPS in the mid-2000s to increase fuel and cargo delivery capacity and reduce reliance on LC-130 aircraft. The SPoT fleet delivers fuel and cargo to SPS and transports waste retrograde materials back to McMurdo to be shipped via vessel to the continental U.S. for disposal. After the first mission proved to be a successful alternative to LC-130 delivery of supplies, the number of SPoT missions per year was gradually increased to three (3) over the course of the austral summer. The result has been a significant reduction in LC-130 supply chain constraints related to restocking the station and a higher potential delivery capacity for fuel and cargo overall. Due to the short length of the austral summer, additional SPoT missions are not currently possible.

The heavy science traverse (HST) fleet, which generally supports large field projects out of McMurdo, has recently started several seasons of East Antarctic operations through SPS, including prestaging fuel and cargo. The HST has also proven to be an effective and efficient solution to delivering field supplies because it is not subject to the same restrictions and constraints as small aircraft in Antarctic weather and climate. The SPoT fleet has been used to support East Antarctic science from SPS in addition to its normal resupply mission. SPoT also has assisted HST with moving science cargo to and from various locations along the McMurdo - SPS route. In crevasse-free regions, this has allowed the HST to move forward in accordance with scientific research schedules without costly weather-related delays. Similarly, light science traverse systems could improve access to East Antarctica research sites from SPS.

Traverse Bladders. Source: NSF, 2023.

AGILE OVERLAND TRAVERSE. Small overland traverse vehicles have been used in Antarctica in the past and may be a cost and time saving alternative to field flights in crevasse-free areas. Source: NSF, Undated.

Due to aircraft and science activity restrictions caused by the COVID-19 pandemic, the SPoT and HST fleets were combined to deliver all fuel and cargo to SPS for the 2020-21 season. This was the first total resupply of the station by traverse platform, and it was highly successful. The efforts demonstrated both the feasibility and utility of traverse as a means of annually resupplying the station. It drastically reduced delivery costs, increased the efficiency of waste retrograde efforts, and reduced the population impact on SPS. Traverse platforms are preferable for population and bed space management at SPS, as the fleet includes integrated bed space for its operators and does not rely on external bed space at SPS.

Traverse platform efficiencies could also be bolstered by SPS cargo handling upgrades. Cargo slated for delivery by traverse or LC-130 must currently be palletized in Christchurch, New Zealand (if delivered to McMurdo by Ship or LC-130 under special circumstances) and/or McMurdo (if delivered to SPS by LC-130 or traverse) before shipment.

The existing SPoT fleet can deliver full 20- and 40-foot shipping containers, but there is no infrastructure available at SPS to unload or reload these containers onto the traverse platform. The lack of such infrastructure increases staging, packaging, and storage demands throughout the cargo supply chain. Adding such infrastructure to SPS could expedite cargo delivery timelines. The supply storage inherently provided by the containers during on-site inventory and sorting efforts would also help foster a sustained departure from the current snow-berm storage model, eliminating the demand for personnel devoted to digging out and relocating buried supplies.

According to the 2014 CRREL report Economic Analysis of the South Pole Traverse, "SPoT's net economic benefits of $2.0M/ year [using 2011 dollars] result from significantly lower delivery costs per pound compared with LC-130 airlift ($3.60/pound (lb.) versus $6.10/lb., respectively)." However, current projections estimate that expanded SPoT capabilities could further reduce the reliance on LC-130s for fuel delivery and significantly reduce long-term fuel delivery costs. The relative ease of platform scalability (an expanded fleet) supports the development of an expanded traverse platform.

STATION APPROACH. The traverse route curves around the skiway before heading grid-north to the Elevated Station.
Source: NSF, Mike Lucibella, 2023.

LOGISTICS AND TRANSPORTATION

The logistics of transporting personnel, fuel and cargo to the SP can be an arduous effort. Maintaining an efficient supply chain system is critical to the operations at the SP. Material commodities (Cargo) destined to the South Pole are delivered to the USAP cargo hub at Port Hueneme, California (CA). Once in the USAP Supply Chain materials are transshipped from Port Hueneme to Christchurch, New Zealand (NZ) via a variety of modes, including charter vessel, commercial vessel, and commercial air.

A chartered, U.S.- flag cargo vessel sails annually from Port Hueneme to New Zealand, then on to McMurdo Station, usually arriving the last week of January. The ship carries resupply items for McMurdo and South Pole and returns retrograde cargo and waste to the United States. To meet this timeline, cargo for this ship must be received in Port Hueneme by November. This vessel is the preferred mode of transport for delivering materials to McMurdo, as well as for ongoing transport to SPS. When possible, cargo should be planned to be positioned in Antarctica the season before scheduled field work. Vessel-delivered materials that are to traverse overland to South Pole must arrive on-continent the season before the traverse due to the late arrival of the vessel and the early departure of traverses relative to the vessel arrival. In other words, materials being delivered overland must be on the cargo ship two seasons before planned construction or by the fiscal year before the planned construction.

Cargo destined for vessel shipment to the South Pole must be received in Port Hueneme in November. In December the ship is loaded, then sails for Antarctica via New Zealand. The Ship arrives at McMurdo Station in late January or early February to be offloaded. Cargo destined for the South Pole can then be transferred to an LC-130 aircraft for same-season delivery to South Pole or staged for aircraft or traverse delivery to the station the following austral summer. Staging prior to delivery to the South Pole must occur at McMurdo. The ship's arrival at McMurdo Station occurs near the end of the austral summer season thus only prioritized cargo can be shipped on to South Pole in the same year due to a short remaining window for the LC-130 to reach the South Pole. The end of the LC-130 season is driven by temperatures at South Pole and closes in mid-February. The next flights will not occur until early November when the temperatures return to operational temperatures. The first traverse arrives in late November after a 30-day trip from McMurdo.

Cargo to and from SPS is transported only during the summer by LC-130s, Basler aircraft and South Pole Traverses from McMurdo Station. These aircraft operate from late October through mid-February. During the summer, some cargo (mostly fuel) is transported via South Pole Traverse. The station is isolated the rest of the year. Science Cargo personnel at McMurdo and South Pole stations determine cargo plans and schedules.

Nearly all USAP personnel reach SPS via a three-hour flight from McMurdo Station aboard LC-130 aircraft that are operated and maintained by the Air National Guard's 109th Airlift wing located at Stratton Air National Guard Base in New York.

The annual fuel tanker vessel delivers approximately six million gallons of fuel purchase through the Defense Fuels Agency to McMurdo, which provides the forward supply of fuel for SPS, delivered from McMurdo to South Pole by traverse and LC-130.

As with all coastal locations in the southern Ross Sea region, heavy icebreaking is needed to open the roughly ten-mile channel from the sea ice edge to McMurdo Station to enable the offload of cargo and fuel.

McMurdo operates two airfields that are used at different times of summer because of seasonal conditions and aircraft type. The primary means of moving USAP participants from Christchurch, NZ to McMurdo is via C-17 Globemaster III, operated by the US Air Force's 62nd Airlift Wing located at Joint Base Lewis McChord near Tacoma, Washington.

USAP airlift refers to the scheduled movement of cargo and passengers from Christchurch, NZ to McMurdo via aircraft capable and certified to operate in Antarctica. The airlift period is generally from late August to the end of the operating season. Although there have been winter flights that may occur.

Commercial surface vessel shipments to Christchurch (via Port Lyttelton) are the preferred transport mode for cargo. In general, airlift cargo needs to arrive at Port Hueneme by established shipping dates (1 December).

Commercial Air Cargo. If circumstances prohibit shipment by sea, NSF may authorize ASC to ship cargo by commercial air to Christchurch. This is the most expensive way to transport cargo and will be used only for essential material that cannot go by sea. Commercial air shipments need to provide sufficient benefit to warrant the added cost of this transport mode. Air cargo will not be authorized as a substitute for inadequate advance planning.

Commercial Surface Cargo (COMSUR). ASC books multiple voyages on oceangoing commercial vessels to position cargo to Punta Arenas, Chile and Christchurch, NZ. COMSUR voyages are a more economical method for the program to position cargo than utilizing commercial airlines.

A Continental Acquisition Schedule provides the shipping deadlines and required delivery dates to meet the associated Required on Site (ROS) dates for the operating seasons. These schedules are built off the long lead timelines to accommodate the lengthy ocean voyages between the continental U.S. (CONUS) and the foreign ports.

The following diagram illustrates the typical duration and mode of transportation for materials to make the journey from Port Hueneme, CA to their destination at the South Pole.

Logistics and Transportation Route to South Pole Overview Map.
Source: NSF, Undated.

LOCATION	AIRCRAFT	DATES OF TYPICAL OPERATION	LIMIT TO OPERATIONS
McMurdo	C-17	Late Aug; 1 Oct - Late Feb	Seasonal Tasking
McMurdo	LC-130	Late Oct - Late Feb	Seasonal Tasking
McMurdo	Small Fixed-Wing	Mid Nov - Mid Feb	Seasonal Tasking
McMurdo	Helicopter	Early Oct - Early Feb	Seasonal Tasking
South Pole	LC-130	Early Nov - Mid Feb	Temperature
South Pole	Small Fixed-Wing	Late Oct- Late Feb	Seasonal Tasking
Deep Field Camps	LC-130	Early Nov - Mid Feb	Temperature
Deep Field Camps	Small Fixed-Wing	Mid- Nov - Mid Feb	Seasonal Tasking

Table 5.1 Air support operations periods

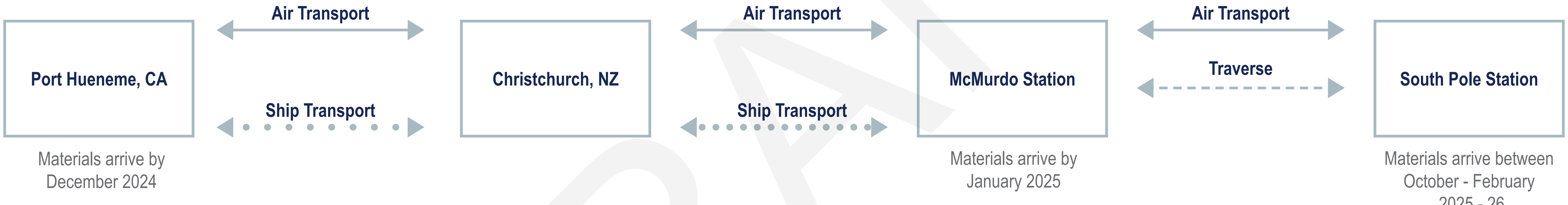


Figure 5.3 Transportation journey to the SPS.

Figure 5.4 LC-130 Air Cargo. Source: NSF, Undated.

Figure 5.5 Giant Cargo. Source: NSF, Lauren Lipuma, 2023.

TOURISM

The ASMA set aside areas of the Operations Zone for historical markers and Non-Governmental Organization (NGO) tourism activities. These areas are intended for use as NGO tourism campgrounds and related vehicle or aircraft parking. An NGO parking area and associated visitors camp is located grid-north of the Elevated Station and only used in the summer months.

In the 2011-2012 summer, over 300 tourists visited the South Pole in honor of the station's Centenary. Although there was a large decrease in the number of tourists following the Centenary, the number of annual tourists has grown larger over time. Approximately 300 tourists now visit the South Pole each year on NGO expeditions with private tour operators. Visits to the Geographic South Pole are the pinnacle of trips to the South Pole, and most visitors walk or ski to both the Ceremonial South Pole and the Geographic South Pole, both of which are within the immediate station area.

The USAP allows use of the airfield for NGO aircraft and designates a separate groomed parking area grid-north of the station for NGO aircraft. The USAP also positions a small, mobile, modular visitor's center and outhouse. However, the USAP does not provide supplies, use of the Elevated Station facilities, or any other non-emergency support to private expeditions. A fixed number of limited tours of the Elevated Station are apportioned among the tour operators through a pre-season, off-continent agreement between NSF and the operators, who are coordinated through the International Association of Antarctic Tour Operators (IAATO).

As tourism continues to grow, the potential for impacts on the operations and infrastructure at the SPS will increase. Separation of uses, especially surrounding the Geographic South Pole, is becoming more important each year.

NSF has designated approach routes to avoid scientific sectors and hazard areas encroachment. Current access to the NGV sites is as follows:

DO NOT ENTER CLEAN AIR SECTOR OR QUIET SECTOR

- To avoid entry into Clean Air Sector do NOT travel south of S88° 39' between longitude lines W020 and E110.
- To avoid entry into Quiet Sector do NOT travel south of S89° 49' between longitude lines E110 and W170.

WEST APPROACH – FROM HERCULES INLET, MESSNER START, RONNE ICE SHELF

- Expeditions approaching between W020 and W110, call ALE Comms 24 hours before arrival and advise intentions.
- Aim for 'West Waypoint' S89° 59.0' W016° 00.0'. Look for a 'Welcome to the South Pole' sign. Do not enter the Clean Air Sector.
- From West Waypoint, continue about 1 km to the NGV campsite at approximately S89° 59.45' W004° 15.0'. Do not cross the lag line that marks the Clean Air Sector boundary.

SOUTH APPROACH – FROM AXEL HEIBERG, LEVERETT, BEARDMORE GLACIER, ROSS ICE SHELF.

- Expeditions approaching between E110 and W110 aim for 'Pole Turn 1 Waypoint' S89° 55.29' W132° 00.00'. Avoid entering Quiet Sector.
- Call ALE Comms when you arrive at 'Pole Turn 1 Waypoint'. DO NOT PROCEED beyond Waypoint until advised by ALE Comms. Be prepared to camp as air operations may delay onward passage to South Pole.
- When approved to continue, proceed 5.2 km to waypoint S89° 57.78' W149° 45.35', west of skiway threshold.
- Continue 4 km along west side of skiway, to the crossing beacon at S89° 59.65' W047° 53.45'. Stay at least 30m from the flagged edge of the skiway.
- Cross skiway at designated crossing point, marked by a red beacon, and proceed towards South Pole markers and NGV campsite.
- ***DO NOT CROSS SKIWAY IF BEACON IS FLASHING.***

NGO CAMP. Source: NSF, 2023.

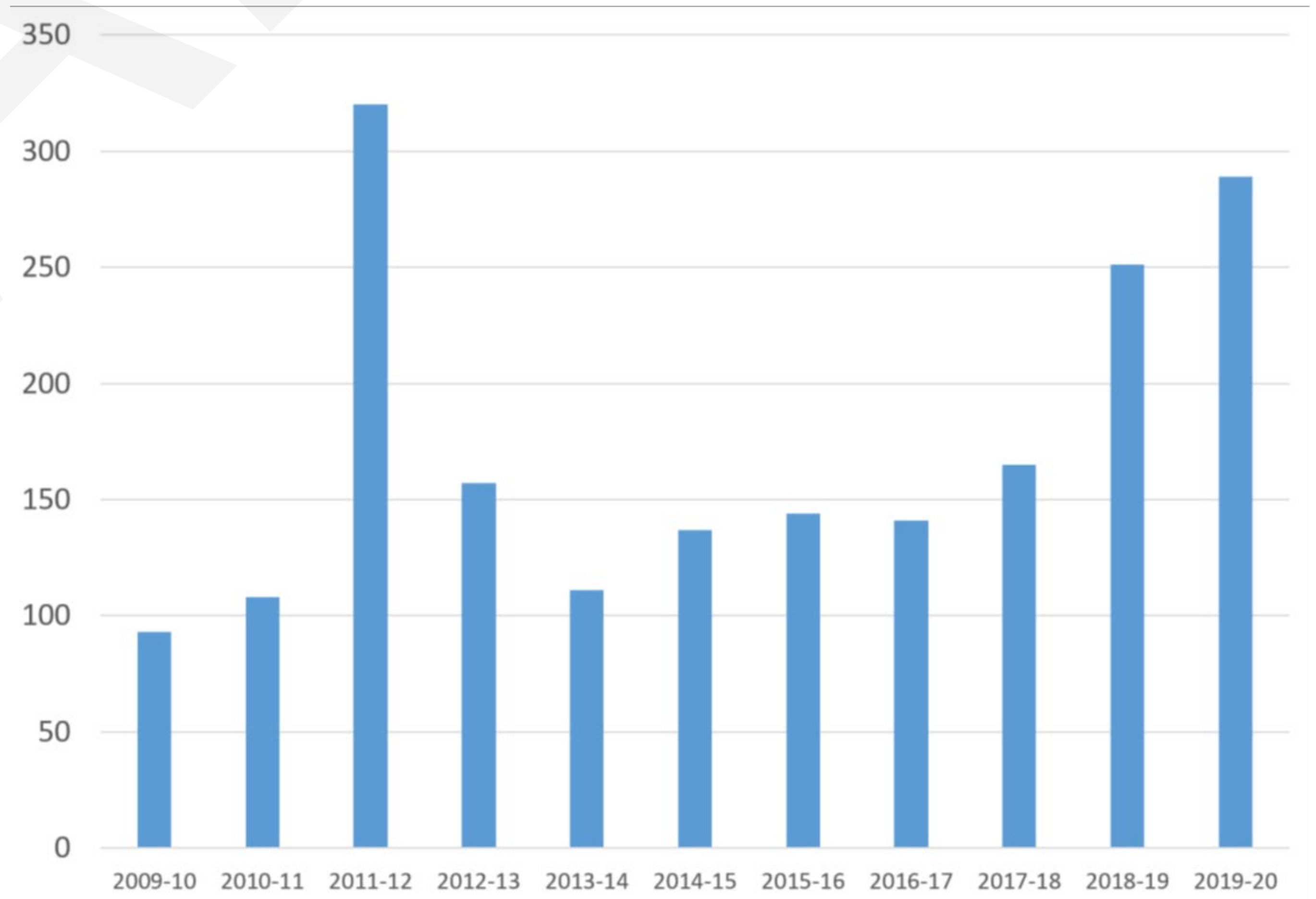


Figure 5.6 NGO VISITORS BY SUMMER SEASON. The number of tourists who visit SPS has continued to grow over the past decade. The 2011-2012 Centenary summer season population may soon be surpassed. Source: IAATO, 2020 .

DOWNWIND SECTOR

AIRFIELD

The Airfield is in the Operations Zone where airfield support activities (e.g., aircraft landing and parking, refueling, and cargo staging) occur. The Airfield requires proper separation from other station service activities in order to prevent cross contamination of supplies and mitigate air and sound pollution to protect the health of station personnel. The Airfield contains the skiway, aircraft parking areas, refueling stations and a variety of structures and infrastructure used to support airfield operations. Siting of all future Air Support facilities and services will require a site study and environmental analysis, where applicable, before final placement.

The skiway is a snow-surface, groomed runway that runs along the Dark Sector and Operations Zone boundaries. Routes to the Dark Sector currently cross the skiway threshold. Incoming passengers disembark at a parking apron along the side of the airfield and walk to the Elevated Station.

Air support to the station is provided by a mix of LC-130 and Basler DC3 aircraft that transport people and supplies from McMurdo. Twin Otter aircraft also support the station on a limited basis, but they must refuel once at fuel caches in the Transantarctic Mountains while enroute from McMurdo to SPS. Twin Otters are used primarily for close support of field science and East Antarctica sites and are subject to delays due to adverse weather conditions.

NSF has an agreement with the 109th Air National Guard (ANG), located in Stratton, New York, to provide LC-130 support for the USAP. Historically, SPS has relied primarily on near-daily LC-130 missions during the austral summer to transport fuel, cargo, and passengers to and from SPS and deep-field camps. In the past decade, the traverse fleet has been developed to enable overland movement of more fuel and heavy materials to SPS, which has lowered the overall reliance on LC-130s. In recent seasons, the LC- 130 presence at the South Pole dropped to a historical low of 65-80 missions per season. As traverse capabilities continue to grow, dependency on LC-130s for cargo and fuel delivery could be further reduced. However, reliance on LC-130 support for personnel transport is anticipated to continue.

Using Baslers to move passengers and baggage has become more frequent. However, the Basler requires a larger good weather window to fly from McMurdo to SPS because its unpressurized cabin limits its capability to fly above weather when crossing the TransAntarctic Mountains. The lower takeoff weight limit at the South Pole's altitude also makes the northbound leg of the trip less cargo efficient. Current use of Twin Otter aircraft for near-field transportation of scientific and support personnel often results in delays due to multiple-location weather conditions. Twin Otters experience no-fly days at SPS due to unfavorable forecasts, which makes it difficult to get into the field to conduct research. This results in adverse effects on scientific research and places an additional bedspace and resource burden on SPS. An operational model of near-field overland travel may reduce the frequency of these issues, as the traverse is not as sensitive to adverse weather conditions. Basler's, Twin Otter's, and traverse platforms must all refuel at SPS, inherently depleting fuel supplies at SPS that must be restocked by additional LC-130 flights or traverses.

The position of the airfield (specifically the clearance zones for departing planes) has been a concern for Clean Air Sector research operations in the past. Future development within the SPS area will require the airfield to shift further grid-southwest along its existing axis to provide additional development space for SPS core infrastructure.

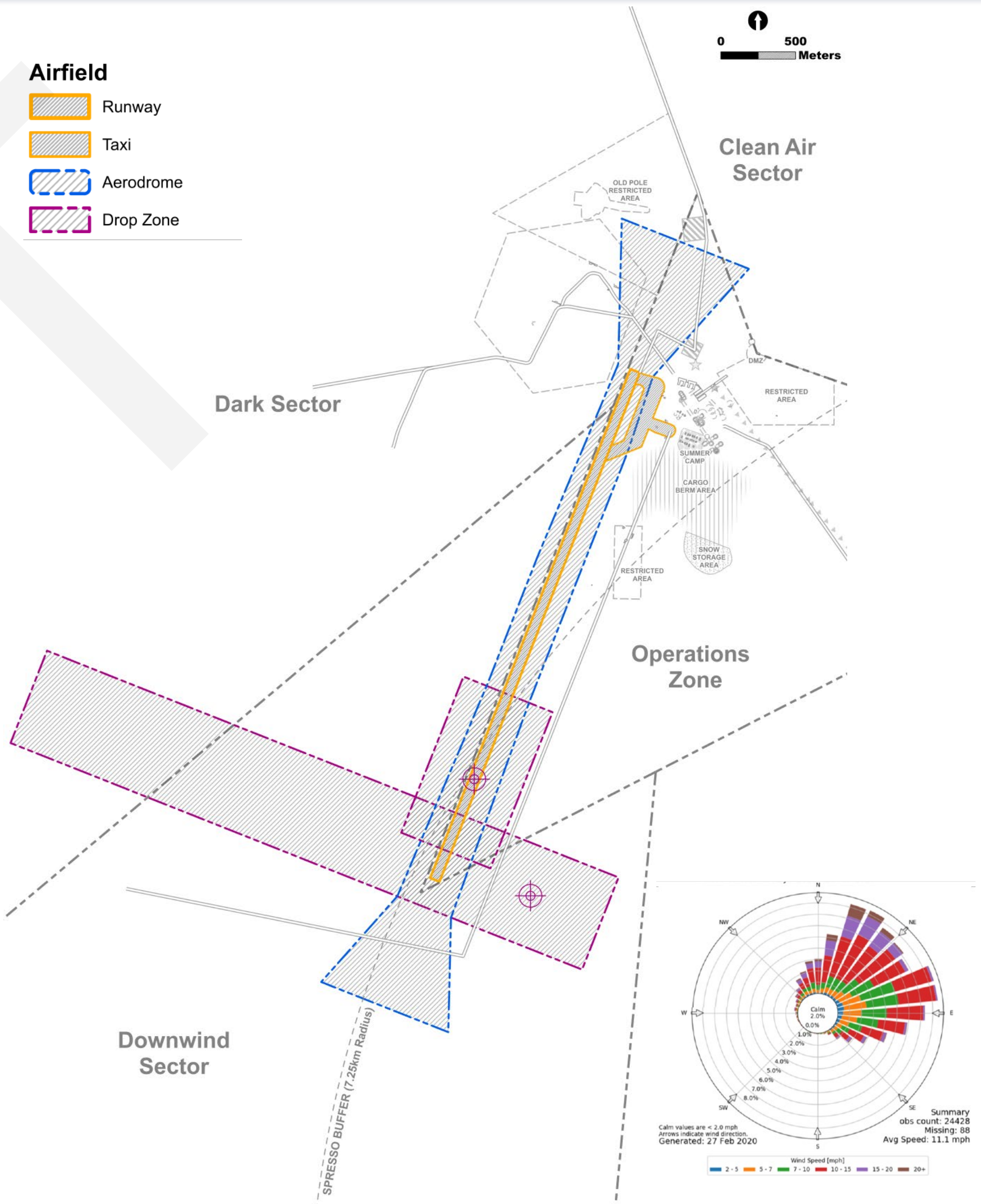


Figure 5.7 Airfield Configuration. Source: NSF, Undated. Not to scale

TWIN OTTER (LEFT). A modified Twin Otter aircraft owned and operated by Kenn Borek Air in support of the U.S. Antarctic Program sites at SPS. Source: NSF, Unknown, 2018.

LC-130 DISEMBARKATION. Scientists and support staff arrive at SPS after a three-hour flight from McMurdo Station. Source: NSF, Mike Lucibella, 2019.

BASLER. A modified DC-3 Basler aircraft owned and operated by Kenn Borek Air in support of the USAP sits at SPS. Source: NSF, Luis Gonzalez, 2018.

Aurora Australis blends into Milky Way over Dark Sector. Source: NSF, Robert S., Undated.

South Pole Station Area Plans

STATION AREA PLANNING

Area Planning examines sub areas of a Master Plan in more detail. Sub area designations in the Master Plan align with the sectors and zones established by ASMA No. 5 and each have a primary function dedicated to either science or operations. This Section synthesizes concerns identified through the Scientific Community Charrette and previously complete SPS infrastructure assessment as an integrated, viable list by sector. Recommendations to address these concerns are also presented. These recommendations include: 1) physical site recommendations to be reflected in the Master Plan, 2) action items to be undertaken, or 3) items that require further study outside of the scope of this Master Plan. Recommendations that require funding to complete are also identified as a project in Section 8.

Aurora Australis near IceCube. Source: NSF, Sven Lidstrom, 2018.

SOUTH POLE STATION

The SPS functions as a single complex to support the Science Research Facilities. There are concerns that apply generally to the complex as a whole. The following are the concerns and recommendations identified for the SPS.

CONCERNS

- Science Research Facilities are being buried by accumulated snow. These facilities need to be raised to new elevations.
- Electro Magnetic Interference (EMI) emitting from the NGO sites and the Operations Zone impacts science research.
- The frequency and volume of personnel movements and cargo in and out of South Pole is lower than desired.

RECOMMENDATIONS

SPS 1 Conduct a cost-benefit analysis regarding whether lifting or full replacement of Science Research Facilities and communications facilities is the most practical and cost-efficient path.

- Raise Science Research Facilities and communications facilities in the near future to prevent structural failure and maintain researcher access to the buildings.
- Evaluate if structural skids or skis can be attached to the foundations (i.e., Science Research Facilities and other science) where possible to simplify snowdrift management and allow regular building relocation via towing.

SPS 2 Develop EMI governance/management plan with implementing procedures for SPS, to include EMI screening criteria for the selection of future electro-mechanical systems, facility UPS systems, and other EMI-emitting infrastructure and equipment. Implement a sustainable Radio Frequency (RF) spectrum monitoring system to track background noise emissions and to provide a real-time aid for finding and resolving spurious EMI events.

Crossing Airfield from Dark Sector to Elevated Station. Source: NSF, 2023 .

DARK SECTOR

The Dark Sector contains three primary Science Research Facilities that need lifting and/or relocation due to ice accumulation and burial in snowdrifts. The following are the concerns and recommendations identified for the Dark Sector.

SECTOR CONCERNS

- Building 61 is at the deepest level of burial and should be raised or unburied to maintain telecommunications and electrical power to the Dark Sector.
- MAPO is being buried by snowdrifts. The immediate concern of the MAPO burial is the potential loss of egress of the first story doors, difficulty servicing with fuel and cargo, and increased maintenance costs of snow removal. In the near future, there is also a high potential of structural damage due to the snow loading on the roof.
- ICL building, and the DSL buildings need to be raised.
- EMI emissions from the NGO camps causes interference on science.
- Personnel crossing the skiway to access the Dark Sector, can cause conflicts with airfield operations.

RECOMMENDATIONS

D1 Raise Building 61 to maintain telecommunications and electrical power distribution to the Dark Sector.

D2 Raise MAPO, ICL, and DSL buildings in the near future.

D3 Conduct engineering evaluations in cooperation with the radio astronomers to devise safe distance estimates for typical RF emitting devices (e.g., consumer grade equipment, and satellite communications earth stations)

D4 Deconflict crossing the skiway for personnel accessing the Dark Sector.

CLEAN AIR SECTOR

The Clean Air Sector has one primary building, the ARO, and the NOAA scaffold tower. ARO and the two Automatic Weather Stations (AWS) are structurally independent of each other, but operation and data collection cabling must be maintained between each structure. The following are the concerns and recommendations identified for the Clean Air Sector.

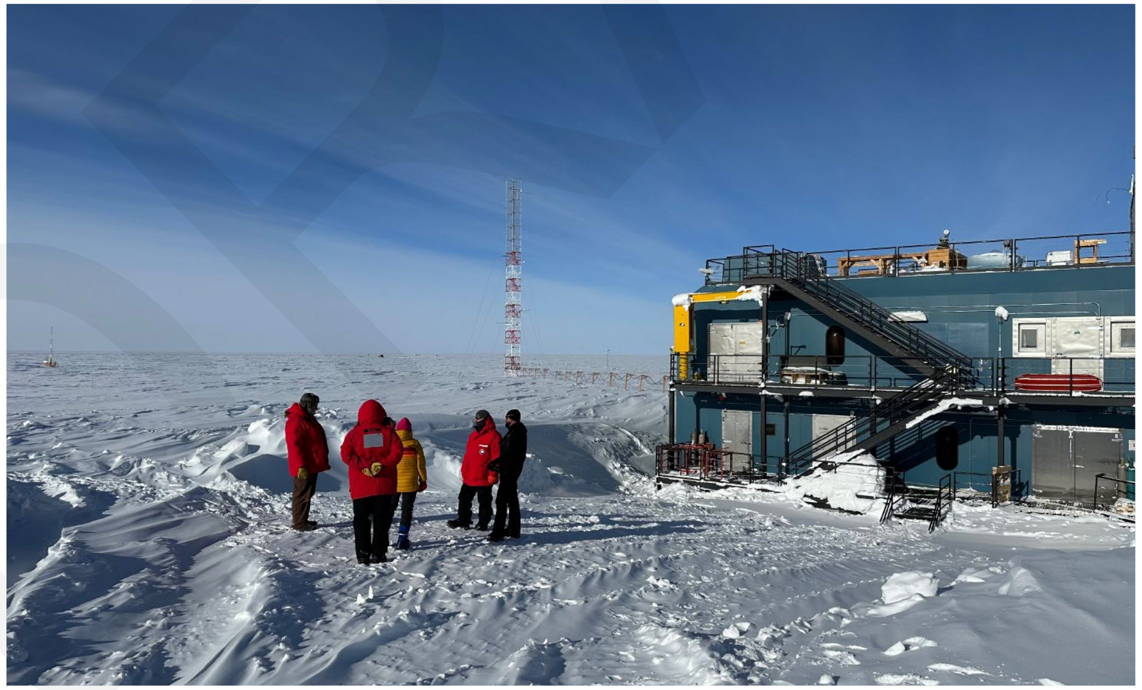
SECTOR CONCERNS

- Emissions and contamination risk from the NGO camp interferes with atmospheric testing in the Clean Air Sector.
- Uncontrolled access by pedestrians or vehicles into the Clean Air Sector can contaminate the snow and air quality.
- Snowdrift maintenance is an ongoing challenge and impacts the ARO building.

RECOMMENDATIONS

CAS 1	Locate a new NOAA science building up to 1 km northeast of the current ARO building, to add operational space, de-conflict NGO activities, and ensure air quality.
CAS 2	Identify an access control easement along the 110-degree and 340-degree line to manage access into Sector.
CAS 3	Consider management of buffer area upwind of CAS line as an ASMA designation.
CAS 4	Raise the ARO building to prevent structural failure and maintain researcher access to the building.

ARO and AWS tower. Source: NSF, 2023.



ARO Entrance Excavated. Source: NSF, 2023 .

ARO. Source: NSF, Gabe Nerf, 2020.

QUIET SECTOR

The Quiet Sector contains the SPRESSO, built in 2003. This facility was designed for 15 years of use and is now nearly 20 years old. The SPRESSO vault was originally design as a crush wall exterior frame and was pre-buried in the ice with its access at surface level. However, after 20 years the entrance is now 29 feet under ice and the facility needs to be raised/moved if use is continued in the future. SPRESSO is approximately 5 miles (8 km) from the Elevated Station. The SPRESSO utility cabling is strained due to differential movement of the ice sheet, which moves the facility farther from the station each year. Fiber-optic cabling and other utilities need to be comprehensively evaluated for replacement, as the annual movement of the ice sheet is stretching the cabling beyond its specified limits. Expedited replacement of SPRESSO would simultaneously address the facility age and cabling replacement concerns. There is an opportunity when replacing the SPRESSO facility to move it to a more optimal location. The following are the concerns and recommendations identified for the Quiet Sector.

SECTOR CONCERNS

- SPRESSO experiences various forms of interference from the Operations Zone.
- SPRESSO poses access challenges during servicing events.
- SPRESSO utility cables are being stretched beyond reliability limits.
- Communications technology needs improvement.

RECOMMENDATIONS

QS 1 If the SPRESSO program will continue, a replacement SPRESSO should be relocated northeast of the current location closer to Clean Air Sector to deconflict developable area in the Operations Zone.

QS 2 If the SPRESSO program will continue, establish a SPRESSO buffer of 8 km radius creating a buffer to restrict interference.

QS 3 Redefine ASMA Quiet Sector boundary to deconflict developable area in the Operations Zone.

QS 4 Continue monitoring the quality and function of SPRESSO power and data cables to anticipate when they need to be replaced.

OPERATIONS ZONE

The Operations Zone is where all SPS support facilities are located. The primary structures include the Elevated Station and the arches. A variety of other auxiliary structures are scattered within the Operations Zone but are not necessarily organized for efficiency, rather many were repurposed from the original use.

Several research projects and operations have been located within the Operations Zone over the years to enable easy winter technician access. The positioning of scientific research facilities in the Operations Zone has created the need for Restricted Zones within the operational space. These Restricted Zones have limited the area within the Operations Zone where support operations may occur without conflicting with scientific measurement and communications tools. Although these science projects may change over the years, the structures and vaults that are left behind are repurposed and can create potential building hazards in the Operations Zone.

Although vaults are primarily unoccupied and unheated, the V8 vault, which is located near SuperDARN, now contains scientific projects that require heated instrumentation and regular servicing. However, V8 was not designed to be heated or used for scientific research purposes and does not have an air turnover system, which is a safety concern for personnel entering the V8.

The Cryogen building supports the BIF, temporary scientific research projects, and field staging. The Cryogen building was dragged to its current location in 2013 and will need to be relocated in the future to stay above the ice. However, the Cryogen building will need to be evaluated before it is moved to see if the structure can handle the strain of another relocation or whether it will need to be entirely replaced.

The SuperDARN building is still above the surface. Snow is currently at the base of the elevated building (after 12 feet of accumulation) and will need to be lifted in the future.

Additional laboratory space is contained within the Elevated Station. The Elevated Station laboratory space is currently fully subscribed for existing scientific projects. As each project is completed, the space that it occupied in the Elevated Station laboratory is reallocated to newly funded research projects.

The following are the concerns and recommendations identified for the Operations Zone.

CONCERNS

- The ongoing impacts of snowdrift is enveloping the Elevated Station. The elevated building will need to be raised in the future.
- The arches are buried beyond the design assumptions. The arches are forecasted to come into contact with interior structures in coming years. The facilities within the arches must be relocated.
- Various auxiliary buildings need to be moved or raised to higher elevation out of the snow accumulation.
- Cargo storage is inefficient and inadequate. More cargo capacity is needed to consolidate materials for better efficiency.
- The vehicular circulation is inefficient within the Operations Zone.
- The storage of waste materials in the berm storage area is excessive and inefficient.
- Summer Camp needs to be removed or reimagined.
- The Operational Zone has a limited capacity for the staging of a field science hub.
- Utilities need to be locatable and managed as part of a master utility plan.
- The effect of differential settlement and ice sheet movement on fixed point and subsurface fiber optic cable and utilities.
- The number of flights to support personnel rotations does not meet demand.
- The number of current flights and traverses for cargo delivery may not be able to support future capacity demands for major construction, and infrastructure needs.
- Snow management continues to be a challenge.
- Practice of dumping snow is causing an increase over natural rates of drifting, burial, and eventual damage of the High-Frequency (HF) Radio long-haul antennas that are used for aircraft communications and emergency communications.

Arch Construction. Source: NSF, Jack Corbin, 1990s.

RECOMMENDATIONS

OZ 1 Construct replacement structures for all facilities and uses within existing arches. Additional storage and warehouse spaces to be included in future structure designs. Auxiliary structure storage should be consolidated into a new structure to reduce the energy demands of disparate, decentralized structures serving similar purposes.

OZ 2 Evaluate moving some science functions to new facilities and/or locations to reduce EMI.

OZ 3 Designate vehicular circulation organized around an efficient station layout.

OZ 4 Inventory all berm contents to determine what can be repurposed to reduce retrograde, storage, and shipping demands. Retrograde reduction plans shall be included with each new project to maintain a compact station footprint and prevent future berm growth and warehousing overruns.

OZ 5 Raise the Elevated Station.

OZ 6 Evaluate needs and location of a new Construction Camp to replace Summer Camp. Auxiliary structures in the Construction Camp should be located within walking distances of primary personnel support functions.

OZ 7 Designate an area for facilities to support a field science hub.

OZ 8 Develop a Utility Master Plan that establishes utility rights-of-ways for routing of fiber optic telecommunications cables, electrical lines, and water and sewer lines. The Utility Master Plan should monitor geospatial locations of the rights-of-way from year to year to account for ice sheet movement.

OZ 9 Determine the future demands for SPoT and other traverse options for improving personnel rotations and cargo deliveries.

OZ 10 Conduct a retrograde initiative to reduce accumulation, maintenance costs, labor and resource demands, and the station's environmental impact.

OZ 11 Expand the current area for snow storage to manage the snow and ensure snow accumulation does not impact the Operations Zone activities.

OZ 12 Replacement/relocation of the large HF radio communications antennas to avoid drifting from Operational Sector activity.

PRIMARY INFRASTRUCTURE

WATER SYSTEM

Water supply at the SPS is provided by via a Rodwell and water treatment system. The system has functioned well for the SPS. The following are the concerns and recommendations identified for the Operations Zone.

CONCERNS

- The logistics of reconnecting the water system to a new Elevated Station and replacement buildings.
- A new Rodwell will need to be located and installed in the next decade.
- Keeping service tunnels accessible and functioning as the utility tunnel system is now deep and difficult to maintain.
- The maintenance and upgrades of water lines when buildings are raised.
- The capacity of the back-up snow melt system during emergencies in summer season.
- Alternative water supply systems to extend the life of the Rodwell.

RECOMMENDATIONS

WS 1 Investigate and propose methods so future water lines and associated infrastructure avoid critical point failures.

WS 2 Replace the existing Water Rodwell by 2030. Locate the replacement Rodwell building relative to the ice tunnel beneath the structure so that a ladder shaft from the ice tunnel to the building can be configured for easier waterline and utility maintenance.

WS 3 Evaluate utility tunnel replacement options.

WS 4 Design piping systems, appendages, and structures to enable periodic building raises.

WS 5 Conduct an analysis to determine if the back-up snow melt system capacity needs to be upgraded to support the summer population at SPS in the event of a Rodwell outage.

WS 6 Evaluate the existing Rodwell building to determine its lifespan and ability to be relocated.

WS 7 Investigate and recommend grey-water treatment and re-use solutions to be used in future station designs to extend Rodwell lifespans and reduce long term Rodwell planning and installation costs.

HUMAN AND SOLID WASTE

Human waste storage at the SPS is provided by the sewer outfall system via a decommissioned Rodwell. The waste system has functioned well for the SPS. Solid waste, known as retrograde, has been stored on snow berms waiting to be removed from the SPS. The South Pole Retrograde Initiative (SPRI) is encouraged to continue for the removal of retrograde material.
The following are the concerns and recommendations identified for the Operations Zone.

CONCERNS

- The logistics of connecting the human waste system to a new Elevated Station and other structures.
- The maintenance and upgrades of sewer lines when buildings are raised.
- The timing of moving to a new sewer outfall.
- Increasing sewer outfall capacity via alternative methods of waste-to-energy systems.
- The long-term environmental impacts of human waste disposal in the sewer outfalls.
- Keeping service tunnels accessible and functioning as the utility tunnel system is now deep and difficult to maintain.
- Solid waste retrograde represents a long and costly supply chain for disposal of solid waste materials to CONUS.
- The solid waste supply chain has not kept pace with a backlog of retrograde materials resulting in increased bermed storage

RECOMMENDATIONS

HSW 1 Design piping systems, appendages, and structures to enable periodic building raises.

HSW 2 Replace the sewer outfall Rodwell immediately.

HSW 3 Add a Wastewater Treatment Plant (WWTP) to the human waste system to mitigate environmental impacts.

HSW 4 Investigate and recommend grey-water treatment and re-use solutions to be used in future station designs to extend Rodwell lifespans and reduce long term Rodwell planning and installation costs.

HSW 5 Investigate black water and waste technology as potential alternative fuel sources in future station designs to reduce the environmental impacts of SPS activity.

HSW 6 Evaluate utility tunnel replacement options.

ENERGY

The existing energy systems are the lifeblood of the SPS. They are not only necessary for the continued operation of the scientific facilities but are also essential from a life safety standpoint. The energy facilities at SPS currently center on the existing power plant which provides both electrical and thermal energy to the surrounding facilities. The power plant consists of reciprocating internal combustion (diesel) engines and associated waste heat recovery equipment. Electrical energy is distributed from the plant to most buildings at SPS. The thermal energy is utilized for building heating in the Elevated Station as well as several outbuildings that are in reasonably close proximity. The power plant, along with its fuel storage facility, are located in the power plant and fuel storage arches respectively. As with the other arches located at SPS, these arches are currently buried, sinking, and it is expected that they will cease to be suitable for their current use within 10 years.

CONCERNS

- The power plant arches are buried and being crushed by snow. A replacement for a new power plant facility and fuel storage are needed.
- Reliable power and heat generation cannot be interrupted at any time during the transition to the new facilities. Construction phasing will be critical to successful project completion.
- Increased power needs for future science projects.
- Finding alternative sources of energy to supplement SPS increasing energy needs.

RECOMMENDATIONS

E 1 Replace the power plant and fuel storage.

E 2 Conduct a comprehensive study of the life expectancy of all main power plant components, including the structures beneath the arch and the arch itself, to finalize replacement timelines.

E 3 Conduct a comprehensive study of energy production feasibility to determine the appropriate energy production portfolio for a replacement power plant.

E 4 Conduct on-site testing of current renewable energy technologies to determine suitability for the South Pole environment.

E 5 Engage in future partnerships with academic institutions to engage the academic community in the continued study of and/or creation of alternative energy production systems that could reliably perform in the South Pole environment.

UTILITY CABLING

Utility cabling supplies the electrical and communications cables throughout the SPS and sciences facilities in the Sectors. Many of the cables are aging and being stretched due to differential movement of the ice sheet. New cables will be installed as buildings are raised, moved, or replaced. A Cabling Master Plan would provide guidance for consolidating lines, looping networks and exploring method for dealing with differential movement.

CONCERNS

- Buildings 61 and 68 needs to be maintained to ensure electrical power distribution to current facilities.
- Some cabling is nearing its lifespan due to the ice sheet movement.
- Existing cable fixed cable connections are susceptible to the ice sheet differential movement.
- Utility cables are not easily located due to a lack of surveyed utility mapping.

RECOMMENDATIONS

UC 1 Evaluate timing for the replacement of the main trunk fiber optic cables and local Dark Sector fiber optic cables if appropriate to occur co-incident with Building 61 raising.

UC 2 Discontinue fixed-point connections for cabling and implement a connection system that accounts for ice sheet movement.

UC 3 Proactively account for network expansion at precise locations to prevent future ad hoc cabling decisions.

UC 4 Explore the co-location of utility cables.

INFORMATION TECHNOLOGY & TELECOMMUNICATIONS

Communications at the SPS connect all the facilities to each other and provide data links to points around the world. Having reliable data transmissions and station communication is critical.

CONCERNS

- Existing RF Building
  - » Is undersized to meet mission need.
  - » Distance from the Elevated Station to locations beyond the RF Building pose a heightened risk to wintering communications technician personnel traveling to the RF Building area for corrective maintenance.
- Radio communications systems are out of date.
- Existing 9 meter (m) satellite antenna underneath the large radome is obsolete and decommissioned.
- Life-safety/operational Land Mobile Radio
  - » System is obsolete, losing parts support and at high risk of failure.
  - » System coverage areas within the elevated and sub-surface station, as well as the outdoor operating area, must be preserved for safety-of-life communications in addition to station operations.
- Dark Sector Interference
  - » The Land Mobile Radio system has demonstrated harmful interference to Dark Sector science (radio astronomy).
  - » Satellite communications earth station operations and Starlink testing in proximity of the RF Building have been documented to cause EMI with Dark Sector radio telescopes.
- HF radio long range curtain antennas are becoming buried by snowdrifts with risk of permanent damage, exacerbated by snow clearing/dump activities for annual snow maintenance of Operations Zone.
- Existing antenna structures (esp. South Pole TDRS Relay antenna platform) are constrained by the airstrip safety height restriction zone perpendicular to the airstrip centerline

RECOMMENDATIONS

ITT 1 Conduct right-sizing assessment on RF Building size to support future requirements to include space for needed equipment redundancy to minimize the need for high-risk winter personnel visits.

ITT 2 Identify potential site for a future communications complex.

ITT 3 Upgrade the existing Iridium Mobile Satellite System and high frequency radio systems to maintain aviation communication capabilities.

ITT 4 Conduct a cost benefit analysis of the emergent broadband polar orbiting, satellite-based, communications systems to evaluate the viability of emerging technologies for science data movement.

ITT 5 Deinstall 9m antenna and retrograde, evaluate potential reuse of the radome, and preserve the antenna platform as a future resource to support future wideband low earth orbit satellite sysems for Enterprise-scale high speed communications (examples: SpaceX Starlink Community Gateway, Telesat Lightspeed Private Access terminal, AWS Kuiper private gateway terminal).

ITT 6 Upgrade the Land Mobile Radio system to maintain communications availability for timely emergency response.

ITT 7 Research communication methods that do not rely on the same technologies and not be subject to the same failure points to increase the resiliency and redundancy of emergency communications.

ITT 8 Coordinate spectrum selection and waveforms (i.e., occupied spectrum) of Land Mobile Radio system with Dark Sector research community to harmonize on emissions that minimize harmful EMI while maximize safety/operational needs.

ITT 9 Conduct engineering assessments in coordination with the Dark Sector research community to identify safe operating ranges for existing and expected future wideband satellite earth stations (per ITT 5) and define site facility requirements (support buildings, utility runs, radhaz safe zones, etc.) for future site build-out.

ITT 10 Conduct engineering studies to find optimum trade-off between distance from airstrip centerline to main Elevated Station for winter personnel safety and utility runs vs. isolation distance needed to minimize EMI risks to Dark Sector (especially radio astronomy) to acceptable levels.

ITT 11 Refresh HF antenna requirements (design, number, purpose) to align with near-term NIWC HF Radio Modernization Capital Project for NIWC project to implement needed replacements.

ITT 12 Research new technologies that may reduce data and communications service gap hours each day and installed at SPS to reduce communication-related safety risks and meet growing science data requirements.

FIELD SCIENCE

Field science expeditions from the SPS are supported with field equipment by McMurdo Station. Although field science expeditions do use SPS as a staging base, there has not been adequate supply storage space and staging support facilities to fully support them. SPS currently is not equipped to be a field science hub.

CONCERNS

- Providing field science staging areas, temporary housing and logistics support needs to be evaluated if the SPS is going to be a hub.
- Field science is often delayed when Baslers and Twin Otter aircraft are grounded due to weather.
- Emergency rescue equipment and support needs for expeditions need to be allocated.
- The number of flights to support field science does not meet demand.

RECOMMENDATIONS

FS 1 Conduct an analysis assessing the cost-benefits to procuring, operating, and storing light science polar equipped wheeled vehicles based out of SPS for access to Eastern Antarctica science sites.

FS 2 Locate a field science staging area near the airfield and overland departure points to improve efficiency for field team staging.

FS 3 Complete an evaluation for temporary housing models to provide accommodation for field science teams at the South Pole for temporary, pass-through populations.

FS 4 Continue to centrally manage field support and Search and Rescue assets from a centralized location at McMurdo Station to provide continuity, efficiency, and a lighter footprint at SPS.

FS 5 Provide a field or remote emergency response equipment storage structure adjacent to the airfield to enhance resiliency of the emergency response program.

FS 6 Utilize the existing arches, once vacated, for field science supplies as a temporary location.

FS 7 Include dedicated VMF/warehouse space in a future station for staging the large and often voluminous equipment of multi-year, field science projects.

EMERGENCY SERVICES

The SPS on-site emergency services capability functions well but lacks adequate storage and staging space. The emergency services are supported by a qualified medical team and brigade teams.

CONCERNS

- Operational space is inadequate and could impact response efficiency at the current station. Storage space is inadequate.
- Radio communications systems need to be upgraded for emergency services.

RECOMMENDATIONS

EMS 1 Consolidate Emergency Services storage and staging space in the Elevated Station and directly adjacent to or integrated with field and aircraft staging areas.

EMS 2 In Future Station, account for gurney space and maneuverability in Emergency Services treatment areas.

TRAVERSES

SOUTH POLE TRAVERSE (SPoT)

Overland traverse platforms are a well-established technology in Antarctica and specifically to the SPS. A SPoT platform is used for fuel and cargo delivery capacity and reduce reliance on LC-130 aircraft. The SPoT fleet is also used to transport waste retrograde materials back to McMurdo to be shipped back to the U.S.

CONCERNS

- The SPoT fleet has limitations on capacity which impacts costs, and efficiencies.
- The current fuel offloading process has limitations on turnaround time of the SPoT platform.
- The increase in construction projects for science, raising structures, and new buildings will increase fuel and cargo capacity needs.
- The current VMF capacity limits the capacity for repairing and servicing SPoT/traverse within station facilities.

RECOMMENDATIONS

SPoT 1 Evaluate increasing traverse capacities and capabilities toward providing 100 percent of the required fuel to SPS to reduce the reliance on and costs related to using LC-130s for fuel delivery.

SPoT 2 Expand SPoT fleet to reduce delivery costs, increase efficiency of retrograde efforts and free up capacity of LC-130s.

SPoT 3 Evaluate infrastructure upgrades to allow for loading and unloading full 20 and 40-foot shipping containers onto and from the traverse platform at McMurdo and SPS to expedite cargo delivery and reduce reliance on berms.

OVERLAND SCIENCE TRAVERSE

The heavy science traverse (HST) fleet, and the SPoT fleet have been occasionally used to support field science departing from SPS. The HST has also proven to be an effective and efficient solution to delivering field supplies because it is not subject to the same restrictions and constraints as small aircraft in Antarctic weather and climate. Cargo traverse platform efficiencies have been proven to bolster SPS cargo capabilities.

CONCERNS

- Many field science experiment teams are delayed when Baslers and/or Twin Otters are not able to fly due to weather.
- The lack of storage and staging areas at the SPS places limitations on overland science traverse.

RECOMMENDATIONS

TR 1 Conduct an analysis assessing the cost-benefits to procuring, operating, and storing light science polar equipped wheeled vehicles based out of SPS for access to Eastern Antarctica science sites.

TR 2 Provide storage space in a future warehouse and VMF building for wheeled vehicles.

NGO/TOURISM

Tourism continues to grow at the SPS and the potential for impacts on the operations and infrastructure will also increase. Separation of uses, especially surrounding the Geographic South Pole, is becoming more important each year.

CONCERNS

- The NGO operations have EMI impacts on Dark Sector and other science facilities.
- Current NGO approach corridors and operations conflict with both Dark and Clean Air Sector science.
- The geographic south pole trajectory needs to be protected for access of NGO visits.

RECOMMENDATIONS

NGO 1 Encourage NGO operators to evaluate new communications equipment and deploy solutions that minimize EMI conflicts.

NGO 2 Maintain current practices and protocols while adapting approach corridors to the Geographic South Pole that account for the movement of the Geographic South Pole to the grid-east of the archway systems.

NGO 3 Transition the NGO campsite to an area closer to the Elevated Station and the NGO aircraft parking area to increase the buffer between the campsite and the Clean Air Sector.

NGO 4 Create an easement over the Geographic South Pole trajectory to prevent future operational and facility conflicts with NGO-visitor foot, ski, and vehicle traffic.

NGO 5 Designate an NGO camp site grid-east of the future Elevated Station. The relocated NGO camp will be located immediately adjacent to the Geographic South Pole trajectory for ease of visitor access and elimination of potential conflicts with operational activities. This would occur when a new station is built around 2060 or beyond.

DOWNWIND SECTOR

AIRFIELD

The Downwind Sector is for the airfield operations. The Sector provides protected airspace for the airfield. The position of the airfield (specifically the clearance zones for departing planes) has been a concern for Clean Air Sector research operations in the past. The clearance zones created by the imaginary surfaces, which overlap areas of the Dark Sector and the Operations Zone, limit development for potential expansion within the clearance zone.

CONCERNS

- Restrictions from the imaginary surfaces on the Dark Sector and Operations Zones ability to utilize areas for new science expansion.
- Conflicts with aircraft flying over the Clean Air Sector.
- The continued use of the LC-130's airframe due to its operational reliance.
- The limitations on crossing the skiway to and from the Dark Sector during flight operations.

RECOMMENDATIONS

AIR 1 Shift the skiway grid-southwest along its existing bearing to open areas for developing new operational facilities and allow freedom of movement into and out of the Dark Sector.

AIR 2 Conduct a cost-benefit analysis to compare other aircraft models versus continued use of LC-130s, Baslers, and Twin Otters for potential cost savings and improved air travel reliability for the USAP.

AIR 3 Explore alternative methods of field fuel cache restocking currently supported by LC-130 airdrops to reduce the number of small aircraft flights required to recover the dropped supplies for each primary flight to the field.

EXPLORING OTHER AIRCRAFT

The use of Baslers and Twin Otters for SPS personnel and field team movement is largely reliant on good weather and requires drawing from SPS fuel supplies. The addition of smaller aircraft that are not as susceptible to poor weather conditions, do not need to refuel at SPS, and do not require a hard surface runway would improve the availability and reliability of air transportation. An airframe with a pressurized cabin and the ability to travel a greater distance without a refueling stop could make it an advantageous addition to SPS operations. However, a comprehensive study of alternative airframes and their snow-based skiway surface compaction requirements is needed. If such airframes are compatible with mission needs and capabilities, a revision to the ASMA and other policies may also be required.

NOAA Balloon Release Time Lapse. Source: NSF, 2016.

Master Plan

The master planning process for the SPS Master Plan started with understanding the history and current conditions (Section 5) of the SPS. This provided a foundation from which area specific concerns were identified (Section 6). The concerns are a compilation of items/issues known to NSF and ASC, identified from the science community, and expressed to the master planning team during the master planning process. To address the concerns, recommendations were provided. The recommendations were evaluated and used to guide the development of the master plan and compile a list of Capital Projects (Section 8). Not all the recommendations are reflected in the physical master plan, as some recommendations are operational or logistics improvements. Additionally, some recommendations are concerning science projects whose planning is beyond the scope of this master plan, and several recommendations are for the completion of additional studies.

This Section looks to the next 35-50 years and presents guidance for how the station area can be developed in an organized manner. Although planning beyond 30 years into the future cannot provide a high level of certainty, a master plan can provide a roadmap for multiple, potential divergent interests to move in the same direction. In the coming decades, priorities, budgets, science, environments, and politics will change. This SPS Master Plan also must change and be updated accordingly as improvements are made at the SPS. This SPS Master Plan should be reviewed every 10 years.

Sub sections of this SPS Master Plan focus on Sustainability, Natural, Historic, and Cultural Resources, Community Health, and Safety provide best practices and guidance in protecting and promoting a viable SPS future.

The last section, Physical Planning, includes physical site arrangements, use relationships, and building forms for SPS infrastructure. The Capacity section conveys the space requirements and building types of the buildings that will replace the arches. Using the building types / forms and sizes as templates, three master plan concepts were developed to evaluate different site planning configurations. The concept plans also look at other station area changes that are designed to address operational and science efficiencies. The preferred master plan is the plan that best achieves the goals and objectives of the SPS Master Plan.

Section 8 is the Capital Infrastructure Plan, which is based on the completion of the preferred master plan and includes a list of projects and associated recapitalization costs.

SUSTAINABILITY

EFFICIENCIES AND ADJACENCIES

The SPS is an assemblage of buildings, structures, and connected underground utility lines that has been constructed over decades without a master plan to guide efficient placement for optimum operations since the first structure was built at the station in 1974. The location criteria of buildings was generally based on “close proximity” to existing buildings with the intention that keeping facilities clustered was good to minimize travel distances. As more and more science projects have been added to the SPS over the years, challenges have materialized that need to be addressed by proposing future building and operational function siting to:

- Minimize exterior exposure.
- Reduce utility runs and distance for logistics movements.
- Reduce snowdrift removal demand.
- Minimize EMI by increasing distances from emitting sources.
- Provide acceptable distances from NGO activities.
- Maintain orientation to the geographic South Pole.

STATION SUSTAINABILITY

A community-produced 2018 report provided some guidance on how to promote a community of sustainability at SPS. The report addressed Community, Environment and People as areas for improved management.

Key goals for environmental sustainability include:

- Introduce renewable energy sources.
- Provide remote monitoring and automation technologies to reduce energy consumption.
- Increase compliance with environmental regulations.
- Improvements to insulation for windows.
- Improvements to human waste management systems by installing a gray-water system.
- The use of lower-energy tech (i.e. LED lights, high efficiency appliances, electric equipment, and vehicles), and associated interfaces with the extreme cold weather environment and science demands (consider & coordinate EMI implications of low power devices to minimize conflict with EMI reduction objectives).
- Replace the arches with energy efficient facilities.
- Consolidate storage items into a single building reducing human and building energy consumption.
- Provide a heated parking facility for winterizing vehicles.

CLIMATE RESILIENCE

The South Pole Station Master Plan seeks to establish a strategic direction for infrastructure investments that will enable scientific research to continue for the next 30-50 years. Over this timeframe climate conditions throughout the continent are projected to change and pose a threat to the continued operation of the station and the upstream suppliers on which it depends.

Antarctica and the South Pole are experiencing profound impacts from climate change, with observable changes in temperature, ice melt, and sea level. According to data from the Intergovernmental Panel on Climate Change (IPCC), the continent of Antarctica has warmed by between 1°C and 3°C, or approximately three times faster than the global average over the past 50 years (British Antarctic Survey). Additionally, ocean currents that transport warm water from the equator to Antarctica have also warmed, resulting in the degradation of the coastal ice network around the continent (Convey & Peck, 2019). Satellite observations confirm this trend and reveal a substantial decrease in sea ice extent around the continent (NASA Earth Observatory, 2009). Climate model projections indicate that these trends are expected to persist (Tewari, Mishra, Salunke, & Dewan, 2022; Comiso, 2000). This could result in over a meter of global sea level rise by the end of the century, the effect of which is only compounded by the continued degradation of the continental ice mass (Davies, 2020).

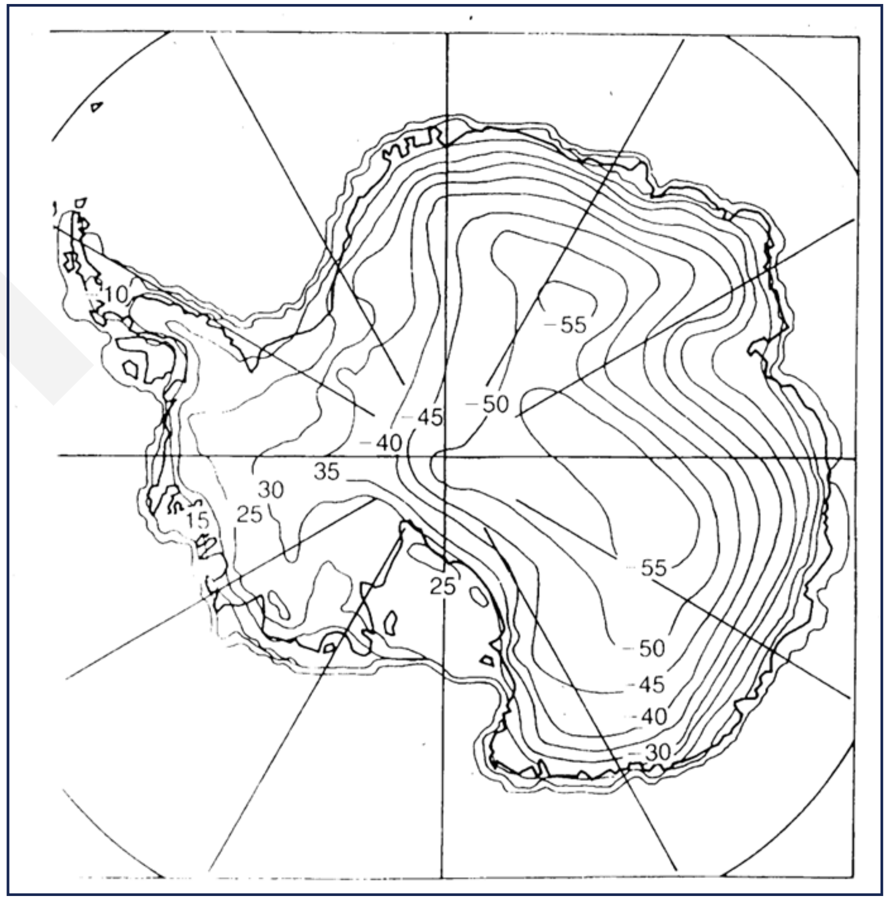


Figure 7.1 Annual mean surface temperature (Linacre & Geerts, 1999) Source: Linacre & Geerts, 1999.

While climate impacts to the Antarctic continent are significant, the location of the SPS at 9,000 feet above sea level and 800 miles inland mitigates some of the climate impacts (National Science Foundation). In terms of temperature, the inland location lessens the threat of localized ice melt even in the face of warming, as annual mean temperatures drop from -10°C on the coast to -60°C at the highest inland elevations (Antarctic Weather, 2019). Additionally, the inland location will not be affected by the combined threat of coastal degradation and sea level inundation. However, while such a remote location may be a benefit in terms of resilience to these hazards for the South Pole Station itself, the remoteness enhances the vulnerabilities that may exist amongst key nodes within the station’s supply and operational network. To ensure a climate resilient SPS, the climate threats across all the station’s upstream operational sites, such as McMurdo Station, should be evaluated using a scenario analysis of the latest climate model projection data to inform localized resilience strategies for each. A similar approach can also confirm the vulnerabilities, or lack thereof, that may exist to the SPS from changes in climate conditions like temperature and precipitation.

A preliminary investigation into future climate projections at and around the South Pole found that studies to date have focused on the Antarctic continent as a whole or on regions such as the Antarctic Peninsula, Western Antarctic, or the Eastern Antarctic. Studies also generally focused on temperature and precipitation trends while there was a lack of study with a geographic focus on the South Pole and no studies were identified that focused on future ice sheet movement. Findings from the preliminary investigation are summarized below.

Temperature-related findings for Antarctica parallel those in the rest of the world, with Antarctic temperatures also projected to increase in the coming decades. For example, using the latest climate model data, Bracegirdle et al. (2020) indicate that the end-of-century Antarctic surface-air temperature is expected to increase between 1.3°C and 4.8°C when compared to the time period of 1995–2014. Tewari et al. (2022) project about a 5°C increase by the end of the century under a high emission scenario (RCP8.5 or SSP5-8.5) as shown in and below. Similar changes are indicated by other authors as well (Beaumet et al. 2021; Zhu et al. 2023). According to the Intergovernmental IPCC there is medium confidence in the increase of extreme heat events (warmer days and nights, for example) for Antarctica. IPCC also indicates that there is low confidence in the decrease of cold spells over the continent (Ranasinghe et al. 2021).

Precipitation is also expected to increase due to an increase in the water holding capacity of the warming air. Palerme et al. (2017) projects between a 9.6% and 39.6% increase in annual precipitation for the continental interior (with elevation above 7380 feet or 2250 m) by the 2080-2099 time period when compared to 1986-2005. Meanwhile, Krinner et al. (2019) indicate a 41% increase in precipitation by the end of the century based on a global atmospheric model under a high emissions scenario. Using the latest climate models, precipitation rate changes were projected to be between 8% and 31% by the end of the century by Bracegirdle et al, (2020). Beaumet et al. (2021) also indicate an increase, and Tewari et al. (2022) project a 44% to 50% rise in precipitation under a high emissions scenario. This increase is considered “very likely” according to the IPCC report from 2021 (Ranasinghe et al. 2021) and there is a “medium confidence that some of the coldest regions will see higher total snowfall given increased precipitation”.

Snow accumulation depends on the amount of precipitation and a variety of processes such as sublimation, evaporation, meltwater run-off, and blowing snow (Palerme et al. 2017). In the interior of the Antarctic ice sheet precipitation is usually very light due to very low temperatures (Palerme et al. 2017). A large fraction of the precipitation there “falls in the form of ‘diamond dust’ (ice crystals) under clear sky conditions” (Bromwich 1988; Fujita and Abe 2006, cited in Palerme et al. 2017). Snow accumulation is expected to increase in the future. Krinner et al. (2019) found that continental-scale snow accumulation (precipitation minus sublimation) is projected to increase by approximately 6.9% per degree (Celsius) of warming. Similar results of about 5% per degree Celsius (+/-1%) are indicated by Frieler et al. (2015).

While these studies aid in the understanding of climate change trends, climate data geographically tailored to the South Pole Station may be able to inform a more detailed vulnerability assessment that can be used to determine the adaptations necessary for the station operation to continue unabated in the face of a changing climate.

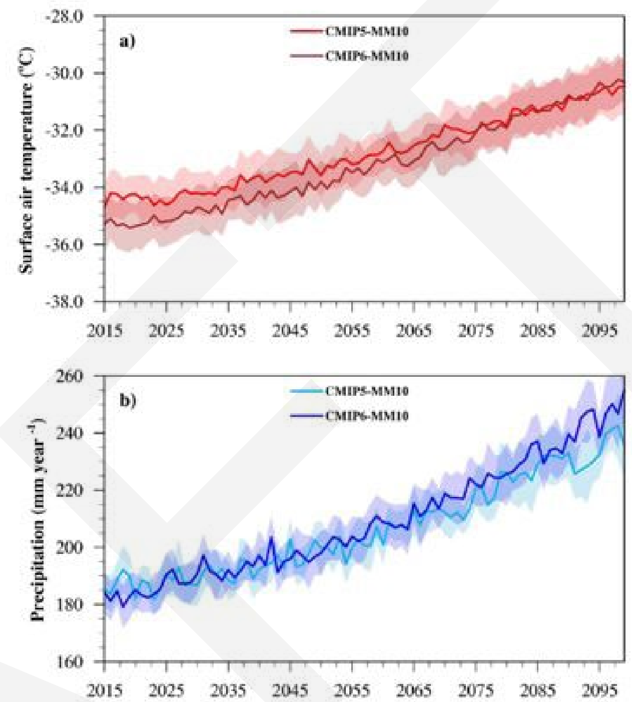


Figure 7.2 Time series of a) annual mean surface air temperature and b) annual precipitation rate over the Antarctic landmass. Source: Tewari et al., 2022.

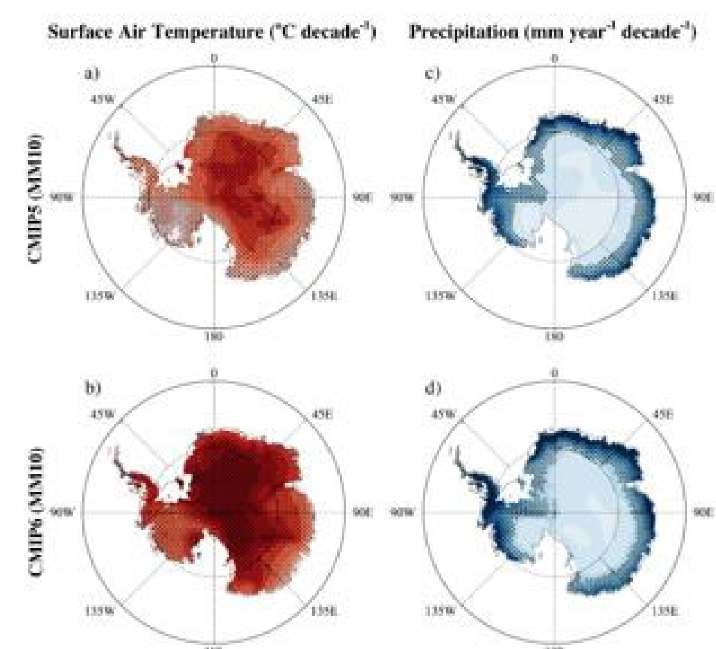


Figure 7.3 Decadal change in a) mean annual surface air temperature and b) annual precipitation over Antarctica. Texture indicates values are significant at a 99% confidence level. Source: Tewari et al., 2022.

CITATIONS

“Amundsen-Scott South Pole Station | NSF - National Science Foundation.” Accessed November 14, 2023. https://www.nsf.gov/geo/opp/support/southp.jsp.

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British Antarctic Survey “Discovering Antarctica.” “Impacts of Climate Change.” Accessed November 14, 2023. https://discoveringantarctica.org.uk/climate-change/impacts-of-climate-change/.

Comiso, Josefino C. “Variability and Trends in Antarctic Surface Temperatures from In Situ and Satellite Infrared Measurements.” Journal of Climate 13, no. 10 (May 15, 2000): 1674–96. https://doi.org/10.1175/1520-0442(2000)013<1674:VATIAS>2.0.CO;2.

Convey, Peter, and Lloyd S. Peck. “Antarctic Environmental Change and Biological Responses.” Science Advances 5, no. 11 (November 27, 2019): eaaz0888. https://doi.org/10.1126/sciadv.aaz0888.

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Linacre, E., and B. Geerts. “Surface Temperature in Antarctica,” June 1999. http://www-das.uwyo.edu/~geerts/cwx/notes/chap03/antarctica.html.

Tewari, Kamal, Saroj K. Mishra, Popat Salunke, and Anupam Dewan. “Future Projections of Temperature and Precipitation for Antarctica.” Environmental Research Letters 17, no. 1 (January 2022): 014029. https://doi.org/10.1088/1748-9326/ac43e2.

CIRCULATION

SPS is primarily managed as a pedestrian campus in both the summer and winter seasons. Circulation routes are not defined by paved roads, but rather by plowed corridors and marker flags. Circulation must be efficient and direct to conserve vehicular fuel consumption. Due to the extreme climate conditions, minimizing pedestrian exposure outside is critical. A general rule for pedestrian routes is that one kilometer is the maximum safe distance to walk between heated buildings or facilities, especially during the austral winter. Safe vehicular or motorized distances are based on the type of vehicle, such as, a vehicle with a heated compartment versus a snow mobile or traveling with skis.

Road to berms. Source: NSF, 2023.

The SPS Master Plan considers distances between buildings and operations in the future facility plan layout. Establishing efficient, direct routes and safe distances will be a primary basis of design.

NATURAL, HISTORIC, AND CULTURAL RESOURCES

MISSION COMPATIBILITY

HISTORIC SOUTH POLE SITE PRESERVATION

Preservation of the location of the Historic South Pole is Governed by ASMA No, 5. Located grid north of the MAPO blue building in the Dark Sector, the historic site is protected within a Restricted Area. This area will continue to be protected in the master plan.

Historic Significance:

- HSM No. 1 (1972) to memorialize the flag mast erected by the First Argentine Overland Polar Expedition in 1965.
- HSM No. 80 to recognize Amundsen's tent which was erected by the Norwegian expedition upon their arrival in 1911; the first expedition to reach the South Pole.

PROTECTION OF CEREMONIAL SOUTH POLE

The "Ceremonial South Pole" established by the United States commemorates the 1957/58 International Geophysical Year and all expeditions that have reached the South Pole. The ceremonial location will continue to be a prominent feature, but as the Geographic South Pole moves and a new Main Station is relocated in the future, the ceremonial location will also be relocated.

PROTECTION OF GEOGRAPHIC SOUTH POLE TRAJECTORY

The Geographic South Pole appears to "move" due to the constant flow of the ice sheet on which the SPS is located. The ice sheet shifts approximately 32.81 feet (10 meters) per year. To protect the path of the Geographic South Pole, the SPS Master Plan will provide an easement along the trajectory of the Geographic South Pole. The easement will prevent any buildings or structures from being constructed within the easement and will also stipulate that all buildings and structures be setback a specified distance from the easement.

NATURAL ENVIRONMENT

SNOW MANAGEMENT/SNOWDRIFT

One of the primary natural environmental determinants at SPS is snowdrift. Snowdrift clearance is a constant management operation required to keep the buildings and structures from being buried. The following is an excerpt from a Snowdrift Guidance study, 2006, that summarizes how snowdrifting is analyzed and the importance of placing buildings and structures to minimize snowdrift impacts.

"Various snow simulation "tools" are available to predict snowdrift patterns around buildings. The selection of the "right" analytical tool is not only driven by the level of detail required in the results, but also by budgetary constraints. Physical scale model tests in water flumes and wind tunnels are well suited to short duration and repetitive investigations of wind and snowdrift patterns. For example, the effects of changes to a building mass or feature on local wind or snowdrifting can be readily assessed. Computer simulation techniques are more labor intensive to perform and are more appropriate when an increased precision in the prediction of detailed wind flow and snowdrift patterns is required.

Key design guidance derived from the snow simulation studies included the need to sufficiently elevate buildings above the snow surface and to orient a row of linked buildings perpendicular to the prevalent winds. Of equal importance is to understand that snowdrifting will invariably occur and that sensitive activities should be located away from the snow deposition area."
Source: Waechter, B. and Williams, C. 2006, "Snowdrift Design Guidance for The New South Pole Station." Pg. 68
Design Recommendations for future work at the SPS were included in a 2006 presentation with the following recommendations:

- Additional computer modeling should be undertaken to refine the design. C-shape Buildings, links and vertical circulation tower concept tested should be retained in the design of the replacement Science Facilities at the South Pole.
- Snowdrift deposition around the entire future station (buildings, tower and links) should be predicted through Finite Area Element (FAE) and Computational Fluid Dynamics (CFD) computer modelling techniques.
- Long term (5-year, 10-year, etc.) snow deposition around the entire future station should be predicted through computer modeling techniques (CFD and FAE).

Another study, “Effects of Support Structures Porosity on the Drift Accumulation Surrounding an Elevated Building”, Song, A. and Haehnel, R. 2012, provides additional guidance for future buildings at the SPS.

“In austere environments, such as Antarctica, snowdrift accumulation around buildings not only presents safety hazards to personnel, but also can significantly shorten the service life of the building. Elevated structures are a common and effective design strategy to combat drift accumulation in proximity to buildings. However, the foundation structure or substructure that is used to elevate the building above grade may impede or choke off the flow thereby increasing the drift accumulation and reducing the effectiveness of elevating the building.”

“Some features under the building, such as the support structure, can promote drifting close to the building and cause the drift to rapidly encroach on the building. This is a potentially dangerous drifting behavior that may also lead to a shorter building service lifespan. We observed that a substructure composed of a dense matrix of support posts increased the rate that the drift approached the front of the building by 1.5 times. But, porosity was not the only factor affecting drift encroachment. The support structure may have span-wise cross members. These will serve as nucleation points for drift formation and allow the drift to form much closer to the building than would occur for a substructure clear of these features. Careful thought during the design phase needs to be given to avoiding such structural features that promote drifting. The results of this study suggest that applying such care in the design could prolong the life of a building having the same configuration as the MAPO by 2 or more years.”

One recent study, “Amundsen-Scott South Pole Station Snow Drift Simulation Overview”, CRREL, 2021, presented the following conclusions:

Though changes in drift volume vary with extents of region chosen to calculate volume, overall trends change little with region extents shown here.

- *West drift volume increases when Pod B is raised (either independently or with entire station).*
- *Total drift volume is reduced when the station is lifted (all lift scenarios).*
- *Total drift volume is reduced the most when Pod A is lifted first (5 – 8%).*
- *Drift Volume over arches is reduced the most (5 – 9%) when Pod A is raised (either independently or with entire station).*
- *Changes in drift volume for all cases, in comparison to baseline, is generally less than 10%.*

Snowdrift formation on Rodwell Building. Source: NSF, 2023.

Snowdrift pile behind Elevated Station. Source: NSF, 2023.

Future buildings at the SPS, i.e., the replacement of the arches and a Main Station replacement, will need to be located with snowdrift mitigation as a primary basis of design.

COMMUNITY HEALTH

MORALE, WELFARE, AND RECREATION

Being stationed at SPS for an extended period can pose challenges to the community of personnel. Especially those who are stationed at the South Pole over the austral winter. Maintaining physical and mental health and providing a safe environment is critical to sustaining a healthy station environment. A key part of maintaining a healthy, safe work environment is in providing support services for both mental and physical health. Each year an Amundsen-Scott South Pole Station Guide is issued outlining all the services and resources available at the station. Contained in the guide are resources for emergency response, safety, medical services, recreational resources, faith-based services, and mental counselling.

Within the Elevated Station there are various facilities that are accessible to residents to be utilized for maintaining physical, mental, and emotional health. These include a library, lounge, café / bar, dining room, workout room, a gymnasium, and a green house. All these facilities should be maintained, and personnel encouraged to use them as they see fit to foster good physical, mental, and emotional health. The following spotlight on Health and Wellbeing highlights some best practices for personnel stationed at the South Pole to consider.

SPOTLIGHT ON HEALTH AND WELLBEING

GREEN SPACE FOR IMPROVED WELLBEING

The ability to directly view and/or interact with green spaces has been proven to improve mental wellbeing and recovery rates in a variety of international medical studies since the 1980s. Green space, in the context of the built environment, traditionally refers to areas partially or completely covered with vegetation, such as parks, green roofs, and community gardens. In absence of the ability to provide outdoor green space at the South Pole, the internal green space provided by the station greenhouse should be leveraged to the fullest extent practical.

Slater SJ, Christiana RW, Gustat J. Recommendations for Keeping Parks and Green Space Accessible for Mental and Physical Health During COVID-19 and Other Pandemics. Prev Chronic Dis 2020; 17:200204. https://pubmed.ncbi.nlm.nih.gov/25874859/

DAYLIGHTING FOR IMPROVED WELLBEING

Exposure to natural light generally improves mental health and feelings of wellbeing across all ages, cultures, and geographic locations. When sufficient natural light is not available (as is the case during the austral winter at the South Pole), daylighting technologies may help reduce the impacts of the loss of natural light exposure. However, the color of the artificial light is critically important, as blue lights have been shown to be more disruptive to circadian rhythms. Sleep deprivation and sleep disorders due to the unusual natural light experienced at the South Pole is a serious year-round concern. In the winter, reduced exposure to natural light and subsequent low-quality sleep has been linked to the development of mental health disorders, such as anxiety and seasonal affective disorder (SAD). In the summer, 24 hours of light can disrupt sleep patterns in a similar fashion if the population is unable to reduce their exposure to the light before bed. Reducing or eliminating natural light exposure at least two hours before bed has been shown to improve sleep quality and reduce the chances of developing a sleep disorder.

Marqueze EC, Vasconcelos S, Garefelt J, Skene DJ, Moreno CR, Lowden A (2015) Natural Light Exposure, Sleep and Depression among Day Workers and Shift workers at Arctic and Equatorial Latitudes. PLoS ONE 10(4): e0122078. https://doi.org/10.1371/journal.pone.0122078

PRIVACY FOR IMPROVED WELLBEING

The ability for people to control their immediate surroundings has been shown to reduce feelings of helplessness, anxiety, and depression. Private bed spaces allow SPS personnel to control their level of personal social engagement, which helps reduce feelings of irritability and anxiety. The rooms offer a respite in an often crowded and isolated area that may otherwise become overwhelming.

Evans GW. The built environment and mental health. Journal of Urban Health. 80(4):536-555, 2003. https://www.ncbi.nlm.nih.gov/pmc/ articles/PMC3456225/pdf/11524_2006_Article_257.pdf | Basic Information about Sleep and Fatigue: Effects of light. The National Institute for Occupational Safety and Health (NIOSH). 2020. https://www.cdc.gov/niosh/emres/longhourstraining/sleepfatigue.html

PHYSICAL ACTIVITY FOR IMPROVED WELLBEING

Physical activity provides a plethora of health benefits beyond body composition and weight management. Regular activity lowers blood pressure, cholesterol, and the risk of a wide variety of chronic illnesses, such as Type 2 diabetes and certain cancers. Bursts of moderate-to-vigorous activity also stimulate the brain to release endorphins that can help manage feelings of anxiety and depression in adults, and regular activity of this intensity has also been proven to help regulate sleep cycles—a critical health concern for the SPS population.

Benefits of physical activity. Center for Disease Control & Prevention. 2021. https://www.cdc.gov/physicalactivity/basics/pa-health/index. htm?CDC_AA_refVal=https%3A%2F%2Fwww.cdc.gov%2Fphysicalactivity%2Feveryone%2Fhealth%2Findex.html

SOCIAL INTEGRATION FOR IMPROVED WELLBEING

Building a positive sense of community is essential for isolated populations that depend on each other to survive. Social interactions remain positive when they are integrated into people's daily lives but also easily controlled on an individual level. In residential built environments, having a wide variety of social spaces of various sizes has been shown to give residents a sense of agency and stability. This helps create a positive environment where each person can develop a sense of security and belonging within a larger group.

Evans GW. The built environment and mental health. Journal of Urban Health. 80(4):536-555, 2003. https://www.ncbi.nlm.nih.gov/pmc/ articles/PMC3456225/pdf/11524_2006_Article_257.pdf

REDUCED NOISE POLLUTION FOR IMPROVED WELLBEING

While extremely loud noises are often considered to have the biggest impact on physical wellbeing, sustained levels of noise pollution can have a similarly disruptive effect on the population exposed to it. Reactions to noise pollution include, but are not limited to, heightened levels of anxiety, frustration and annoyance, cognitive impairment, and poor sleep quality. Prolonged poor sleep quality can contribute to the development of insomnia and the related physical and mental impacts of chronic fatigue. Sounds proofing or dulling materials should be considered in the construction of spaces that will be regularly occupied, and ear plugs or white noise machines should be recommended or made available as sleep aids while on station.

World Health Organization. Healthy Environments for Healthier People. 2018. https://www.euro.who.int/__data/assets/pdf_file/0006/367188/eceh-eng.pdf

SECURITY AND SAFETY

SITE SECURITY AND SAFETY CONSIDERATIONS

Station security for the SPS is managed from McMurdo. Security from external forces at SPS has not been an issue due to the location. Internal security issues such as personal conflicts or aggressions would be managed by the NSF McMurdo Station Manager, who is also the Special Deputy US Marshal.

For significant events, emergencies are managed at a program level by the McMurdo Emergency Operations Center, which makes resource distribution decisions. Incident command of the SPS brigade remains local. Examples of large events conducted out of SPS include aircraft emergencies, Search and Rescue operations for field groups, aid to other national programs or private expeditions, humanitarian aid, international diplomacy, and medical evacuations.

Medical facilities at SPS are located in the Elevated Station for on-station medical needs, but the location of emergency service equipment, supplies, and servicing areas does not provide ease of access. Medical supply storage, for example, is located on the lower level of the station, while the medical center is located on the upper level. Storage for emergency response team gear was not included in the Elevated Station plans. The gymnasium provides adequate space for staging and response in the event of a mass-casualty or large-scale emergency response. However, none of the medical servicing areas are located for ease of access during patient transport.

The Elevated Station and arches primarily employ a water sprinkler fire suppression system. The power plants and certain information technology spaces are equipped with gas-led suppression systems. Auxiliary structures outside of the Elevated Station employ localized fire suppression systems that are meant to protect only specific high-value equipment. These systems are subject to annual maintenance and testing to ensure code compliance and reliability.

SEXUAL ASSAULT / HARASSMENT PREVENTION AND RESPONSE (SAHPR)

The NSF will not tolerate harassment or assault within the agency or at awardee organizations, United States Antarctic Program (USAP) stations and field sites, or anywhere science or education is conducted. The safety of all personnel, grantees, and visitors at SPS is paramount to the success of the USAP's mission; no person should feel that their personal safety or bodily autonomy is at risk at SPS. NSF is also dedicated to holding people accountable for their actions and to working closely with the NSF Office of Inspector General and other law enforcement officials when appropriate.

In response to the 2022 Sexual Assault and Harassment Prevention and Response (SAHPR) Report (NSF, OPP, USAP; Final Report, June 22,2022), the SAHPR Office was created to serve as NSF's central point of contact for reporting sexual assault and harassment incidents in the U.S. Antarctic Program. The SAHPR Office is also responsible for overseeing comprehensive prevention policies and practices. Its mission is to promote safe and inclusive research environments by eliminating instances of sexual assault and sexual harassment through prevention education, victim-centered support, retaliation-free reporting and organizational accountability.

In addition to communication, reporting, and accountability initiatives instituted by the NSF, the following built environment strategies are to be incorporated into the design of new structures at SPS wherever feasible as part of NSF's comprehensive sexual assault and harassment prevention strategy:

- Provide single-occupancy locked bedrooms.
- Provide CCTV/surveillance.
- Reduce dead-end corridors.
- Improve lighting.
- Improve communications tools.

PHYSICAL PLANNING

CAPACITY - DEVELOPABLE AREAS

One of the first steps in a master plan of an existing site, is identifying where future development can occur. The developable areas map identifies these areas. These areas are free of buildings, structures, and subsurface utilities or obstacles that cannot be relocated. They are areas where new improvements are less likely to interfere with current science. At SPS there are numerous utility lines buried in the ice, abandoned outfall, outbuildings, and antennas that could be relocated if needed freespace for expansion. The shaded areas in Figure 7.4 are areas that are off limits to future improvements. The areas outside of the red dashed line and inside the Operations Zone, are potential developable areas. However, all future improvement projects at the SPS will require site specific investigations to confirm suitability for development. Every location being considered for development at SPS also needs to be evaluated for EMI, impacts on science, utility connections, and walkability during winter months.

South Pole Station Aerial. Source: NSF, Undated.

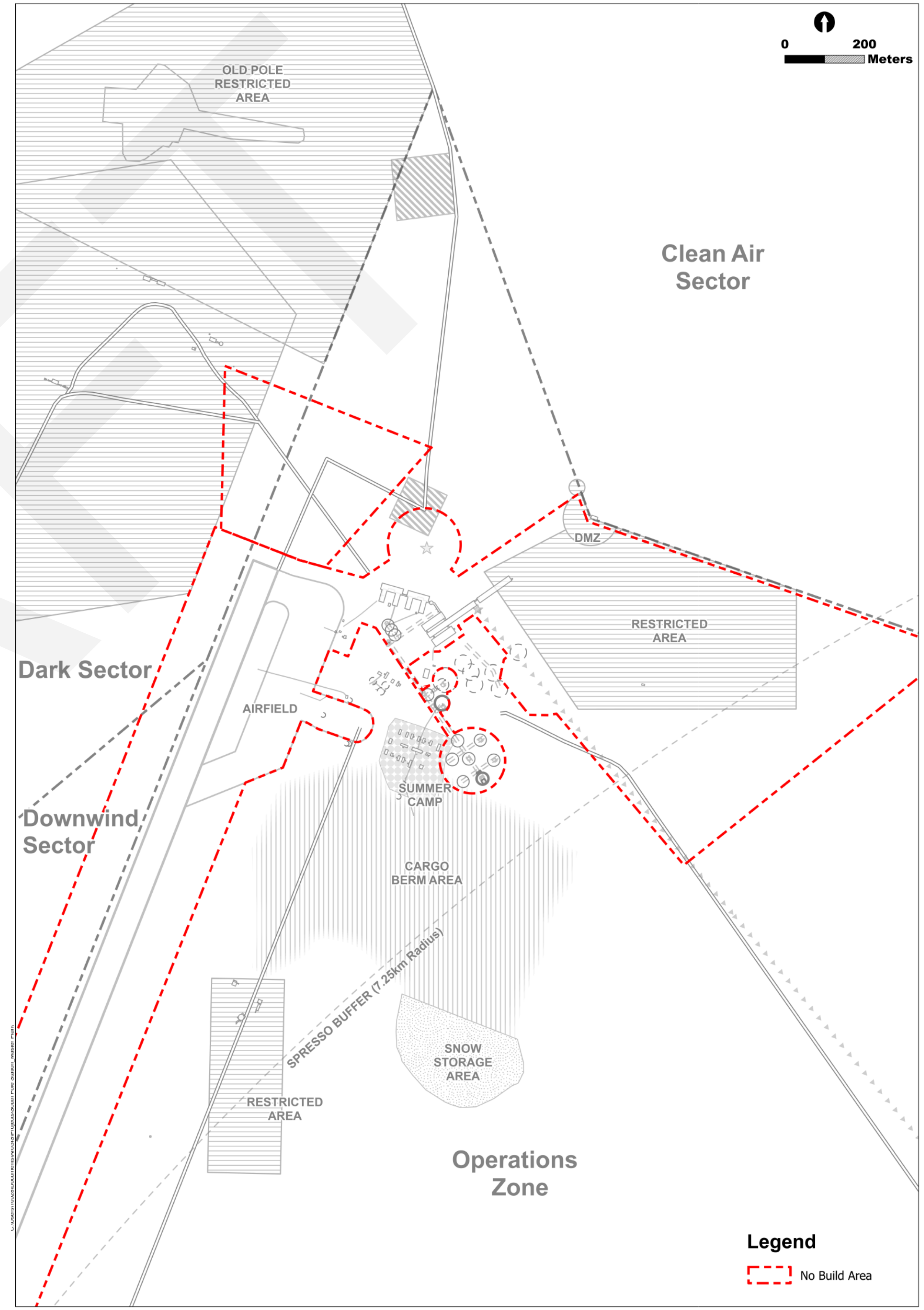


Figure 7.4 No Build Areas.

CONCEPTUAL BUILDING FORMS

There are four key structures at the SPS that are in need of replacement. These structures include the Power Plant, Fuel Storage, VMF, and the Logistics / Warehouse building. The SPS Master Plan has considered the approach to replacing each of these buildings. The replacement structures should be sized to meet current and projected needs. A square footage assessment was conducted for each building to determine a proposed footprint size. Three different building types were then explored for suitability for the Antarctic conditions at the SPS. Building templates were developed and used to layout three conceptual layouts for consideration in the SPS Master Plan.

SQUARE FOOTAGE ASSESSMENT

The gross square feet (GSF) of building footprint of the arches are summarized below.

Existing Arches Square Foot Assessment

BLDG #	NAME	USE	STRUCTURE	ARCH GSF	REPLACEMENT GSF
101	Garage Shops	Vehicle Maintenance	Metal Arch	13,068	18,000
103	Power plant	Power generation	Metal Arch	11,542	12,000
104	Fuel Facility	Fuel storage	Metal Arch	15,275	16,000
109	Logistics (warehouse)	Cargo Storage	Metal Arch	22,137	55,000

TABLE 7.1

To determine the size for replacement buildings the following assumptions were made:

- The Power Plant building would assume the same footprint for the generators. A new building would increase by 10% for storage and office space. The building size used for the master plan concepts is 12,000 square feet (sf).
- The Fuel Facility assumed the same footprint as the existing structure, plus 10% for storage, and access. The footprint size used for the master plan concepts is 16,000 sf.
- The size of a new Grage Shops (VMF) structure was determined by the SPS based on the desired number of bays, vehicle parking stalls, storage, and office space. The footprint size used for the master plan concepts is 18,000 sf. An additional new building was recommended for the storage of vehicles and equipment over winter months. A heated parking structure is an optional building being considered. The footprint size of a heated parking structure is 30,000 sf.
- The logistics/warehouse will be sized to accommodate the station storage items that were identified to move into a structure. Table 1 tabulates the total square feet of stored items throughout the SPS. The square foot number represents the actual footprint of the store item. Aisles, space between shelves, common areas and offices are not included. Table 2 represents a tabulation of which stored items should move into a building, which items are optional to be in a building, and which items can stay outside or at their current location.

Current Stored Material Inventory

	SQUARE FEET OF STORAGE ITEM					
STORAGE TYPE	BERMS	OUT BUILDINGS	ARCHES	ELEVATED STATION A	ELEVATED STATION B	TOTALS
Construction	12,160	0	0	0	0	12,160
Emergency Management	160	0	180	100	0	440
Fleet	6,400	0	3,760	0	0	10,160
Food/Dry Good	0	560	0	91	0	651
Fuels	160	320	0	0	0	480
Greenhouse	0	0	0	68	0	68
IT/Communications	160	0	0	124	237	521
Janitorial	4,000	0	0	102	99	4,201
Lodging Supplies	0	563	0	48	55	666
Maintenance	22,960	2,922	56	8	118	26,064
Medical	0	0	0	0	66	66
Miscellaneous	0	0	0	38	0	38
Postal Service	0	0	0	12	0	12
Recreation	0	0	0	0	100	100
Science	640	1,126	0	0	0	1,766
Store Stock	160	0	0	0	0	160
Utilities	4,800	0	624	0	0	5,424
Waste	1,160	0	0	0	0	1,160
TOTAL	52,760	5,491	4,620	591	675	64,137

TABLE 7.2

* The square foot numbers represent the actual footprint of the material, i.e. the size of a pallet.

Existing Arches Square Foot Assessment

MOVE TO ARCHES (SF) Includes 560 sf DNF

29,720	Berms
5135	Outbuildings
102	E-S A
176	E-S B
4,620	Arches
39,753	**TOTAL**

OPTIONAL MOVE/STAY (SF)

10,720	Berms
36	Outbuildings
201	E-S A
192	E-S B
0	Arches
11,149	**TOTAL**

STAY IN CURRENT LOCALE (SF)

12,320	Berms
320	Outbuildings
288	E-S A
307	E-S B
0	Arches
13,235	**TOTAL**

TABLE 7.3

To determine the size of a new logistics/warehouse structure, a building was sized to accommodate the items identified by ASC as "Move to Arches" in the reallocation of storage items chart above. The 39,753 sf of material is the net footprint of storage. A multiplier of 1.38 was used to account for additional space for aisles, and offices. The GSF used for the master plan is 55,000 sf. Estimating a building footprint assumed storage racks could be stacked three pallets high, approximately 20 feet and assumed 12 feet access aisle. The arch and dome building types accounted for the loss of stack high due to the curvature of the ceiling.

CONCEPTUAL BUILDING FORMS

Four facility needs were identified that need near-future upgrades for the modernization of the station: a power plant, fuel storage, vehicle maintenance facility, and logistics warehousing. These facilities will replace existing structures at the site which may be removed or repurposed. An evaluation was conducted to determine building forms and locations which are presented in the site plan options.

Logistics Operations building inside Arch.Source: NSF, 2023.

ELEVATED STRUCTURES

Elevated structures, which would be constructed in a similar configuration to the Elevated Station, are an option for consideration for the replacement structures. The elevated structure provides clearance under the facility footprint such that wind and wind driven snow is free to flow underneath the structure. This elevated structure approach drastically reduces the air stagnation point at the windward face of the building and aerodynamic shade at the leeward face of the building, reducing windward and leeward drift accumulation. Air velocity also increases when flowing underneath elevated structures, reducing wind driven snow deposition underneath the building. The Elevated Station also features an airfoil shape on its windward face that acts to further increase wind velocity underneath the structure.

The existing Elevated Station was constructed on a grid of grade beams embedded in ice. A network of columns projects upwards from the grade beams. Each individual column is adjustable to account for differential movements of the icepack. Additionally, the station was designed to be lifted globally by as much as 13 feet, twice in its lifetime.

Building on the success of the Elevated Station, elevated structures considered for future infrastructure should be designed to be both easily adjusted for differential movements and have the ability to be lifted globally in the event of widespread snow deposition in the vicinity of the structure.

PROS

- Longevity. Individual support legs of the structure can be adjusted to account for snowpack differential settlements. The entire structure can be globally lifted when necessary.
- The elevated feature greatly reduces the effects of snow drifting both underneath the facility and at the building perimeter.
- Reduced ongoing labor required to address drifting and maintain access to the facility.
- Can be subdivided into 'pods' which allow non-critical areas to be sealed off in the event of a critical power failure to conserve resources.

CONS

- Cost. The complexity of this type of building form is greater than the others considered. This results in additional material and labor for the construction translating to higher cost.
- A global building lift has not been conducted at the Elevated Station. Therefore, the cost and challenges of this effort are not well defined.
- This, however, may be considered a positive result. It would seem the elevated approach and airfoil shape of the structure effectively mitigates drifting, negating the need for periodic large-scale lifts of the structure.

Columns Supporting the Elevated Station. Source: NSF, Jack Corbin, 2008.

ARCHES

Arches are used extensively at the South Pole for a variety of functions including the powerplant, fuel storage facility, various materials storage, and vehicle garage space. The arches provide coverage to interior building structures. The interior buildings have historically been constructed on their own footings. Though not without pitfalls, they are a proven construction method at this site with a building history dating back to the 1970s when the first arches were built.

If used for future infrastructure, new arches should not be recessed into the ice to match surrounding building foundation elevations. This approach reduced the life of the vehicle maintenance facility and the powerplant, which were constructed to match the foundation elevation of the existing arches. Instead, arches should be built at an elevated grade, atop a reinforced snowpack.

PROS

- Simple, efficient construction. While all construction at the Pole has complexities, compared to other options considered, the arches provide a simpler alternative that can be constructed relatively quickly.
- Light weight and modular. The individual ribs used to construct the domes nest within themselves during transportation, are light and efficient (relative to other structure types) and are straightforward to assemble.
- Lower cost compared to elevated structures.
- Arches are a tested solution at the South Pole. The fuel storage arch and logistics arches were constructed in 1974. The drawbacks are known from multiple installations of this form and therefore their performance over time is predictable.
- Snow floors can be regraded periodically to counteract long term snowpack settlement along arch bearing lines.

CONS

- Arch clear spans can only be so wide, this is a limiting factor in building overall dimensions.
- Due to the covered nature, the interior building windows are limited to facing the entry. Therefore, access to natural light is limited.
- Entry points are generally limited to the open face of the arch.
- Susceptible to burial from snow drifts.
- Historically snow drift loading on the arch has caused structural damage in the form of local buckling of the steel ribs. However, this can be mitigated in future designs by increasing the steel gauge and adjusting the profile of the steel ribs.
- Snow floors experience “doming” over time where the center portion of the snow floor appears to be crowning. This causes the interior overhead clearance to reduce significantly over time. So much so that the interior structure approaches the height of the dome, eventually making contact, compromising the integrity of the facility.
- The actual failure mechanism is that the snow floor is experiencing settlement at the bearing lines due to long-term loading. This settling is both caused by snow consolidation under applied loading and the long-term deformation, or “creep” of ice and snow under sustained loading. Settlement at bearing lines causing the floor doming effect can be partially mitigated by providing wider footings at the arch bearing lines. Additionally, a structurally rigid floor that spans from beneath one side of the arch to beneath the other would better distribute the arch load and lessen differential settlement at the bearing lines. While the doming rate can be slowed, it cannot be eliminated and releveling of the floor will be required as a periodic maintenance item.
- Unlevel floors, where floors are constructed overtop of the ice surface, can create unsafe conditions for the operation of equipment such as forklifts. This can impact the ability to retrieve supplies and relocate stockpiles of station supplies if used for a warehousing function.
- Significant labor is required to clear snow drifts at the entries.

Arches and Covered Buildings during Construction. Source: NSF, 1999.

GEODESIC DOME

The station previously included a large aluminum dome that served to protect structures within from the harsh climate at the Pole. The dome remained in place for 30 years before it was deconstructed following the completion of the Elevated Station, housing many of the functions that began as dedicated structures under the dome.

The half-sphere shape offers benefits to the station, particularly related to maintenance associated with snow drift management. Unlike angular structures that accumulate snow on flat surfaces, the rounded shape reduces potential for accumulation with the wind flowing around the sides, reducing the drifts on both the windward and leeward sides. This inherent ability to resist snow accumulation enhances the overall longevity of the structure.

The dome was a critical portion of the station layout upon its construction, providing protection to the galley, science, and comms structures, among others. The dome was connected to other infrastructure buildings including the power plant and garage through a network of connectors.

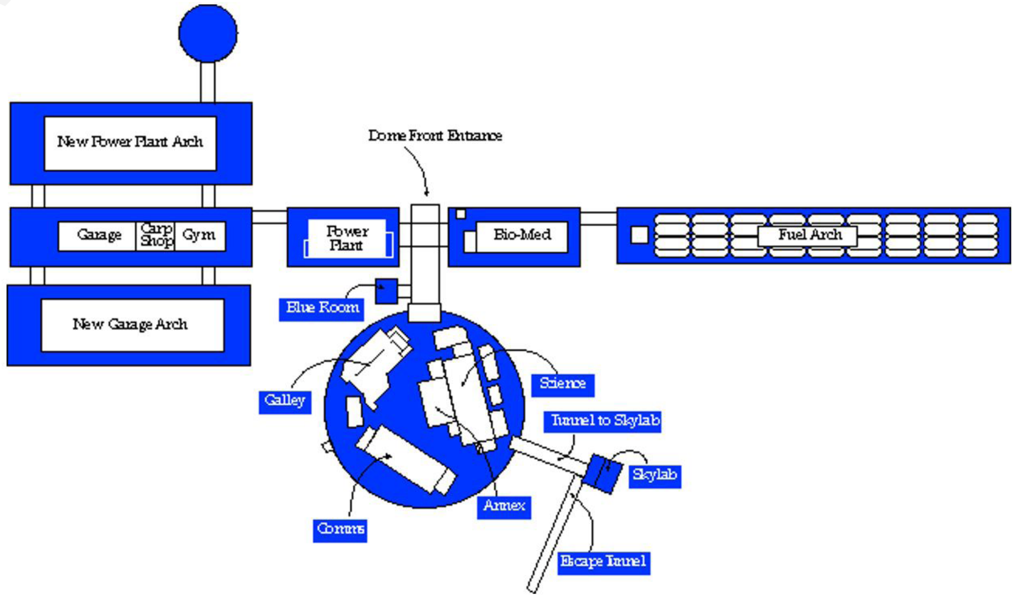
PROS

- The aerodynamic shape of the dome minimizes the accumulation of snowdrift at both the leeward and windward sides of the structure. Over time a moderately sized but stable drift forms around the building. This stable drift pattern requires less snow removal maintenance than other at-grade rectilinear shaped structures.
- Interior structures are protected from snow loads.
- Free space within the dome could be used as an alternative to berm storage for small quantities of materials or materials that do not need long term storage.
- Due to the panelized nature of geodesic domes, some panels can be translucent, bringing natural light or diffuse light in abundance into the space during summer months.

CONS

- The dome is not as efficient for use of square footage as rectangular structures due to its circular floorplan and the low headroom at the perimeter. The curved walls result in unused square footage within the dome when accounting for vehicle and pedestrian travel paths and facility access.
- Dome clear spans can only be so wide, this is a limiting factor in building overall dimensions.
- A ventilation system is required to ventilate the dome's interior from emissions from the structures within.
- The dome cannot be easily subdivided. This prohibits segments/areas within the dome from being sealed off in the event of a critical power failure in which the station would need to conserve resources.
- Structural settlement due to creep. Similar to other surface structures like the arch, the dome will experience settlement as the supporting snow and ice experience creep caused by building loads at the perimeter. This creep can be slowed by distributing the dome's reaction forces over a wider area, but foundation settlement due to creep will occur.

The original station dome during deconstruction in 2009. Source: https://antarcticsun.usap.gov/features/1984/.



The dome and station interconnectivity. Source: https://antarcticsun.usap.gov/features/1984/.

SNOWDRIFT CONSIDERATIONS

Drift modeling will be an essential component to siting and building new permanent structures. In addition to the new structures discussed here, passageways between facilities and existing infrastructure are anticipated to impact drift characteristics of the overall site and should be an integral component of future drift modeling. While drift modeling will ultimately inform locations of structures, each master plan concept discusses general drift characteristics.

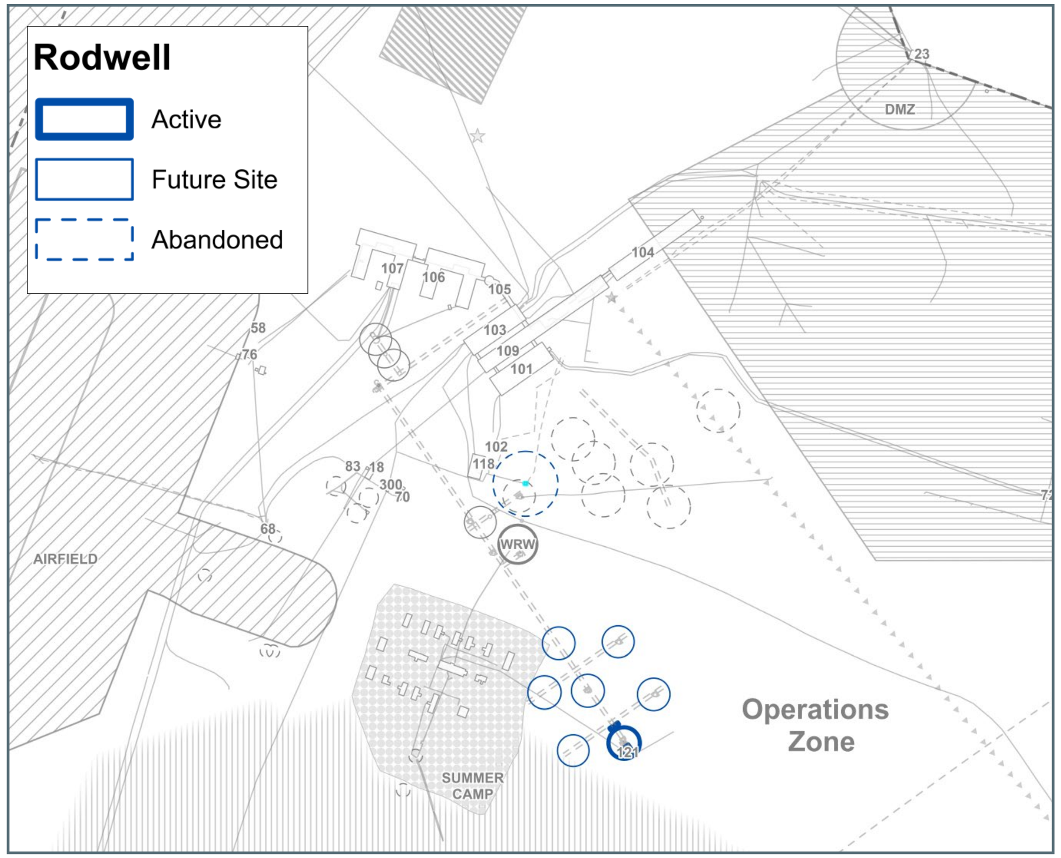


Figure 7.5 Water System

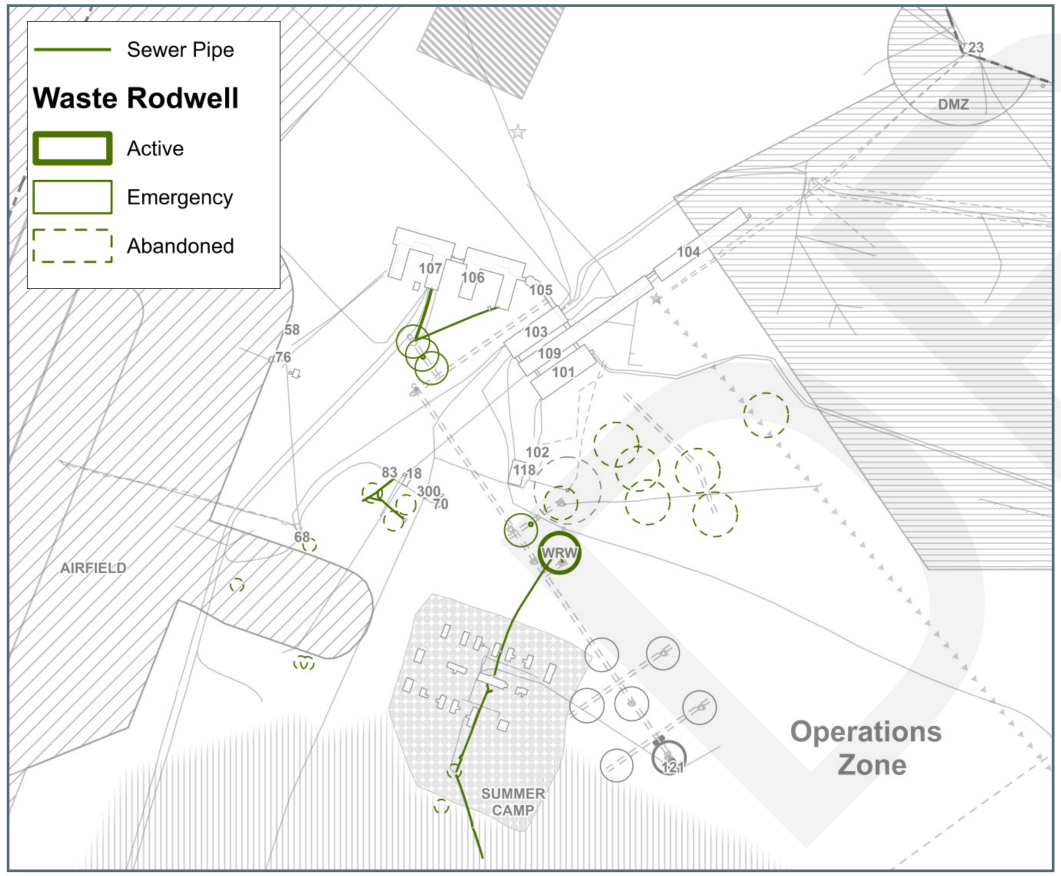


Figure 7.6 Human Waste System

Systems

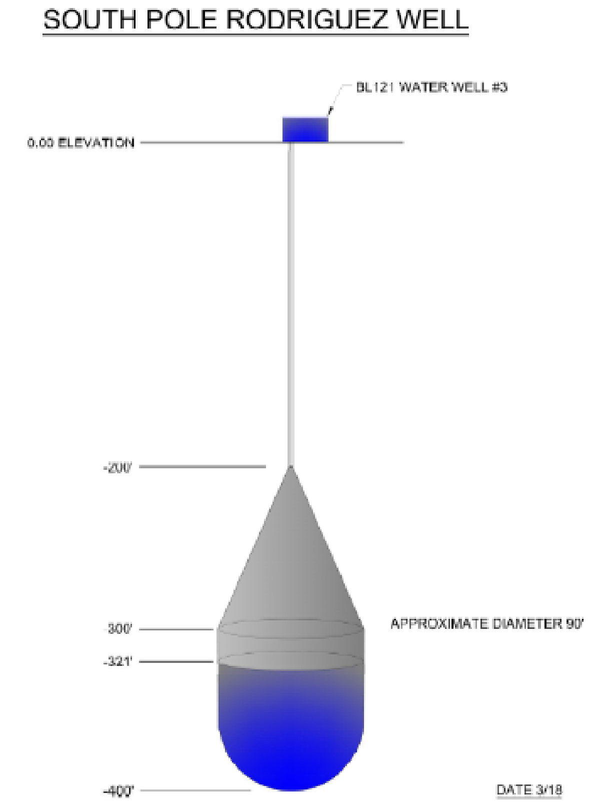
PRIMARY INFRASTRUCTURE

WATER SYSTEM

The current water treatment system functions well and will continue to serve the Elevated Station. The current water Rodwell will continue to function for the station, maintaining existing water supply and daily flows. When the Rodwell reaches its lifespan a new Rodwell will be started. Locations for future Rodwells have been identified along the existing utility tunnel corridor, as shown in the 'Water Network' graphic. A new Rodwell will be built and is forecasted to be completed in early 2029. Included with the new Rodwell, all water piping between the Rodwell and existing power plant/water treatment will be replaced.

When a new power plant is built a new water treatment system will be installed and connected to the current water distribution system. The existing utility tunnels will be expanded as needed to connect future Rodwell locations to the new power plant.

As outbuildings for bed facilities are installed, such as a construction camp or a field science staging facility, water lines will be extended from the current water system to these facilities.



SEWER SYSTEM

The current sewer outfall Rodwell is in good condition and will continue to function for the station. When the sewer Rodwell reaches its capacity, it will be capped in the same way as previous sewer outfalls, and the current water supply Rodwell will become the next sewer outfall. Locations of abandoned water supply Rodwells will eventually serve as sewer outfalls after they reach their water supply design life. The existing sewer outfall is forecasted to be full in 2028. A new intermediate sewer outfall was drilled in 2024. The intermediate sewer outfall will be used until the new water Rodwell is completed in early 2029.

As new buildings are constructed, the existing utility tunnel will be expanded to connect new buildings to sewer outfall locations. Waste sewer lines will be expanded and connected to the active sewer outfall distribution system through the existing and future utility tunnels.

As outbuildings for bed facilities are installed, such as a construction camp or a field science staging facility, localized waste outfalls will be installed for these facilities.

ELECTRICAL NETWORK.

POWER PLANT

The current power plant arch is failing due to the snow load. While the current engines are only approximately halfway through their useful life, the electrical equipment that supports the distribution of the electricity has reached its end-of-life. Given this information a new power plant needs to be constructed. The new power plant will contain the following new equipment:

- Three Similarly Sized (750 kW prime rating at site) Diesel Engine Generators, each including:
  - » Heat recovery heat exchangers.
  - » Engine cooling systems (radiators).
  - » Engine exhaust systems.
  - » Liquid fuel day tanks.
- One Similarly Sized (239 kW prime rating at site) Diesel Engine Generator, each including:
  - » Heat recovery heat exchangers.
  - » Engine cooling systems (radiators).
  - » Engine exhaust systems.
  - » Liquid fuel day tanks.
  - » ALTERNATE: Replace the new peaking generator with one of the existing
  - » 750 kW generators).
- Electrical switchgear.
- Motor control centers
- Plant control system and operator interface.
- Heating fluid circulating pumps and expansion tanks.
- Piping, valves, instruments, and cable as required.
- A waste water treatment plant (WWTP), size to be determined.

FUEL

The current fuel storage arch is failing due to the snow load. A new fuel storage building needs to be constructed simultaneously with the construction of a new power plant. The new fuel storage building will provide the same fuel capacity as the current facility. However, new technology and storage tanks could yield improvements to capacity and distribution. The new fuel storage building will be located next to the new power plant.

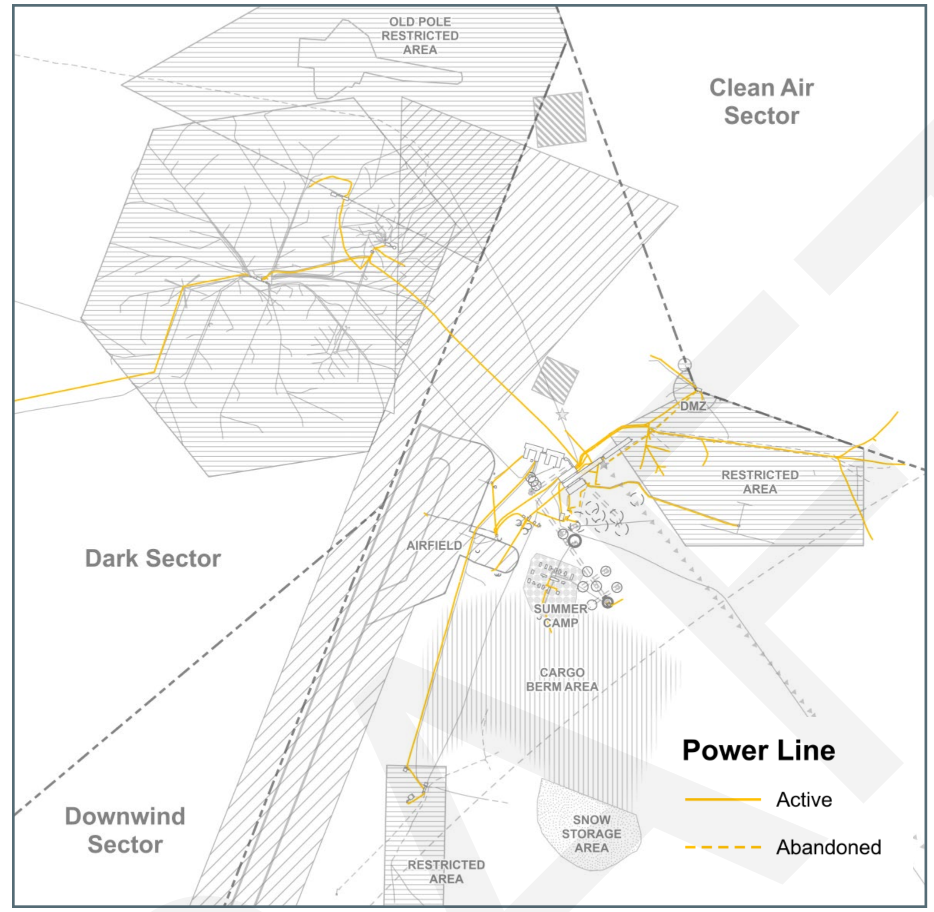


Figure 7.7 Electrical Cabling Overall Station

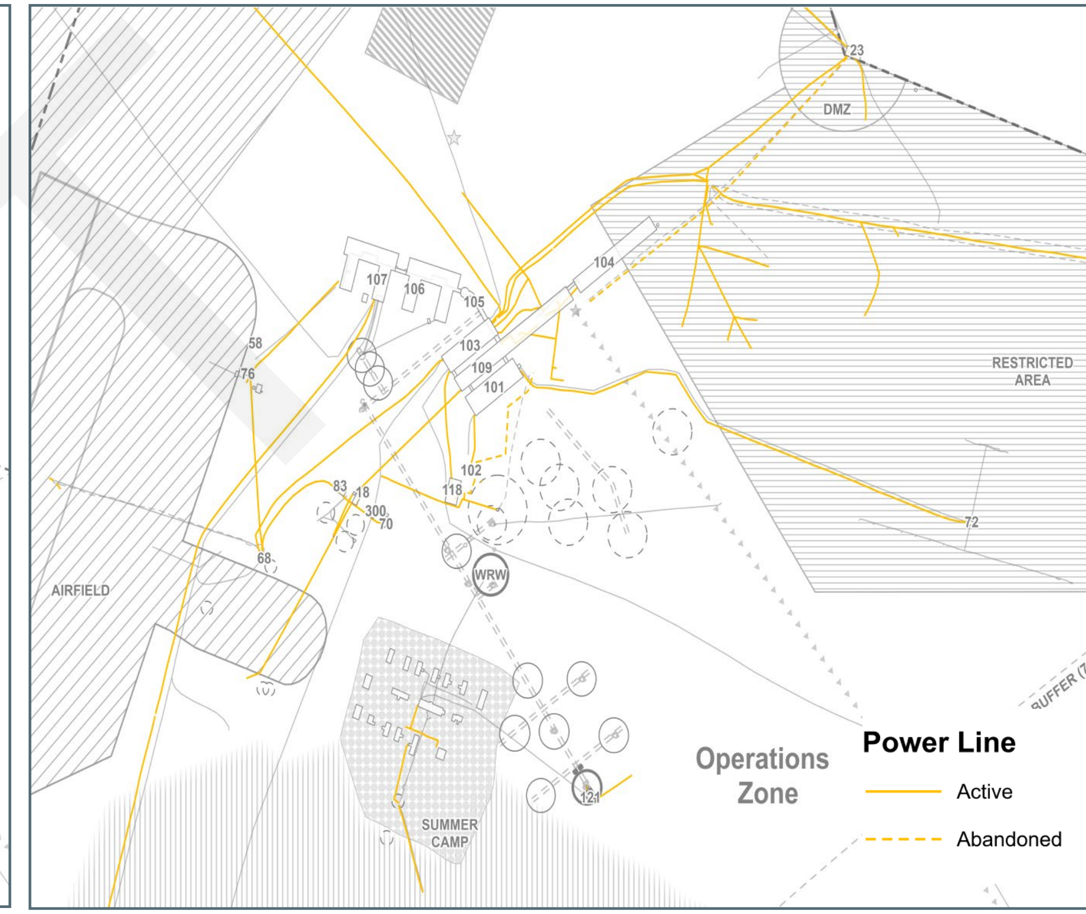


Figure 7.8 Electrical Cabling Core Area

ELECTRICAL LINES

The electrical lines throughout the SPS are aging and reaching their useable lifespan. As lines are scheduled to be replaced or added, every attempt should be made to collocate them in a utility easement. The utility easement should be laid out as part of a SPS utility master plan to consolidate dry utility lines. The following are recommendations for current and future electrical lines.

- To transition from the new power plant to the existing electrical connections, a new consolidated utilidor from the new power plant to the existing power plant will be used to bridge the old to the new connections. Electrical utilidors/panels at the existing power plant will be used to splice new lines into existing electrical cables that go out to the SPS.
  - » When a new power plant is ready to come online, temporary outages will occur during the switch over.
  - » As existing and new structures are renovated/developed, new electrical utilidors will be constructed from the new power plant to those structures and the existing splices can be abandoned/removed over time.
- Electrical cabling will be looped at both ends of utilidor to allow for ice sheet shifts that stretch the cables.
- Utilidors/Utility Ice Tunnels can be used to consolidate wet and dry utilities. A master utility plan should be done to provide a plan for consolidating utilities as they are replaced.

COMMUNICATIONS NETWORK

Communication lines throughout the SPS are aging and reaching their useable lifespan. As lines are scheduled to be replaced or added, every attempt should be made to collocate them in a utilidor. Utilidors should be laid out as part of a SPS utility master plan to consolidate dry utility lines. As part of a utility master plan, current and future utility lines should be surveyed to establish utility easements.

Communications systems connect all the SPS facilities and science facilities. IT/COMMS systems are vital to maintaining daily communications and data links to at the SPS and to points around the world. Minimizing EMI, maintaining reliable radio communications and maximizing satellite connections are imperative. The following are recommendations for maintaining a high-quality communications system at the SPS.

Spectrum Coordination and Optimization:

- Coordinate with all Sector science facilities for spectrum selection and waveforms in Land Mobile Radio system.
- Harmonize emissions to minimize harmful EMI and RF while ensuring safety and operational requirements are met.
- Establish ongoing collaboration mechanisms to adapt to emerging spectrum-related challenges and advancements.
- Research and adopt technology strategies that minimize or localize RF emissions to necessary only levels. Example: widespread use of Distributed Antenna Systems interconnected by fiber optic cables for localized low power emissions where needed; sector antennas for broadcast service to direct energy away from Dark Sector, etc.

Modernization of HF Radios and Antennas:

- Continue collaboration with NIWC for the modernization of HF radios.
- Prioritize antenna refreshes to enhance overall system performance and reliability.
- Monitor industry advancements for potential upgrades to HF communication technologies.

Space Assessment for RF Building Redesign:

- Conduct a thorough space assessment of RF Building size to support future facility redesign.
- Include provisions for equipment redundancy to minimize high-risk winter personnel visits.
- Evaluate the spatial requirements for emerging technologies and adaptability to evolving communication needs.
- Research and adopt technology advancements without reduction in capability to reduce equipment footprint and to include enhanced use of redundancy and automation to minimize the need for high risk mid-winter technician calls for corrective or preventative maintenance.

Permanent Utility Right-of-Ways for Fiber Optic Cables:

- Establish permanent utility easements for the routing of fiber optic telecommunications cables.
- Maintain geospatial documentation of easement locations to account for ice sheet movement and changes over time.
- Implement protocols for regular inspections (locating) and maintenance to prevent disruptions due to environmental factors.
- Research and adopt state-of-art telecom industry best practices and technology innovations to enable geolocation and dynamic protection of buried cable routes (example - use of Distributed Acoustic Sensing for cable protection).

Satcom construction. Source: NSF, Jack Corbin, Undated.

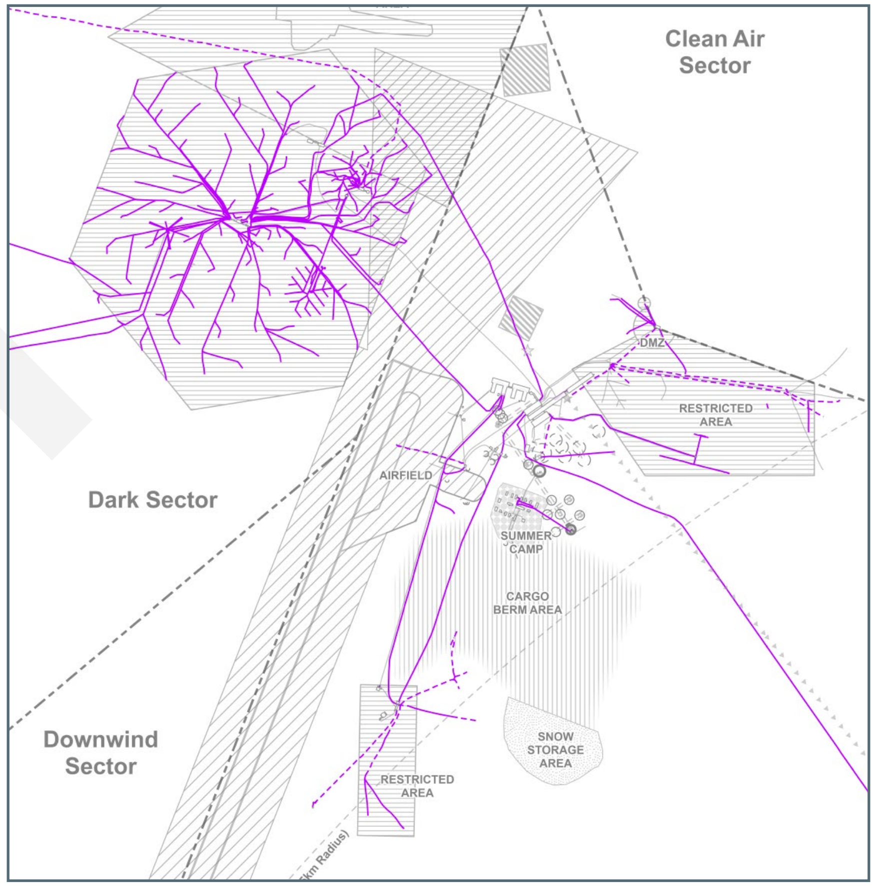


Figure 7.9 Communications Network

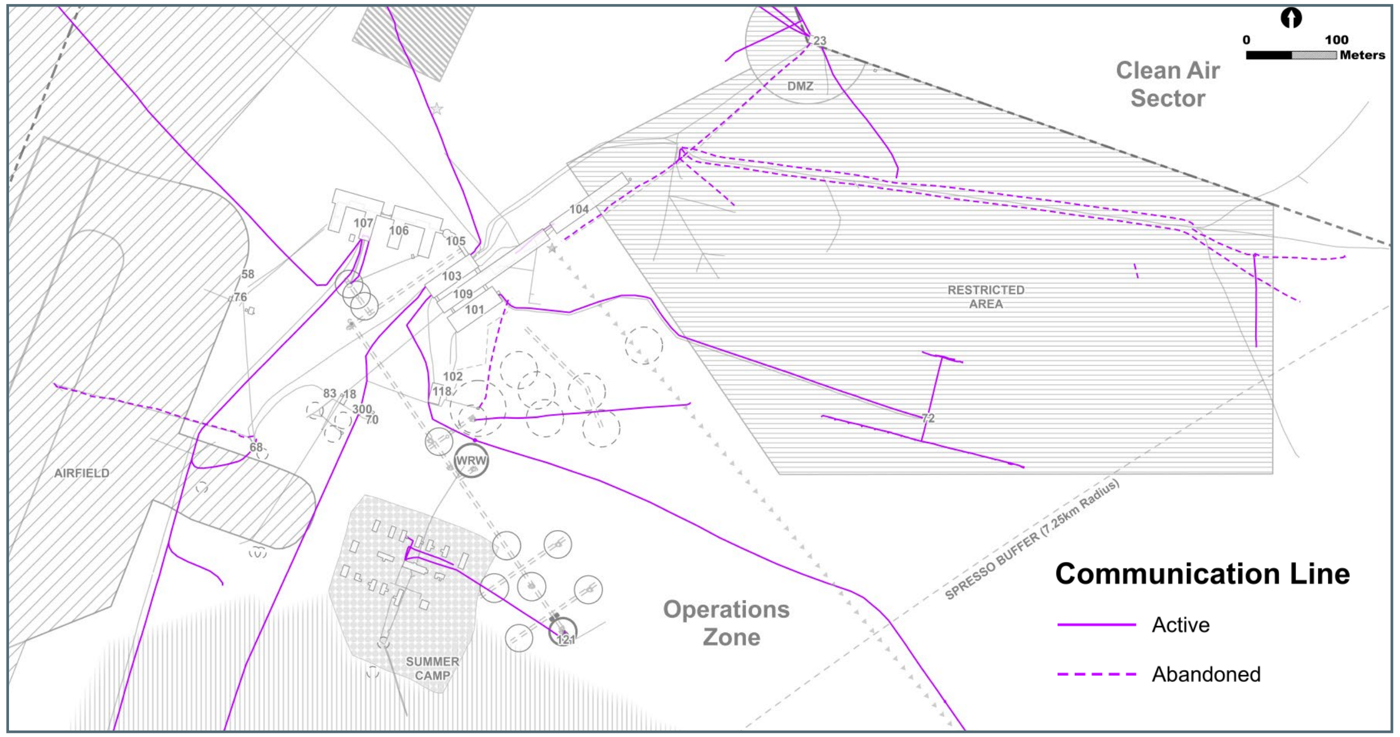


Figure 7.10 Communications Network Core Area

Adopting New Technological Developments

- Continuously evaluate and embrace new technological developments in the telecommunications field.
- Prioritize innovations that allow for additional throughput in network bandwidth.
- Ensure that the adoption of new technologies does not disrupt the scientific communities in the dark sector and aligns with their operational requirements.
- Establish a proactive communication strategy to keep stakeholders informed about technology changes and potential impacts on ongoing operations.
- Emphasize high reliability and low labor ‘touch-factor’ design with redundancy, automation and remote operations/management.

ALTERNATIVE ENERGY

Renewable energy at SPS is being reviewed as a way to reduce the dependence on carbon-based fuel and to reduce carbon emissions. This research is ongoing and should be considered as technology provides a reliable, renewable energy source. A science-produced white paper on the subject entitled Feasibility of renewable energy for power generation at the South Pole, 23 June 2023, provides an overview of considerations for the use of renewable energy sources at the SPS.

Transitioning from fossil-fuel power generation to renewable energy generation and energy storage in remote locations has the potential to reduce both carbon emissions and cost. A techno-economic analysis for implementation of a hybrid renewable energy system at the South Pole in Antarctica, which currently hosts several high-energy physics experiments with nontrivial power needs should be conducted. A tailored model for the use of solar photovoltaics, wind turbine generators, lithium-ion energy storage, and long-duration energy storage at this site should be explored in different combinations with and without traditional diesel energy generation.

For the SPS Master Plan, areas have been identified as potential sites for solar or wind fields. These sites are only conceptual locations based on available geography to minimize EMI and vibrations conflicts. The actual location of future fields will need to be researched and tested for optimum performance, minimal EMI and vibration, and consideration of energy loss due to the distance of transmission lines to the station. The master plan has identified two potential locations for alternative energy fields. Whether the fields are solar arrays or wind farms will be determined by further studies. A general location has been identified in the master plan for a field. A location east of the airfield and south of the RF/COMMs facilities. The actual size of the field will be determined by further studies. The field on the master plan represents a grid of six, one square acre fields.

Sundog over Geographic South Pole. Source: NSF, Peter Rejcek, 2015.

AIRFIELD

The airfield is an instrument flight rules (IFR) certified skiway designed under Federal Aviation Administration (FAA) guidelines and the Department of the Air Force Manual (DAFMAN) 13-217 dated 19 April 2022. It currently serves LC-130s on the 20 runway with the 02 approach only used in emergencies. Two primary concerns with the airfield include the 02 approach/departure contaminating the air quality in the Clean Air Sector and the development limitations imposed by the height restrictions with the Imaginary Surfaces on the 02 runway. The imaginary surface for each Option below is depicted in Figures 7.11, 7.12, and 7.13. The contours show in the Figures represent the elevation above the runway elevation. The all-physical objects must be below the contour elevation. The contours are show as individual lines, but the imaginary surface is a plane. To address these concerns the master plan has evaluated three options for repositioning the airfield.

Option One - No change to the airfield

1. The cost to shift the airfield does not justify the benefits.
2. Flight patterns can be required to avoid flying over the Clean Air Sector.
3. The development areas north of the runway are not being considered as viable sites for SPS and science expansion.
4. Vehicular and pedestrian access to and from the Dark Sector would still need to be controlled during flight operations and when NGO planes taxi north to NGO camp sites.

Option Two - Shift the airfield south along the current runway centerline 1,000 feet (305m).

1. The airfield support facilities and parking apron would remain in their current location.
2. Vehicular and pedestrian access to and from the Dark Sector would be deconflicted from flight operations. Crossings would still need to be controlled for when NGO planes taxi north to NGO camp sites.
3. Planes will need to taxi a longer distance to the parking apron. This would cause an increase in fuel consumption.
4. This would provide additional airspace for flight patterns to avoid the Clean Air Sector.
5. Science project expansion could occur grid east of the MAPO facility.
6. SPS development could occur grid west of the Elevated Station between 90-120 feet above the runway elevation.
7. Traverse routes will need to be adjusted further south to avoid the airfield.
8. Cargo drop zones will be further away from the SPS requiring increase travel distance and increase fuel consumption.
9. The FMQ and supporting infrastructure would need to be moved.

Option Three - Shift the airfield south along the current runway centerline 2,500 feet (762m).

1. The airfield support facilities and parking apron would remain in their current location.
2. Vehicular and pedestrian access to and from the Dark Sector would be deconflicted from flight operations. Crossings would still need to be controlled for when NGO planes taxi north to NGO camp sites.
3. Planes will need to taxi a longer distance to the parking apron. This would cause an increase in fuel consumption.
4. This would provide additional airspace for flight patterns to avoid the Clean Air Sector.
5. Science project expansion could occur grid east of the MAPO facility.
6. SPS development could occur grid west of the Elevated Station between 120-150 feet above the runway elevation
7. Traverse routes will need to be adjusted further south to avoid the airfield.
8. Cargo drop zones will be further away from the SPS requiring increase travel distance and increase fuel consumption.
9. The FMQ and supporting infrastructure would need to be moved.

Should Option Two or Three be implemented, The ASMA boundaries for the Downwind Sector and Operations Zone will need to be amended so the skiway remain in the Operations Zone.

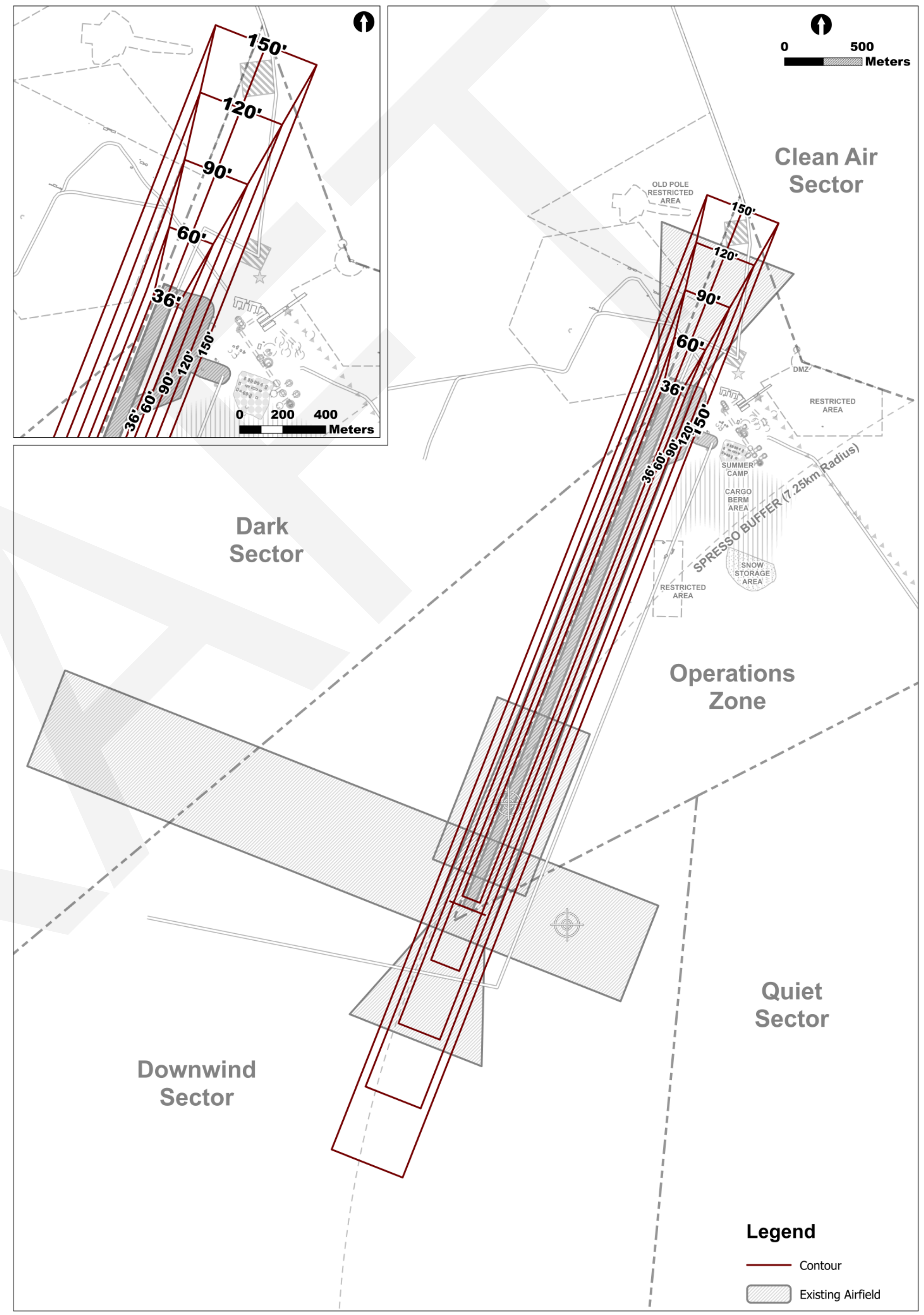


Figure 7.11 Skiway Option One - No Change

FMQ23 for Airfield. Source: NSF, Undated.

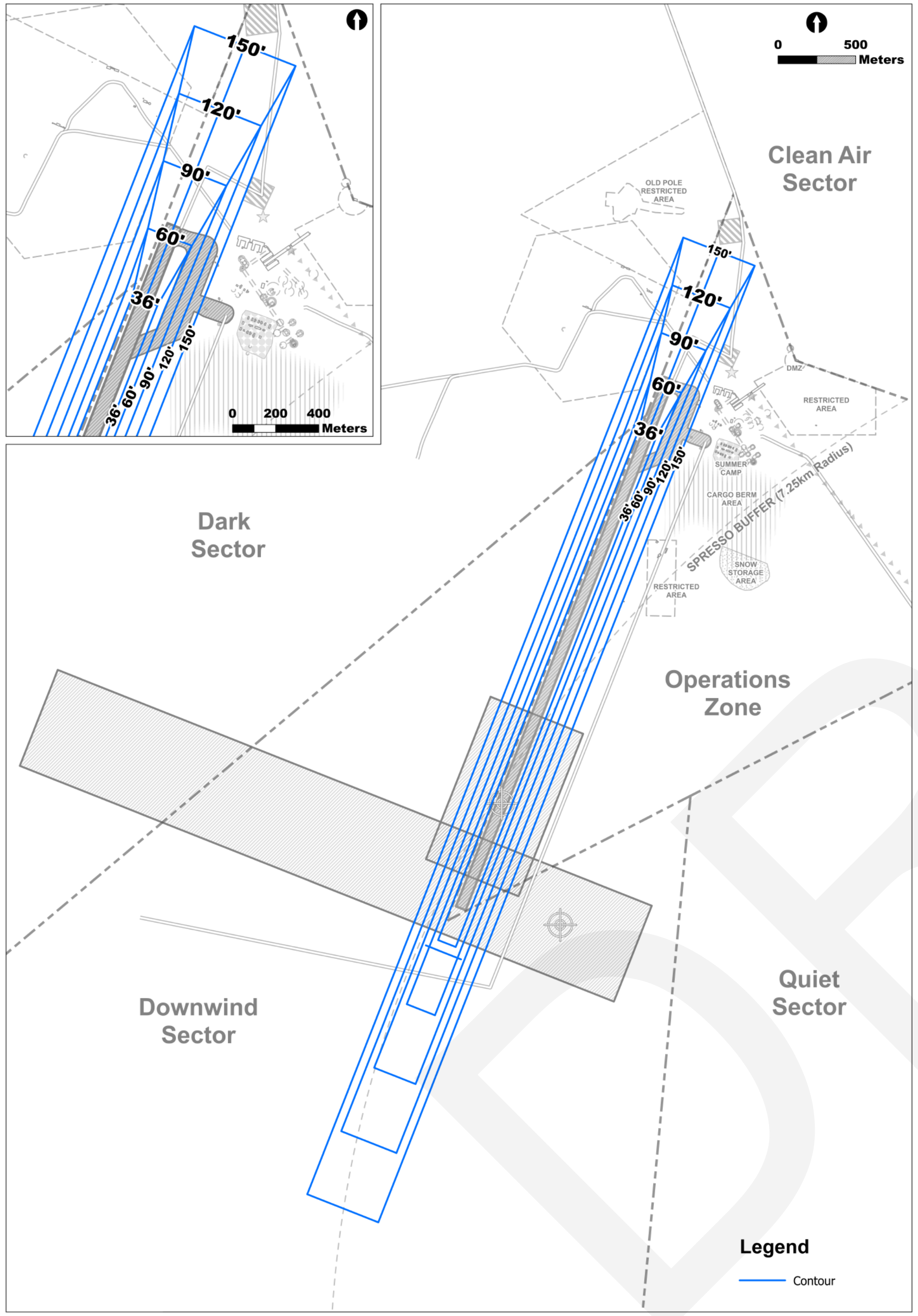


Figure 7.12 Skiway Option Two - Shift of 1,000 feet

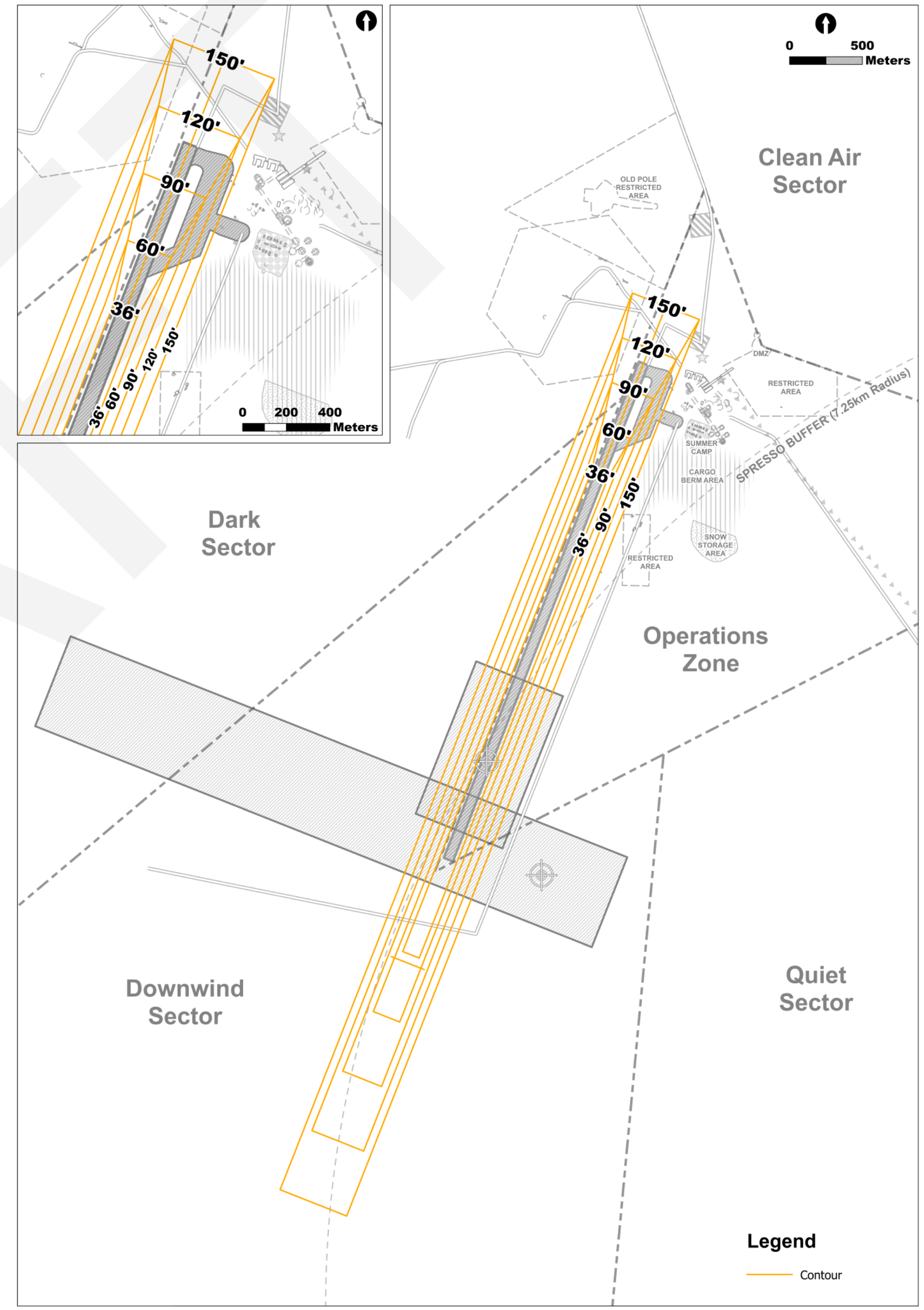


Figure 7.13 Skiway Option Three - Shift of 2,500 feet

Regulating Plans

The SPS Operations Zone and Downwind Sector have expanded over the years in an unorganized fashion responding to temporary or emergency needs. The SPS Master Plan contains Regulating Plans that will provide guidance for future development within the Operations Zone. The Sectors are regulated by the ASMA and science. Other planning tools that will begin to organize future development include Design Principles, land use districts, district overlays, and easements. These tools will guide and better align USAP resources, encourage a more efficient, orderly, and aesthetically pleasing station design, and eliminate potential conflicts between scientific research activities and the infrastructure activities needed to support science.

DESIGN PRINCIPLES

Design principles are foundational land use and master planning ideals that guide the design of the built environment and are applicable across a wide variety of recommendations and objectives for maintaining, replacing, and operating current and future buildings and infrastructure at SPS. Design principles are foundational guidance factors that work to ensure a cohesive, comprehensive approach to design challenges, but they are not planning mandates. No hierarchy of application is assigned to the design principles. It is at the sole discretion of NSF to determine, on a case-by-case basis, which design principles are most important for the completion of future large infrastructure projects. Most action statements are subject to multiple design principles. In the event that multiple design principles are applicable to the planning and execution of an action but are found to be in conflict during the design and completion of an infrastructure project, NSF reserves the authority to omit the conflicting design principle(s).

SAFETY & RELIABILITY

The safety of personnel and visitors is the single most important goal of station operations. Future building and infrastructure designs should improve SPS operations and disaster response and recovery capabilities. Reducing single-point failure risks and promoting fail-soft systems to improve system reliability should also be encouraged where possible.

SIMPLICITY & STANDARDIZATION

Simplicity and standardization of systems and components promotes ease of installation, operation, and maintenance of station buildings and infrastructure. Where possible, structural, and functional systems should be designed in a way that reduces the variety of specialty parts, tools, and labor needed to operate, maintain, and service them. Easily replicable and easily serviced buildings and infrastructure that can be built off-site should also be encouraged. For example, modular, stackable building components (such as prefabricated wall panels) that conform to the size and weight requirements of available transportation methods would standardize shipping and installation processes.

FLEXIBILITY & ADAPTABILITY

Future station buildings and infrastructure should be flexible and adaptable in order to support the evolving nature of scientific inquiry in Antarctica, while at the same time considering potential future needs or constraints. Easily scalable structures and infrastructure systems should be encouraged. Infrastructure that can be adapted or reconfigured based on current needs should also be considered where appropriate.

RIGHTSIZED & COMPACT

To increase logistical and resource efficiencies, future buildings, infrastructure, and vehicles should be appropriately rightsized for the scale and intensity of each use, which may result in a reduced or increased structure or service footprint at the station. Spatial relationships between uses should also be intentionally planned to encourage compact operational nodes throughout the station area. Compact nodes encourage local walkability, energy efficiency, and reduced reliance on vehicular traffic.

INTEROPERABILITY

Ensuring interoperability of mission support and scientific activities is paramount to the continued success of SPS and of NSF as an international leader in scientific research and exploration. This includes continuing enforcement of sector boundaries and regulations, preventing interferences or contaminations in accordance with Antarctic Treaty provisions, and mitigating impacts of large-scale infrastructure and science projects on small scale science resources. Future designs should evaluate potential adverse impacts of one infrastructure or science project on other functions in the area. Where possible, these impacts should be mitigated during the design of large projects to allow continuous station operation and scientific exploration for all fields of research.

SUSTAINABILITY

Sustainability refers to the pursuit of renewable on-site energy production and adaptive re-use of climate-appropriate materials to maximize energy efficiencies, reduce fuel consumption and its associated resupply demands, and maximize the life of the station, while complying with all environmental regulations. Fossil fuel delivery is one of the largest current annual logistics constraints for the station. Future designs should consider the potential for reducing resupply demands and re-using materials wherever possible. Future structure placements should also consider walkability in their siting to reduce the reliance on vehicular traffic and its associated staffing, maintenance, and fuel consumption.

ENVIRONMENTALLY RESPONSIVE

Buildings, infrastructure, and vehicles should be designed to respond appropriately to the environmental, terrain, and weather conditions of the South Pole. Special consideration of snowdrift implications should be included in the siting and structural design of all infrastructure. Where possible, easily elevated structures and technologies to combat snow accumulation and maximize the life of station infrastructure should be pursued. Potential uses for snow removed during the annual snow removal efforts should also be explored.

LIVABILITY

Building and infrastructure designs should ensure that SPS provides a habitable, healthy environment for personnel and visitors, which includes ensuring healthy indoor air quality, supporting mental and physical health by means of spatial programming and architectural design, and integrating social spaces to support collaboration and a sense of community. The use of architectural design features that improve privacy in the station should be pursued, and the provision of single-occupancy rooms wherever possible should continue. All future designs should take particular care to ensure livability for the winter-over population, including adequate emergency facility planning.

AESTHETICALLY INDICATIVE OF THE NSF'S STATURE

Future modernization and designs should include an orderly, intentionally planned site layout and forward thinking, cost-effective architectural design. The appearance of the SPS campus and structures should be aesthetically indicative of the stature of NSF, the world-class science conducted in Antarctica, and the professionalism of the staff supporting SPS operations.

OPERATIONAL EFFICIENCY

The operational efficiency design principle encompasses several concepts that would improve spatial organization and use of the station but may also require process modifications beyond the scope of this document to achieve. Storage and warehousing, for example, is currently drastically undersized at SPS. Robust life cycle planning of resources, including pre-planning of retrograde or re-use of materials, should be encouraged to reduce resupply demands and the required warehousing footprint. This may include pursuing regulatory waivers for staffing requirements where health and life-safety standards would not be compromised.

Elevated Station Vertical Tower. Source: NSF, 2021.

LAND USE DISTRICTS

Land Use Districts are planning tools that help to organize uses within a defined area. The district has development standards to mitigate the impacts of incompatible activities by separating land uses and organizing land use adjacencies in each area. The land use districts, district overlays, and easements presented in this this document have been created for USAP-internal guidance of future development at the Station. A Land Use District matrix is provided in the Appendix. The matrix list the permitted uses for each District.

AIR SUPPORT DISTRICT

The Air Support District denotes areas in the Operations Zone where airfield support activities (e.g., aircraft landing and parking, refueling, and cargo staging) may occur and should be reasonably separated from other station service activities in order to prevent cross contamination of supplies and mitigate air and sound pollution to protect the health of station personnel. This district will contain the skiway, aircraft parking areas, and a variety of structures and infrastructure used to support airfield operations. Siting of all future Air Support District facilities and services will require a site study and environmental analysis, where applicable, before final placement.

- Structure Setback: Governed by U.S. Air Force regulations and USAP building codes.
- Existing, non-conforming structures and infrastructure in the Air Support District may continue current operations as long as they do not conflict with existing U.S. Air Force regulations, but they may not be expanded or replaced.

STATION AREA SCIENCE DISTRICT

The Station Area Science District sets aside an Operations Zone area for scientific research activities that require immediate station proximity for year-round pedestrian access. The boundaries of the Station Area Science District reflect Operations Zone space that is already used for this purpose. Dedicating a specific area in the Operations Zone to scientific activities and infrastructure de-conflicts operational and scientific activities and promotes improved interoperability with the necessary functions of the Operations Zone. Delineating a specific area also prevents sprawl and preserves the Operations Sector for future operational development, such as renewable energy production fields and heavy equipment operations that may otherwise interfere with scientific equipment or measurements. Access to the district is restricted to USAP personnel and researchers. All personnel working in the district should coordinate with the scientific research organizations working in the area to avoid disturbing any areas where sensitive scientific or antenna infrastructure may be affected by vehicular or pedestrian activity. This district is proposed to eventually take the place of the ASMA Antenna Field Restricted Zone, as that zone no longer matches the actual footprint or extent of scientific activities in the Operations Zone. Siting of all future Station Area Science District structures will require a site study and environmental analysis, where applicable, before final placement.

- Structure Setback: 150 feet from any previously established Primary Infrastructure District uses and as required by USAP building codes.
- Existing non-conforming structures and infrastructure in the Station Area Science District may continue current operations as long as their presence does not conflict with scientific research activity. Conflicting non-conforming structures and infrastructure should work toward relocation and may not be expanded or replaced.

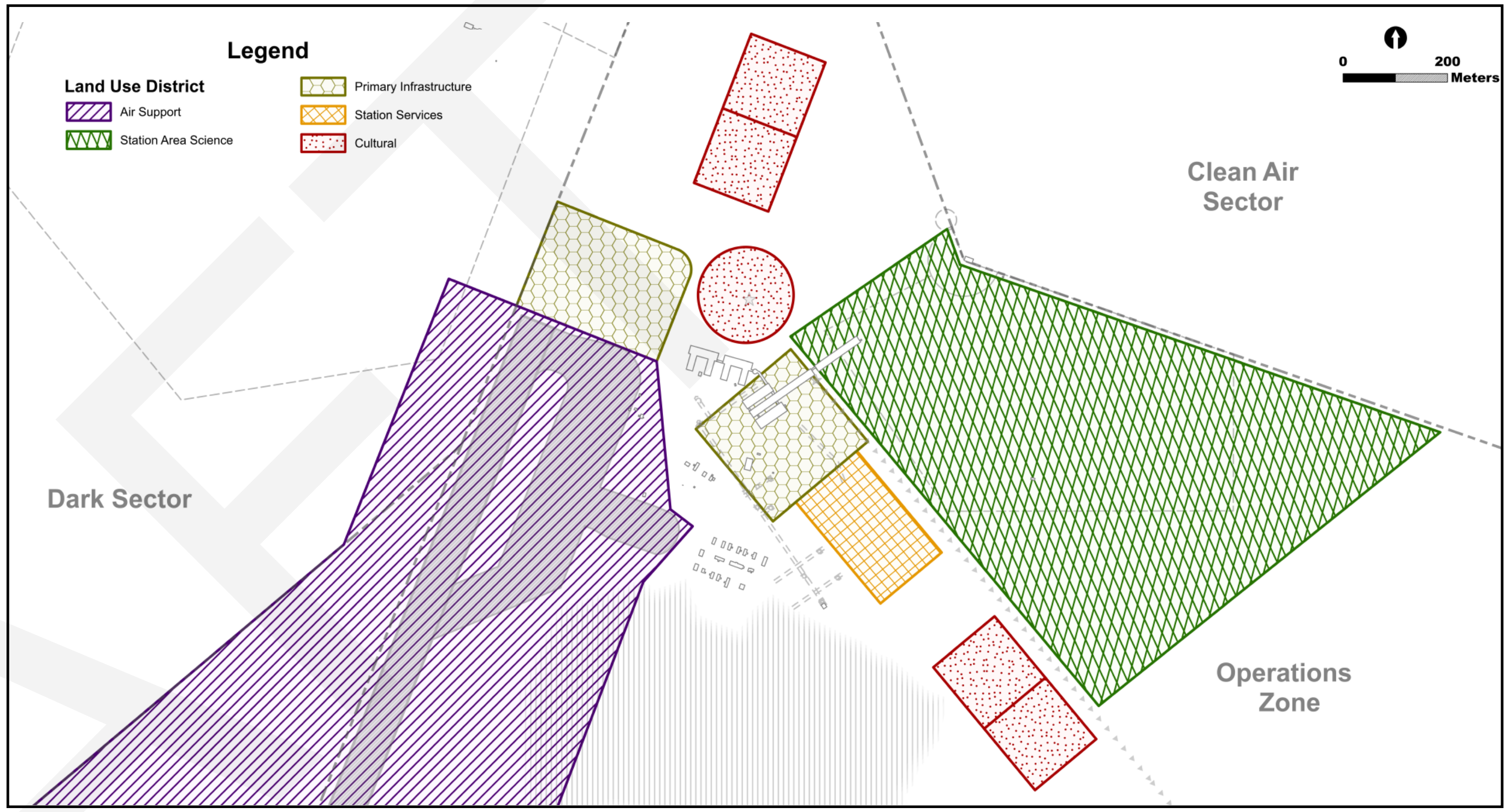


Figure 7.14 Land Use Districts.

PRIMARY INFRASTRUCTURE DISTRICT

The Primary Infrastructure District denotes areas within the Operations Zone where critical infrastructure uses such as power generation, fuel storage, heavy equipment operation, and equipment warehousing may create byproducts that hinder or otherwise negatively impact station services and scientific activities and therefore should be reasonably separated from these activities to prevent cross contamination of food and life safety supplies. Separation of these uses will also mitigate air and sound pollution to protect the health of station personnel. This district will contain the future Primary Infrastructure Complex and its associated major utility grid. Siting of all future Primary Infrastructure District facilities and services will require a site study, plume analysis, and environmental analysis (where applicable) before final placement. A utility master plan should be developed before future cabling in the district is completed.

- Structure Setback: 100 feet from any previously established Station Services District uses and as required by USAP building codes within the district.
- Existing non-conforming structures and infrastructure in the Primary Infrastructure District may continue current operations but not be expanded or replaced.

STATION SERVICES DISTRICT

The Station Services District denotes the proposed area for a future SPS complex that will provide lodging, dining, recreation, medical, and office services to station personnel. These uses are sensitive to the byproducts of industrial processes, such as power generation and fuel storage, and should be reasonably separated from such processes to prevent cross contamination of supplies and mitigate air and sound pollution to protect the health of station personnel. A central and compact location of station services within the district increases visitor safety by de-conflicting the heavy equipment traffic in the Primary Infrastructure District and the pedestrian and light vehicle traffic associated with the Station Services District. The Station Services District has been located for future adjacency to the projected 2070 location of the Geographic South Pole. A new campus-specific master plan and a complete siting study and environmental analysis must occur before final siting of the future station.

- Structure Setback: 150 feet from any previously established Primary Infrastructure District uses and as required by USAP building codes within the district.
- Existing non-conforming structures and infrastructure in the Station Services District may continue current operations but not be expanded or replaced. Relocating existing station services structures to the Station Services District should not occur until a campus-specific master plan for a future station has been completed.

CULTURAL DISTRICT

The Cultural District is intended to set aside areas of the Operations Zone for historical markers and NGO tourism activities. Cultural District areas noted with a Temporary Structure Overlay are intended for use as NGO tourism campgrounds and related vehicle or aircraft parking. Siting of all future Cultural District facilities and services will require a site study and environmental analysis, where applicable, before final placement. The placement of an NGO camp grid-east of the Future Station Area would only be implemented if SPRESSO moves further from the SPS.

- Structure Setback: None.
- Existing non-conforming structures and infrastructure in the Cultural District may continue current operations but not be expanded or replaced.

DISTRICT OVERLAYS

District Overlays are land use organization tools applied to areas where increased complex and varied activities occur. These activities require additional guidance to maintain proper adjacency and operational relationships. District Overlays sit onto of Land Use districts and the requirements only apply to the functions that occur within the District Overlay boundaries used to identify areas where additional development standards or restrictions apply to the underlying land use district.

TEMPORARY STRUCTURE OVERLAY

The Temporary Structure Overlay identifies areas where moveable structures may be located to serve a specific and temporary use. The locations of the Temporary Structure Overlay correspond to future anticipated temporary uses, such as tourism campgrounds and surge housing facilities for major infrastructure project support. Temporary structures placed within a Temporary Structure Overlay should be modular or otherwise easily reconfigured, repurposed, or dismantled. Once all temporary uses have ceased within a structure, the structure should be removed from the overlay district or dismantled and stored in a covered location for future use. Existing non-conforming temporary structures outside the Temporary Structure Overlay may continue current operations but not be expanded or replaced. Relocating such structures to an applicable Temporary Structure Overlay area is encouraged.

CONSTRUCTION HAZARD OVERLAY

The Construction Hazard Overlay indicates areas where new structures may be subject to structural problems resulting from snow settlement or buried obstacles. New structures may be built within the Construction Hazard Overlay, but each structure will require a complete siting study that includes identifying buried hazards before placement. Potential hazards within the area include, but are not limited to, existing buried structures and building foundations, science and utility vaults, current or decommissioned Rodwells and sewer outfalls, utility lines, and fuel lines.

SNOW STORAGE OVERLAY

The Snow Storage Overlay indicates the area where snow from drift removal may be deposited when it is not able to be repurposed. Within the district, snow deposits must be located far enough away from existing structures to prevent additional snowdrift accumulation around those structures. Existing non-conforming structures and infrastructure may continue current operations but not be expanded or replaced within the Snow Storage Overlay. This includes, but is not limited to, snow berm storage of supplies.

EASEMENTS

Easements are land use organization tools commonly applied to areas that require specific regulation. Typically, easements are used for granted or protecting access. Easements can be applied across Land Use Districts or ASMA Zones. They are similar in nature to the ASMA Restricted Zones.

CLEAN AIR SECTOR (CAS) BUFFER EASEMENT

The Clean Air Sector (CAS) Buffer Easement follows the boundary of the CAS and extends 1 km into the CAS from the boundary. All CAS structures should be located a minimum of 100 feet into the CAS to prevent contamination and emissions interference with CAS scientific operations. Existing non-conforming structures and infrastructure (including CAS structures) may continue current operations but not be expanded or replaced within the easement.

CLEAN AIR SECTOR (CAS) ACCESS CONTROL EASEMENT (ACE)

To minimize contamination in the CAS, access into the CAS will be managed by an Access Control Easement (ACE). The ACE will be placed along the 110 degree and 340-degree CAS boundary for a distance of 2 km originating at the intersection of the 110- and 340-degree lines. Access across this easement into the CAS is not permitted without approval from SPS and or the science community conducting research in the CAS. Access into the CAS beyond the ACE must still be approved and recorded and can only be accessed at a specified coordinate determined by the SPS. Routes to the point of access into the CAS shall follow the CAS boundary. Return routes shall follow the exact same route.

GEOGRAPHIC SOUTH POLE (GSP) EASEMENT

A 100-foot easement shall be established along the trajectory of the Geographic South Pole to maintain unobstructed pedestrian and vehicular access to the Geographic South Pole, which is a popular destination for South Pole visitors and which experiences frequent summer foot traffic. No structures may be placed within this easement. Existing non-conforming structures, infrastructure, and station area science may continue current operations but not be expanded or replaced within the easement.

UTILITY ACCESS EASEMENTS (UAE)

Utility access easements (UAE) are surveyed corridors used for installing, constructing, and maintaining utility lines and infrastructure. UAEs at the SPS will be part of a utility master plan to organize, consolidate and identify utility lines and infrastructure. UAEs can be in the Operations Zone or in any Sector. Permanent buildings/structures shall not be constructed over a UAE. UAEs can contain wet and dry utilities and must provide sufficient width to allow for required utility separations, access in the case of ice tunnels, and snow storage during trenching. Existing non-conforming utility lines and infrastructure may continue in their current location but not be expanded or replaced without being in a UAE. Siting of all future UAEs will require a site study and environmental analysis, where applicable, before final placement.

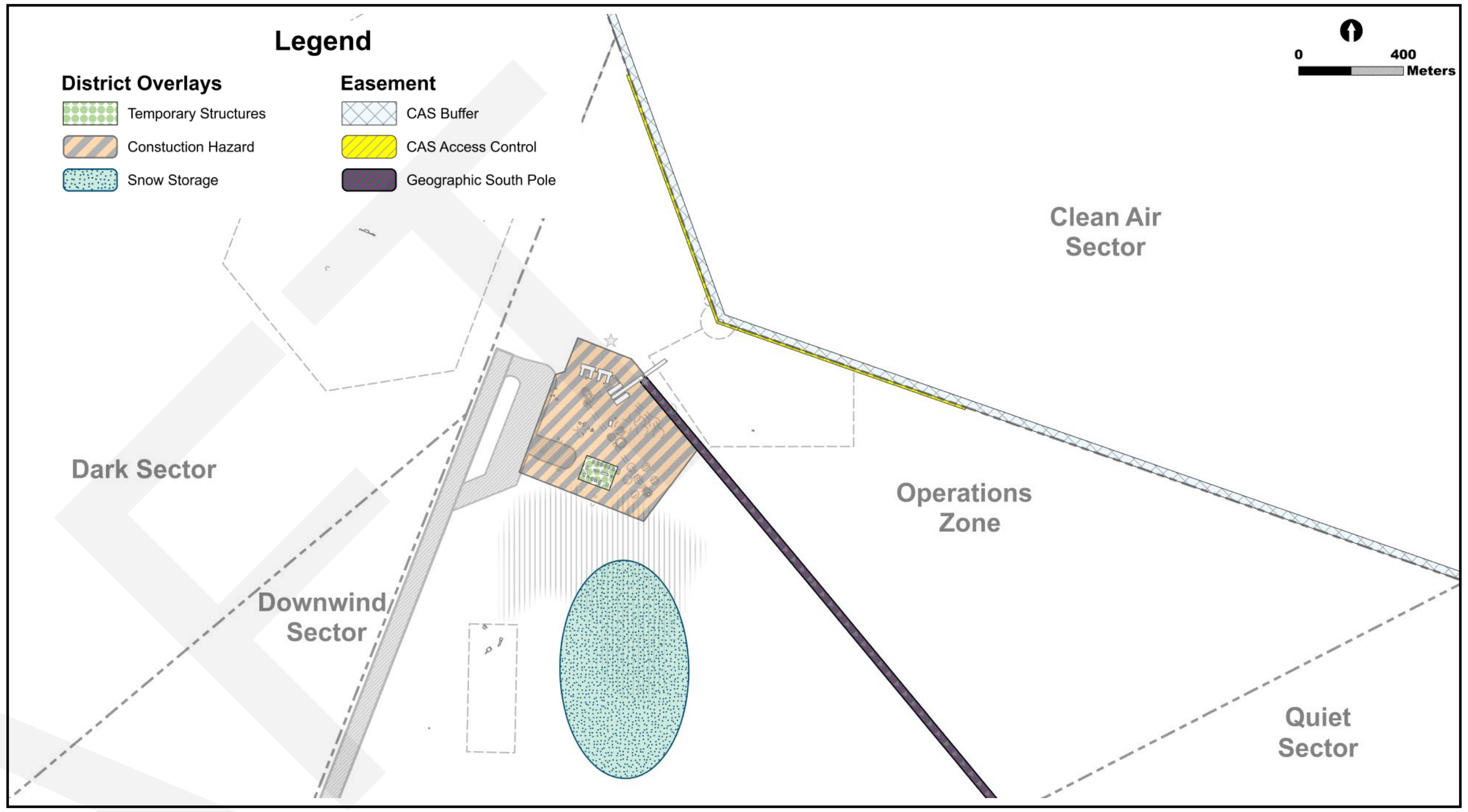


Figure 7.15 District Overlays and Easements.

SNOWDRIFT EASEMENT (SDE)

Snowdrift Easements are general easements place around new buildings denoting potential snow accumulation from drifting snow. The easement will restrict any new improvement within the SDE that would be in jeopardy of being buried by snow. A SDE will also prevent any improvements within the SDE from being constructed that could cause a snowdrift accumulating around a building. Figure 7.16 is an example of drift areas around the Elevated Station. Figure 1.17 are wind rose used for snowdrift modeling at the South Pole. The prevailing wind direction used was 10 to 30 degrees grid east.

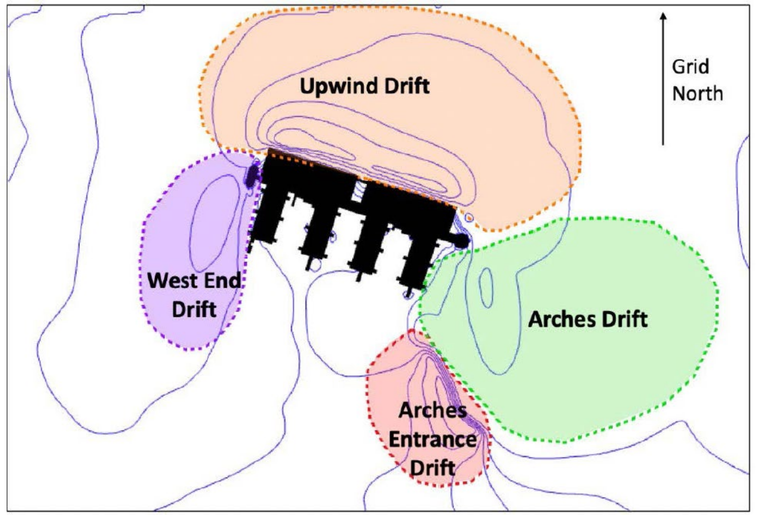


Figure 7.16 Snowdrift Areas.
Source: South Pole Station Drift Model, ERDC/CRREL TR-22-7, August 2022.

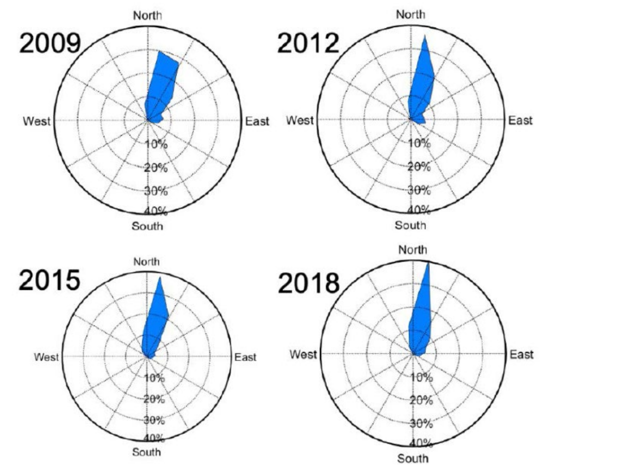


Figure 7.17 South Pole wind roses used for snowdrift modeling.
Source: South Pole Station Drift Model, ERDC/CRREL TR-22-7, August 2022.

MASTER PLAN

The SPS Master Plan is a guide for the SPS area to include future station buildings, structures, and general improvements. The following three Concept Plans present potential patterns of development to serve as a guide to future projects over the next 35-50 years. The SPS Master Plan reviewed existing station conditions identified concerns and recommendations to address the concerns and developed a list of projects to be considered based on known requirements and the identified recommendations. The Concept Plans illustrate how the station can be organized to achieve efficiencies, aesthetic order, and deconflictions. The plans are only a guide and do not propose final or exact locations for future structures or utilities at the station. A comprehensive siting study, including environmental assessments per Article 8 of the Protocol on Environmental Protection to the Antarctic Treaty, must be completed before placing any new structures or relocating existing structures in the SPS area. A snowdrift analysis should also be completed before any structure placements or relocations in the station area to avoid undue snowdrift impacts.

The Recommendations presented in Section 6 South Pole Station Area Plans were used to develop each concept. Not every Recommendation was applied to every concept. Not every Recommendation has a physical site component. Some of the Recommendations call for a study, policy changes, or future considerations. For each concept plan bulleted item, corresponding Recommendation item numbers are noted in parenthesis. A consolidated Recommendations list is provided in Appendix B.

MASTER PLAN - CONCEPT ONE

Concept One is the preferred concept. This concept views the 35-50 year horizon as an opportunity to implement as many Recommendations as can be achieved. The following describes the items proposed for Concept One.

SECTORS

DARK SECTOR

- The Dark Sector ASMA boundary does not change.
- The Dark Sector will continue to function as it is currently. New science facilities will be added and expanded over time as part of continued science projects. As part of the SPS Master Plan the MAPO building, ICL building, Building 61, and the DSL buildings will be raised. (SPS 1, D1, D2)
- Access to the Dark Sector will be improved once the airfield skiway is shifted south 1,000 feet (305m). This will allow pedestrians and vehicular traffic to cross north of the airfield threshold without having to wait for aircraft approaches and departures. Pedestrian and vehicular traffic will still need to be controlled when aircraft taxi north to the NGO camp sites. (D4)

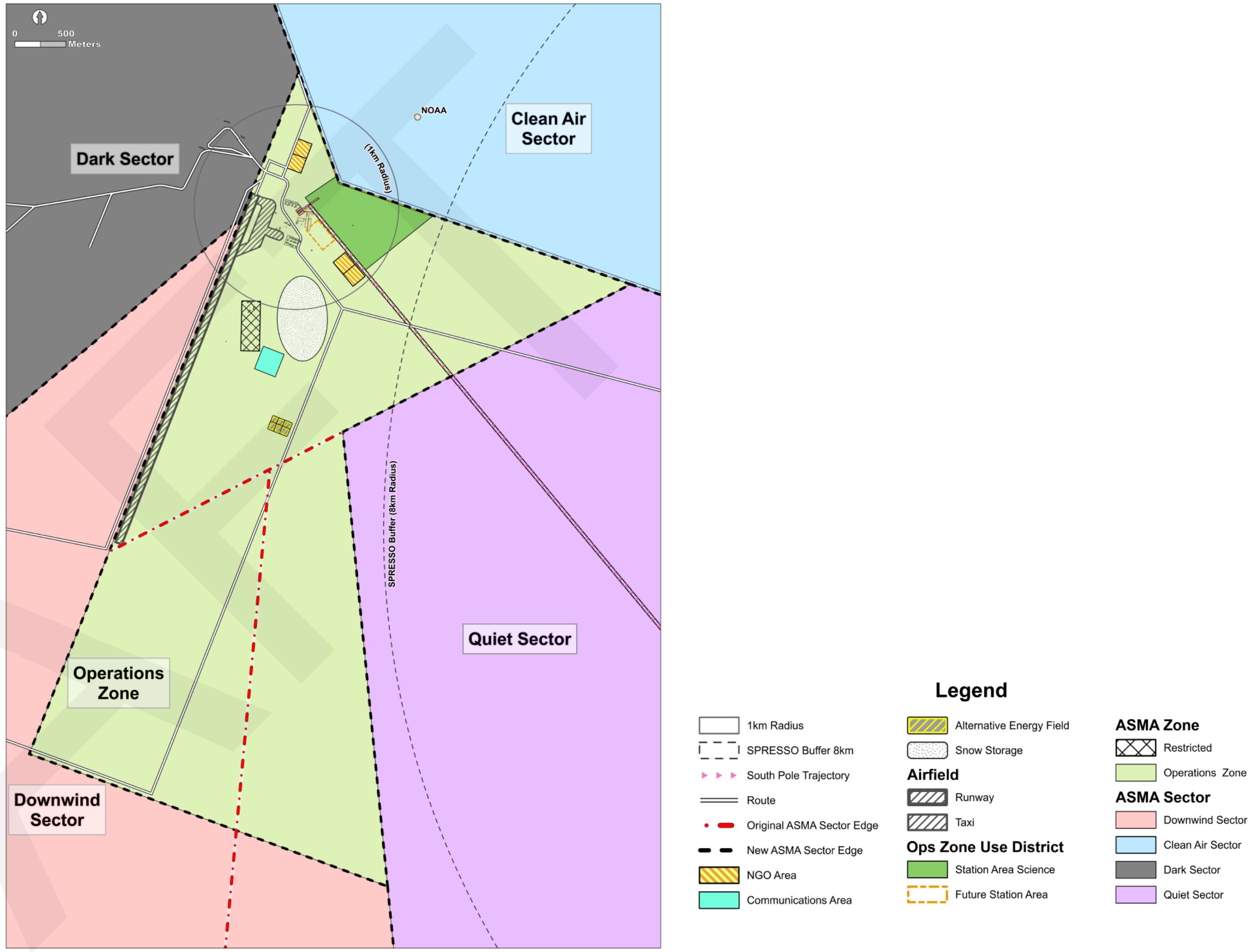


Figure 7.18 Concept One - New Sector Configuration.

CLEAN AIR SECTOR

- The Clean Air Sector ASMA boundary does not change.
- Raise the ARO building. (CAS 5)
- The contamination of air quality by emissions from aircraft, NGO camps, and unauthorized pedestrian or vehicular access into the Clean Air Sector has been a concern. To help mitigate these three actions are proposed.
  - » Move the NGO camp site south closer to the ceremonial south pole placing it further away from the Clean Air Sector boundary. Providing separation from the boundary should reduce air contamination. (D3, CAS 1)
  - » NOAA has supported the placement of a new building further into the Clean Air Sector to achieve "cleaner" air. The location of this building would be determined by NOAA. For the SPS Master Plan a location is shown 1km northeast of the current ARO building. This distance is greater than 1km from the SPS but would only be visited when servicing equipment and for snow maintenance. The existing ARO building will remain. The new building would allow some equipment to move out of ARO freeing space for other uses. A Clean Air Sector buffer extending 1km into the Clean Air Sector along the 340- and 110-degree lines would be established with added restrictions for access. (CAS 2)
  - » An ACE will be placed along the 340- and 110-degree lines for 1km originating from the ARO building. The ACE is defined in the Regulating Plan section above. (CAS 3)

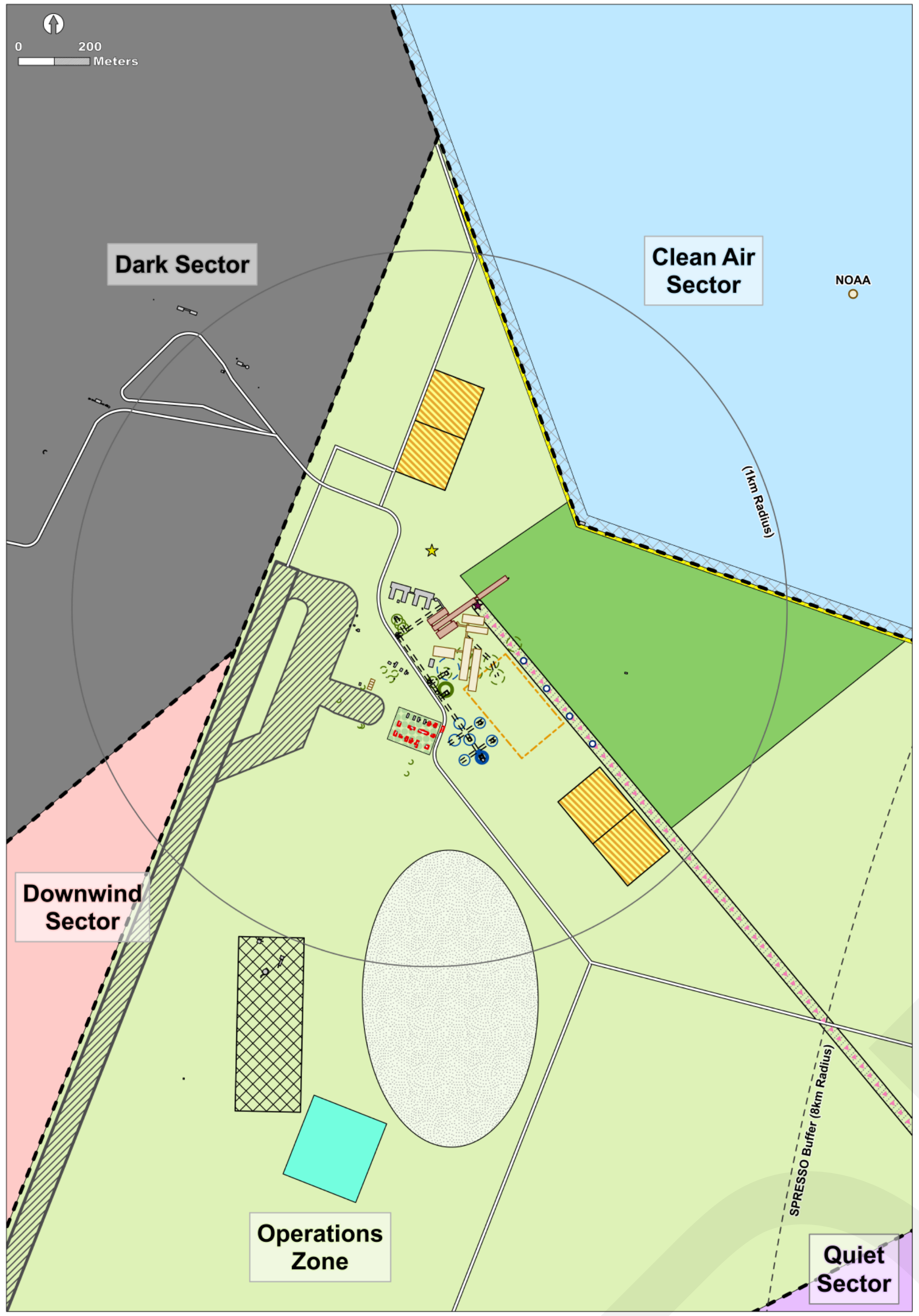


Figure 7.19 Concept One - Operations Zone .

Legend

- Ceremonial South Pole
- Geographic South Pole
- Pole
- South Pole Trajectory
- Route
- Tunnel
- ASMA Sector Edge
- 1km Radius
- SPRESSO Buffer 8km
- Clean Air Buffer 1km
- Construction Camp
- NGO Area
- Communications Area
- Snow Storage

Structure

- NOAA Proposed Building
- Building Demolition
- Repurposed Building
- Future Building/Walkway
- Existing Building/Walkway

Easement

- Geographic South Pole 100ft
- CAS Access Control

Airfield

- Runway
- Taxi

Ops Zone Use District

- Station Area Science
- Future Station Area

ASMA Zone

- Restricted
- Operations Zone

ASMA Sector

- Downwind Sector
- Clean Air Sector
- Dark Sector
- Quiet Sector

QUIET SECTOR

- SPRESSO and all the supporting infrastructure will need to be replaced. Science supports moving SPRESSO northeast closer to the Clean Air Sector boundary at a similar or greater distance away from the SPS. SPRESSO would not impose any negative impacts on the Clean Air Sector. The SPS Master Plan proposes a location, but the actual location will be determined by science. When SPRESSO is moved, a new buffer radius will be established. As shown on the SPS Master Plan, the new location of SPRESSO would mean the buffer is further away from the SPS. This would permit the Operations Zone boundary to be revised providing new areas for operations. (QS 1, QS 2, QS 4)
- The SPS Master Plan proposes that the Quiet Sector ASMA boundary be revised based on the new location of SPRESSO. (QS 3)

DOWNWIND SECTOR

- The Downwind Sector does not contain any new facilities.
- The skiway will shift 1,000 feet (305m) south along the current skiway centerline and the FMQ and supporting infrastructure will be moved. (AIR 1)
- The aircraft parking, apron and flight line will remain in the current location.
- Aircraft will need to taxi a greater distance to the flight line.
- The SPoT route will be revised further south when the skiway is extended due to the shift. The traverse route is proposed to move to the east side of the airfield. (Figure 7.18)
- The SPS Master Plan proposes that the Downwind Sector ASMA boundary be reviewed to accommodate the skiway being shifted south. The Downwind Sector boundary would also change as the Quiet Sector boundary is adjusted. (QS 3)

OPERATIONS ZONE

- The SPS Master Plan proposes that the Operations Zone ASMA boundary be reviewed for adjustment to allow for the extension of the skiway and the Quiet Sector adjustment discussed above. (QS 3)
- Establish Land Use Districts, Overlays and Easements.
- Raise Elevated Station, and SuperDARN. (OZ 1, SPS 1)
- Raise Radome building, RF building, HF Antennas and TDRS platform. (OZ 1, SPS 1)
- Deinstall the 9m antenna and retrograde. (ITT 5)
- Replace the DNF cargo Jamesway.
- Water and Waste: Add a new Rodwell, outfall and waterline as needed. Add a WWTP. Maintain/upgrade utility ice tunnels. Remove retrograde. (OZ 5, OZ 10, WS 1 thru 7, HSW 1 thru 7)
- Move and enlarge the north NGO site closer to the Ceremonial South Pole to increase separation from the Clean Air Sector. This will minimize movement from the NGO site to the Ceremonial South Pole. As the GSP migrates along its projected alignment it will eventually be located closer to the New Station Area. A new NGO camp site is proposed southeast of the new station facility when a new station facility is constructed. (NGO 5)
- Establish new/revised NGO operations guidance. (NGO 1, NGO 3)
- Develop EMI governance/management plan with implementing procedures for SPS, to include EMI screening criteria for the selection of future electro-mechanical systems, facility UPS systems, and other EMI-emitting infrastructure and equipment. Implement a sustainable RF spectrum monitoring system to track background noise emissions and to provide a real-time aid for finding and resolving spurious EMI events. (SPS 2)
- Increase SPoT capacity and or introduce a new airframe to improve the capacity for personnel and cargo delivery. Upgrade cargo/fuel loading and uploading efficiencies. (OZ 9, SPoT 1 thru 4, AIR 2, AIR 3)
- A Snow Storage Overlay has been identified south of the SPS. This area is enlarged to accommodate future storage needs. (OZ 11)
- A primary road/route has been identified to simplify circulation through the SPS. This route connects to the SPoT south of the airfield and extends to the northeast providing access to the Downwind Sector and the north NGO camp. (OZ 4)
- Construct a new Field Science Support and Staging Facility (FSF). The FSF would provide four modular buildings (similar to one module of Building 118). The modules would be fitted for storage, testing, garage, and temporary berthing. The FSF is located near the airfield for efficient logistics cargo transfer. (OZ 7, FS 2, FS 3, FS 5, FS 6, FS 7)

- Procure a light traverse platform to support Field Science. (TR 1, TR 2, TR 3, FS 1)
- Provide emergency services with ample storage and staging space in the Elevated Station and directly adjacent to or integrated with field and aircraft staging areas. (EMS 1 thru 4)
- Construct a Construction Camp. A Construction Camp will be established to accommodate up to 100 personnel. Four existing hypertats have been renovated which will accommodate 34 personnel. Additional hypertats or new facilities will be added to reach the desired number of personnel. A community building/ module will be provided for restrooms, common area, and small kitchen facilities. All Construction Camp facilities are encouraged to explore the use of alternative energy sources. Localize waste Rodwells will be used. The location of the Construction Camp is designated as a Temporary Structures Overlay as defined above. This site has been known as the Summer Camp. All existing structures, except for the four renovated hypertats, will be removed as retrograde. (OZ 6)
- Develop a Utility Master Plan that establishes utility rights-of-ways for routing of fiber optic telecommunications cables, electrical lines, and water and sewer lines. The Utility Master Plan would monitor geospatial locations of the rights-of-way from year to year to account for ice sheet movement. (OZ 8, UC 1 thru 5)
- Initiate an alternative energy production system design and construction effort. The SPS Master Plan proposes a site for an alternative energy field, but the actual location will be determined at the time of design. (E 4, E 5)
- The communications facilities south of the SPS (RF and Radomes), could be relocated to reduce EMI and improve satellite orientations. A site is identified on the master plan, but the actual location will be determined by design requirements. (OZ 12, ITT 1, ITT 2, ITT 12)
- Replace the four Arch buildings. The Power Plant, Fuel Storage, Logistics, and VMF buildings. (OZ 2, E 1, E 2, E 3)

Figure 7.20 shows a building complex layout for the replacement buildings. The Power Plant and Fuel Storage buildings are located in close proximity to existing facilities to minimize the distance to reconnect power and fuel lines. Connected to the Power Plant are two Logistics buildings (L1, L2). Two separate buildings are proposed to accommodate a phased expansion. The final building is the VMF located off the Logistics building to the west. All buildings will be connected by enclosed walkways. The VMF has been located to have direct access to the open workspace west of the building and for easy access to the existing VMF and arches. Once the arches are abandoned, they can serve as an extension of the new VMF and used for storage and heated parking space. At some point the abandoned arches will need to be removed as their structural integrity is compromised. The Logistics buildings are shaped and configured to serve as a bridge to a future Station to the southeast. Once a new Station building is constructed, the intent is that it would be located close to the southern corner of the L2 building.

All the replacement buildings are located in an area where abandoned Rodwells and some small facilities are located. Initial discussions determined that the Rodwells and facilities could be mitigated to permit building construction. Extensive surveys and studies will need to be conducted to prepare the site prior to development, but the expectation is that these areas would be repurposed (brownfields) for the replacement buildings, thereby not developing in virgin areas (greenfields). This is environmentally sound and adheres to the Design Principle of Rightsized & Compact.

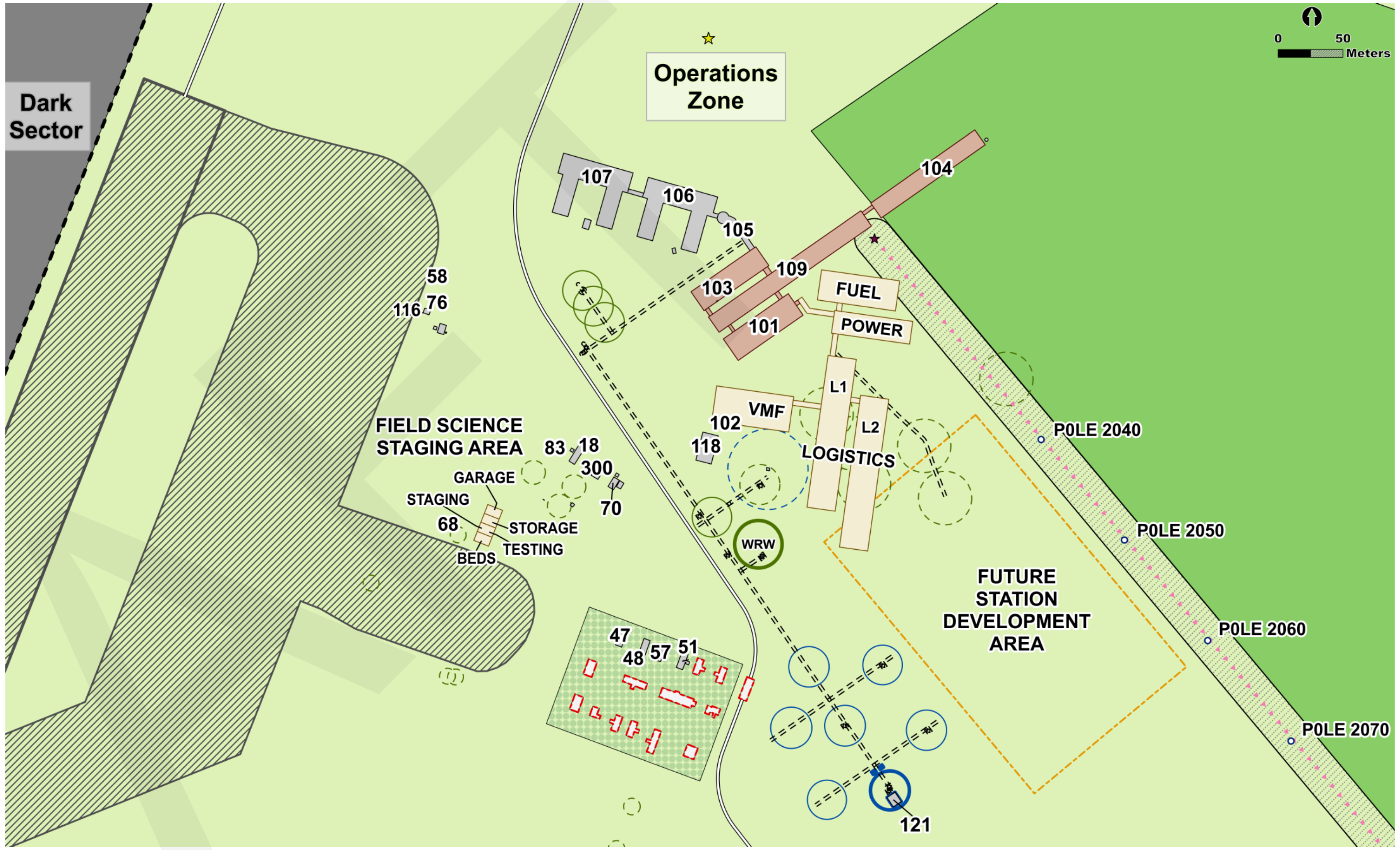
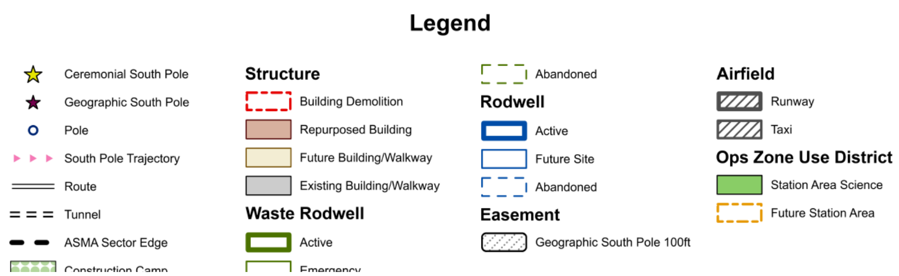


Figure 7.20 Concept One - Overall SPS.



The following describes the proposed Building Type for each replacement building and the rational.

BUILDING TYPES

POWER PLANT

Building form: Elevated

Rational: The powerplant is a critical infrastructure component to the station, providing power and heat needed to support the residents across all four seasons. Due to the critical nature of the plant, it was determined that this facility warrants the most robust construction type that will provide a reliable facility with the longevity needed to support ongoing operations.

The elevated structure would be designed to accommodate lifts, similar to the existing Elevated Station. This prolongs the life of the facility by increasing the time it takes to reach the snow surface when drifts will begin to bury the structure without significant and ongoing snow removal.

FUEL STORAGE

Building form: Elevated

Rational: While the powerplant provides heat and power to the station, essential for the continued occupancy of the station, the fuel storage infrastructure is essential to support the diesel generators in the powerplant. The fuel storage building was identified as critical infrastructure warranting a building form with the longest anticipated useful life.

LOGISTICS

Building form: Arches

Rational: Two arches are envisioned for this concept. While both could be heated, one could be unheated storage with DNF materials consolidated to the heated arch. Arches are relatively quickly constructed and could be assembled on at-grade foundations to slow the burial process experienced by the existing arches that were constructed below surrounding snow elevations.

VEHICLE MAINTENANCE FACILITY (VMF)

Building form: Elevated

Rational: In this site concept the VFM was elevated to provide the station as a whole with a lower snow drift burden. Elevated structures permit snow to path through the open space below the floor structure, reducing the overall drift accumulation with time. One consideration for the VMF as an elevated structure is that the ramp needed for vehicle access will need to be maintained to ensure that it is always accessible. Though the building will have reduced drifting, the ramp itself will be susceptible to snow drifts and will require regular drift clearing.

SNOWDRIFT CONSIDERATIONS

PRO:

The upwind power plant and fuel storage building, being elevated structures that allow for the free flow of air underneath the structure, significantly reduce leeward drift volumes. The reduction in leeward drifting is expected to reduce drift impacts on the downwind logistic arches. Foundation design of the power plant and fuel storage buildings should focus on minimizing obstructions underneath the buildings as leeward drift volumes increase as under-building airflow decreases (CRREL TR-12-7).

CON:

The VMF building situated to the west of the arches is directly downstream of the existing buried arches. Windward drift accumulation in front of the elevated VMF building may detrimentally impact access to the existing easternmost buried arch.

Dome. Source: https://antarcticsun.usap.gov/features/1984/

Elevated Structure. Source: NSF, Undated.

VMF Snowdrift. Source: NSF, Gabe Nert, 2020 .

MASTER PLAN - CONCEPT TWO

Concept Two is the most aggressive concept as it proposes to shift the skiway. This concept also views the 35-50 year horizon as an opportunity to implement as many Recommendations as can be achieved. In addition to a different building configuration for the replacement buildings, this Concept proposes shifting the skiway 2,500 feet south to ensure aircraft can avoid the Clean Air Sector. The following describes the items proposed for Concept Two. Only items that are different from Concept One are described below.

SECTORS

DARK SECTOR

- Access to the Dark Sector will be improved once the airfield skiway is shifted south 2,500 feet (762m). This will allow pedestrians and vehicular traffic to cross north of the airfield threshold without having to wait for aircraft approaches and departures. Pedestrian and vehicular traffic will still need to be controlled when aircraft taxi north to the NGO camp sites.

DOWNWIND SECTOR

- The skiway will shift 2,500 feet (762m) south along the current skiway center-line and the FMQ and supporting infrastructure will be moved.

OPERATIONS ZONE

- The SPS Master Plan proposes that the Operations Zone ASMA boundary be reviewed for adjustment to allow for the extension of the skiway.
- Replace the four Arch buildings. The Power Plant, Fuel Storage, Logistics, and VMF buildings.

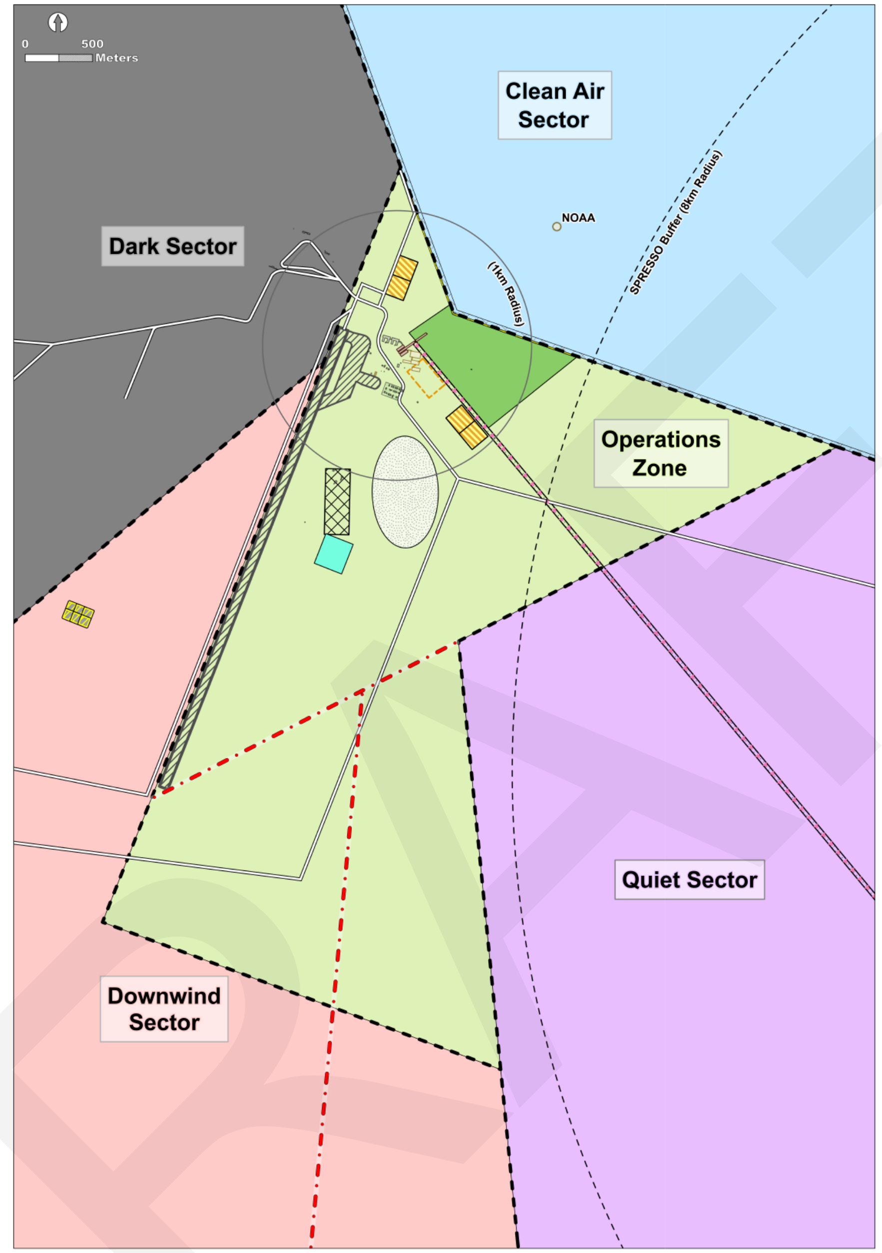


Figure 7.21 Concept Two - New Sector Configuration .

Legend

1km Radius
SPRESSO Buffer 8km
South Pole Trajectory
Route
Original ASMA Sector Edge
New ASMA Sector Edge
NGO Area
Alternative Energy Field
Snow Storage
Airfield
Runway
Taxi
Ops Zone Use District
Station Area Science
ASMA Zone
Restricted
Operations Zone
ASMA Sector
Downwind Sector
Clean Air Sector
Dark Sector

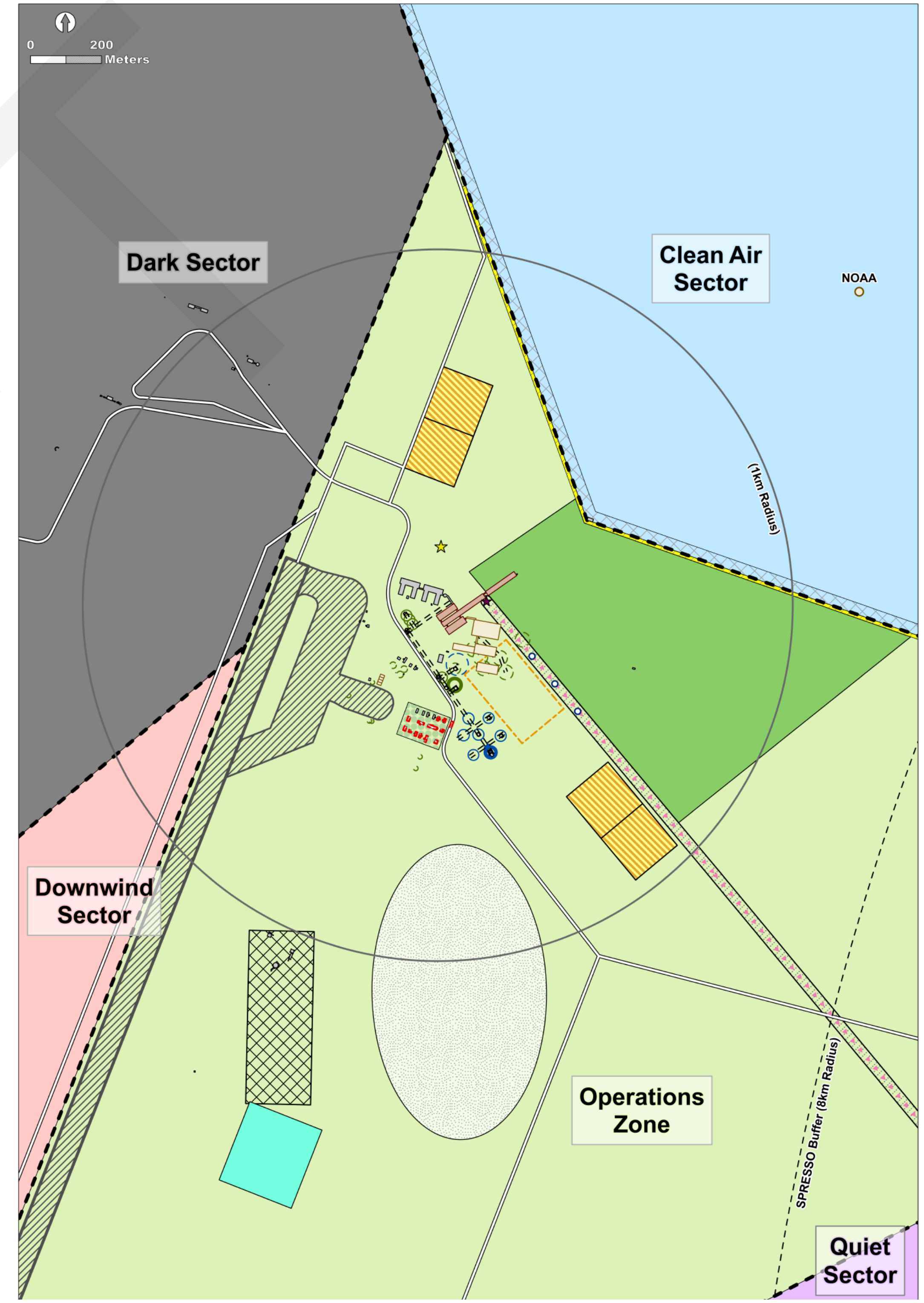


Figure 7.22 Concept Two - Operations Zone.

Legend

Ceremonial South Pole
Geographic South Pole
Pole
South Pole Trajectory
Route
Tunnel
ASMA Sector Edge
1km Radius
SPRESSO Buffer 8km
CAS Buffer 100ft
Construction Camp
NGO Area
Communications Area
Snow Storage
Structure
NOAA Proposed Building
Building Demolition
Repurposed Building
Future Building/Walkway
Existing Building/Walkway
Waste Rodwell
Active
Emergency
Abandoned
Rodwell
Active
Future Site
Abandoned
Easement
Geographic South Pole 100ft
CAS Access Control
Airfield
Runway
Taxi
Ops Zone Use District
Station Area Science
Future Station Area
ASMA Zone
Restricted
Operations Zone
ASMA Sector
Downwind Sector
Clean Air Sector
Dark Sector
Quiet Sector

Figure 7.23 shows a building complex layout for the replacement buildings. The Power Plant and Fuel Storage buildings are located in close proximity to existing facilities to minimize the distance to reconnect power and fuel lines. The Logistics building is located northeast of the Fuel Storage to minimize contamination of food from fumes and to maintain a short distance to the Elevated Station. The VMF building is located southeast of the Power Plant building. This allows for a drive-thru building and ample room around the building for equipment movement. All buildings will be connected by a continuous enclosed walkway. Once the arches are abandoned. They can be used for storage and heated parking spaces. At some point the abandoned arches will need to be removed as their structural integrity is compromised. The configuration of the four buildings is designed to create a bridge to a future Station to the southeast of the VMF. Once a new Station building is constructed, the intent is that it would be located close to the VMF building which would provide an enclosed walkway to all buildings.

All the replacement buildings are located in an area where abandoned Rodwells and some small facilities are located. Initial discussions determined that the Rodwells and facilities could be mitigated to permit building construction. Extensive surveys and studies will need to be conducted to prepare the site prior to development, but the expectation is that these areas would be repurposed (brownfields) for the replacement buildings, thereby not developing in virgin areas (greenfields). This is environmentally sound and adheres to the Design Principle of Rightsized & Compact.

The following describes the proposed Building Type for each replacement building and the rational.

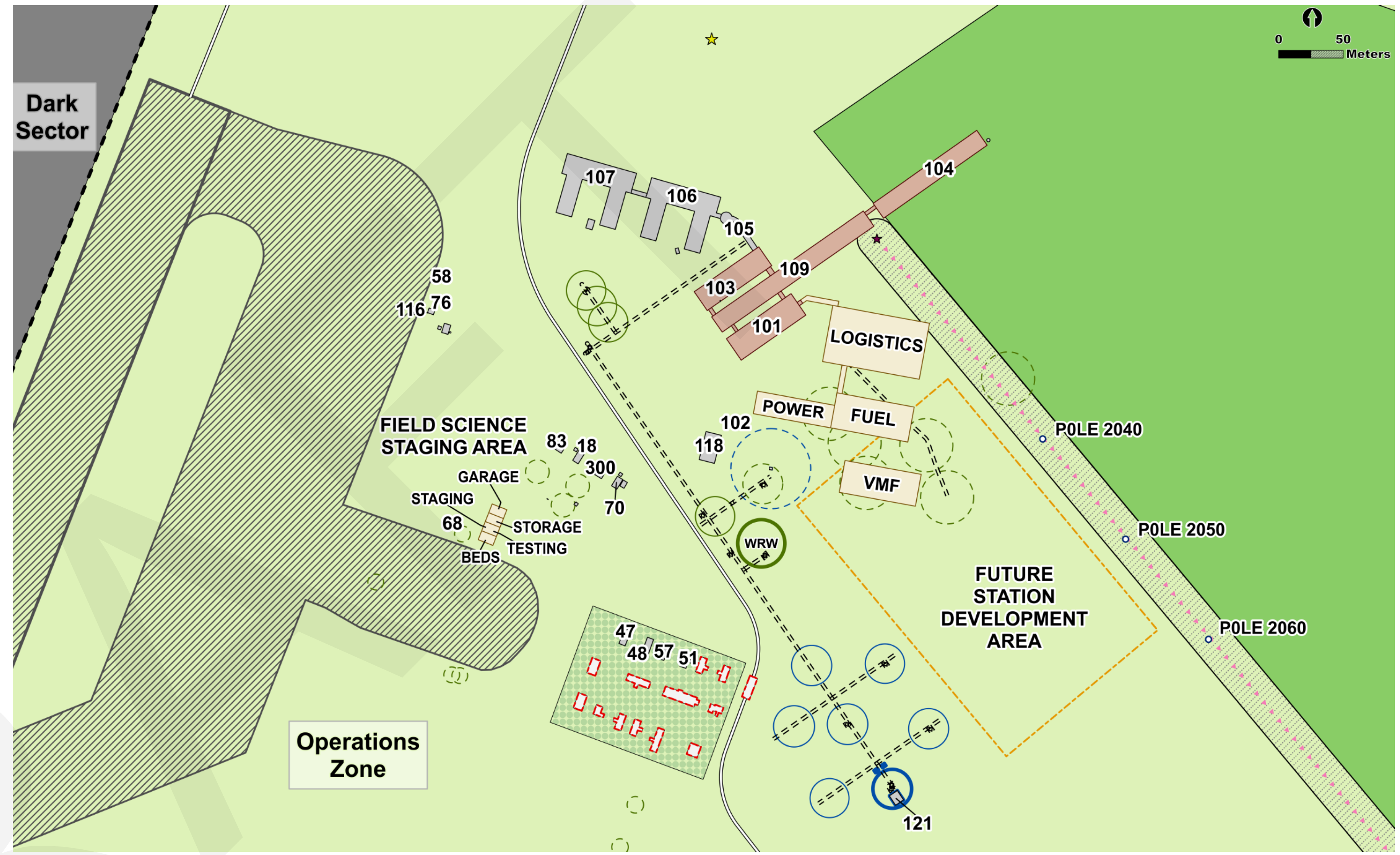
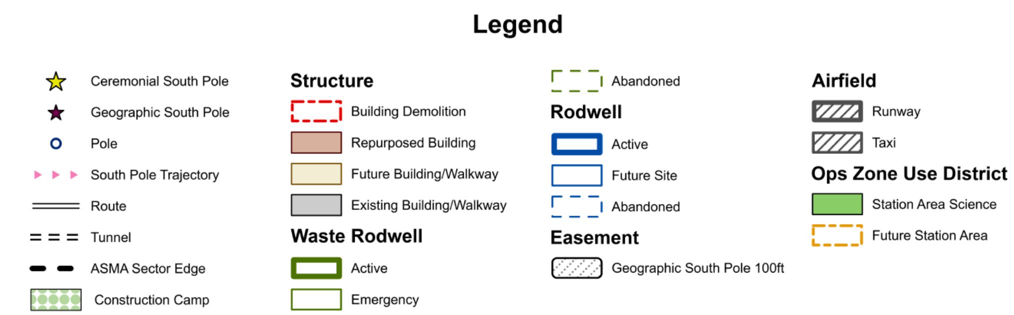


Figure 7.23 Concept Two - Overall SPS



BUILDING TYPES

POWER PLANT

Building form: Elevated

Rational: See Concept One rationale.

FUEL STORAGE

Building form: Elevated

Rational: See concept 1 rationale.

LOGISTICS

Building form: Elevated

Rational: In this site plan the logistics storage area is consolidated into a single, robustly constructed, elevated structure. With the positioning of the logistics facility in this site plan drifting that accumulates around the logistics facility will negatively impact the nearby fuel storage and powerplant structure as well as the VMF. Elevating this structure, given the positioning within the site plan and prevailing wind direction, will reduce the maintenance burden for snow clearing.

VMF

Building form: Arches

Rational: The VMF in this concept is constructed using the arch. The longevity of the arch can be improved over the current application of this construction method by developing a compacted snow pad that elevates the floor of the VMF above the surrounding grade, thereby increasing the time to a burial condition. Arches can be built efficiently and quickly on the site, allowing this structure to replace the existing facility relatively quickly. This is of great benefit due to the condition of the existing VMF and the need for replacement in the near future.

SNOWDRIFT CONSIDERATIONS

PRO:
Similar to Concept One, siting the elevated structures north of the at-grade structures should lessen the detrimental impacts of leeward drifting onto the downwind VMF arch.

CON:
The elevated fuel and power building is situated directly downwind of the existing buried arches. As such, leeward drifting effects from the buried arches may detrimentally impact the drift performance of the elevated combined fuel & power facility. This may cause adverse drift effects at both the east side of the existing buried arches and the new VMF arch.

VMF to Logistics Operations Arch tunnel. Source: NSF, 2023.

MASTER PLAN - CONCEPT THREE

Concept Three is the least aggressive concept. Besides a third building configuration for the replacement buildings, the main difference from Concept One is that the SPRESSO does not move to a new location. The following describes the items proposed for Concept Three. Only items that are different from Concept One are described below.

SECTORS

DARK SECTOR

- The skiway does not change so access to the Dark Sector and during NGO aircraft taxiing will need to continue to be controlled.

QUIET SECTOR

- The SPRESSO facilities will be replaced generally in its current location, and new cabling installed. The location of a new SPRESSO will be determined by science. The master plan assumes the SPRESSO buffer will remain generally the same and continue to limit operations within the buffer and the Operations Zone.
- The Quiet Sector ASMA boundary does not change. .

DOWNWIND SECTOR

- The Downwind Sector does not contain any facilities.
- The skiway will remain unchanged.
- A NGO camp area is shown along the traverse route as a future location away from the SPS.
- The SPoT route will remain in its current location.
- The Downwind Sector ASMA boundary does not change.

OPERATIONS ZONE

- The Operations Zone ASMA boundary does not change.
- A primary road/route has been identified to simplify circulation through the SPS. This route connects to the SPoT south of the airfield and extends to the northeast providing access to the Downwind Sector and the north NGO camp.
- Replace the four Arch buildings. The Power Plant, Fuel Storage, Logistics, and VMF buildings.

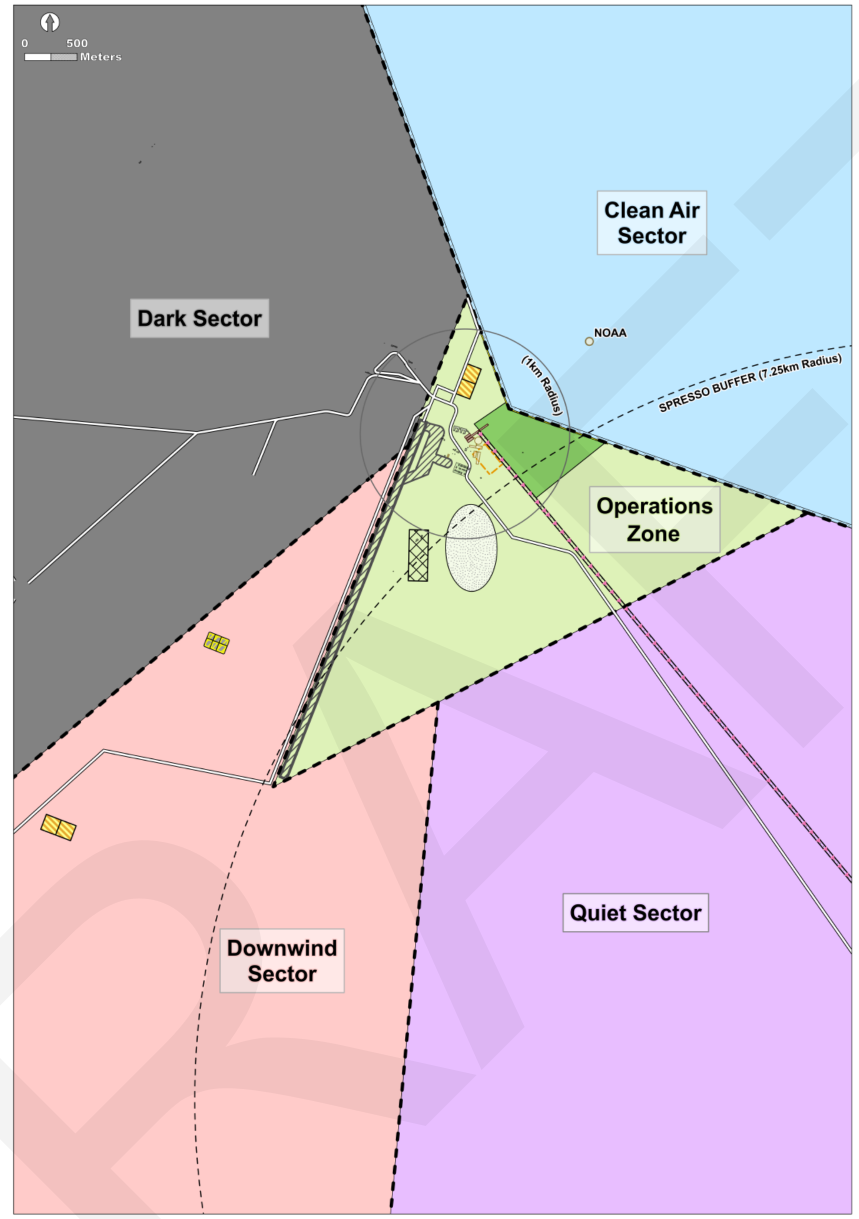
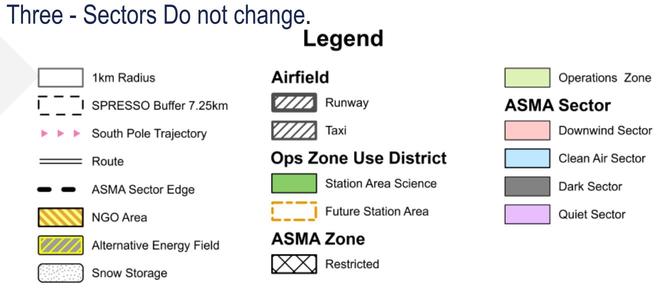


Figure 7.24 Concept Three - Sectors Do not change.



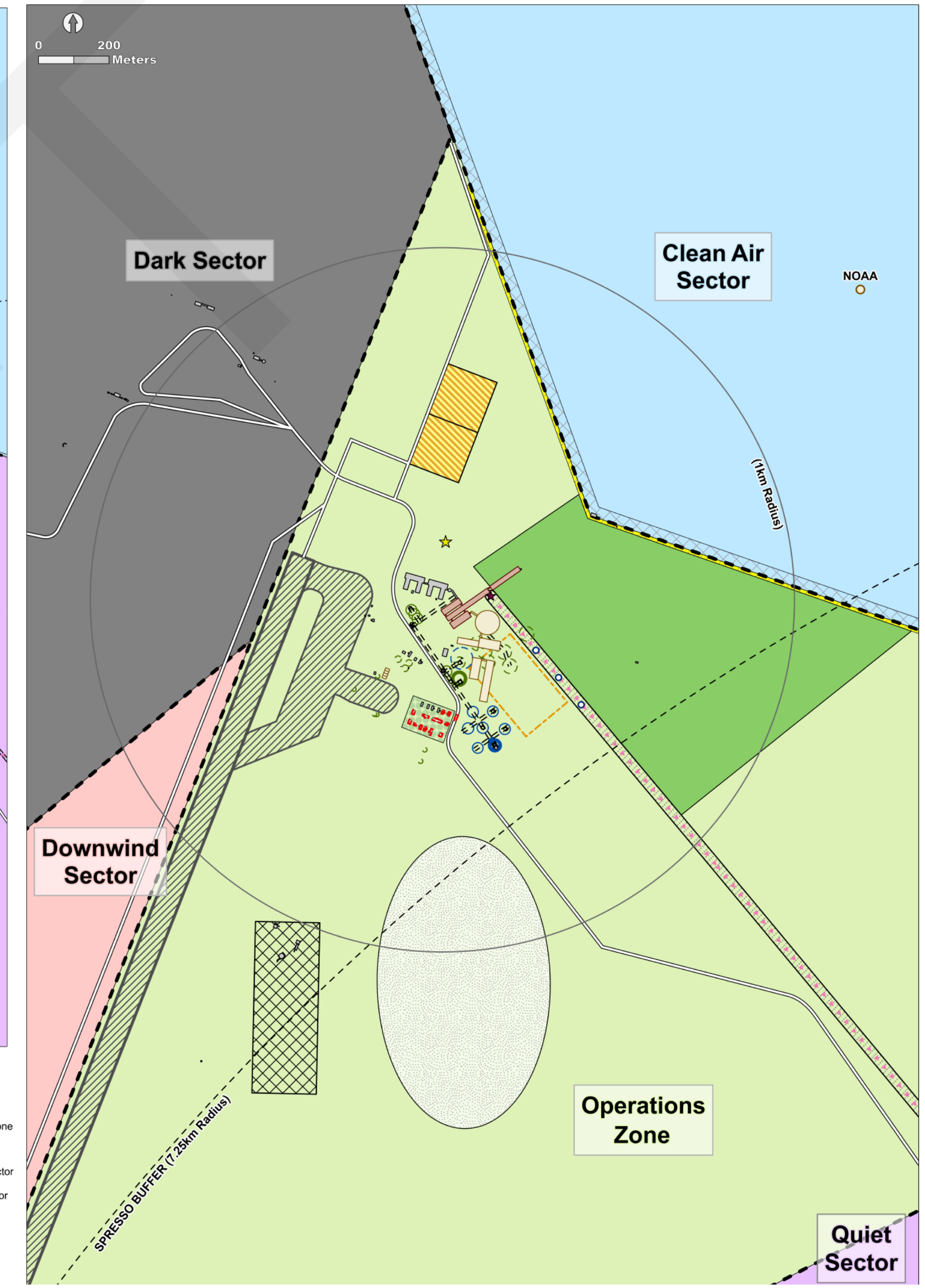


Figure 7.25 Concept Three - Operations Zone.

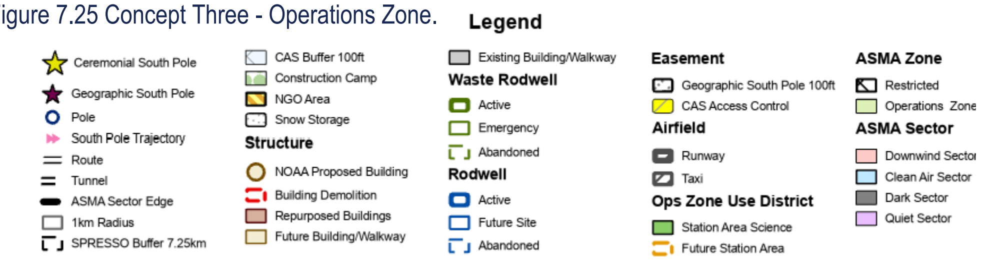


Figure 7.26 shows a building complex layout for the replacement buildings. The Power Plant and Fuel Storage buildings are located in close proximity to existing facilities to minimize the distance to reconnect power and fuel lines. The Logistics building is located northeast of the Fuel Storage to minimize contamination of food from fumes and to maintain a short distance to the Elevated Station. The VMF building is located southeast of the Power Plant building. This allows for a drive-thru building and ample room around the building for equipment movement. A heated parking structures in located next to the VMF for winter over of equipment. All buildings will be connected by enclosed walkways. Once the arches are abandoned they can be used for storage and heated parking spaces. At some point the abandoned arches will need to be removed as their structural integrity is compromised. The configuration of the four buildings is designed to create a bridge to a future Station to the southeast of the VMF / Heated Parking structures. Once a new Station building is constructed, the intent is that it would be located close to the VMF / Heated Parking structures which would provide a continuous enclosed walkway to all buildings.

All the replacement buildings are located in an area where abandoned Rodwells and some small facilities are located. Initial discussions determined that the Rodwells and facilities could be mitigated to permit building construction. Extensive surveys and studies will need to be conducted to prepare the site prior to development, but the expectation is that these areas would be repurposed (brownfields) for the replacement buildings, thereby not developing in virgin areas (greenfields). This is environmentally sound and adheres to the Design Principle of Right Sized & Compact.

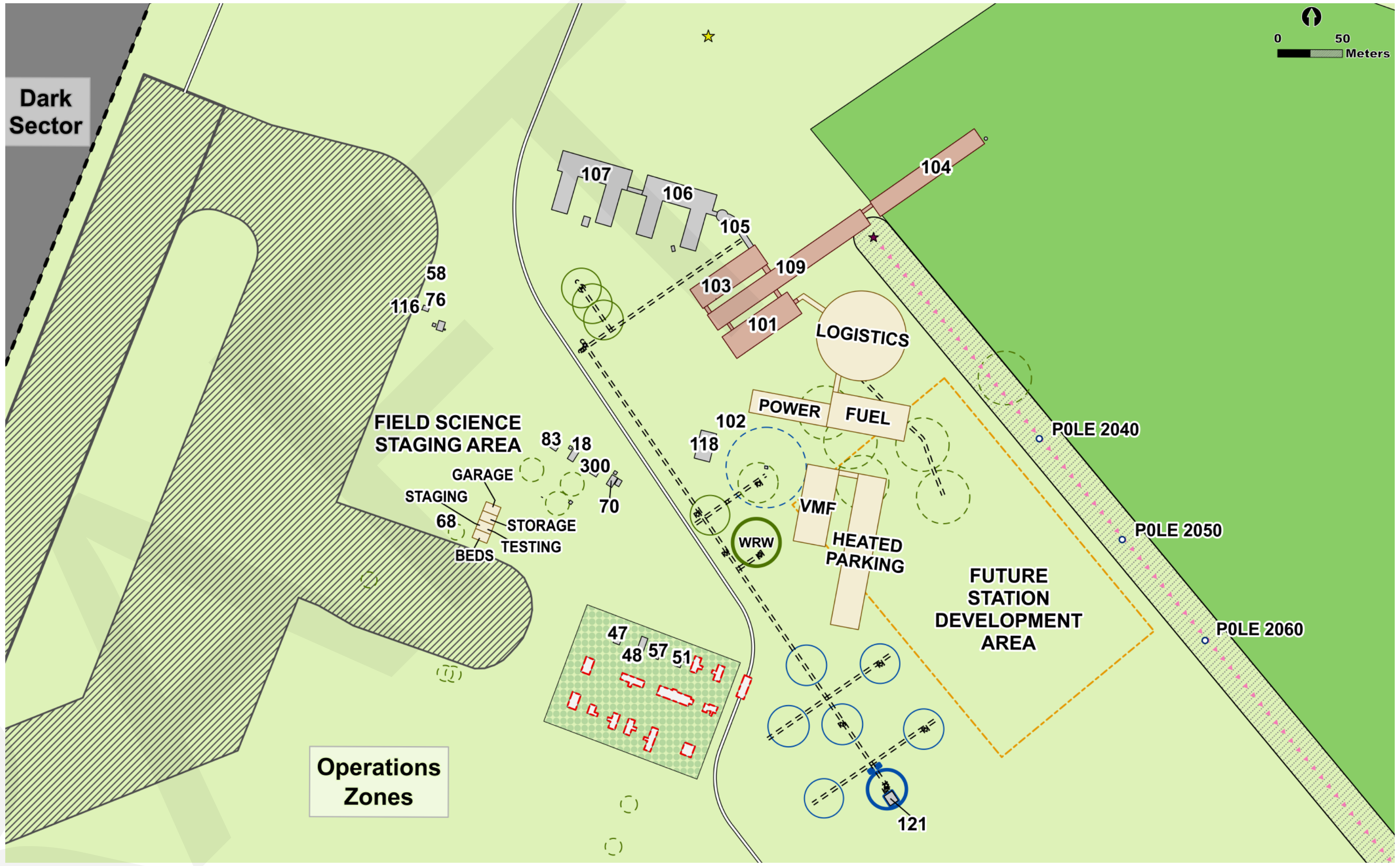
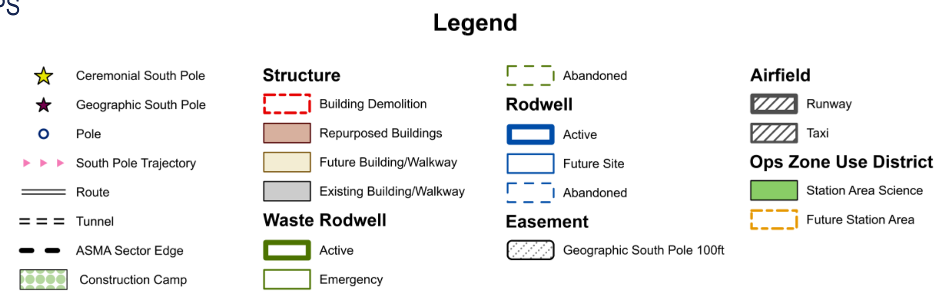


Figure 7.26 Concept Three - Overall SPS



The following describes the proposed Building Type for each replacement building and the rational.

BUILDING TYPES

POWER PLANT / FUEL STORAGE

Building form: Elevated

Rational: This concept includes an elevated structure for the powerplant and fuel storage. However, in this option these two facilities are combined. Utilizing the elevated approach provides the same benefits as described in Concept One but in addition it consolidates two buildings into one, which can reduce the overall footprint depending on layout, and does not rely on utility corridors for transport of fuel between the storage tank and the plant.

LOGISTICS

Building form: Dome covered structure

Rational: This site concept utilizes a dome, similar to that which was in use at the station prior to the construction of the Elevated Station. The dome provides flexibility in the size and orientation of the structures within it. Various surface structures could be constructed within the dome where they are protected from the crushing force of drifted snow. Multiple smaller logistics facilities could be added over time as funding permits, allowing a phased construction approach. The free spaces within the dome, outside the footprint of the interior structures and travel paths, could be used as cold storage, where burial is not a concern.

VMF

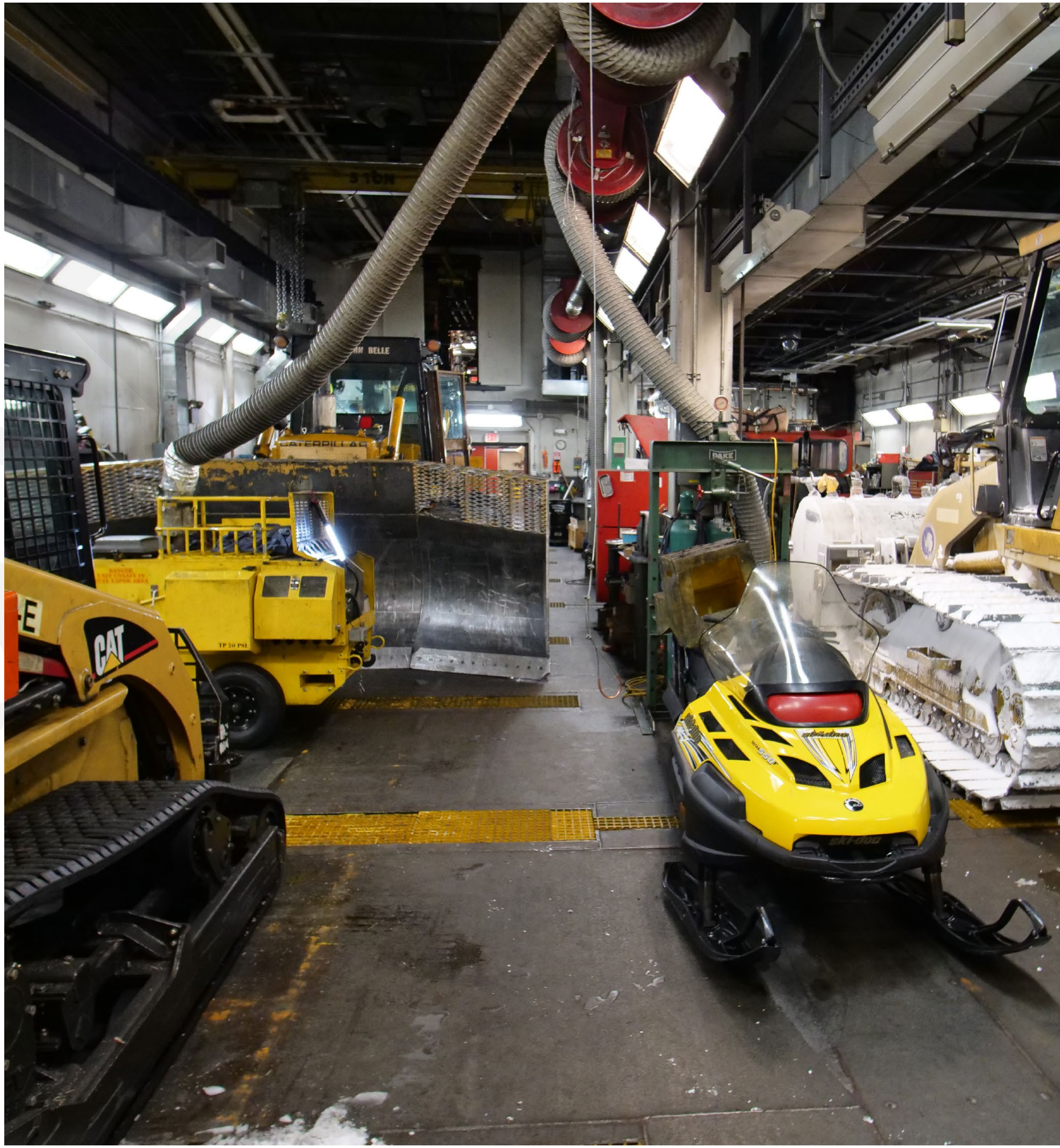
Building form: Arch

Rational: This concept locates the VFM downwind of the other facilities, connected to the powerplant with a covered pedestrian path. In this concept the VFM is constructed as an arch, similar to the existing. The new arch could be constructed at an elevated grade, my mounding and compacting snow to elevate the arch above the current surround surface. This will extend the life of the facility by slowing the rate of burial. Continuous maintenance will be required for snow drift mitigation and to ensure continuous access to the vehicle drive entry. This concept balanced initial cost investments by prioritizing critical facilities and opting for more cost conservative approaches for support structures, including the VMF.

SNOW DRIFT CONSIDERATIONS

PRO:
Pulling from institutional knowledge of how the original south pole station dome functioned, we assume drift accumulation around the new geodesic dome will reach a steady state of windward and leeward drifts that require little or no clearing.

CON:
Similar to Concept Two, the elevated fuel and power building is situated directly downwind of the existing buried arches. As such, leeward drifting effects from the buried arches may detrimentally impact the drift performance of the elevated combined fuel & power facility. This may cause adverse drift effects at both the east side of the existing buried arches and the new VMF arch.



VMF. Source: NSF, Josiah Horneman, 2021.

Capital Infrastructure Plan

The prioritization of infrastructure projects proposed in the SPS Master Plan serves as a baseline for large infrastructure projects at SPS. In instances where infrastructure elements must be addressed outside of this Master Plan based on new or adjusted priorities, including, but not limited to, emergency situations, new safety concerns, new regulatory requirements, and new directional policy, the NSF reserves the authority to reprioritize infrastructure projects accordingly.

8.1 CAPITAL INFRASTRUCTURE PROJECTS PHASING

PHASE 1: MOBILIZATION/CONSTRUCTION

This phase prepares SPS and the SPS logistics chain for major construction activities, while also raising smaller utility structures and the deepest buried science structures.

PHASE 2: PRIMARY INFRASTRUCTURE

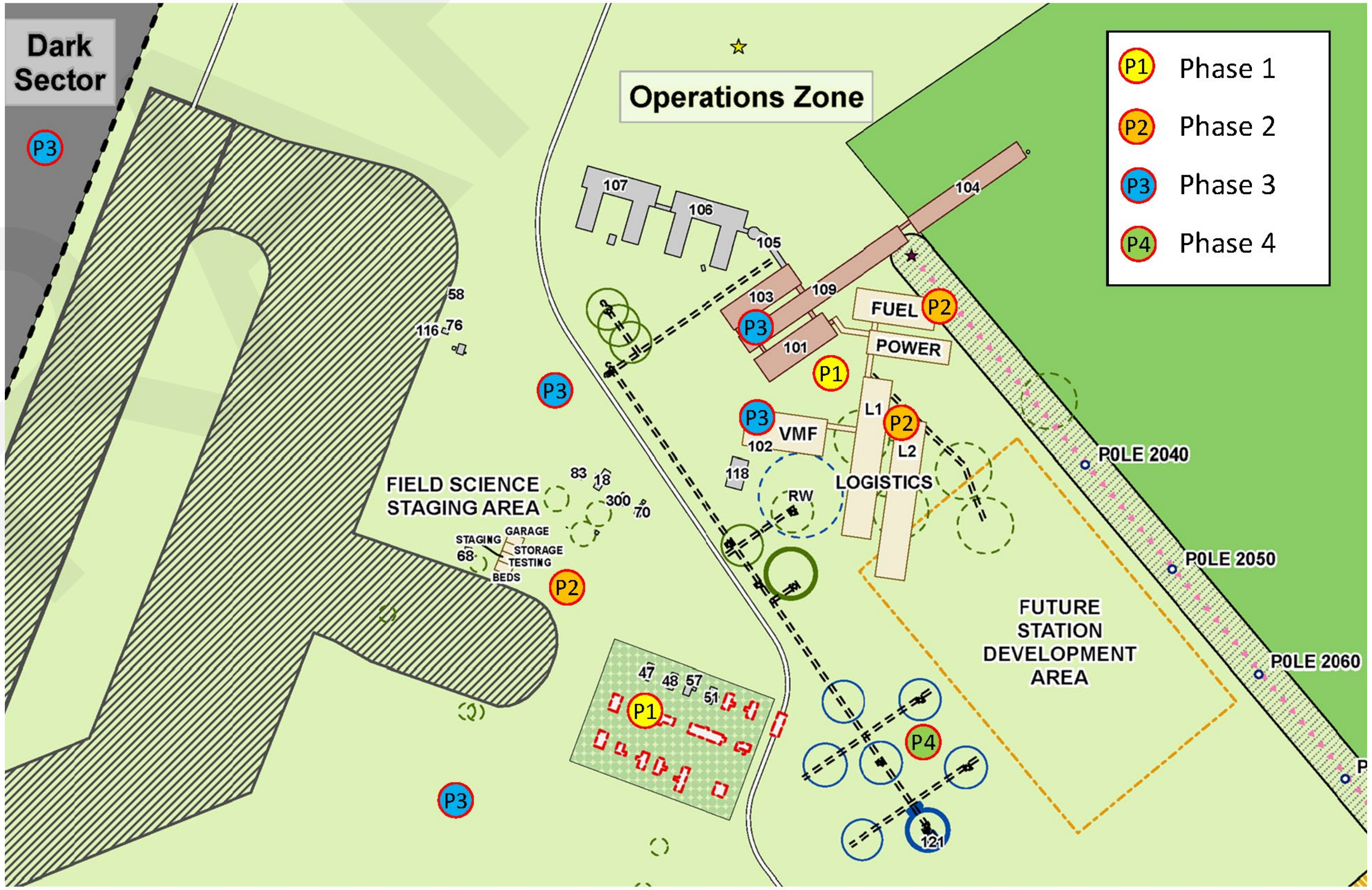
This phase focuses on arch replacements, while also raising additional science structures.

PHASE 3: SUPPORT FACILITIES

This phase focuses on completing the remaining arch replacement and the elevated station raise, while also raising the remaining science structures.

PHASE 4: MAINTENANCE CYCLES

This phase establishes maintenance rhythm for future raises and replacements to prevent future backlogs.



Proposed Capital Infrastructure Projects Phasing Plan .

8.2 CAPITAL INFRASTRUCTURE PROJECTS PRIORITIZATION - DRAFT

The following projects list is a draft prioritization of capital investments that support NSF's Vision for the future of SPS and implement the recommendations of the SPS Master Plan. For a compiled list of recommendations, please refer to Appendix B.

These projects have been prioritized based on current project activities, current conditions, projected station and logistics resource availability, and anticipated project cost profiles. Many of these projects will require the completion of detailed studies before project activities can begin; these additional studies are beyond the scope of the SPS Master Plan.

Phase	Proposed Project Title
Phase 1 Construction Mobilization	HF Radio Modernization
	South Pole Land Mobile Radio (LMR) System Full Replacement
	Scientific Research Facility Lifting System Procurement
	Raise ARO Scientific Research Facility
	Mitigate Garage Building and VMF Arch Interface
	South Pole Traverse (SPoT) Module Improvements
	Satellite Communications Upgrade
	New Rodwell (Rodwell 4), Outfall, and Waterline
	South Pole Operations Traverse (SPoT) 6-Tractor Fleet Expansion
	Arch System Replacement Design
	South Pole Fleet and Construction Equipment Refresh
	Construction Camp Completion
	Raise Electrical Building 61
	Berm Inventory and Retrograde Plan
Phase 2 Primary Infrastructure	Replace NOAA Tower
	Raise MAPO Scientific Research Facility
	BICEP Array Replacement Tower (BART) Installation
	McMurdo Airfield Refueling Module Replacement
	South Pole Alternative Energy Production System Design and Construction
	South Pole Utility Master Plan
	South Pole Arch Replacement - Fuel Arch
	South Pole Arch Replacement - Power Plant Arch
	South Pole Arch Replacement - VMF Arch
Phase 3 Support Facilities	South Pole Arch Replacement - Logistics Arch
	Raise DSL Scientific Research Facility
	Raise ICL Scientific Research Facility
	Raise Elevated Station
	Construct Field Science Staging Structure
	Raise SuperDarn Scientific Research Facility and Antennas
Phase 4 Maintenance Cycles	Replace SPRESSO Infrastructure
	Raise Radio Frequency (RF) Building
	Raise Defense Satellite Communications System (DSCS) Building
	Raise Radome Building
	Raise South Pole Tracking and Data Relay Satellite System (TDRSS) Relay (SPTR) Buildings
	South Pole Wastewater Treatment Plant (WWTP)
	Elevated Station Replacement Design
	Cyclical Raises of Scientific Research Facilities
	Cyclical Raises of Station Auxiliary Structures

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APPENDIX A

Glossary

° degree
- Negative/minus
% Percent
ACE Access Control Easement
AIR Airfield
ANG Air National Guard
ARFF Aircraft rescue fire fighters
ARO Atmospheric Research Observatory, operated by NOAA
ASC Antarctic Support Contractor
ASMA Antarctic Specially Managed Area: the Management Plan for Antarctic Specially Managed Area No.5 AMUNDSEN-SCOTT SOUTH POLE STATION, SOUTH POLE is referred to as "the ASMA" in the SPSMP
ASPA Antarctic Specially Protected Area
ATCM Antarctic Treaty Consultative Meeting
AWS Automatic Weather Station, operated by NOAA
BASLER Modified Douglas DC-3 aircraft, updated with new avionics and engines
BIF Balloon Inflation Facility, operated by NOAA
Bldg. Building
BLUE BUILDINGS Colloquial name for the scientific structures MAPO, ICL, DSL, SPT, and ARO
BOD Basis of Design
C Celsius
CA California
CAS Clean Air Sector
CEP Committee for Environmental Protection
CFD Computational Fluid Dynamics
CLEAN AIR SECTOR Grid area northeast (upwind) of SPS within the Scientific Zone designated by the ASMA, dedicated to atmospheric research, and established to avoid contamination from exhaust fumes
COMM Communications
COMSUR Commercial Surface Cargo
CONSTRUCTION CAMP Worker Housing
CONUS Continental U.S.
CRREL Cold Regions Research and Engineering Laboratory
D Dark Sector
DAFMAN Department of the Air Force Manual
DARK SECTOR Grid area west of SPS within the Scientific Zone designated by the ASMA, where light pollution and electromagnetic interference are reduced; dedicated to astrophysical, astronomical, and aeronautical research
DESIGN PRINCIPLE Foundational guidance factor that informs the design of the built environment and is applicable across a wide variety of recommendations and objectives for maintaining, replacing, and operating current and future buildings and infrastructure at SPS; it is not a mandate
DISTRICT OVERLAY Land use organization tool used to identify areas where additional restrictions apply to the underlying land use district or Zone
DNF Do Not Freeze
DOE-Science Department of Energy/Office of Science
DOI Department of the Interior
DOMING Ice-floor surfaces of all arches are subject to gradual upward deflection while the arch wall foundations simultaneously settle under the weight of snowdrift and ice accumulation
DOWNWIND SECTOR Grid area southwest of SPS within the Scientific Zone designated by the ASMA, free from obstructions for balloon launches, aircraft operations, and other activities; it has operated largely as an extension of the Operations Sector for airfield and overland traverse purposes
DSCS Defense Satellite Communications System
DSL Dark Sector Laboratory (houses the South Pole Telescope)
E Energy
EASEMENT Land use organization tool applied to areas that should remain free of obstructions and where additional restrictions apply to the underlying land use district or ASMA Zone; they are similar to the ASMA Restricted Zones
EMI Electromagnetic interference
EMS Emergency Services
F Fahrenheit
FAA Federal Aviation Administration
FAE Finite area element
FS Field Science
FSF Field Staging Facility
gal Gallon
GPS Global Positioning System
GSP Geographic South Pole
GSF Gross Square Feet
HF High-Frequency
hr Hour
HST Heavy Science Traverse
HSW Human and Solid Waste
HVAC Heating, ventilation, and air conditioning
HYPERTAT Blue modular housing facility, an improved Quonset hut design; named after the now defunct company that manufactured the structure
IAATO International Association of Antarctic Tour Operators
ICL IceCube Laboratory, a deep-ice neutrino observatory
IFR Instrument flight rules
IGY International Geophysical Year
Imaginary Surface Imaginary areas in space which are defined by the airport approach safety zone, transitional zones, horizontal zone, clear zone and conical surface and in which any object extending above these imaginary surfaces is an obstruction.
IPCC Intergovernmental Panel on Climate Change
IRIDIUM Satellite radio communications system
IT Information technology
ITT Information technology & telecommunications
JTF-SFA Joint Task Force - Support Forces Antarctica, a combined unit of the U.S. military that supports the USAP
km kilometer
kW kilowatts
lb Pound
m meter
MAPO Martin A. Pomerantz Observatory
MW Megawatt
NASA National Aeronautics and Space Administration
NGO Non-Governmental Organization or Non-Government Organization /Tourism
NGV Non-Governmental Visitor
NIOSH National Institute for Occupational Safety and Health
NIWC Naval Information Warfare Center
No. Number
NOAA National Oceanic and Atmospheric Administration
NSF National Science Foundation
NYANG New York Air National Guard
NZ New Zealand
Old Pole The first station
OPERATIONS ZONE Contains the science support facilities and human activity areas.
OPP Office of Polar Programs
OZ Operations Zone
QS Quiet Sector
RF Radio Frequency
RICE Reciprocating Internal Combustion Engine
Rodwell Rodriguez Well
ROM Rough Order of Magnitude
ROS Required on Site
SAD Seasonal Affective Disorder
SAHPR Sexual Assault/Harassment Prevention and Response
sf square foot / square feet
SME Subject Matter Expert
SP South Pole
SPoT South Pole Traverse
SPRESSO South Pole Remote Earth Science and Seismological Observatory
SPRI South Pole Retrograde Initiative
SPS Amundsen-Scott South Pole Station (the Station)
SPT South Pole Telescope
SPTR South Pole TDRS Relay
Summer Camp Worker Housing
SuperDARN Super Dual Auroral Radar Network
TDRS Tracking and Data Relay Satellite System
Temp. Temporary
The Protocol 1991 Environmental Protocol to the Antarctic Treaty
TR Overland Science Traverse
UAE Utility access easements
UC Utility Cabling
U.S. United States
USACE U.S. Army Corps of Engineers
USAF United States Air Force
USAP U.S. Antarctic Program
USGS United States Geological Survey
VMF Vehicle Maintenance Facility
WS Water System
WWTP Wastewater Treatment Plant

APPENDIX B

South Pole Station Master Plan Recommendations

The following is a consolidated list of master plan recommendations from Section 6 South Pole Station Area Plans.

SOUTH POLE STATION

SPS 1 Conduct a cost-benefit analysis regarding whether lifting or full replacement of Science Research Facilities and communications facilities is the most practical and cost-efficient path.
- Raise Science Research Facilities and communications facilities in the near future to prevent structural failure and maintain researcher access to the buildings.
- Evaluate if structural skids or skis can be attached to the foundations (i.e., Science Research Facilities and other science) where possible to simplify snowdrift management and allow regular building relocation via towing.

SPS 2 Develop EMI governance/management plan with implementing procedures for SPS, to include EMI screening criteria for the selection of future electro-mechanical systems, facility UPS systems, and other EMI-emitting infrastructure and equipment. Implement a sustainable RF spectrum monitoring system to track background noise emissions and to provide a real-time aid for finding and resolving spurious EMI events.

DARK SECTOR

D1 Raise Building 61 to maintain telecommunications and electrical power distribution to the Dark Sector.

D2 Raise MAPO, ICL, and DSL buildings in the near future.

D3 Conduct engineering evaluations in cooperation with the radio astronomers to devise safe distance estimates for typical RF emitting devices (e.g., consumer grade equipment, and satellite communications earth stations)

D4 Deconflict crossing the skiway for personnel accessing the Dark Sector.

CLEAN AIR SECTOR

CAS 1 Locate a new NOAA science building up to 1 km northeast of the current ARO building, to add operational space, de-conflict NGO activities, and ensure air quality.

CAS 2 Identify an access control easement along the 110-degree and 340-degree line to manage access into Sector.

CAS 3 Consider management of buffer area upwind of CAS line as an ASMA designation.

CAS 4 Raise the ARO building to prevent structural failure and maintain researcher access to the building.

QUIET SECTOR

QS 1 If the SPRESSO program will continue, a replacement SPRESSO should be relocated northeast of the current location closer to Clean Air Sector to deconflict developable area in the Operations Zone.

QS 2 If the SPRESSO program will continue, establish a SPRESSO buffer of 8 km radius creating a buffer to restrict interference.

QS 3 Redefine ASMA Quiet Sector boundary to free up area for Operations Zone.

QS 4 Continue monitoring the quality and function of cables to anticipate when they need to be replaced.

OPERATIONS ZONE

OZ 1 Construct replacement structures for all facilities and uses within existing arches. Additional storage and warehouse spaces to be included in future structure designs. Auxiliary structure storage should be consolidated into a new structure to reduce the energy demands of disparate, decentralized structures serving similar purposes.

OZ 2 Evaluate moving some science functions to new facilities and/or locations to reduce EMI.

OZ 3 Designate vehicular circulation organized around an efficient station layout.

OZ 4 Inventory all berm contents to determine what can be repurposed to reduce retrograde, storage, and shipping demands. Retrograde reduction plans shall be included with each new project to maintain a compact station footprint and prevent future berm growth and warehousing overruns.

OZ 5 Raise the Elevated Station.

OZ 6 Evaluate needs and location of a new Construction Camp to replace Summer Camp. Auxiliary structures in the Construction Camp should be located within walking distances of primary personnel support functions.

OZ 7 Designate an area for facilities to support a field science hub.

OZ 8 Develop a Utility Master Plan that establishes utility rights-of-ways for routing of fiber optic telecommunications cables, electrical lines, and water and sewer lines. The Utility Master Plan would monitor geospatial locations of the rights-of-way from year to year to account for ice sheet movement.

OZ 9 Determine the future demands for SPoT and other traverse options for improving personnel rotations and cargo deliveries.

OZ 10 Conduct a retrograde initiative to reduce accumulation, maintenance costs, labor and resource demands, and the station's environmental impact.

OZ 11 Expand the current area for snow storage to manage the snow and ensure snow accumulation does not impact the Operations Zone activities.

OZ 12 Replacement/relocation of the large HF radio communications antennas to avoid drifting from Operational Sector activity.

PRIMARY INFRASTRUCTURE

WATER SYSTEM

WS 1 Investigate and propose methods so future water lines and associated infrastructure avoid critical point failures.

WS 2 Replace the Water Rodwell by 2030. Locate the replacement Rodwell building relative to the ice tunnel beneath the structure so that a ladder shaft from the ice tunnel to the building can be configured for easier waterline and utility aintenance.

WS 3 Evaluate utility tunnel replacement options.

WS 4 Design piping systems, appendages, and structures to enable periodic building raises.

WS 5 Conduct an analysis to determine if the back-up snow melt system capacity needs to be upgraded to support the summer population at SPS in the event of a Rodwell outage.

WS 6 Evaluate the existing Rodwell building to determine its lifespan and ability to be relocated.

WS 7 Investigate and recommend grey-water treatment and re-use solutions to be used in future station designs to extend Rodwell lifespans and reduce long term Rodwell planning and installation costs.

HUMAN AND SOLID WASTE

HSW 1 Design piping systems, appendages, and structures to enable periodic building raises.

HSW 2 Replace the sewer outfall Rodwell immediately.

HSW 3 Add a Wastewater Treatment Plant (WWTP) to the human waste system to mitigate environmental impacts.

HSW 4 Investigate and recommend grey-water treatment and re-use solutions to be used in future station designs to extend Rodwell lifespans and reduce long term Rodwell planning and installation costs.

HSW 5 Investigate black water and waste technology as potential alternative fuel sources in future station designs to reduce the environmental impacts of SPS activity.

HSW 6 Evaluate utility tunnel replacement options.

ENERGY

E 1	Replace the power plant and fuel storage.
E 2	Conduct a comprehensive study of the life expectancy of all main power plant components, including the structures beneath the arch and the arch itself, to finalize replacement timelines.
E 3	Conduct a comprehensive study of energy production feasibility to determine the appropriate energy production portfolio for a replacement power plant.
E 4	Conduct on-site testing of current renewable energy technologies to determine suitability for the South Pole environment.
E 5	Engage in future partnerships with academic institutions to engage the academic community in the continued study of and/or creation of alternative energy production systems that could reliably perform in the South Pole environment.

UTILITY CABLING

UC 1	Evaluate timing for the replacement of the main trunk fiber optic cables and local Dark Sector fiber optic cables if appropriate to occur co-incident with Building 61 raising.
UC 2	Discontinue fixed-point connections for cabling and implement a connection system that accounts for ice sheet movement.
UC 3	Proactively account for network expansion at precise locations to prevent future ad hoc cabling decisions.
UC 4	Explore the co-location of utility cables.

INFORMATION TECHNOLOGY & TELECOMMUNICATIONS

ITT 1	Conduct right-sizing assessment on RF Building size to support future requirements to include space for needed equipment redundancy to minimize the need for high-risk winter personnel visits.
ITT 2	Identify potential site for a future communications complex.
ITT 3	Upgrade the existing Iridium Mobile Satellite System and high frequency radio systems to maintain aviation communication capabilities.
ITT 4	Conduct a cost benefit analysis of the emergent broadband polar orbiting, satellite-based, communications systems to evaluate the viability of emerging technologies for science data movement.
ITT 5	Deinstall 9m antenna and retrograde, evaluate potential reuse of the radome, and preserve the antenna platform as a future resource to support future wideband low earth orbit satellite sysems for Enterprise-scale high speed communications (examples: SpaceX Starlink Community Gateway, Telesat Lightspeed Private Access terminal, AWS Kuiper private gateway terminal).
ITT 6	Upgrade the Land Mobile Radio system to maintain communications availability for timely emergency response.
ITT 7	Research communication methods that do not rely on the same technologies and not be subject to the same failure points to increase the resiliency and redundancy of emergency communications.
ITT 8	Coordinate spectrum selection and waveforms (i.e., occupied spectrum) of Land Mobile Radio system with Dark Sector research community to harmonize on emissions that minimize harmful EMI while maximize safety/operational needs.
ITT 9	Conduct engineering assessments in coordination with the Dark Sector research community to identify safe operating ranges for existing and expected future wideband satellite earth stations (per ITT 5) and define site facility requirements (support buildings, utility runs, radhaz safe zones, etc.) for future site build-out.
ITT 10	Conduct engineering studies to find optimum trade-off between distance from airstrip centerline to main Elevated Station for winter personnel safety and utility runs vs. isolation distance needed to minimize EMI risks to Dark Sector (especially radio astronomy) to acceptable levels.
ITT 11	Refresh HF antenna requirements (design, number, purpose) to align with near-term NIWC HF Radio Modernization Capital Project for NIWC project to implement needed replacements.
ITT 12	Research new technologies that may reduce data and communications service gap hours each day and installed at SPS to reduce communication-related safety risks and meet growing science data requirements.

FIELD SCIENCE

FS 1 Conduct an analysis assessing the cost-benefits to procuring, operating, and storing light science polar equipped wheeled vehicles based out of SPS for access to Eastern Antarctica science sites.

FS 2 Locate a field science staging area near the airfield and overland departure points to improve efficiency for field team staging.

FS 3 Complete an evaluation for temporary housing models to provide accommodation for field science teams at the South Pole for temporary, pass-through populations.

FS 4 Continue to centrally manage field support and Search and Rescue assets from a centralized location at McMurdo Station to provide continuity, efficiency, and a lighter footprint at SPS.

FS 5 Provide a field or remote emergency response equipment storage structure adjacent to the airfield to enhance resiliency of the emergency response program.

FS 6 Utilize the existing arches, once vacated, for field science supplies as a temporary location.

FS 7 Include dedicated VMF/warehouse space in a future station for staging the large and often voluminous equipment of multi-year, field science projects.

EMERGENCY SERVICES

EMS 1 Consolidate Emergency Services storage and staging space in the Elevated Station and directly adjacent to or integrated with field and aircraft staging areas.

EMS 2 In Future Station, account for gurney space and maneuverability in Emergency Services treatment areas.

TRAVERSES

SOUTH POLE TRAVERSE (SPoT)

SPoT 1 Evaluate increasing traverse capacities and capabilities toward providing 100 percent of the required fuel to SPS to reduce the reliance on and costs related to using LC-130s for fuel delivery.

SPoT 2 Expand SPoT fleet to reduce delivery costs, increase efficiency of retrograde efforts and free up capacity of LC-130s.

SPoT 3 Evaluate infrastructure upgrades to allow for loading and unloading full 20 and 40-foot shipping containers onto and from the traverse platform at McMurdo and SPS to expedite cargo delivery and reduce reliance on berms.

OVERLAND SCIENCE TRAVERSE

TR 1 Conduct an analysis assessing the cost-benefits to procuring, operating, and storing light science polar equipped wheeled vehicles based out of SPS for access to Eastern Antarctica science sites.

TR 2 Provide storage space in a future warehouse and VMF building for wheeled vehicles.

NGO/TOURISM

NGO 1 Encourage NGO operators to evaluate new communications equipment and deploy solutions that minimize EMI conflicts.

NGO 2 Maintain current practices and protocols while adapting approach corridors to the Geographic South Pole that account for the movement of the Geographic South Pole to the grid-east of the archway systems.

NGO 3 Transition the NGO campsite to an area closer to the Elevated Station and the NGO aircraft parking area to increase the buffer between the campsite and the Clean Air Sector.

NGO 4 Create an easement over the Geographic South Pole trajectory to prevent future operational and facility conflicts with NGO-visitor foot, ski, and vehicle traffic.

NGO 5 Designate an NGO camp site grid-east of the future Elevated Station. The relocated NGO camp will be located immediately adjacent to the Geographic South Pole trajectory for ease of visitor access and elimination of potential conflicts with operational activities. This would occur when a new station is built around 2060 or beyond.

DOWNWIND SECTOR

AIRFIELD

AIR 1 Shift the skiway grid-southwest along its existing bearing to open areas for developing new operational facilities and allow freedom of movement into and out of the Dark Sector.

AIR 2 Conduct a cost-benefit analysis to compare other aircraft models versus continued use of LC-130s, Baslers, and Twin Otters for potential cost savings and improved air travel reliability for the USAP.

AIR 3 Explore alternative methods of field fuel cache restocking currently supported by LC-130 airdrops to reduce the number of small aircraft flights required to recover the dropped supplies for each primary flight to the field.

Land Use Districts Matrix

LAND USES	GENERAL ASMA OPERATIONS ZONE	LAND USE DISTRICTS					EASEMENTS	
		AIR SUPPORT	CULTURAL	PRIMARY INFRASTRUCTURE	STATION AREA SCIENCE	STATION SERVICES	CAS BUFFER	GSP
SCIENCE								
Scientific research activities minimally impacted by daily operational activities, including but not limited to: vibrations, signals, frequencies, emissions, water vapor plumes, and traffic	●	*If no impact on airfield operations			●			
Equipment shelters and balloon inflation facilities	●	●			●			
Fixed scientific instrumentation	●	*If no impact on airfield operations			●			
Heated science staging and storage	●	●		●	●	●		
Field science staging and supply storage	●	●		●	●	●		
SUPPORT STAGING & STORAGE								
Hazardous, combustible, or noxious cold storage	●	●		●	*Scientific use only			
Non-hazardous, non-combustible cold storage	●	●		●	*Scientific use only	●		
Hazardous, combustible, or noxious Do Not Freeze (DNF) storage	●	●		●	*Scientific use only			
Non-hazardous, non-combustible Do Not Freeze (DNF) storage	●	●		●	*Scientific use only	●		
Fuel storage	●	●		●				
Heavy equipment storage	●			●				
Spare parts storage	●			●		●		
Construction materials storage	●			●				
General cargo staging	●	●		●				
Waste retrograde staging	●	●		●				
TRANSPORTATION								
Pedestrian pathways	●		●	*For station use only	●	●	●	●
Vehicle and equipment roadways	●	●	●	●	●	●		●
Transportation that does NOT produce emissions	●	●	●	●	●	●	●	●
Transportation that produces emissions	●	●	●	●		●		●
Airfield and associated infrastructure	●	●						
Aircraft parking or hangar	●	●	●					
Vehicle maintenance facilities	●			●				
Vehicle storage	●		●	●		●		
Heavy equipment maintenance facilities	●			●				
Fueling stations	●	●		●				

LAND USES	GENERAL ASMA OPERATIONS ZONE	LAND USE DISTRICTS					EASEMENTS	
		AIR SUPPORT	CULTURAL	PRIMARY INFRASTRUCTURE	STATION AREA SCIENCE	STATION SERVICES	CAS BUFFER	GSP
EMERGENCY SERVICES								
Medical treatment facilities	●	●		●		●		
Life safety infrastructure	●	●	●	●	●	●	●	
Emergency response staging and equipment storage	●	●	●	●	●	●	●	
Winter emergency survival accommodations	●	●		●		●		
UTILITIES								
Telecommunications facilities and infrastructure	●	●	●	●	●	●	●	
Renewable energy infrastructure that does NOT produce emissions	●	●	●	●	●	●		
Renewable energy infrastructure that produces emissions	●	●	●	●				
Buried utility lines	●	●	●	●	●	●	●	●
Overhead utility lines	●		●	●	●	●	●	●
Power production facilities	●			●		*Emergency only		
Combined heat/power (CHP) system facilities and equipment	●			●				
Water and waste treatment and/or processing facilities and equipment	●			●				
OTHER								
Tourism and NGO activities	●		●					
Historic markers	●		●					
Visitor's center	●	●	●					
Heavy trades shop	●			●				
Light carpentry and trades shop	●			●		●		
Offices	●					●		
Recreation	●					●		
Food and beverage services	●					●		
Lodging	●					●		
Commissary	●					●		
Restroom facilities	●		*By NGO only	●		●		
All other personnel support services	●					●		
Temporary structures	●		*By NGO only	*Only with overlay		*Only with overlay		