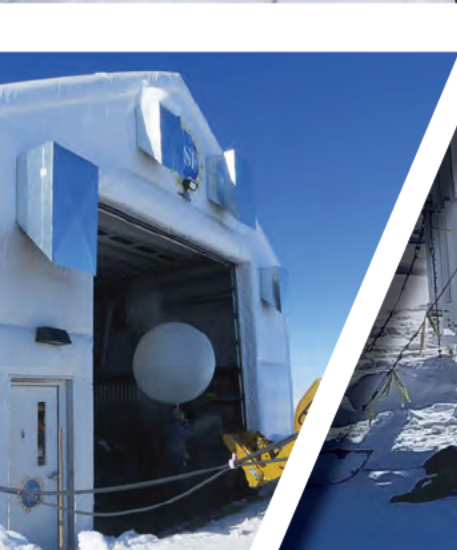


Summit Station Long-Range Facilities Plan 2018

December 2018



THE U.S. NATIONAL SCIENCE FOUNDATION WELCOMES
YOU TO THE SUMMIT OF THE GREENLAND ICE SHEET

SUMMIT STATION
72° 35' N, 38° 25' W  ELEVATION 10,530 FEET

The U.S. National Science Foundation (NSF) established Summit Station in 1989 as the Greenland Ice Sheet Project 2 (GISP2) ice core drilling site and remains the principal supporter today. Additional contributions are made by the National Oceanic & Atmospheric Administration and the station is operated by CH2M HILL Polar Services.



Acknowledgements

This document is a compilation of source information developed by subject experts, government agencies, and contractors associated with the National Science Foundation's (NSF) mission to support fundamental research at the forefront of understanding the Arctic, including its human and natural components, and its global linkages.

Federal Agency Support Contributors

In addition to the NSF, other federal entities have provided collaboration and support in the development of a plan for new, sustainable infrastructure on the Greenland Ice Sheet. Agencies such as the ones listed below provide specialized engineering and technical support.

U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory: U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory's (CRREL) mission is to solve scientific and engineering challenges in cold and complex environments through effective, interdisciplinary solutions. To learn more about CRREL, visit <http://www.erdc.usace.army.mil/>.

U.S. Air National Guard 109th Airlift Wing: The Scotia, New York-based 109th Airlift Wing has provided airlift support to the National Science Foundation's research programs for many years. The wing operates LC-130 Hercules aircraft, modified with wheel-ski gear, in support of Arctic and Antarctic operations. To learn more about the 109th Airlift Wing, visit <http://www.109aw.ang.af.mil/>.

National Renewable Energy Laboratory: The National Renewable Energy Laboratory advances the science and engineering of energy efficiency, sustainable transportation, and renewable power technologies and provides the knowledge to integrate and optimize energy systems. For more information about the National Renewable Energy Laboratory, visit <http://www.nrel.gov/>.

U.S. Department of Energy: The mission of the U.S. Department of Energy is to ensure America's security and prosperity by addressing its energy, environmental, and nuclear challenges through transformative science and technology solutions. To learn more about the U.S. Department of Energy, visit <http://energy.gov/>.

Other Federal Agency Users

Federal agency users include agencies that fund research or plan to fund research at Summit Station in the future. In some cases, the research is conducted directly by federally employed scientists and in others, the agency supports academic research through grants.

National Oceanic and Atmospheric Administration: The National Oceanic and Atmospheric Administration's (NOAA) mission is to understand and predict changes in climate, weather, oceans, and coasts, to share that knowledge and information with others, and to conserve and manage coastal and marine ecosystems and resources. NOAA is dedicated to the understanding and stewardship of the environment. For more information, visit <http://noaa.gov/>.

Harvard & Smithsonian Center for Astrophysics: The Harvard & Smithsonian Center for Astrophysics is a research bureau of the Smithsonian Institution/Academia Sinica Institute of Astronomy and Astrophysics. For more information, visit <https://www.cfa.harvard.edu/> and <http://www.asiaa.sinica.edu.tw/>.

National Aeronautics and Space Administration (NASA): The National Aeronautics and Space Administration (NASA) is an independent agency of the United States federal government that has a focus of enhancing the ability of the scientific community to advance global integrated Earth system science using a fleet of science spacecraft and instruments in orbit. For more information, visit <http://www.nasa.gov/>.

Science Affiliations/Other

QED Enterprises Inc.—QED Enterprises, Inc. provides experienced expertise for the NSF and its contractors by provision of management services and assisting in development of solutions for engineering, construction, and operations in polar environments.

Science Coordination Office—The Science Coordination Office provides liaising between the science community who conduct work on the GIS (including at Summit Station), the NSF, and NSF's prime support contractor, CH2M HILL Polar Services.

Joint Science Education Program (2007–present)—The Joint Science Education Program is a joint committee project comprised of a field program for Greenlandic, Danish, and American high school students and teachers at both Kangerlussuaq and Summit Station.

Danish Meteorological Institute—The Danish Meteorological Institute has a weather station installed at Summit Station.

Executive Summary

Over the coming decades, research conducted at Summit Station (Summit) will provide unique insights into Arctic-wide and global climate processes and answer transformative science questions about the role of the Greenland Ice Sheet in the global climate system. **Summit will remain the only high altitude, high latitude, inland, year-round observing station in the Arctic.** Summit offers immediate access to the free troposphere and is relatively free of local influences that could corrupt atmospheric observations. As such, it is ideally suited for studies aimed at identifying and understanding long-range, intercontinental transport and its influences on the ice sheet surface, boundary layer, and overlying atmosphere. The pristine and remote location in a year-round dry snow and ice region provides an optimal facility for energy and surface mass balance, radiation measurements, and remote sensing validation studies. Summit is also a prime site for astronomy and astrophysics research due to its high altitude and dry and stable atmosphere (NSF, 2018b).

Summit will be maintained, augmented, and upgraded as a research support and infrastructure hub based on both available funding and the requirements of research awards made through the National Science Foundations (NSF's) competitive process as well as research funded by other United States and international organizations, as appropriate. The vision is to preserve Summit's clean air and snow sectors for science investigating processes in the coupled atmosphere—cryosphere—climate systems, while also providing and allocating space for science not reliant on pristine air and snow and continue to serve as a platform for training next generation scientists.

The purpose of this Long-Range Facilities Plan (LRFP) is to provide a framework to transition from the current state to an upgraded station that meets the vision of the NSF and the needs of the user community while maintaining the unique characteristics of the Summit region for research. Meeting these goals will require flexible designs, scalability, and winterization capability.

This version of the LRFP was developed over a period of several years and founded on site-specific experience and data, projected science requirements, user experiences in various regions, and solutions from other polar programs. It is intended as a "roadmap" that provides recommendations for improvements and future developments. It is recommended that the focus for the immediate short-term be toward completing mission-critical, life safety, and sustaining projects. The outyear plan is arranged into a 12-, 24-, 36-, 48-, and 60-month plan. The proposed projects are prioritized to help segregate scope, schedule, and costs into executable and fundable plans. Table ES-1 provides the recommended LRFP plan with identified scope and rough order-of-magnitude costs associated with each project and presents a project site plan layout.

The summary level schedule, presented in Section 6, depicts completion of the recommended work over a period of 60 months. The cumulative total estimated rough order of magnitude (ROM) cost for the projects is included in Section 7.

Significant additional work is required to expand upon the conceptual information provided herein to confirm viability, scope, costs, and schedules.

The vision for Summit Station is to become an efficient, flexible observing platform supporting seasonal campaigns for research and training as well as a variety of research fields using state-of-the-art technology to enable year-round measurements made autonomously or with minimal human presence.

VISION

Table ES-1. LRFP Project Plan

Project	Scope	Total ROM Project Cost	Approximate Productive Field Labor Hours
Annually			
Facility-Sustaining and Science Support Projects	Perform O&M activities on existing facilities and infrastructure to ensure that systems are operating safely and efficiently to maximize the life of equipment and reduce the risk of failure.	Varies	Varies
12-Month			
P-01: Summer Hard-Sided Berthing	Design, fabricate, and transport hard-sided protected berthing for summer season occupants. It is recommended that this project be completed before beginning construction of the EBF to provide adequate berthing for field staff. This assumes a total of eight additional beds would be provided. Commissioning is expected to occur early the following season.	\$420,000	700
P-02: Relocation of Berthing Module	Relocated berthing module to provide sufficient winter berthing space for staff.	\$90,000	700
24-Month			
P-01: Construct EBF, Platform, and Utilidor	Design, fabricate, transport, and construct a facility that provides an adequate supply of indoor berthing to support summer staff levels. This project also includes a standardized platform to be used in supporting the EBF to minimize drifting impacts, and a flexible, easily assembled and disassembled utilidor that can be winterized and provides utility services to the newly constructed facility.	\$2,150,000	8,000
36-Month			
P-01: Science Relocation	Relocate science technician workstation space to more permanent location.	\$30,000	80
P-02: Demolish GH/BM	Conduct activities to fully decommission and demolish the GH/BM and begin preparing to remove demolished sections to be properly discarded.	\$160,000	600
P-03: Summit Mobile Garage Relocation and Repair	Relocate Summit Mobile Garage and repair floor, as needed, to preserve functionality of the structure.	\$500,000	1,500
48-Month			
P-01: Construct Mobile Cold Storage	Design and construct a Mobile Cold Storage facility on a towable base that would be used to store essential structures and materials.	\$610,000	2,500
P-02: Usage Assessment of Structures and Materials	Consolidate station footprint by relocating essential structures and materials to the Mobile Cold Storage facility and retro unused materials and buildings to an offsite location.	\$70,000	0

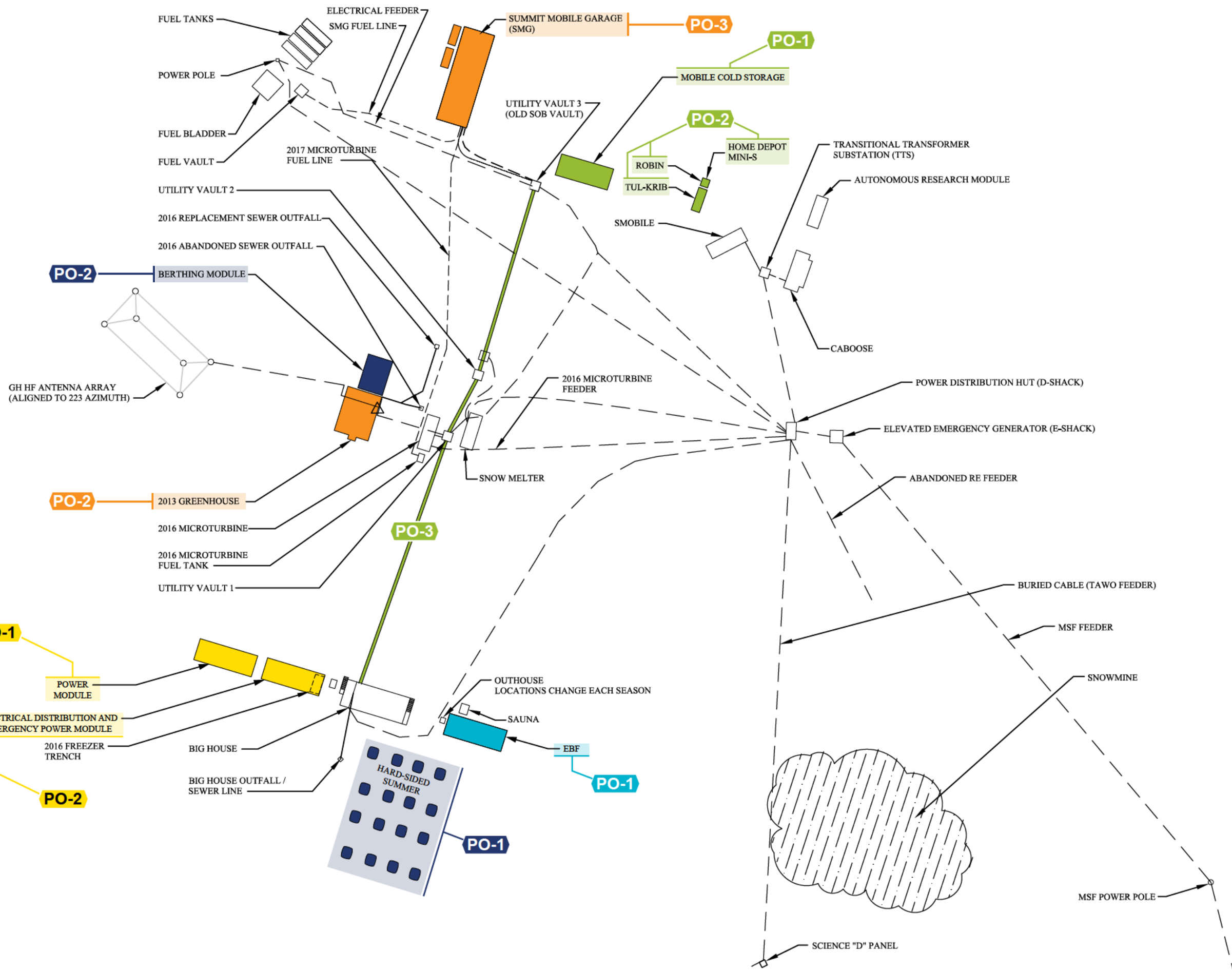
Table ES-1. LRFP Project Plan

Project	Scope	Total ROM Project Cost	Approximate Productive Field Labor Hours
P-03: Construct Minimal Distance Utility Corridor	Design and construct a minimal distance utility corridor with a main hub vault for all elevated and relocatable surface facilities to tie into the power and waste heat systems. This corridor can be underground, surface, or elevated; however, it must have the ability to be winterized.	\$340,000	1,800
60-Month			
P-01: Construct Power Module	Design, fabricate, transport, and construct a power module complete with combined heat and power systems, renewable technologies, and chemical/thermal storage.	\$1,050,000	3,000
P-02: Construct Electrical Distribution and Emergency Power Module	Design, fabricate, transport, and construct an electrical distribution and emergency power module. These modules would also contain critical utility distribution and communication equipment required for remote operations and autonomy in the future.	\$680,000	2,000
P-03: Winterization Test	Conduct a winterization test on unstaffed conditions.	\$40,000	350
Totals		\$5,630,000	21,000

Notes:

- EBF = Elevated Berthing Facility
 GH/BM = Greenhouse/Berthing Module
 HVAC = heating, ventilation, and air conditioning
 O&M = operation and maintenance
 TBD = to be determined

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LEGEND

- 12-MONTH
- 24-MONTH
- 36-MONTH
- 48-MONTH
- 60-MONTH

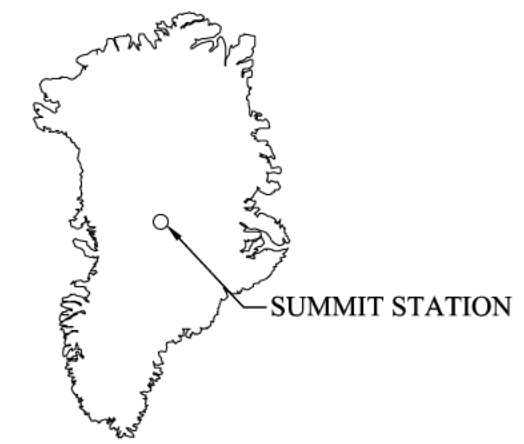
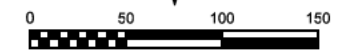


FIGURE ES-1
Proposed Projects
Summit Station LRFP

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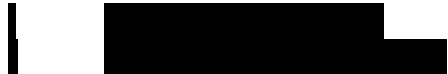
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Acronyms and Abbreviations

°C	degree(s) Celsius
\$/lbs	dollars per pound
AHJ	Authority Having Jurisdiction
ANG	Air National Guard
ARM	Autonomous Research Module
CHP	combined heat and power
CMBR	cosmic microwave background radiation
CPS	CH2M HILL Polar Services
EBF	Elevated Berthing Facility
FHPSB	Federal High Performing Sustainable Buildings
ft ²	square foot
GH/BM	Greenhouse/Berthing Module
GIS	Greenland ice sheet
GISP2	Greenland Ice Sheet Project 2
GRIP	Greenland Ice Core Project
GrIT	Greenland Inland Traverse
HVAC	heating, ventilation, and air conditioning
ICC	International Code Council
ICECAPS	Integrated Characterization of Energy, Clouds, Atmospheric state, and Precipitation at Summit
ICESat	Ice, Cloud, And Land Elevation Satellite
in.	inch(es)
KISS	Kangerlussuaq International Science Support
kW	kilowatt(s)
LRFP	Long-Range Facilities Plan
m	meter(s)
MBh	thousand British thermal units per hour
MSF	Mobile Science Facility
N/A	not applicable
NSF	National Science Foundation
O&M	operation and maintenance
ROI	return on investment
ROM	rough order of magnitude

ACRONYMS AND ABBREVIATIONS

SCO	Science Coordination Office
SE	southeast
SIP	structural insulated panel
SMG	Summit Mobile Garage
SOB	Science and Operations Building
Summit	Summit Station
SW	southwest
TAWO	Temporary Atmospheric Watch Observatory
TBD	to be determined
Thule	Thule Air Base
USAF	U.S. Air Force
USAP	United States Antarctic Program

NSF Vision and Science Objectives

1.1 Summit Station

Summit Station is in a high polar environment at the peak of the Greenland ice sheet (GIS). Summit Station is located on more than 3,000 meters (m) (9,842 feet) of ice and is nearly 400 kilometers (km) (248 miles) from the nearest point of exposed land. Summit is the home of the Greenland Environmental Observatory (GEOSummit)¹ where year-round observations of key climate variables are currently used across the research spectrum, including numerical weather predictions, atmospheric reanalyses, surface process models for understanding ice sheet mass balance, models of clouds and atmospheric water vapor, tropospheric and stratospheric chemistry modeling, regional climate and general circulation models, and to investigate the early universe.



Figure 1-1. Summit Station

The NSF plans to upgrade Summit Station to allow continued support of peer-reviewed science funded by the NSF Division of Polar Programs and other NSF directorates while reducing long-term operational expense and impacts on the environment surrounding Summit. The redevelopment plan also includes provisions to accommodate research funded by other United States agencies and entities as well as international entities at Summit while minimizing interference between projects that have different requirements. However, progress in development and new research investigations has an ethical responsibility toward the people of the North, their cultures, and the environment and should observe the following core principles, developed by the Interagency Arctic Research Policy Committee in support of promoting mutual respect and communication between scientists and northern residents (NSF, 2018c). The identified Core Principles for Conducting Research in the Arctic are as follows:

¹ GEOSummit. 2018. Summit Station, Greenland. <https://www.geosummit.org>.

- Be accountable
- Establish effective two-way communication
- Respect local culture and knowledge
- Build and sustain relationships
- Pursue responsible environmental stewardship

Although, the core principles focus primarily on science researchers and their responsibilities, it is recommended that all persons associated with Summit Station observe the adopted principles noted above.

1.1.1 NSF Vision for Summit Station

Summit will become an efficient, flexible observing platform supporting seasonal campaigns for research and training as well as a variety of research fields using state-of-the-art technology to enable year-round measurements made autonomously or with minimal human presence.

Summit will remain an important polar research station contributing to an arctic network of observations and supporting cutting-edge research in a variety of disciplines by international teams, as well as providing a training platform for next generation research scientists. Building on more than 30 years as a research site, Summit is anticipated to continue to serve as a platform for these studies and as a test bed for new sensors and technology designed for remote and/or autonomous operation and exploration in isolated regions and harsh environments. Continued improvements in communication technology will soon allow scientists and the public to fully participate in experiments and events at Summit from anywhere (NSF, 2018a).

Summit will be maintained, augmented, and upgraded as a research support and infrastructure hub subject to available funds and successfully competed NSF science projects as well as research funded by other United States and international organizations, as appropriate. The vision will preserve Summit's clean air and snow sectors for science investigating processes in the coupled atmosphere—cryosphere—climate systems, while also providing and allocating space for science not reliant on pristine air and snow and continue to serve as a platform for training next generation scientists.

To achieve this vision, NSF will do the following:

- Develop a flexible site with facilities that meet changing requirements through designs aimed toward efficiency and safety that allow for easy reconfiguration of space and autonomous operation of heat, energy, and other requirements, including the capability to safely and easily winterize all infrastructure for unmanned periods and subsequently reactivate it.
- Provide scalability to allow for future project additions or reductions, depending on the demands of the NSF science community.
- Implement systems that allow for autonomous data collection.
- Develop the capability to support funded research during unmanned periods.

Summit will be augmented and upgraded to meet the following:

- Preserve Summit's pristine air and snow environment for science.
- Provide and allocate space for science activity not reliant on pristine air and snow.
- Implement a new logistics and infrastructure hub that supports NSF-funded science activities as well as provide support to both large and small science projects funded by other United States and international entities.

Summit has proven to be a safe, inclusive field camp where senior researchers work alongside undergraduate students fostering a collaborative work environment that produces valuable, unquantifiable science results, enable transformative research, and trains the next generation of scientists.

1.2 Setting Priorities

A critical planning step for the Long-Range Facilities Plan (LRFP) is to ensure that the identified vision, goals, standards, and objectives are included in the consideration of projects to assist in justifying and guiding decisions. A project goal checklist can help stakeholders mitigate a constraint or identify potential project issues. The project goal checklist is presented in **Appendix A**.

1.3 Justification for Investment in Arctic Science Facilities

1.3.1 Arctic Change as an Indicator and Feedback of Climate Change

The Earth's polar ice sheets, in Antarctica and Greenland, are pristine, high-altitude observatories that host researchers seeking to answer fundamental Earth and space science questions, including past climate, sea level and atmospheric composition, future changes societies can anticipate, and how the universe began. The geography of ice sheets in the northern and southern hemisphere provide insight into timing, magnitude, and causes of glacial/interglacial cycles, allow for monitoring the dynamics of atmospheric circulation, and widen the views of our galaxy of telescopes. The arctic region, in particular, is currently undergoing significant atmospheric, terrestrial, and oceanic changes related to notable variations in climate.

Observations obtained from Summit serve scientists across the research spectrum, including numerical weather prediction, atmospheric reanalyses, surface process models of understanding ice sheet mass balance, models of clouds and atmospheric water vapor, tropospheric and stratospheric chemistry modeling, and regional climate and general circulation models. Observations from Summit contribute to global predications of sea level rise and Arctic change through the Intergovernmental Panel on Climate Change.



Science technicians measure accumulation stakes in the bamboo forest.

1.3.2 Operational and Scientific Advantages of Summit Station

A core value of Summit Station is the availability of year-round baseline measurements of climate and chemical variables in the atmosphere. These measurements are used by numerous investigators studying the region around Summit as well as larger-scale pan-Arctic and Arctic systems science analyses. Summit Station is the location of the Greenland Ice Sheet Project 2 (GISP2)² ice core, which was completed in 1993, and provides a continuous paleo-climate record reaching back 110,000 years, the deepest ice core retrieved from the GIS at that time. Along with the companion Greenland Ice Core

² Climate Change Institute, University of Maine. N.D. Greenland Ice Sheet Project 2. <https://climatechange.umaine.edu/gisp2/>.

Project (GRIP)³ core, drilled 28 km (17 miles) to the east, the two ice cores represent a unique high-resolution climate record. Extracting deeper understanding of the records of past atmospheric chemistry preserved in these ice cores motivates many of the process studies conducted at Summit. However, in the remote environment of Summit, the slightest pollution can cause ‘noise’ in the signal, creating a challenge to evaluate long-term changes. As such, a critical requirement of the facility is to remain a ‘clean air’ station and to use best practice approaches to minimize the generation of pollution and to mitigate impacts when possible.

1.4 Science Objectives and Opportunities

Summit supports a mixture of long-term observation programs that are building extended time series for detection and quantification of large-scale changes in the Arctic system. In addition, Summit supports an ever-changing set of short-term "campaign-based" investigations examining process-based research questions.

1.4.1 Science Opportunities at Summit Station

Research interest in Greenland and Summit has been consistent since the late 1980s and will likely grow as ever more attention on the Arctic is focused on the Arctic. The research opportunities at Summit Station are described in the March 2017 Summit Station Science Workshop Report *Sustaining the Science Impact of Summit Station, Greenland* (NSF, 2017), which brought together researchers involved in a range of disciplines to lay out future science questions that can be uniquely addressed at Summit Station. Key points of the report are highlighted in the following subsections.

1.4.1.1 Earth Systems Modeling

Summit Station plays a critical role as a component of the observing system for the Arctic region. Observations obtained from Summit Station are important to various aspects of environmental modeling that bridge regional to global spatial scales. The utility of Summit Station for modeling is based on its location, near the center of the ice sheet at the highest elevation with low spatial variability, and the availability of long, ongoing, time series of high quality (i.e., calibrated, low uncertainty) data. Summit Station provides a crucial boundary condition for atmospheric models over the data-sparse GIS. The spatial homogeneity of Summit Station combined with the variety of available measurements allows for the investigation of questions associated with the climate in combination with models and satellite data. Several studies suggest that due to its location, Summit Station is one of the best global locations for assessing evolving anthropogenic climate change. The location of Summit Station is ideal for studies related to the atmospheric boundary layer and surface processes due to the large distances from anthropogenic emission sources and the homogeneous nature of the snow surface. The large homogeneous footprint, low interannual variability,



Photo of the Temporary Atmospheric Watch Observatory currently used by NOAA for long-term observations along with Helmig, Cahill, and Steffen science groups.

³ European Science Foundation. 1997. Greenland Ice Core Project (GRIP). <http://www.nerc-bas.ac.uk/public/icd/grip/griplist.html>.

and availability of co-located temperature and energy flux measurements allows for reduced ambiguity in model evaluation. Adequate model validation is critical to understanding and predicting future changes in surface mass balance and its associated impact to sea level rise. Snowfall at Summit Station is representative of the total ice sheet snowfall variability.

The need for increased attention to the role of mixed-phase clouds in surface warming of the GIS has recently been recognized based on modeling studies, satellite data, and in situ observations, as the importance of clouds in total surface energy budget of the Arctic becomes more apparent. Summit Station, along with Eureka, Canada, and Barrow, Alaska, has been characterized as a “supersite” that provides invaluable cloud and radiation observations and evaluation of cloud theory in combination with atmospheric models. Summit Station observations in combination with satellite data are used to understand and diagnose cloud parameterizations in global climate models.

Key data needed for Earth systems modeling and weather forecasting now and, in the future, include pressure, air temperature, humidity, and winds from surface meteorological stations and from upper air radiosonde. These data need to be transmitted near-real time to be effectively used.

1.4.1.2 Astrophysics

Atmospheric conditions at Summit Station make it a particularly good site for a range of potential astrophysics applications, including telescopes used for very long baseline interferometry, measurement of cosmic microwave background radiation (CMBR), and neutrino detection. Full-sky coverage is especially important for learning about the properties of dark energy, neutrinos, and other relic particles. Millimeter-wave telescopes rely on high, dry sites with a stable atmosphere to make high-quality measurements of the millimeter-wave sky. Summit Station may be the best place in the northern hemisphere to make low-noise CMBR measurements, due to its high altitude and dry, stable



Science technician preparing for an Integrated Characterization of Energy, Clouds, Atmospheric state, and Precipitation at Summit radiosonde balloon release.

atmosphere. Measurements of atmospheric opacity at 225 gigahertz at Summit Station show that the site is significantly better compared to the Mauna Kea site for submillimeter astronomy. The South Pole site remains the best in all seasons. While Summit Station and the Atacama Large Millimeter Array site in the high Chilean desert are comparable in winter, Summit Station provides better atmospheric opacity in summer. In addition, ice properties at Summit Station may prove advantageous for neutrino telescope applications if detectors that are currently being built discover these highest energy neutrinos when deployed in Antarctica in the coming years, then a complementary detector at Summit Station would allow observation of sources in the northern sky.

1.4.1.3 Atmospheric Science

Understanding the broad-scale Arctic response to climate change and how these changes in turn affect climate, tropospheric and stratospheric ozone in the northern hemisphere isn't possible without measurements at Summit Station. Results from Summit Station provide a spatially integrated view of Arctic-wide (even hemispheric in some cases) changes that aren't possible at coastal Arctic sites, and

thus provide the critical information for understanding how the Arctic atmosphere is changing overall in response to a warmer climate, reduced ice cover, and an increased anthropogenic presence. Likewise, Summit Station is one of the best locations in the northern hemisphere to document and understand trends in the amount of trace gases in the atmosphere. Many of the trace gases studied directly force climate processes, impacting key large-scale environmental systems, and many reactive halogen species profoundly impact the Arctic environment through the destruction of ozone. These species can be traced to natural or anthropogenic sources, which helps understand the impact of human activity on large scales. Summit Station represents the most pristine measurement site in the Arctic and northern hemisphere. It is far from infrastructure and anthropogenic pollution sources and this isolation is not likely to change in the future. The remoteness of Summit Station makes it a valuable location from which long-term trends and large-scale atmospheric processes can be clearly identified without confounding local effects.

1.4.1.4 Atmosphere and Snow Interactions

The chemical and physical processes occurring at the cryosphere-atmosphere boundary are not unique to central Greenland; they occur throughout the Arctic, Antarctic, and seasonally snow-covered mid-latitudes. This significantly increases the relevance of the process studies conducted at Summit Station, because even small chemical fluxes between the snow and atmosphere measured can have major impacts on Arctic biogeochemical cycles when scaled to the whole Arctic.

Summit Station's position within the dry snow zone removes much of the complexity associated with snowpack melting, freeze/thaw cycles, and meltwater migration that can convolve the processes of interest. However, experiments investigating the effect of freeze/thaw and melt can be conducted by artificially introducing meltwater to the system under controlled conditions (Wong et al., 2013) and taking advantage of infrequent natural melt events. Furthermore, dry-snow conditions throughout the year allow photochemical experiments to be conducted under a wide range of photon fluxes.

Air-snow boundary layer experiments have been conducted at Summit Station since the early 1990s after collection of the GISP2 and GRIP ice cores. This multi-decadal sample and data legacy is invaluable for evaluating how these processes are evolving through time under changing environmental/climate conditions. Furthermore, this legacy means that data are available from a particular snowfall event beginning with the atmospheric conditions and chemical signature during the event, the chemical and physical attributes immediately after initial deposition, its progressive post-depositional evolution during advection down into the snowpack, and it can be resampled in the future to evaluate longer-term post-depositional processes. This archive of atmospheric, surface snow, and snow pit samples spanning more than a decade is not available at any other cryospheric location, allowing studies to be developed at Summit Station that would be impossible anywhere else. These past atmospheric and snow studies can be further used to relate to the ice core records to have a real understanding of past climate signals.

Summit Station's position on the GIS increases its relevance because of societal concern about Greenland's current and projected ice mass loss and the consequential impacts on global sea level. As one example, Summit-based studies focused on changes in snow albedo due to changes in snow grain properties and impurity concentrations provide critical constraints on Greenland surface energy and mass balance. Studies focused on climate-driven changes to snow metamorphism and densification processes also have important implications for satellite altimeter estimates of Greenland ice mass balance.

1.4.2 Glaciology

One of the defining questions associated with ice sheets is their ice mass balance; that is, how much ice mass is gained or lost, and the relative impact to sea level rise. Spatially and temporally extensive

accumulation time series are needed to quantify robustly any recent temporal trends, evaluate relationships with regional climate patterns, and constrain the impact on GIS ice mass balance. Long accumulation records have been obtained from the deep ice core sites, and from a series of shallow, (15- to 30-m) firn core sites mostly in the southern and western sectors of the ice sheet as part of the Program for Regional Arctic Climate Assessment. The Summit Station accumulation record, however, explicitly covers spatial variability over scales from 10 m to 10 km (32.8 feet to 6.2 mile), and temporal variability, on scales from weeks to decades to millennia (GISP2). The length and breadth of this record are important for providing context for shorter or more localized records; for example, the variability from snowdrifts must be characterized to know how much of the variability in a single core could arise from drifts. Assessing such variability at Summit Station supplies prior and ongoing studies needed context.

Since 2006, a monthly assessment of surface height is currently being done along an 11-km (6.8-mile) traverse, referred to as the Ice, Cloud, And Land Elevation Satellite (ICESat) traverse. The monthly ICESat traverse represents the most temporally long and dense in situ observation of ice-sheet elevation change.

1.5 Research Sponsors and Future Directions

Summit Station and its co-located observatories will be one of the preeminent polar research stations in the world. It is likely that investigators of tropospheric chemistry, snow chemistry, air-snow exchange, and climate change will remain prominent users of the facility, but other geophysical fields will also be well represented (e.g., seismic, stratospheric, ionospheric, space weather, particle physics, astronomy, and astrophysics). In addition, Summit Station will also increasingly serve as a test bed for new sensors and technology designed for autonomous exploration on the moon, Mars, and other objects in the solar system.

1.5.1 National Science Foundation-funded Projects

Projections about future science activities are difficult in general because they require assumptions about federal funding at several levels. In the case of researchers supported by NSF, the fact that proposals are generated by numerous individual investigators and are submitted to multiple programs within the foundation limits the informed planning horizon to 2 or 3 years at best.

1.5.2 National Oceanic and Atmospheric Administration

The National Oceanic and Atmospheric Administration's (NOAA) near future plans are more specific yet face similar uncertainty due to the nature of the federal budget process. Recent reduction in the NOAA footprint at Summit Station includes the elimination of some redundant measurements (i.e., high resolution in situ gas measurements) and relocation of logistically challenging ozonesonde program to a coastal location. However, NOAA has great interest in maintaining surface ozone observations, flask sampling for trace gases, maintaining climate quality meteorological measurements, and measuring optical properties of aerosol reaching Summit Station.

1.5.3 National Aeronautics and Space Administration

One of the longest available records of surface elevation change over time on a polar ice sheet has been collected at Summit Station; and the site has been the frequent target of recent National Aeronautics

and Space Administration (NASA) Icebridge missions.⁴ Summit Station (and, in particular, the existing ICESat traverse line) was selected by NASA as the pinning point from which to define the orbit of the ICESat-2 mission. NASA has recently increased its presence at Summit Station to support the ongoing ICESat traverses as well as conduct smaller processed-based accumulation studies at the station, including a firm compaction and densification study.

1.5.4 Other United States and International Entities

Positive decisions about proposals pending currently would also add radio detection of neutrinos and deployment of prototype telescopes mapping the CMBR to the ever-changing mix of research near the highest point of the GIS.

⁴ National Aeronautics and Space Administration (NASA). 2018. IceBridge Mission Overview. Page accessed October 11. https://www.nasa.gov/mission_pages/icebridge/mission/index.html.

Summit Station Overview

Summit Station is scientifically powerful because it leverages a suite of scientific measurements, co-located over time and at one point in space, allowing researchers to go beyond their own study and put their research into the larger climate perspective. Observations at Summit Station contribute to a broad scientific understanding of the atmosphere and cryosphere, including tracking atmospheric pollution and Arctic-wide transport, snow chemistry, air-snow interactions, weather prediction, understanding changes in the Arctic climate system, the surface mass balance of the GIS, and the physics of snow and ice. Research involving observations of the atmosphere, cryosphere, space weather, particle physics, seismology of the ice sheet, and astronomy and astrophysics is potentially transformative and improves the understanding of the Earth, the influence of the sun on Earth's atmosphere, and the origins of the Universe. The time series at Summit Station makes it the only site on the GIS with a long enough suite of climatologic, atmospheric, and glaciologic measurements to understand, model, and validate change processes. Summit Station is a highly representative location for surface climate conditions over the GIS dry snow zone. The presence of a pristine snowfield and low internal climate variability allows for small regional and larger-scale Arctic and hemispheric trends to be detected quickly. The deep ice core records from Summit Station from the GISP2 and the GRIP extend the records of northern hemisphere climate and atmospheric states back more than 100,000 years, spanning a full glacial cycle.



Summit Sign and Big House. Note the lifting system being used.

2.1 History

Beginning as a base camp in 1989 for the drilling of the GISP2 ice core, Summit Station, (72°35'46.4"N 38°25'19.1"W, 3,216 m [10,551 feet] above sea level), is the longest continually operating station on the GIS. A historical timeline is presented on Figure 2-1 and a timeline representing the proposed projects from this plan is presented on Figure 2-2.

One of the first buildings constructed to support the base camp was the Big House built in 1989 for use as a galley, common space, and office. Over the years, the Big House has been renovated but remains the center of station activity and is used as originally intended with a full kitchen, communication, bathroom, laundry, and common area dining space.

The original team used pre-way heated weatherports, and Scott tents. Eventually, arctic oven tents began being used as berthing.



Mobile Science Facility

In 1997, the Greenhouse was constructed to support the first winter crew and provide hard-sided berthing. In 2001, a berthing module was procured to support more science and operational activities. In 2005, the two structures were joined together via an arctic entry. In subsequent years, the arctic entry has been increased and two of the original Greenhouse bedrooms have been converted to lab space. Currently, the 260-square-meter (2,800-square-foot [ft²]) Greenhouse/Berthing Module (GH/BM) consists of a medical clinic, berthing, common entertainment space, science labs, backup kitchen, science storage, laundry, backup voice communication, and restrooms.

As the need for maintenance of the facilities increased, mobile structures were created in 2002 and used by the facility maintenance team for storing materials and tools. These structures are called Tul-Krib, Mini S, and Home Depot. A flammable storage space, Robin, was built in 2008.

The Bally Building, a mobile science facility, was brought onsite in 2003 and is commonly used as cold storage for science gear or as a remote science camp facility.

In 2005, the Science and Operations Building (SOB), a 3,200-ft² facility, was built to house the diesel generators that powered Summit Station and a snowmelter for water production. Additional areas included a mechanic workspace and launch preparations for the weather balloon and radiosonde. In 2006, the tent was deconstructed and rebuilt in 2009 where it remained until demolition in 2018.

Two elevated power distribution and generation structures, the Distribution Shack and Emergency Generator, were built to support Summit Station in 2005.

The two main science structures, Temporary Atmospheric Watch Observatory (TAWO) and the Mobile Science Facility (MSF) were built in 2007 and 2009. The TAWO serves as the home for NOAA's long-term observatory measurements and is located at the boundary of Summit's clean air sector. The MSF serves as a science facility for experiments that require a climate-controlled environment.

In 2008, the Summit Mobile, colloquially referred to as the Smobile, was originally constructed for science workspace. In 2010, it was reconfigured into berthing space and repurposed again for science space in 2014. In 2015, the structure was repurposed once more as a construction shop space that is still used today.



View of SMG and Microturbine and SOB demolition activities.

Additionally, the Autonomous Research Module (ARM) was originally placed in 2008 to support remote science camp operations and in 2015 was reconfigured to off-grid berthing.

In 2009, two utility vaults (Vault 1 and 2) were constructed to provide occupants access to the buried utility corridor. Two more vaults for the Fuel Tanks and Vault 3 were constructed throughout the years to accommodate Summit Station layout changes.

Two hard-sided fuel tanks were placed in 2011 with two more following in 2013 to store fuel for heavy equipment being operated onsite and for the generators that produce power for Summit Station.

Additional off-grid mobile berthing, the Caboose, was placed in 2014 with nine beds to accommodate occupants and visitors and support remote science camps.

In 2016, a 3,136-ft² Summit Mobile Garage (SMG) was built to replace the SOB and houses the main power and waste heat generation system, heavy equipment maintenance shop, storage, balloon launch preparation station, and snowmelter system. Currently, the snowmelter system at this facility is not used.

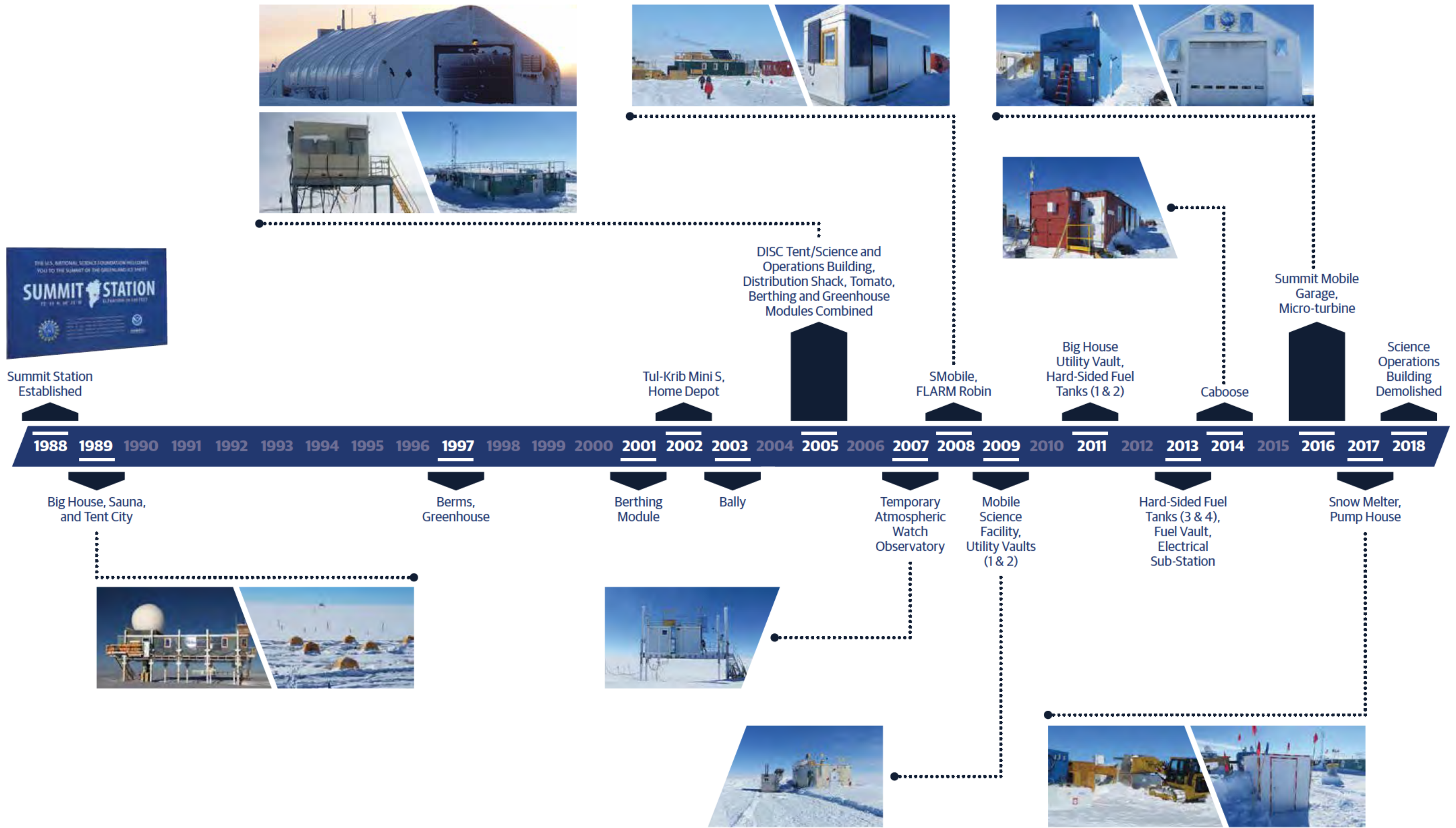


Figure 2-1 Historical Graphic

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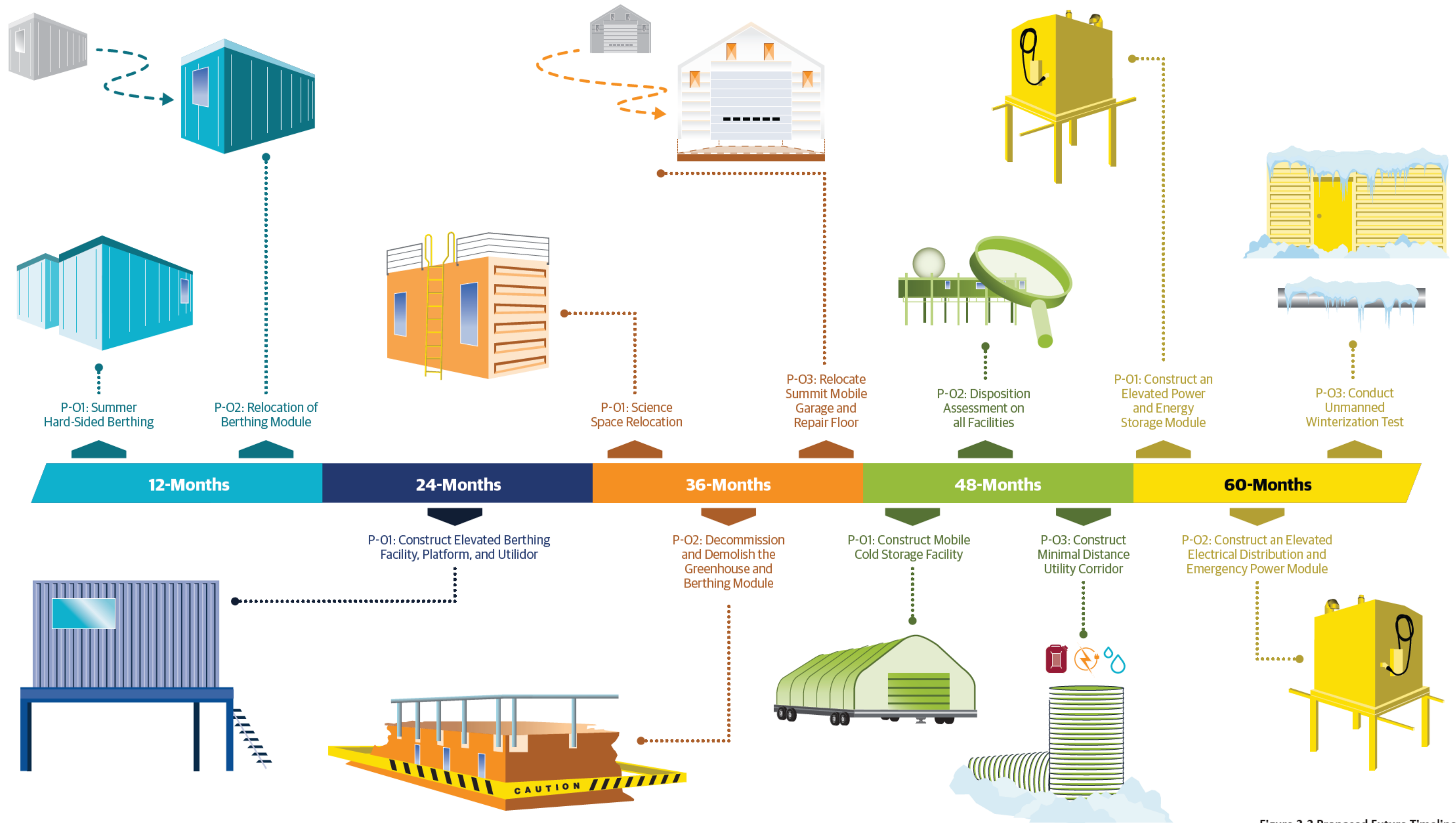


Figure 2-2 Proposed Future Timeline

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A micro-turbine generator with a built-in heat recovery system was placed centrally on Summit Station in 2016. This system provides power to Summit Station and uses the exhaust for space heating, domestic hot water heating, and to melt snow for potable water. The micro-turbine is installed in a heated and insulated module on towable skids. The unit was conceived as proof-of-concept with intermittent testing being completed from original installation to current date.

In 2017, a mobile snowmelter was placed next to the micro-turbine system and provides potable water to Summit Station. The snowmelter system uses waste heat from the micro-turbine and reciprocating generators to melt the snow and treats and stores the potable water before being distributed to the main facilities.

A full inventory list of facilities and infrastructure are presented in **Appendix B**.

2.2 Population

Summit's highest population occurs during the summer season between April and August. Historically, the GH/BM, Caboose, and ARM facilities have been used for primary berthing and the Arctic Oven tents for overflow. Currently, discussions are being conducted regarding the use of soft and hard-sided berthing options. A crew of 11 is used currently for sustaining operations, which include a station manager, a medic, cargo and field coordinators, heavy equipment operators, science technicians, mechanics, and a chef. The remaining available berthing beds are provided to additional science researchers and facilities maintenance staff.

During the winter season (the months of September to May), the Station consists of a four-person team, including a station manager, mechanic, and two science technicians.

Over the last 8 years, Summit Station has seen significant variations in maximum population in the summer months ranging from a low of 37 to a high of 57, as presented on **Figure 2-3**. Science represents an average of approximately 46-percent of the summer population while camp operations and construction teams make up the remaining 54-percent as presented on **Figure 2-4**.

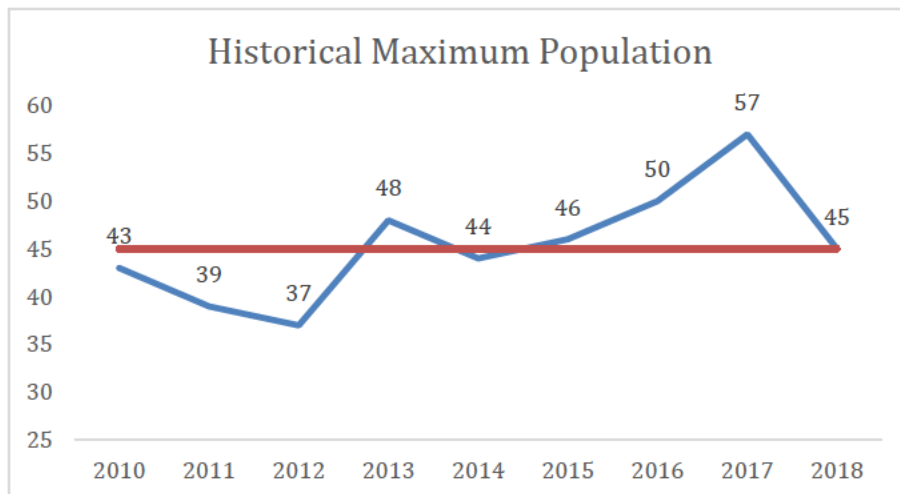


Figure 2-3. Historical Maximum Population

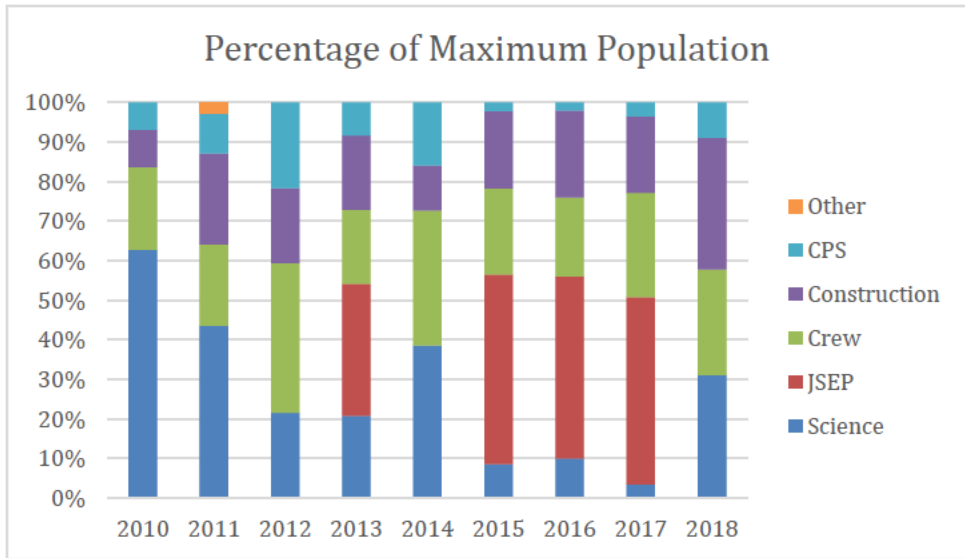
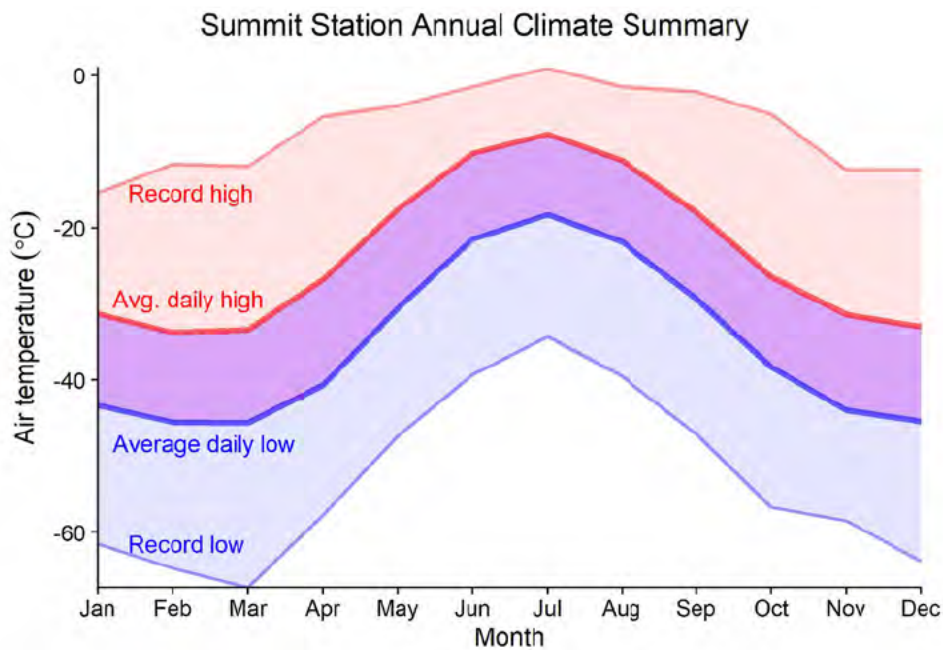


Figure 2-4. Percentage Maximum Population

2.3 Climate

Weather is a major factor at Summit Station with typical daily maximum temperatures around -23 degrees Celsius ($^{\circ}\text{C}$) (-31°C in winter [January] and -8°C in summer [July]). Winter minimum temperatures are typically about -45°C and only rarely exceed -20°C . Figure 2-5 presents a summary of the annual climate with record highs and lows and average temperatures.



NOAA 1-minute data; 2008-07-01 to 2018-09-30

Figure 2-5. Annual Climate Summary

The extreme environment at Summit Station should be considered when planning for future developments. This means keeping facilities close together to minimize exposure time in traveling between facilities in the winter. Buildings must be designed to consider wind directions and ensure that development mitigates rather than exacerbates snow drifting. These issues will be explored in greater detail later in the sustainability, design guidelines, and site development considerations sections.

2.4 Remote Location Support

2.4.1 Kangerlussuaq

Kangerlussuaq is approximately 100 miles (161 km) inland from the mouth of the Kangerlussuaq Fjord on the west coast of Greenland and approximately 200 miles (322 km) north of the capital of Greenland, Nuuk. It serves as a hub to access Summit Station and other areas of Greenland through commercial airlines, U.S. military flights, or ocean vessels. The NSF leases the Kangerlussuaq International Science Support (KISS) facility, which provides housing and administrative services for researchers and field staff. The facility has two-person dormitory rooms and communal areas such as lavatory/shower suites, kitchens, lounges, and meeting space. The logistics manager office is in KISS and provides a central point of contact and liaison with local and national governmental agencies and in-country vendors. In addition, NSF leases Buildings 415 and 416, two warehouses that provide storage and critical shipping and receiving of packages and cargo. Building 415 also houses shop facilities with woodworking and metalworking equipment that can be used to build and fabricate project needs prior to the flight to Summit. For example, to remove construction waste from Summit Station efficiently, waste crates need to be built. Building the waste crates in Kangerlussuaq would save significant time for the Summit maintenance staff allowing staff to use the crates immediately after delivery.

2.4.2 Raven Camp

Raven Camp is a prepared skiway and alternate landing area located at 66 degrees 29 minutes North by 46 degrees 17 minutes West and is used primarily for Air National Guard Base (ANG) training and can provide limited support for science research projects. During the boreal summer months, Raven Camp is staffed by two personnel who maintain the skiway and provide communication to the aircraft.

2.4.3 Thule Air Base

Thule Air Base (Thule) is owned by the U.S. Air Force (USAF) and located in the northwestern part of Greenland, more than 1,100 km north of the Arctic Circle at almost 77 degrees North. Through cooperative agreements between the USAF and NSF, Thule provides science research support through lodging, dining, and logistics support and the use of several facilities. However, there is no permanent or seasonal Arctic Research Support and Logistics Services personnel presence. Personnel and cargo can be transported to Thule through weekly commercial or military flights through Copenhagen and Kangerlussuaq or ocean vessels.

In addition, Thule is the primary operations hub that provides logistics, maintenance, and storage of the Greenland Inland Traverse (GrIT), an option for cargo transport to Summit Station. It is recommended that the warehouse used for maintenance and storage be evaluated for efficiency and operational upgrades.

2.4.4 Stratton Air National Guard Base

Stratton ANG is owned by the USAF and located in Schenectady, New York. The New York ANG 109th Airlift Wing unit provides polar airlift mission support to the NSF and possesses the ski-equipped C-130 aircraft used to transport cargo, researchers, and field staff to Summit Station, along with additional arctic and Antarctic regions. A civilian team at Stratton ANG Base provides support to researchers by receiving, processing, packaging, and shipping field equipment and cargo, in addition to ensuring that transportation is arranged for a safe ANG flight. The Small Air Terminal is primarily used to check personnel, baggage, and prepare cargo for loading onto the C-130.

2.5 Site Limitations

2.5.1 Zoning

Science clean air and snow sectors all preserve the unique atmospheric and terrestrial conditions found at the top of the GIS from Summit Station influences. It is proposed that the northern section of the snow sector be designated as the dark sector. The dark sector would provide science an area with reduced light and radio interference. Except for special circumstances, access to all sectors are strictly prohibited. This includes foot and vehicle traffic. Aircraft activity is limited and guidelines for scientific or other activities have been established by NSF and CH2M HILL Polar Services (CPS) in consultation with the Science Coordination Office (SCO). The pristine nature is strictly preserved, not just for the current scientific activities, but also for future scientific interests at Summit.

Summit Station maintains a skiway that measures 5,120 m by 61 m (16,800- by 200-foot) used primarily by the New York ANG 109th Air Wing and is an important part of the infrastructure for air transport capabilities. Specific requirements for maintenance and preparation of the skiway can be found in *Engineering a Smooth Landing on the Greenland Ice Cap* (Weatherly, 2017). However, ANG requires a minimum distance of 304.8 m (1,000 feet) for occupied facilities from the skiway boundaries. Additional landing zone distance and height criteria can be found in the Air Force Instruction 13-217 (Department of the Air Force, 2014) and should be coordinated with ANG personnel.

An operational undisturbed snow sector needs to be maintained and free of science and operational traffic. **Figure 2-6** shows the zoned sectors.

LEGEND

- CLEAN AIR SECTOR
- SNOWMINE
- SKIWAY
- UNDISTURBED SNOW SECTOR
- CLEAN CAMPAIGN SECTOR
- DARK SECTOR

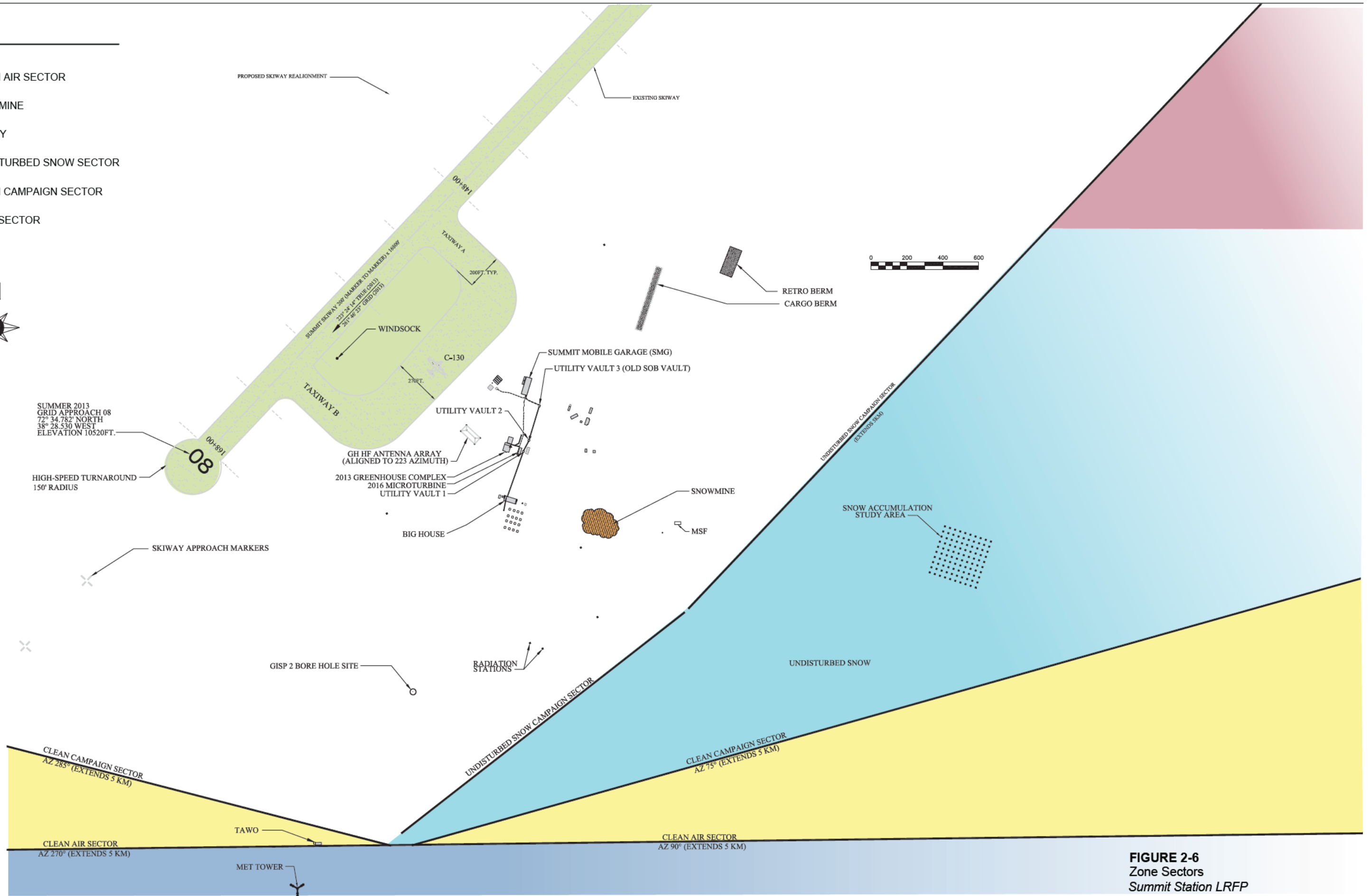


FIGURE 2-6
Zone Sectors
Summit Station LRF

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2.5.2 Cargo Transport

There are three transport methods that can be used in the cargo transport routes to Summit Station: aircraft, ocean vessel, and GrIT. The following subsections provide additional details for each cargo transport option and Figure 2-7 presents the typical cargo transport routes.

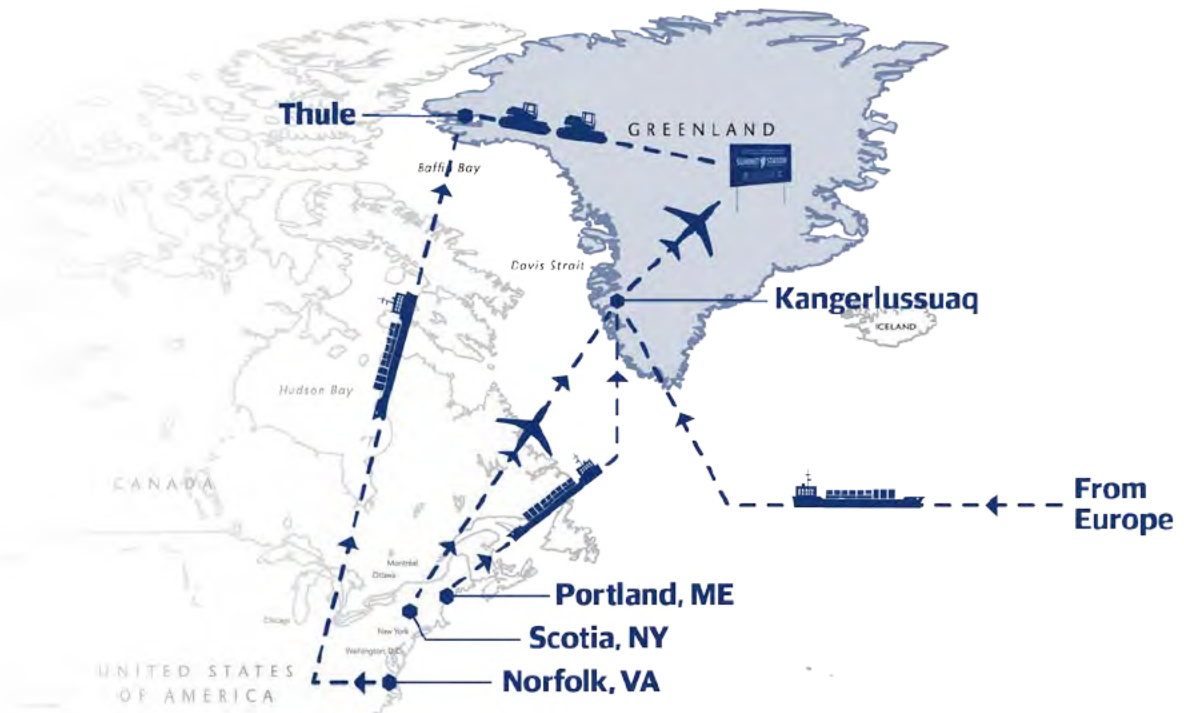


Figure 2-7. Cargo Transport Routes

Each transport method has advantages and disadvantages and must be carefully considered as projects are being designed and procured. The costs for each method vary each season and in some cases are dependent upon the carrier. Estimated costs are presented in Table 2-1 and are compiled from data provided by the operations and procurement teams and specific analyses previously completed.

Table 2-1. Transport Costs

Transport Method	Costs (\$/lbs)	Notes
Air	\$1.95	2019 Estimated Cargo Rates
GrIT	\$4.59	2013 GrIT Economic Analysis, Baseline Summary
Commercial Ocean Vessel	\$2.13	2018 Commercial Shipping Cost for EBF Panels from Maine to Iceland to Kangerlussuaq
Military Sealift Command	\$0.00	No charge for transport

Notes:

\$/lbs = dollars per pound

EBF = Elevated Berthing Facility

2.5.2.1 Air Transport

ANG provides flights out of Scotia, New York, for the majority of cargo bound for Summit Station using the C-130 Hercules. In special circumstances, a larger aircraft, the C-17, can be used. Specific shipping timelines and packaging along with security and customs requirements are enforced. The aircraft cargo interior designs presented in Table 2-1 represent standard cargo dimension parameters; however, general design requirements and operating limits as stated in the Military Standard 1791B, 2014 (MIL-STD-1791B) should be followed to ensure safety of personnel and cargo. ANG flights are typically available between April and August and require significant planning to ensure ANG resources are available.

Small cargo and personnel can also be transported using smaller ski-equipped Twin Otter or Basler, which are most often used during shoulder seasons to transport field personnel who begin preparations for the summer season population.

Table 2-2. Aircraft Dimensions

Dimensions	C-130	C-17	Twin Otter
Length (in.)	492	778	26.8 m (88 cubic feet)
Width (in.)	107	204	
Height (in.)	102	142	
Max Weight (pounds)	25,000	170,000	5,500

in. = inch(es)

2.5.2.2 Greenland Inland Traverse

The GrIT provides a third alternative transporting heavy or over-sized cargo over the GIS from Thule to Summit Station. The route is approximately 2,253 km (1,400 miles) round-trip and takes around 2 months to complete. The crew typically departs in early April and aims to return near the end of May before the ice melt impacts the route. The GrIT was last used in 2016. Due to the extensive amount of preparation required project planning should begin no later than 24 months in advance to ensure a safe and reliable mission.

It is also recommended that before use of this asset, an assessment of the sleds stored on the ice edge be conducted and repairs, if needed, be completed to ensure the sled decks are fully functional for the long and demanding trip.

2.5.2.3 Ocean Vessel

When space limitations are presented, ocean transportation can be an effective alternative; however, cargo must still be transported via aircraft or GrIT for the final leg. There are two options available for ocean cargo transport: a dry cargo ship chartered by the Military Sealift Command or commercial vessels. Greenland ports are accessible during the summer months after the ice is thin enough for passage. Delivery to Thule requires coordination with Norfolk Naval Station located in Virginia where the Naval chartered ship, capable of carrying 1,200 metric tons of cargo departs on its journey. Departing in early July, the route is 5,794 km (3,600 miles) and takes approximately 11 days.

Commercial maritime transport is another option available. Greenland has a limited number of ports capable of receiving a large commercial vessel and other ports are small and widely dispersed, which requires an integrated approach to link cargo vessels with smaller crafts to smaller fishing industry style ports. This requires close coordination with logistics providers to develop a successful delivery plan and comply with international transport regulations.

2.5.3 Fleet Operation and Support

Operation and maintenance of the Station relies heavily on the main vehicle fleet that is maintained onsite. Without the vehicle fleet, critical activities necessary to Station occupants would not be possible. These activities include receiving supplies, transport of scientists and staff, scientific research preparation and support, snow management, and production of potable water. The existing vehicle fleet at Summit Station and their specific purposes are presented in Table 2-3.

Table 2-3. Fleet List and Operation

Equipment	Quantity	Model Year(s)	Primary Purpose	Usage Timeframe
Dozer	2	1999 and 2013	Snow Maintenance	Year-Round
953 Loader (Tracked)	1	2012	Snow Transport for Potable Water Production and Cargo Support	Year-Round
335 Tractor (Tracked)	1	2010	Snow Maintenance, Skiway Maintenance, Science Support	Summer Only
Aerial Boom Lift	1	2018	Construction	Summer Only
Snowmobiles	6	2004 to 2015	Science Support, Local Transport, and Supplies	Summer Only
Tucker Snowcat	1	2006	Search and Rescue, Science Support	Year-Round
Zaugg Snow Blower	1	1999	Snow Maintenance and Trenching	Year-Round

Note:

This table does not account for any recent change requests that have been written to replace equipment in poor condition.

If not properly maintained, any reduction in the fleet size would impact the Station and its ability to support any long-term upgrades. Because onsite repairs are essential, the fleet requires trained labor staff, a maintenance facility to provide interior heated work space, and storage space for parts and tooling. All these requirements are tied to the size of the fleet and the amount of use it gets annually. Currently, the Station has sufficient fleet support and storage space. However, it is recommended that in the short-term, the current fleet continues to be managed with life-cycle replacement as needed. Life-cycle replacements allow the opportunity to explore options for improvements in fuel efficiency, capabilities, and reliability as newer technologies and vehicles are developed and available.

In seasons where fleet requirements are impacted by science requirements or new construction, an analysis of renting versus leasing versus buying should be conducted. Rental options allow for parts and maintenance contracts to be included and is recommended for the fluctuating seasons. Using a combination of ownership and rental vehicles, a core fleet can be maintained with a predictable budget while allowing the ability to adjust to specific project requirements with identifiable costs associated with renting.

Planning and Design

Planning standards provide guidance that support the vision and objectives of Summit Station. This section establishes principles and guidelines to ensure that, as redevelopment occurs, it will be implemented with minimal impact.

3.1 Planning Standards

Using best practices will minimize the generation of pollution and mitigate impacts when practical while still preserving the core values of the Summit Station for researchers. The principles and design standards identified in this section represent the goals of the NSF in maintaining the fragile and rapidly changing environment while providing a safe and healthy research station for scientists and staff. Extreme weather conditions should be factored into new development design and redevelopment decisions.

3.1.1 Planning Principles

- **Reliability.** Replace or augment aged structures and implement appropriate levels of redundancy for critical systems.
 - Deploy new structures to replace ones that are operationally burdensome to maintain, and relocate surface structures to platforms, if appropriate.
 - Provide conventional power capacity that meets continuous, prime, standby, and emergency requirements and that can be augmented with renewable energy systems such as wind and photovoltaic or state-of-the-art power storage and production technology.
- **Cost Effectiveness and Efficiency.** Create solutions that minimize capital expenditures and/or subsequent operational costs.
 - Evaluate all projects for full life-cycle costs and return on investment to the NSF.
 - Invest in high performance/energy efficient systems when return on investment (ROI) is acceptable.
 - Ensure any surface structures are designed to be efficiently moved, as needed, to mitigate effects of snow drifting.
 - Within budgetary constraints, incorporate innovations and efficiencies that reduce module weight, operational fuel consumption, and fuel transport.
- **Prioritization.** Identify and mitigate any life-safety issues first. Follow all other prioritization by assignment of mission-critical, sustaining operations, energy and operations efficiency.
- **Scalability.** Design facilities and utilities to efficiently and cost-effectively address population fluctuations.
- **Standardization.** Where possible, design and material selection should streamline construction, reduce training, minimize spare parts inventory, and simplify operations.
 - Simplify and standardize components; service features will be low-maintenance and be simple to operate.
 - Incorporate modularity and other creative construction techniques to limit onsite construction in response to logistical, labor, and equipment constraints.

- Platforms and modules should use standardized footprints and base designs where practical.
- Structures and components for systems upgrades should be designed in such a way that they can be transported, either in part or in whole, via ski-equipped LC-130 from either Thule Air Base or Kangerlussuaq.
- *Longevity.* Focus solutions on the long term and try to avoid interim or temporary fixes to the extent possible.
 - Summit Station will be based upon a 25-year design service life with rigorous maintenance protocols to maximize the service life and systems performance.
 - Comprehensive renovations can be undertaken at key intervals to extend service life of building well beyond the 25-year design service life.
- *Social Considerations.* Cluster similar activities and populations together (quiet vs. loud; individual vs. group; industrial vs. living).
 - Integrate occupant comfort into designs: robust thermal envelope, limited thermal bridging, natural light, sound attenuation, fresh air exchange, and aesthetic spaces.
 - Design efficient use of space for systems, provide required service clearances, and storage components.
 - Incorporate collaborative spaces for scientists to interact.
- *Compliance.* Non-NSF-Division of Polar Programs-funded research will bear responsibility for required infrastructure and logistics.
 - Projects shall conform to construction and operational limitations, integrate minimal energy consumption solutions, and incorporate zero- and low-maintenance materials.
 - Teams shall coordinate plans to identify potential synergies or specific support requirements.
 - Project and field teams shall assume accountability regarding compliance with host nation expectations and codes.
- *Knowledge Management.* Leverage existing expertise, previous work efforts, and breadth of resources.
 - Strive for an empowering research model to foster development and collaboration.
 - Hold regular meetings across programs and nations to share information.

3.1.2 Design Standards

The following subsections are summaries from the technical memorandum *Building Code Considerations for Greenland Projects* (2014), prepared and submitted by CPS to the NSF. A copy of this technical memorandum is provided in **Appendix C**. The following information summarizes previous code considerations specific to designing and constructing facilities in Greenland. Subsequent to this memorandum, the 2015 International Code Council (ICC) series was adopted by the NSF, though there are no foreseeable changes to the recommendations listed hereafter. Additionally, code waiver requests for ceiling height and door thresholds have been submitted to the NSF as the Authority Having Jurisdiction (AHJ) specifically for the GH/BM for the short period these buildings will remain in service.

3.1.2.1 Code Compliance

Projects will fully comply with all applicable codes and energy conservation standards; however, remote site-specific conditions exist in Greenland that require prudent waivers to specific life safety and

accessibility code provisions. Proposed code exceptions, including those not referenced herein, require review and approval by CPS, NSF, and AHJ.

- At the earliest stages of project requirements gathering and design, licensed design professionals will develop a code summary outline and identify code provisions that will potentially require special dispensation, including those listed in this document.
- The designer shall develop options or design measures that will mitigate the negative consequences of the code provision deviations. Proposed solutions will be evaluated with the project stakeholders with respect to life safety, functionality, and cost.
- At the Concept Design Phase, develop a detailed code summary, highlighting proposed deviations and design approach to mitigate negative consequences. Submit code summary write-up to CPS for review and approval by the NSF-AHJ.
- Subsequent design submittal drawings will reference AHJ findings in the Code Summary.

3.1.2.2 Key Code Provisions

The two principal code sources used are the ICC and International Code Council A117.1 Accessible and Usable Buildings and Facilities.

- *Automatic Sprinkler Systems.* Remote science camps in Greenland lack infrastructure and water resources to support conventional design assumptions for various uses. Water is produced by melting snow, is treated, and then stored in small quantities. Usage is restricted and designed for minimal domestic uses, including human consumption, kitchen food prep and cleanup, and a limited quantity of plumbing fixtures. In consideration of limited access to water, projects will be designed to code and without automatic fire suppression. At key design milestones, AHJ will evaluate the impacted ICC and National Fire Protection Association life safety code provisions and proposed solutions.
- *Manual fire alarm systems.* If required by the ICC, these systems will be provided in all normally occupied buildings. The fire alarm system shall be activated by both automatic fire detectors and manual fire alarm boxes. It is also recommended that, if practical, the fire alarm system use Wi-Fi-connected units to improve alert functionality.
- *Means of Egress.* Cold storage-type doors perform well at exterior locations and shall comply with code requirements, including opening force and hardware operation. All exterior doors will be inward-swinging due to the potential for rapidly accumulating snow drifts at the building perimeter.
- *Restrooms.* To conserve water, researchers, staff, and visitors are directed to use outhouses during periods of peak station occupancy in the summer months. Future facilities will be evaluated by project stakeholders and AHJ to determine whether—and how many—indoor plumbed fixtures and appliances are required.
- *Accessibility.* Strict compliance with the 1990 Americans with Disabilities Act and the Federal Uniform Accessibility Standards is not required for project planning. The nature of the work, limited medical facilities, and accessibility at Summit Station dictate restrictions of personnel to the able-bodied.

3.1.2.3 Design Standard Assumptions

- Station operations and science activities shall continue through all phases of construction.
- Winter berthing shall be provided in hard-sided, elevated structures. Summer berthing shall be provided in modular hard-sided structures.

- Practical and proven design and engineering features (e.g., commercial off the shelf) will be incorporated into solutions when appropriate to help manage costs.
- Previous designs from this program and the United States Antarctic Program (USAP) along with designs from the Danish Stations and the British Antarctic Survey Program can be leveraged to help reduce implementation costs.
- Deployment of the Greenland Telescope will not be a requirement for designs; however, the possibility of the future deployment will continue to be considered with major planning efforts.
- Existing structures shall remain in service and appropriately maintained until funding is available to deploy replacements.
- Decisions regarding the future disposition (repurposing or retrograde) of existing structures that are replaced through upgrades shall be made as each upgrade is funded.

3.1.3 Design Considerations

Due to the variability of weather conditions at Summit Station, snow mitigation, thermal performance, and wind design speeds are an important element in the planning and design process. Redevelopment planning decisions can use these previously conducted studies to ensure designs can sustain in this harsh environment.

3.1.3.1 Snow-drift Mitigation

Snow drift mitigation is achieved by effective building design and a station facilities layout that will either minimize drift formation or allow drifts to form in places that will not inhibit normal station activities. Figure 3-1 presents the transport rose for the period of June 28, 2008, through May 14, 2015, representing a long-term average where two transport directions are evident, southeast (SE) and southwest (SW). Snow accumulation is approximately 70 centimeters (28 inches) per year. Due to the extreme cold temperatures, any precipitation or windblown snow tends to accumulate permanently. Structures and equipment tend to exacerbate the problem by initiating localized drifting, which increases operational support requirements. The optimum and highest priority solution is to elevate structures in a manner that mitigates snow drifting. Alternatively, aerodynamic building forms help to minimize air turbulence that results in snow drifting and should be incorporated into designs within budgetary constraints. In addition to energy and clean air considerations, snowdrifts can produce uneven loading on building foundations that can cause differential settlement and affect projected building lifespan if not properly accounted for at the design stage.

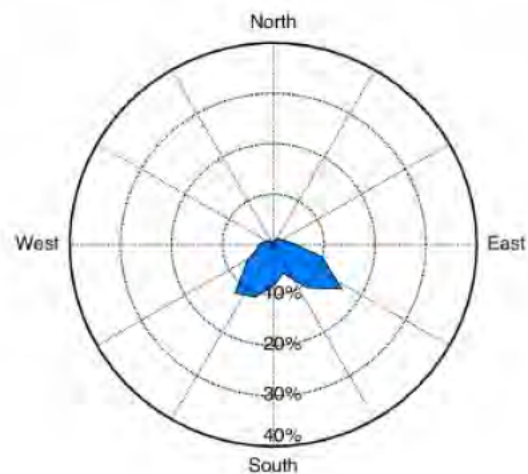


Figure 3-1. Transport Rose for the Period June 26, 2008, to May 14, 2015

Snowdrift analysis will be part of all facility planning at Summit Station and will follow the preliminary considerations for building design and Station layout provided in the report *EBF and Surrounding Structure Placement Suggestions to Minimize Snow Drift Management* (Courville and Haehnel, 2018). The full version of this report is provided in Appendix D, which concludes that practically square

buildings with their sides turned toward and aligned on the SE/SW axis should reduce drifting due to the bimodal distribution of dominant snow transport directions.

3.1.4 Thermal Performance

The building envelopes for new or renovated structures at Summit Station (surface or elevated) shall be designed to minimize heat, moisture, and air transfer to the greatest extent practical through the use of robust thermal and moisture/air barrier assemblies as is detailed in the *Summit Field Station Thermal Energy Standard* (Armstrong, 2017; **Appendix E**). This guide provides R-Value and U-Factor minimums for various building envelope systems based on type of buildings. R-value requirements range from R-42 to R-60 for roof, wall, and floor systems on most typical structures at Summit Station.

All designs need to recognize the first cost of the new facilities in terms of construction materials, transportation costs, and transportation constraints (specifically air travel on C-130 aircraft), while still assuring a reasonable cost related to fuel and power required to operate them. There are also justified reasons to exempt certain building occupancies from needing the proposed higher R-values, such as for equipment storage buildings, unheated outhouses, summer-only occupancies, etc. that should be considered with each building project.

3.1.5 Design Wind Speed

A wind analysis was conducted to identify design wind speeds that should be used in wind load calculations for planned facilities. The analysis included 1-minute wind speed data from January 2008 to April 2018. The analysis recommended that 142.1 miles per hour be used as the maximum design wind speed. Weather and wind data indicate that the highest wind speeds occur during the winter season. A significant peak wind event occurred during February 23 and February 24, 2018, resulting in the highest wind observations recorded to-date at Summit Station. Meteorological data indicate that Summit Station had an unusual heat wave during February 2018 when the jet stream interacted with the strong storm conditions in the northern Atlantic Ocean. The temperature difference between Summit Station and the west coast resulted in these strong easterly winds. As the potential for these warm air intrusions to become more common and intense, the observed peak winds from the February event were included in the analysis. Further details can be found in the *Determination of Design Wind Speeds* (Novus Environmental, 2018, pers. comm.; presented in **Appendix F**).

3.2 Sustainability

Summit Station has a responsibility to maintain the long-term health and viability of the Arctic environment. Operating in such a fragile environment and understanding the global ramifications of conducting research in such an environment makes it critical that Summit Station pursue policies that support the intent of its research. The NSF identified five principles to guide redevelopment at Summit Station that are applicable for evaluation and implementation at Summit Station. The five principles are presented in **Figure 3-2**.

Focusing on remaining a viable, cost-effective, socially responsible research facility, Summit Station will continue to plan, design, and construct using energy-efficient,

- » Lower Operating Costs
- » Robust and Sustainable Construction and Materials
- » Increase Use of Renewable Energy Technologies
- » Healthy Interior Environment
- » Reduced Shipping Weights

NSF

Figure 3-2. Sustainability Principles

sustainable design principles. Summit Station will measure and analyze resources used to support the Station to help prioritize improvements. Combined heat and power plants will be used and analyzed for expansion and waste heat will continue to be captured to reduce the power and fuel consumption of diesel generators. Viable renewable energy and other advanced energy technologies will be evaluated and implemented to reduce electrical and fossil fuel dependence.

Operations shall continue to educate researchers and staff about energy use and implement an energy conservation awareness program. Materials and equipment will be procured that minimize energy use while still meeting the requirements for the extreme environment. Materials and equipment will be reused as much as possible to reduce waste.

Existing facilities shall be weatherized, retrofitted, or upgraded for better energy performance. Summer season-only facilities shall be shut down and winterized. Energy efficient technologies shall be incorporated with integrated utilities or retrofitted with energy storage technologies, if viable. Existing facilities will not impact climate observations and science research. Snow drift mitigation measures will be taken for existing surface and elevated facilities.

New facilities shall employ high-efficiency technologies such as insulation, windows, and heating systems. Utility systems will be capable of integrating into the existing waste heat and utility infrastructure. Orient to minimize snow drifting and allow for efficient snow removal while taking advantage of potential passive solar heat, lighting, and photovoltaics. New facilities will be capable of easy winterization, surviving extreme temperatures, flexible and responsive to changing requirements, and use of sustainable materials and products. New structures will also maximize building comfort and indoor air quality with innovative solutions.

Infrastructure

The success of Summit Station relies upon utilities and infrastructure systems functioning year-round. These components are a critical factor in ensuring safe and efficient operations through winter and summer seasons. Providing a safe, reliable, hybrid electrical grid is a high priority for Summit Station to reduce and stabilize long-term operating costs, minimize emissions, and provide a means of autonomous operation. **Figure 4-1** highlights the infrastructure currently supporting Summit Station.

At present, the expectation is that Summit Station will use an inverter-based hybrid power grid with energy storage capacity and high penetration of renewable energy power generation sources. A team has been assembled to develop the overall energy plan for Summit Station and determine specific energy production and storage projects that will be included in this plan. **Figure 4-2** presents the proposed infrastructure changes; however, any redevelopment in the infrastructure system should be evaluated thoroughly to ensure that it meets Summit Station's requirements.

4.1 Power and Waste Heat Generation

The cost of energy varies across the Arctic, largely dependent upon the remoteness of the location and complexity of the logistics chain. The base cost of fuel is only a fraction of the total cost which also includes transportation, handling and storage. At Summit Station, fuel is delivered in either C-130 aircraft or via the GrIT. The average station load for summer is currently 40 kilowatts (kW) but peaks have been observed up to 70 kW. The average station load for winter is around 35 kW.

4.1.1 Power and Waste Heat

A main power source at Summit Station is a generator module located in the SMG that includes two Perkins diesel generators with site ratings of 79 kW. The two generators are alternated, and the schedule varies according to demand. The generator module is capable of waste heat recovery for use throughout Summit Station. The generator module is critical in meeting the peak demand loads when other systems are down for maintenance or cannot meet the demand. The generator module should be maintained, and control optimization practices should continue.

Backup power for the site consists of an emergency genset power plant rated for 75 kW that does not have waste heat recovery capabilities. A portable structure that is used for remote science camps has two 52-kW site-rated generators with a small snowmelter attached but has no heat recovery capability. A 24-kW portable generator is primarily used for construction support.

Combined heat and power (CHP) was successfully introduced at Summit Station almost 2 decades ago and has been an integral part of the power and heat production system ever since. The CHP system is housed within an Arctic-insulated module located centrally on the site. The module contains a 65 kW microturbine generator with a built-in heat recovery system and fuel, hydronic, and air handling systems along with a transformer and associated electrical equipment. Due to the high elevation, a reduced output is estimated to be approximately 42 kW constant load with 52 kW short-term peaks with an available heat output of 29.2 thousand British thermal units per hour (MBH). This unit is currently set up as a standalone generator set. With modifications, the CHP can be configured to provide auxiliary power or to be coupled with another microturbine with load-sharing options.

Deployment of any new power production system, either traditional diesel-fueled reciprocating engine generators or microturbines, will incorporate the most robust CHP technology available (including exhaust gas heat and engine jacket heat) for the system procured that is also compliant to current budgetary constraints and requirements for easy winterization.

4.1.2 Renewable Technologies

In addition to obtaining station power from traditional diesel fuel generators, multiple renewable energy proof of concept projects have been successfully executed. Although technical challenges remain, renewable energy has been shown to be a cost-effective solution to offset high energy prices, with very rapid ROI.

Successful renewable technologies currently used involve photovoltaic panels, passive solar panels, and a solar heating unit. A 6-kW wind turbine was installed at Summit Station in the summer of 2007. Operationally, the turbine performed satisfactorily but the harsh climate and extreme winds introduced icing, production, and stability issues. It is recommended that wind turbines continue to be evaluated for inclusion at Summit Station as technologies improve in design that are more practical for uses in the environment.



Microturbine Generator

4.2 Water and Wastewater

As Summit Station is retrofitted and augmented with new utility modules, the philosophy guiding water production and wastewater handling will likely remain very similar to the current practices. For example, water will continue to be produced by melting snow with excess waste heat. Slight variations in execution will be implemented to account for elevating the structures and other modifications, as needed.

4.2.1 Domestic Water

Domestic water is currently produced by melting snow using waste heat captured from the generators or through a backup diesel boiler when waste heat is not available. Snow is obtained from a pristine source (“snow mine”), which is marked and kept free of foot and vehicle traffic. Currently, a loader delivers the clean snow to the snowmelting and water treatment module, where a heating coil inside the snowmelter transfers heat from the circulating glycol loop to the snow. Water from the snowmelter is filtered, treated with ultraviolet and chlorination systems and transferred to a storage tank before being distributed to the site. In the future, alternative means for delivery of snow to the snowmelter could be considered (e.g., a conveyor bucket powered by alternative energy).



Existing Snowmelter Used to Make Potable Water

Water piping is surrounded by insulation and includes electric heat trace as backup for additional freeze protection. Most of the domestic hot water is preheated by recovered generator waste heat and heated to final temperature at the points of use by conventional electric water heaters. Any existing standalone electric hot water heaters not included in the central system are being evaluated for replacement and integration into the waste heat system.

4.2.2 Wastewater

Untreated wastewater is discharged directly into the snowpack at specified outfall locations using a drainage piping system. Drainage piping within buildings is routed inside the heated envelope to the greatest practical extent. Exterior drainage piping is insulated and jacketed and includes electric heat trace. Piping terminates at the outfall location by turning downward and extending into a local prepared pit, typically with a wooden enclosure over the outfall to provide piping support and inspection access. The program can consider requiring macerator pumps on all sewage ejection systems, including gravity, to provide at least basic treatment. The Antarctica Treaty requires maceration of sewage as a minimum treatment.

4.3 Communication

The existing Summit Station communication infrastructure will remain in place and will be augmented as required with future site development.

The Summit communication systems support the following five primary functions:

- *Safety.* Systems support safety of life situations, whether locally or in a remote portion of the site.
- *Science.* Includes the following: data transfers to and from Summit Station in real time as well as long latency transfers; status checking and reprogramming of instrumentation; and voice calls/messaging sessions.
- *Logistics.* Progress and planning reports, flight manifests, fuel, food, and parts resupply orders, and environmental and power monitoring data are examples of records handled by the systems.
- *Reasonable Personal Use.* System allows for limited access personal use connecting to the internet and personnel calling in emergency situations.
- *Outreach.* Netcams provide live images of Summit Station. Weather/environmental data is displayed. Scientists can conduct live outreach events over the Summit Station communication infrastructure.

Site systems and capabilities consist of the following:

- *Very Small Aperture Terminal (VSAT)* for routine off-station data and voice transmissions via satellite.
- *Wireless Local Area Network (WLAN)* extends the reach of the Ethernet backbone to station modules.
- *High Frequency* transceivers offer simple and reasonably reliable long-range voice communications.
- *Land Mobile Radios* provide local communication and paging capability amongst station personnel.
- *Air-to-Ground* provides a vital communication link to aircraft operating at or near Summit Station.
- *Safety-related location-based reporting* ensures real time position location information is available to station management for people and equipment operating outside the immediate vicinity.

4.4 Infrastructure Recommendations

Renewable energy will play a key role in meeting power generation requirements; however, there are long periods of time when these systems will be nonproducing due to lack of resources. Fossil fuel-powered reciprocating- and turbine-driven generators are expected to be the primary component of the power generation infrastructure. Table 4-1 provides the proposed long-term recommendation regarding the existing generators and highlights advantages and disadvantages. Viability and costs associated with these recommendations, in addition to introduction of new technologies, will be evaluated by the Energy Red Team.

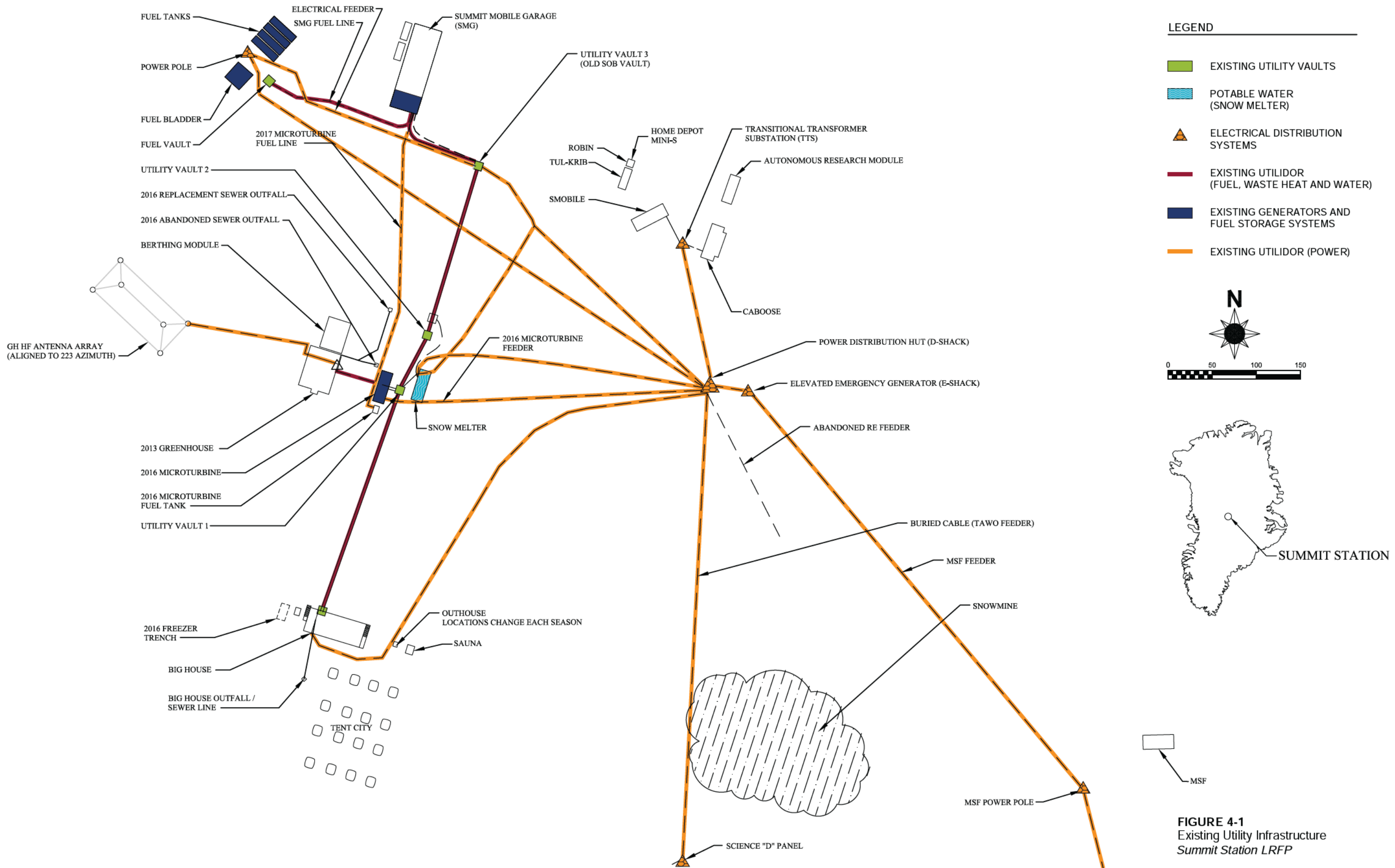
Table 4-1. Infrastructure Recommendation

Systems	Operation	Recommendation	Advantages	Disadvantages
79 kW Diesel Generators	Power and Waste Heat	Decommission and retro to an offsite location. These generators will be past their useful lives and will require replacement in the future.	Reduces fossil fuel dependence, increases storage space in SMG by eliminating spare parts required to maintain the generators.	None
New Power and Waste Heat Module	N/A	Install a multi-microturbine module with supplemental renewable technologies and battery storage for primary power and waste heat production.	Would reduce fossil fuel dependence and provide lower maintenance and better reliability as well as cleaner combustion emissions.	Potentially high implementation costs.
65 kW Microturbine	Power and Waste Heat	With the 79 kW and 75 kW generators both disconnected from the utilidor, use the existing microturbine system as backup for power and waste heat for HVAC systems to the new proposed power and waste heat module.	Uses existing procured microturbine, adequately sized to meet average load demands, requires minimal reconfiguration. Can be supplemented with electric car batteries for peak demand loads, load maximization, and efficiency of microturbine.	Cannot meet high peak loads for long periods.
75 kW Diesel Generator	Emergency Power (E-Shack)	Decommission and retro to an offsite location or reconfigure with waste heat recovery capabilities. Using this system as backup for redevelopment would require all buildings to have backup electrical heat systems as this system does not have heat recovery capabilities.	Decreases footprint of Summit Station and reduces fossil fuel dependence. Uses existing procured generator.	None

Notes:

HVAC = heating, ventilation, and air conditioning

N/A = not applicable



LEGEND

- EXISTING UTILITY VAULTS
- POTABLE WATER (SNOW MELTER)
- ELECTRICAL DISTRIBUTION SYSTEMS
- EXISTING UTILIDOR (FUEL, WASTE HEAT AND WATER)
- EXISTING GENERATORS AND FUEL STORAGE SYSTEMS
- EXISTING UTILIDOR (POWER)

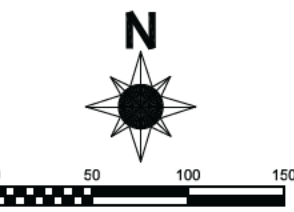
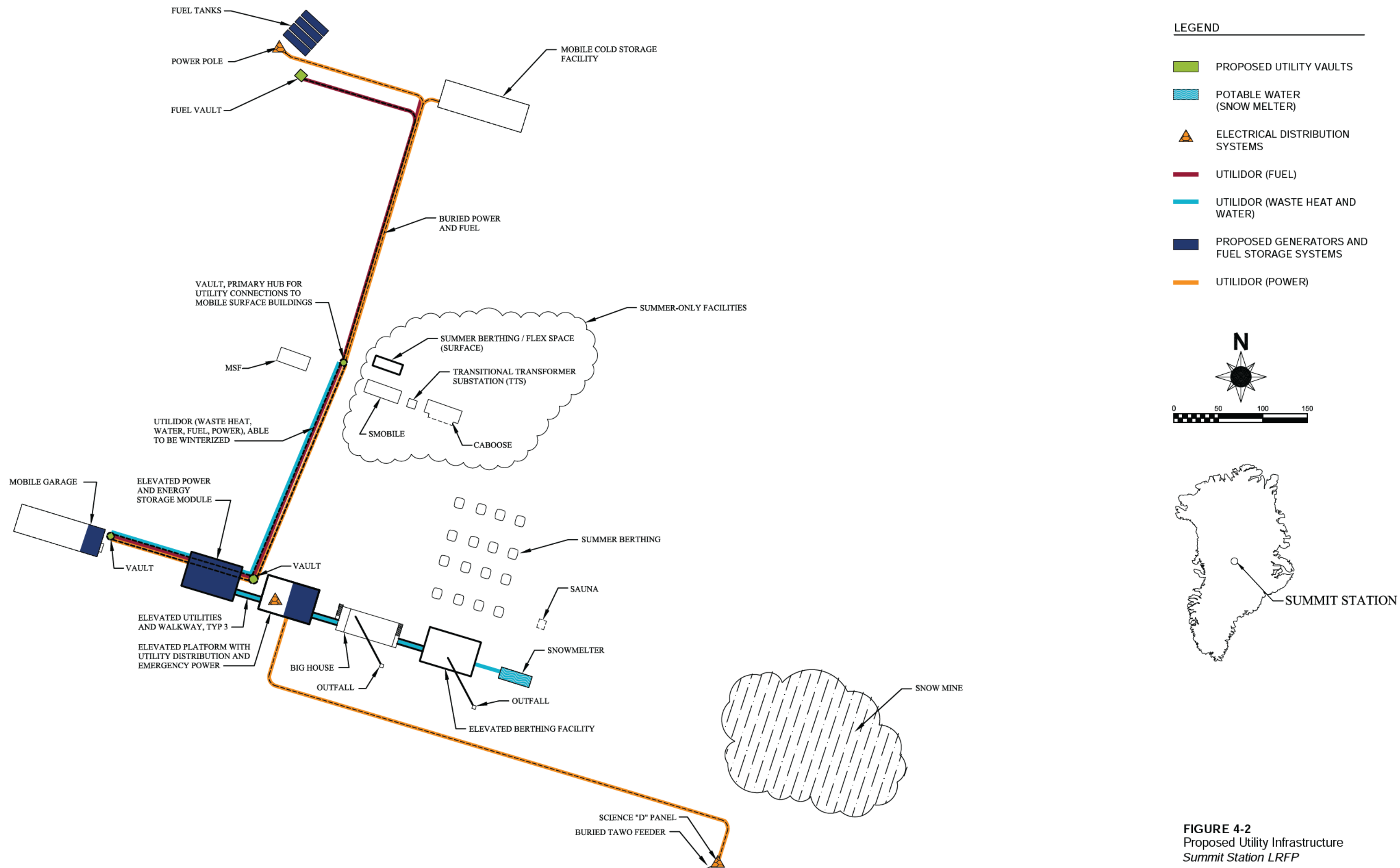


FIGURE 4-1
Existing Utility Infrastructure
Summit Station LRFP

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Station Redevelopment

5.1 Current Year Developments

In October 2017, a similar LRFP was developed to propose major projects prioritized into phases. Recently, completed projects, further discussions, science activity, and future projections have driven the need to update this plan. A few of the 2018 improvements are identified below:

- Demolished the SOB.
- Corrected the Big House columns with adjustable footings and using procured lifting system raised the building.
Procured a new offload sled.
- Began design and procurement of elevated berthing facility (EBF) components.
- Procured a lifting system to be used in the raising of facilities that can be assembled and disassembled for storage when not in use. The system has the capacity and dimensions required for lifting the largest and heaviest foreseeable structures included in this plan as well as existing structures.
- Lifted emergency and distribution shacks using procured lifting system.
- Completed design of a new standardized elevated platform.
- Began development of an energy management plan.



Lifting System Used on D-Shack

For full scope descriptions, reference the Summit Station Long Range Facilities Plan (CPS, 2017).

5.2 Redevelopment Vision

Summit will evolve from its current configuration to a station aligned with the vision established by the NSF to support advanced science research and observation activities for the next several decades.

Summit Station will consist of a series of new and existing modules (elevated when possible) arranged around the Big House. The platforms will be raised periodically with a universal lifting system to maintain clearance between the platform and snow surface. The platforms will have the ability to be relocated in the future, if required.

Surface structures will be towable for periodic relocation or offsite winter storage to prevent significant drift buildup. Current plans envision retaining the Big House as the primary hub for station operations, food service, and management headquarters. In addition, plans call for adding new hard-sided modules to house winter and summer berthing, with flexibility to convert for various needs (living activities, storage, multipurpose recreation, and potentially science work space), and utilities (power and communication) to create the core portion of Summit Station.

Summit Station will also include the relocatable SMG and towable summer-only buildings offset from the elevated platforms connected to a minimal utility corridor and main hub vault. These summer-only

buildings will be periodically rotated around the hub to help manage drifting and will be relocated away from Summit Station during the winter. A Mobile Cold-Storage Building will be constructed from structurally insulated panel (SIP) previously procured and will be used to store required equipment and materials, which will be relocated periodically to prevent significant drifting.

Full site layouts are provided in **Appendix G** for the current configuration and **Appendix H** for the proposed future site layout. Additionally, a pre-review was completed for this redevelopment plan and comments and responses are included in **Appendix I**.

5.3 Project Plan Forecast

Projects are listed in **Table 5-1** and are semi-sequential, with major projects running in parallel. Projects that are deemed necessary to address life-safety and mission-critical needs are planned for completion during the 2019 season. The projects identified after 2019 represent critical upgrades and new facilities and infrastructure to progress toward meeting the vision for Summit Station. The project scopes defined are conceptual and may require further clarification before implementation.

Table 5-1. Project Plan Outlook

Project Name	Project Description	NSF Vision and Justification
Annually		
Facility-Sustaining and Science Support Projects	Perform O&M activities on existing facilities and infrastructure to ensure that systems are operating safely and efficiently to maximize the life of equipment and reduce the risk of failure.	Providing continuous O&M preserves facilities and infrastructure and high reliability while reducing the cost of repairs. The ability to provide science support allows flexibility for the science community to use multiple assets throughout Summit Station for instrumentation and laboratory space.
12-Months		
P-01: Summer Hard-Sided Berthing	Construct hard-sided berthing for summer season occupants. It is recommended that this project be completed before beginning construction of the EBF to provide adequate berthing for field staff. This assumes a total of eight additional beds would be provided.	Implements facility designs that are flexible and scalable to meet population demands while being capable of safe and easy winterization. Peak summer populations drive high demand for warm, indoor berthing. Common areas accessible to all residents are essential to resident well-being and morale. A convertible summer-only facility will support both requirements as needed.
P-02: Relocation of Berthing Module	Relocated berthing module to provide sufficient winter berthing space for staff.	Uses an existing facility to provide a winter berthing option for staff that has safe access and egress without major costs.
24-Months		
P-01: Construct EBF, Platform, and Utilidor	Design, fabricate, transport, and construct a facility that provides an adequate supply of indoor berthing to support summer staff levels. This project also includes a standardized platform to be used in supporting the EBF to minimize drifting impacts, and a flexible, easily assembled and dissembled utilidor that can be winterized and provides utility services to the newly constructed facility. This project is expected to extend over two seasons.	Implements facility designs that are flexible and scalable to meet population demands. The GH/BM is near the end of its useful life and is inadequate for further long-term use at Summit Station. The level of effort and cost required to maintain the structures will continue to escalate if the GH/BM is not replaced with newer and more appropriately designed and engineered buildings. Development of a standardized platform will mitigate snow drifting and the design will be used for elevated future structures. The utility services will have the capability of being winterized to support existing needs as well as future considerations for autonomous or winter shut-down situations.

Table 5-1. Project Plan Outlook

Project Name	Project Description	NSF Vision and Justification
36 Months		
P-01: Science Relocation	Relocate science technician workstation space to more permanent location.	Provides allocated space for science researchers and next generation scientists, flexible and scalable solution, potential for implementation of systems for autonomous data collection. Maintaining the existing science platforms and functionality is critical to the mission of Summit Station. With the retirement of existing structures that support science, short-term and long-term solutions are required.
P-02: Demolish GH/BM	Conduct activities to fully decommission and demolish the GH/BM and begin preparing to remove demolished sections to be properly discarded.	Reduction of footprint due to the increasing maintenance and operations costs of the GH/BM coupled with the life-safety issues plaguing the facility require consideration for decommissioning and eventually demolition. Many of the repairs required to gain a few more years of service from the GH/BM would require major reconstruction. A new facility will be constructed before this effort that will provide a safer, more efficient facility that will replace many of the functions provided by the GH/BM currently.
P-03: Summit Mobile Garage Relocation and Repair	Relocate Summit Mobile Garage and repair floor, as needed, and design and install a snowmelt water containment to prevent intrusion into floor and preserve functionality of the structure.	Due to annual snow accumulation, year-round surface structures must be periodically relocated to avoid being buried by snow accumulation. This can cause increased maintenance and impact the life expectancy of a structure.
48 Months		
P-01: Construct Mobile Cold Storage	Design and construct a Mobile Cold Storage facility on a towable base that would be used to store essential structures and materials.	The storage of equipment and materials in berms (winter and year-round) leads to significant operations costs for storage and recovery, increases the likelihood of damage to equipment with exposure to the elements, and increases snow drifting at Summit Station. A Mobile Cold Storage facility would offer a solution to these issues and allow for the consolidation of surface structures while using existing materials.
P-02: Usage Assessment of Structures and Materials	Consolidate Station footprint by relocating essential structures and materials to the Mobile Cold Storage facility and retro unused materials and buildings to an offsite location.	The increasing maintenance and operations costs of the facilities at Summit Station coupled with the life-safety issues presented with facilities past their useful life require disposition action on all structures not only those specifically addressed in this plan.
P-03: Construct Minimal Distance Utility Corridor	Design and construct a minimal distance utility corridor with a main hub vault for all elevated and relocatable surface facilities to tie into the power and waste heat systems. This corridor can be underground, surface, or elevated; however, it must have the ability to be winterized.	The current subsurface utilidor lines are not capable of being winterized, which prevents the ability for Summit Station to “go cold” in the future. These lines are also subject to subsurface movement of the snow, which can lead to deformation and or failure of the lines, presenting a large risk to Summit Station.

Table 5-1. Project Plan Outlook

Project Name	Project Description	NSF Vision and Justification
60 Months		
P-01: Construct Elevated Power Module	Design, fabricate, transport, and construct a power module complete with combined heat and power systems, renewable technologies, and chemical/thermal storage.	A new power module that meets Summit Station's electrical and waste heat needs will allow for more efficient and reliable operations. In addition, the ability to store and use both electrical and waste heat energy offers significant advantages to lowering emissions and allowing for potential autonomous operations.
P-02: Construct Electrical Distribution and Emergency Power Module	Design, fabricate, transport, and construct an electrical distribution and emergency power module. These modules would also contain critical utility distribution and communication equipment required for remote operations and autonomy in the future.	The existing emergency generator provides a quick response to any primary power outages; however, the generator does not have the capability of providing waste heat, which is a critical asset for providing water to Summit Station. The current electrical distribution center (D-Shack) is reaching the space limitations for additional circuits to be added. Though both facilities are on elevated platforms, the facilities require separate, time-consuming periodic lifts and are situated away from the core facilities and require long feeder runs to connect to facilities.
P-03: Winterization Test	Conduct a winterization test on unstaffed conditions.	Achieving the NSF vision of developing Summit Station to support funded research during unmanned periods requires that the Station be easily winterized with the ability to be reactivated. Before full implementation of a winterized plan, issues can be mitigated by conducting a test to ensure assets are protected during the harsh winter conditions and are ready to be reactivated when necessary.
Independent		
Renewable Technologies	This initiative creates a phased power project and energy audit that will be overseen by the Energy Red Team.	This phase prioritizes efficiency upgrades, incorporates energy storage, and increases renewable penetration into an inverter-based grid.

Note:

O&M = operation and maintenance

5.4 Reoccurring Projects

5.4.1 Facility-Sustaining and Science Support Projects

Perform operation and maintenance (O&M) activities on existing facilities and infrastructure to ensure that systems are operating safely and efficiently to maximize the life of equipment and reduce the risk of failure.

Conducting O&M projects annually is critical to ensure that systems are operating safely and efficiently. These projects are often low-cost and can quickly be addressed. If equipment is not maintained properly, the life expectancy is reduced and there is a higher risk of system failure. The impact of systems not maintained correctly could be costly and potentially a life safety risk. Additionally, there is a recurring need to provide support to address the changing science needs.

This project encompasses a variety of tasks that include maintaining existing heating, ventilation, and air conditioning (HVAC) equipment, water and power plants, facility envelope, along with many other low-

cost maintenance-related tasks. In addition, other activities minimize snow drifting impacts by relocating surface facilities or lifting elevated facilities.

5.5 12-Month Project Plan

5.5.1 P-01: Summer Hard-Sided Berthing

This project would construct a facility or multiple facilities to provide sufficient hard-sided summer berthing for researchers and field staff. The current indoor berthing is limited in space and is often used for full-time researchers and staff. The hard-sided berthing space would be used during peak summer months when demand for indoor berthing increases. In addition, with the proposed construction of the EBF, it is anticipated that an increase in the construction crew will be required and this facility would provide sufficient indoor berthing that is safe and provides comfortable accommodations for the harsh working conditions. The facility would be located near the main vault hub (in the summer months only) to tie into waste heat and power systems or would use renewable technologies for heat and power.

This scope is conceptual, and discussions are still being conducted to determine the feasibility of all options available. There are multiple options available, and costs will be dependent upon the size of the preferred unit(s). Unit sizes range up to 8 feet by 20 feet and can sleep multiple individuals. For this effort, the project assumes two modules capable of sleeping a total of eight persons will be provided. The units will be modified for the arctic conditions and provide heating and ventilation either through grid power or renewable technologies.

5.5.2 P-02: Relocation of Berthing Module

This project will relocate the Berthing Module to provide sufficient winter berthing space for staff. The Berthing Module and the Greenhouse Module are connected through an arctic entry that includes a medic module. The modules will be split, and the Berthing Module will be raised to the snow surface to restore safe access and egress. Excavation is required to free up the module and a new foundation will be prepared near Utility Vault 2 using wood footers and a layer of 6-inch structural insulated panels. Utilities must be disconnected, drained, and reconnected for both modules along with HVAC and electrical system connections. Repairs to any envelope systems on both facilities will be conducted.

5.6 24-Month Project Plan

5.6.1 P-01: Construct Elevated Berthing Facility, Platform, and Utilidor

This project would construct a new berthing facility elevated on a platform with utility infrastructure to connect to the main utilidor. Currently, the GH/BM provides space for berthing, science, and medical operations as well as emergency kitchen and communication equipment. This facility is occupied year-round and is seen as critical for living and operating activities for the staff. However, the GH/BM has reached the end of its life and requires considerable upgrades and maintenance. An engineering evaluation and condition assessment of the GH/BM determined life-safety issues that have been mitigated but it is recommended that this facility be decommissioned and replaced by the new facility. The facility is designed to provide an adequate supply of indoor berthing to support the summer staff with convertible areas to support needs of staff during the winter. A small kitchen, medical, laundry, shower, and restroom areas will be provided.

With the primary goal of elevating future facilities at Summit Station, the platform designed for the EBF would provide a platform to support the new facility along with standardized features capable of being replicated and scaled to meet future facility's needs. Using a standardized platform not only mitigates

snow drifting, it also minimizes out-year costs in design and construction labor. The columns of the platform would have adjustable, recoverable, and replaceable footers with approximately 4.6 m (15 feet) of clear space between the bottom of the steel and snow surface when initially placed. Access to the EBF will be provided by two sets of stairs, one on each end of the platforms. The platform will be capable of interfacing with the previously procured lifting system.

Utility infrastructure for electrical, water, waste-heat, and sewer would be required for the new facility. All but the sewer utilities would be connected to the main utilidor. A dedicated sewer outfall would be constructed to dispense in a location away from the main site. All utility connections would be flexible to allow for differential settlement and disconnection during lifting activities in addition to being capable of being drained and winterized, as needed.

5.7 36-Month Project Plan

5.7.1 P-01: Science Space Relocation

This project would construct a dedicated science workspace to match existing and future science research needs. A science technician space exists within the GH/BM and with the planned demolition of the GH/BM the space would need to be relocated within an existing facility or a new dedicated facility. Options for relocation of technician workspace to existing facilities, such as the MSF or SMG, would need to be carefully reviewed as difficulties exist with either possibility. The MSF is currently used for the Integrated Characterization of Energy, Clouds, Atmospheric state, and Precipitation at Summit (ICECAPS) science research and is located a significant distance from the Big House making it difficult to access in winter conditions; however, the ICECAPS project is scheduled to finish in 2020 and use of this facility could be a highly recommended option if the ICECAPS team decides not to continue. The SMG provides a slightly more difficult option but has available room for a built-in mezzanine in the garage maintenance space.

This scope is conceptual and would establish a project manager to lead the effort of assessing feasible options that would evaluate potential permanent options within existing facilities against an elevated science facility commensurate with the development of future science needs. For this effort, the project assumes reconfiguration of the MSF with a common workspace and science instrumentation room capable of maintaining temperature requirements.

5.7.2 P-02: Decommission and Demolish the Greenhouse and Berthing Module

This project will decommission and demolish the GH/BM, a joint science and berthing facility. With the replacement of many surface facilities onto elevated platforms, there is a recognition that consolidation of surface structures is required to mitigate drifting and O&M costs for the remaining facilities. The GH/BM mainly consists of science lab space and storage, a medical clinic, backup communications, and berthing. The GH/BM has been used as a year-round facility and required specific utilities to remain occupied. The building uses electric, waste heat, water, and sewer. The building sits on the ice surface and has begun to succumb to many years of



GH/BM to be decommissioned and demolished.

differential settlement. In addition, repeated dismantling and relocating has taken a toll on the building both structurally and aesthetically.

This scope includes decommissioning activities such as disconnecting utilities to the building, switching off the water supply, and draining pipes, and shutting down the HVAC systems. Hazardous, flammable, or waste materials should also be removed and any salvageable systems or equipment that would be repurposed will be removed and stored appropriately. In addition, this scope includes deconstruction of all building components using heavy equipment and disposal materials will be packaged and transported offsite.

5.7.3 P-03: Relocate Summit Mobile Garage and Repair Floor

This project will relocate the Summit Mobile Garage to higher ground to avoid being buried by snow accumulation. It is anticipated that the SMG will be relocated near Vault 1 on the main utilidor or in alignment with the other core facilities, such as the Big House and EBF. The SMG weighs approximately 230,000 pounds and was last moved in 2017 using two heavy tracked vehicles. The most efficient operations in the past have consisted of installing a tow nose with cable and spreader bar and using the largest tracked vehicle to pull the tow bar while the second tracked vehicle pushed the structure as needed.

In addition, this project will analyze and implement repairs required for the SIP flooring. During the relocation efforts in 2017, the steel plate and SIP floor system undulated with the snow surface and caused fasteners to slip. This section of the SMG floor is used by the mechanics to maintain heavy equipment. The heavy equipment had snow that began to melt from the interior heat causing water infiltration into the SIP flooring. The snowmelt included glycol, petroleum, oil, and lubricant products, and other potential contamination that destroyed the ice and water shield barrier.

The scope for relocation includes constructing a level road pad leading to the newly constructed placement pad, preparing the structure by disconnecting utilities, removing relocatable equipment, securing interior equipment, and using heavy equipment to push and pull the facility to the new location. Furthermore, because the extent of damage to the SIP floor, if any, is unknown, it is assumed for this scope that a full floor replacement will occur along with design and installation of a permanent snowmelt water containment to prevent future water intrusion and preserve the life of the floor system.

5.8 48-Month Project Plan

5.8.1 P-01: Construct Mobile Cold Storage Facility

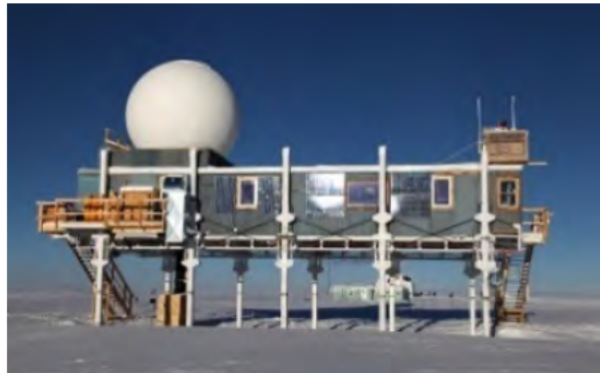
This project will construct a Mobile Cold Storage facility on a towable base. Recent efforts to minimize equipment stored on the berm has demonstrated the need to continue to consolidate the footprint of surface items and minimize drifting. The facility will use the 13 previously procured towable SIPs and a perimeter steel package currently stored at Thule Air Base and the undamaged structural steel frames from the previously demolished SOB facility. The facility will provide storage for equipment and materials not required during winter months. In addition, this project would focus on continuing efforts to reduce and eliminate the usage of the berms.

The scope includes construction of a facility with a tensioned fabric exterior over a structural steel frame. The building would be constructed using the existing SIPs and perimeter steel base and would have the ability of being periodically relocated as needed. The facility would have electrical service for lighting and power requirements. This scope also includes maintaining the current berm inventory log and monitoring the retrograding of materials and taking advantage of the aircraft cargo space availability for return flights from Summit.

5.8.2 P-02: Disposition Assessment on all Facilities

This project will conduct a disposition assessment on facilities, including the Big House and ARM facility. Facilities such as the Big House are functioning past their expected lifespan of 25 years and should be evaluated for use, condition, and long-term feasibility. A replacement plan should be developed for key core facilities to ensure that activities are not interrupted, and sufficient resources are in place during replacement activities.

This project would assign a disposition activity to all structures not specifically addressed in this plan. Each building would be evaluated for use, condition, and long-term feasibility. Disposition actions will include either consolidation, demolition, or repurposing.



30-Year-Old Big House

5.8.3 P-03: Construct Minimal Distance Utility Corridor

This project will construct a minimal distance utility corridor with hub vaults to tie-in remaining relocatable surface facilities that require power, water, and waste heat. This corridor can be underground, surface, or elevated. The existing utilidor is a subsurface system that is susceptible to deformation from snow movement and does not have the ability to be inspected or drained.

With the reconfiguration of the structures into elevated core facilities, the remaining surface structures would be consolidated into an area where they can tie into power, water, and waste heat. These structures would be mobile and the majority of them would be relocated during the winter months. This reconfiguration along with the requirement to inspect, maintain and winterize lines requires the construction of a new utility corridor.



Photo of SMG Vault and Utility Corridor

This project would design and construct a utility corridor that places pre-insulated and heat-traced lines in a corrugated metal tunnel and SIP base leading from the elevated utility systems to a major vault hub connecting the remaining surface facilities. The vault would be periodically raised as the surface elevation changes similar to other vaults currently used onsite.

5.9 60-Month Project Plan

5.9.1 P-01: Construct an Elevated Power and Energy Storage Module

This project will construct an elevated power module complete with CHP systems and chemical/thermal storage, moving Summit Station to an inverter-based grid, maximizing the potential for renewable energy.

The current electrical and waste heat power systems (reciprocating generators and a microturbine, both with waste heat recovery systems) are housed in surface facilities that lead to drifting and the



Current Microturbine Energy Module located on Snow Surface

requirement for periodic relocation. In addition, the capacity of the microturbine electrical output is strained to meet the current power requirements of Summit Station and neither power generation source can store excess power or waste heat energy. Implementing a new power module with energy storage capability would add reliability and operational efficiency to Summit Station and allow for an inverter-based grid to be created.

The Energy Red Team will develop an overall vision for an energy and power plan at Summit Station, which would include the configuration of new power systems. This module would include proven power generation technology (microturbine or reciprocating engines), waste heat, and battery storage. The systems would be constructed and tested prior to deployment to Greenland, with disassembly as required for air transport.

5.9.2 P-02: Construct an Elevated Electrical Distribution and Emergency Power Module

This project will construct an electrical distribution and emergency generator module. This module would also contain critical utility distribution and communications equipment required for remote operations and would provide autonomy in the future. Utilization of existing generation or distribution equipment would be considered to minimize costs.

Reliability of power systems is critical to maintaining science and operations at Summit Station. Back-up power systems are crucial with the extreme conditions of Summit Station and a safe, reliable distribution system is required to support all power systems. With the development of new power generation and storage systems, elevated back-up power and distribution systems would need to be incorporated.

In conjunction with the Energy Red Team's development of the future power systems, the emergency power and distribution systems would also be upgraded in this project. These systems would be elevated on a newly constructed platform and would utilize existing equipment to the maximum extent (microturbine or reciprocating generators with waste heat capability should be considered candidates). The utility distribution (electrical and waste heat) systems would be designed to handle the incorporation of energy storage and a newly constructed utilidor.

5.9.3 P-03: Conduct Unmanned Winterization Test

This project will conduct an unmanned winterization test at Summit Station fulfilling the NSF vision of becoming capable of supporting funded research during unmanned periods. Projects completed to this

point will implement systems that allow for autonomous data collection. Designs of facilities and infrastructure will be capable of being easily winterized and subsequently reactivated. It is recommended that redevelopment projects implemented conduct small winterization tests to mitigate issues that could arise from the harsh conditions.

The scope of this project is conceptual and needs further development. However, it is assumed that utility lines would be drained and all power and building systems would be shut down except for any systems supporting autonomous data collection activities.

5.10 Energy Management Plan

5.10.1 Incorporation of Renewable Energy into an Inverter-Based Grid

This phase creates a phased power project and energy audit assessments. Prioritize efficiency upgrades, incorporate the use of energy storage, and increase renewable penetration into an inverter-based grid. Conceptual information is provided below for deployment of an inverter-based grid and implementation of an energy storage system supported by an appropriately sized hybrid wind, solar, and diesel power production array. This concept assumes that incremental, small projects would continue to be deployed as solutions that provide limited reductions in the use of fossil fuels. The Energy Red Team would manage the vision and projects associated with this phase.

Summit Station currently relies heavily on fossil fuels (primarily low temperature rated AN-8 turbine fuel) for power generation, heavy equipment operation, and personnel movement. There are strong financial and environmental incentives for reducing this reliance. All-inclusive onsite fuel costs are extremely high when handling and delivery costs are included with the base fuel price, resulting in extremely high energy production prices. In addition to being costly, the emissions resulting from the combustion of fossil fuel can be deleterious to atmospheric science and near surface photochemistry experiments. It is estimated that up to 15 percent of atmospheric data must be discarded due to influence from local pollution sources.

The NSF, SCO, and a majority of users and stakeholders have stated a desire to move toward greater reliance on renewable energy. While the technological challenges are significant, the greater challenge is one of funding projects of this type, which tend to require high up-front capital investments.

This project would deliver and commission an inverter-based power grid which can connect solar, wind-powered, and other renewable energy sources that would supplement traditional fossil fuel power generation capabilities.

Energy costs for the program at Summit Station are extraordinarily high, routinely claiming a disproportionate amount of the overall budget even during periods of relative market price stability. Fuel costs can also be volatile, making it difficult to budget costs from year to year. Using historical data, it is reasonable to expect that these costs would rise over time, claiming a greater portion of limited operational budgets unless existing power production is augmented or replaced with renewable energy. In addition to budgetary impacts, there is a strong impetus both internally and externally to pursue renewable energy in the NSF Arctic program. Federal agencies are continuously encouraged to adopt energy efficiency and renewable energy technologies to lower long-term operating costs and reduce environmental impacts resulting from their operations. Also, a recent blue-ribbon panel reviewing the USAP identified the high and rising cost of energy as a key impediment to supporting scientific research and recommended implementing renewable energy as a key strategy to overcome this problem.

Renewable energy in the form of sun and wind is abundant on the GIS, and the two sources tend to complement each other by peaking in opposing seasons (solar maximum in summer and wind energy

peaks in winter). The technology has advanced markedly in recent years, and prices have decreased to near grid parity in the continental U.S. Due to these reasons, the ROI tend to be more attractive even with higher up-front capital investments. As these implementations grow, an economy of scale can be expected to reduce ROI even further while lowering and stabilizing long-term operating costs.

Utilizing a hybrid approach to energy generation and management offers excellent ROI, capitalizing on the best aspects of each technology. Renewable energy technologies are diverse and scalable. In addition to large format renewable energy systems for powering Summit Station, there are opportunities to use renewable energy to power and heat individual facilities or satellite camps. Similarly, summer berthing can readily be made autonomous from the central grid using simple, proven renewable energy systems.

If proven viable and cost-effective, this concept could be used to support science campaigns requiring either mobility or quick deployment to maximize field time. The solution could also possibly be used in other Arctic areas where berthing may be in limited supply.

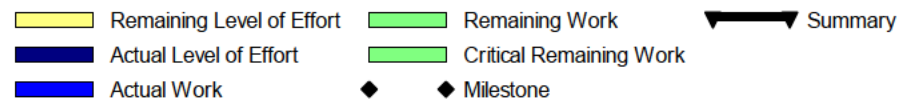
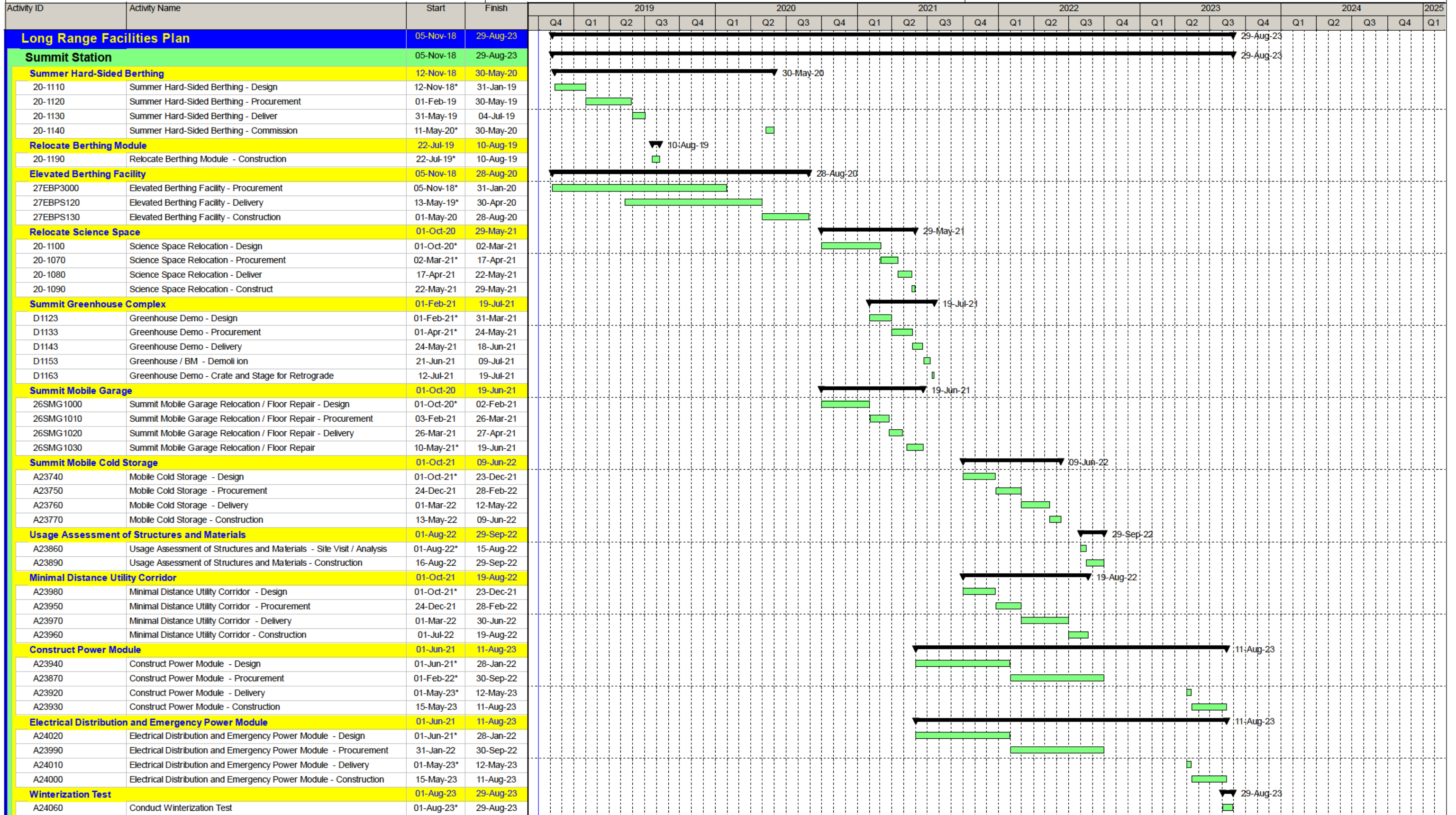
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Schedules

6.1 Schedules for Major Projects

A schedule has been developed for the major projects defined in this LRFP. This schedule is based on project descriptions and scope of work as currently defined. Given the conceptual project definitions, these schedules should be considered as a guidance only and should be refined as scope developments become more tangible. **Table 6-1** presents a proposed schedule for the project represented in this LRFP.

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Cost Estimates

7.1 Cost Estimates for Major Projects

Rough order of magnitude (ROM) cost estimates have been developed for the major projects defined in this long-range plan. These estimates are based on project descriptions and scope of work as currently defined. Given the limited project definition and engineering, these estimates should be considered as budgetary only. Where possible, historical program costs and supplier pricing was utilized. Various assumptions and allowances were developed for each project and incorporated into an individual basis of estimate and summary sheet. Table 7-1 represents costs for the projects represented in this LRFPP

Table 7-1. Costs for the Projects Represented in this LRFPP

Project	Project Cost (\$)	Transport Cost (\$)	Total (\$)
12-Month			
P-01: Summer Hard-Sided Berthing	\$360,000	\$60,000	\$420,000
P-02: Relocate Berthing Module	\$90,000	\$0	\$90,000
Subtotal	\$450,000	\$60,000	\$510,000
24-Month			
P-01: Construct EBF, Platform, and Utilidor	\$1,900,000	\$250,000	\$2,150,000
<i>P-01a: Platform</i>	\$470,000	\$80,000	\$550,000
<i>P-01b: Berthing Facility</i>	\$1,300,000	\$160,000	\$1,460,000
<i>P-01c: Utilidor</i>	\$130,000	\$20,000	\$150,000
Subtotal	\$1,900,000	\$250,000	\$2,150,000
36-Month			
P-01: Science Relocation	\$30,000	\$0	\$30,000
P-02: Demolish GH/BM	\$40,000	\$120,000	\$160,000
P-03: Summit Mobile Garage Relocation and Floor Repair	\$400,000	\$100,000	\$500,000
Subtotal	\$470,000	\$220,000	\$690,000
48-Month			
P-01: Construct Mobile Cold Storage	\$320,000	\$290,000	\$610,000
P-02: Usage Assessment of Structures and Materials	\$70,000	\$0	\$70,000
P-03: Construct Minimal Distance Utility Corridor	\$340,000	\$0	\$340,000
Subtotal	\$730,000	\$290,000	\$1,020,000
60-Month			
P-01: Construct Power Module	\$950,000	\$100,000	\$1,050,000
P-02: Construct Electrical Distribution and Emergency Power Module	\$580,000	\$100,000	\$680,000
P-03: Conduct Winterization Test	\$40,000	\$0	\$40,000
Subtotal	\$1,570,000	\$200,000	\$1,770,000
Total	\$4,670,000	\$960,000	\$5,630,000

Note: Costs do not include markups and are unburdened. Some EBF costs have already been incurred to the program, such as EBF panels and these costs are included in the cost estimate shown above.

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Appendix A

Project Development Checklist

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Appendix A Project Goals and Planning Checklist

Goals and Guiding Principles	Discussion Results
Does the project incorporate a modern, winterizable, energy-efficient design?	
Does the project allow for or support autonomous operation for science instrumentation?	
Does project comply with Government of Greenland expectations and codes?	
Does project improve health and safety?	
Does the project support science missions?	
Does the project reduce the Station's footprint?	
Does the project support other activities?	
Does the project enhance reliability of activities and/or the Station?	
Does the Station have the ability to maintain the project once completed?	
Does the project allow for scalability to address population fluctuations?	
Does the project impact sensitive areas?	
Federal High Performing Sustainable Buildings (FHPSB) Goals	
Does the project employ Integrated Assessment, Operation, and Management Principles by establishing energy and environmental goals in the design process, examining design choices that improve environmental performance and climate risks and health and wellness of building occupants?	
Does the project optimize energy performance measures?	
Does the project protect and conserve water?	
Does the project enhance environmental quality?	
Does the project reduce environmental impact of materials?	
Design Standards	
Does the project meet thermal standards requirements?	
Does the project design and site location minimize snow-drifting?	
Does the project meet wind speed criteria?	
Does the project have the capability to be standardized for future projects?	
Does the project impact existing facilities or do existing facilities impact the project?	
Does the project use materials that do not interfere with science and sensitive atmospheric measurements?	
Does the project have the ability to hook into existing utility or has off-grid capability?	
Transportation	
Does the project comprise a plan for reduced shipping weights and efficient shipping means?	

Appendix B

Inventory List

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Appendix B
Summit Station Facility and Infrastructure Inventory

Existing								
Structure Name	Current use	Number of Beds	Foundation Type	Wi-Fi	Sq. Footage	Year Built/Delivered at Summit	Historical Info / Recent History	Suggested LRFP Disposition
Big House	Galley, general station operations, DNF storage, bathing and laundry, common area		Elevated Infinite Leg	Y	1456	1988/89	• 2018 Columns corrected with new adjustable footings and lifted	Reassess and assign disposition based on life expectancy.
Green House Complex	Science lab space, medical clinic, science tech office space, berthing, common entertainment space, DNF storage, bathing and laundry	14	On Surface	Y	2,800	1997 and 2001	• 1997 Greenhouse procured and Built • 2001 Berthing Module procured and Built • 2005 2 Structures combined	Decommission and eventually demolish; a new structure will replace berthing function
Mobile Science Facility	Science		Mobile	Y	576	2009		Assess for permanent science technician workstation space
TAWO	Science		Elevated Infinite Leg	Y	168	2007	• 2007 built • 2010 Placed on elevated platform and infinite leg	Reassess and assign disposition based on life expectancy.
Summit Mobile Garage	Power and waste heat generation, HE shop space, Balloon launch, storage		Mobile	Y	3136	2016		Relocate and conduct floor repair activities.
Distribution Shack	Power distribution		Elevated Structure	N	125	2005	• 2018 Placed on elevated platform	Decommission and demolish; a new elevated combined D- and E-shack will replace these functions.
Emergency Generator Shack	Redundant power generation		Elevated Structure	N	144	2005	• 2018 Placed on elevated platform	Decommission and demolish; a new elevated combined D- and E-shack will replace these functions.
Smobile	Construction shop space, exercise/recreation (recreation side used as needed for science groups), utilities		Mobile	Y	600	2008	• Originally a science specific structure • Reconfigured to berthing in 2010 • Reconfigured into remote science space in 2014 • Reconfigured to shop/recreation in 2015 • Placed on mobile skid in 2016	Reassess and assign disposition based on life expectancy.
Caboose	Berthing	9	Mobile	Y	515	2014	Is this on the grid?	
ARM	Berthing	6 to 9	Mobile	N	310	2008	• 2008 established as subsurface Science Facility • 2010 Removed from subsurface config. • 2013 modified and placed on skis for remote science camp • 2015 Reconfigured to off grid berthing	Reassess and assign disposition based on life expectancy.
Tul-Krib	Tool/material storage for construction		Mobile	N	160	2002		Reassess and assign disposition based on life expectancy.
Tomato	During summer as needed, winter emergency shelter/cache		Mobile	N	112	2005		Reassess and assign disposition based on life expectancy.
Bally Building	As needed for science groups, current cold storage for science gear		Mobile	N	144	2003		Reassess and assign disposition based on life expectancy.
Mini S	Materials storage		Mobile	N	160	2002		Reassess and assign disposition based on life expectancy.
Home Depot	Materials storage		Mobile	N	160	2002		Reassess and assign disposition based on life expectancy.
Robin	Flammables storage		Mobile	N	96	2008		Reassess and assign disposition based on life expectancy.
Micro Turbine	Power and waste heat generation		Mobile	N	240	2016		Elevate the module with capability to tie-in to renewable path forward.
Snow Melter	Water production, treatment and storage		Mobile	N	215	2017		
Sauna	Recreation		Mobile	N	100	1989		Reassess and assign disposition based on life expectancy.
Hard Sided Fuel Tanks #1	Fuel storage		Mobile	N	270	2011		
Hard Sided Fuel Tanks #2	Fuel storage		Mobile	N	270	2011		
Hard Sided Fuel Tanks #3	Fuel storage		Mobile	N	280	2013		
Hard Sided Fuel Tanks #4	Fuel storage		Mobile	N	280	2013		
Fuel Bladder	Fuel storage		On Surface	N	324	N/A	Rotational every 5-7 years	Decommission.
Vault #1	Utilities access		Subsurface	N	96	2009		Potentially decommission and tie utilities to new minimal utilidor with a central vault.
Vault #2	Utilities access		Subsurface	N	64	2009		Decommission.
Vault #3	Utilities access		Subsurface	N	78	2018		Decommission.
BH Vault	Utilities access		Subsurface	N	80	2011		Potentially decommission and tie utilities to new minimal utilidor.
Fuel Vault	Utilities access		Subsurface	N	64	2013		
Transitional Transformer Sub-Station	Power grid tie-in		On Surface	N	8	2013		
BH Outfall	Waste		Subsurface	N	N/A	2017	80' Depth	
GH Outfall	Waste		Subsurface	N	N/A	2016	40' Depth	Decommission with building.
Pump House	Temporary utilities		Mobile	N	58	2017		Reassess and assign disposition based on future utilidor
Berms	Cold Storage		Surface / Subsurface	N	N/A	1997	Winter storage	Eliminate / reduce / replace with mobile cold storage facility.
Tent City	Berthing	16	Temporary Surface	N	N/A	1989	Seasonal	Replace with hard-sided berthing.

Appendix B
 Summit Station Facility and Infrastructure Inventory

Demolished or Removed								
Structure Name	Previous use	Number of beds	Foundation Type	Wi-Fi	Sq. footage	Year Built/Delivered at Summit	Historical Info / Recent History	Suggested LRFP Disposition
Science and Operations Building	Power and waste heat generation, HE shop space, Balloon launch, storage		On Surface	N	3,200	2005	<ul style="list-style-type: none"> • 2005 Built • 2006 Disc tent deconstructed • 2009 SOB built in current location • 2018 SOB demolished 	Potential excavation of floor materials and package for removal off-site. This requires decision from Government of Greenland.

Appendix C
Building Code Technical Memorandum

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The following information summarizes previous code considerations specific to designing and constructing facilities in Greenland. Subsequent to this memorandum, the 2015 International Code series was adopted by the NSF, though there are no foreseeable changes to the recommendations listed below. Additionally, code waivers requests for ceiling height and door thresholds have been submitted to the AHJ specifically for the Greenhouse and Berthing Module for the short period these buildings will remain in service.

TECHNICAL MEMORANDUM

CH2MHILL

PREPARED FOR: CH2M HILL Polar Services
PREPARED BY: Monique Lussier, AIA NCARB LEED^{BD+C}
DATE: October 2014

Building Code Considerations for Greenland Projects

Background

National Science Foundation projects in Greenland support year-round research and education that creates greater scientific understanding of the Arctic in relationship to the global environment. NSF facilities and CPS staff provide housing, meals, science workspace, maintenance workspace, and utilities infrastructure in support of Arctic field research and education. Scientists and students from universities, institutions, and agencies from throughout the US and the world utilize these constructed resources.

Unlike structures in populated geographies, visiting scientists and researchers to the Greenland ice sheet agree to – and face – challenges and limitations associated with an off-grid, remote Arctic science research field station. The purpose of this memorandum is to define the site-specific life safety, plumbing, and accessibility code issues. This document also outlines the approval process for code exceptions on future work.

Climate

Greenland is a high polar, ice cap environment. During the peak of the boreal summer, the sun is above the horizon 24 hours a day, and the air temperature can reach a high of 10 degrees Celsius (°C) (50 degrees Fahrenheit [°F]). In winter, the sun does not rise above the horizon for 3 months, and the air temperature can reach a low of –66 °C (-87 °F).

The physical altitude Greenland facilities locations will vary from sea level to ten thousand six hundred feet (10,600'); however, the pressure altitude can reach as high as thirteen thousand feet (13,000'). Average annual wind speeds are expected to be approximately 5.83 m/s (11.66 knots or 13.04 miles per hour [mph]), but wind speeds exceeding 100 mph have been recorded.

Snow accumulation is approximately 70 centimeters (cm) (28 inches [in]) per year. Due to the extreme cold temperatures at Summit Station, any precipitation or windblown snow tends to accumulate permanently. Structures and equipment tend to exacerbate the problem by initiating localized drifting, and greater than a meter of permanent snow accumulation per year is possible.

Building Code Evaluation Process

Projects designed, but not yet constructed, and all future projects will fully comply with all applicable codes and energy conservation standards. However, remote site-specific conditions exist in Greenland that require prudent waivers to specific life safety and handicap accessibility code provisions. Proposed

code exceptions, including those not referenced herein, require review and approval by CH2M HILL Polar Services (CPS), National Science Foundation (NSF), and the Authority Having Jurisdiction (AHJ).

1. At the earliest stages of project requirements gathering and design, licensed design professionals will develop a code summary outline and identify code provisions that will potentially require special dispensation, including those listed in this memorandum.
2. The designer shall develop options or design measures that will mitigate the negative consequences of the code provision deviations. Proposed solutions will be evaluated with the project stakeholders with respect to life safety, functionality, and cost.
3. At the Concept Design Phase develop a detailed code summary, highlighting proposed deviations and design approach to mitigate negative consequences. Submit code summary write-up to CPS for review and approval by the AHJ.
4. Subsequent design submittal drawings will reference AHJ findings in the Code Summary.

Discussion of Key Code Provisions

The two principal code sources used in this memo are International Building Code (IBC) 2009 and International Code Council (ICC) A117.1 Accessible and Usable Buildings and Facilities.

Life Safety

IBC Chapter 9 – Automatic Sprinkler Systems

903.2 Where required. Approved *automatic sprinkler systems* in new buildings and structures shall be provided in the locations described in Sections 903.2.1 through 903.2.12.

Remote science camps in Greenland lack infrastructure and water resources to support conventional design assumptions for various uses. Water usage is restricted and designed for minimal domestic uses. Water is produced by melting snow. It is treated and stored in small quantities for human consumption, kitchen food prep and clean-up, and a limited quantity of plumbing fixtures.

In consideration of limited access to water, future projects will be designed to code and without automatic fire suppression. At key design milestones, the AHJ will be evaluate the impacted IBC and NFPA life safety code provisions and proposed solutions.

Manual fire alarm systems, if required in section 907.2, which activate the occupant notification system in accordance with Section 907.5, will be provided in all future normally occupied buildings. The fire alarm system shall be activated by automatic fire detectors and manual fire alarm boxes.

IBC Chapter 10 – Means of Egress

1008.1.3 Door opening force. The force for pushing or pulling open interior swinging egress doors, other than fire doors, shall not exceed 5 pounds (22 N). For other swinging doors, as well as sliding and folding doors, the door latch shall release when subjected to a 15-pound (67 N) force. The door shall be set in motion when subjected to a 30-pound (133 N) force. The door shall swing to a full-open position when subjected to a 15-pound (67 N) force.

Cold storage type doors perform well at exterior locations. Confirm manufacturer specifications comply with code requirements including opening force and hardware operation. All exterior doors should be inward-swinging due to the potential for rapidly accumulating snow drifts at the building perimeter.

Restrooms and Plumbing Fixtures

IBC 2902.2 Separate Facilities

Where plumbing fixtures are required, separate facilities shall be provided for each sex.

Exceptions:

1. Separate facilities shall not be required for *dwelling units* and *sleeping units*.
2. Separate facilities shall not be required in structures or tenant spaces with a total *occupant load*, including both employees and customers, of 15 or less.
3. Separate facilities shall not be required in mercantile occupancies.

IBC 2902.3 Required Public Toilet Facilities

Customers, patrons and visitors shall be provided with public toilet facilities in structures and tenant spaces intended for public utilization. The number of plumbing fixtures located within the required toilet facilities shall be provided in accordance with Section 2902.1 for all users. Employees shall be provided with toilet facilities in all occupancies. Employee toilet facilities shall either be separate or combined employee and public toilet facilities.

To conserve water, researchers, staff, and visitors are directed to use outhouses during periods of peak station occupancy. Future facilities will be evaluated by project stakeholders and AHJ to determine whether – and how many – plumbed fixtures and appliances are required.

Accessibility – Site and Building

IBC Chapter 11 – Accessibility

Section 1105 Accessible Entrances

1105.1 Public entrances. In addition to *accessible* entrances required by Sections 1105.1.1 through 1105.1.6, at least 60 percent of all *public entrances* shall be *accessible*.

Exceptions:

1. An *accessible* entrance is not required to areas not required to be *accessible*.
2. Loading and *service entrances* that are not the only entrance to a tenant space.

Section 1106 Parking and Passenger Loading Facilities

1106.1 Required. Where parking is provided, *accessible* parking spaces shall be provided in compliance with Table 1106.1, except as required by Sections 1106.2 through 1106.4. Where more than one parking facility is provided on a *site*, the number of parking spaces required to be *accessible* shall be calculated separately for each parking facility.

Due to the extreme climate, challenging logistics, and minimal facility amenities, there are no wheelchair accessible site features or building entrances in remote Greenland facilities, therefore NSF staff, scientists, and visitors to Greenland are presumed to be able-bodied. There are no personal vehicles at Greenland sites. Site planning of future buildings in Greenland will consider prevailing winds, snow accumulation, visibility, safety and convenience for pedestrians and transport vehicles.

2010 ADA Standards for Accessible Design

Section 35.151 of 28 CFR Part 35

35.151 New Construction and Alterations

(a) Design and Construction

(1) Each facility or part of a facility constructed by, on behalf of, or the use of a public entity shall be designed and constructed in such manner that the facility or part of the facility is readily accessible to and usable by individuals with disabilities, if the construction was commenced after January 26, 1992.

206.2.3 Multi-Story Buildings and Facilities

At least one *accessible* route shall connect each *story* and *mezzanine* in multi-story buildings and facilities.

Exceptions:

5. Within multi-story *transient lodging* guest rooms with mobility features required to comply with 806.2, an *accessible* route shall not be required to connect *stories* provided that *spaces* complying with 806.2 are on an *accessible* route and sleeping accommodations for two persons minimum are provided on a *story* served by an accessible route.

Accessibility – Restrooms

Toilets, lavatories, and restroom accessories shall be fully accessible, except for wheelchairs.

Accessibility – Dwelling Units and Sleeping Units

Transient Lodging

A *building* or *facility* containing one or more guest room(s) for sleeping that provides accommodations that are primarily short-term in nature. *Transient lodging* does not include *residential dwelling units* intended to be used as a residence, inpatient medical care *facilities*, licensed long-term care *facilities*, detention or correctional *facilities*, or *private buildings* or *facilities* that contain not more than five rooms for rent or hire and that are actually occupied by the proprietor as the residence of such proprietor.

IBC Section 1107 Dwelling Units and Sleeping Units

1107.1 General. In addition to the other requirements of this chapter, occupancies having *dwelling units* or *sleeping units* shall be provided with *accessible* features in accordance with this section.

1107.2 Design. *Dwelling units* and *sleeping units* that are required to be *Accessible units*, *Type A units* and *Type B units* shall comply with the applicable portions of Chapter 10 of ICC A117.1. Units required to be *Type A units* are permitted to be designed and constructed as *Accessible units*. Units required to be *Type B units* are permitted to be designed and constructed as *Accessible units* or as *Type A units*.

1107.3 Accessible spaces. Rooms and spaces available to the general public or available for use by residents and serving *Accessible units*, *Type A units* or *Type B units* shall be *accessible*. *Accessible* spaces shall include toilet and bathing rooms, kitchen, living and dining areas and any exterior spaces, including patios, terraces and balconies.

1107.6.2.2 Group R-2 Other Than Apartment Houses, Monasteries and Convents

In Group R-2 occupancies, other than apartment houses, monasteries and convents, *Accessible units* and *Type B units* shall be provided in accordance with Sections 1107.6.2.2.1 and 1107.6.2.2.2.

1107.6.2.2.1 Accessible units. *Accessible dwelling units* and *sleeping units* shall be provided in accordance with Table 1107.6.1.1.

1107.6.2.2.2 Type B units. Where there are four or more *dwelling units* or *sleeping units intended to be occupied as a residence* in a single structure, every *dwelling unit* and every *sleeping unit intended to be occupied as a residence* shall be a *Type B unit*.

ICC 2009 A117.1 Accessible and Usable Buildings and Facilities

Chapter 10 – Dwelling Units and Sleeping Units

1002.11.2 Accessible Toilet and Bathing Facility. At least one toilet and bathing facility shall comply with Section 603. At least one lavatory, one water closet and either a bathtub or shower within the unit shall comply with Sections 604 through 610. The accessible toilet and bathing fixtures shall be in a single toilet/bathing area, such that travel between fixtures does not require travel through other parts of the unit.

Accessible lodging shall be provided in adherence to code requirements with the exception of wheelchair accessibility. Sleeping rooms will not be occupied as a residence; therefore none are required to be IBC Group R-2 Type B units.

Appendix D
Snow Transport and
Drift Mitigation

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EBF and surrounding structure placement suggestions to minimize snow drift management.

Zoe Courville and Robert Haehnel, CRREL

Prepared for NSF-RSL

Snow transport at Summit Station: Haehnel and Bigl (2016) examined snow transport at Summit and found that the majority of transport occurs primarily in the winter with a bimodal distribution, i.e., the main direction of the winds that results in snow transport occur from the SW and SE, with considerable inter-annual variability. Table 1 lists the winter wind transport data for the years 2008 - 15; the mean of the data is 190 t/m. For comparison, the total summer transport is on average 35 t/m in the same time frame, less than 20% of the winter snow transport. Figure 1 shows the transport rose for the period of 28 June 2008 through 14 May 2015 representing a long-term average for transport at Summit. Two transport directions are evident on the rose as a major and minor lobe, roughly oriented SE ($126^\circ \pm 18^\circ$) and SW ($207^\circ \pm 18^\circ$) and nearly orthogonal (a separation of 81°). The bisecting angle between the two lobes is 166.5° . One-quarter to one-half of all the snow transported annually originates from a direction other than the SW or SE during the winter, though the percentage transported in any one direction is relatively small (e.g., less than 5%). The variability in transport direction from year-to-year is illustrated in Figure 3, in which winter-only transport roses are shown.

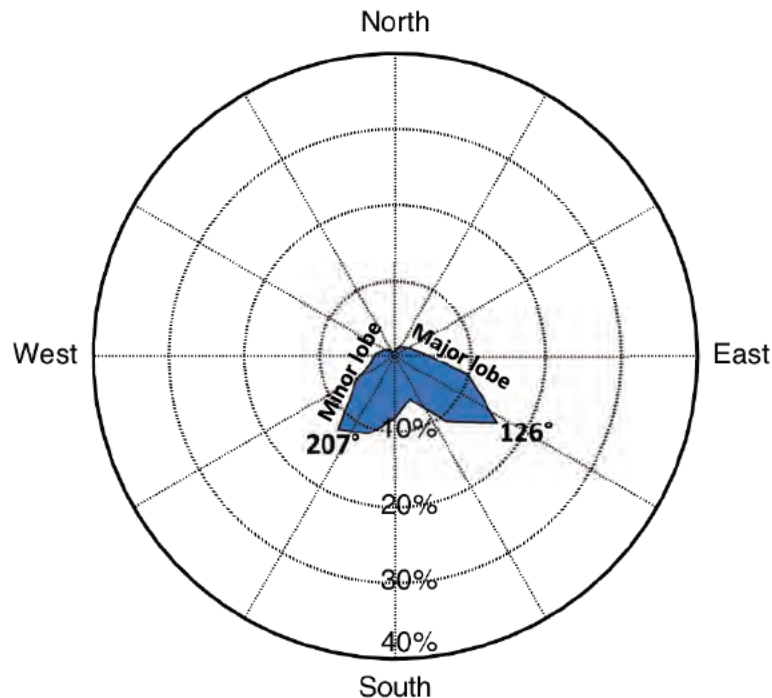


Figure 1. Transport rose for the period 26 June 2008 – 14 May 2015.

The amount of snow deposited is reported as snow transport, Q_t (Figure 2) which is in a measure of mass flux per time per meter of width across the wind, and includes evaporation considerations over the fetch, F , of snow redistribution. For the values calculated in Table 1, the annual transport per width across the wind.

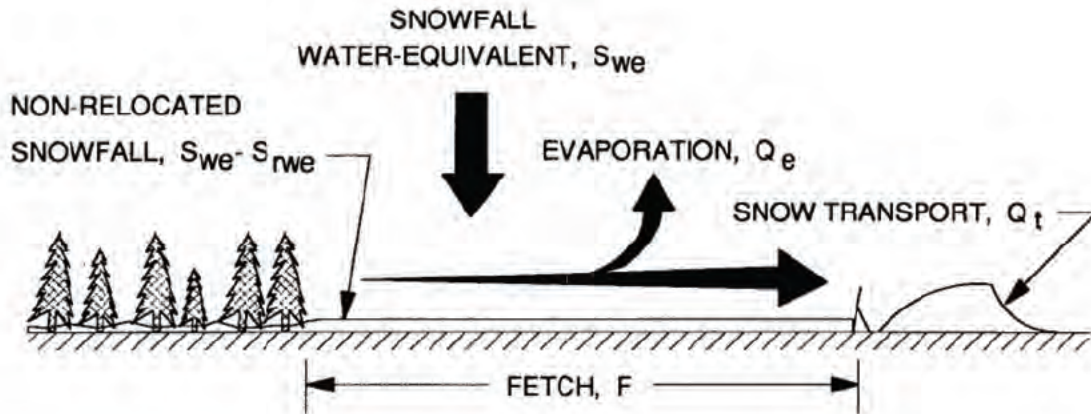


Figure 2. Diagram of snow transport concept from Taber (1994)

Table 1. A breakdown of estimated potential winter snow transport by dominate transport directions, with deposition reported in metric tonnes per meter (t/m).

Year	Potential Deposited Snow (t/m)					
	Total	ESE*	SE	SSW	SW	Other Direction
2008-09	197.5		73.1		67.2	57.3
2009-10	206.0		41.2		107.1	57.7
2010-11	271.0	135.5			13.6	121.9
2011-12	183.1		95.2			87.9
2012-13	115.5		60.1		23.1	32.3
2013-14	183.5		68.0	34.9		80.7
2014-15	180.5		45.1	41.5		93.9

* East-southeast

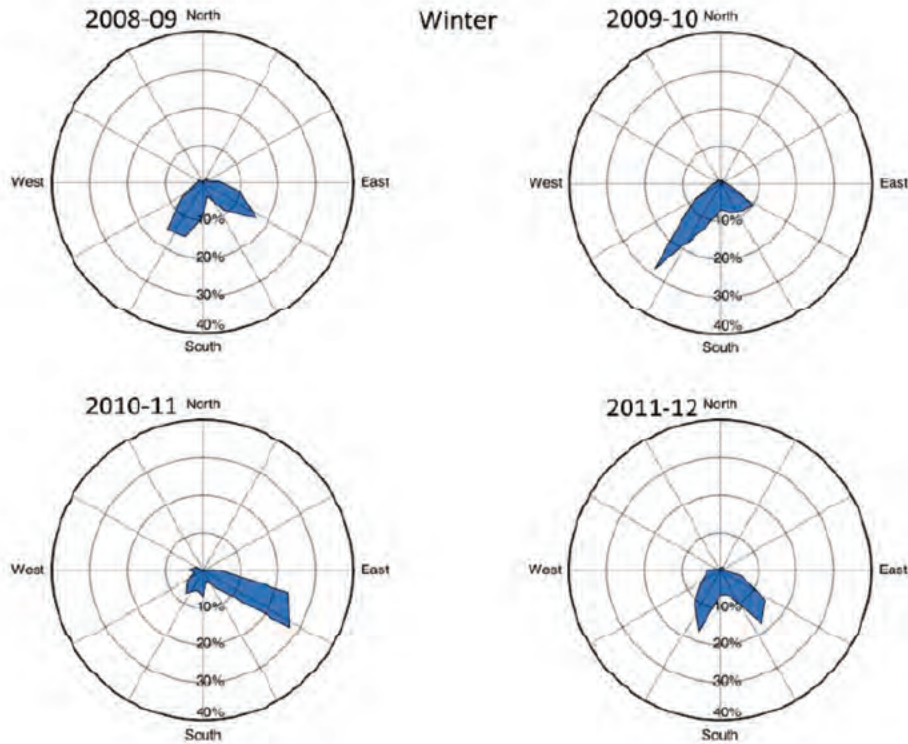


Figure 3. Example of variation in predominant transport direction(s) per winter season. 2008-09 and 2011-12 exhibited bimodal transport from the SE and SW, while 2009-10 had transport primarily from the SW and 2010-11 had transport primarily from the SE.

The transport roses are validated by satellite imagery (WorldView1) of Summit Station in the early spring months before extensive snow clearing activities at the station have started for the summer season (Figure 4 and Figure 5). The image from 2 April 2011 (Figure 4) shows the drift pattern caused by the transport regime shown in Figure 3 for the 2011-12 season, which was bimodally distributed from the SW and SE, with resulting drifts to the NE and NW, as indicated by the yellow arrows in the image. The bisect of the angle of the two transport lobes is approximately SSE in 2011. The orientation of the Big House and the cargo berm are different resulting in noticeably differently oriented drifts, but both structures have two primary drifts that form during the winter due to the two predominant transport directions.

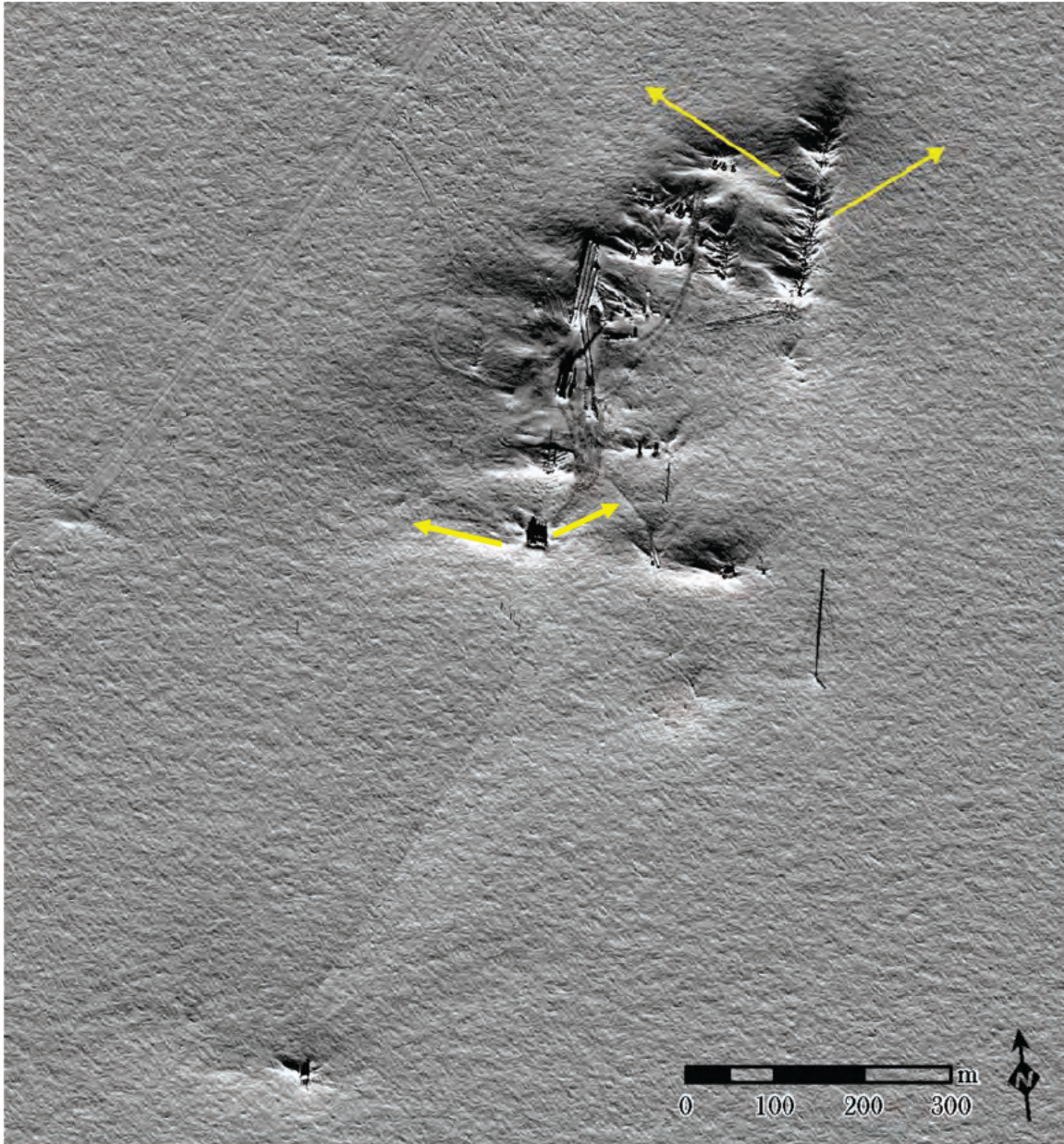


Figure 4. WorldView-1 image of Summit ca. April 2011 showing drift volumes resulting from the bimodal transport shown in Figure 3. Yellow arrows indicate the drift orientation from the cargo berm, North in the figure, and the Big House to the South.

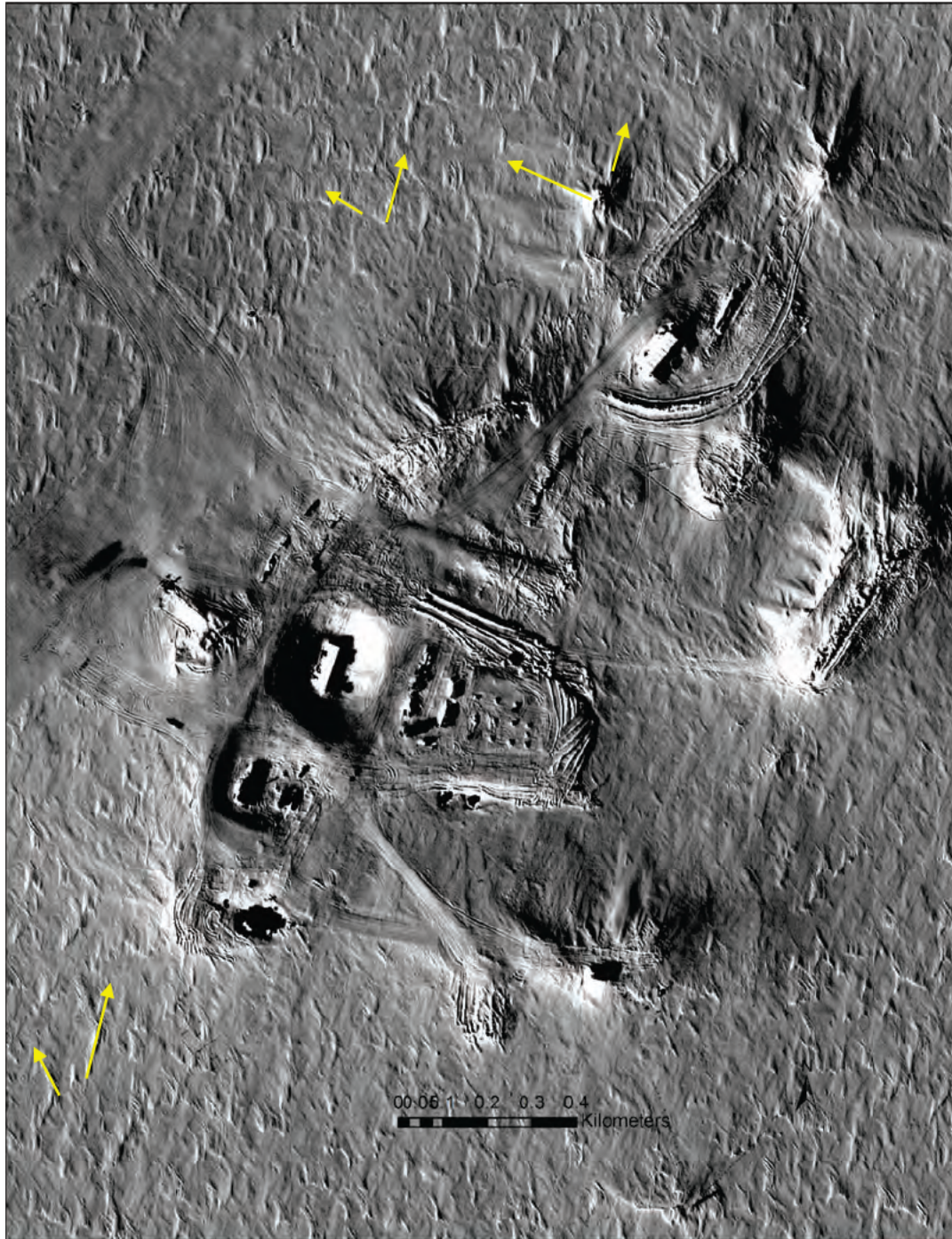


Figure 5. June 2017 WorldView-1 image of Summit station with bimodal drift patterns evident in sastrugi orientation and drifts around structures (drift mitigation had already started in this image). Drift orientation around cargo berm and sastrugi is noted by yellow arrows.

General guidance for minimizing drift around polar structures: Conventional designs for minimizing drifting around surface buildings assume that the wind and snow transport originates from one

predominate direction (Tabler, 1994; Haehnel and Weatherly, 2014) and will not perform as well in the bimodal transport conditions present on Summit. For general guidance, where possible, elevated and equi-axis (e.g., square) buildings will likely perform better in locales that are subjected to omni- or multi-directional winds. Larger, multi-functional buildings tend to accumulate less snow than many smaller buildings that occupy the same volume as a single larger building (Haehnel and Bigl, 2016).

To further refine guidance for the proposed Elevated Berthing Facility (EBF) at Summit we conducted a simple analysis as follows. Kwok et al. (1992; 1993) and Kim et al. (1992) conducted a series of wind tunnel tests of rectangular, scale models to determine the drift volume based on spacing grouped buildings, varying building orientation with respect to wind direction, building dimensions, and height of elevated building off the ground. They also examined the impact of differently sized building radius and chamfers, which was not considered for this analysis; we assume that the EBF will be of sharp corner (radius near zero) construction. We note however, the studies of Kwok et al. (1992) and (1993) and Kim et al. (1992) showed that increasing the corner radius of the structures significantly reduced deposited snow drift volume in comparison to a sharp corner construction.

What is most germane to our analysis is that Kwok et al. (1993) examined wind orientations at 0°, 45°, and 90° to the long side of the scale buildings and recommend the following:

- Positioning the building so that long axis is parallel to the wind direction (i.e., 0° in the wind tunnel tests) produces the smallest drifts (see Figure 6 for schematic of wind tunnel models).
- Elevating the building as much as possible. Kwok et al. (1993) studied with the scale buildings elevated at $h/H = 0.32$ and 0.43 building height, where h is the height the building is elevated above the snow surface and H is the height of the building structure excluding the elevation height (Figure 6), with the 0.43 building height elevation showing significantly lower drift volumes.
- Increasing the height of the elevated structure will reduce the volume of the snowdrift, irrespective of incident wind angle.

For groups of buildings, recommendations are (Kwok et al., 1992):

- On-ground and elevated buildings should be spaced a building-width apart in the windward direction to minimize drift in between the structures.
- Elevating buildings increases the total volume of snowdrift, but the drift remains clear of the buildings.
- Buildings with heights $1.2x$ the width of the building seem to perform better than taller buildings ($1.6x$ the height) or buildings that are shorter than they are wide ($0.8x$).

Kim et al. (1992) found that increasing the width of the building does significantly increase the volume of snow drift for elevated structures, while increasing the height and length of the buildings reduces the volume of the drift.

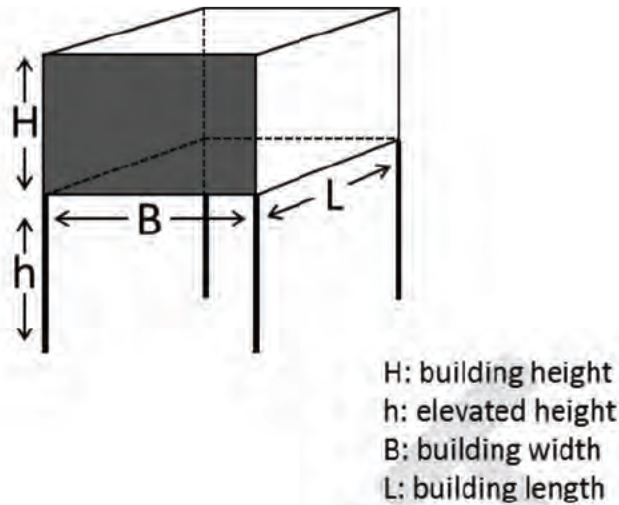


Figure 6. Schematic of building model dimensions after Kwok et al. (1992; 1993) and Kim et al. (1992)

These studies all assume a predominant wind direction, and do not pertain explicitly to the bimodal distribution that occurs at Summit. As a first order approach, we can examine the effects of having a drift volume predicted by Kwok et al. (1993) in the predominant wind direction (i.e., the largest, or major, lobe oriented at 126° from Figure 1) superimposed by the drift volume predicted from the secondary wind orientation, or 207° for the minor lobe in Figure 1, based on the fraction of total drift volume from each direction as determined by Haehnel and Bigl (2016). The percent of the overall drift volume from these two directions is on average 37% for winds originating from 126° and 23% for winds originating from 207° . The drift volume from these two directions combined accounts for 60% of the total drift volume. The remaining 40% of the drift volume originates from other wind directions, with less than 5% coming from any one direction and more evenly distributed across the surface.

In Table 2, we summarize the findings in Kwok et al. (1993) for drift volume (normalized as drift volume per building volume) for three different wind orientations (i.e., 0° or parallel to the long axis of the building, 45° to the long axis of the building, and 90° or perpendicular to the long axis of the building) at different building elevation heights (reported as the elevated building height, h , relative to the height of the building, H). In Table 3, we calculate the total volume of drift due to the two predominant wind directions as a fraction of the total drift in each direction multiplied by the normalized drift volume predicted by Kwok et al. (1993) with the building oriented with the long axis parallel to the major lobe at 126° , perpendicular to 126° , and at an angle of about 45° between these two (i.e., long axis aligned with bisecting angle of 167°) for two different elevated heights (where $h/H = 0.43$ and 0.32). We also report the normalized drift volume compared to the smallest drift volume (at $h/H = 0.43$ with the building oriented with the long axis parallel to 126°).

Angle of wind with long side of building	Elevated height/building height, h/H	
	0.43	0.32
0	0.13	0.32
45	0.29	0.44
90	0.37	1.4

Building orientation	Elevated height/building height, h/H			
	0.43		0.32	
	Drift volume/building volume	Normalized to smallest drift	Drift volume/building volume	Normalized to smallest drift
Long Axis Parallel to 126°	0.133	1	0.440	3.31
Short Axis Parallel to 126°	0.167	1.25	0.592	4.44
Long Axis Parallel to 167°	0.174	1.31	0.264	1.98

The smallest drift volume is predicted for a building elevated at $h/H = 0.43$, oriented with the long axis parallel to 126° (0.133 drift volume/building volume). For building orientations with the short axis parallel to 126° and long axis parallel to 167°, the drift volume is 25% and 31% larger for this elevated height, respectively.

For building elevations that are 0.32 of the building height, the smallest drift volume is achieved with the long axis parallel to 167° --almost twice the drift volume of case of the $h/H = 0.43$ elevated building oriented parallel to the wind. The other orientations at $h/H = 0.32$ have 3-4.5 times the smallest drift volume. Note that the "total" drift volumes reported in Table 3 only account for 60% of the total transport. The other 40% of the total transport is due to wind directions that are much more even distributed as drift, with as mentioned any one wind direction accounting for less than 5% of the total drift volume.

Summary and recommendations: The Big House is currently in a sub-optimal orientation with its widest side facing in between the two predominant winter wind directions of SE and SW and an estimated elevated height, $h/H \approx 0.7$ (based on photographic interpretation). Since the Big House cannot be moved, and following the guidance of Kwok et al. (1992, 1993) and applying the analysis conducted in this work it could be best to orient the remaining buildings upstream or downstream, at least one building's width away, with the long side of the building parallel to 126° if the elevation height $h/H \approx 0.43$. The remaining structures should be placed along this line, with the longest side parallel to this direction and one building width apart as depicted in Figure 7. However, this

analysis suggests that if the elevated height is lower (e.g., $h/H \approx 0.32$) the buildings should be turned with the long axis approximately parallel to the bisecting angle of 167° (Figure 8).

Square buildings would be best in the bimodal transport regime that Summit is in, with structures elevated at least $h/H = 0.32$ of the building height, or more (i.e., $h/H = 0.43$) without compromising the structure of the elevated legs for the platform.

The bimodal transport regime, and the need to keep the Big House in its current configuration, does warrant further study as no current guidelines exist for drift mitigation in bimodal wind patterns. What is provided is a first order estimate, we have examined the effect of superimposed drifts from the two primary wind transport directions based on the limited data that do exist for single wind directions. It is not entirely clear where to best place the new buildings relative to the Big House, and that will likely require a compromise among construction/function considerations, overall camp layout, and the need to reduce potential drifting volumes. The layouts provided in Figures 7 and 8 are possible layouts that may help reduce drift accumulation but does not take into account all of the considerations enumerated. We recommend a comprehensive examination using a computational fluid dynamics (CFD) model to better determine a final layout that takes into account other design constraints and to verify the simple analysis provided here.

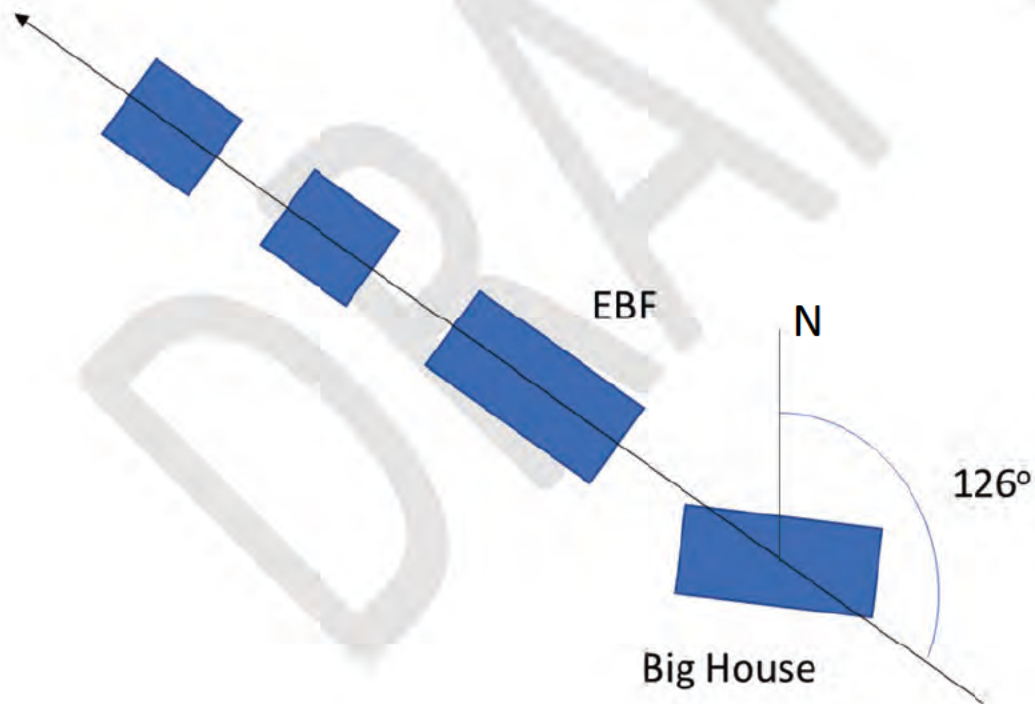


Figure 7. Cartoon depicting proposed building layout for alignment at elevation $h/H = 0.43$.

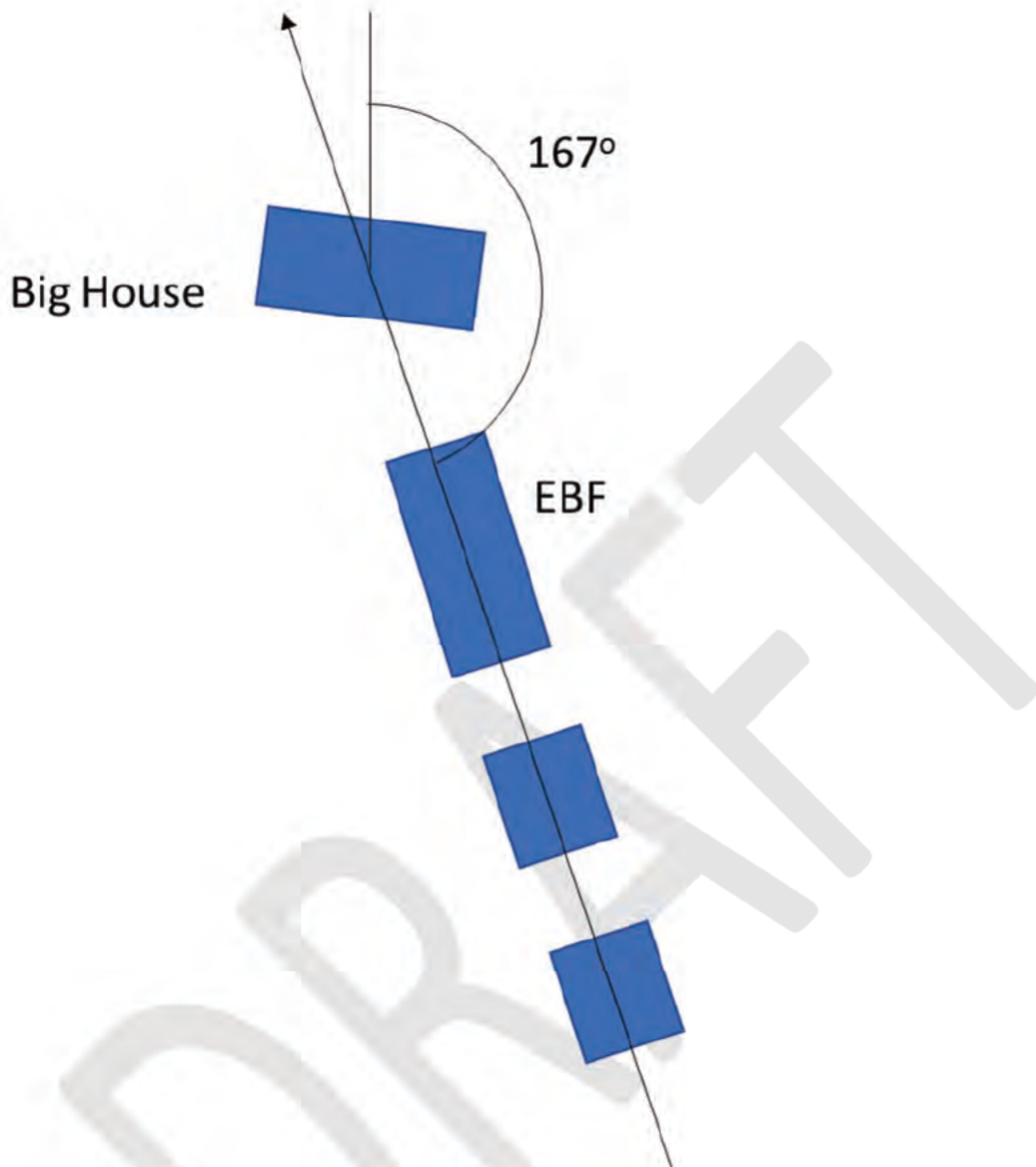


Figure 8. Alignment for elevation $h/H = 0.32$.

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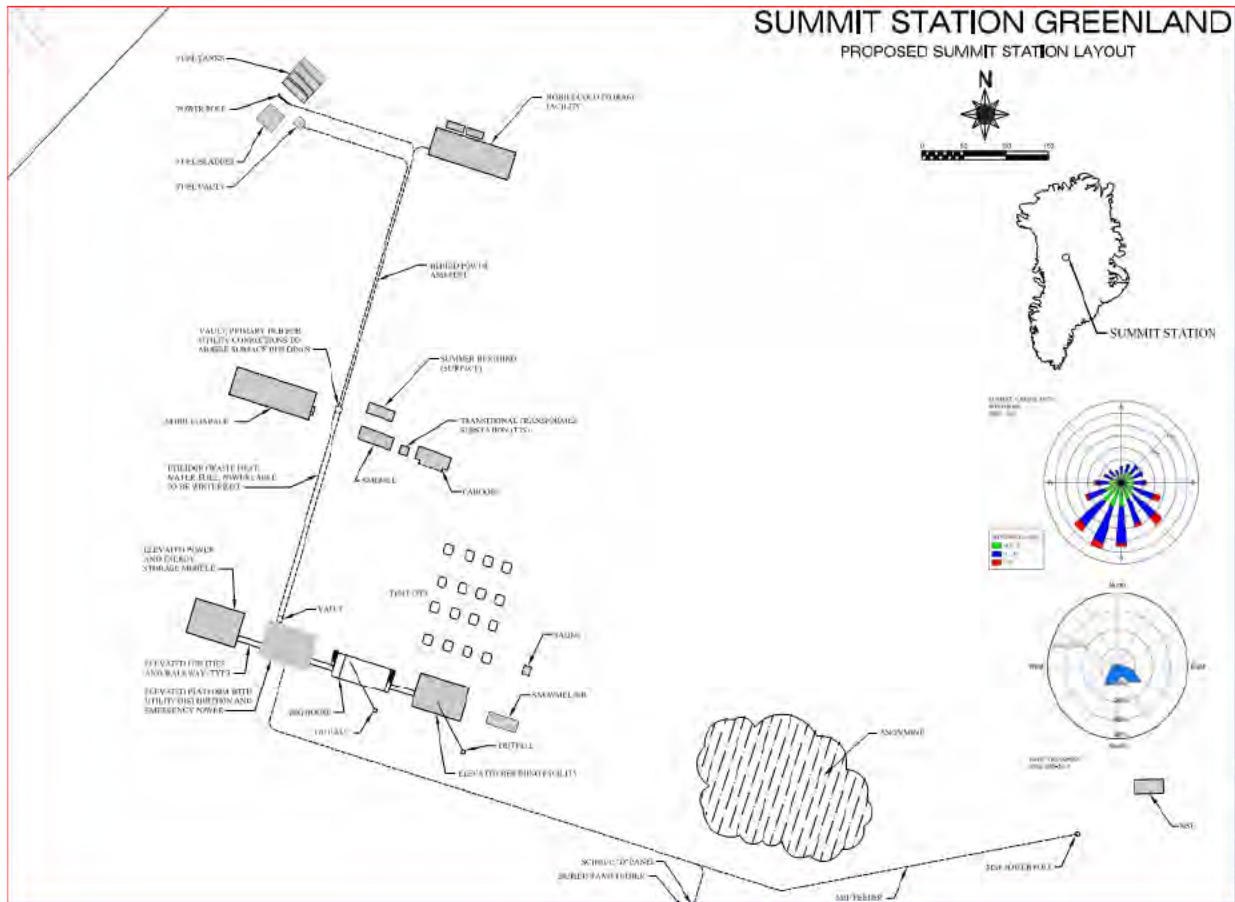
Appendix E

Thermal Energy Standard

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Summit Field Station Thermal Energy Standard

September 27, 2017



Prepared for National Science Foundation, Division of Polar Programs
Arctic Research Support & Logistics (RSL) Arlington, VA

Prepared by: *Richard S. Armstrong, PE, CEM*

QED Enterprises, Inc

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EXECUTIVE SUMMARY

The National Science Foundation will fund the design, construction and inspection of various new elevated and at-surface buildings at the Summit Station in the near future. Their desire is to develop these buildings using energy standards that are code compliant as well as reasonable considering the cost of heating and transportation to Summit. This document needs to recognize the ultimate intent of the NSF to increase use of renewables, which would then decrease availability of waste heat which would drive the need to have optimum insulation values as the station develops toward a net energy balance of zero if that is possible in the future.

The scope of this document does not include the entire energy budget for buildings such as lighting, motor efficiency, pipe insulation, equipment efficiency, thermostatic or other HVAC controls, ventilation rates, etc. since this recommended standard is limited to those factors that are especially impacted by long durations of extreme cold weather, such as insulation and infiltration, as exists at Summit Station. The NSF has adopted the 2015 International Energy Conservation Code (IECC) to assure that all the other factors discussed in the Code (outside of those insulation criteria discussed herein) affecting energy consumption are recognized and incorporated into construction.

The basis used in developing this insulation recommendation starts with the 2015 IECC. The IECC insulation requirements were originally based on the 1995 edition of the Model Energy Code promulgated by the Council of American Building Officials (CABO). The IECC recognizes ASHRAE 90.1 (C401.2) based on the ASHRAE Energy Standard for Buildings Except Low-Rise Residential Buildings, updated in 2016. ASHRAE develops consensus standards for the HVAC industry using volunteers in the industry along with numerous reviews before being adopted. It is recommended that the user refers to the IECC for specific application and interpretation of the requirements herein, since the code is prescriptive with various compliance paths suggested.

The IECC was prepared specifically for areas within the USA, so the eight climatic zones that specify insulation values only go to the coldest areas (as measured by heating degree days) within the USA. For example, Barrow, Alaska has a heating degree day base 65 (HDD65) average over the last 11 years of 18,338 HDD65. Summit Station in Greenland has an 11-year average of 30,219 HDD65, which is 65% more than Barrow Alaska. For this reason, the standards set forth in IECC Zone 8 need to be adjusted for the much higher HDD65 values at Summit to attain the same relative *minimum* construction standards. Nothing prevents use of higher insulation values, since the IECC code, as with the other building codes, only present minimum requirements which are not necessarily optimum requirements. Using this concept, the basic recommendations for R-value and U-value requirements listed at Summit are generally 65% higher than the Zone 8 figures.

There are also justified reasons to exempt certain building occupancies from needing the proposed higher R-values, such as for equipment storage buildings, unheated outhouses, summer only occupancies, or other related occupancies that are described within this document.

The R-values presented in the Summit tables for Summit are simplified to composite values for an entire assembly, (similar to U-value derivation) and not just the R-value of the insulation between framing, since the entire assembly R-value would include the inside and outside air film, the siding, sheathing, framing, insulation, and inside wall values. For this reason, the composite R-value for a building with framing at 16" on center would be different from a building using 24" on center framing.

Additionally, air leakage is a large component in overall building heat loss and comfort, so infiltration rates should also be considered in any energy standard. Infiltration rates for a completed building are generally measured using a blower door test that evacuates air from the building at a measured rate using a pressure differential of 50 Pascals to determine a uniform infiltration value. This test is a good way to determine the overall building tightness that is resulting from proper installation and sealing of vapor barriers, window quality and tightness, air leakage barriers, weather-stripping, and overall tightness of the entire construction assembly.

BACKGROUND & PURPOSE

The National Science Foundation (NSF) Research Support & Logistics (RSL) within the Arctic Sciences Section, Office of Polar Programs (OPP) will be funding design and construction of new elevated buildings at the Summit Station in Greenland. This facility presently supports year-round research on the apex of the Greenland Ice Sheet. It is the intent of NSF to construct facilities that are energy efficient to minimize the cost of operations of the facilities while maximizing the value of the investment in the new projects. The design needs to recognize the first cost of the new facilities in terms of construction materials, transportation costs, and transportation constraints (such as available dimensional space within LC-130 ski equipped aircraft typically used to fly materials to Summit), while still assuring a reasonable operating cost related to fuel and power required to operate them. Additionally, the NSF has determined that it would follow the International Code Council (ICC) suite of building codes, which includes the International Energy Conservation code (IECC), all using the current 2015 code series.

The purpose of this document is to set forth minimum thermal insulation and infiltration standards for all new projects at Summit Station that will provide a guide to designers, contractors and inspectors for the planned buildings. This Standard is intended to supplement and not replace the IECC.

DISCUSSION

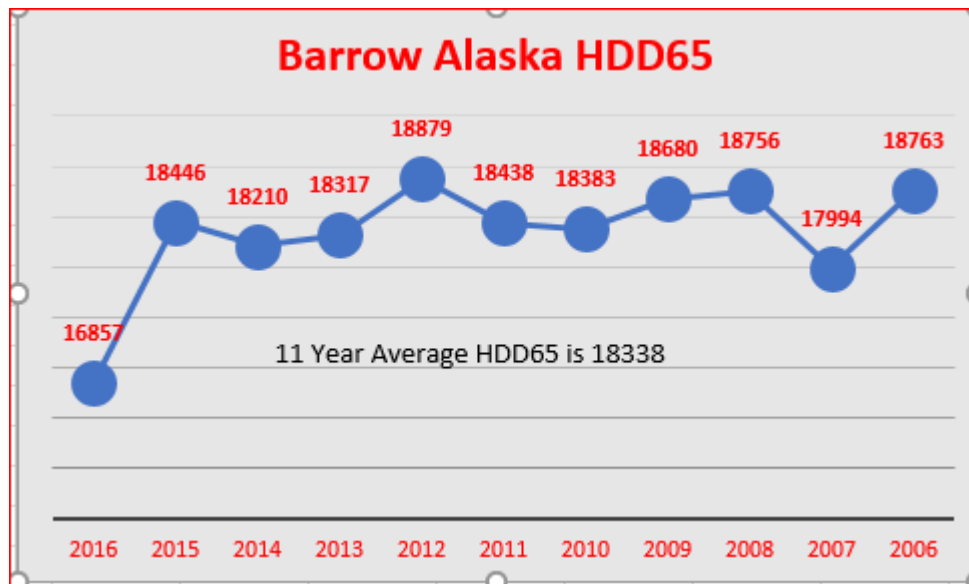
Thermal resistivity: There are many thermal energy standards and guidelines presently published, and for this study the IECC has been considered as the minimum applicable code standard, but the recommended thermal resistance values for Summit Station need to be adjusted higher since the code is based on eight climate zones within the United States and its territories, none of which represent the extremes found at Summit Station in Greenland. The IECC also provides international climate zone definitions (Table C301.3(1)) which break out major climate types to marine, dry, moist and warm-humid, and then further refine the zone definitions in table C301.3(2) to thermal criteria by climate

zone. The coldest climate zone is Zone 8, which is defined as having greater than 12,600 heating degree days (HDD65F). Summit Greenland has an 11-year HDD65F average of 30,219 which is 65% more than 12,600 HDD65F, so it is appropriate to further adjust the thermal insulation requirements proportionally to reflect the colder climate at Summit.

Heating degree days: A good discussion about heating degree days (HDD) can be found in the article <http://www.degreedays.net/introduction>. A short definition of HDD65F is defined on the Web under Investopedia as "HDD' The number of degrees that a day's average temperature is below 65° Fahrenheit (18 Celsius), the temperature below which buildings need to be heated. The price of weather derivatives traded in the winter is based on an index made up of monthly HDD values". The 65-degree F base is commonly quoted since that is typically the outside air temperature threshold that would require heating of the interior of a building as the outside air falls below the 65 degrees F. Due to internal heat gains or occupant preferences, other base temperatures can be used, although the 65-degree basis is the most common. For simplicity, this discussion will use HDD65 as the basis of recommendations.

The city with the highest HDD65 average within the Zone 8 climatic areas is Barrow, Alaska. The 11-year average of all HDD65 at Barrow is 18,338 HDD average. (ASHRAE uses an average of 19,228 HDD65 since it is using a different basis for its average.) See figure 1 below:

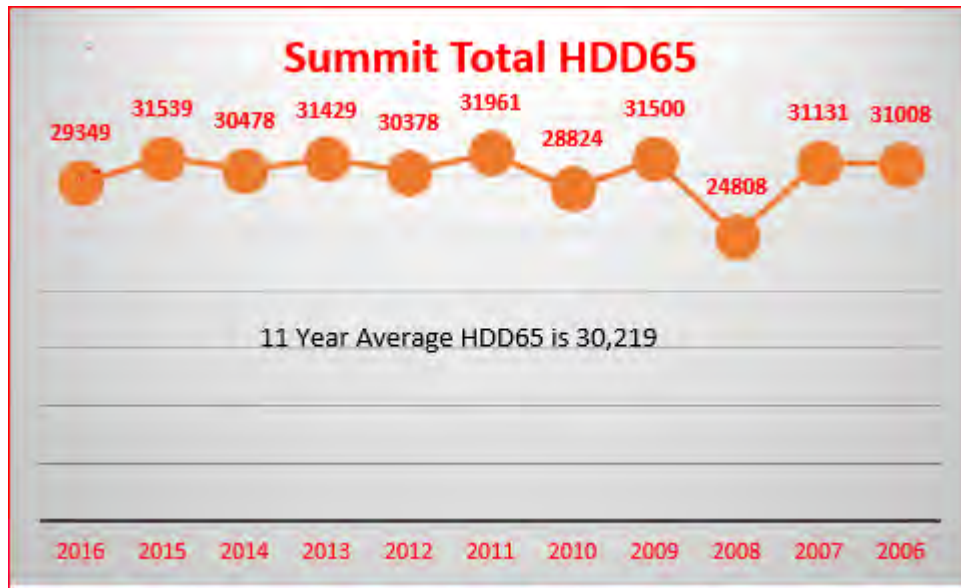
Figure 1: Heating Degree Day 11-year history for Barrow, Alaska



By comparison, the 11-year average heating degree days at Summit, Greenland is 30,219 HDD65, (see graph below) which represents a 65% increase in heating degree days over Barrow. Because Barrow has the most HDD65 of all the Zone 8 areas included in the IECC code, this 65% increase justifies an increased thermal resistivity in construction when compared to Zone 8. Also keep in mind the fact that codes are considered minimum standards, so this information justifies significantly more insulation for

buildings in Summit than buildings in Zone 8 sites of Alaska. It is noted that architects in Alaska typically use insulation values much higher than the zone 8 IECC or ASHRAE recommendations.

Figure 2: Heating Degree Day 11-year history for Summit, Greenland



Building air leakage: Another significant factor that will cause the need for additional heating due to building heat loss is infiltration of cold air into a building. Infiltration is defined in the IECC as “The uncontrolled inward air leakage into a building caused by the pressure effects of wind or the effect of differences in the indoor and outdoor air density or both.” Outside air (OSA) ventilation can offset some of the infiltration losses by pressurizing buildings and reducing the admission of excessive OSA, so we typically see air leakage testing requirements targeted more on residential buildings compared to large commercial or industrial buildings that have complex air handling systems. Since the buildings at Summit are typically small and not very complex in terms of ventilation, an air infiltration requirement is appropriate for all planned buildings in Summit that are to be heated. Application of the air infiltration testing requirements and limits that presently exist for Alaska residential property should be adopted for all heated buildings in Summit. It is noted that the Corps of Engineers has been requiring envelope tightness testing on large commercial and industrial buildings for a few years now.

Waste Heat Considerations: Several of the key buildings at Summit are heated with waste heat from the generators, which amounts to “free” heat since it would be discharged out of radiators if it were not used to heat buildings or generate hot water. While the existence of waste heat in buildings would indicate that less money needs to be spent on insulation since the heating is otherwise free, this may not always be the case. As the Station becomes more energy efficient using LED lights, more efficient motors, and indirect heated water heaters, there will be less heat gain in the building, and less waste heat will be available since the waste heat is cogenerated with the generation of electricity if diesel

reciprocating or microturbine generators are used. There is also the desire to utilize more renewable sources of energy, and the solar or wind generated power does not cogenerate waste heat – another reason to not rely excessively on the existence of waste heat in the future.

Special Use Buildings: There are some building occupancies that will justify less insulation due to the nature of their occupancy. Some examples of these occupancies include:

- **Outhouses:** These buildings are typically only used in the summer, and are heated using solar Lexan panels with black walls that absorb sufficient heat to provide a comfortable experience without the need for any supplemental heat. These buildings are typically not insulated at Summit or the South Pole, and rely solely on the solar gain system.
- **Freezer trench enclosures:** These spaces are dug into the snow and are intended to remain frozen for the life of the structure, and to provide a space to keep food frozen, so no insulation is needed for any of these enclosures. The surrounding ice is always sufficiently cold to assure that the stored food will remain frozen, even during the summer, with no need for any insulation in the ceiling, floors, or walls.
- **High internal heat gain occupancies:** Buildings that are specifically designed and used to house science electronics that generate large amounts of heat in their normal operations should still be well insulated to account for future energy efficiencies of the internal equipment that would reduce the internal heat gain, but not necessarily to the proposed Summit standard. Also, if some science has equipment removed due to loss of funding or due to consolidation of equipment functions, then the building should still have adequate insulation to assure efficient operation into the future. It is proposed that this type of building occupancy be required to comply with the minimum IECC Zone 8 insulation requirements, but higher insulation values are encouraged due to the ever changing requirements of the Science occupancies.
- **Generator buildings:** Those facilities that are specifically designed to house generators (diesel reciprocating or microturbines) will be in a heat rejection mode when that equipment is operating. When the equipment is in stand-by mode, however, the enclosure needs to be insulated from the OSA if the building will remain in stand-by mode for any appreciable length of time. It is suggested that the prime power generators that are exposed to the outside air ambient climate be insulated to IECC Zone 8 requirements, and not the proposed Summit requirements.
- **Standby and emergency generator buildings:** When generator equipment is in standby mode most or all the time, such as the emergency generator building, it needs to be heated to maintain a ready-to-start status. Therefore, these buildings should be insulated to Summit Standards since they will be heated and maintained above freezing almost all of the time, and the engines will have internal heaters to assure that the engines can pick up load without delay.
- **High ventilation requirement buildings:** Occupancies such as welding shops, equipment maintenance shops, or any other facility that requires significant amounts of continuous outside air ventilation should not require the same amount of thermal insulation as a building with just normal ventilation requirements. It is recommended that these buildings be insulated

to the IECC Zone 8 requirements as a minimum, with higher insulation values if the ventilation levels are intermittent or relatively minimal.

- **Switchgear & transformer buildings:** Those buildings that house switchgear and transformers will produce some heat by themselves. The switchgear that includes thermally operated or electronic circuit breakers or controls should be maintained at temperatures within the manufacturer’s environmental specifications to assure proper operation. For example, Square D, who manufactures most of the switchgear at Summit, requires that the electronic circuit breakers be in an ambient temperature of no colder than -13°F, and thermal magnetic breakers be maintained in a climate no colder than +10°F in order to function as designed. Based on the intended normal operating temperature of the building and the internal heat gain, there should be no need to meet the higher Summit insulation requirements, but the IECC Zone 8 requirements are still appropriate.
- **Summer use only buildings:** Certain buildings will only be used in the summer by the Station. These buildings will not be heated in the dead of winter when the extreme temperatures are prevalent, so insulation to the IECC Zone 8 levels should be adequate. Examples of summer use only buildings include the following:
 - **Construction crew berthing quarters:** These are hard sided buildings that are used for summer assigned construction workers only during the summer season.
 - **Construction Meeting rooms and special work spaces:** These are buildings that are typically shut down all winter, and only operated and heated during the summer in support of special construction projects.

COMPLIANCE MEASURES

Energy efficiency of buildings should be verified at the design stage, during construction, and at construction completion with methods shown below:

Design stage:

Design plans should include a listing of building R-values, U-values, and potential alternate methods planned to meet the intent of the code. The designer should provide the calculations and material thermal specifications to demonstrate compliance. The design submittal should include vapor barriers as well as means and methods of insulation and vapor barrier installation and sealing.

Where the designer used special use building exceptions listed above, those exceptions should be noted in the design submittal package.

The IECC provides for an alternate component performance calculation that considers the entire building assembly where shortcomings of one system can be overcome by additional insulation on another system. While the IECC formulas (Section C402.1.5) consider some assemblies that are not used at Summit, such as below grade floors and walls, slab on grade buildings, or masonry buildings, the performance alternative works nonetheless because it considers the U value and area of each system to accommodate shortcomings on any given

system. The component performance alternative, edited for applications at Summit, allow building envelope values and fenestration areas determined in accordance with the equation

$A + B + C + D + E \leq 0$, where:

A = Sum of the UA Dif values for each distinct assembly type of the building thermal envelope,

UA Dif = UA Proposed – UA Table 1.1 or 1.2

UA Proposed = Proposed U-value * Area

UA Table = U-Factor from Table 1.1 or 1.2

B = Slab on grade which is not used, =0

C = Below grade walls that are not used, =0

D = $(DA * UV) - (DA * U \text{ Wall})$, but not less than zero

DA = $(\text{Proposed vertical glazing area}) - (\text{Vertical glazing area allowed, which is } < 30\% \text{ of the gross above-grade wall area})$

UA Wall = Sum of the (UA Proposed) values for each opaque assembly of the exterior wall.

U Wall = Area weighted average U-value for all above-grade wall assemblies

UAV = Sum of the (UA Proposed) values for each vertical glazing assembly.

UV = UAV/total vertical glazing area

E = 0 if the area of skylights is less than 3% of the gross roof area (recommended). If the skylights need to be in excess of 3% of the gross roof area, apply the following formula for the value of E:

$E = (EA * US) - (EA * U \text{ roof})$, but not less than zero, where,

EA = Proposed skylight area >3% of gross roof area

U Roof = Area-weighted average U-value of all roof assemblies

UAS = Sum of the (UA Proposed) values for each skylight assembly

US = UAS/total skylight area

Note: Quadruple glass with e=0.10 on two panes and ¼" krypton spaces have a U-factor of 0.22, compared to triple pane glass with e=0.10 on two panes and ½" argon spaces. However, shipping multipane windows to summit at 10,600' ASL may cause damage to the assembly or loss of the gas so special arrangements need to be made to accommodate this altitude.

Windows, skylights, and sliding doors shall have an air infiltration rate of no more than 0.3 cfm per square foot and swinging doors no more than 0.5 cfm per square foot when tested according to NFRC 400 or AAMA/WDMA/CSA

101/I.S.2/A440 and listed and labeled by the manufacturer. (Reference: Alaska Building Energy Efficiency Standard (BEES)).

Construction phase

There should be a required material and equipment submittal review of building construction assemblies, insulation, air barrier, doors & fenestration materials, caulking and adhesives.

There should be periodic construction inspections to include:

- Framing and rough-in phase, to include vapor barrier inspection, insulation, fenestration, air leakage
- Device installation including gasketing of switches, outlets, recessed lighting
- Blower door testing: Infiltration shall be tested using blower door testing protocol.. The air tightness level shall be less than 4 air changes per hour (ACH) at 50 Pascals total pressure difference

Completion Inspection

The final inspection of a building should include blower door testing of the completed building, as well as visual inspections of construction details, weatherstripping, and related elements. All systems should also be commissioned to assure that they are functioning as designed.

SUMMIT MINIMUM THERMAL INSULATION STANDARDS

Table 1.1: Opaque Thermal Envelope Insulation Minimum Requirements

	IECC Table 402.1.1 Zone 8	ASHRAE Std 90.1 Table 5.5-8 Reference Alt for Zone 8	Summit * Recommended Requirements See exceptions
Roofs			
Insulation all above deck	R=35 c.i. U=0.028	R=35 c.i. U=0.028	R=60 U=0.016
Metal building	R=30+R=11 LS U=0.029	R=25+R=11+R=11 ls U=0.026	R=60 U=0.016
Attic and other	R=49 U=0.021	R=60 U=0.017	R=100 U=0.010
Above Grade Walls			
Metal building	R=13+R=13 c.i. U=0.052	R=0+R=25 c.i. U=0.039	R=42 U=0.023
Steel-framed	R=13+R=7.5 c.i. U=0.045	R=13+R=18.8 c.i. U=0.037	R=50 U=0.020
Wood framed and other	R=20+R=10 c.i. U=0.036	R=13+R=18.8 c.i. U=0.032	R=50 U=0.020
Floors			
Steel joist	R=30 U=.033	R=38 U=0.32	R=50 U=0.020
Wood frame and other	R=30 U=0.033	R=38 U=0.027	R=50 U=0.020
Doors			
Swinging doors	R=4.75 U=0.37	U=0.37	R=7.8 U=.13

- * For recommended insulation criteria, All R-values shown are assembly values and not just the insulation portion of the assembly, to include all components of the assembly except windows and doors
- Notes: C.I.=Continuous insulation; LS=Linear system

Table 1.2 Windows and skylights

	IECC Table 402.1.1 Zone 8	ASHRAE Std 90.1 Table 5.5-8 Reference Alt for Zone 8	Summit * Recommended Requirements See exceptions
Fenestration			
Non-metal framing	U=0.29	U=.25 Assy max U=0.32	U=0.17
Metal framing-fixed	U=0.29	U=0.29 Assy max U=0.38	U=0.17
Metal framing-operable	U=0.37	U=0.35 Assy max U=0.44	U=.22
Metal framing-entry door	U=0.77	U=0.68 Assy max U=0.77	U=.46
Skylights	U=0.50	U=0.41 Assy max U=0.85	U=.30

GLOSSARY

Air Barrier: Materials assembled and joined together to provide a barrier to air leakage through the building envelope. An air barrier may be a single material or a combination of materials.

Climate Zone: A geographical region based on climatic criteria as specified in the IECC.

Fenestration: Products classified as either vertical fenestration or skylights.

Skylight: Glass or other transparent or translucent glazing material installed at a slope of less than 60 degrees from horizontal

Vertical fenestration: Windows (fixed or moveable), opaque doors, glazed doors, glazed block and combination opaque/glazed doors composed of glass and other transparent or translucent glazing materials and installed at a slope of at least 60 degrees from horizontal.

Infiltration: The uncontrolled inward air leakage into a building caused by the pressure effects of wind or the effect of differences in the indoor and outdoor air density or both.

Linear system (LS): A system that includes the following:

1. A continuous vapor barrier liner membrane that is installed below the purlins and that is uninterrupted by framing members.
2. An uncompressed, unfaced insulation resting on top of the liner membrane and located between the purlins.

For multilayer installations, the last rated R-value of insulation is for unfaced insulation draped over purlins and then compressed when the metal roof panels are attached.

R-Value (Thermal Resistance): The inverse of the time rate of heat flow through a body from one of its bounding surfaces to the other surface for a unit temperature difference between the two surfaces, under steady state conditions, per unit area ($h \cdot ft^2 \cdot ^\circ F/Btu$).

U-Factor (Thermal Transmittance): The coefficient of heat transmission (air to air) through a building component or assembly, equal to the time rate of heat flow per unit area and unit temperature difference between the warm side and the cold side air films ($Btu/h \cdot ft^2 \cdot ^\circ F$).

Ventilation: The natural or mechanical process of supplying conditioned or unconditioned air to, or removing such air from, any space.

Wall, above grade: A wall associated with the building thermal envelope that is more than 15 percent above grade and is on the exterior of the building or any wall that is associated with the building thermal envelope that is not on the exterior of the building.

Note: Many of the definitions above have been taken from the Definitions section in Chapter 2 of the 2015 International Energy Conservation Code. Some other definitions are taken from the web.

Appendix F

Design Wind Speed

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August 7, 2018

Jacobs
9193 Jamaica Street
Englewood, CO 80112

Attn: Ms. Fawn Stinchcomb

Fawn.Stinchcomb@jacobs.com

**Re: Determination of Design Wind Speeds
NSF Summit Station - Greenland
Novus File No. 18-0149**

At the request of Jacobs, Novus Environmental Inc. (Novus) has determined two (2) return period design wind speeds for the National Science Foundation (NSF) Summit Station in central Greenland. This objective was achieved through the analyses of available historical wind data from the site. This information will be used by others in their wind load calculations for the structural design of the new buildings for the station.

BACKGROUND

The NSF Summit Station is located at approximately 72° 34' 49" N 38° 27' 19" W, in central Greenland. The station includes several single-story buildings, including those for research, equipment and facilities. The station also includes an anemometer for recording wind speed and direction; it is from this data that the design wind speed will be extrapolated. An aerial view of the station, taken June 15, 2014, is shown in **Figure 1**.



Figure 1: Aerial view of Summit Station

DATA ANALYSIS AND PROCESSING

Structural design criteria, including design wind speeds, are derived from the American Society of Civil Engineers (ASCE 7) – Minimum Design Load for Buildings and Other Structures publication. The computation of the design wind speeds has evolved over the years, from the “fastest-mile” in the 1988 version of the code, while in 1995 the design wind speed was based on the “three-second gust”.

This change, in 1995, was to align the design wind speeds more closely with the wind speeds reported by meteorologists. In the most recent editions of the ASCE 7-10 and ASCE 7-16, the wind speeds increased again, to calibrate the wind speed maps of the United States with the overall design philosophy of “ultimate strength design”, as opposed to the previous “allowable stress design”. While wind speeds increased, the design pressures remain equal or were reduced for most geographic locations.

This analysis is similar to the ASCE 7 approach to estimate three-second gust wind speeds for “ultimate strength design” based on on-site wind speed measurement at Summit Station. Novus received both 1-min and 1-hour mean wind speed data from the Summit Station for the period January 2008 to April 2018. For this analysis, only the 1-min wind speed data was reviewed for quality assurance. Suspected invalid data and outliers were removed, and then the 1-min wind speed data was applied to the ultimate design wind speed analysis.

The practice of converting between wind speeds that are obtained from different wind averaging periods (e.g. 10-min, 1-min, 3-second, etc.) is only applicable if the shorter averaging period wind is regarded as a gust (i.e. the highest average wind speed of that duration within some longer period of observation). Thus three-second gust wind speeds can be converted from 1-min wind speeds, but not vice versa. In practice, the 1-min average wind speed data is reliable, while the effects of turbulence (shorter-acting winds of greater velocity) can be estimated using a gust factor. This gust factor is a theoretical conversion between an estimate of the mean wind speed and the expected highest gust wind speed of a given duration within a stated observation period. The World Meteorological Organization (WMO) released their guideline for converting between various wind speed averaging periods in 2010 (Harper, et al, 2010). This method was applied to this analysis for 3-second gust wind speed conversion.

A height correction was utilized, assuming a winter snow depth of 6.5 ft (2m) and 1.5 ft (0.5m) for summer snow, to ensure the correct wind speed at the standard anemometer height of 33 ft (10m). This data was then processed as part of determination the peak annual wind speed (3-second gust).

A numerical analysis of the wind data using the Best Linear Unbiased Estimator (BLUE) Gumbel distribution statistical fit was then used (Lieblein, J. 1974), and the extreme wind speeds corresponding to specific mean return intervals (MRI) of 700 years and 1,700 years were calculated. This analysis assumed an exposure C category (flat open terrain with scattered obstructions have heights generally less than 30 ft), but possibly an exposure D (very smooth coastal-like field). The Gumbel model is often used to fit annual maximum wind speeds or wind pressures. The commonly used fitting methods include the method of moments, the method of maximum likelihood, the method of L-moments, and the Lieblein BLUE (i.e., generalized least-squares method (GLSM)). Some studies (Hong and Mara, 2013) have suggested that the Lieblein BLUE (or GLSM) provides the best overall performance in extreme wind speed fitting. Therefore, in this analysis the Lieblein BLUE Gumbel model was applied. An in-house developed MATLAB program of the Lieblein BLUE Gumbel fitting was utilized to process the analysis.

RECOMMENDED WIND SPEEDS

Weather and wind data analysis based on the Summit Station data (2008-2018) indicates that the highest wind speeds occur in the winter season. For example, the record-high 1-minute wind speed (> 36 m/s) was observed in February 2018. But before then, the recorded peak 1-minute wind speeds have never exceeded 30 m/s. Thus, the extreme high wind speeds that occurred in February 2018 result in a much higher 3-sec gust design wind speed.

A review of the meteorological data for this region during this period (early 2018) showed this area of the Arctic had an unusual heat wave in February 2018. For instance, on February 20th, the temperature in Greenland was above 32°F (0°C) and the temperature stayed above freezing for 24 hours, according to data from the Danish Meteorological Institute. Then on February 24, 2018, the temperature on Greenland's northern tip reached 43°F (6°C). These high temperatures occur in the Arctic when the jet stream (i.e., conveyor belts of wind that carry heat and water vapor around the planet) interacts with strong storm condition in the northern Atlantic Ocean. As the region of Summit Station was colder, the temperature gradient (i.e., difference) between central Greenland and the west coast resulted in strong easterly winds across Greenland.

As there is the potential for these warm air intrusions to become more common and more intense, we have included the observed peak winds from February 2018 in the design wind speed fitting procedure.

The ASCE 7-16 design wind speeds (3-second gusts) from off-land Alaska and inland continental United States were compared with the modeled 3-second gusts at the Summit Station (**Table 1**). As a reference, design wind speeds with and without the data from February 2018 are included in the table. Notice the 3-sec gust wind speeds from February 2018 significantly increase the recommended wind speeds.

For the required MRI of 1,700 years, the 3-second gust design wind speed at Summit Station was slightly higher than the off-land speed in Alaska and much higher than the inland continental United States wind speed, especially when the February 2018 data is included. The 700-year MRI design wind speed is slightly higher than the off-land wind speed in Alaska with the included February 2018 wind data. Also, the 50-year MRI design wind speed at Summit Station is about 5 mph higher than the off-land data in Alaska. Therefore, in general, the design wind speeds MRI for 700 and 1,700 are slightly higher than the off-land wind speeds in Alaska.

Table 1: Design Wind Speeds at Summit Station Compared with ASCE 7-16 (Alaska and US Inland)

Return Year MRI	10	15	20	25	50	100	300	700	1700
3-sec Gust (mph) – Max ¹	96.0	99.8	102.4	104.5	110.7	116.9	126.7	134.2	142.1
3-sec Gust (mph) – Max ²	89.3	92.1	94.0	95.4	100.0	104.5	111.6	117.1	122.8
3-sec Gust (mph) – ASCE-7 Alaska off-land	-	-	-	-	105	-	120	130	140
3-sec Gust (mph) – ASCE-7 continental United States	-	-	-	-	90	-	106	114	122

Notes:

1 – Summit data includes February 2018

2 – Summit data excludes February 2018

We recommend the design team consider the following MRI 3-second gust wind speeds:

700-year Return Period = 3-second gust, maximum = 134.2 mph (60.0 m/s)

1,700-year Return Period = 3-second gust, maximum = 142.1 mph (63.5 m/s)

CLOSING

Should you have any questions or comments, please feel free to contact Novus.

Sincerely,

Novus Environmental Inc.



Xin Qiu, Ph.D., ACM, P.Met, EP
Principal, Senior Specialist – Meteorology



Tahrana Lovlin, MAES, P.Eng.
Specialist – Microclimate

References:

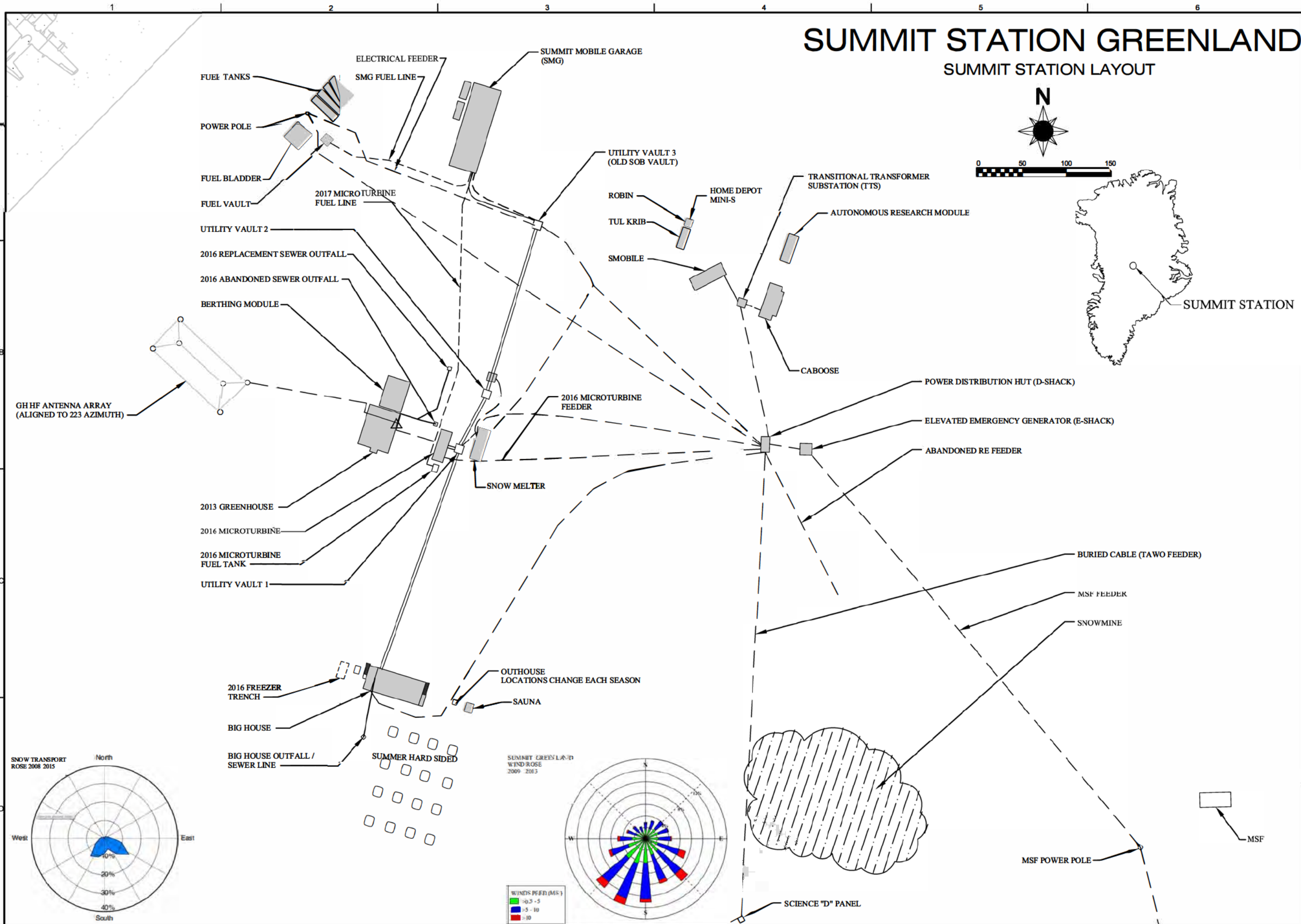
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- Lieblein, J. (1974), "Efficient Methods of Extreme-value Methodology". *National Bureau of Standards*, Washington, Report NBSIR74-602.

Appendix G
Existing Site Plan

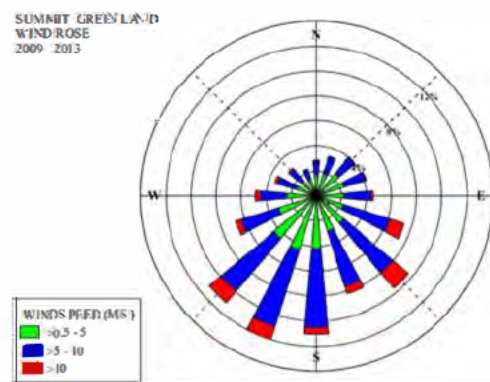
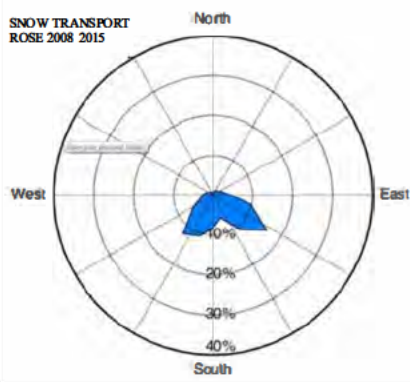
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SUMMIT STATION GREENLAND

SUMMIT STATION LAYOUT



SUMMIT STATION



WINDS PER (MS)
 -0.5 - 5
 -5 - 10
 >10

NO.	DATE	DR	CHK	APVD	BY	APVD
DGN		R		JDS		JDS

CH2M HILL POLAR SERVICES
 9191 SOUTH JAMAICA ST.
 ENGLEWOOD, CO. 80112 - 5946

NATIONAL SCIENCE FOUNDATION
 OFFICE OF POLAR PROGRAMS
 ARLINGTON, VIRGINIA
 NSF CONTRACT - NSFDACS11C1875

CH2MHILL
 Polar Services

SUMMIT STATION, GREENLAND
 SUMMIT STATION
 SITE PLAN - ENLARGED

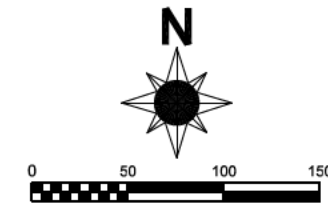
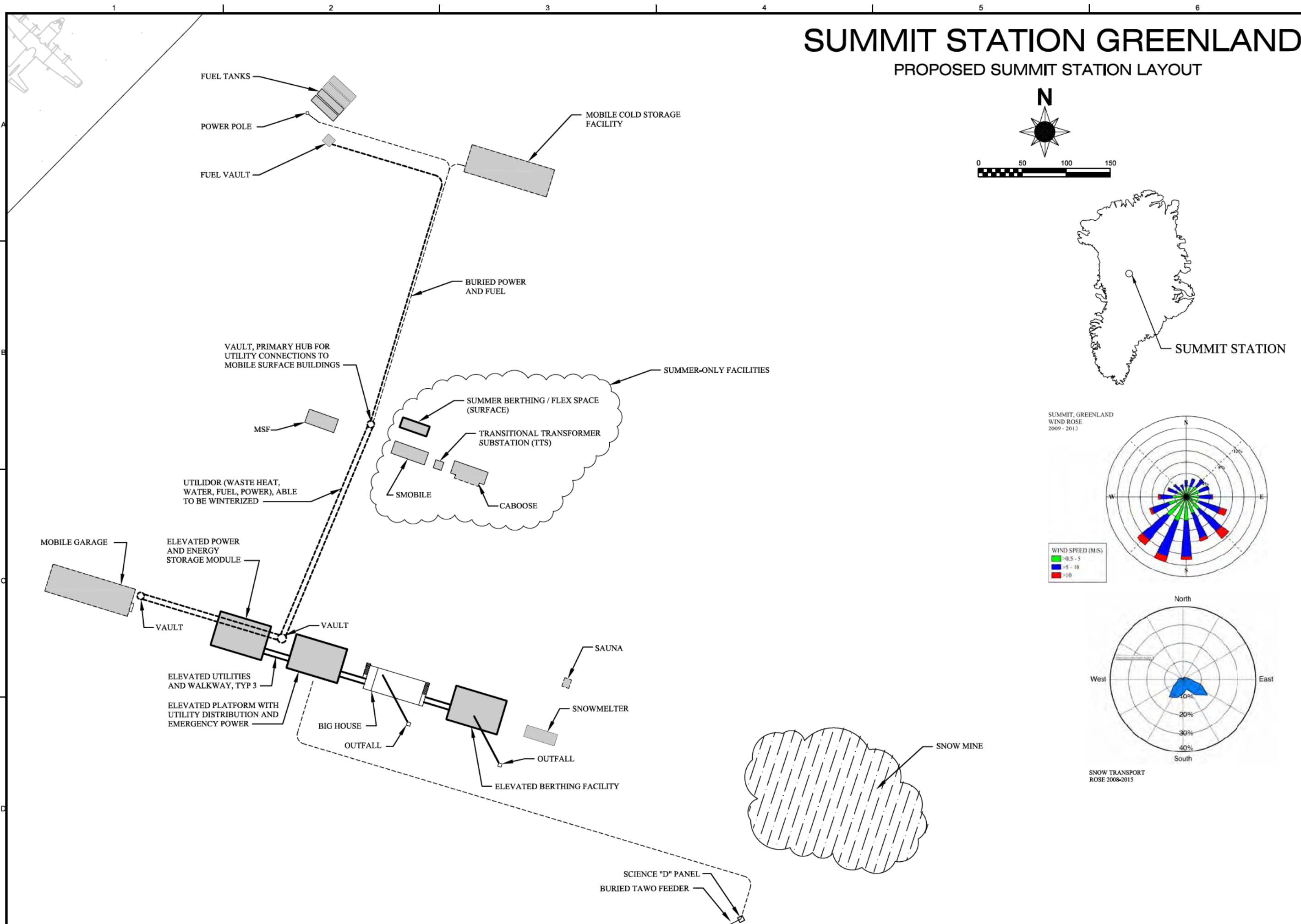
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DATE	SEPTEMBER 2018
PROJ	700362
DWG	C-3
SHEET	3 OF 5

Appendix H
Future Site Plan

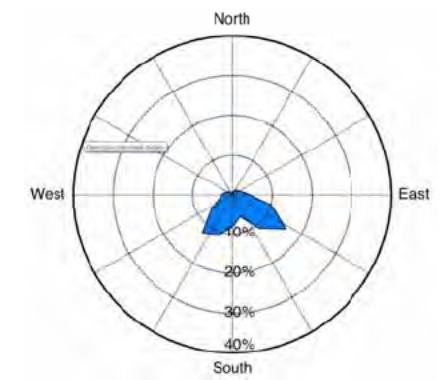
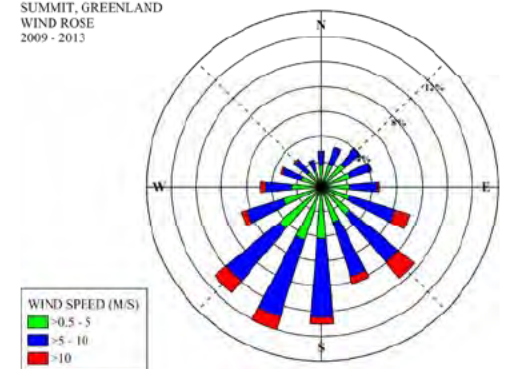
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SUMMIT STATION GREENLAND

PROPOSED SUMMIT STATION LAYOUT



SUMMIT, GREENLAND
WIND ROSE
2009 - 2013



SNOW TRANSPORT
ROSE 2008-2015

NO.	DATE	DR	CPS
DESIGN			
REVISION	CHK	RB	
APVD			
BY	APVD		J. SEYER

CH2M HILL POLAR SERVICES
9191 SOUTH JAMAICA ST.
ENGLEWOOD, CO, 80112-5946

NATIONAL SCIENCE FOUNDATION
OFFICE OF POLAR PROGRAMS
ARLINGTON, VIRGINIA

NSF CONTRACT - NSFDACS11C1675

CH2M HILL
Polar Services

SUMMIT STATION, GREENLAND
SUMMIT STATION
CONCEPTUAL LRFP SITE PLAN

VERIFY SCALE	
BAR IS ONE INCH ON ORIGINAL DRAWING.	
DATE	OCTOBER 2018
PROJ	700362
DWG	C-6
SHEET	6 OF 6



THE U.S. NATIONAL SCIENCE FOUNDATION WELCOMES
YOU TO THE SUMMIT OF THE GREENLAND ICE SHEET

SUMMIT STATION

72° 35' N, 38° 25' W  ELEVATION 10,530 FEET

The U.S. National Science Foundation (NSF) established Summit Station in 1989 as the Greenland Ice Sheet Project 2 (GISP2) ice core drilling site and remains the principal supporter today. Additional contributions are made by the National Oceanic & Atmospheric Administration and the station is operated by CH2M HILL Polar Services.



