UFC 3-130-02
16 January 2025

UNIFIED FACILITIES CRITERIA (UFC)

ARCTIC AND SUBARCTIC SITE ASSESSMENT AND SELECTION

This Page Intentionally Left Blank

UNIFIED FACILITIES CRITERIA (UFC)

ARCTIC AND SUBARCTIC SITE ASSESSMENT AND SELECTION

U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

NAVAL FACILITIES ENGINEERING SYSTEMS COMMAND

AIR FORCE CIVIL ENGINEER CENTER

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	**Date**	**Location**

This UFC supersedes UFC 3-130-02, dated 16 January 2004.

This Page Intentionally Left Blank

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States, its territories, and possessions is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA). Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Military Department's responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Systems Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Technical content of UFC is the responsibility of the cognizant DoD working group. Defense Agencies should contact the respective DoD Working Group for document interpretation and improvements. Recommended changes with supporting rationale may be sent to the respective DoD working group by submitting a Criteria Change Request via the Internet site listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide website http://www.wbdg.org/dod.

Refer to UFC 1-200-01, *DoD Building Code*, for implementation of new issuances on projects.

AUTHORIZED BY:

THOMAS P. SMITH, P.E., SES
Chief, Engineering and Construction
U.S. Army Corps of Engineers

S. KEITH HAMILTON, P.E., SES
Chief Engineer and Assistant Commander
Planning, Design and Construction
Naval Facilities Engineering Systems Command

THOMAS P. BROWN, SES
Deputy Director of Civil Engineers
DCS/Logistics, Engineering &
Force Protection (HAF/A4C)
HQ United States Air Force

MARK S. SINDER, SES
Deputy Assistant Secretary of Defense
(Infrastructure Modernization and Resilience)
Office of the Secretary of Defense

This Page Intentionally Left Blank

TABLE OF CONTENTS

FIGURES

TABLES

CHAPTER 1 INTRODUCTION

1-1 BACKGROUND.

The field of Arctic and Subarctic engineering, also known as cold regions engineering, covers a wide range of multidisciplinary topics and principles. Unique issues exist in the planning, design, construction, and operation of infrastructure and facilities in Arctic and Subarctic regions. Among them are permafrost, seasonal ground frost heave and thaw settlement, extreme low temperatures, high wind loads, heavy snow loads, and remote construction sites. Additionally, the implications of the rapidly changing climate in Arctic and Subarctic regions exacerbate these unique challenges.

The Unified Facilities Criteria (UFC) Arctic and Subarctic series includes five volumes that summarize relevant information and the most feasible approaches and solutions for planning, design, construction, and maintenance of infrastructure and facilities in the Arctic and Subarctic areas of the globe.

1-2 NEED FOR SPECIAL APPROACHES.

The importance of selecting the proper project site in Arctic and Subarctic regions cannot be overemphasized. The type of data collected for site selection is essentially the same as that used for engineering design in temperate regions, but due to the high probability of heterogenous ground ice conditions in the Arctic and Subarctic, it is essential to collect more detailed information. It is not feasible to provide a detailed list of the information required for a given site-selection problem because each project requires unique judgment in the development of an adequate program of investigation and analysis; however, understanding the basic principles and considerations of cold regions site assessment and selection is crucial. Observations made in the Arctic and Subarctic, or cold regions, of North America form the basis for this UFC, and while local details may vary considerably, the basic concepts presented are generally applicable.

1-3 REISSUES AND CANCELS.

This document supersedes and cancels inactivated UFC 3-130-02, dated 16 January 2004.

1-4 PURPOSE AND SCOPE.

The Arctic and Subarctic UFC series provides technical guidance and available technical requirements for planning, design, construction, and maintenance of DoD facilities worldwide for all service elements in Arctic and Subarctic environments. These guidance and technical requirements are based on the International Building Code (IBC) and the requirements in UFC 1-200-01. The UFC 3-130 series covers many aspects of Arctic and Subarctic engineering with the specific exception pavements, which is incorporated into the UFC 3-250 and 3-260 series as discussed in UFC 3-130-01, paragraph 1-6.3. In addition to this volume, there are four other series volumes:

- UFC 3-130-01, *Arctic and Subarctic Engineering*. UFC 3-130-01 serves as an introduction to the Arctic and Subarctic UFC series.

- UFC 3-130-03, *Arctic and Subarctic Foundations for Freezing and Thawing Conditions*. UFC 3-130-03 includes horizontal and vertical foundations, considerations affecting foundation design, and construction and monitoring of facilities in the Arctic and Subarctic areas.

- UFC 3-130-04, *Arctic and Subarctic Buildings*. UFC 3-130-04 includes building design in the Arctic and Subarctic areas.

- UFC 3-130-05, *Arctic and Subarctic Utilities*. UFC 3-130-05 provides criteria and guidance for the design of utility systems for military facilities in Arctic and Subarctic regions.

This UFC provides criteria and guidance for selecting sites for military facilities in Arctic and Subarctic regions. Only criteria and guidance unique to cold regions, where extreme low temperatures, permafrost, and seasonally frozen ground are likely to occur, are provided. UFC 3-130-02 is in no way all inclusive, and other cold regions resources are cited to provide sources of additional information. These minimum technical requirements are determined by UFC 1-200-01. Where other statutory or regulatory requirements are referenced, the more stringent requirement must be met. This UFC describes a phased approach to site assessment; the phases include planning, preliminary assessment, ground reconnaissance, detailed geotechnical site investigation (geophysical and geotechnical subsurface exploration), and reporting. Additional topics include general considerations for site characterization and, within the phases, data and data acquisition, desktop survey, remote sensing, ground reconnaissance, and geotechnical data analyses.

1-5 APPLICABILITY.

This UFC follows the same applicability as UFC 1-200-01, paragraph 1-3, for those geographic locations in Arctic and Subarctic regions worldwide.

1-6 GENERAL BUILDING REQUIREMENTS.

This UFC is an integrated part of the Arctic and Subarctic UFC 3-130 series. Use the other documents of this series in conjunction with this UFC to address construction aspects unique to cold regions. See UFC 3-130-01, Chapter 2 for the definitions of Arctic and Subarctic.

Often, conventional construction practices are acceptable in Arctic and Subarctic regions with appropriate modification to account for extreme cold temperatures, frost heaving soils, and permafrost areas. This UFC modifies and supplements the criteria found in the core UFCs. Utility provider’s or Installation specific requirements must be considered.

1-7 LEVEL OF CONSTRUCTION.

See UFC 1-200-01, paragraph 1-3.2, for the definitions of permanent construction, temporary construction, and facilities in support of military operations.

1-8 CYBERSECURITY.

All facility-related control systems (including systems separate from a utility monitoring and control system) must be planned, designed, acquired, executed, and maintained in accordance with UFC 4-010-06, and as required by individual Service Implementation Policy.

1-9 BEST PRACTICES.

In cold regions engineering planning, design, and construction, much of the state of the practice is not codified. Lessons learned and the experiences of the Installation engineering staff are invaluable and may help avoid costly and catastrophic infrastructure failures. Appendix A, Best Practices, provides guidance for accomplishing certain utilities design and engineering services in extreme Arctic and Subarctic environments. The Designer of Record (DoR) must review and interpret this guidance as it conforms to criteria and contract requirements and apply the information according to the needs of the project. If a Best Practices document guideline differs from any UFC, the UFC takes precedence. For Best Practices guidelines not discussed in a UFC, the DoR must submit a list of the guidelines or requirements being used for the project to the Government Project Manager, with documentation sufficient for review and approval, prior to completing the design.

1-10 GLOSSARY.

Appendix B contains acronyms, abbreviations, and terms. See UFC 3-130-01 for definitions of additional terms that are specific to cold regions.

1-11 REFERENCES.

Appendix C contains a list of references used in this document. The publication date of the code or standard is not included. Unless otherwise specified, the most recent edition of the referenced publication applies. In addition, the fundamentals for Arctic and Subarctic engineering are widely available in cold regions textbooks. See Appendix C in UFC 3-130-01 for a list of these resources.

This Page Intentionally Left Blank

CHAPTER 2 PLANNING

2-1 INTRODUCTION.

Use UFC 3-201-01 for general site development, design, and planning requirements and for specific issues, such as natural hazards, drainage, grading, and infrastructure siting. Also see UFC 3-220-01 prior to starting the project design phase to determine geotechnical requirements and other site classification requirements.

2-2 COORDINATION.

Site selection planning requires coordinated processes, including knowledge of environmental requirements, land use restrictions, building setbacks, flood hazard areas, utility connections, utility offsets, vehicle circulation, and buffers from natural and manmade features.

Coordinate all site work, including topographic, hydrographic, and soil surveys, with representatives of the Command, District, and Installation engineering staff and with other design personnel. The exact location of the geotechnical subsurface exploration, whether by drilling or excavation, must be approved by the appropriate authorities, such as the local utility service or a company hired by the geotechnical engineering firm to locate utilities.

2-3 APPROVALS AND PERMITS.

See UFC 3-130-01, paragraph 1-13, for the general approval and permit processes for Arctic and Subarctic planning, design, and construction, including site investigation and its associated drilling and excavations.

2-4 PERSONNEL.

Project site selection requires personnel who are cognizant of engineering problems peculiar to Arctic and Subarctic regions and familiar with the various types of data collection and interpretation used in site assessments. To ensure the best possible site is selected and that an optimal amount of accurate and detailed information is obtained, the combined effort of a number of specialists is essential. Different phases of the site assessment require different expertise and different personnel.

Interpreting remote sensing data requires trained, experienced interpreters who, if possible, participate in the field verification program to enhance their understanding of the terrain patterns to be viewed from acquired data. For high-risk and mission-critical Installations, personnel should include an air photo analyst, a coordinator who is a civil or geological engineer and is familiar with the immediate and ultimate uses of the Installation, a geotechnical engineer, a civil engineer (hydrologist), a geologist, and an ecologist. Ground and subsurface surveys require a survey crew and party chief, a geophysical technician and data interpreter, a drill crew and foreman, and a guide to provide local knowledge. Frequently, crews are required to go into the field with preliminary soil and terrain maps as their only means of orientation. In undeveloped regions where readily identified cultural features, such as roads, structures, and cleared areas, are absent, field crews must be able to identify landforms on the ground and on profile maps to aid in their interpretation.

2-5 UNCERTAINTY.

A large part of permafrost analysis, in the context of this UFC, relies on the likelihood of occurrence and variability based on surface expression. Ground ice content is inherently difficult to predict in Arctic and Subarctic regions because of the complex, mutually dependent, and highly dynamic nature of the many factors influencing permafrost occurrence and expression. Surficial expressions commonly associated with ice intrusion and freeze-thaw processes are used as markers and are assigned a high or low likelihood of indicating permafrost based on how closely tied they are to perennially frozen ground and its co-existing features. These surficial features must be interpreted while considering climate, region, topography, vegetation, and so on. The presence of multiple surficial features in the same area increases the likelihood that permafrost is present. Unfortunately, an absence of markers does not necessarily indicate a lack of permafrost. Due to the complex, codependent, and dynamic nature of climate, hydrology, vegetation, and landform in cold regions, evaluating surficial features is the best starting point from which to determine areas most likely to be underlain by permafrost.

2-6 RISK.

UFC 3-130-01, Chapter 4, discusses risk assessment principles as they apply to cold regions. For site selection, the intensity of the site assessment process is proportionally dependent on the risk and sensitivity of the proposed construction, as outlined by the risk assessment method appropriate to the project. Risk reflects unknowns and relates to the variability of the site conditions, which are described by the site characterization. The characterization process consists of a range of resolutions and costs, from low resolution, perhaps using remote sensing methods, to high-resolution geotechnical investigations with drilling and sampling. Installation risk and risk assessment must be carefully considered throughout the site selection process to determine which resolution and methods of site characterization are appropriate. Risk assessment is to occur on a project-by-project basis.

2-7 SITE SELECTION AND ASSESSMENT PROCESS.

Arctic and Subarctic regions are host to unique site characterization features that are not found in temperate regions and require additional attention for engineering planning, design, and construction purposes. Use UFC 3-130-01 for guidance on various factors that may be encountered when working in cold regions and are critical to effective site assessment and selection. This UFC is broken into chapters to describe both the general workflow and the step-by-step processes for site characterization.

2-7.1 General Workflow.

The primary objectives of site selection and assessment are to obtain data on the

- boundaries of frozen and thawed zones within the depth influenced by construction activities,
- amount and mode of occurrence of ice in frozen soil, and
- composition and properties of the soil itself.

The type of exploration is dictated, to a large extent, by the relative inaccessibility of many northern areas, expensive and limited logistics, and climatic limitations. In addition, special techniques are frequently required for explorations in frozen ground due to its properties. Figure 2-1 illustrates general steps and strategies, from preliminary characterization to quantitative examination, for site evaluation and assessment. However, all site assessment must be performed and documented as prescribed in the approved contract documents.

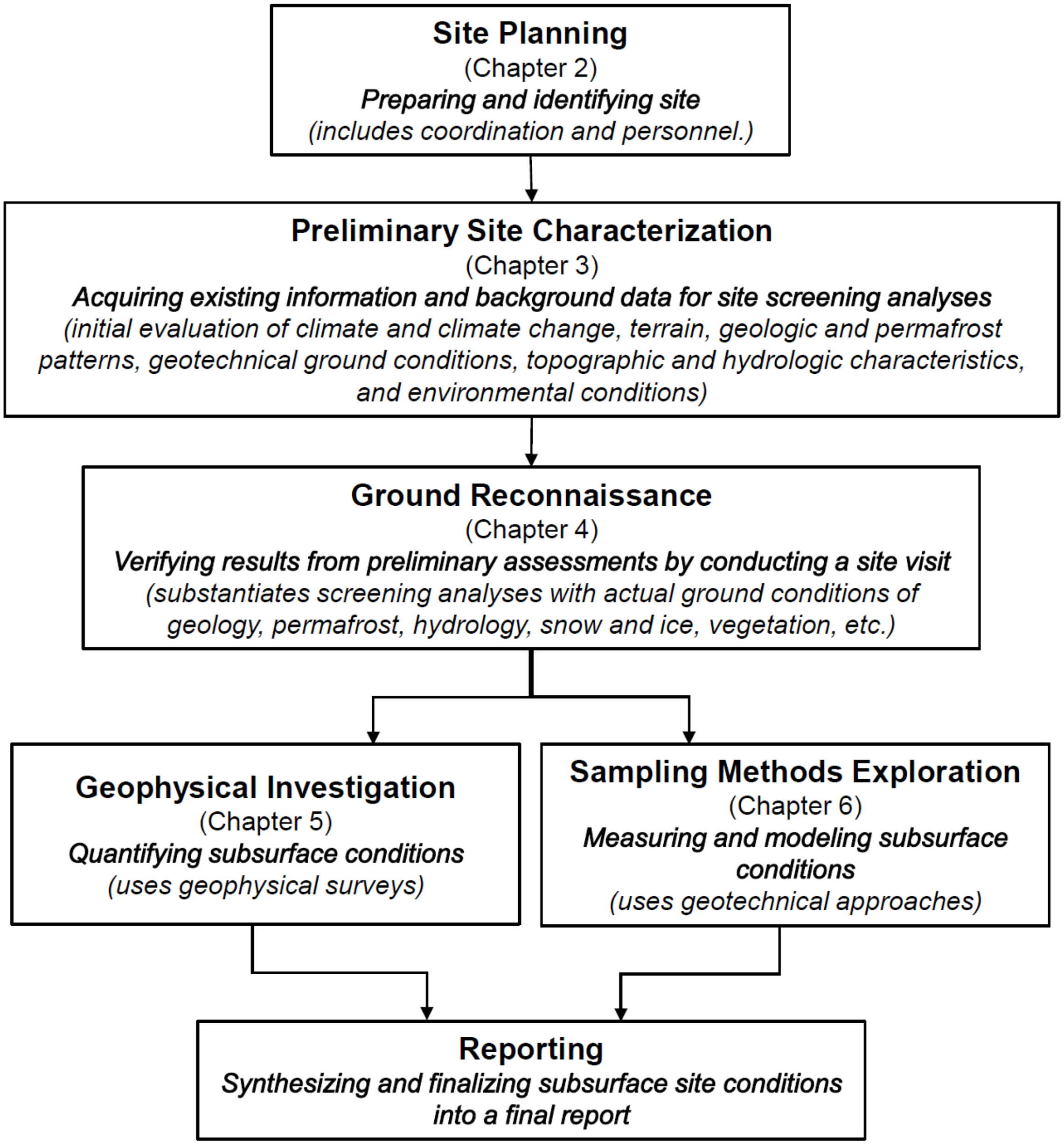
2-7.2 SUBSURFACE EXPLORATION WORKFLOW.

Once background data have been collected, detailed geophysical and geotechnical investigations (described in Chapters 5 and 6) can begin. An example workflow is shown in paragraph A-2 and highlights detailed processes. This workflow applies to organizing geotechnical investigations for both large projects, such as multibuilding installations and linear infrastructure developments (such as dams, roads, airfields, pipelines, or dikes), and small-scale projects.

2-7.3 Final Reports.

The site selection and assessment final report is the product of the investigation, as shown in Figure 2-1. The report synthesizes the final geotechnical profile, ground conditions (such as ground ice), and material properties of the site. More detailed reporting requirements are project or design specific (for example, draft and final reports; 35%, 65%, 95%, and 100% design submittals; number of document copies submitted and format; review procedures). The outline of the report includes, but is not limited to, the scope of the project, climate conditions, site screening, seismicity, geology, geomorphology, ground water, vegetation, permafrost (profile and spatial distribution), active layer, snow, ice, geotechnical properties, recommendations, and limitation of investigation. However, final reports must be followed as prescribed in the approved contract documents.

Figure 2-1 Arctic and Subarctic Site Selection and Assessment Process



CHAPTER 3 PRELIMINARY ASSESSMENT

3-1 INTRODUCTION.

Conduct detailed consultations with the Government to clearly define requirements and preferences. Use UFC 2-100-01 to develop a preliminary approach that is appropriate for the site and adjacent facilities and integrates sustainable strategies with a long-term outlook on the climate. Conduct a preliminary site analysis by obtaining photographs of the site. Research and obtain the Installation's master plan, utility maps, and as-built record drawings for information related to topography, utilities, and storm drainage availability in the project vicinity. Evaluate the likelihood of abandoned and unmapped utilities. Research and review available subsurface investigation data and reports to evaluate subsurface conditions. Identify flood hazard areas in accordance with the International Building Code (IBC), Section 1612, and UFC 3-201-01, paragraph 2-7.1. Research and adhere to safety requirements. Consult with the Government Project Manager to establish contact with the Installation's environmental personnel to determine if the site has environmental concerns, such as radon, pesticides, or known contamination. Evaluate the need for additional analysis based on project requirements and site conditions.

3-2 DATA ACQUISITION AND NECESSARY INFORMATION.

When preparing for site selection and development, existing information and data pertinent to the project requirements are essential for enhancing understanding of the climate, terrain, geologic and permafrost patterns, geotechnical ground conditions, topographic and hydrologic characteristics, and environmental conditions. Adequate maps and existing reports are beneficial for the selection of the site for any structure. In more populated areas, a wide variety of maps and reports are available. In more remote areas, there may be a limited number of preexisting maps and data available. Geographic information systems (GIS) are very useful for displaying data, creating maps, and storing collected information. The information required for a given site varies considerably according to the size and complexity of the project and the Installation's importance or focus, its geographical location, and whether the proposed facilities are in an unmapped or undeveloped area or are an addition to an existing Installation. Important considerations in information types with respect to Arctic and Subarctic regions are discussed in the sections that follow.

Existing reports and records published by various government agencies, engineering firms, mining companies, researchers, and others that give information on the characteristics of the terrain and on the climate, hydrology, and geology of the site must be thoroughly examined. These sources provide excellent background information for preliminary site assessment. Make effort to investigate and acquire reports from the project area because they may contain pertinent information for future construction or information on known conditions in an area. Reports of any type must be critically examined to ensure conclusions drawn hold true for current site conditions.

3-2.1 Access.

The availability of existing commercial and military surface, water, and air routes for the transportation of personnel and materials, the location of way stations and terminals, and prospective sites for such facilities must be determined. Obtain information on existing or abandoned access roads. Determine navigable depths of rivers, lakes, and harbors where water transportation is contemplated. Obtain data on the beginning and end of shipping seasons where shipments of materials, equipment, and supplies by oceangoing vessels may be scheduled. Determine the availability of calm water for the landing of float planes. Analyze weather phenomena, such as fog prevalence, low ceiling prevalence, and high wind conditions, that affect the availability of air operations. Determine appropriate vehicles to be used for overland transportation during winter and summer.

3-2.2 Climate.

UFC 3-130-01 discusses where to obtain data on climate. Obtain temperature information so that freezing and thawing indexes can be computed for use in estimating depths of freeze and thaw and so that possibilities of degradation or aggradation of permafrost can be determined. UFC 3-130-01 also describes the effects of climate change on the project. In particular, the long-term effect on the mean annual ground temperature (MAGT) is important when constructing in a manner that utilizes the strength of the frozen ground for bearing or adfreeze capacity.

3-2.3 Snowfall.

Snow data can come in several forms, such as snowfall maps, snow depth maps, and snow water equivalent maps. See UFC 3-130-01.

3-2.4 Vegetation.

Profiles of vegetation type and distribution must be carefully constructed. Also, past vegetation reports and characterizations must be considered. Current vegetation distribution maps can be constructed based upon remote-sensing data and recent imagery. See paragraph 2-5 for surface indicators and see UFC 3-130-01 for general descriptions of vegetation characteristics.

3-2.5 Geological.

Accurate information on surface and subsurface conditions is very important; in many instances, it may be the determining factor in the selection of a site. Geological maps are an important basis for terrain mapping and site characterization, and they depict the type and distribution of surficial discernable geological features in a region. These features can include soil and rock units and geologic structures such as faults and stratigraphic orientations, and they may identify areas of specific geotechnical hazard (for example, landslides). Obtain soil maps, if possible, because they depict the type and distribution of soils in a region; soil maps are useful for determining areas of thaw-stable or thaw-unstable material.

Well-drained gravels and sands are frequently found in coastal plains, river terraces, glacial deposits, and outwash plains. Such soils are generally ideal for almost any type of construction in Arctic and Subarctic regions because they are generally ground-ice poor to ground-ice free, and thus thawing is not a major problem. However, any type of construction can be troublesome if located on frost-susceptible soils, such as clays and silts. Where such foundation materials must be built upon, it is usually necessary to employ special design and construction measures to maintain structural stability. These measures are discussed in UFC 3-130-03. Obtain subsurface information to a degree commensurate with the importance, complexity, and size of the proposed structures. Minimum laboratory soil tests typically include density, moisture content, and Atterberg limits for various horizons, while additional tests, such as permeability, consolidation, shear strength, and compaction, may be required to support the project design. These test results, coupled with the survey data regarding topography, ground type, and location, can be compiled into a terrain unit map (see paragraphs 3-2.5.3 and 3-3.3.4).

3-2.5.1 Permafrost.

In Arctic and Subarctic regions, permafrost is often a determinant in the selection or rejection of a building site. Additionally, it can have major impacts on costs and the functionality of an Installation if it is not properly addressed early in the process. As such, it is important to determine the extent and characteristics of permafrost under any proposed building site. Update permafrost maps as more detailed data become available. Until confirmed through geophysical and geotechnical investigation, permafrost maps should be treated as probability-of-occurrence maps.

Knowledge of the extent and nature of the permafrost is vital where segregation ice occurs because this is generally the result of a supersaturated condition. Determine the depth and thickness of the permafrost layer, the depth of the annual freezing or thawing zone (active layer), and the nature of the soils present. Information on whether the permafrost contains massive ground ice and if the ice is homogeneously or heterogeneously distributed is very important. The frozen versus thawed boundaries within discontinuous permafrost, as often found in the Subarctic latitudes, are important because the thawed zones most often provide more stable foundation conditions. Also, baseline data are especially important in areas where permafrost may be discontinuous or sporadic; where ground temperature is relatively warm, defined as >28° to 30° Fahrenheit (F) (>−2 to −1° Celsius [C]); or where saline conditions may be present in coastal areas (such as around Utqiagvik [formerly Barrow], Alaska) that have been influenced by historic changes in sea level. Permafrost is generally continuous north of the Arctic Circle (latitude 66.56° N) and in Antarctica, some mountainous areas, and offshore in northern latitudes.[1] See UFC 3-130-01, paragraph 2-2, for the description, characteristics, and distribution of permafrost.

[1] “Recent Advances in the Study of Arctic Submarine Permafrost,” Angelopoulos et al.; “Northern Hemisphere Permafrost Map Based on TTOP Modeling for 2000–2016 at 1 km^2 Scale,” Obu et al.

3-2.5.2 Drainage and Groundwater Table.

Hydrological maps detail waterways, drainages in an area, and general maximal and minimal runoff data. Hydrological reports detail the movement of water in an area via rainfall, runoff, evapotranspiration, and so on. Hydrological studies can be useful for site characterization in several ways, such as classifying groundwater and soil permeability and identifying permafrost occurrence markers. For structures located near a river, information on stream-flow variations throughout the year and on the levels and frequency of flooding are of substantial importance for proper selection of the site. Obtain information on the ice-forming characteristics of the stream and on the locations of previous ice jams. For any structure or other infrastructure such as pavements, drainage is an important consideration. Define the usefulness of existing drainage courses for the removal of excess storm water. Where applicable, determine the position of the water table and patterns of subsurface flow.

When the groundwater table is encountered, provide the stabilized groundwater elevation with the anticipated variation and the local causes for variation (for example, seasonal or tidal). Measure the stabilized groundwater elevation 24 hours after drill-hole completion, unless determined otherwise by the registered design professional. If drilling techniques that prevent the measurement of the water table levels are used, the contractor should install at least two piezometers per drilling site to accurately measure the depth to the water table. Obtain a sufficient number of readings (locations) to establish a representative groundwater depth profile for the project site. Piezometers are required for stormwater pond investigations. Piezometers are not required if the groundwater levels can be accurately measured during drilling operations, if significant seasonal variations in groundwater level are not anticipated, or if there is good evidence that the water table is not within the depth of the borings or zone of influence for the foundation or structure.

3-2.5.3 Terrain Unit.

A terrain unit is a delineation of landscape elements often outlining zones of thaw-stable or thaw-unstable soil types and ice-rich or ice-poor soils of the site. Terrain-unit maps are generally derived from soil maps or aerial photographs. These map types are useful in the selection of stable foundation sites and material sources. Terrain-unit maps are most likely found in geotechnical reports or foundation reports from existing construction. They can also be generated as iterations of published geologic maps or surficial geologic maps. Terrain-unit maps must be as detailed as possible and updated as more detailed data, including the mechanical and engineering properties, become available.

3-2.5.4 Topography.

Accurate topographic information, including data on surface features and vegetative cover, is necessary. Obtain survey information for planning drainage, roads, and infrastructure layout. In investigations for airbases, consider topography in accordance with UFC 3-260-01 and for future snow removal operations on the airfield. For structures adjacent to bodies of water, information on shorelines, harbor lines, high-water marks, hydrographic and bathymetric data, and wave action is important.

Topographic maps or digital elevation models (DEMs) exist for nearly all areas of the earth's surface and should be acquired at both higher and lower scales for the given region. Topographic maps provide a ready base map on which to build further site characterizations (such as hydrological and vegetative). See UFC 3-130-01, Appendix A, for sources for topographic maps. Refer to UFC 3-201-01, paragraph 2-4.2.1, for additional resources and considerations.

3-2.5.5 Seismology.

See UFC 3-130-01, paragraph 2-10, for additional information on seismic considerations when performing site assessments. For site assessments, take note and examine any evidence of seismic activity in or near the selection area (such as active or potentially active faults, surface breaks or ground subsidence from past seismic events, and offset drainage and topographic features). Information regarding regional seismic features (from maps or reports) must also be consulted to construct a full seismic assessment of the selection area.

Seismic maps and site-specific seismic hazard assessment reports (if available) depict the likelihood and possible severity of an earthquake event based on known seismic hazards, past events, or conditions likely to result in seismic events.

3-2.6 Water Supply and Wastewater.

Obtain information on the feasibility of developing a water supply for the needs of the Installation. Perform pumping tests and water analyses for proposed wells. In some instances, a dam site may need to be selected for impounding water. In addition to determining sources of potable water and possible means of waste disposal, location conditions and regulations must be examined to avoid conflict. If water supply is to be developed from surface water, possible pollution sources must be identified. It may prove necessary in the Arctic to develop water supplies from two different sources, one for summer and one for winter. For example, where groundwater supplies cannot be developed and surface sources freeze in the winter, the surface source may be used during the summer, while melted snow or ice or storage tanks may have to be the source of supply in winter. See UFC 3-130-05 for additional information.

3-2.7 Construction Materials.

Knowledge of the location of suitable sources of quarry stone or rock deposits, gravel, and sand for aggregates is essential. Identify local sources of materials to aid in the production of pavements and concrete and determine the nearest points at which non-native materials and supplies can be obtained.

3-2.8 Existing Construction.

Map any construction or land development on or near the selection area, including both current structures and past projects. Maps of existing construction projects provide useful information regarding data sources in the form of previously collected construction reports.

3-2.9 Electrical Grounding.

Frozen earth materials offer high resistance to electrical current flow, preventing adequate earth grounding that is typically required for safe electrical distribution operations at structure locations. Locations are required to allow for a common electrical grounding site, where earth ground is created in a district configuration. These locations may be near water features (rivers or lakes), where the heat from the water allows limited thawed ground to exist. Grid arrays have been placed in such thawed areas or laid in water bodies, such as salt-water bays, where seasonal ice does not reach to the depth of the water body. See UFC 3-130-05 for further discussion.

3-2.10 Existing Reports.

3-2.10.1 Construction.

Construction reports are likely to contain as-built drawings and information on the scope of the construction project, permitting, engineering reports, storm water and hydrology mitigation planning, and site condition. Construction companies or state and federal regulatory bodies may have these reports.

3-2.10.2 Geological and Soil Survey.

Geological and soil survey reports, and their accompanying maps, contain important site details that aid with infrastructure siting. Locate previous geological and soil surveys conducted in the area of interest when possible. Surveys adjacent to areas of interest may be of use as well. State and federal geological or agricultural services may have these geological and soil survey reports.

3-2.10.3 Geophysical.

Geophysical reports detail the process and returns of geophysical survey methods, such as ground penetrating radar (GPR), electrical resistivity, electrical conductivity, and seismic refraction. Geophysical reports contain site characterizations, descriptions of the geophysical method used, data collected, and an interpretation of subsurface conditions based upon the collected data. Geophysical reports are useful in the interpretation of subsurface conditions over the survey area but are best verified by geotechnical means. Mining operations, academic sources, and construction site evaluations may have these geophysical reports.

3-2.10.4 Geotechnical.

Locate and examine geotechnical reports in and around areas of interest because they contain information pertaining to previous subsurface exploration, site evaluation, laboratory and field test results, and soil and rock conditions. State and federal geological or transportation services, academic sources, mining operations, and survey and construction companies that have operated in the region of interest may have these reports.

3-2.10.5 Mining.

Mining reports and mineral exploration literature generally contain information regarding subsurface mineral deposits, geotechnical data, and geological characterization. Mining reports can be a dense source of information regarding characterization of an area. State and federal geological services and mining companies may have these reports.

3-2.11 Local Considerations.

If possible, consult local knowledge sources. Local records and long-time residents are excellent sources of information on prevalent seasonal and weather patterns, changes in weather and natural conditions, changes in permafrost and ground freezing conditions, and other points of interest.

3-2.12 Remote Sensing.

Remote sensing encompasses a wide variety of sources and platforms, from satellites, to high altitude aerial platforms, to low altitude and geophysical methods and platforms, including multispectral imaging, radar, and lidar. Some of these remote-sensing platforms and methods are relatively recent, so older datasets may not exist. However, there may be legacy datasets of satellite imagery and archival air photos or aerial imagery for most regions of the globe. Make effort to locate and incorporate legacy datasets into site characterization because changes over time are difficult to account for without a long-term dataset. Air photos and satellite imagery are useful for locating boundaries of soils with different characteristics, identifying the extent of frozen and unfrozen soils, and predicting the engineering characteristics of soils in a given area. Air photos can also be used to eliminate the selection of totally undesirable areas and to suggest possible usable sites.

The resolution of remote-sensing data is an important consideration in regard to ground surface. Obtain datasets of the highest spatial resolution for the purpose of site characterization. Use image resolutions of 1:10,000 or better when possible. In addition, obtain other geospatial datasets in the highest resolutions possible.

3-3 INITIAL DESKTOP ASSESSMENT.

In the selection of a suitable site for military Installations, information is usually available (from maps, aerial imagery, or other sources) for the identification of general areas that may be suitable. To identify a specific site of interest within a general area, more detailed information, if available, is required prior to conducting any site reconnaissance. Begin initial investigations and preliminary assessments with a comprehensive desktop survey of current and historical maps and records pertaining to the general area.

3-3.1 Climate Profile.

Climate characterization must include expected or observed winter precipitation because snow and ice loading can have a significant effect on the design of an Installation. Snow loading can also have major effects on the hydrological characterization and regime of an area. See UFC 3-130-01 for snow considerations.

Climate profiles of an area provide context for site characterization and aid in analyses of later steps in the process. A large part of Arctic and Subarctic site selection is permafrost based, and accurate and complete climate profiles improve permafrost likelihood estimates, both directly (climatic conditions do or do not favor permafrost occurrence and growth) and indirectly (vegetation profiles are influenced by the occurrence of frozen ground). Accurate climate profiles on a regional scale provide information on possible permafrost conditions occurring where mean annual air temperature (MAAT) values are near 31°F (−0.5°C). Important parameters to be collected are air thawing degree-days (ATDD), air freezing degree-days (AFDD), MAAT, MAGT, wind rose for month of the year, mean seasonal precipitation (rain and snow), and graphs of hours of daylight versus months of the year.

3-3.2 Aerial Reconnaissance.

Aerial reconnaissance is especially valuable in initial regional studies to obtain data on factors such as flooding and icing conditions, the presence of flight hazards, possible access-route locations, the suitability of lakes and clearings for landing small aircraft, and military considerations, such as logistics and defense. Large areas can be covered in a relatively short time, and the less-constructable sites can be eliminated. Aerial reconnaissance is also valuable in recognizing geologic and environmental ground conditions (such as faults and delineations of landslides and rock outcrop features with erosion potential and distinctive changes in vegetation cover) that may otherwise be difficult to visualize from on-site inspection.

3-3.3 Analysis and Mapping.

Utilizing current or most recent datasets, construct a base map and overlays of the entire region. Historical images are used to track changes in slope stability, permafrost degradation, drainage, and settlement over time. Include the entire area of interest in the initial analysis of remote-sensing data, with an emphasis on ground conditions. A special note is needed to plot the construction sequence of existing structures. Note any changes in the natural condition due to infrastructure placement. Include the focus areas discussed in paragraphs 3-3.3.1 through 3-3.3.6 in the analysis. GIS is a very powerful tool that allows for plotting, viewing, and analyzing the mapped data. In addition, vast amounts of metadata can be stored with the GIS layers and shapefiles.

3-3.3.1 Vegetation.

Use image analysis to construct vegetation profiles of the region, and focus on large-scale trends such as forested areas, brush land, shrub land, tundra, and so on. Subdivide forested areas into evergreen and deciduous. Note stand density and height when possible. Differentiate areas of scrub brush and second-growth brush and tundra as possible. Demarcate forest fire scarring if present. If resolution allows, look for tussock ground, grasses, and heavy moss layers. Mapping must be accompanied by documentation of local vegetation types and identifiers to aid in the mapping process. Research characteristics of local vegetation types; specifically, average root depth and general habitat (such as well drained, wetland, or marshland).

3-3.3.2 Topographic.

Generate topographic overlays and DEMs for the area of interest.

3-3.3.3 Geological.

Map geological conditions via image analysis, as possible, noting origin, deposition type, and areal extent of soil and rock units. Indications of underlying geologic structure (such as apparent fault traces, surface lineations, exposed rock outcrops, areas of subsidence, and possible unstable slopes) as obtained from imagery and local or regional published information should also be delineated. Estimate geological characteristics of each soil and rock unit based upon site location, local geomorphology, and unit type. Published geological maps provide an initial baseline from which to begin geologic mapping for engineering design study. It is common for existing published geological maps to be incomplete or inaccurate at the scale needed for a detailed investigation. When existing information is incomplete or outdated, supplemental information and data and detailed information taken from field reconnaissance are required.

3-3.3.4 Terrain-Unit Maps

Construct terrain-unit maps, as possible, based on geological maps, aerial photographs, historical boring data, drainage patterns, and vegetation patterns. Update preliminary terrain-unit maps based on on-site observations and investigations to be performed.

Terrain-unit maps should map the extent of, and characterize, each unit on the map by its composition and basic engineering properties. There are many ways to map rock and soil units. Where time and budget constraints preclude a complete detailed mapping effort, prioritize mapping in the following order:

1. Type, extent, and location of permafrost terrain units
2. Type, extent, and location of major rock and soil units
3. Orientation and location of contacts between major soil types
4. Orientation and location of contacts between major rock types

5. Orientation of major faults and weak zones
6. Orientation and location of erosion, landslides, and subsidence features
7. Surface properties of discontinuities

3-3.3.5 Permafrost.

Construct permafrost feature maps using available remote-sensing data. Note beaded streams, pothole lakes, pingos, polygonal ground, thermokarst, and other permafrost surface expression features when discernable.

3-3.3.6 Hydrology.

Hydrological details of the area of interest should include all waterways, drainages, watersheds, and so on when discernable.

3-3.4 Interpretation.

The culmination of remote sensing data is to create a detailed base map (elevation and imagery) of the entire area of interest with overlays delineating vegetation, geology, terrain unit, and hydrology. Compile historical information collected during the desktop survey into separate overlays (GIS layers) and contextualize it on the base map. Once data compilation is complete, areas can often immediately be identified as undesirable and can be eliminated from selection based upon inferred ground-ice content, soil type, hydrology, topography, geology, hydrology, and so on. Conversely, sites of interest can be selected for further investigation. Verifying the unsuitability of previously eliminated sites may also be a part of further investigation.

CHAPTER 4 GROUND RECONNAISSANCE

4-1 INTRODUCTION.

Ground reconnaissance is used to verify results from preliminary assessments based on remote sensing and historical datasets, collect detailed information on site conditions, improve site profile resolution, and further refine criteria for desirable versus undesirable building sites. Features that may not be visible in remote-sensing datasets or unexpected occurrences can be addressed during ground reconnaissance.

4-2 GEOLOGICAL CHARACTERIZATIONS.

Ground-based geological characterizations of a site provide more detailed information than is possible with remote-sensing datasets. These written reports include maps of particular soil and rock units and geological features. Much of the geological characterization is focused on the site features in paragraphs 4-2.1 through 4-2.4, but note any anomalous geological features in detail.

4-2.1 Lithological Profile.

The lithological profile is a characterization or description of the stratigraphic section of geologic units in the project area. The geologic units are composed of surficial deposits, typically soils and sediments, and bedrock formations. The lithological profile describes all the geologic units of the project area in order, from youngest to oldest.

4-2.1.1 Bedrock.

Bedrock units are typically divided into three primary lithologic divisions, which are as follows:

- Igneous rocks—Igneous rocks are formed when molten rock cools and crystalizes. Igneous rocks are classified based on texture and composition, where texture describes the physical characteristics of the minerals, such as grain size, and this relates to the cooling history of the molten magma from which it came. Composition refers to the rock's specific mineralogy and chemical composition. Cooling history is also related to changes that can occur to the composition of igneous rocks. Identifiers include color, texture, alteration, and accessory minerals. Color is taken from the Munsell Rock Color Chart (Munsell Color [https://munsell.com/color-products/color-communications-products/environmental-color-communication/munsell-rock-color-chart/]). Alteration is a description of the chemical and physical weathering processes that are dominant in a rock. Accessory minerals are a list of secondary minerals that are visible in a hand sample. An example of igneous rock is granodiorite of the Talkeetna Formation.
- Metamorphic rocks—Metamorphic rocks are formed when a source rock is subjected to high temperature or to high-pressure geologic processes,

including, but not limited to, contact with plutons or lava sources or tectonic burial and exhumation, that alter the parent rock's original structure and minerology. Metamorphic rocks are classified based on foliation (orientation of mineral texture in rock), field relationships, the chemical composition of the rock, and inferred pressure–temperature conditions of metamorphism. An example is of metamorphic rock is schist of the Neruokpuk Formation.

- Sedimentary rocks—Sedimentary rocks are formed by weathering or decomposition of rock masses and redeposition of weathered particles via wind or water or by chemical processes in sedimentary basins where the particles are compacted over time and lithify to form rock. Sedimentary rocks are classified as chemical (formed by chemical precipitates), evaporates (formed by evaporation of sea water and consolidation of remaining chemical constituents), or clastic (formed by lithification of weathered detritus). An example of sedimentary rock is sandstone of the Sagavanirktok Formation.

4-2.1.2 Structural Classification of Rocks for Engineering Purposes.

Rocks are typically classified by petrologic type, such as from an intact hand sample (for example, coarse-grained granite), and are then described with physical properties of the larger rock mass as occurs in the field, which may be broken by numerous discontinuities (such as planes of weakness, including faults, shears, joints, and fractures). Physical properties of rock that are of interest in engineering analysis include, but are not limited to, the following:

- Rock strength
- Weathering or alteration
- Hardness
- Discontinuity description and orientation
- Joint or fracture infilling
- Mineralogy affecting foundation performance
- Specific gravity and unit weight
- Moisture content and porosity

For more information on the classification of rock types, refer to "Classification of Rocks," by Travis.

4-2.1.3 Soil and Sediment.

Soil and sediment can be classified in several different ways. In the engineering profession, soil is typically described via the Unified Soil Classification System (USCS) and follows ASTM D2487.

The field description of soils is based on the size and distribution or volume of coarse-grained particles and the volume and behavior of fine-grained particles in a given representative sample of soil. In the absence of laboratory testing, USCS symbols and descriptions can be used in accordance with the visual-manual procedure of ASTM D2488. Typically, soils are broken down into the following constituents:

- Boulders—rocks 12 in.(30 cm) in diameter or greater
- Cobbles—rocks with diameters between 3 and 12 in. (7.5 and 30 cm)
- Gravel—particles of rock with diameters between 0.19 in. and 3 in. (0.48 and 7.5 cm)
- Sand—particles of rock with diameters between 0.003 in. and 0.19 in. (0.0075 and 0.48 cm)
- Silt—soil particles that are smaller than 0.003 in. (0.0075 cm) but exhibit little or no plasticity and have negligible dry strength
- Clay—soil particles that are smaller than 0.003 in. (0.0075 cm), exhibit plasticity within a range of certain moisture contents, and have significant dry strength
- Organic soil—soil composed primarily of organic matter in various stages of decomposition

4-2.2 Surficial Lineation.

Natural surficial lineation can have many implications for design. Surficial lineation often indicates the presence of faults, which are tectonic structures occurring at the point where rock formations fracture and slide past, over, or under each other as they are driven by tectonic forces. The actual plane of fracture and movement is the fault line, which is a planar surface that can be measured spatially. Faults have serious implications for construction because they can destroy structures by shearing foundations with relative fault movement or with severe seismic-induced vibrations from earthquakes. For design purposes, active faults are of the utmost concern and are typically classified as active when the oldest movement on the fault is Holocene (11,650 years) or younger. Linear drainages, tree lines, or offset drainages along a linear path are often good indicators of a fault line.

The wide majority of faults are not active; however, significant fault zones may still have negative impacts on site development due to changes in drainage patterns and rock lithologies below the site and the presence of low strength zones of sheared rock along the fault trace.

Other surface expressions commonly associated with fault lines include the following:

- Abrupt and imposing hillside fronts
- Linear base on scarps

- Sharp V-shaped canyons
- Suddenly increasing stream gradients (fault benches)
- Springs along the base of the scarp
- Sudden loss of drainage on down-gradient side of scarp

Another significant feature of outcropping or underlying bedrock is its resistance to weathering. Distinct changes in slope angle, debris material size, and stratigraphic contact occurs when stronger rock abuts weaker rock. These lineations are easily identified in the field and from aerial and satellite imagery.

4-2.3 Ground Disturbance.

In Arctic and Subarctic regions, disturbed ground can indicate recent changes in the hydrological or permafrost regime, among other changes. Disturbed ground includes, but is not limited to, landslides, tension cracking, area subsidence, thermokarst, erosion, and heaving. Take special note of the chronological sequence of the disturbed ground.

4-2.4 Geo-Hazard Assessment.

Geologic-hazard assessments at the reconnaissance level begin with desktop identification and assessment of terrain units and geomorphological features. Some terrain units are associated with common geological hazards, including the following:

- Permafrost terrain units—These units commonly contain geological hazards, including ice-rich permafrost, ice wedges, thermokarst, retrogressive thaw slumps, and perched water tables.
- Bedrock terrains with intersecting joint sets, bedding planes, or foliation planes—These units have potential for planar, wedge, or toppling risks if adversely oriented along slopes and excavations.
- Terrain units with clay—It is common for clay to exhibit excessive shrinkage and expansion.
- Soil slopes with groundwater seepage, shallow active layers, or hummocky terrain—It is common for landslides in these units.
- Artesian conditions and water tables—These present a significant risk, especially if the potentiometric surface is above the permafrost table, where it can cause widespread accelerated permafrost degradation if drilled.
- Seismic—Seismic history is required to understand the overall seismic hazard of the project area. In general, the seismic hazard (liquefaction hazard) is low provided the site location remains in the frozen condition; it increases by many factors if the site has been forcefully thawed.
- Flooding—Examine the flood recurrence interval and look for surficial indicators of scour to determine if flooding is a risk in the project area.

- Aufeis—Groundwater flowing over frozen terrain in the winter season causes sheets of slow moving ice to move toward and across valley bottoms. This is known as aufeis, and it occurs chronically or intermittently at a certain area. Often, these sheets of ice block river and drainage flow, creating flooding and difficult maintenance operations for roadways and airfields (see paragraph 4-5.1).
- Volcanic hazards—Construction in volcanically active regions may be at risk of damage from mudflows, pyroclastic flows, airfall tephra, lava flows, floods or tsunamis, and even direct blast hazards. Although rare, permafrost regions composed of historic lava flows require special attention because this porous rock may be mischaracterized as containing detrimental percentages of matrix (pore) ice.
- Frozen debris lobes (products of hillside erosion)—Contained on steeper slopes, frozen debris lobes may have a central core of ice that slows the movement downslope, where the debris lobe may be masked or determined to not be an immediate hazard. Careful examination can find entire overturned trees, the lobe front moving at only meters per year, and basal water generation during winter and summer. Over the longer term, frozen debris lobes can cause serious maintenance issues if not avoided or mitigated early on.

4-3 HYDROLOGICAL CHARACTERIZATION.

Identify small-scale hydrological features that are not discernable from airborne or remote sensing during ground reconnaissance.

4-3.1 Surficial Hydrology.

Note any standing water, episodic or seasonal waterways, evidence of past flooding events, and other high water events, such as from river ice jamming. Water-killed standing forests are indicative of rapid changes in the hydrological regime. Drunken forests in permafrost terrain are indicative of thawing ground, often due to flooding or slow inundation.

4-3.2 Hydrogeological Indicators.

At the reconnaissance level, basic surface hydrology can be assessed by first examining the site drainage patterns, where the ground monitoring equipment locations can be planned and installed during the site-exploration phase (Chapters 5 and 6). Drainage patterns are highly indicative of the underlying soil or rock type, the frozen or thawed condition, massive ice features and bulk ground ice content, the degree of slope, and the effect of the vegetation. A list of common drainage patterns is as follows:

- Dendritic—Dendritic drainage patterns are irregular branching streams with confluences oriented at angles less than 90° and depicting a stream pattern that suggests no control by underlying rock structure. This is often a mature drainage pattern that signifies shallow dipping horizontal bedding and is found on shallow dipping slopes.

- Parallel—Parallel drainage patterns are consistently branching streams with parallel drainages in a preferred orientation. These typically form on steep slopes with a relatively uniform gradient and are often found on recently tectonically uplifted terrain.
- Trellis—Trellis drainage patterns show drainage directions in intersecting, sometimes perpendicular, patterns. This drainage pattern requires structural control to form and is typically associated with strongly bedded bedrock. The pattern forms as the water moves along bedding planes and crosses between existing planes via intersecting cleavages.
- Rectangular drainage—This refers to channels created at right angles. This pattern is created by structural control via right-angle jointing and faulting.
- Radial—Radial drainage patterns are multiple semiparallel stream channels branching out away from a certain point. This drainage pattern develops when water is running off a dome.
- Annular—This refers to a ring-like pattern in drainage channels joined together by subparallel drainages perpendicular to the rings. This pattern typically forms on eroded up-warped domes and down-dropped basins.
- Thermo-erosion gullying—This occurs in moderate to high slopes composed of frozen fine-grained materials, such as silts and sandy-silts. Surface water generally migrates through the active layer and at the top of the permafrost table, but in this case, aggressive thermo-mechanical erosion removes frozen material and creates gullies that rapidly expand with continued running water and above freezing air temperatures.

4-4 PERMAFROST CHARACTERIZATION.

Permafrost characterization is best done during midsummer to early fall. During months when snow is prevalent, permafrost markers may not be visible, except in very windy locations. Features indicative of ice-rich permafrost may be difficult to differentiate with snow cover. Frost probing of the active layer is best implemented during late summer or early fall, when the active layer is at its deepest thaw depth of the year.

4-4.1 Surficial Expression.

Permafrost surface expressions of underlying soil types and massive ice features are most often visible during airborne and remote sensing, but at ground level, they may appear as indicators of other features, such as disturbed ground, surface hydrology, and vegetative cover. This is especially the case in many boreal forest areas, where massive ice expression is masked by the trees and ground cover. Identify areas with evidence of recent permafrost degradation (thermokarst). For example, note pothole lakes or standing water with sharp or shear banks, as they may be evidence of rapid degradation with bank-lined trees tilted toward the pothole (drunken forest) or stress cracking occurring parallel to the bank.

4-4.2 Frost Probe.

Current active layer depth and permafrost table depth can be accurately determined by driving a tile probe (rod with T-handle) into the ground by hand and recording the depth of deepest rejection; permafrost tables of 10 to 12 ft (3 to 3.7 m) are detectable. Frost probing is a relatively simple, lightweight, and effective field method of detecting active layer thickness and depth to the permafrost table. However, accurate measurements can only be made at the very end of the summer thawing season, when air freezing degrees become approximately equal to air thawing degrees.

4-5 SNOW AND ICE CHARACTERIZATION.

Snow and ice characterizations may not be possible, depending on the season. If winter reconnaissance is not feasible, probable occurrence based on regional weather patterns and historical records suffice.

4-5.1 Aufeis.

During winter seasons, aufeis may be directly observed as massive, multilayer ice buildup in or near an active stream or waterway, at the toe of a slope, or along the length of a slope. Likely areas of aufeis formation are shallow streams with abundant groundwater under elevated hydraulic head pressures. The toes of hills with perennial water sources should be noted as likely sources of aufeis.[1]

4-5.2 Drifting.

Snowdrifts form on the lee side of an obstacle if prevailing winds are strong enough to transport snow and ice crystals. Drifting severity directly depends upon the prevailing seasonal winds and the relative position of obstacles (or disruption of air currents) that allow a drift to begin forming. Large, open areas upwind of obstacles provide ample opportunity for snow or ice entrainment and provide the source of snow or ice for drift building. Snow is a very efficient thermal insulator. Drifted snow and snow plowed into piles, or deposited along ditches from roadway or airfield snow removal, insulate the ground from the severe winter cold, locally raising the overall permafrost temperature.

4-5.3 Avalanche.

Note evidence of avalanche and slope failure in detail for further analysis. It is important to note that avalanches travel great distances downslope with considerable speed and force. As such, if an area of interest is at the foot of substantial terrain, areas upslope of the site must be evaluated for avalanche hazard.

[1] *River Ice Engineering*, Ashton.

4-6 VEGETATION CHARACTERIZATION.

Note vegetation variation and typology during ground reconnaissance because it is often hard to discern from air photos or remote-sensing datasets. With respect to permafrost, give careful consideration to groundcover types because, often, heavy moss layers create a subsurface environment that is conducive to permafrost occurrence.

4-7 INTERPRETATION.

Compile and interpret ground reconnaissance observations as a means of developing a more complete, higher resolution representation of the area under investigation. Many of the characteristics observed during ground reconnaissance are interdependent and should be carefully examined to determine the nature of any possible interactions.

CHAPTER 5 GEOPHYSICAL INVESTIGATION

5-1 INTRODUCTION.

Chapter 5 provides an overview of some of the geophysical methods available for characterizing subsurface conditions. The geophysical methods discussed specifically pertain to characterizing permafrost, such as frozen regions versus thawed regions in discontinuous terrain or ice-rich versus ice-poor regions, because these characteristics are a major consideration when undertaking any construction project in Arctic or Subarctic regions. Alternate geophysical technologies are used to ascertain specific engineering properties, such as seismic refraction used in cross-borehole surveys to determine potential for mobilization during earthquakes.

5-2 GROUND PENETRATING RADAR.

GPR is a geophysical method that transmits high frequency radio waves (10 megahertz [MHz] to 4 gigahertz [GHz]) into the subsurface and records the reflections of these waves from subsurface discontinuities. The velocity of radar waves is altered due to the differing dielectric permittivity of substances. This contrast results in electrical phase changes that visually produce an image for interpretation. Radar waves reflect most readily from regions of dielectric contrast. In most cases, the radar is operated at the surface and the radar energy is directed downward; in this case, horizontal contrasts, such as the top of the water table, the top of the permafrost, and the bottom of the active layer, are most readily imaged.

5-2.1 Strength and Limitation.

GPR provides detailed subsurface returns, often to within inches of accuracy if calibrated to a known dielectric constant. Without calibration, absolute depth is less accurate, but it is still acceptable for shallow (~30 ft [~9 m]) survey depths. GPR survey systems, however, do not provide usable returns to the same depths possible from other geophysical survey methods. The advantages of GPR units include their rapid data acquisition, ease of deployment, and short survey start length. Active layer depth and the depth of permafrost are often defined by a layer of liquid water or heavily saturated soil, and such polarity change between reflective water and dry soils is easily discernable in GPR returns. However, water attenuates radar signal, and it is often difficult to discern features beyond saturated areas with any reasonable accuracy. As a result of the radar–water interaction, GPR systems are not optimal in areas with standing water or heavily saturated soils. Clay and silt-sized earth mineral derivatives are known to absorb radar energy,[1] especially when the material is wet or saturated.

[1] "Complex Permittivity and Clay Mineralogy of Grain-Size Fractions in a Wet Silt Soil," Arcone.

Radar data often require filtering during collection mode to eliminate cultural electronic noise, and postprocessing is almost always required to deconvolute complex reflections, conduct migrations to reveal hidden reflections, and conduct other filtering and resolution gaining processes. This makes the process less user friendly and requires significant training for the operator to be proficient from collection to final data display.

5-2.2 Effective Survey Length.

Radar units can easily produce very long (thousands of feet) survey lengths. Because of the compact nature of GPR units, when the radar survey is initiated the data received is immediate and collected from the soil directly below the radar unit. There is no offset in distance or time between the equipment at the surface and location of data collection at depth.

5-2.3 Resolution.

GPR accuracy under ideal conditions is approximately within one to two feet-scale in the horizontal direction and the inch-scale in the vertical direction. Vertical resolution of this order requires a known depth, to within an inch, to an object easily discernible in the radargrams, which allows for the exact determination of the dielectric constant. Soil drilling and coring, or digging of pits, may be required to determine the depth to subsurface features or material changes that reflect the radar energy.

5-3 ELECTRIC RESISTIVE TOMOGRAPHY.

In electric resistive tomography (ERT), subsurface earth material resistivity is measured by injecting current (galvanic) into the subsurface via two current electrodes and reading the resultant voltage via two potential electrodes. Cable arrays often consist of 50 to 100 electrode positions; therefore, the current and voltage pairs are re-ordered for each pulse measurement, moving through a multitude of configurations per survey setup. Modern systems use a computer to cycle through the many possible pair configurations, greatly reducing work for the operator. By measuring the current, voltage, and geometry of the electrodes, one can calculate the resistivity of the subsurface. Averaging algorithms are then used to calculate the apparent resistivity over a range of depths along an electrode line. This type of system is time consuming to set because the electrodes must be hammered into the subsurface, and each survey is limited to the length of the cables at maximum electrode spacing. Surveys can use different measurement geometries and different electrode pair separation distances to alter the overall survey depth and resolution. Subsequent surveys can be sequentially conducted and overlapped with preceding surveys in what are called *leap-along* surveys.

5-3.1 Strength and Limitation.

ERT provides subsurface returns to depths in the magnitude of hundreds of feet, depending on the surface geometry of the electrode array and the geological conditions. This method is robust in data collection, provided good contact between the electrode array and the ground is maintained. ERT is suitable for a wide variety of ground conditions, and it generally has less noise in return data because of stable ground contact between the electrode array and subsurface. If the physical position of the electrode array is recorded, these surveys can be accurately repeated. Acquisition of raw data via computer switching can take a few hours. The survey method is minimally postprocess intensive because instrument returns require little processing and can be averaged with commercial software rather quickly.

5-3.2 Effective Survey Length.

ERT is a static, array-based method, and survey length is dictated by electrode configuration. The effective depth of the ERT survey directly correlates to array geometry at the surface, primarily to the spacing between electrodes. Most systems can conduct leap-along surveys, where subsequent electrode arrays can be coupled with the previous, allowing for total survey lengths of many thousands of feet. The limitations to this process are computation time and the stability of the averaging algorithms with large amounts of data.

5-3.3 Resolution.

Due to the averaging nature of ERT postprocessing, the resulting pseudosections typically produce graphical changes in color contours, where the colors represent levels of resistivity in units of ohm-meters. The averaged results graphically present boundaries between highly resistive frozen ground (ice-rich) and highly conductive thawed ground (ice free or ice-poor) materials. As a consequence of the averaging process and the large electrode spacings utilized for engineering surveys, these boundaries cannot be depicted by tight contour intervals, such as high resolution. This method is less precise than what can be achieved with the reflection returns from GPR. Based on the electrode spacing, the boundaries between high and low resistive units may be as long as 10 ft (3 m).

5-4 CAPACITIVE-COUPLED RESISTIVITY.

Capacitive-Coupled Resistivity (CCR) surveying is an earth resistivity method that does not require installing stationary electrodes into the ground. The drag-along system uses the earth as one conductor of a parallel plate capacitor. The transmitter and receivers are composed of two coaxial cables, or dipoles. The transmitter sends a continuous-current sine wave through the dipole, polarizing the surrounding earth material; the passing receiver then measures the induced polarization, from which the resistivity can then be calculated. This system does not require inserted electrodes and can continuously collect pulsed readings at one-second intervals while traveling along the surface. Altering the separation between the transmitter and the receivers provides additional survey depths.

5-4.1 Strength and Limitation.

CCR units operate along principles that parallel those of ERT, although they do not require a static array. As a result, CCR units are easier to deploy than ERT arrays and are capable of covering much longer transects in less time, much like GPR. CCR units do not have the capability to penetrate to the same depths as ERT, and they often produce datasets with more noise than ERT. Comparisons of CCR and ERT surveys generally yield very similar to often identical results, when comparing the location and extent of the varied resistive materials. Due to the collection method, the absolute value of the measurements often disagree by hundreds of ohm-meters between CCR and ERT. However, for engineering studies and for determining frozen versus thawed ground, or ice-rich versus ice-poor ground, these differences are not consequential. As with ERT, CCR does not require a substantial amount of postprocessing before interpretable results are available.

The cable dipoles are available in two different lengths, 8.2 ft and 16.4 ft (2.5 m and 5.0 m). As an example, when using the 16.4 ft (5.0 m) cables for deeper surveys, the length of the electronic component of the array is 120 ft (40 m). Additionally, the system requires the transmitter portion to be separated from the receiver portion by a nonconductive rope, and while this separation is variable by the user, it is most often equal to or longer than 33 ft (10 m). The total length of the array is now at least 164 ft (50 m). Careful planning of the transect is required to ensure the array follows the operator in the manner required, and this often requires helpers to keep the system guided on the correct alignment.

When mineralogical clays and silts may be present, especially near the ground surface, careful ground truth analysis is required to ensure masking or amplification of the underlying soils true electrical signature does not occur. In addition to the ability to retain more soil moisture, the mineral content of these soils can cause an increase in electrical conductivity, which can decrease the frozen resistivity value.

5-4.2 Effective Survey Length.

Depending on the geometry of the CCR array, the minimum effective survey length depends on the length of the transmitter and receiver array. One rule of thumb is to assume the minimal effective survey length is 1.5 times the length of the array’s longitudinal footprint.

5-4.3 Resolution.

As with ERT, CCR postprocessing relies on averaging algorithms to produce usable data plots. Because of the capacitive nature of the voltage generation, the boundaries between resistive and conductive bodies can be less definitive than with ERT. However, as with ERT, the value is the information gained in identifying ice-rich versus ice-poor regions, or identifying frozen versus thawed regions. The CCR system collects this information more rapidly and continuously than the ERT system.

CHAPTER 6 GEOTECHNICAL EXPLORATION METHODS

6-1 INTRODUCTION.

Perform soil exploration, testing, and evaluation under the direction of a licensed professional geotechnical or civil engineer who is experienced in cold regions site investigations. Determine the required extent of exploration and testing based on recommendations from the geotechnical engineer, structural engineer (for foundations), and civil engineer (for pavements, wells, septic systems, and retention ponds). Geotechnical site investigations (sampling, testing, and evaluation) must be in accordance with UFC 3-201-01, UFC 3-220-01, UFC 3-250-01, and UFC 3-260-02. EM 1110-1-1804 is a supplementary reference with extensive guidance on performing geotechnical site investigations.

Geotechnical data are the baseline for foundation design in buildings, roadways, airports, bridges, dams, and levees, as discussed in UFC 3-130-3. Upon completion of the initial desktop data acquisition, desktop survey, remote sensing data acquisition, ground reconnaissance, and geophysical data acquisition, detailed geotechnical investigation and exploration can begin. Investigations and evaluations must be in accordance with applicable ASTM standards to the fullest practical extent. Where ASTM methods are not applicable, procedures and apparatuses used must be in accordance with generally accepted cold regions engineering practice. Indicate the results of the subsurface investigation, including boring locations, boring logs, groundwater observations, summary of laboratory test results, and any details required to convey requirements for site preparation, on the contract documents.

6-2 DRILLING AND SAMPLING.

The majority of data collected during a detailed geotechnical investigation is collected from hand samples, drilling, and test pits or trenches. Table 6-1 and Table 6-2 are designed to be used in conjunction with data collected during the desktop study, geophysical data, and field reconnaissance studies to determine which drilling method is most suitable, where the drilling should take place, and the drilling density (number of boreholes).

Table 6-1 Material Tests and Applicable Standards

Material Quality					Atterberg Limits	
	Los Angeles Abrasion	Degradation	Sodium sulfate loss	Gradation	Liquid limit	Plastic index
Applicable standard	ASTM C131	ATM 313*	ASTM C88	ASTM C117/C136	ASTM D4318	ASTM D4318

*Alaska Test Method (ATM) 313, Degradation Value of Aggregates (*Alaska Test Methods Manual*)

Table 6-2 Data Needs and Drilling Techniques

	Data Needs								
Drilling Method	**SPT or LPT***	**Continuous Soil Coring**	**Water Table Depth**	**Soil Class**	**Bedrock Class/ Quality/ RQD****	**Permafrost Cryostructure**	**Undisturbed Soil Samples**	**Torvane**	**Groundwater Pressure**
Solid stem auger	Not effective	Not effective	Effective	Limited	Not effective	Limited	Not effective	Not effective	Not effective
Hollow stem auger	Effective	Effective	Effective	Effective	Limited	Effective	Effective	Effective	Limited
Core drilling	Not effective	Not effective	Limited	Not effective	Effective	Not effective	Not effective	Not effective	Not effective
Air percussion	Effective	Not effective	Limited	Effective	Limited	Effective	Limited	Effective	Not effective
Air rotary	Effective	Not effective	Limited	Effective	Limited	Limited	Effective	Not effective	Not effective
Direct push technology	Not effective	Effective	Effective	Effective	Not effective	Effective	Limited	Not effective	Not effective
Wash bore rotary	Effective	Not effective	Limited	Effective	Effective	Limited	Effective	Effective	Effective
Excavated test pits, trenches	Not effective	Effective	Effective	Effective	Effective	Effective	Effective	Effective	Not effective

Note: *SPT is standard penetration test and LPT is large penetration test. These tests provide material for laboratory testing but should not be used for soil consistency or density correlations, as the frozen soils have artificially elevated blow counts. **RQD is Rock Quality Designation.

6-3 HAND SAMPLES.

Hand samples are typically limited in that they can only be collected at the surface or from disturbed samples taken from the auger flights during auger drilling. The advantage of hand sampling campaigns is that they are relatively inexpensive compared to drilling or trenching and require minimal logistical planning and execution, but they are limited in deep-depth collection. Hand samples can be broken down into the construction-related categories presented in Table 6-3.

Table 6-3 Hand Sampling Breakdown

	Typical Sample Size	Generalized Analyses Methods	Limitations	Optimal Uses
Materials	• 25–150 lb (11–68 kg) • Sample size is dependent on test method (small volume for gradation, large volume for quality testing) • Gradation sample size dependent on particle size	• Gradations • Los Angeles Abrasion • Degradation • Nordic Abrasion • Sodium Sulfate Soundness • Acid-Base Accounting	• Limited to surficial sampling, no quantification of material at depth • Contamination with fill is likely	• Material site reconnaissance • Bedrock sampling for quality testing and acid-base accounting
Foundation	• 1–25 lb (0.5–11 kg) • Sample size is dependent on test method (small volume for moisture contents, larger volume for gradations) • Gradation sample size dependent on particle size	• Gradations • Moisture content • Expansion/collapse potential • Atterberg limits • Organic content • Soluble sulfates • Thaw consolidation	• Limited to surficial sampling, no quantification of material at depth • Contamination with fill is likely	Index testing of material on surface where deep fills are to be placed and no subexcavation is needed
Environmental	Variable	Various analyses for contaminants	Limited for surficial contaminants	Baseline screening
Naturally occurring asbestos	1–5 lb (0.5–2.3 kg)	CARB 435* with Transmission Electron Microscopy or Polarized Light Microscopy	Limited to surficial exposures	Documentation of naturally occurring asbestos hazards easily identified in the field.

*California Air Resources Board (CARB) Test Method 435, California Environmental Protection Agency

6-4 DRILLING.

Seven types of drilling are typically used for geotechnical investigations. This section is not intended to be an all-inclusive list of drilling techniques but, rather, to give an overview of the more common cold region geotechnical drilling techniques and the capabilities of each technique. Table 6-2 includes a list of data that are commonly needed in geotechnical explorations and the suitability of each drilling method to fulfill those needs. Specific site conditions (such as include ground ice content, soil type, depth to bedrock, presence of surface and ground water, and allowable risk for structure damage) determine final borehole density and depth. For horizontal projects that cover long distances, such as roads, changing conditions may dictate changes in drilling strategy.

6-4.1 Solid Stem Auger Drilling.

Solid stem auger drilling is generally limited to environments with silty or cohesive soils, or frozen fine-grained soils, because the walls of the boring remain stable throughout the drilling process. The flights on the augers are continuous throughout the drill string and convey cuttings to the surface. Samples are acquired by stopping drilling at the desired depth and pulling (tripping) the entire string to allow for grab-sampling from the lead auger. Alternatively, the drill string is rotated quickly until returns are spun to the surface. This method yields a highly disturbed sample and should only be used to estimate changes in strata or other gross indicators.

In permafrost regions, solid stem augers are useful for documenting depths to frozen soil because the transition from thawed to frozen soil is highly recognizable due to the dramatic change in drilling resistance. Solid stem augers have limited effectiveness for identifying ice content and cryostructure due to the disturbed nature of the samples, although ground ice is often easily discernable and can help to identify massive ice features.

6-4.2 Hollow Stem Augers.

Hollow stem augers advance in the same manner as solid stem augers. The hollow stem allows the use of soil samplers like split-spoons, Shelby tubes, and continuous samplers driven through the auger flight, and in this manner, the hollow stem auger acts as a casing to prevent collapse of the drill hole and allow for continuous sampling. Other geophysical tools, like torvanes, thermistors, and piezometers, can be inserted in the ground through the hollow stem auger. Samples, such as core samples collected with continuous samplers, are collected during drill advancement.

Hollow stem augers are effective in both cohesive and granular soils, where they provide a cost-effective method to collect representative soil samples, blow counts, and samples for determining moisture content and organic content. In permafrost regions, hollow stem augers are a cost-effective method for identifying cryostructure.

6-4.3 Core Drilling.

Core drilling is primarily used in bedrock or in frozen soil or sediment environments. Core drilling is used to recover cylindrical cores. Core tooling consists of a coring bit attached to a core barrel, while the lifter advances the sample through the barrel. Core drilling can be completed using a wide array of barrel types (single, double, and triple tube), and core sizes are widely variable and generally range from 21.5 mm to 85.0 mm in diameter. To facilitate core drilling of frozen soils or sediment, chilled brine can be circulated down the hole to maintain the drill hole and sample in the frozen condition. Samples retrieved in this manner are contaminated with brine fluid on the outside and interior of the core, where fractures and joints may exist. For a more detailed explanation of core drilling, see ASTM D2113 and AASHTO T 225.

6-4.4 Air Percussion Drilling.

In air percussion drilling, both the drill bit (attached to the end of an air percussion hammer) and the casing are advanced at the same time through the use of an under-reamer. Air flows through the rods and the hammer and up the casing, removing the cuttings through the casing up to the surface. Once the desired sampling depth has been reached, the rods and air percussion are removed, and sampling tools are installed.

Air percussion drilling is particularly effective in environments where excessive cobbles prevent time-effective progress using augers, and it is also effective for very deep holes. Air percussion drilling is less effective beneath the water table and in frozen fine-grained materials, where the hot air thaws the frozen soil. Cuttings using air percussion are delivered to the surface relatively instantaneously, although they are pulverized and not closely representative of gradations in situ.

6-4.5 Air Rotary Drilling.

Air rotary drilling is accomplished by advancing a rotating drill bit through the substrate while moving cuttings to the surface via high pressure air. This method is useful in arid environments with soils that have high dry strengths or in thawed silts and clays where the hole stays open. As the drill advances to desired sample depths, the rod and bit can be extracted from the boring, and the sampler is attached to the rods, taking the place of the bit. Cuttings are moved to the surface relatively instantaneously, and this is useful for detailed logging of complex stratigraphy. Maintaining materials in the frozen state is generally not possible with this method.

6-4.6 Macro Core.

Macro core drilling, also known as *direct push technology*, is accomplished by driving a continuous core barrel into the substrate utilizing a high-frequency hammer. The core barrel is filled with a clear plastic liner that receives the sample, and the liner is extruded once at the surface. This method is very useful for logging detailed stratigraphy, particularly in environments with fine-grained sediments. This method also provides for detailed logging of permafrost cryostructure. Larger size core barrels are required for gravelly soils to prevent plugging of the core. Also, sampling in massive ice, such as in ice-wedge features, can cause the ice to compress and, upon retrieval, to expand outward through the end of the sample barrel. However, this can be prevented with experience.

6-4.7 Wash Bore Rotary.

In wash bore, a rotary drilling casing is advanced ahead of a drill bit with a mechanical or sonic hammer. The casing is driven into the ground, and the material in the casing is drilled out with the drill bit. Once the drill bit reaches the desired depth for sampling, the rods are pulled out of the hole, and the sampler is attached to the end of the rod and lowered down to collect the sample.

To stabilize the boring or control heaving sands below the water table, drilling muds (typically bentonite) or polymers are used to keep positive pressure on soils below the bit as the bit is removed. This is generally the most effective method for drilling below the water table. However, samples above the water table are likely to have contaminated moisture contents due to the water required for the drilling process leaking into the system. Examinations of cuttings pumped to the surface between sample intervals are typically accomplished by using a wire mesh sieve or strainer to collect cuttings from the stream of water that is pumped out of the casing at the surface.

6-5 FREQUENCY AND DEPTHS OF BORINGS.

An experienced geotechnical engineer or geologist familiar with the region is required to determine the frequency and depths of borings. In general, the location, frequency, sampling method and interval depend on the type of structure to be built, degree of heterogeneity in subsurface conditions, and type of soil and rock formations. The drilling program is also influenced by the anticipated presence of any geotechnical or environmental conditions of concern to the project (for example, faulting and seismicity, unstable slopes, ground contamination). Geophysical data allows for a higher level of subsurface mapping resolution and can be used to help guide subsurface investigations.

6-6 EXCAVATED TRENCHES AND TEST PITS.

Sampling trenches and test pits are typically excavated with backhoes or excavators and offer superior stratigraphic data collection because sediments can be seen in long horizontal lengths and in vertical detail that is not attainable with drilling techniques. Hand samples can also be collected very effectively in trenches. The disadvantage of test pits and trenching is the depth profile, which is typically limited by the length of the excavator or backhoe armature or water table. However, benching can be conducted to allow for deeper operation levels for the excavating equipment. Frozen ground disaggregation is accomplished with buckets equipped with frost teeth or by the installation of a single tooth ripper attachment. Take proper to ensure the safety of personnel within test pits and trenches, and this may include widening the trench with safe bench intervals or utilizing a trench box.

6-7 GEO-HAZARD ASSESSMENT.

Exercise professional diligence when collecting data for and designing around geologic hazards. Geological hazards cover a wide range of topics. The Alaska Department of Transportation and Public Facilities' *Alaska Geological Field Investigations Guide* provides a list of common geological hazards, which has been supplemented by this publication:

- Permafrost terrain and thaw-unstable soils (yedoma, syngenetic permafrost)
- Organic soils and deep peat deposits
- Unsuitable soil gradations
- Metastable soils (loess, mud flows, permafrost terrain)
- Highly weathered rock with variable competency
- Faults, joints, bedding planes, foliation planes, slickensides, and other planar weakness surfaces in rock (unstable rock slopes)
- Naturally occurring asbestos in soil and rock
- Moisture-sensitive or quick clays
- Landslides and debris flows
- Meandering streams (stream cutoffs and oxbow lakes)
- Preconsolidated glacial soils
- Boulders and cobbles (particularly when not adequately described)
- Loose granular soils, particularly gap-graded soils
- Noxious or explosive formation gasses
- Substandard fill material
- Shallow groundwater, groundwater in artesian conditions, and saturated soils
- Misleading sample data collected from beneath the water table
- Nonrepresentative sample data from coarse-grained deposits
- Contaminated soils

6-8 INSTRUMENTATION.

A wide array of different instrumentation techniques is deployed in geotechnical investigations. A breakdown of some of the most common types of instrumentation, including their function and application, are presented in Table 6-4.

Table 6-4 Downhole Instrumentation

Type	Function	Application
Piezometers	Groundwater level measurement	Groundwater Earthwork and foundation design
Vane shear	Shear strength measurement of soils	Design in plastic soils Slope stability investigation
Thermistors	Ground temperature measurement	Permafrost investigation
Slope indicator tubes	Subsurface movement	Slope stability investigations
Spontaneous potential electric loggers	Record naturally occurring potentials between borehole fluid, formation, and surrounding rock as a function of depth	Determination and correlation of lithology, bed thickness, and salinity of formation water
Resistivity logging	Measures impedance to flow of electricity in rock formations	Lithology determinations
Cone penetrometer test (various downhole sensors)	Measures soil shear strength, shear wave velocity, and pore pressure, with soil classification interpretations	Foundation design Seismic response analyses
Optical and acoustic televiewers	Provide 360° view and interpretation of soil and rock conditions within unlined boreholes	Lithology and geologic structure determinations Foundation design

6-9 SAMPLE ANALYSIS.

Obtain representative samples of soil and rock during the field reconnaissance and field exploration phases of geotechnical investigations in a way that allows them to be classified according to existing classification schemes (for example, AASHTO and USCS soil classification) and to have their engineering properties quantified. Samples are acquired at considerable cost to the project and must be properly stored, preserved, catalogued, and shipped to avoid sample disturbance and loss.

Preserving, protecting, and transporting samples may be accomplished by the following methods:

- Inventory all samples daily and store in a central location. Do not store samples in areas where they can be agitated, especially if they are undisturbed samples.

- Rock cores need to be stored in purpose-built containers (core boxes) that protect the rock from shock. Rock cores must be logged by a trained geologic professional and photographed at the drill site before being transported off-site. Typical core log information includes lithology descriptions, depth of recovery, core run length, percent core recovery, and Rock Quality Designation (RQD).
- Store permafrost samples at temperatures as close to in situ conditions as possible. Do not freeze thaw consolidation samples to temperatures below those of the natural environment for the soil.

A breakdown of some of the more common geotechnical tests is presented in Table 6-1 and Table 6-2. Further information on sampling can be found in the AASHTO *Manual on Subsurface Investigations*, section 7.9, and in EM 1110-1-1804.

This Page Intentionally Left Blank

APPENDIX A BEST PRACTICES

A-1 INTRODUCTION.

The Best Practices Appendix is considered to be guidance and not requirements. Its main purpose is to communicate proven facility solutions, systems, and lessons learned but may not be the only solution to meet the requirement. It identifies additional background information and practices for accomplishing site assessment and selection in the Arctic and Subarctic. The DoR must review and interpret this guidance as it conforms to criteria and contract requirements and apply the information according to the needs of the project. If a Best Practices document guideline differs from any, the UFC takes precedence. For Best Practices guidelines not discussed in a UFC, the DoR must submit to the Government Project Manager a list of the guidelines or requirements being used for the project with documentation sufficient for review and approval prior to completing the design.

A-2 EXAMPLE ASSESSMENT WORKFLOW.

The steps for organizing geotechnical investigations include basic scenarios, such as those described in Figure A-1, that are applicable for large- and small-scale projects, which are defined here:

- Large scale: multibuilding Installations that cover 50 acres or more on land with three or more terrain units and linear infrastructure developments, including roads, airfields, and pipelines
- Small scale: linear infrastructure and small developments with single buildings

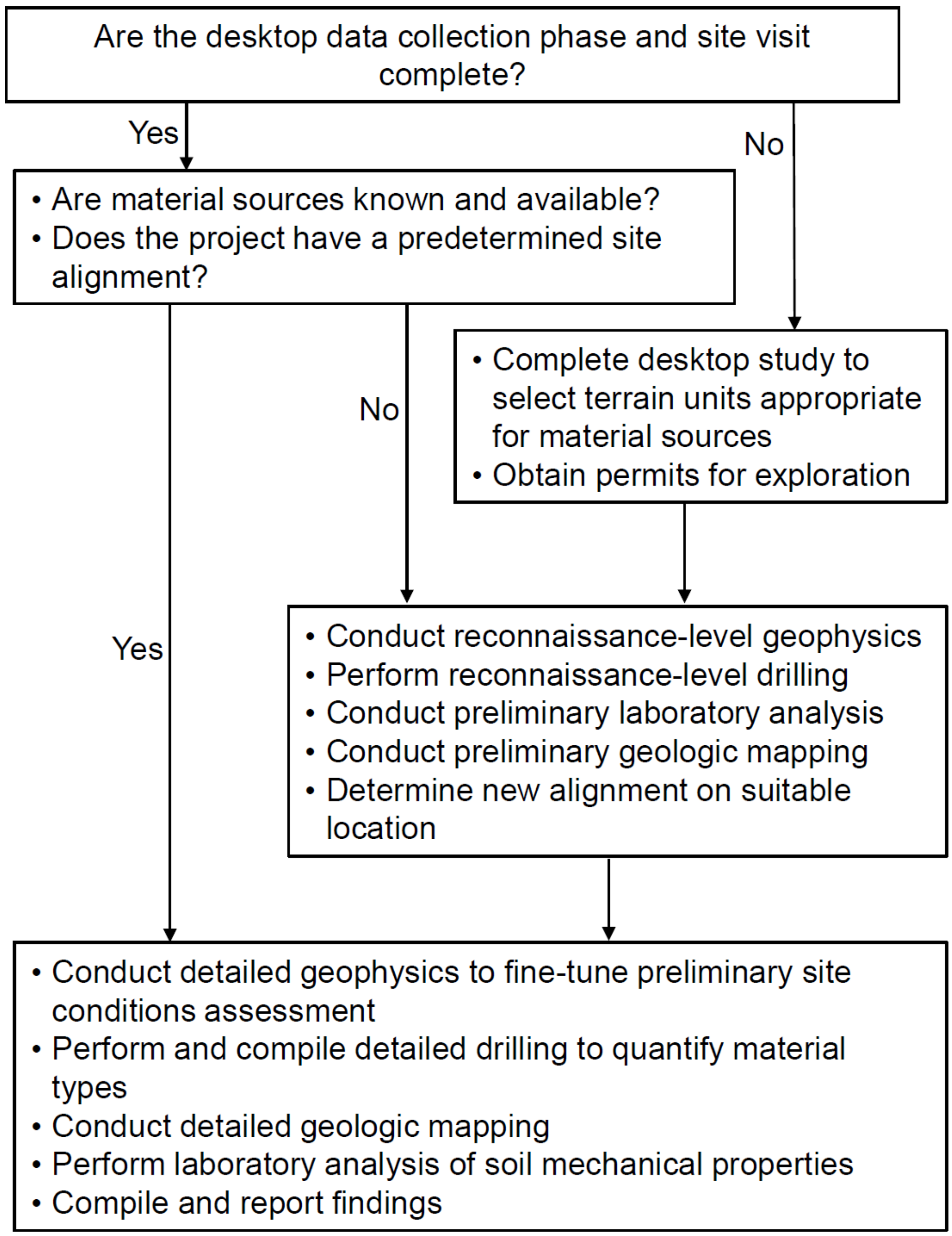
In general, once the background data have been collected, the workflow for most geotechnical investigations follows the flow chart in Figure A-1.

A-3 LARGE-SCALE AND LINEAR INFRASTRUCTURE.

Repair or improvement of large scale (airfields) or linear (roads and pipelines) infrastructure on predetermined or existing alignments requires far less data acquisition as critical infrastructure siting decisions have previously been made. In this case, a single geophysical transect that runs parallel to the centerline followed by detailed geotechnical drilling is typically sufficient unless there is a particular area experiencing geotechnical issues. In the case where predetermined alignment does not exist, geophysical reconnaissance transects designed to obtain the characteristics and boundaries of the terrain units involved is of primary importance.

Borehole spacing and depths are typically controlled by the diversity of terrain units at the reconnaissance level. Identify adverse terrain units (for example, heaving sands, permafrost, and expansive clays) and the more solid foundation soils (alluvial plains, bedrock, colluvium, and so on) at the reconnaissance level, especially if the studies are used to provide a detailed alignment location. Basic geological descriptions of each terrain unit need to be completed in the field along with baseline descriptions of geological hazards present in the project area. Also identify candidate locations for crossings of rivers and canyons at the reconnaissance level.

Figure A-1 Geotechnical Site Investigation Flow Chart



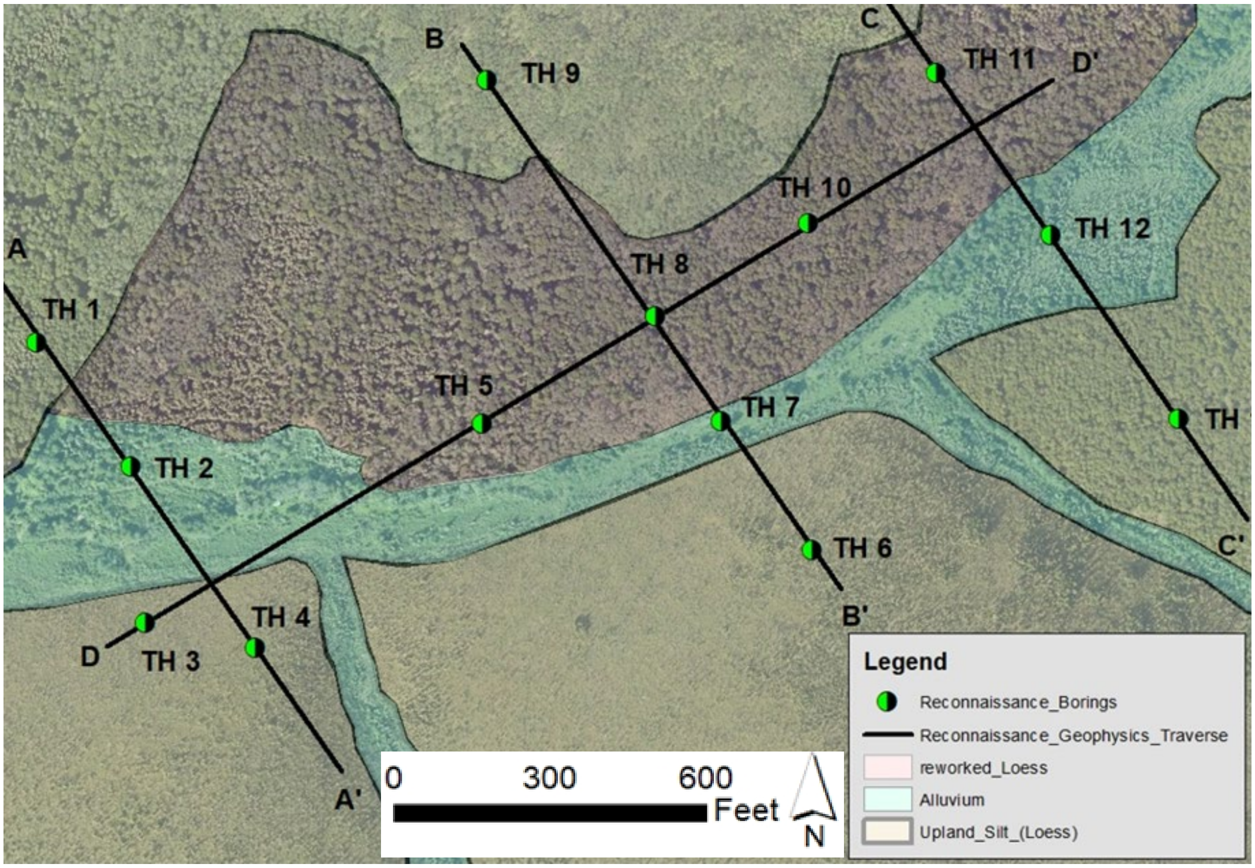
A-4 FIELD RECONNAISSANCE EXAMPLES.

Construction projects for large developments of linear infrastructure and multibuilding vertical construction share many similarities. Both types of development require a multiphase design. Regardless of the type of infrastructure to be constructed, large areas with multiple terrain units are best explored in several phases, the first of which is the reconnaissance phase. In the reconnaissance phase, the primary objectives are as follows:

1. Assess material availability. This is especially important for linear infrastructure, where it is best to have an available material site every 5–10 miles (8–16 kilometers) of pipeline, road, or tunnel alignment.
2. Identify and describe geological features located in geophysical transects, if available.
3. Fine-tune existing terrain-unit maps.
4. Provide preliminary characterization of each of the terrain units present in the area so that the critical structures can be located in the most favorable terrain units and construction can be minimalized on structurally adverse terrain units. The preliminary characterization should including the following:
    - Foundation information at candidate locations for high-load structures
    - Type and extent of adversarial terrain units' characteristics
    - Type and extent of favorable terrain units
    - Geological hazards
    - Drainage assessment
    - Vegetation types

Figure A-2 shows a hypothetical project area with an area of greater than 50 acres and three terrain units. The reconnaissance-level geophysical transects are plotted so that they provide soil deposit geometry via three transects oriented perpendicular to the strike of terrain units and one transect oriented parallel to the strike of terrain units. Reconnaissance-level boreholes are positioned to provide ground truth information and explore anomalies identified in the geophysics information.

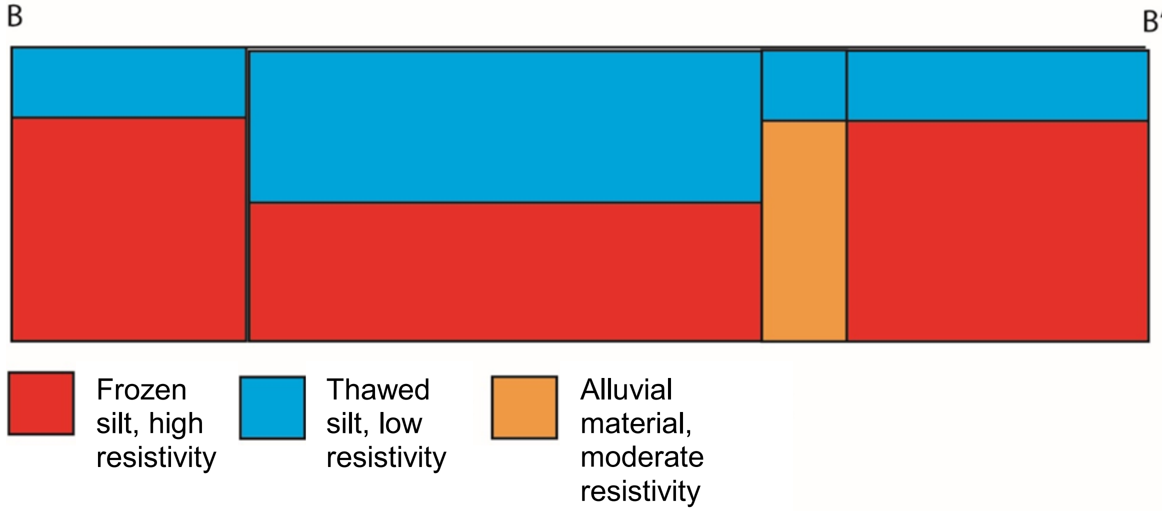
Figure A-2 Reconnaissance-Level Geophysical Transect Layout and Drilling Footprint



The reconnaissance phase relies on both geophysical data and traditional boring data as the backbone of subsurface data on which the detailed geotechnical investigation is built. Identify locations for critical structures in the reconnaissance phase.

Each geophysical transect and subsequent drilling provides a base of data to describe terrain units so that the units with optimum foundation conditions can be identified. Figure A-3 depicts a graphical-type cross section that depicts B-B’ in Figure A-2. In this cross section, we see three terrain units. Two units consist of ice-rich loess (wind-driven silt) and reworked loess, while the third consists of alluvial material. This base-level reconnaissance cross section suggests limiting building locations to the terrain unit with alluvial material in foundation soils. Once favorable locations for key structures have been identified, the detailed phase of investigation begins.

Figure A-3 Generalized Cross Section Showing Resistivity and Corresponding Soil Conditions from Transect B-B' in Figure A-2



A-5 SMALL-SCALE INSTALLATIONS.

For small-scale Installations, of less than 50 acres, and to be built on a predetermined location, a single phase of geophysical and geotechnical drilling data collection is sufficient (Figure A-4). Existing information may be available for the site and geophysics may not be required. When needed, geophysical data should be collected prior to drilling to help identify subsurface anomalies to be explored further with drilling or test pits. For small-scale Installations on land with two terrain units or less, one geophysical transect parallel to the strike of the terrain units and two geophysical transects perpendicular to the strike of terrain units is sufficient. Drilling frequency, spacing, and depth are controlled by design parameters specific to the structure and the acceptable risk; with risk being the detriment to the mission if the infrastructure should need foundation maintenance, foundation repair, or if the infrastructure should become unusable.

A-6 DETAILED DRILLING AND FIELD INVESTIGATION EXAMPLES.

Once baseline reconnaissance has been completed, detailed investigation can begin. Critical structures are ideally constructed on favorable terrain units identified during the reconnaissance phase. Detailed geotechnical investigations consisting of geophysical transects and soil borings are then planned and executed. It is preferred to span the foundation footprint with at least two geophysical transects oriented perpendicular to the terrain unit and at least one geophysical transect oriented parallel to the strike of the terrain unit (Figure A-5). As the geophysics data become available, they can be used to formulate for more geophysics if required and provide planning for the geotechnical drilling campaign (Figure A-4).

Figure A-4 Example of Geophysical Transect Layout in Small-Scale Development with One Terrain Unit

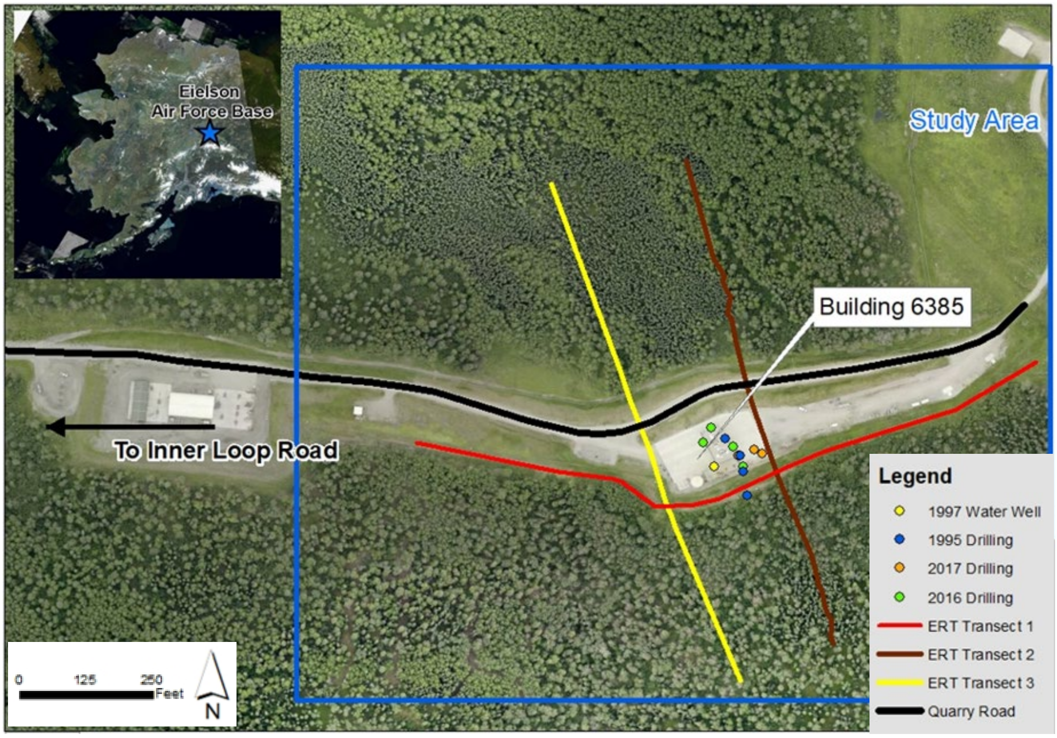
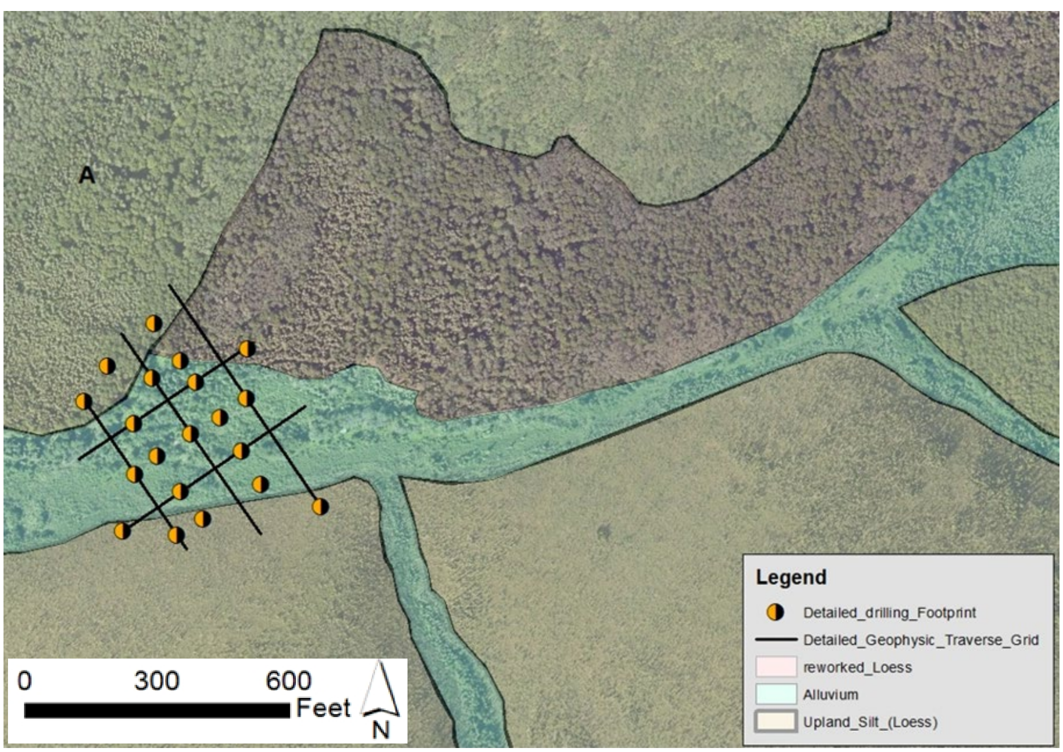


Figure A-5 Orientation of Geophysical Transects and Drilling Footprint for Collection of Detailed Subsurface Data



This two-phase approach works well for large projects that cover an area in excess of 50 acres. The reconnaissance-level geophysics and reconnaissance-level drilling allow designers to narrow down the best locations within a large plot of land to build foundation-critical structures. Once the structure's foundation design requirements have been identified (such as refined building footprint, tentative foundation loads, and allowable settlement criteria), the more rigorous geophysical and drilling data can be collected for the design.

This Page Intentionally Left Blank

APPENDIX B GLOSSARY

B-1 INTRODUCTION.

The following acronyms and terms are used in this document. UFC 3-130-01 provides a more comprehensive list of acronyms and terms for general cold regions engineering.

B-2 ACRONYMS.

AFCEC	Air Force Civil Engineer Center
AFDD	Air freezing degree-days
ATDD	Air thawing degree-days
ATM	Alaska Test Method
BIA	Bilateral Infrastructure Agreements
CARB	California Air Resources Board
CCR	Capacitive-Coupled Resistivity
cm	Centimeters
DEM	Digital elevation model
DoR	Designer of Record
ERT	Electric resistive tomography
FHWA	Federal Highway Administration
ft	Feet
GHz	Gigahertz
GIS	Geographic information systems
GPR	Ground penetrating radar
HNFA	Host Nation Funded Construction Agreements
HQUSACE	Headquarters, U.S. Army Corps of Engineers
IBC	International Building Code
in.	Inch
kg	Kilogram

lb	Pound
LPT	Large penetration test
m	Meters
MAAT	Mean annual air temperature
MAGT	Mean annual ground temperature
MHz	Megahertz
mm	Millimeter
NAVFAC	Naval Facilities Engineering Systems Command
NOAA	National Oceanic and Atmospheric Administration
RQD	Rock Quality Designation
SOFA	Status of Forces Agreements
SPT	Standard penetration test
UFC	Unified Facilities Criteria
USCS	Unified Soil Classification System

B-3 DEFINITION OF TERMS.

Heterogenetic permafrost growth: A mode of permafrost growth whereby freezing temperatures penetrate into previously unfrozen ground of uniform composition.

Syngenetic permafrost growth: A mode of growth of permafrost whereby additional material is deposited on a permafrost site during freezing conditions, causing the permafrost layer to build upward.

Yedoma: Ice-rich silty deposits penetrated by large ice wedges ("Yedoma Permafrost Genesis: Over 150 Years of Mystery and Controversy," by Shur et al.)

APPENDIX C REFERENCES

ALASKA DEPARTMENT OF TRANSPORTATION AND PUBLIC FACILITIES

Alaska Geological Field Investigations Guide

Alaska Test Methods Manual

AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS (AASHTO)

http://www.transportation.org

AASHTO T 225, *Standard Method of Test for Diamond Core Drilling for Site Investigation*

Manual on Subsurface Investigations

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

https://www.astm.org

ASTM C88, *Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate*

ASTM C117, *Standard Test Method for Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing*

ASTM C131, *Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine*

ASTM C136, *Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates*

ASTM D2113, *Standard Practice for Rock Core Drilling and Sampling of Rock for Site Exploration*

ASTM D2488, *Standard Practice for Description and Identification of Soils*

ASTM D4318, *Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils*

INTERNATIONAL CODE COUNCIL

http://www.iccsafe.org

International Building Code

FEDERAL HIGHWAY ADMINISTRATION (FHWA)

FHWA-NHI-01-031, *Subsurface Investigations—Geotechnical Site Characterization, Reference Manual*

UNIFIED FACILITIES CRITERIA

https://www.wbdg.org/dod/ufc

UFC 1-200-01, *DoD Building Code*

UFC 2-100-01, *Installation Master Planning*

UFC 3-130-01, *Arctic and Subarctic Engineering*

UFC 3-130-03, *Arctic and Subarctic Foundations for Freezing and Thawing Conditions*

UFC 3-130-05, *Arctic and Subarctic Utilities*

UFC 3-201-01, *Civil Engineering*

UFC 3-220-01, *Geotechnical Engineering*

UFC 3-250-01, *Pavement Design for Roads and Parking Areas*

UFC 3-260-01, *Airfield and Heliport Planning and Design*

UFC 3-260-02, *Pavement Design for Airfields*

UFC 4-010-06, *Cybersecurity of Facility-Related Control Systems*

U.S. ARMY CORPS OF ENGINEERS

EM 1110-1-1804, *Geotechnical Investigations,* https://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-1-1804.pdf?ver=X3odvxc01j8BVoN9mwxWCw%3d%3d

OTHER

"Classification of Rocks," *Quarterly of the Colorado School of Mines* 50 (1), R.B. Travis, 1955

"Complex Permittivity and Clay Mineralogy of Grain-Size Fractions in a Wet Silt Soil," *Geophysics* 73 (3): J1–J13, S.A. Arcone, S.A. Grant, G. Boitnott, and B. Bostick, 2008

Determination of Asbestos Content of Serpentine Aggregate: Field Sampling and Laboratory Practices, Implementation Guidance Document: Air Resources Board Test Method 435, California Environmental Protection Agency, Air Resources Board, 2017, https://ww2.arb.ca.gov/sites/default/files/2022-05/2017%20Apr28%20M435%20Guidance%20Version4%20POST.pdf

"Northern Hemisphere Permafrost Map Based on TTOP Modeling for 2000–2016 at 1 km^2 Scale," *Earth-Science Reviews* 193: 299–316, J. Obu, S. Westermann, A. Bartsch, N. Berdnikov, H. Christiansen, A. Dashtseren, R. Delaloye, B. Elberling, B. Erzelmüller, A. Kholodov, A. Khomutov, A. Kääb, M. Leibman, A. Lewkowicz, S. Panda, B. Romanovsky, R. Way, A. Wesergaard-Nielsen, T. Wu, J. Yamkhin, and D. Zou, 2019, https://doi.org/10.1016/j.earscirev.2019.04.023

"Munsell Rock Color Chart," MUNSELL COLOR, https://munsell.com/color-products/color-communications-products/environmental-color-communication/munsell-rock-color-chart/

"Recent Advances in the Study of Arctic Submarine Permafrost," *Permafrost and Periglacial Process* 31: 442–453, M. Angelopoulos, P.P. Overduin, F. Miesner, M.N. Grigoriev, and A.A. Vasiliev, 2020

River Lake Ice Engineering, G.D. Ashton (ed.), Water Resources Publications, LLC., 1986

"Yedoma Permafrost Genesis: Over 150 Years of Mystery and Controversy*," Frontiers in Earth Science* 9, Y. Shur, D. Fortier, M.T. Jorgenson, M. Kanevskiy, L. Schirrmeister, J. Strauss, A. Vasiliev, and M. Ward Jones, 2022