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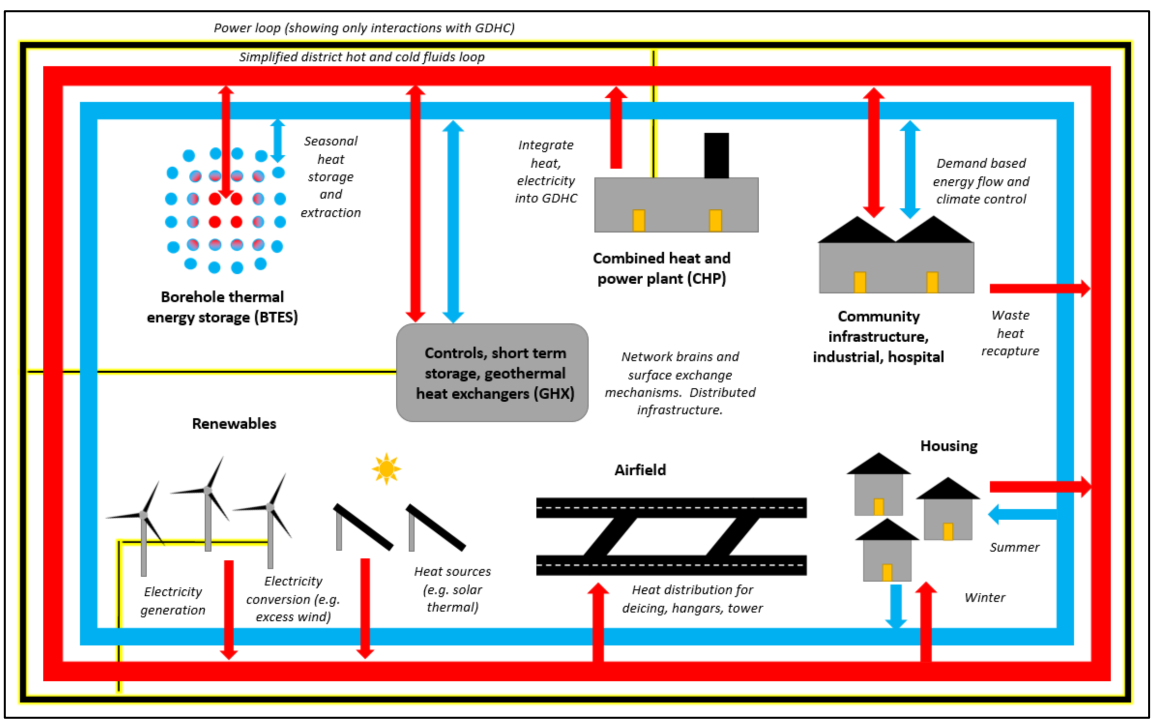
March 2023



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Abstract

The DoD considers improving Arctic capabilities critical (DoD 2019; HQDA 2021). Deployment of shallow geothermal energy systems at cold regions installations provides opportunity to increase thermal energy resilience by lessening dependence on fuel supply and supporting installations' NetZero transitions. Deployment can be leveraged across facilities, for example using Fort Wainwright metrics for implementation of geothermal in cold region bases. Fort Wainwright is an extreme case of heating dominant loads owing to harsh conditions in Alaska, making it ideal for proving feasibility in most heating dominant installations. Proven feasibility and potential mass deployment will help reduce emissions and increase resilience across the DoD cold region network. This report introduces the shallow geothermal energy and storage technology combination that would best fit demonstration in Alaska. Focus is on leveraging shallow, low-temperature geothermal for the development of a larger geothermal district heating and cooling (GDHC) system with underground thermal energy storage (UTES) and geothermal heat exchangers (GHX). Such systems are proven in cooling dominant climates, and individual components are proven in heating dominant climates, but deployment of a larger system in a heating dominant climate is not well established. Deployment at Fort Wainwright would represent an improvement in the technology.

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Preface

This study was conducted for the US Army Corps of Engineers (USACE) under program element 0603734A, project number T15, “Shallow Geothermal Technology, Opportunities in Cold Regions, and Related Data for Deployment at Fort Wainwright.”

The work was performed by the Terrestrial and Cryospheric Science Branch of the Research and Engineering Division, US Army Engineer Research and Development Center–Cold Regions Research and Engineering Laboratory (ERDC-CRREL). At the time of publication, Dr. John W. Weatherly was branch chief; and Dr. Caitlin A. Callaghan was division chief. The acting deputy director of ERDC-CRREL was COL Ivan P. Beckman, and the director was Dr. Joseph L. Corriveau.

COL Christian Patterson was commander of ERDC, and Dr. David W. Pittman was the director.

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1 Introduction

1.1 Background

Resilient energy and heating systems are critical in extreme cold environments like interior Alaska. Deployment of shallow geothermal energy may be an opportunity to increase resilience by using technology that can be retrofitted to existing infrastructure. Geothermal district heating and cooling systems with seasonal energy storage are implemented in more cooling dominant climates, and small shallow geothermal systems are used in heating dominant climates but implementing an advanced system with seasonal storage in a cold climate is an opportunity for technology development.

1.2 Objectives

The objectives of this report are as follows:

1. Introduce shallow geothermal technologies, describe their benefits and limitations, identify best fit for Alaska, and discuss how they can be introduced at Fort Wainwright.
2. Communicate the opportunity for technology transfer of geothermal district heating and cooling coupled with seasonal storage to cold regions installations.
3. Describe initial fact finding effort on Fairbanks' geohydrology for study of deployment at Fort Wainwright.

1.3 Approach

Through conducting a literature review, useful geospatial data were collected, analyzed, and used to determine technology fit. This report can be viewed as an initial fact finding effort for a feasibility study on a potential deployment of shallow geothermal at Fort Wainwright.

2 Shallow Geothermal and Cold Regions Opportunity

Shallow geothermal energy systems provide significant amounts of energy in heating and cooling applications around the world. Many different technologies are used, with three categories of focus in this report being (1) geothermal heat exchangers (GHXs), (2) geothermal district heating and cooling (GDHC) systems, and (3) underground thermal energy storage (UTES). All these take advantage of the thermal properties of the Earth, but the different technologies are distinguished by their scale, complexity, and intended function. GHXs exchange heat between the surface and ground, UTES stores large amounts of seasonal energy in the subsurface by utilizing thermal inertia, and GDHCs integrate ground heat into community-scale heating and cooling systems, which can include GHXs and UTES as subsystems. The implementation of a large scale GDHC with UTES and GHX in a cold environment (e.g., Alaska) is not well established, but individual components of such a system are. This is a technology development avenue worth exploring because of clear potential benefits of this kind of system. These benefits include increasing thermal resilience, supporting the DoD's transition to NetZero, and the opportunity to integrate diverse energy loads and potentially incorporate renewables into the GDHC. Successful deployment at Fort Wainwright will help prove feasibility in other cold regions, as interior Alaska is on the extreme end of temperature conditions and thermal demand.

Various forms and architectures of GHXs, GDHCs, and UTES are independently deployed around the world, but there is opportunity for further utilization and technology development. As of 2020 the worldwide installed capacity of geothermal heat pumps (GHPs) accounted for 77,547 MWt* power around the world, with China, the United States, and Europe leading in installed capacity (Lund and Toth 2021). Installed GHP systems exist across climates, including at a number of DoD installations (OSD 2007), cold regions like Scandinavia (Gehlin 2019), and even limited deployment in Alaska (Meyer et al. 2011; Garber-Slaght and Stevens 2014). As of 2020 worldwide installed capacity of geothermal space heating was 12,768 MWt, of which about 91 percent is believed to

* For a full list of the spelled-out forms of the units of measure used in this document, please refer to US Government Publishing Office Style Manual, 31st ed. (Washington, DC: US Government Publishing Office, 2016), 248–52, https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

be incorporated into district heating systems (Lund and Toth 2021). Deployed district heating systems incorporating ground heat exist in major regions such as Europe (Sayegh et al. 2017), China (Hardarson 2021), and the United States (Robins et al. 2021). Some of these incorporate direct use geothermal—utilization of natural hot fluid reservoirs (e.g., hot springs)—which is distinct from the thermal harvesting approach discussed here. Direct use systems usually have a higher temperature input and working fluid is often directly returned to the environment. Above ground infrastructure and technological approach is often similar to the thermal harvesting approach discussed here, a key difference being the technologies in this report are feasible at much lower fluid temperatures. Bulk numbers on UTES deployment are less available, but examples of deployed systems can be found. Some active countries in the space include the Netherlands, which is a leader in aquifer thermal energy storage (ATES) (Fleuchaus et al. 2018; Nordell 2012), and Sweden, which has a history and significant recent investment in borehole thermal energy storage (BTES) (Gehlin and Andersson 2019; Andersson et al. 2003).

While many elements of shallow geothermal technology are well established, most deployed shallow geothermal systems in cold regions are not of matching complexity to the type of integrated system examined here. An example of such system in a more temperate climate is a US military demonstration of a GDHC in Georgia that shows efficiency and resilience improvements coupling GHXs with UTES in a cooling dominant climate (Hammock and Sullens 2017). A system of similar scale and complexity has not been demonstrated in a heating dominant climate like Alaska.

2.1 Cold regions opportunity

The DoD recognizes the importance of maintaining a foothold in the Arctic and cold regions (DoD 2019; HQDA 2021). Reliable and resilient energy systems are a key component of this, and are amplified in importance in harsh, dangerous environmental conditions. In cold regions, a failure of the energy system also means a failure of heating and exposure of personnel and materiel to harsh conditions. Heat is key for survival, and this is reflected in the energy budget, as up to 70 percent goes to heating in cold regions (Wiltse et al. 2014). Fort Wainwright is one of four installations in Alaska with a fossil fuel driven combined heat and power (CHP) facility that is used for significant heating needs (CHP Alliance 2021). As of 2020, the CHP facility was undergoing evaluation for renovations, which has been in service since 1955, serves over 400 buildings, has had four near catastrophic failures in the last decade, and struggles to meet emissions standards (US Army 2020). Taking stress off of this system provides opportunity to increase base resilience. General case analysis on deploying different GHX architectures involving GHPs into cases with an existing CHP has shown potential to both offset the cost of GHP installation via energy recovery and help take load off of the CHP when the heat pumps are powered via the CHP (Foster et al. 2016). Foster et al. (2016) describe GHP efficiency and CHP activity as key components of this coupling. This analysis related to balanced heating and cooling loads, and results have the potential to be more robust in a heating dominated environment like Fort Wainwright where the CHP is often throttled up and costs of energy are generally high.

Many isolated arctic and subarctic communities rely primarily on diesel generators for power needs and reintegrate waste heat and energy as a necessity (Holdmann and Asmus 2019). The Alaska Energy Authority (AEA) estimates that at least 80 communities use heat recovery of some kind, most of which occurs in the form of CHP from diesel generators (AEA 2019). These systems introduce additional logistical supply challenges and pollution concerns. Integration of shallow geothermal systems has the potential to help mitigate these challenges. Such integration, even with smaller, residential scale CHP systems may be cost effective in climates with unbalanced heating loads (Alqaed et al. 2020). Deployment at Fort Wainwright would reduce risk for Arctic communities by demonstrating feasibility and deployment strategy and potentially open up opportunity for deployment beyond military installations in remote and cold climate communities.

In cold regions, integrating geothermal heating systems into the overall energy installation can be advantageous owing to the high percentage of energy consumption for heating. Geothermal heating has potential to enhance energy resilience at implemented sites, but a synthesis of current technology is novel for the deployment of GDHC systems in cold climates or heating dominant environments. Such systems have been successfully implemented in temperate climates within the US (Hammock and Sullens 2017; Sayegh et al. 2017) and technology transfer to cold regions is an opportunity. Similarly scaled GDHC systems with UTES would help address challenges specific to cold regions geothermal systems, namely performance degradation over time because of overconsumption of ground heat as a result of unbalanced heating and cooling demand. Installation of a large scale cold region system with UTES would provide opportunity to leverage prior successes in GDHC development and known UTES capabilities in cold regions for immediate benefit while providing data for further large scale cold region deployments.

2.2 Geothermal in cold regions

Successful examples of shallow geothermal technology implementation into cold regions exist, but deployment of a large scale GDHC with UTES in heating dominated energy systems is not well established. Implemented smaller scale GHX systems exist in interior Alaska (Meyer et al. 2011; Garber-Slaght and Stevens 2014) and both Scandinavia (Lund and Toth 2021; Gehlin 2019; Kallio 2019; Poulsen et al. 2019; Kvalsvik et al. 2019) and cold areas of China (Lund and Toth 2021; Song et al. 2021) have implemented a significant number of GHPs. UTES is less common than smaller scale GHX but sees regionally significant utilization. For example, Sweden has a long history of UTES implementation (Andersson et al. 2003; Gehlin and Andersson 2019) as does the Netherlands (Provoost et al. 2019), where 85% of implemented ATES systems exist (Fleuchaus et al. 2018). Many other European countries, China, and the United States have experimented with UTES (Kallesoe and Vangkilde-Pedersen 2019; Xu et al. 2021). In Europe more than 250 district heating systems with some elements of geothermal heat have been developed (Sayegh et al. 2017), although a number of these facilities utilize direct use as opposed to shallow geothermal technology. Some examples of advanced GDHCs in colder climates include GDHCs coupled with GHXs in Sweden (Averfalk et al. 2017), a state of the art GDHC with GHXs and UTES coupling in the Netherlands (Boesten et al. 2019), a community in Canada operating with a GDHC and UTES (Mesquita et al. 2017), and both significant investment plans for GDHCs in China (Hardarson 2021) and an existing, modern GDHC with UTES in Chifeng near Mongolia (Xu et al. 2021). Further details on examples of deployed systems can be found in Table 1.

Cold regions with permafrost, such as Fort Wainwright, will have additional design considerations in comparison to cold climates with unbalanced heating loads and no permafrost, but this can be addressed by avoiding the permafrost and by sustainably maintaining the ground heat. Past implementation of shallow geothermal technology in Alaska has shown issues specific to the region such as the possible introduction of new frozen ground from using too much ground heat without sufficient recharge and efficiency losses over time for similar reasons (Meyer et al. 2011; Garber-Slaght et al. 2017). These challenges need mitigation with careful planning and implementation of other technology such as solar thermal collectors (Emmi et al. 2015) and implementation of seasonal and diurnal cycling of the heat via UTES or other storage (Lanahan and Tavares-Velasco 2017; Mahon et al. 2022) to ensure the total energy stored in the ground does not drop to a level that induces issues. One such small scale GHX system coupled with solar collection in Fairbanks has shown promising maintenance of the ground heat (Garber-Slaght and Keays 2014).

2.3 Shallow geothermal systems

For the purpose of contextualizing the data and understanding shallow geothermal technology, general definitions and system architectures are presented here to provide a working understanding of each. Shallow geothermal systems are a focus for this study rather than larger high temperature geothermal systems—deep geothermal—because of less location dependence and less initial risk. A distinguishing factor between the two (shallow and deep) is that deep geothermal must be found, like any resource, whereas shallow is more akin to an engineered system and can be deployed without dependence of subsurface temperature as long as it is above freezing (Garber-Slaght and Peterson 2017; Eslami-nejad and Bernier 2012). However, the efficiency and other metrics of consideration for shallow geothermal are site and infrastructure dependent.

For this report, primary nomenclature for shallow geothermal systems includes GHX, GDHC, and UTES. These technologies can combine well together in an energy system. One technology is not better than the other, therefore selection of which system to use is determined by harmonizing the right technology combination with economics, geohydrologic regime, energy demand, and existing infrastructure.

The objective here is to explore opportunity for an advanced GDHC coupled with GHX and UTES in a heating dominant climate. Table 1 details examples of modern, larger shallow geothermal systems with implemented UTES systems that represents systems that could meet the thermal energy demand of a portion or all of a military installations energy needs.

Table 1. Examples of newer operating heating systems leveraging underground thermal energy storage (UTES).

Location	Technology Elements	Details	Usage as Reported	Year Built	Citation
Albany, Georgia, United States	• UTES using boreholes • GHPs coupled to UTES storage • Interconnected with building HVAC system (GDHC at building level) • Adiabatic coolers to help release heat	• 306 boreholes • Demonstration project for military installation • Cooling dominated load • Effective enough that 3 more systems installed post demonstration to service 10 more buildings	168,000 ft^2 administration building with a maximum cooling load of 425 ton	2017	Hammock and Sullens 2017
Chifeng, China	• UTES using boreholes • Integrated into district heating system • Solar thermal collection • Industrial waste heat integrated • Short term thermal storage tanks	• 468 boreholes added to existing district heating (DH) system • Excess energy from industrial copper plant stored in boreholes • 4th generation system • Services 11,000 residents	2.94 GWh/year storage in BTES	2013	Xu et al. 2021
Neckarsulm, Germany	• UTES with vertical boreholes • Charged with solar thermal collectors • Coupled with district heating system and short term thermal storage tanks	• 528 boreholes • Feeds a residential area • Originally 160 accommodation units plus public buildings; currently over 600 units with plans to expand to 1300	3 GWh total energy	1997/1999 2002	Nubbicker et al. 2003; Kallesoe and Vangkilde-Pedersen 2019

Table 1 (cont.). Examples of newer operating heating systems leveraging UTES.

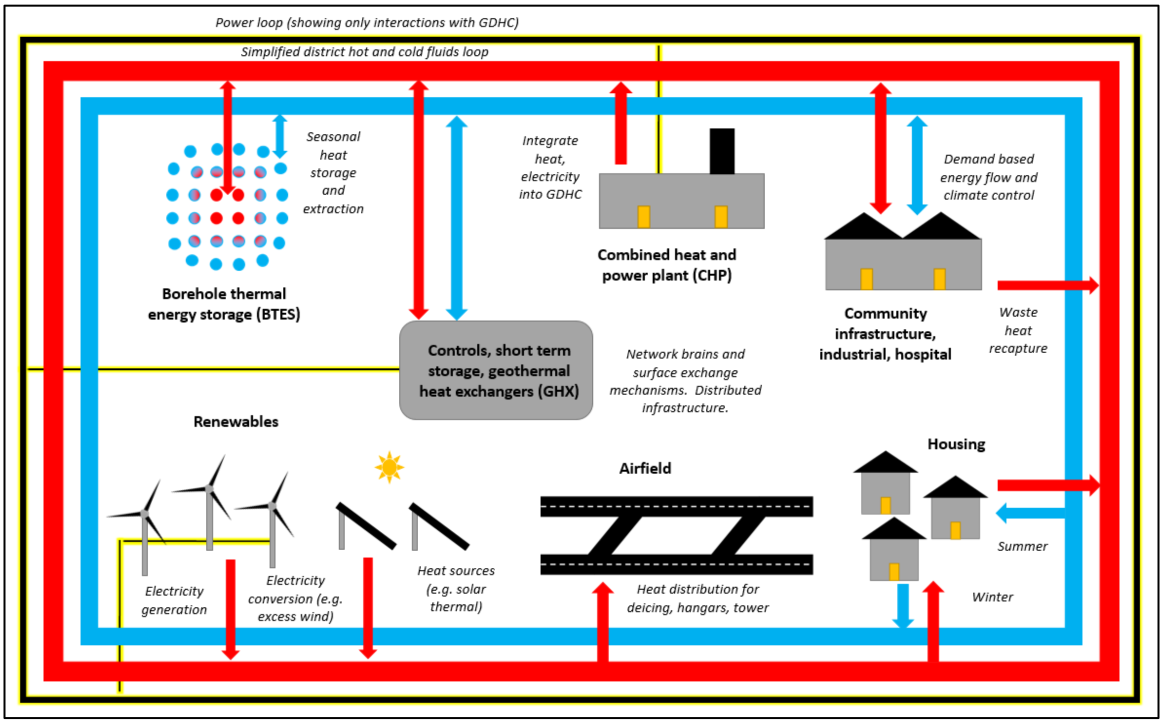
Location	Technology Elements	Details	Usage as Reported	Year Built	Citation
Heerlen, the Netherlands	• Fully functional GDHC capable of demand based acceptance and rejection of hot/cold • UTES at the district level using boreholes and legacy abandoned mine cavern storage • Individual GHPs at building level • Poly-generation with bio-CHP, solar, waste heat, and cooling towers	• State-of-art 5th generation GDHC system • Incorporates old and new energy technology and built on top of legacy heating architecture • Can supply heat to existing, renovated, and new buildings, is low temperature, and has low grid losses • Seasonal storage at district level is key to operation	Services 200,000 m^2 of floor space in a region of over 250,000 people	2008/2013	Verhoeven et al. 2014; Boesten et al. 2019
Utrecht University, Netherlands	• UTES using aquifer • Integrated into district heating system • Advanced temperature monitoring and control	• UTES system originally built in 2002 and updated in 2014 • Services university (5 academic buildings) • Updates added controls and integration into district heating	Data not reported	2002/2014	Velvis and Buunk 2017
Drake Landing, Alberta, Canada	• UTES using vertical boreholes • Integrated into community heating and energy system • Control for acceptance and rejection based on demand • Solar thermal collectors • Short term thermal storage tanks	• 52 home community • 144 boreholes • “First of its kind in North America”	1370 GJ average yearly extracted energy	2006	Mesquita et al. 2017; Kallesoe and Vangkilde-Pedersen 2019

Table 1 (cont.). Examples of newer operating heating systems leveraging UTES.

Location	Technology Elements	Details	Usage as Reported	Year Built	Citation
Arlanda Airport, Sweden	• UTES using aquifer • Open loop system • Thermal collectors	• World's largest open loop system • Heating and cooling needs for airport	13–19 GWh heat and electricity savings per year	2009	Gehlin et al. 2021; Hellstrom 2012
Project Emmaboda, Sweden	• UTES using vertical boreholes • Integrated into HVAC • External district heating system linking UTES with waste heat using heat pumps • Closed loop design, may have fractures in rock matrix	• 141 boreholes • Supplies Xylem Water Solutions manufacturing plant • Collects waste heat from foundry in summer • Heats factory in winter	3600 MWh stored, 2000 MWh extracted	2010	Nordell et al. 2015; Kallesoe and Vangkilde-Pedersen 2019; Hellstrom 2012
Helsinki, Finland	• UTES using boreholes • Integrated with district heating	• Services Meilahti Tower Hospital	Data not reported	2014	Kallio 2019
Braedstrup, Denmark	• UTES using boreholes • Integrated with natural gas CHP • Solar thermal collectors • Short term thermal storage tanks	• 48 boreholes • 1481 consumers • Consumer owned services area	39,633 MWh heat produced in 2015	2005/2007 2008	Sorensen and Schmidt 2018

GDHC refers to an integrated network built into community infrastructure that is designed to heat and cool more efficiently than individualized systems. Heating and cooling are centralized, and then warm or cold fluid is distributed to different parts of the community. Many such systems are implemented without any use of geothermal, but here the focus is on those that do implement geothermal energy systems such as 250 systems in Europe (Sayegh et al. 2017). Figure 1 shows generalized architecture of a GDHC system that can be deployed at a military base like Fort Wainwright. Each component shown may be present but is just a possible inclusion to the architecture and not a requirement.

Figure 1. Simplified geothermal district heating and cooling system with seasonal energy storage at a military installation.



Optimization of specific cases of GDHC with UTES requires implementation and design, but any of the components shown in Figure 1 could feasibly be part of a GDHC at Fort Wainwright. Existing infrastructure such as the CHP could be retrofitted to the system. Additionally, the size of the GDHC could be scaled to service a portion or all the fort depending on needs, economics, and feasibility from further study. Maintaining thermal balance under a heating dominated load would be key, and this could include various forms of UTES or other elements such as solar thermal collectors, which may help improve performance in cold and unbalanced heating loads (Emmi et al. 2015).

Technology in GDHC systems has been iterating for decades (Lund et al. 2021). Over time cooler fluids have become more viable, starting with steam, and progressing to ground temperature water. Increased awareness and interest in smart grids and energy efficiency has led to modern systems being incorporated into complex control schemes (Lund et al. 2021). Once technology grew beyond just a heat distribution system, the possibility for system level improvements became apparent, for example via integration of seasonal storage (Lund et al. 2016; Lanahan and Tavares-Velasco 2017; Mahon et al. 2022), thermally efficient buildings and load balancing (Foster et al. 2016), and solar thermal collectors (Emmi et al. 2015). Regardless of nomenclature, state of the art GDHC systems have the five properties listed in the following (Lund et al. 2014):

- The ability to supply low temperature heat to existing, renovated, and new buildings.
- Low grid losses within distribution.
- The ability to recycle heat and integrate renewables.
- The ability to be integrated into smart energy systems and provide demand based heating and cooling for energy conservation.
- The ability to be implemented with economics and sustainability in mind.

A distinct advantage of GDHC systems over conventional CHP systems is nonlinear distribution of heat and cool (i.e., cool, or warm fluid can be accepted or rejected and redirected as needed for different use). Fort Wainwright can support the deployment of a GDHC system in parts if not at all the installations with both newly installed systems and retrofits to existing infrastructure. Such a system has an opportunity to introduce resilience into the base's energy network.

Shallow geothermal energy systems such as GHX and UTES utilize heat properties of the earth to conduct energy transfers for use in heating and cooling systems. In simplified terms, this is accomplished via the use of a working fluid, a flow loop, and zones of differing temperature or energy potential, not unlike a typical heat exchanger or battery. More specific details vary in each technology, but each type of shallow geothermal system utilizes the earth which is a more stable temperature than the ambient above ground environment. This stability (i.e., resistance to bulk temperature change) leads to the emergent property that the earth is generally cooler than ambient air in the summer and warmer than ambient air in the winter. This allows for various kinds of surface-subsurface "heat exchangers" to be designed. For the purposes of this report, shallow geothermal energy loosely refers to energy extraction or storage at a subsurface depth of no more than 200 m.

A GHX is a system that exchanges heat energy between the surface and subsurface. Some examples include solar thermal collectors, adiabatic coolers, and GHPs. GHPs require a pump to move the fluid carrying the heat (or cool) energy. The shallow subsurface remains relatively constant in temperature throughout the year making it warmer than the surface in the winter and cooler in the summer. These systems generally have a higher up-front cost than traditional heating and cooling systems with a later payoff in energy savings five to ten years from installation if well implemented. There are four different configurations of GHPs each suited to different use cases. These are horizontal, vertical, pond or lake, and open loop systems (DOE n.d.). Table 2 describes each system and provides use case examples. Documented implementations in Alaska include a mix of horizontal, vertical, and lake configurations and one open configuration (Meyer et al. 2011; Garber-Slaght and Stevens 2014).

Table 2. GHP configurations (DOE, n.d.).

GHP Configuration	Description	Use Cases
Horizontal	Flow loop laid in trenches at least 4 ft deep. Number of pipes and length depends on energy needs.	Cost-effective method for residential buildings with sufficient land available.
Vertical	Holes drilled 100 to 400 ft deep. Pipes placed in holes and connected with U-bend at the bottom.	Large commercial buildings and schools, applications where land surface is limited.
Pond or Lake	Flow loop is coiled at least 8 ft under a water body.	Sites with adequate bodies of water that meets environmental requirements.
Open Loop	Exchange fluid comes from the environment. Extracted from wells or a water body and returned once circulated through the system.	Practical where there is an adequate supply of usable water and no environmental concerns.

UTES refers to the utilization of the subsurface for excess energy storage, often cycled seasonally in implementation. Instead of only exchanging heat with the ground like a GHP, the goal is to use the natural stability of the ground temperature to insulate a larger body from energy loss or gain. Differences in energy supply and demand are used to heat and store or extract and utilize reservoir fluid in times of surplus or scarcity. UTES as a technology refers to several systems distinguished by storage method such as ATES, BTES, and rock cavern thermal energy storage (CTES) (Nordell 2012; Matos et al. 2019).

ATES systems are geologically dependent and conceptually akin to a ground water reservoir. Fluid is confined to a subsurface storage space via the naturally occurring geology—a reservoir—and extracted for human use. Many such systems have been utilized in applicable areas such as the Netherlands (Nordell 2012) and Sweden (Andersson et al. 2003). BTES systems can generally be implemented within range of the serviced infrastructure, but their feasibility is still constrained by the local geohydrology and costs. Instead of using a natural reservoir, boreholes are drilled in optimized patterns for a heat exchange loop. Many of the example GDHCs in Table 1 utilize BTES for thermal storage, and some countries, like Sweden, have a significant number of BTES systems deployed (Gehlin and Andersson 2019). CTES systems are geologically dependent. These involve the use of large underground caverns filled with water for thermal storage, for example abandoned mines, and are generally less common than ATES and BTES (Nordell 2012).

Small scale UTES systems have been implemented in Alaska some of which have demonstrated the impact of mitigating degradation from unbalanced heating and cooling loads (Garber-Slaght and Keays 2014). There is great potential to scale up those systems to support GDHC systems, a mature technology, in cold regions such as Alaska. Fort Wainwright lies in a geologic setting that can be conducive to UTES if permafrost interactions and extensive drilling into bedrock (cost) are avoided. The installation infrastructure requirements also align with BTES, as BTES can be implemented with a small surface footprint. Additionally, there is potential to explore other efficiency enhancing options such as integration with solar thermal heaters, retrofitting of existing systems, and diurnal-seasonal coupling of UTES systems (Lanahan and Tavares-Velasco 2017; Mahon et al. 2022).

The remainder of this report presents relevant existing data and literature on the subsurface heat and hydrologic regime for Fort Wainwright, Alaska, and the surrounding area. The focus is on information relevant to the study of deployment of shallow geothermal at Fort Wainwright. Current understanding of the geohydrologic regime near Fort Wainwright and additional information that would enhance future analysis are discussed in following sections.

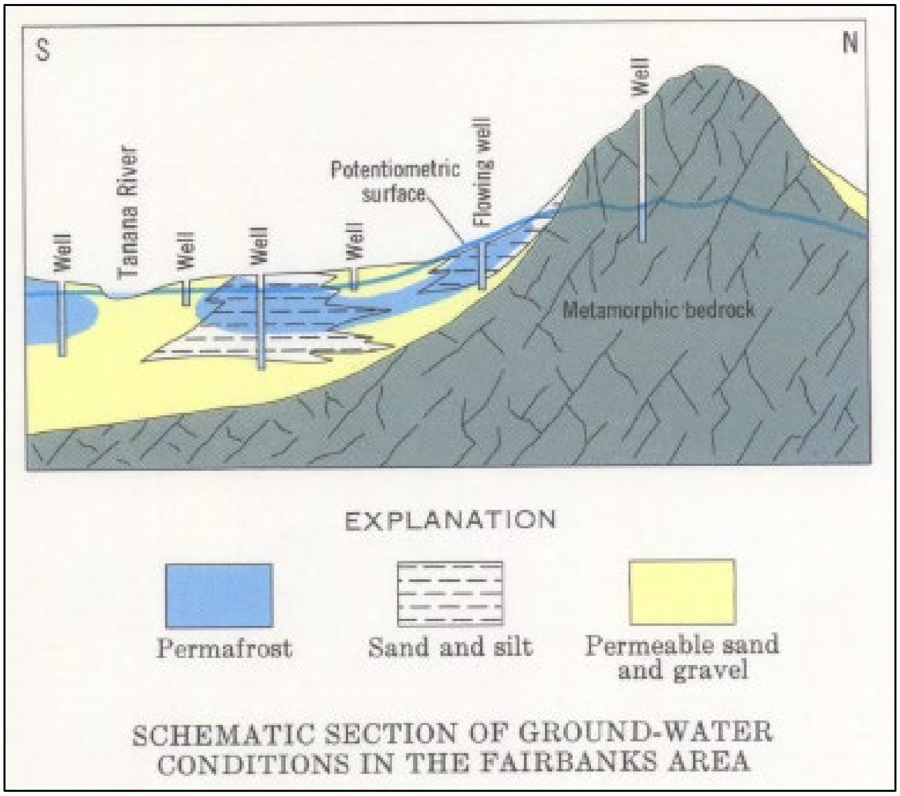
3 Preliminary Data Screening for Fort Wainwright Area

Data presented here represents a starting point for planning of field study in preparation for a GDHC design. In general, shallow geothermal systems are designed around geohydrologic, infrastructure, and energy demand constraints. This report includes geologic and hydrologic considerations, information on existing wells, and estimated thermal properties of the ground. Infrastructure and energy demand considerations determined during planning and site selection are not included here since considerations for a specific deployment are not in the scope of this report. Links to most referenced data can be found in the Appendix Table A-1 and data extracted from publicly available well logs is transcribed in the Appendix Table A-2. Data on Army owned wells is available for use in any potential study at Fort Wainwright but is not publicly available.

3.1 Geology and hydrology

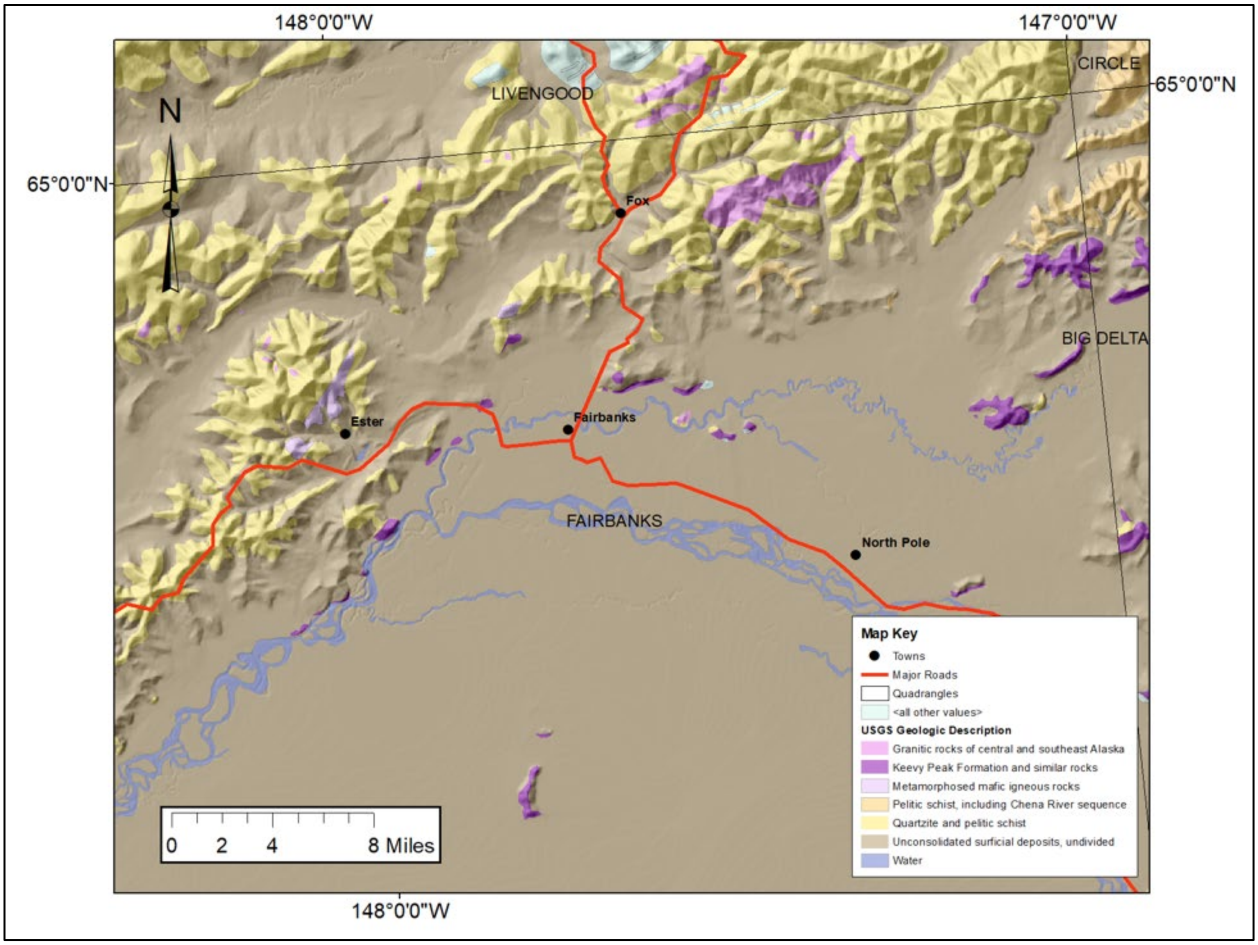
Fort Wainwright and Fairbanks exist on a floodplain south of mountainous terrain. The Chena and Tanana rivers go by the north and south sides of the urban area and merge west of the town. Additionally, the region is intermittent with permafrost (Anderson 1970). This convergence of multiple geologic features produces a variety of different near surface geologic units, spatial heterogeneity, and subsurface phenomenon. Lawson et al. (1996) describes the hydrogeology as "extremely complex" and "difficult to predict the direction and rate of ground water flow." Geochemical studies in the area provide evidence for communication between surface flow activities and shallow ground transport (Hinzman et al. 1999; Verplanck et al. 2008). Figure 2 shows the generalized South-North (S-N) hydrogeological regime in Fairbanks to illustrate this complexity (Anderson 1970).

Figure 2. Hydrogeology cross section in Fairbanks, Alaska. (Image reproduced from Anderson 1970. Public domain.)



Near surface geology is an important constraint on the thermal gradient and recharge properties of the ground, and both anthropogenic and natural surface coverings can alter heat transfer behavior. For example, coarse blocky materials or debris slopes can have thermal gradients 4–7 degrees lower than surrounding mineral soils because of differences in heat transfer physics (Harris and Pedersen 1998). Similarly, mining tailings may induce permafrost formation after deposition under the right conditions (Knutsson et al. 2018). The USGS maintains Geographic Information System (GIS) data covering the surficial geology of the entire state (see Table A-1). Figure 3 shows different geologic units near Fairbanks with data curated from the USGS (Wilson et al. 2015).

Figure 3. Geologic units near Fairbanks, Alaska (data source: Wilson et al. 2015, map made by Engineering Research and Development Center-Cold Regions Research and Engineering Laboratory [ERDC-CRREL]).

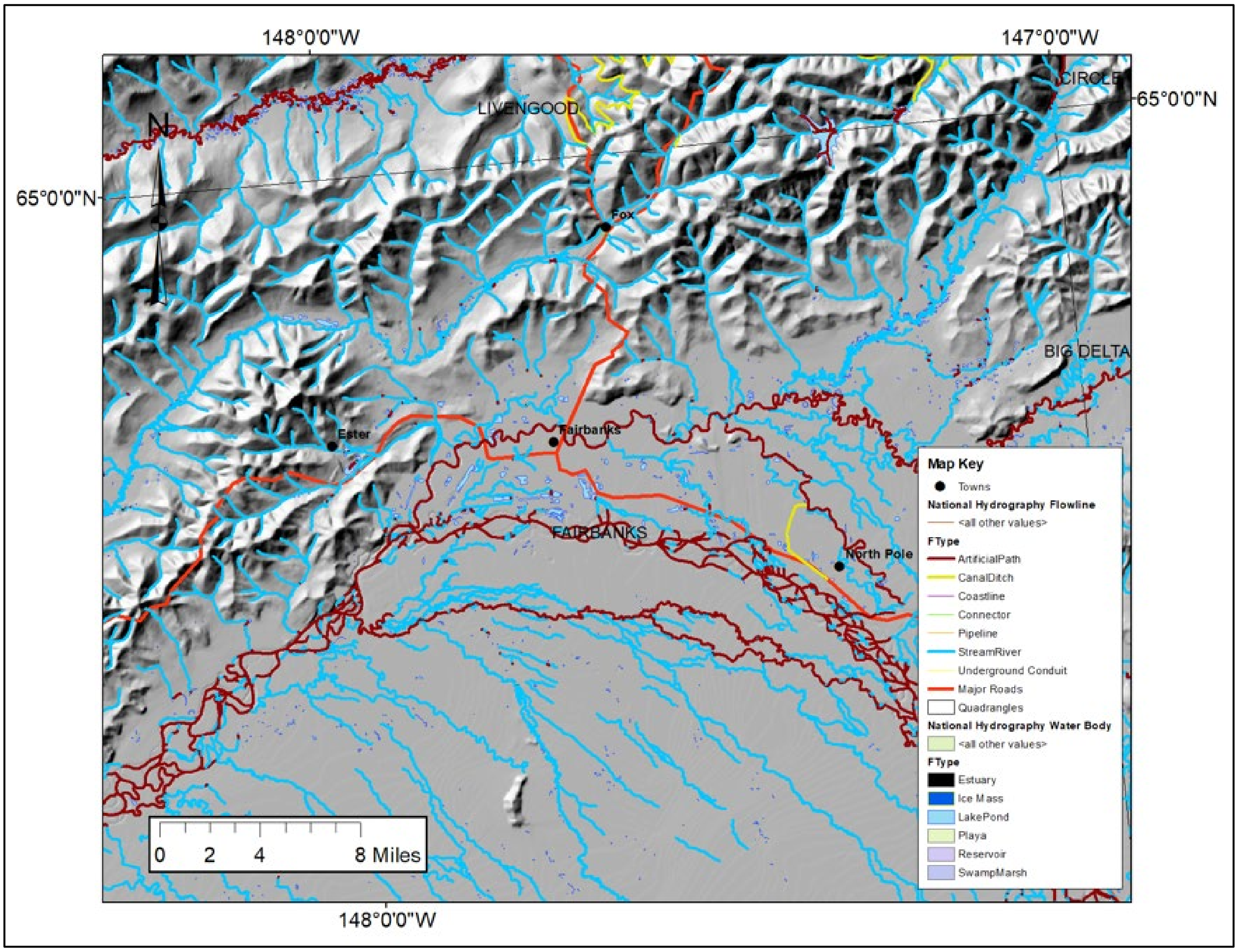


Additionally, the USGS has curated databases of seismic events and hundreds of geochemical composition data from stream sediments in Alaska (see Table A-1). The geochemical database was created for mineral prospecting, but here it can be applied as one additional data source and may provide clues to transport phenomena when examining Fairbanks's scale, which is important as the direction and rate of groundwater flow can alter the performance of shallow geothermal systems (Deng 2004).

The Fairbanks hydrological setting is dominated by the Chena and Tanana rivers, which are tributaries of the larger Yukon River that enters the Bering Sea to the west. This places it roughly in the south-center of the US portion of the Yukon River basin, a primary hydrogeologic unit in Alaska (Callegary et al. 2013). In addition to this, the area is categorized as discontinuous in permafrost (Anderson 1970). These factors make the subsurface hydrologic regime complex, as corroborated by studies local to

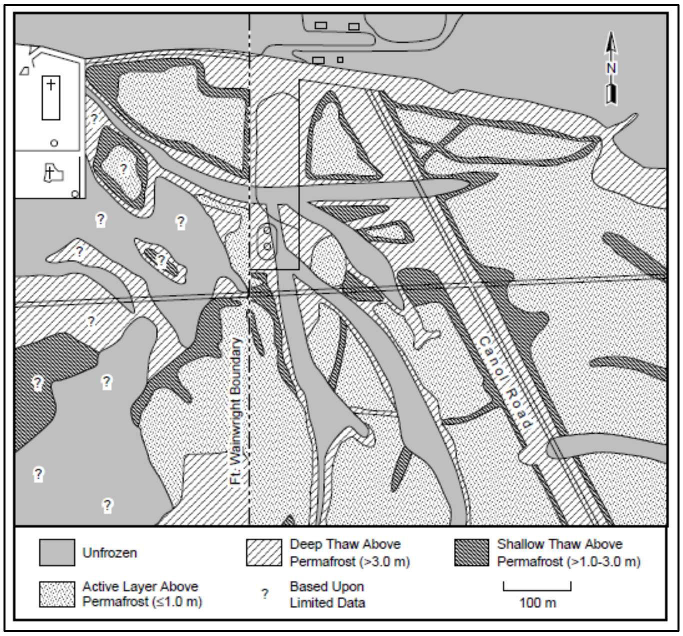
Fairbanks (Lawson et al. 1996; Hinzman et al. 1999; Verplanck et al. 2008). Figure 4 shows an overview of the surface hydrology. The map was created using public USGS data (NHD, n.d.; see Table A-1).

Figure 4. Surface hydrology in Fairbanks Alaska (data source: Bankey et al. 2020 map made by ERDC-CRREL).



Aquifers near Fort Wainwright have been described as occurring “above, below, and adjacent to permanently frozen materials, as well as within thaw zones surrounded by permafrost” (Lawson et al. 1996). Figure 5 shows a permafrost map of the Canol Road study area (within Fort Wainwright) produced by Lawson et al. (1996).

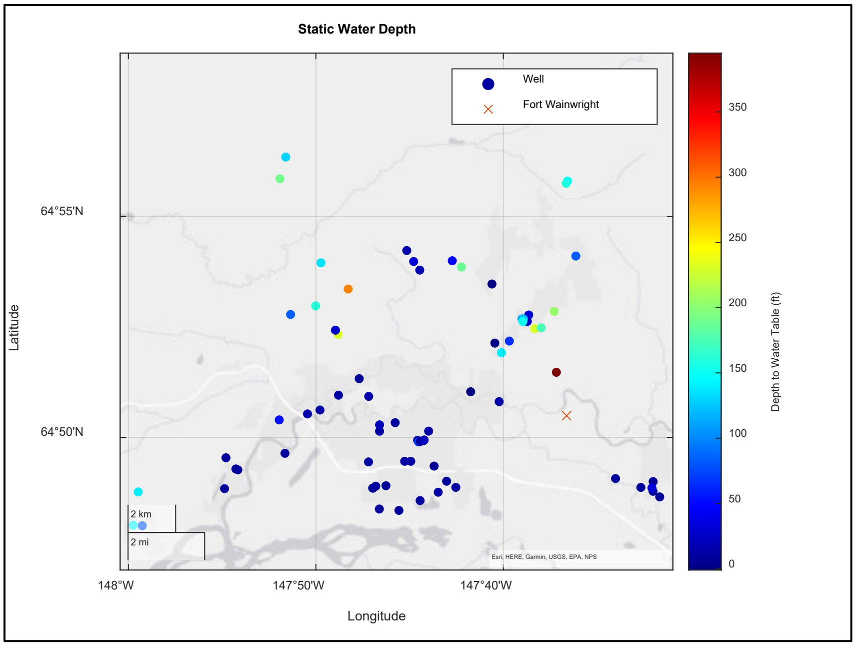
Figure 5. Permafrost extent in Canol Road study area. (Image reproduced from Lawson et al. 1996. Public domain.)



The state of Alaska Department of Natural Resources (ADNR) upholds reporting requirements for drilling of water wells. Part of this is maintaining a database of well log records. Seventy-five well logs recorded 2001–2021 were pulled from the Fairbanks area to create a reference dataset of the subsurface at the borough mesoscale (see Table A-2). This does not include all wells drilled within the area. Well logs for wells drilled on military property are not publicly available, but there is a significant database of over 2,000 pdfs scanned well logs available for reference. The data from these has not been fully transcribed to date.

Both sets of logs are limited in utility and imperfect owing to inconsistent recording practices, but overall, the trends appear to corroborate with descriptions in literature and indicate intermittent permafrost, a heterogenic depth to bedrock, and a top layer of various unconsolidated sediments. For publicly available logs, no pulled wells were within the Fort Wainwright boundaries. ADNR logs that listed wells owned by the Army had location data redacted and are thus unusable. Figure 6 shows the static water depth at time of drilling based on the recorded logs from ADNR (n.d).

Figure 6: Static water depth in water wells near Fairbanks, Alaska (data source: ADNR, n.d.).



Water depths change seasonally, but as seen in Figure 6, areas within the floodplain have water tables near the surface. This begins to change at locations in mountainous terrain where the bedrock is near the surface. Fort Wainwright's approximate location is indicated by the red marker.

Figure 7 shows the depth to basement rock, where basement rock is defined as any type of underlying rock formation as opposed to unconsolidated sediments or soils as described in the well logs (ADNR, n.d.). Some wells never intersected basement rock and were not included in this figure.

Comparison of Figure 6 and Figure 7 shows that most of the logged wells south of Fort Wainwright never intersected bedrock. Most of these wells are relatively shallow and drilling was likely stopped once water was hit. Similarly, the Army owned wells documented rarely intercept bedrock. As such there is a limit to soil and lithology information that can be deduced from fully transcribing all wells into the database.

The catalog of well logs documented at the fort mesoscale is a much denser set of data. Figure 8 shows a location plot of all such wells that have been identified. These are not representative of every well that exists, and there are inconsistencies in record keeping and recording practices. For example, logs that span across multiple decades use different coordinate systems and units and do not contain consistent entries across all logs. Soil and lithology details were not transcribed from all shown to date, but information from these well logs may be of use for site selection and planning of additional data collection (e.g., running surveys down existing wells near a potential new system site).

Figure 7. Depth to basement rock in water wells near Fairbanks, Alaska (data source: ADNR, n.d.).

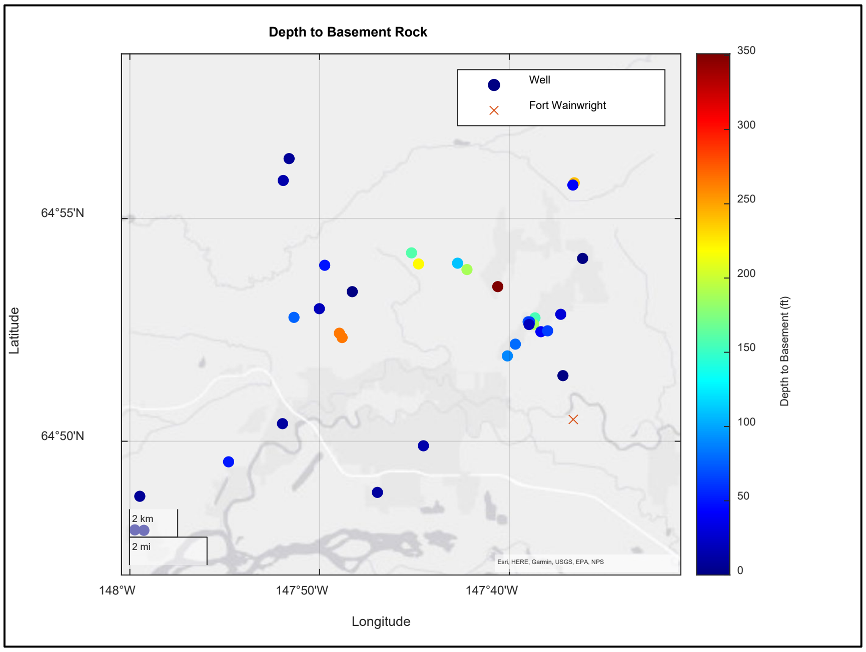
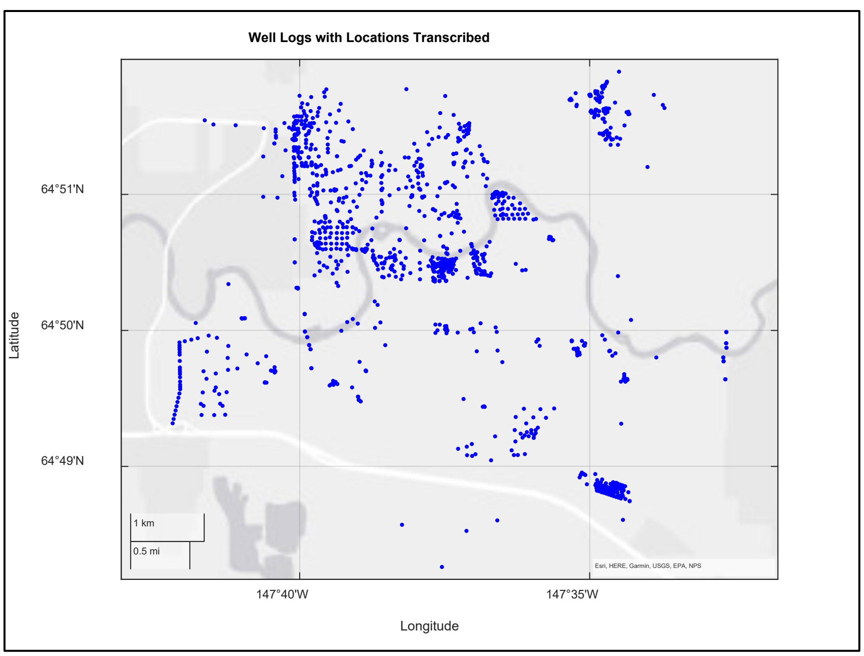
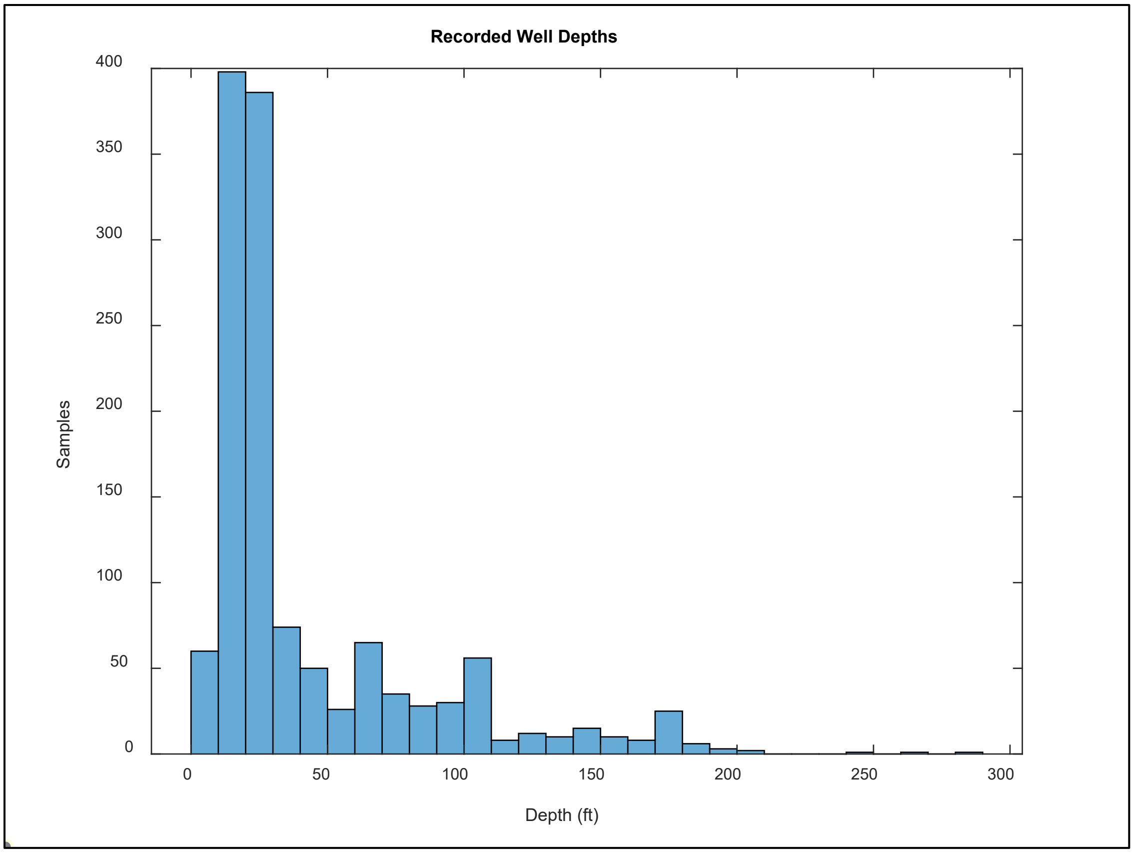


Figure 8. Army-owned wells at Fort Wainwright.



As mentioned previously, most of these well logs do not run deep enough to intercept bedrock and are limited as inputs to subsurface models as a result. Figure 9 shows a histogram of Army owned wells sorted by depth. Most wells do not reach 50 ft total vertical depth, which is not as deep as many architectures of shallow geothermal systems.

Figure 9. Wells sorted by total vertical depth of hole.



While this data is of limited use because of inconsistency and missing information, awareness of the Army owned wells is important for further planning and consideration.

3.2 Geophysical surveys and tests

For the purposes of this study, geophysical surveys include any test recordings and literature results from noninvasive means of sensing and testing such as wellbore surveys, seismic surveys, aerial flyover surveys, and satellite collected data. Publicly available data were collected at a regional and state scale, but this is not of superior resolution and thus is limited in use. These data can help contextualize the Fairbanks mesoscale when combined with other data sources. Publicly available, regional surveys of note include magnetic (USGS 2002) and airborne element concentration (Hill et al. 2009) data. Links to these data can be found in Table A-1.

In addition to publicly available data, specific projects have conducted testing at Fort Wainwright. Most important of these is thermal response testing conducted in a shallow groundwater well. Table 3 shows estimated thermal properties for the ground formation intersected by the tested well. These values should not be taken as indicative of the regime anywhere within the fort, but they are potentially useful during early planning.

Table 3. Estimated thermal properties from testing Fairbanks wellbore (GRTI 2009).

Average Heat Capacity (Btu/ft^3-°F)	Thermal Conductivity (Btu/hr-ft-°F)	Thermal Diffusivity (ft^2/day)
33.0	1.55	1.13

Additional thermal property testing and surveying would likely be required for any potential large-scale system design.

4 Summary

We introduced shallow geothermal concepts, appropriate technologies for Alaska and cold regions, and identified relevant data and literature in preparation of conducting a feasibility study GDHC with UTES model demonstration and design at Fort Wainwright. Large-scale shallow geothermal has been demonstrated in the United Sates in cooling dominant climates, and elements of shallow geothermal technology is proven in heating dominant climates, but deployment of a large-scale GDHC with UTES has not been done in heating dominant climate (a.k.a. cold regions). There is opportunity for deployment of such a large-scale system in cold regions military installations, and Fort Wainwright is at the extreme end of climate and would thus represent an ideal location for data gathering for metric setting for across cold regions installations. These installations have high energy costs of heating and failure of heating systems can have severe consequences. Incorporation of shallow geothermal provides opportunity to enhance resilience by decoupling heating systems from supply chains and providing an efficient source of heat energy that would help support the transition towards NetZero.

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Appendix: Referenced Data

Table A-1. Links to noted datasets.

Data	Publisher	Description	Link	Ref
Geochemical Samples	USGS	Access database of curated sediment sample studies conducted in Alaska, generally done for mineral prospecting	https://mrdata.usgs.gov/agdb/	Granitto 2013
Surficial Geology	USGS	GIS layer of surficial geologic units in Alaska	https://mrdata.usgs.gov/sim3340/	USGS 2015
Aerial Gamma Ray	USGS	Processed GIS layer of detected airborne thorium, uranium, and potassium in Alaska	https://mrdata.usgs.gov/radiometric/	Hill et al. 2009
Aerial Magnetic	USGS	Processed GIS layer and raw Excel data of magnetic surveys conducted in Alaska	https://mrdata.usgs.gov/magnetic/	USGS 2002
Hydrology	USGS	ArcGIS package of hydrologic features and units in Alaska	https://www.usgs.gov/core-science-systems/ngp/national-hydrography	USGS n.d.
Water Wells	ADNR	Alaska state repository of water well logs	https://dnr.alaska.gov/welts/	ADNR, n.d
Faults	ADNR-DGGS	GIS layer with Alaska quaternary and prequaternary faults and areas of high seismicity	http://maps.dggs.alaska.gov/qff/	Koehler 2013

Table A-2. Transcribed Fairbanks water well logs 2001–2021 (data source: ADNR 2021).

Well ID	Latitude	Longitude	Total Depth (ft)	Depth to Bedrock (ft)	Depth to Water (ft)	Year Drilled	Frozen Section (1/0 = y/n)?	Depth to Frozen (ft)	Frozen Thickness (ft)	Metamorphic Intersect (1/0 = y/n)?	Depth to Intersect (ft)	Notes
74678	64.84219	−147.8408	40	NaN	16	2020	0	NaN	0	0	No value (NaN)	—
75016	64.89922	−147.8288	320	50	135.2	2020	0	NaN	0	0	NaN	—
58996	64.89762	−147.7038	208	188	188	2019	1	40	40	0	NaN	—
58616	64.87808	−147.6501	220	70	110.8	2019	0	NaN	0	1	180	—
56834	64.84881	−147.7864	40	NaN	15	2019	0	NaN	0	0	NaN	—
60788	64.81777	−147.5669	90	NaN	9.5	2018	0	NaN	0	0	NaN	—
51033	64.81488	−147.7801	40	NaN	10.5	2018	0	NaN	0	0	NaN	—
51094	64.81441	−147.5444	40	NaN	8.5	2018	0	NaN	0	0	NaN	—
76756	64.81675	−147.7171	17	NaN	9	2017	0	NaN	0	0	NaN	—
44895	64.80624	−147.7769	60	NaN	10	2016	0	NaN	0	0	NaN	—
44901	64.82405	−147.7865	40	NaN	12	2016	0	NaN	0	0	NaN	—
44833	64.83565	−147.7767	60	NaN	14	2016	0	NaN	0	0	NaN	Estimated coordinates based on log, decommissioned
43794	64.8214	−147.9045	40	NaN	10	2015	0	NaN	0	0	NaN	—
43795	64.9309	−147.8653	460	15	191	2015	0	NaN	0	1	15	—
46433	64.83223	−147.7429	196.5	NaN	13.16	2015	1	57.5	82	0	NaN	—
43602	64.87955	−147.6441	240	155.4	30	2015	0	NaN	0	1	30	—
46413	64.83569	−147.7331	202	NaN	13.33	2015	1	57	80	0	NaN	—
43817	64.81416	−147.7825	40	10	12	2015	0	NaN	0	0	NaN	—

Table A-2 (cont.). Transcribed Fairbanks water well logs 2001–2021 (data source: ADNR 2021).

Well ID	Latitude	Longitude	Total Depth (ft)	Depth to Bedrock (ft)	Depth to Water (ft)	Year Drilled	Frozen Section (1/0 = y/n)?	Depth to Frozen (ft)	Frozen Thickness (ft)	Metamorphic Intersect (1/0 = y/n)?	Depth to Intersect (ft)	Notes
46434	64.83212	−147.7374	80.5	NaN	15	2015	0	NaN	0	0	NaN	—
46453	64.83164	−147.7421	73.5	15	73.5	2015	0	NaN	0	0	NaN	—
41857	64.87712	−147.6454	240	187	25	2015	0	NaN	0	0	NaN	—
43593	64.87804	−147.6488	158	63	120	2015	0	NaN	0	0	NaN	—
43576	64.87973	−147.8558	138	78	85	2015	0	NaN	0	1	78	—
46473	64.83175	−147.7405	199.5	NaN	12	2015	1	57.5	83	0	NaN	—
43557	64.81083	−147.5277	40	NaN	8	2015	1	6	9	0	NaN	—
39224	64.83807	−147.7767	80	NaN	21	2014	0	NaN	0	0	NaN	—
36653	64.82563	−147.9133	60	52	11	2013	1	20	32	1	52	No coordinates but address
36655	64.81395	−147.9145	40	NaN	9	2013	0	NaN	0	0	NaN	No coordinates but address
36628	64.8001	−147.9956	200	0	145	2013	0	NaN	0	1	0	No coordinates but address
36654	64.93004	−147.6096	280	240	147	2013	0	NaN	0	1	240	No coordinates but address
42553	64.88572	−147.3377	40	NaN	27	2013	0	NaN	0	0	NaN	No coordinates but address
36656	64.8653	−147.6683	215	90	141	2013	0	NaN	0	0	NaN	No coordinates but address
36652	64.82105	−147.9027	100	NaN	8.4	2013	1	18	62	0	NaN	No coordinates but address

Table A-2 (cont.). Transcribed Fairbanks water well logs 2001–2021 (data source: ADNR 2021).

Well ID	Latitude	Longitude	Total Depth (ft)	Depth to Bedrock (ft)	Depth to Water (ft)	Year Drilled	Frozen Section (1/0 = y/n)?	Depth to Frozen (ft)	Frozen Thickness (ft)	Metamorphic Intersect (1/0 = y/n)?	Depth to Intersect (ft)	Notes
36658	64.82732	−147.8608	80	NaN	10.5	2013	0	NaN	0	0	NaN	No coordinates but address
36659	64.85059	−147.6957	100	NaN	0	2013	1	10	60	0	NaN	No coordinates but address, water level sketchy
35052	64.89124	−147.6768	415	351	−1	2013	1	8	75	1	365	No coordinates but address
36660	65.08961	−147.7297	270	0	160	2013	0	NaN	0	1	0	No coordinate but address
36661	64.81506	−147.771	40	NaN	8.5	2013	0	NaN	0	0	NaN	No coordinate but address
35908	64.91858	−148.1695	155	8	123	2012	0	NaN	0	1	8	No coordinate but address
34466	64.96147	−147.6041	400	6	244	2011	0	NaN	0	1	30	No coordinate but address
36632	64.90178	−147.6022	160	0	84	2011	0	NaN	0	0	NaN	No coordinate but address
35928	64.81271	−147.9913	330	7	140	2011	0	NaN	0	1	7	No coordinate but address
34497	64.81294	−147.5336	40	NaN	10	2011	0	NaN	0	0	NaN	No coordinate but address
33863	64.9	−147.7121	125	110	46	2010	0	NaN	0	1	110	No coordinate but address

Table A-2 (cont.). Transcribed Fairbanks water well logs 2001–2021 (data source: ADNR 2021).

Well ID	Latitude	Longitude	Total Depth (ft)	Depth to Bedrock (ft)	Depth to Water (ft)	Year Drilled	Frozen Section (1/0 = y/n)?	Depth to Frozen (ft)	Frozen Thickness (ft)	Metamorphic Intersect (1/0 = y/n)?	Depth to Intersect (ft)	Notes
33864	64.86971	−147.6613	100	80	66	2010	0	NaN	0	0	NaN	No coordinate but address
33869	64.87706	−147.6493	265	20	151	2010	0	NaN	0	0	NaN	No coordinate but address
33867	64.87218	−147.8135	285	265	232	2010	1	10	70	0	NaN	No coordinate but address
33866	64.89972	−147.7464	260	220	32	2010	1	3	97	0	NaN	No coordinate but address
37988	64.93907	−147.8601	302	7	129	2010	0	NaN	0	1	7	—
33607	64.87381	−147.8159	285	265	28	2009	1	10	70	0	NaN	No coordinate but address
38068	64.83889	−147.7628	195	NaN	10	2008	0	NaN	0	0	NaN	—
34991	64.86354	−146.9651	75	NaN	41	2008	0	NaN	0	0	NaN	No coordinate but address
40853	64.88669	−147.3639	300	20	189	2007	0	NaN	0	1	20	—
31584	64.84927	−147.8132	20	NaN	12	2006	0	NaN	0	0	NaN	No coordinate but address
40264	64.83235	−147.7371	210	NaN	23	2006	1	61	89	0	NaN	—
74737	64.83994	−147.8659	110	10	54	2006	0	NaN	0	0	NaN	—

Table A-2 (cont.). Transcribed Fairbanks water well logs 2001–2021 (data source: ADNR 2021).

Well ID	Latitude	Longitude	Total Depth (ft)	Depth to Bedrock (ft)	Depth to Water (ft)	Year Drilled	Frozen Section (1/0 = y/n)?	Depth to Frozen (ft)	Frozen Thickness (ft)	Metamorphic Intersect (1/0 = y/n)?	Depth to Intersect (ft)	Notes
32395	64.8243	−147.7544	135	NaN	12	2006	1	9	119	0	NaN	No coordinate but address, South Davis Park
32146	64.8243	−147.749	117	NaN	12	2006	1	5	100	0	NaN	No coordinate but address, South Davis Park, shifted longitude to reflect local township/range/section relative to 32395
32294	64.84684	−147.6704	100	NaN	14	2005	0	NaN	0	0	NaN	No address used coordinates for Hamilton acres
31537	64.80572	−147.7595	40	NaN	11	2005	0	NaN	0	0	NaN	No coordinate but address
37308	64.79993	−147.9877	120	0	80	2005	0	NaN	0	0	NaN	No coordinate but address
32148	64.88935	−147.8046	500	0	293	2005	0	NaN	0	1	25	PO box address
31411	64.85552	−147.7948	56	NaN	9	2005	0	NaN	0	0	NaN	No coordinate but address
32007	64.84367	−147.8297	40	NaN	12	2005	0	NaN	0	0	NaN	Approximate coordinates only had street (middle of street)
30301	64.80944	−147.7407	36	NaN	10	2004	0	NaN	0	0	NaN	Approximate coordinates only had street (middle of street)

Table A-2 (cont.). Transcribed Fairbanks water well logs 2001–2021 (data source: ADNR 2021).

Well ID	Latitude	Longitude	Total Depth (ft)	Depth to Bedrock (ft)	Depth to Water (ft)	Year Drilled	Frozen Section (1/0 = y/n)?	Depth to Frozen (ft)	Frozen Thickness (ft)	Metamorphic Intersect (1/0 = y/n)?	Depth to Intersect (ft)	Notes
32324	64.90385	−147.7525	216	160	16	2004	1	20	140	0	NaN	No coordinate but address
32339	64.82248	−147.7282	40	NaN	8	2004	0	NaN	0	0	NaN	No coordinate but address
32138	64.88298	−147.8335	240	20	160	2004	0	NaN	0	0	NaN	No coordinate but address
32023	64.81663	−147.5335	91	NaN	8	2004	0	NaN	0	0	NaN	No coordinate but address
35948	65.0448	−147.4112	200	0	70	2004	0	NaN	0	1	0	No coordinate but address
29694	64.89648	−147.741	180	NaN	19	2003	1	35	115	0	NaN	No coordinate but address
32423	64.81425	−147.5346	50	NaN	35	2003	0	NaN	0	0	NaN	Approximate coordinates only had street (middle of street), water line guessed based on perforations and geology description
33127	64.88088	−147.6214	300	29	205	2002	0	NaN	0	1	29	No coordinate but address
32353	64.85792	−147.6195	503	0	395	2002	0	NaN	0	1	0	Approximate coordinates, listed as at ski lodge unclear where

Table A-2 (cont.). Transcribed Fairbanks water well logs 2001–2021 (data source: ADNR 2021).

Well ID	Latitude	Longitude	Total Depth (ft)	Depth to Bedrock (ft)	Depth to Water (ft)	Year Drilled	Frozen Section (1/0 = y/n)?	Depth to Frozen (ft)	Frozen Thickness (ft)	Metamorphic Intersect (1/0 = y/n)?	Depth to Intersect (ft)	Notes
35728	64.91299	−148.177	155	8	123	2002	0	NaN	0	1	8	No coordinate but address
32154	64.87437	−147.6389	250	40	230	2001	0	NaN	0	1	40	No coordinate but address
29285	64.81443	−147.7089	111	NaN	10	2001	1	25	76	0	NaN	No coordinate but address
28960	64.86894	−147.6742	116	NaN	0	2001	1	3	95	0	NaN	No coordinate but address
30284	64.8126	−147.7246	52	NaN	14	2001	0	NaN	0	0	NaN	Approximate coordinates, based on description of at plumbing building on van horn road
29093	64.81416	−147.7829	40	NaN	9	2001	0	NaN	0	0	NaN	Approximate coordinates, based on description of a warehouse on road
28492	64.8747	−147.633	205	65	175	2001	0	NaN	0	1	65	No coordinates, water unclear
30983	64.9292	−147.6108	220	40	158	2001	0	NaN	0	1	40	No coordinate but address

Abbreviations

ADNR	Alaska Department of Natural Resources
AEA	Alaska Energy Authority
ATES	Aquifer Thermal Energy Storage
BTES	Borehole thermal energy storage
CHP	Combined heat and power
CTES	Rock Cavern Thermal Energy Storage
DH	District heating
GDHC	Geothermal district heating and cooling
GHP	Geothermal heat pumps
GHX	Geothermal heat exchangers
GIS	Geographic information system
GRTI	Geothermal Resource Technologies, Inc.
HQDA	Headquarters, Department of the Army
OSD	Office of the Secretary of Defense
UTES	Underground thermal energy storage

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14. ABSTRACT
The DoD considers improving Arctic capabilities critical (DoD 2019; HQDA 2021). Deployment of shallow geothermal energy systems at cold regions installations provides opportunity to increase thermal energy resilience by lessening dependence on fuel supply and supporting installations' NetZero transitions. Deployment can be leveraged across facilities, for example using Fort Wainwright metrics for implementation of geothermal in cold region bases. Fort Wainwright is an extreme case of heating dominant loads owing to harsh conditions in Alaska, making it ideal for proving feasibility in most heating dominant installations. Proven feasibility and potential mass deployment will help reduce emissions and increase resilience across the DoD cold region network. This report introduces the shallow geothermal energy and storage technology combination that would best fit demonstration in Alaska. Focus is on leveraging shallow, low-temperature geothermal for the development of a larger geothermal district heating and cooling (GDHC) system with underground thermal energy storage (UTES) and geothermal heat exchangers (GHX). Such systems are proven in cooling dominant climates, and individual components are proven in heating dominant climates, but deployment of a larger system in a heating dominant climate is not well established. Deployment at Fort Wainwright would represent an improvement in the technology.

15. SUBJECT TERMS
Alaska energy; Cold regions energy; Geothermal district heating and cooling; Shallow geothermal; Thermal resilience; Underground thermal energy storage

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