Technical Feasibility Study for Deployment of Ground-Source Heat Pump Systems: Portsmouth Naval Shipyard—Kittery, Maine

M. Hillesheim and G. Mosey
National Renewable Energy Laboratory

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Prepared under Task No. WFD4.1002

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List of Acronyms

EWT	entering water temperature
GHE	ground heat exchanger
GSHP	ground-source heat pump
GWHE	groundwater heat exchanger
HDPE	high-density polyethylene
HVAC	heating, ventilating, and air-conditioning
PNSY	Portsmouth Naval Shipyard
SCW	standing-column well
SWHE	surface-water heat exchanger
WHE	water heat exchanger

Executive Summary

The National Renewable Energy Laboratory at the behest of the U.S. Environmental Protection Agency, as part of its RE-Powering America's Land initiative investigated the technical feasibility of deploying ground-source heat pump systems at Portsmouth Naval Shipyard. This report summarizes ground-source heat pump systems types and configurations and identifies which ones may be the most applicable to the shipyard based on local geology and hydrology.

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1 Introduction

Portsmouth Naval Shipyard (PNSY) is a U.S. Navy facility located on a series of conjoined islands in the Piscataqua River between Kittery, Maine, and Portsmouth, New Hampshire ("Portsmouth Naval Shipyard" 2013). PNSY's primary mission is to overhaul, repair, and modernize Los Angeles-class submarines. Toward that end, the shipyard employs approximately 4,700 civilian employees along with approximately 100 U.S. Navy officers and enlisted personnel. The site is dominated by a high-density industrial complex that includes 376 buildings; 116 of these buildings are part of the PNSY Historic District, and 50 of these are listed on the National Register of Historic Places.

Shipbuilding at the site started in 1690, and PNSY became a U.S. Navy shipyard in 1800 ("Portsmouth Naval Shipyard" 2013). In part because of shipbuilding and repair efforts, this site has become contaminated and was designated as a U.S. Environmental Protection Agency Superfund site in 1994 ("Waste Site Cleanup and Reuse in New England" 2013).

The U.S. Environmental Protection Agency, as part of its RE-Powering America's Land initiative[1], requested the National Renewable Energy Laboratory to conduct a study to determine the technical feasibility of deploying ground-source heat-pump (GSHP) systems to help PNSY achieve aggressive energy reduction goals mandated by the Energy Policy Act of 2005, Executive Order 13423 and Executive Order 13514, and U.S. Department of Defense and U.S. Department of Navy policies. The overall objective of this study was to assess areas at PNSY that could support GSHP system installation based on land use and local geologic and hydrologic constraints.

[1] http://www.epa.gov/oswercpa/

2 Background

2.1 GSHP Systems

GSHP systems, also referred to as geothermal heat-pump or geoexchange systems, are electrically powered space heating and cooling technologies that take advantage of the earth's (or surface water's) relatively constant temperature, below certain depths, to provide building space conditioning. (The subsurface is a source of heat in the winter and an efficient heat-rejection medium in the summer.) GSHP systems are clean (there are no on-site greenhouse gas emissions, because the systems do not combust fuel), energy-efficient technologies that can effectively replace conventional heating and cooling technologies and improve building comfort.

The primary benefit of installing a GSHP system is a reduction in energy consumption and a resultant decrease in utility expenses. In terms of heating, GSHP systems have a coefficient of performance of 3.0 or higher. This means that for every unit of energy consumed, three units are generated (i.e., GSHP systems are 300% or more efficient). In comparison, the efficiencies of most boiler-based heating systems are 80% or less. For space cooling, GSHP systems have an energy-efficiency ratio in excess of 14.5 (27 is the market best), which is approximately twice the energy-efficiency ratio of conventional air-conditioning. Energy savings of 70% can be achieved; 50% is the norm.

Other GSHP system benefits include:

1. Increased conditioned space comfort: Heat pumps run almost constantly, ramping heating and cooling up and down as needed (i.e., there are no on-off fluctuations); provide superior humidity regulation; and are quiet.
2. Safe operation: Heat pumps are electric and do not combust fuel, which also results in significantly reduced greenhouse gas emissions.
3. Free to low-cost domestic hot water: This can be achieved by adding a de-superheater or an additional heat pump or by installing a three-phase heat pump.
4. Low operations and maintenance costs: Annual costs are typically 50% to 70% less than conventional systems.
5. Long warranty periods: Typically, warranties are 25 years for the interior components and 50 years for the loop-field piping.

GSHP systems work optimally in climate regimes where heating and cooling are relatively balanced. However, they are versatile, and with minor system adaptation, modification, or hybridization, GSHP systems can be deployed effectively in heating-dominated or cooling-dominated climates.[2] Additionally, GSHP systems can be used to supply hot water for domestic purposes and/or commercial or industrial applications (e.g., snow melting, brewing).

Two main components comprise GSHP systems: the interior mechanical system and the exterior loop field, also referred to as a ground heat exchanger (GHE) or water heat exchanger (WHE).

[2] Hybrid configurations combine loop-field technology with conventional technology to reduce loop-field size and thereby cost. In heating-dominant situations, they can be combined with condensing boiler or solar thermal heating technologies. In cooling-dominated regimes, they can be combined with fluid coolers or cooling towers.

Interior equipment consists of the heat pumps and the heating, ventilating, and air-conditioning (HVAC) distribution system.

Building function is probably the single most important factor in determining whether significant energy savings can be achieved with GSHP systems. GSHP systems are best suited for large loads such as commercial buildings and schools (Federal Emergency Management Program 2003). Another important factor is whether the system will be installed in a new building or retrofitted into an existing one (Kavanaugh and Rafferty 1997). In new construction, the best interior distribution system is a hydronic (i.e., radiant) system that is installed in the floor and/or ceiling, and a traditional forced-air delivery system is the next-best option. In a retrofit, it is best to use the existing distribution system as much as possible, unless the system utilizes radiators or radiant baseboards. In these cases, the distribution system should be retrofitted to forced-air or radiant floor or ceiling systems. This is not because the GSHP system will not function (it will, but not optimally) but because indoor comfort would be greatly improved.

Loop fields are used to reject or extract heat from the subsurface or water body and can be configured in a number of ways that comprise open or closed loops. The type (open versus closed) and configuration (vertical, horizontal, or surface water) are constrained by accessibility to surface or groundwater and subsurface parameters, such as thermal conductivity, thermal diffusivity, and in situ temperature.[3] The size of a GSHP system, which is critical to its overall performance, is a function of the building's heating and cooling load (which is a combination of the building's use, envelope quality, and local climate) and loop type and configuration.

Open-loop (or WHE) systems can be installed where groundwater is readily accessible and/or where surface water (e.g., river, stream, lake, pond) can be accessed. Water is typically pumped through a plate heat exchanger to mitigate fouling the heat pump before being discharged or reinjected. In rare cases where the groundwater or surface water is exceptionally clean, water can be pumped directly through the heat pump. Important constraints on the ability to utilize an open-loop system are local, state, and/or federal regulations, especially in areas where contamination may be present.

Closed-loop (or GHE) systems circulate a fluid (typically a water-antifreeze mix, such as glycol) through a high-density polyethylene (HDPE) pipe. Closed-loop systems are installed in areas where groundwater or open water is either inaccessible or not permissible. Typically, GHEs require minimal permitting. Loop fields, whether open or closed, can be installed horizontally, vertically, or in surface water (Figure 1).

[3] Thermal conductivity (BTU/h-ft-°F) is the ability of a medium to transport heat. Thermal diffusivity (ft^2/d) is the ratio of heat transport ability to heat storage capacity; the higher the value, the more rapidly temperatures can change. And in situ subsurface temperature (°F) is the average temperature of the medium at depth.

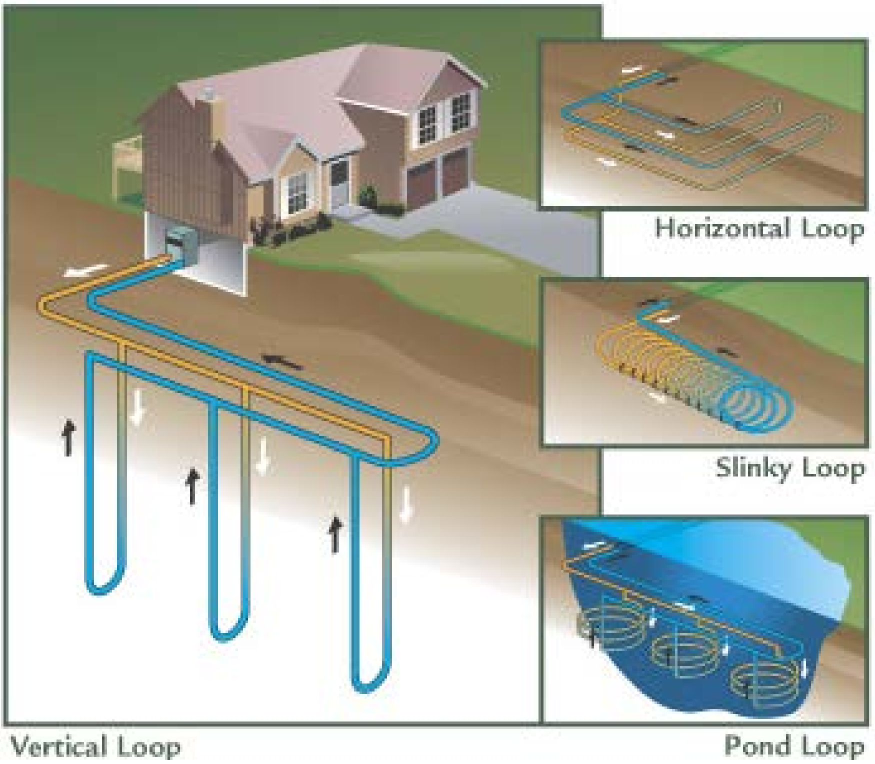

Figure 1. Illustration of various loop-field configurations

Horizontal systems come in the form of large, areal excavations (pits) or trenches in which pipe is laid out linearly or in slinky form (Figure 2). Horizontal systems are closed-loop systems that need to be installed at a depth sufficient to minimize the seasonal influence of solar irradiance on the subsurface. Horizontal systems are typically installed at depths between 3 ft and 8 ft below the ground's surface, depending on climate and soil properties. Horizontal loops can require large land-area disturbances for installation (Table 1) relative to vertical loops; however, they can be installed under parking lots, athletic fields, and within landfill caps, etc.

Figure 2. Examples of horizontal GHEs: (A) areal linear; (B) areal slinky; (C) trench, horizontal slinky; and (D) trench, vertical slinky

Table 1. Land Area Required to Provide 1 t of Heating and Cooling at PNSY for Various Loop-Field Configurations

Loop Type	Area (ft^2) per ton	Area (ft^2) Required for 100 tons
Horizontal	1,000–1,500[4]	100,000–150,000
Slinky	800–1,200[4]	80,000–120,000
Pond	50–100[5]	5,000–10,000

A single borehole or a series of boreholes comprise vertical systems, and they can be open or closed (Figure 3). In an open-loop vertical system, which is often referred to as a groundwater heat exchanger (GWHE), one or more boreholes are completed in an appropriate water-bearing formation (i.e., aquifer), and water is produced from the formation and then discharged or reinjected after passing through the heat exchanger/heat pump.

In a closed-loop vertical GHE, a u-shaped HDPE pipe is installed and grouted in place in each borehole. The number of boreholes, their spacing, and depth (described in Section 3.1.2) are dependent upon the length of loop needed to service the building load, which, in turn, is a function of the aforementioned subsurface parameters. As a result of space constraints in developed areas and regulatory issues, closed-loop vertical GHEs are becoming the most common form of loop installation.

[4] Assumes installed 6 ft below the ground's surface
[5] Assumes installed at or below 8-ft water depth

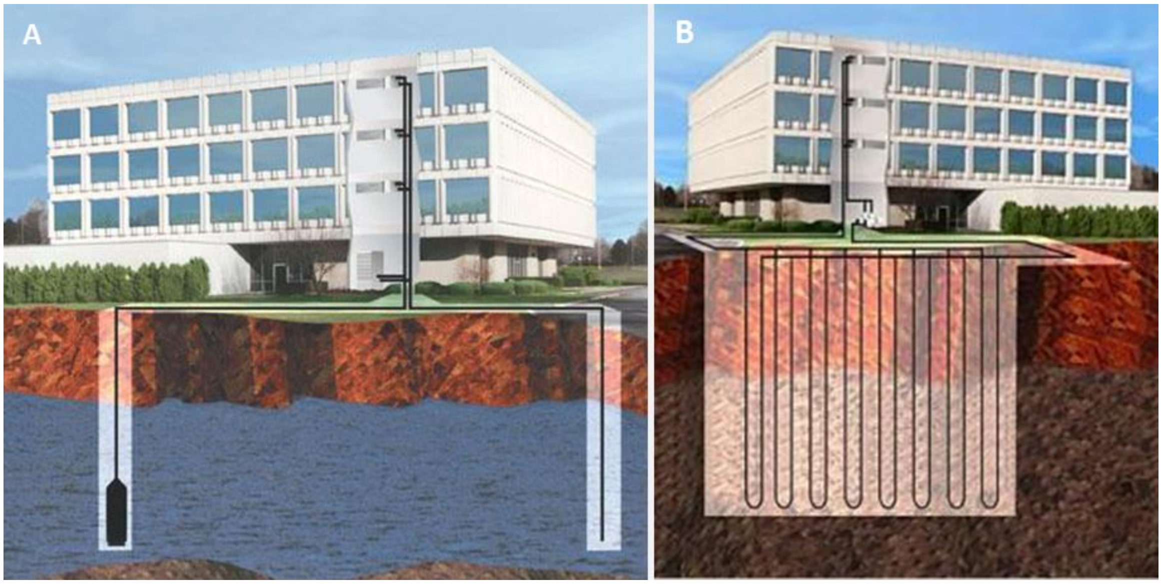

Figure 3. Examples of vertical systems: (A) open-loop GWHE and (B) closed-loop GHE

Surface-water loops, also called surface-water heat exchangers (SWHEs), can be either open or closed and can be placed in ponds, lakes, rivers, wetlands, and even oceans. The primary considerations for the placement of a SWHE are the depth at which the loop (or inlet/outlet) is installed and its proximity to areas of watercraft traffic. Similar to a horizontal GHE, the loop must be placed at a depth at which the influence of seasonal changes in near-surface-water temperature (including icing) and fluctuations in water level (including diurnal fluctuations in tidally influenced areas) are mitigated. More often than not, GSHP systems utilizing ponds or lakes deploy closed-loop systems, either via HDPE pipe coiled in cages or metal-mat heat exchangers. There are very few examples of river or ocean installations because of strong currents, tidal influences, and/or wave action.

Figure 4. Example of a closed-loop SWHE

More recently, innovation and ingenuity have resulted in a number of building-integrated closed-loop concepts. Examples include the integration of HDPE pipes into support piers for buildings, bridges, and building foundations, with the pipes intertwined in the rebar superstructure (Figure 5); however, these concepts apply only to new construction. Another potential alternative could be to integrate HDPE pipes into concrete seawalls; however, no examples have yet been found to determine this feasibility.

Figure 5. Examples of (A) pier and (B) foundation-integrated GHEs

2.1.1 General Design Considerations

GSHP system design considerations fall into two categories: building (interior) and loop field (exterior). Issues such as available land area, utility locations, historical nature of buildings, local codes and regulations, and future expansion (master planning) are also important considerations.

Interior considerations include knowledge of a building's peak (Btu/h) loads and cumulative (Btu) load profile, the type of interior heating and cooling distribution system, and the building's envelope condition. Building load information is a key input to properly size a loop field. If a loop field is undersized, the system will not perform at acceptable or expected levels; if it is oversized, money will be unnecessarily wasted on excessive loop installation. Building loads should be calculated using methods approved by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

The envelopes of older buildings are typically inadequate and should be addressed prior to any HVAC improvement, because true savings will not be realized if a new heating and cooling system is installed in a building that is under-insulated or drafty.

Exterior considerations include establishing a small, consistent range of entering water temperature (EWT) from the loop field to the heat pump(s). The overall efficiency of a GSHP system is most dependent on the EWT, which, in turn, is a function of subsurface and water body parameters. A good GSHP system designer will complete an iterative analysis to establish the minimum and maximum EWT to optimize the size of the loop field and maximize the coefficient of performance and energy-efficiency ratio of the system. General considerations for various loop-field configurations are listed in Table 2.

Table 2. Design Considerations for Various Loop-Field Configurations

Loop Configuration	Considerations
Horizontal	• Installation depth (including frost depth and seasonal temperature changes) • Land availability and infrastructure • Depth to groundwater and/or bedrock • Seasonal and diurnal (e.g., tidal) influences on water table
Vertical	• Depth (based on subsurface parameters) • Spacing (minimum of 20 ft) • Presence or absence of groundwater • Presence of contamination • Land availability and infrastructure
Surface Water	• Depth of water body • Installation depth (including icing during winter and overheating during summer) • Current, tide, and/or water-level fluctuations • Watercraft traffic

A key consideration for a closed-loop vertical GHE is a thermal response test, which seeks to determine the average thermal conductivity throughout the entire length of the vertical borehole (or tested zone) as well as in situ temperature and thermal diffusivity. A thermal response test is completed to prevent over- or under-sizing a loop field and improve the contractor's knowledge of the subsurface.

The bottom line is that GSHP systems must be (1) sized correctly, in terms of both load and loop, and (2) installed correctly for the system to perform optimally. Therefore, it is highly recommend that the U.S. Navy properly vet their GSHP system designers and installers and require them to (1) be certified (e.g., by the International Ground-Source Heat Pump Association or North American Technician Excellence) and (2) have a proven track record of successful installations.

2.2 Local Hydrogeology and Climate

PNSY is built on 278 acres of conjoined islands (including Pumpkin, Dennett's, Seavey, Jamaica, and Clark's Islands) approximately 90 acres of which is filled land (EPA 2013). The islands are low- relief bedrock highs of the Kittery Formation (composed of meta-sedimentary rocks) with a thin veneer of overburden (mostly glacial till, alluvium) and/or fill materials (Klink 1995). In general, the overburden is thinnest at the interior of the historical islands and thickest in the fill areas. For example, depth to bedrock at the island interior is approximately 5 ft and increases to approximately 15 ft along the boundaries. Within fill areas, depths to bedrock can range from 10 ft to 70 ft.

Groundwater is encountered within both the (1) moderately-to-high permeability, pore-dominated, unconsolidated overburden and fill and (2) lower permeability, fracture-dominated bedrock at PNSY (Klink 1995). Groundwater is shallow (typically 10 ft below the ground's surface). Groundwater levels along the shoreline are influenced by tidal fluctuations in the Piscataqua River, although the influence diminishes toward the island interior. Groundwater flow generally mimics the bedrock surface topography and is influenced by the thickness and composition of the overburden and tidal fluctuations. (The diurnal tidal changes are up to 8 ft.) In general, groundwater flows from the original island interior toward the current coastline, and net groundwater flows outward into the Piscataqua River, despite tidal effects near the shorelines that result in a localized back-and-forth movement of water between the overburden and bedrock. In addition to local groundwater, two freshwater ponds are located in the central portion of the facility.

Local climate is described as humid maritime with cold, snowy winters and warm summers. The average annual air temperature is approximately 54°F, with average lows and highs ranging from 34°F to 80°F, respectively ("Portland, Maine" 2013). The climate at PNSY is heating dominated, with 4,522 heating-degree days compared to 371 cooling-degree days. It is worth noting that most of the buildings at PNSY are used for commercial and industrial purposes; in general, these types of buildings have higher cooling demands than degree-day estimates might indicate (i.e., the heating and cooling loads are more balanced than indicated by local climate).

3 Technical Feasibility

This section focuses on identifying areas where GHEs could be installed (Figure 6) and the technical feasibility for installing each type of GHE described in this document.

Figure 6. Map showing potential locations for GHEs, such as (green) mostly open grassy areas, (purple) parking lots, (blue) ponds, (orange) landfill cap, and (red outline) less-than-moderate current zones

3.1 Loop-Field Types

In general, GWHEs can be installed anywhere a building does not currently exist, such as under parking lots, streets, within landfill caps, or green spaces. However, because of the unique configuration of each GHE, local geology and hydrology, and localized contaminated land, siting certain GWHEs can be highly limited. Another consideration is the distance from a GWHE to the building location of the load demand center. GWHEs do not necessarily need to be directly adjacent to a demand center, but they should be within 500 ft.

A primary concern of any GWHE system that comes into contact with or uses river and/or groundwater is that the temperature of both is near the low end of the EWT range for the heat pumps. A temperature that is too high could impact the GWHE's ability to operate at high enough efficiency during heating season to actually reduce energy consumption.

3.1.1 Horizontal GHE

Horizontal GHEs must be installed deep enough to minimize the influence of seasonal changes on subsurface temperatures. At PNSY, the minimum depth below the ground's surface is likely to be greater than 5 ft (most likely 6 ft to 7 ft) because of the area's climate regime. In general, this limits installation areas to the margins of the island and areas of fill between the predevelopment islands, because the thickness of the overburden and fill is not near enough to the island center.

A potential limiting factor to installing horizontal GHEs in the shoreline margin is the shallow groundwater that is influenced by diurnal tidal fluctuations. If a horizontal GHE were to be considered for the shoreline margin areas, it would need to be buried deep enough to mitigate the tidal oscillation (greater than 8 ft), and doing so may be too costly.

The overburden and fill thickness in the vicinity of the gymnasium (Figure 6) appears adequate to support a horizontal GHE. Additionally, the landfill cap has potential; however, few buildings could be serviced by the loop, and regulator buy-in would be required.

3.1.2 Vertical GHE

Closed-loop vertical GHEs require 4-in diameter boreholes at a minimum of 20-ft spacing, and they are typically drilled 250 ft to 400 ft deep (although deeper is possible). In general, each borehole is designed to provide 2 tons of thermal capacity (Ross 2010), the primary variable being borehole depth determined by thermal response test properties. For a commercial building with a 100-t thermal demand, approximately 50 boreholes would need to be drilled in a land area requirement of approximately 16,000 ft^2, which is much less than would be required for a horizontal GHE (see Table 1) but more than that for a GWHE (see Section 3.1.3).

A benefit of this type of system is that the HDPE loop is grouted in place, which inhibits vertical water movement along the boreholes and mitigates the potential for the migration of contamination. Additionally, installing vertical GHEs eliminates shallow subsurface issues caused by seasonal and/or diurnal temperature fluctuations.

The primary concern about a vertical GHE is drilling through bedrock. Hard-rock drilling is not a technical issue; however, this may cause the GHE to not be economically viable. In most vertical GHE installations, wells are completed in unconsolidated or sedimentary formations, which are much easier to drill than harder meta-sedimentary or volcanic rock. Standing-column wells (SCWs; discussed next), however, require hard rock and may provide an alternative to traditional vertical GHEs.

3.1.3 GWHE

GWHE systems with the most potential at PNSY would be open-loop doublets and/or SCWs. The primary concern about either type is related to the open nature of the systems, which could allow contamination, if present, at PNSY to migrate to uncontaminated formations. This could potentially be mitigated with sufficient well engineering (e.g., casing and sealing to depths well below contaminated zones).

Open-loop doublets—one or a series of producer(s) and injector(s)—can typically meet 1 ton of cooling for every 2 gpm of produced water (Ross 2010). This equates to 200 gpm to cover 100 tons of thermal capacity. Based on a review of PNSY well data, it is unclear whether this is an obtainable flow rate from wells completed in the bedrock, which would potentially avoid contaminated groundwater. Even with a well spacing of at least 150 ft, open-loop doublets require less land area (<1,000 ft^2) than that required by closed-loop vertical GHEs. Well diameters tend to be on par with typical water wells, and drilling is done with larger rigs than those typically used for closed-loop vertical GHEs. An example of this type of system exists at the Colorado State Capitol Building in Denver[6].

An alternative would be to utilize existing pump and treat systems (if present) in conjunction with a plate heat exchanger to provide thermal capacity.

An SCW is a large-diameter (8-inch), open-hole well (except for casing through unconsolidated overburden) with an inner shroud liner that circulates water from top to bottom outside the shroud and from bottom to top inside the shroud (Ross 2010). Wells tend to be much deeper than open- or closed-loop vertical boreholes, typically approximately 750 ft to 1,500 ft. A single SCW can provide up to 20 t of thermal capacity, resulting in fewer wells than required for either open- or closed-loop vertical systems. For example, for a 100-ton commercial building, at least 5 wells would need to be drilled at 50-ft spacing, which would result in a land requirement of $<2,000\ ft^2$.

Many installers believe that SCWs are the best application in hard crystalline rocks because they reduce the risk of borehole collapse, which reduces the need for a liner (Ross 2010). SCW systems are becoming more common, especially in the northeast, and are potentially ideal for densely developed areas. Again, the primary concerns about SCW installation at PNSY are difficult drilling and risk of contaminant migration within the boreholes. Both of these concerns can be mitigated by hiring the right driller with the right equipment and through proper well design.

3.1.4 SWHE

There are three potential applications for SWHEs at PNSY: pond, river, and building or foundation integrated. Recall that these types of loops need to be installed at a depth at which thermal stability of the water column is at a minimum (i.e., deep enough to be uninfluenced by seasonal temperature changes or diurnal tidal fluctuations).

Two ponds are located in the south-central portion of PNSY that could potentially be used by an open- or closed-loop system, depending on depth. If the system were open loop, a filter system and plate heat exchanger would have to be included to prevent fouling of the heat pump(s). In a closed-loop system, a sufficient areal extent below 8 ft of water depth would have to exist to service the heating and cooling load of the building or buildings to which the GHE was attached (Table 1).

Placing closed-loop systems in moderate-current zones (identified in Figure 6) is another possible solution, but it is unclear whether either area is deep enough to permit safe watercraft movement at lowest tide with loop cages placed at the bottom. (The cages are typically 3 to 6 ft high). Additionally, the two areas identified at this time are not close to many buildings.

As mentioned previously, an innovative GHE concept is the integration of HDPE pipe into building foundations and/or building piers, which would only be done in newly constructed buildings. Another option would be integration into the seawall. This would permit more buildings to be serviced by GSHP systems and could potentially mitigate the issue of tidal fluctuations; however, additional design work outside the scope of this project would be required

[6] http://www.chevronenergy.com/documents/CaseStudies/Colorado_Capitol_Complex.pdf

to verify the feasibility of this, because there is little published information regarding these types of systems. The National Renewable Energy Laboratory does, however, have expertise in loop-field integration with building foundations that could be leveraged to answer this question. A concern would be low EWT caused by the cool river water or groundwater and its effect on the ability of the heat pump to optimally heat a building.

3.2 Specific Sites

PNSY requested more in-depth investigation of two areas: the parking lot areas near the gymnasium and the parking lots adjacent to the west of B306.

3.2.1 Gymnasium Parking Lot

The PNSY gymnasium is located in the east-central portion of the installation. It is surrounded by a number of buildings that could be serviced by a GHE. Approximately 100,000 ft^2 of open land and parking lots comprise the area that could be utilized for a GHE (Figure 6). Based on the data and information provided, three GHE types are recommended for this area: horizontal slinky, closed-loop vertical, and SCW. The matrix in Figure 7 illustrates the potential for these systems.

Gymnasium Parking Lot	Horizontal Slinky	Closed-Loop Vertical	SCW
Thermal load	L	M	H
Constructability	M/L	M	M
Space constraint	L	M	H
Environmental concerns	H	H	M
Viability[7]	M	H	M
OVERALL	M/L	M	M/H

Figure 7. Success matrix for the gymnasium parking lot—green is high probability, yellow is medium, and red is low

A horizontal slinky GHE could provide 80 to 125 tons of capacity. It would require the excavation of pits or trenches to depths of at least 6 ft. Based on geologic data, it appears that overburden or fill thickness would be adequate to accommodate the required depth of the slinky GHE; however, this would need to be confirmed. Land disturbance during installation would be extensive; because of space constraints, this may pose a serious developmental barrier.

Between 60 and 80 closed-loop vertical GHE boreholes at 20-ft spacing could be installed in the defined area to provide approximately 120 to 160 tons of thermal capacity. Installing a closed-loop GHE would mitigate issues with contaminant migration through the boreholes. The primary concern would be the potential for complicated or difficult drilling conditions through zones of

[7] Viability is a function of the local hydrologic conditions. For a horizontal system, it accounts for performance impacts from tidal or water table fluctuations. For closed-loop vertical systems, it accounts for tidal or water table fluctuations and drilling conditions. And for SCW, it accounts for drilling conditions and groundwater presence or production amounts.

fill and into bedrock, which could be overcome by hiring a competent driller with an appropriately sized rig.

Approximately 12 SCWs drilled at 50-ft spacing could be installed in the defined area to provide 120 to 240 tons of capacity. The land disturbance would be much less than that for the slinky GHE, but well design considerations may need to be made to mitigate contaminant migration.

An approximate 35,000-ft^2 grassy area to the west of the gymnasium parking lot was not considered in this assessment, but it may be worth doing so if a GSHP system project is desired and less land disturbance is warranted.

3.2.2 B306 Parking Lots

Building B306 is located on the northern shore of PNSY. To the west-southwest is a parking lot that covers approximately 200,000 ft^2. Across Goodrich Avenue is another approximate 50,000-ft^2 parking lot. Based on the data and information provided, two GHE types are recommended for this area: closed-loop vertical GHE and SCW. A horizontal slinky is not recommended, because it would require pits or trenches to depths of at least 8 ft to be excavated to mitigate the influence or impact of tidal fluctuations on the GHE. Also, extensive land disturbances during construction could significantly impact PNSY operations. The matrix in Figure 8 illustrates the potential for these systems.

B306 Parking Lot(s)	Closed-Loop Vertical	SCW
Thermal load	M	H
Constructability	M	M
Space constraint	M	H
Environmental concerns	H	L
Viability[3]	H	M
OVERALL	M/H	M

Figure 8. Success matrix for the B306 parking lot(s)—green is high probability, yellow is medium, and red is low

Between 150 and 200 closed-loop vertical GHE boreholes at 20-ft spacing could be installed in the defined area to provide approximately 300 to 400 tons of thermal capacity. Installing a closed-loop GHE would mitigate issues with contaminant migration through the boreholes. The primary concerns are the potential for difficult drilling conditions through zones of fill and into bedrock (discussed above) and ensuring that the GHE design accounts for tidally influenced water table fluctuations.

Approximately 30 SCWs drilled at 50-ft spacing could be installed in the defined area to provide 300 to 600 tons of capacity. As with the gymnasium, land disturbance would be much less than that the slinky GHE. Well designs would need to take into consideration the potential for contaminant migration (if contaminants are present) and the tidal influence on the local water table. Both of these issues could be overcome by casing the wells into the crystalline basement rock to depths below the contaminant level.

4 Summary

The National Renewable Energy Laboratory investigated the technical feasibility of installing GSHP systems at PNSY, with specific emphasis on the GWHE. A well-designed, installed, and maintained GSHP system will work for many decades, and a closed-loop system especially does not pose a threat to the environment. GSHP systems have the potential to greatly reduce the on-site consumption of fossil fuels at PNSY and thereby reduce operating costs to the Navy.

4.1 Recommendations

Although contamination of the subsurface at PNSY is not ubiquitous, it is an issue that is often not encountered at typical GSHP system installation sites. In general, closed-loop configurations are better suited for deployment in contaminated lands. Of the closed-loop configurations described in this assessment, the best option is a closed-loop vertical GHE. These can be installed where adequate open land is available, especially in areas were contamination is or potentially is an issue. Casing the holes through the overburden or fill should be required to ensure borehole stability prior to installing the HDPE u-tube. In areas where the water table is tidally influenced, care must be taken to account for changes in the water table that may impact the performance of the GHE.

SCWs provide a potentially attractive option for buildings where land area is limited, building loads are large relative to the available land area, and contamination is less of a concern. If an SCW were determined to be the best in an area that is or may be contaminated, it should be designed to reduce the chances of contaminant migration. It is not recommended that an SCW be installed in areas where the water table is influenced greatly by tidal fluctuations, unless the SCW is cased to depths well within the water table.

In some instances, horizontal systems may be a good alternative, but horizontal systems of any type are not highly recommended at PNSY, because overburden is thickest along the coastline and the impact of tidal fluctuations on the local water table will adversely impact GHE performance. Other configurations are viable, such as a closed-loop pond system and a closed-loop GWHE integrated into the building or seawall, but more study is needed. Finally, a GWHE-doublet system may be viable if the deeper bedrock can be proven to produce adequate amounts of water (>100 gpm) or if a pump-and-treat system exists that can be modified to accommodate the GSHP system.

A specific recommendation is to focus on one or two buildings or sets of buildings located adjacent to land parcels, parking lots, or ponds that are in need of heating-and-cooling system upgrades. When these buildings or sets of buildings are identified, site-specific technical and economic feasibility and viability assessments should be completed using building load information, the information provided in this assessment, and GSHP cost information.

4.2 Path Forward

The proposed Phase II of this study is to identify a building or area or set of buildings or areas for which a more detailed assessment of GSHP system potential is warranted. Based on the study thus far, it is recommended that the gymnasium and other nearby buildings be considered, because the building density is high, open space is available, and the tidal influence on the local water table is negligible.

Information required in Phase II includes the identification of specific buildings, each building's load data (peak and cumulative), or estimates, as well as the current HVAC system configuration, age, and efficiency.

Phase II will also focus on developing a life-cycle cost assessment; therefore, local HVAC installers and drilling companies will need to be contacted to determine capital and installed cost information. Additionally, energy cost information will need to be compiled. Also, energy service companies (ESCOs) may need to be interviewed to determine what return on investment they desire when entering into a HVAC retrofit project involving GSHP systems.

Finally, PNSY has expressed interest in another feasibility study focused on surface-water GSHP systems for cooling their three dry-dock areas.

5 References

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