HEET Kickstart – Deerfield Networked Geothermal Feasibility Study

DRAFT Technical Report

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Glossary

Term	Definition
GHG	Greenhouse gas
CO_2	Carbon dioxide
TEN	Thermal energy network
BGS	Below ground surface
WSHP	Water-source heat pump
ASHP	Air-source heat pump
GSHP	Ground-source heat pump
ccASHP	Cold climate air-source heat pump
COP	Coefficient of performance
NREL	National Renewable Energy Laboratory
IRA	Inflation Reduction Act
USGS	United States Geological Service
EUI	Energy use intensity
ROW	Right-of-way
ROI	Return on investment

1 Executive Summary

Heating and cooling demand in the buildings sector is responsible for about a third of all energy consumption in Massachusetts.[1] Natural gas is currently the main fuel source that provides heating energy to residential buildings across the state. While air-source heat pumps are becoming increasingly popular solutions to electrify heating in Massachusetts and across the United States, there is a risk that rising electrical demand for heating will shift annual peak loads to the winter months – creating increased strain across an aging electrical grid. Networked geothermal is an emerging technology capable of mitigating this risk through lower energy consumption by increased heating and cooling efficiency and enabling the storage and sharing of thermal energy along a distribution network.

HEET, with support from the Massachusetts Clean Energy Center, created Kickstart Massachusetts, a project to fund feasibility studies to explore networked geothermal technology across the Commonwealth. Deerfield was one of the recipients of a grant to explore the feasibility of geothermal in their town. The town of Deerfield, Massachusetts engaged Buro Happold to complete a feasibility study to determine the viability of a networked geothermal system to serve a subset of their building stock. This project can serve as an example for other communities in western Massachusetts on how to address the challenges of heating electrification and transition away from natural gas.

To understand the viability of installing a geothermal network, a GIS-based assessment using key selection criteria was completed, including key infrastructure network obstructions, areas of biodiverse significance, building typologies, open spaces for the geothermal borefield, pump house siting, and demographic indicators. Across the town, three study areas were identified. The first iteration would include 25 buildings within the center of Deerfield, including Deerfield Town Hall, Deerfield Police Department, Tilton Library, and Deerfield Elementary. A key tenant in this first iteration is Berkshire Brewing Company – a local brewery whose waste heat could be captured in the network and reallocated to other buildings for heating. The second iteration builds upon the first, and extends the loop northward to Frontier High School, South Deerfield Fire Department, South County Emergency Medical Services, and additional residential buildings. Finally, the third iteration would build upon the second, and extend further north to capture and integrate Tree House Brewing and Pelican Products which would provide additional waste heat resources to the network.

The results of the feasibility study show that despite technical feasibility, the current iterations are cost prohibitive and non-competitive with other alternatives. If a networked geothermal system were to operate successfully economically and technologically in the town of Deerfield, it would need to include all of the single-family homes surrounding the three iterations in this study plus an additional population density that could include at least another 200 residents in a cultural living center and an assisted living facility as an example. No further outreach was completed as the iterations studied are not currently feasible under the current configurations. Other alternatives to evaluate in the future may consider standalone ground source heat pump for the school system including Deerfield Elementary and Frontier High School, installation of cold climate air source heat pumps for individual homes and businesses, or a geothermal network that has higher building diversity, total square footage, and waste heat availability.

[1] Clean Energy Group. "Massachusetts Renewable Heating and Cooling." https://www.cleanegroup.org/wp-content/uploads/Meister-MA-renewable-thermal-study.pdf

2 Introduction

2.1 Project Context and Motivation

Natural gas has long served as a significant part of Massachusetts' energy mix – accounting for 76.1% of generation capacity and 52% of the State's residential heating fuel.[2] While natural gas is a critical component of the state's fuel supply, it is also a key contributor of greenhouse gas (GHG) emissions. Along with the downstream emissions produced from combusting natural gas to produce heat or electricity, gas leaks along existing and often antiquated infrastructure can release methane – a GHG with more than 80 times more global warming potential than CO_2.

Scientific findings, economic realities, and policy initiatives across spatial scales are rapidly driving forward the case for electrification and broader decarbonization. To prepare for the energy transition, cities must consider pathways for implementing cost-effective solutions that can provide their residents with electrified, renewables-led heating and cooling energy at-scale while meeting their often-aggressive emissions targets. However, electrifying cities presents several challenges. The increased demand for electricity can strain existing grids, necessitating significant and costly infrastructure upgrades.[3] Additionally, the integration of renewable energy sources requires substantial investment and careful planning to ensure reliability and stability.[4] Urban areas also face logistical challenges, such as the need for extensive retrofitting of buildings and the installation of new electric vehicle charging stations.[5] Furthermore, equitable access to these new technologies must be ensured to avoid exacerbating social inequalities.[6]

Deerfield – a town of a little more than 5,000 residents – is a part of Franklin County, which has set a Regional Plan for Sustainable Development aiming to improve wide-ranging sustainability across its jurisdiction.[7] Currently Franklin County's carbon emissions per capita are the highest across Western Massachusetts and higher than the statewide average. While this is largely the result of high fossil fuel-consuming transportation use, the County has set sustainability goals including:

- Increasing energy efficiency of housing stock
- Increasing the quantity of locally-produced clean energy
- Reducing the use of fossil fuels

Given its rising population and increasing demand for clean energy, Deerfield needs a scalable, low-carbon technology capable of delivering heating and cooling to its building stock. Buro Happold is working with the town of Deerfield to understand the viability of a networked geothermal system to reduce heating and cooling energy demand for homes and commercial businesses. Utilizing geospatial mapping and thermal energy modelling, this study aims to identify the scale and configuration of geothermal network that could deliver resilient clean energy to a region of Deerfield.

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[2] https://www.mass.gov/info-details/how-massachusetts-households-heat-their-homes
[3] https://www3.weforum.org/docs/WEF_Urban_electrification_and_energy_efficiency_2023.pdf
[4] https://news.climate.columbia.edu/2022/06/03/what-makes-electrifying-the-economy-so-challenging/
[5] https://www.weforum.org/agenda/2022/01/the-ev-revolution-obstacles-solutions/
[6] https://www.ifpenergiesnouvelles.com/article/smart-city-energy-challenges-facing-sustainable-cities
[7] Franklin County. "Sustainable Franklin County." https://deerfieldma.us/DocumentCenter/View/359/Sustainable-Franklin-County-Executive-Summary-PDF

2.2 Report Structure

The objective of this report is to provide a summary of the results from the initial feasibility study for a potential networked geothermal project in Deerfield. The remainder of the report is structured as follows:

- Chapter 3 (Site Options): This section introduces the three options Deerfield has presented for a potential networked geothermal system.
- Chapter 4 (Geothermal and Energy Balance Analysis): This section discusses the methodology utilized by Buro Happold to evaluate the geothermal potential of the sites.
- Chapter 5 (Site Feasibility Analysis): This section summarizes the feasibility of the sites including techno-economic analyses and the final conclusions of those studies.

3 Site Options

At project initiation, the project team was provided with three options through which a comparative feasibility assessment could be conducted for a networked geothermal project. The comparative assessment of the techno-economic feasibility of each network option is further detailed in Section 5.

3.1 Iteration 1

Iteration 1 is a proposed network that encompasses 25 buildings in the central part of Deerfield (Figure 3-1). In addition to 25 residential buildings in this site, the proposed network includes key buildings including:

- Deerfield Town Hall
- Deerfield Police Department
- Tilton Library
- Deerfield Elementary
- Berkshire Brewing Company

Figure 3-1. Preliminary network design for Iteration 1.

Within this network, currently measured at about 11,000 feet, there is an opportunity to integrate Berkshire Brewing Company – a local brewer that produces 6,000 barrels of beer annually.[8] Industrial processes that often produce "wasted" heat, such as breweries, can be leveraged as a source of additional thermal energy to help thermally balance a networked geothermal system.

3.2 Iteration 2

Iteration 2 builds on iteration 1 by extending the network further north into Deerfield (Figure 3-2), capturing additional residential buildings and key commercial buildings including:

- Frontier High School
- South Deerfield Fire Department
- South County Emergency Medical Services

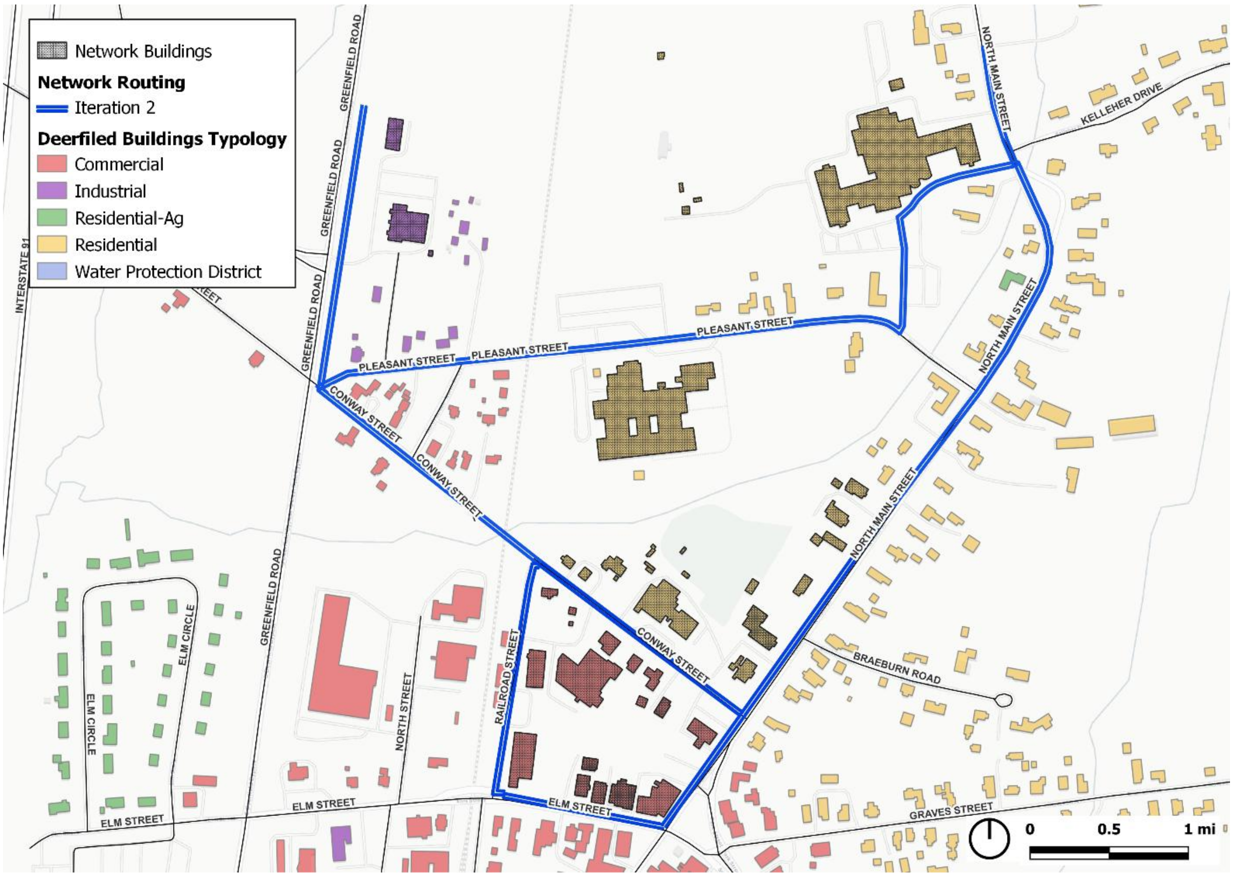

Figure 3-2. Preliminary network design for Iteration 2.

It should be noted that this network, currently estimated to be about 16,000 feet, may face some key routing challenges, such as crossing an existing rail line and Bloody Brook which could introduce easement challenges with the Massachusetts Department of Transportation. However, the addition of Frontier High School represents an opportunity to dramatically increase the thermal load served by the network, improving efficiency for the broader network.

[8] Berkshire Brewing Company. https://www.berkshire-brewing.com/about

3.3 Iteration 3

The final, and largest, iteration proposed builds on iteration 2 by introducing two additional waste heat sources to the network: Tree House Brewery and Pelican Products to the north. These facilities are not assumed to be served by the network but would be explicitly connected for access to consistent operational waste heat sources.

To be able to integrate these two facilities into the network, the system will need to extend further north to a total length of about 24,000 feet along North Main Street and along either the existing rail line or Interstate 5/Greenfield Road, as shown in Figure 3-3.

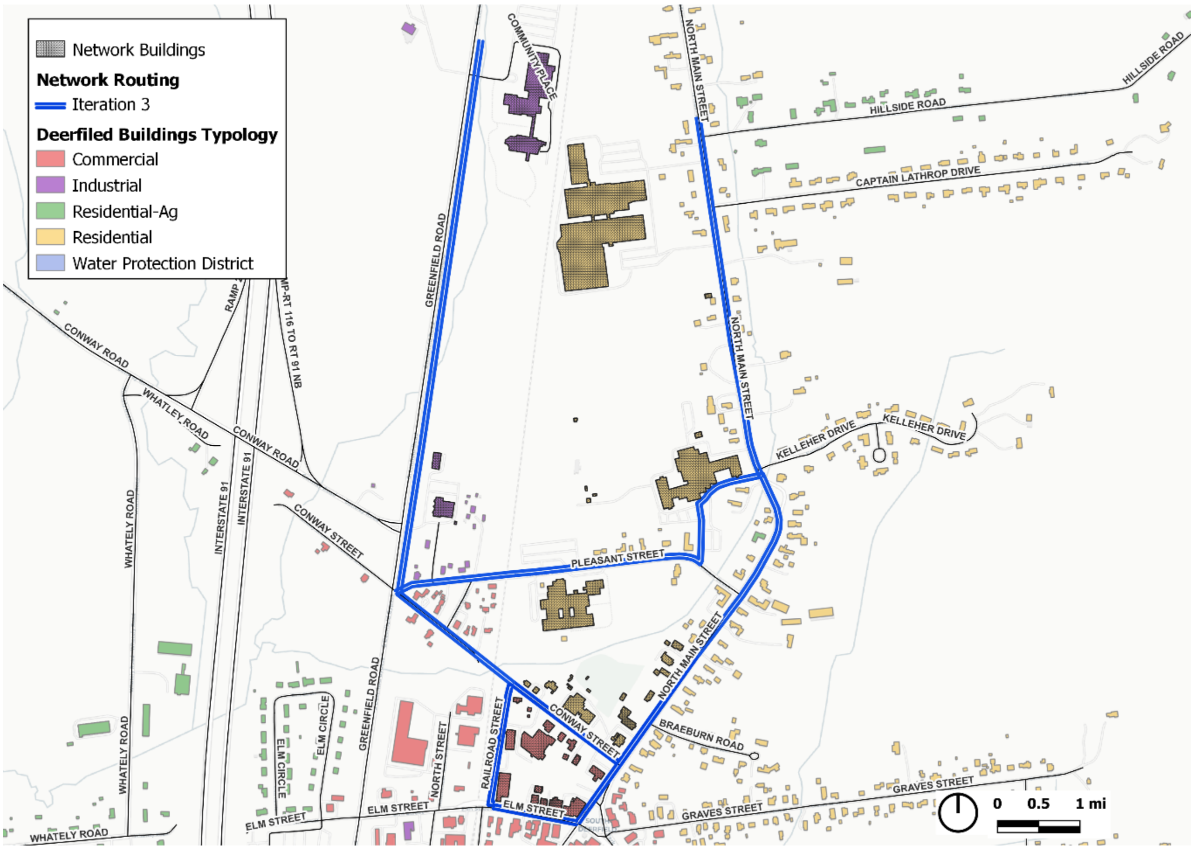

Figure 3-3. Preliminary network design for Iteration 3.

4 Geothermal and Energy Balance Analysis

This section discusses the analyses completed to assess site feasibility based on local geological conditions and building energy demand for the potential network in Deerfield. Networked geothermal systems consist of three main parts: 1) the ground heat exchange system which consists of geothermal boreholes; 2) the civil infrastructure including the distribution network in the streets and pump house used for circulation; and 3) the individual heat pumps within homes and businesses. Building heating and cooling loads are used to size the ground heat exchange system, with the civil infrastructure used for interconnection.

4.1 Bedrock Geology and Ground Heat Potential

Deerfield sits on bedrock predominantly characterized as basin sedimentary rock (**Error! Reference source not f ound.**).

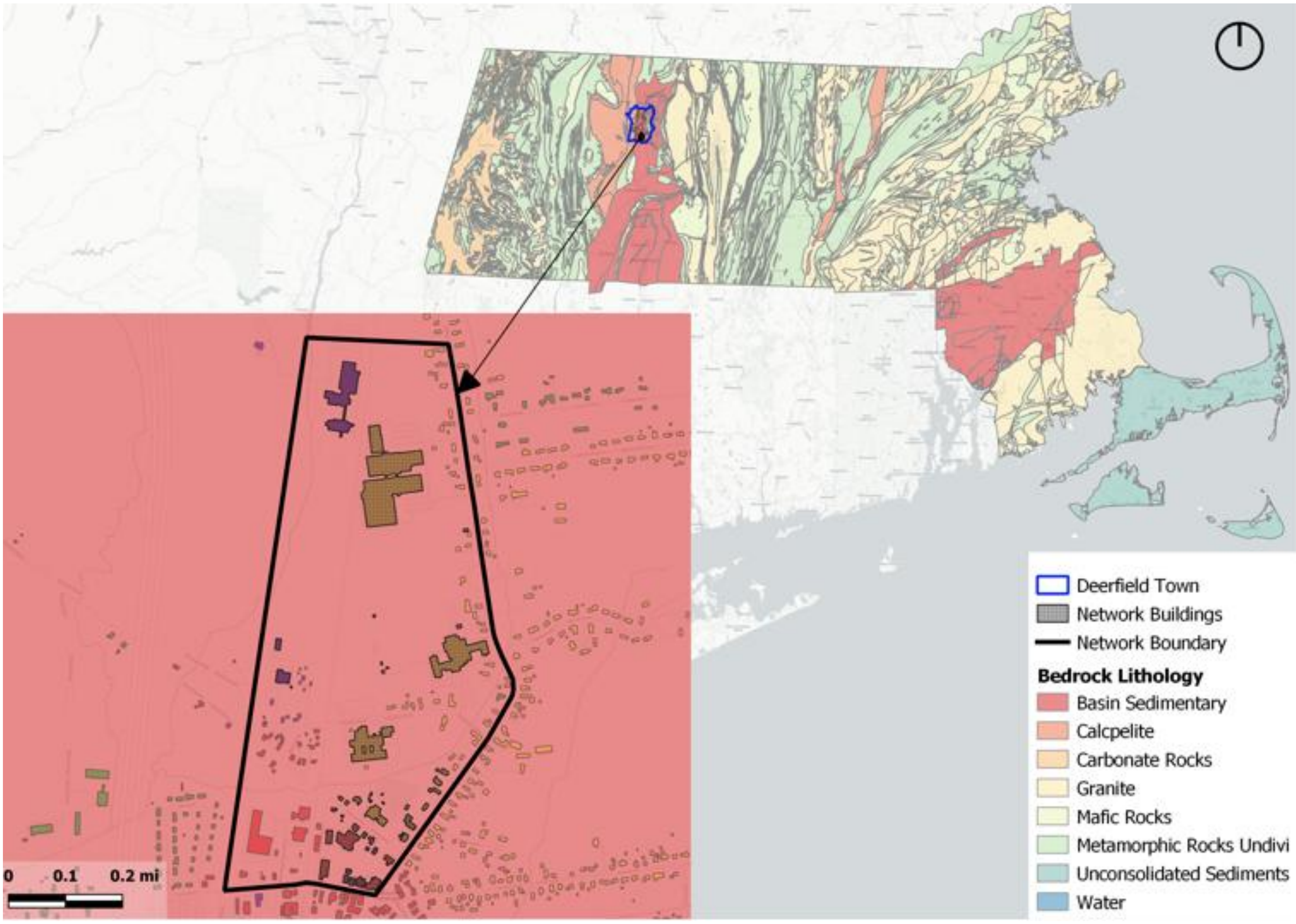

Figure 4-1. Prevailing bedrock geology in Deerfield, Massachusetts.

Based on data provided from USGS, this type of bedrock has a typical thermal conductivity estimated at 17 Watts/foot (**Error! Reference source not found.**).

Table 4-1. Specific heat extraction (Watts/foot) value by bedrock type, based on 1800 full load extraction hours per year.

Rock Type	Specific Heat Extraction (Watts/foot)	Specific Heat Extraction (Watts/meter)
Extrusive Igneous Rocks e.g., basalt	13-20	40-65
Intrusive Igneous Rocks e.g. granite	20-26	65-85
Metamorphic Rocks e.g. gneiss	21-26	70-85
Carbonate Rocks e.g. limestone	14-18	45-60
Basic Sedimentary e.g. sandstone	20-24	65-80
Gravel, Sand, Saturated Water	20-24	65-80
Clay, Loam, Damp	10-15	35-50

The depth to bedrock raster, with a 100-meter resolution, illustrates the thickness of the overburden across Massachusetts. Depth to bedrock within the study area extends to depths ranging from 26 to 72 m (or 85 to 236 feet) below ground surface (bgs). This region of Deerfield generally has the shallowest depth to bedrock within the town.

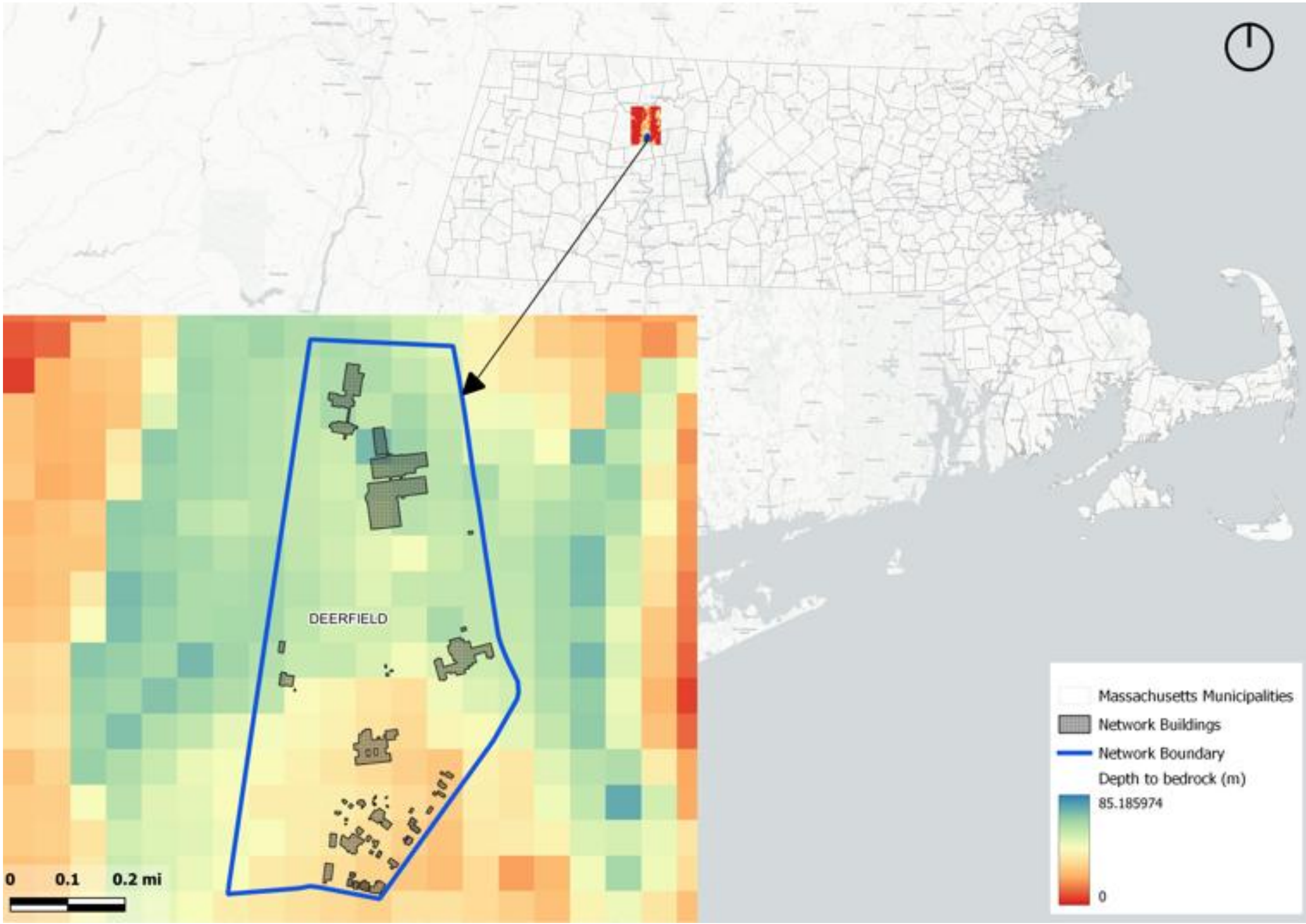

Figure 4-2. Depth to bedrock in Deerfield, Massachusetts.

4.2 Energy Demand Assessment

A key component of site feasibility study is the energy demand assessment for the potential buildings in each iteration. Information from the Deerfield tax assessor dataset was used to determine the square footage of the potential participants along the network.[9]

Only limited amounts of information were available for establishing loads of actual buildings along the network. Therefore, modelling of each building was done based on NREL's ComStock and ResStock databases based on each building typology. These datasets utilize traditional physics-based energy modelling tools, utility data, and building survey data on typical physical characteristics to generate time series datasets of energy end use for ~500,000 buildings across the United States. To establish estimated heating and cooling load profiles for buildings in the study area, the ComStock and ResStock datasets were referenced to calculate energy use intensities (EUI) and thermal load profiles.

[9] https://next.axisgis.com/DeerfieldMA/

5 Site Feasibility Analysis

The feasibility analysis for the site builds on the geothermal and energy balance described in Section 4. Technical and economic parameters were compiled and evaluated to understand the overall feasibility of the proposed project iterations using a comprehensive modelling tool Buro Happold has developed.

5.1 Technical Analysis

Total demand loads for the buildings along each of the network iterations were evaluated to determine the design parameters. Square footage totaled 110,742 square feet for Iteration 1 and 273,991 square feet for Iterations 2 and 3. The total annual network demand was calculated to be approximately 0.9 TWh/year and 1.5 TWh/year, respectively.

Waste heat available in the three iterations was well over the total network demand, however heat that is available during the specific time of need only represented 38%, 42%, and 58% of the demand, respectively. Note that this evaluation does not account for losses of heat in the distribution system which could be significant along the extended iteration 3 loop. Based on the demand requirements and amount of waste heat available, a rough estimate of geothermal wells required to balance the system based on an expected bedrock heat exchange rate of 17 W/ft were calculated (Table 5-1).

Table 5-1: Borehole count requirements based on various drilling depth scenarios

	Number of Boreholes Required		
Variable Installation Depth (feet below ground surface)	**Iteration 1**	**Iteration 2**	**Iteration 3**
500	69	130	120
800	43	82	74
1000	35	65	59

5.2 Economic Analysis

Using a comparative tool developed by Buro Happold, the capital and operational expenses for the proposed geothermal network iterations were developed.

Based on the network demand and system configuration requirements for each of the iterations, capital cost estimates were modeled (Table 5-2). Due to the uncertainty of drilling costs, three variations including $40/linear foot, $60/linear foot, and $80/linear foot were modeled to provide potential ranges in drilling cost associated with each of the iterations.

Table 5-2. Estimated order of magnitude capital costs.

	Modelled Capital Cost ($)		
Variable Cost ($/ft)	**Iteration 1**	**Iteration 2**	**Iteration 3**
40	$11,003,746	$ 19,072,143	$ 24,505,643
60	$11,797,246	$ 20,567,143	$ 26,000,643
80	$12,590,746	$ 22,062,143	$ 27,495,643

Total capital costs for system construction of networked geothermal systems in Deerfield ranged from $11 million to $27.5 million. It is clear based on this analysis that the cost of extending the network northward in iteration 3 to capture waste heat is a costly investment. The value of capturing waste heat at such a large distance should be studied further to understand the true benefit of this addition to the system and understand return on investment (ROI). Iteration 2, however, had the most effective cost per square foot of conditioned space.

In addition to the upfront capital cost and operational costs including electricity, the model calculates a comparative cost associated with installing ASHPs instead of a TEN. In all iterations and cost scenarios, the cost of ASHPs was less expensive over a 60-year modeled period. Of all iterations studied, the second had the fastest breakeven period at over 50 years.

ASHPs are likely less expensive for this network configuration due to the relatively low population density of the study area which would require significant amounts of piping network. Secondary factors include building diversity, which in all iterations was primarily commercial. If significant amounts of housing were added to the system at a later date, the lifecycle cost of the TEN could end up being a less expensive option within a more reasonable timeframe.

5.3 Conclusions and Next Steps

Although the three iterations of networked geothermal systems were all technically feasible, the lifecycle cost of the geothermal network in every iteration was more expensive over a 60-year lifecycle relative to other technologies. Therefore, a geothermal network may not be feasible for this study area of Deerfield if the network's only purpose was to provide a thermal service and there were no other co-located municipal projects to reduce the implementation costs. Alternative heating and cooling technologies should focus on adoption of cold-climate ASHPs (ccASHPs) and individual ground source heat pumps for larger buildings such as the school systems, breweries, and other commercial facilities. Individual home ground source heat pumps could also be an attractive alternative.

Re-evaluation of this area should be completed if future housing developments are built along the network path or other economic co-benefits are co-located through municipal improvement projects to reduce the capital cost of the geothermal network. Additionally, if the cost of natural gas rises more than current forecasts, Massachusetts or the US Federal government adopts a carbon tax like Europe, or the rate of pipeline gas failures in the region increases to the point where the local gas utility must invest in a full replacement, then a geothermal network would be a cost competitive solution that should be reconsidered. As this technology matures, the cost of geothermal networks are anticipated to decrease over time as adoption rate and innovations make it a more attractive economic proposition in less densely populated areas such as Deerfield.