Geology 104
Maps compiled by
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Ground Source Heat Pump Implementation in Massachusetts

Tufts UNIVERSITY

Introduction

Natural energy in Earth's subsurface can be harnessed and greenhouse gas emissions reduced by implementation of ground source heat pumps (GSHP). GSHP use less energy and can be more efficient than conventional HVAC systems, but depend greatly upon the properties of the rock where the well is being drilled, the ground water level and flow, water quality, subsurface temperature and other variables. Massachusetts can benefit from this technology if it is implemented correctly in geologically compatible locations. With proper planning, design and installation, GSHP are an effective alternative to traditional heating and cooling technology.

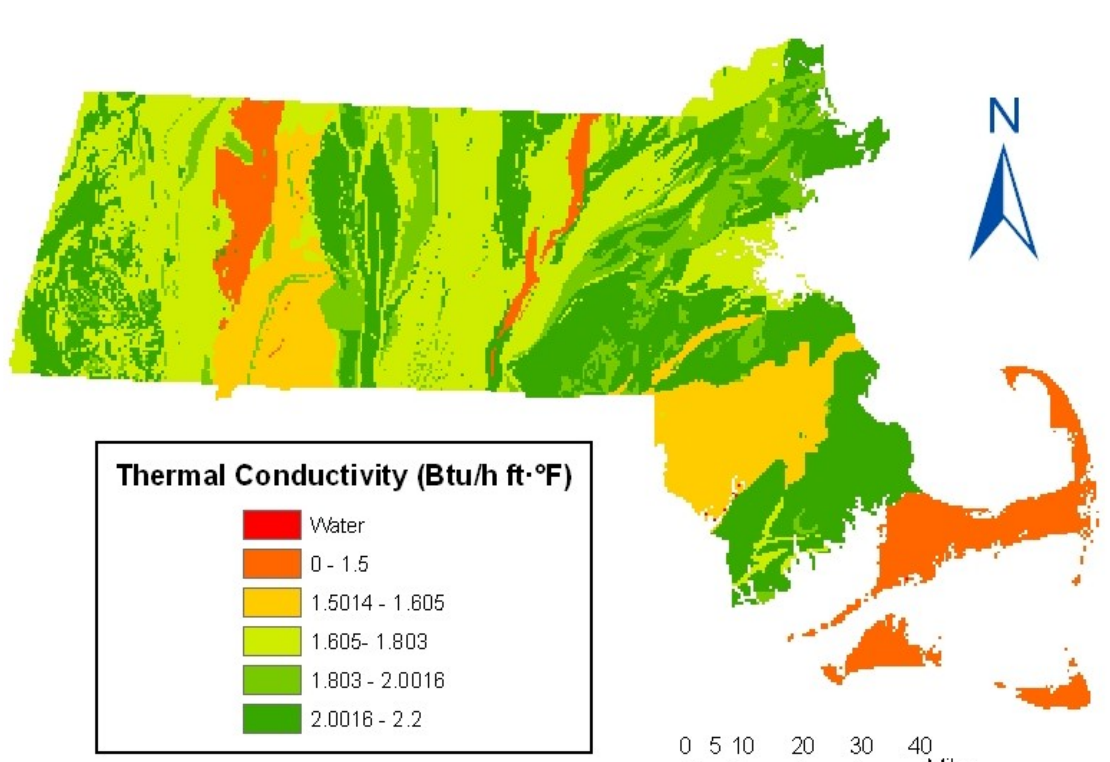
Methods

The temperature difference between the ground and the fluid in the loop of the GSHP allows energy to move. The resistance of the pipe, the grout and the ground restrict this energy movement. Pipe and grout resistance are factors of design and implementation. The energy that the ground provides can be analyzed through ground temperature and the bed-rock's thermal diffusivity, specific heat and conductivity. Ground water movement through the bore hole field also has a large impact on the pump's performance, as it can carry away large amounts of energy. All of these factors were considered to develop a map of sites for potential ground source heat pumps.

Thermal conductivity

The Massachusetts bedrock lithology layer from MassGIS was dissolved so that rock units of the matching lithology became a part of the same multipart polygon. These lithologies were then compared against the data for average thermal conductivity of certain rock types. Often there were more specific conductivity measures than rock types, i.e., the lithology layer had a 'metamorphic' bedrock layer, yet there were data available for marbles, gneiss, schist, quartzite and slate.

Frequently the thermal conductivities (as well as diffusivity and specific heat) were all very similar for the broader categories of rock, so a median value was determined for the analysis. MassGIS bedrock names included categories like 'Narragansett Basin sediment' which had to be generalized 'sandstones'. A field was added to the attribute table of the bedrock lithology layer for thermal conductivity in Btu/h ft·°F, and classified so that the bedrock with the most ideal thermal conductivity (a high value for easy exchange of energy) was green, and the worst, orange. A GSHP would not be implemented in water, which is in red.



How GSHPs work

There are two types of GSHP: open loop and closed loop systems. The open loop system is most often installed in climates similar to that of Massachusetts. Open loop systems draw ground water directly into the building and heat/cool the heat pumps with it. The system requires sufficient ground water to meet the needs of the building. Closed loop systems have a dedicated fluid loop that is circulated through the ground or pond in order to exchange heat.

Geothermal wells transfer heat to or from the ground along their vertical length. The longer the well, the more heat exchange capacity it can provide. The surface area of the well (length) is critical to its function and capacity.

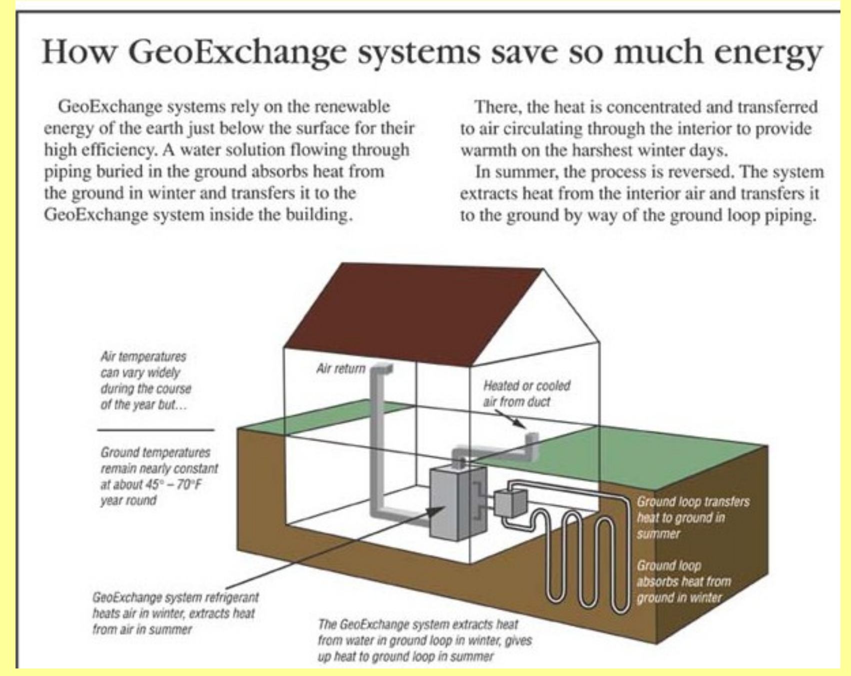
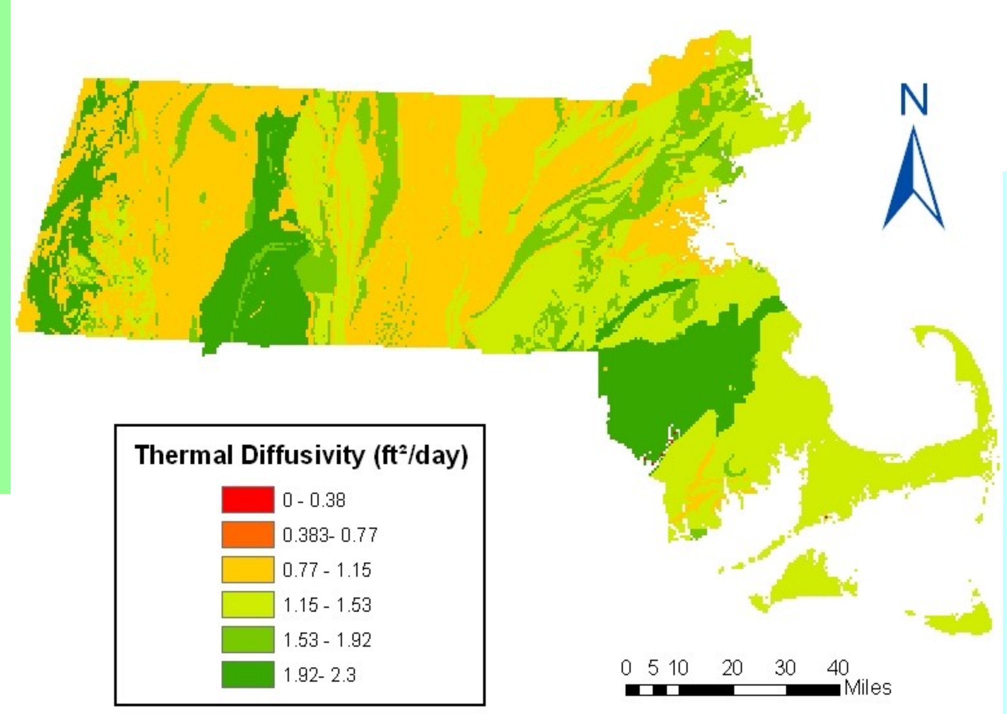


Image from www.geoexchange.org

Thermal diffusivity

A new field was added to the dissolved bedrock attribute table: thermal diffusivity. A layer was created, and was presented with ideal thermally diffusive bedrock in dark green (carbonate rocks and sandstone), and bed rock with lower thermal diffusivity in dark oranges and reds (metamorphic rocks and calcpelite).



Sources

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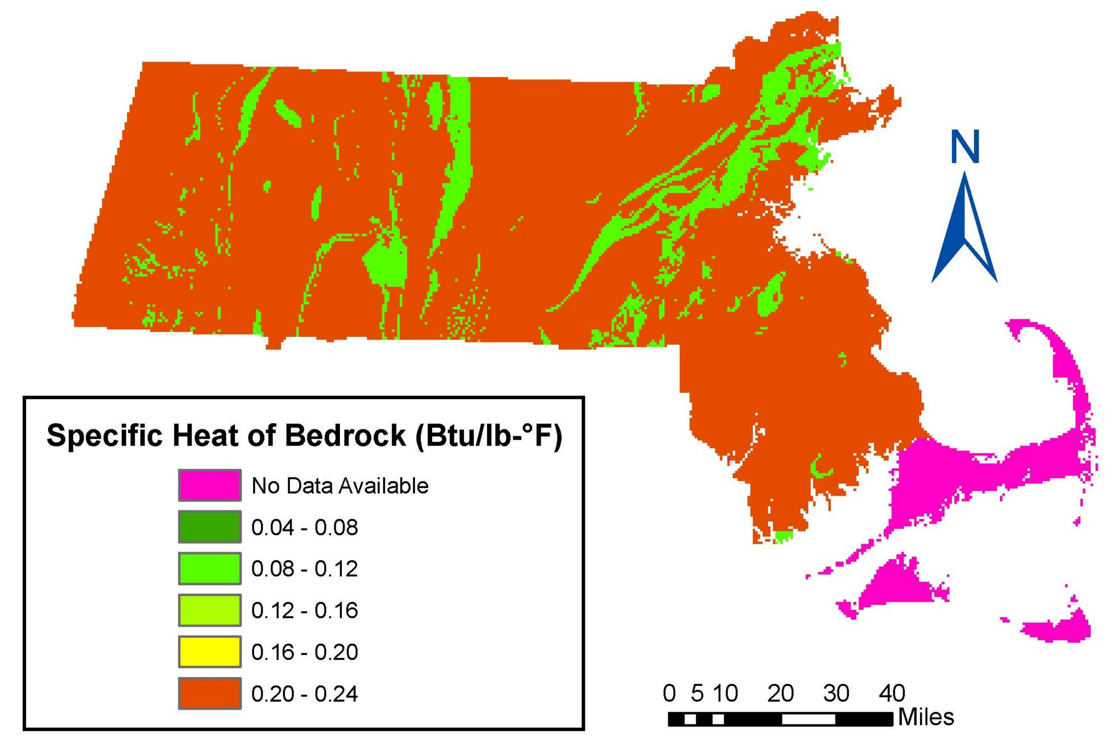
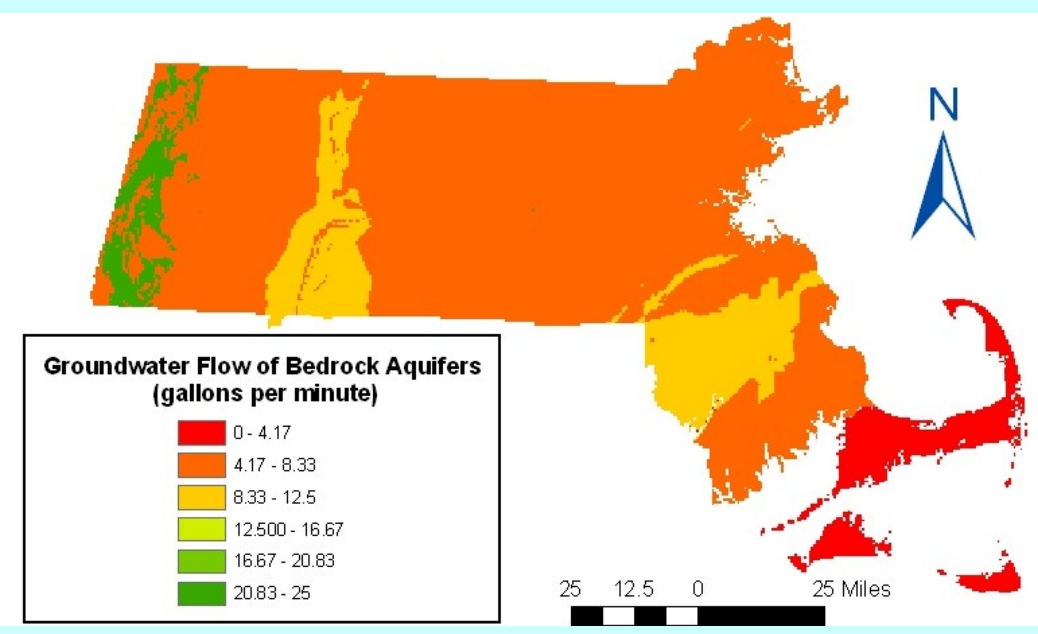
Specific Heat

Another field added to the dissolved bedrock layer was a specific heat (the amount of heat per unit mass required to raise the temperature of the rock) field. A lower specific heat makes for an easier heat transfer from the loop to the ground. The specific heat of most of the bed rock except for Amphibolite and Andesite was between 0.20-0.24, marked in dark orange. This layer was not given much weight in the final analysis, but does affect the efficiency of the GSHP.



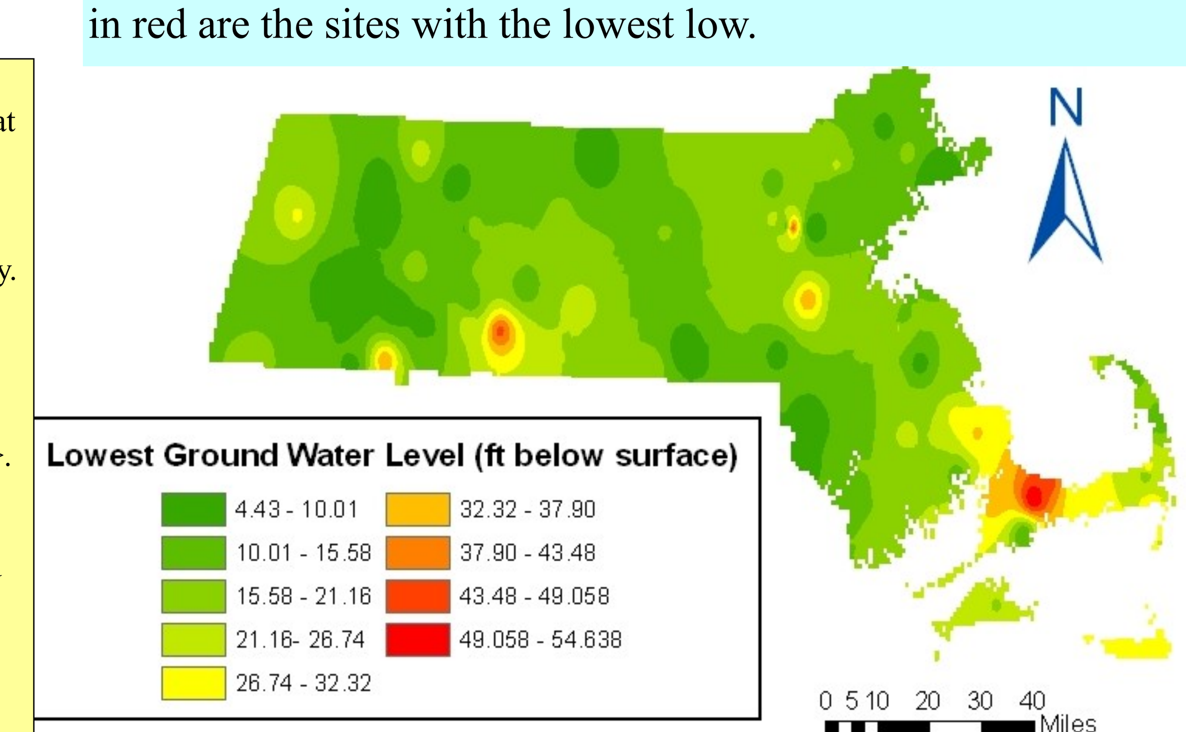
Characteristics of Bedrock Aquifers

The last field added to the dissolved bedrock lithology was the median yields in gallons per minute of bedrock aquifers. Greater flow is idea for GSHP for more energy moving through the system.



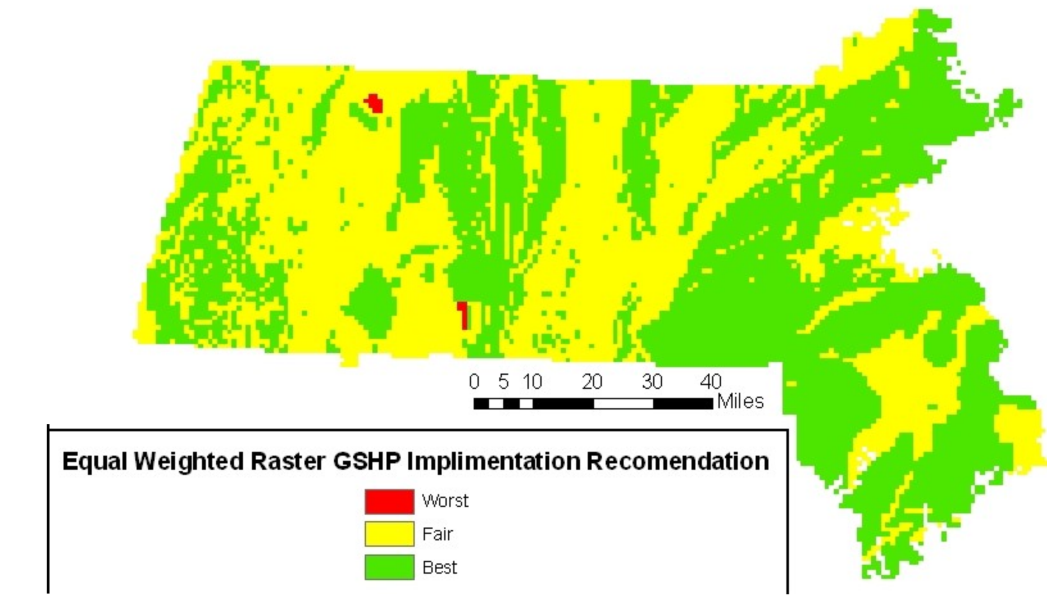
Ground Water Level

Data taken from USGS national ground water database was used to create a table with the latitude and longitude of each sample site, and the all time low of ground water at that site. The table was converted to a layer using the coordinates. This analysis was interested in the lowest groundwater level, to make sure that the well was dug deep enough so that it would never 'dry out'. The lower the water table, the deeper the well would have to be drilled, and the more likely the well would dry out. These points were then converted to raster using IDW technique. In dark green are the sites with the highest low, and in red are the sites with the lowest low.

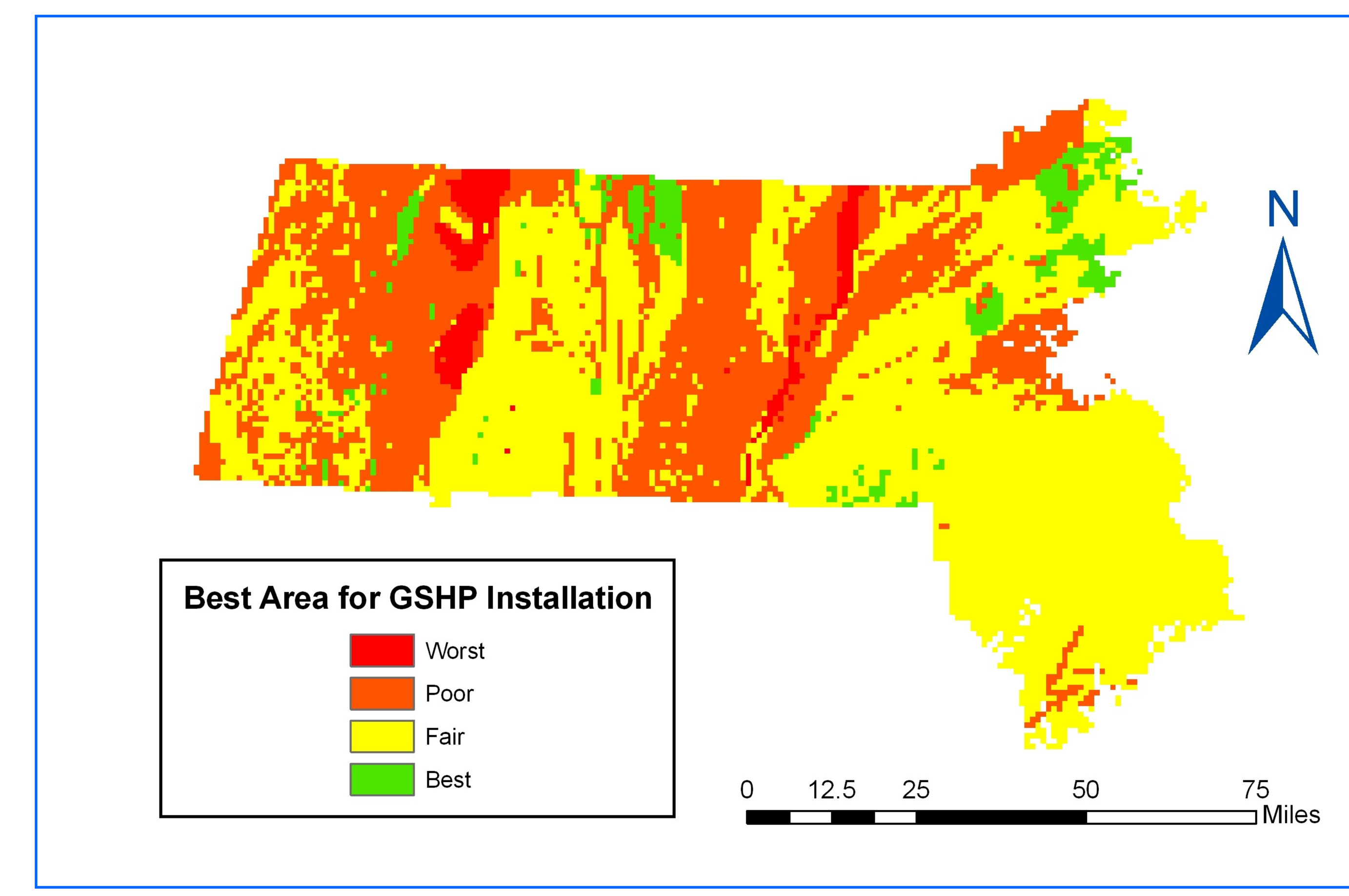


Results and Conclusion

By weighting each of the five raster layers equally, an unfortunately basic map is derived. However, certain attributes of the bedrock are more important for GSHP installation than others. The characteristics such as thermal diffusivity and conductivity play a much larger role in determining the thermal resistance to heat transfer than the depth to water table layer. Below is the final equal weighted raster. Because of the lack of data and consolidated sediment on the cape and the islands, the final weighted overlay did not take those environments into consideration.



A weighted raster overlay provides a better prediction of ideal GSHP implementation. Thermal diffusivity was given the most weight in the raster as it is defined as thermal conductivity divided by volumetric heat capacity. This means that it takes into consideration the rock's thermal conductivity, density and specific heat capacity. Thermal diffusivity was weighted at 40%. Thermal conductivity was weighted at 25%, emphasizing the importance of the bedrock's ability to conduct heat. Heat transfer across materials of high thermal conductivity occurs at a faster rate, and are therefore widely used in heat sink applications like GSHP. Specific heat of the rock was weighted at 15%, to address the issue that some bedrock is much easier to 'heat up'. Ground water and mean aquifer yield were each weighted at 10%. Both of these layers are not critical to the installation process, but provide valuable input on ideal location. Also, from an economic standpoint, the farther down one has to drill, the easier installation and maintenance becomes.



The best areas for GSHP are in green due to the fact that they are located over ideal bedrock and groundwater conditions for a GSHP. GSHP can provide an eco-friendly alternative for both heating and cooling needs in residential and commercial buildings. Massachusetts can take advantage of its geothermal properties for this relatively 'free' and 'clean' energy source.

Limits of the Study

Ground temperature is a vital component to installation of a GSHP. It can dramatically affect the bleed rate and disposal strategy of the pump. Massachusetts ground water temperature is 47-55°F 15 feet below the surface (the frost line). Water with high concentrations of iron and arsenic pose a problem for GSHP. Often these metals corrode and clog the loop of the GSHP, and it is highly recommended to not impliment a GSHP were there are large concentrations of these metals in the ground water. Usually GSHP are not designed for brackish water. Salt water encroachment is usually found at around 1500 feet below the surface for areas near the coast of MA. It is sugessted that before implimentation, at all sites a test well is dug in order to determine ground temperature and water quality.