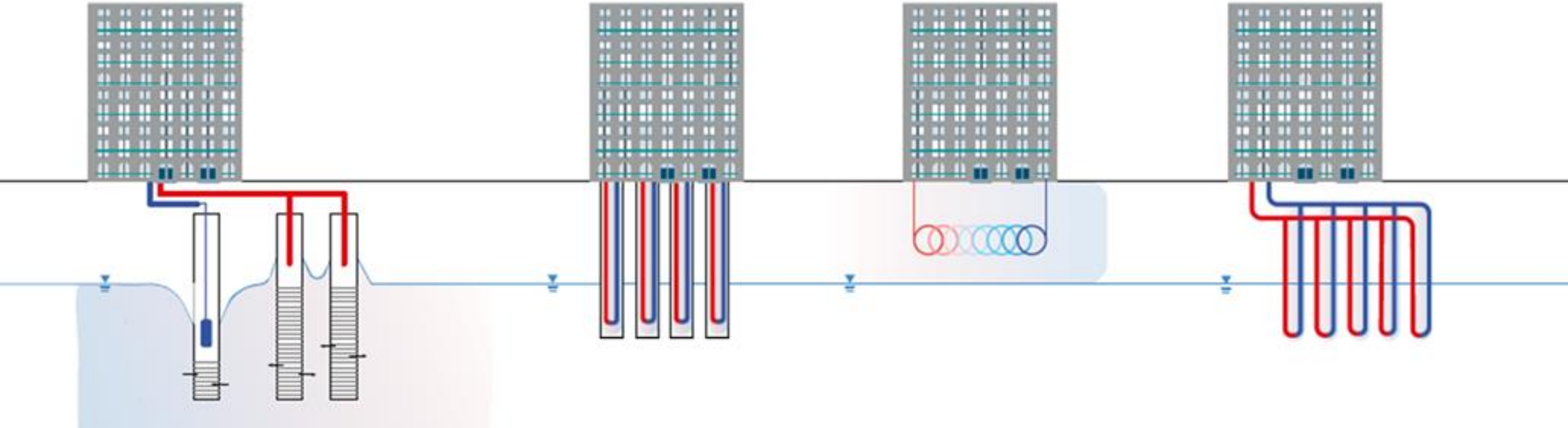


Southwark Borough

Ground Source Energy Opportunity Mapping

4 March 2020

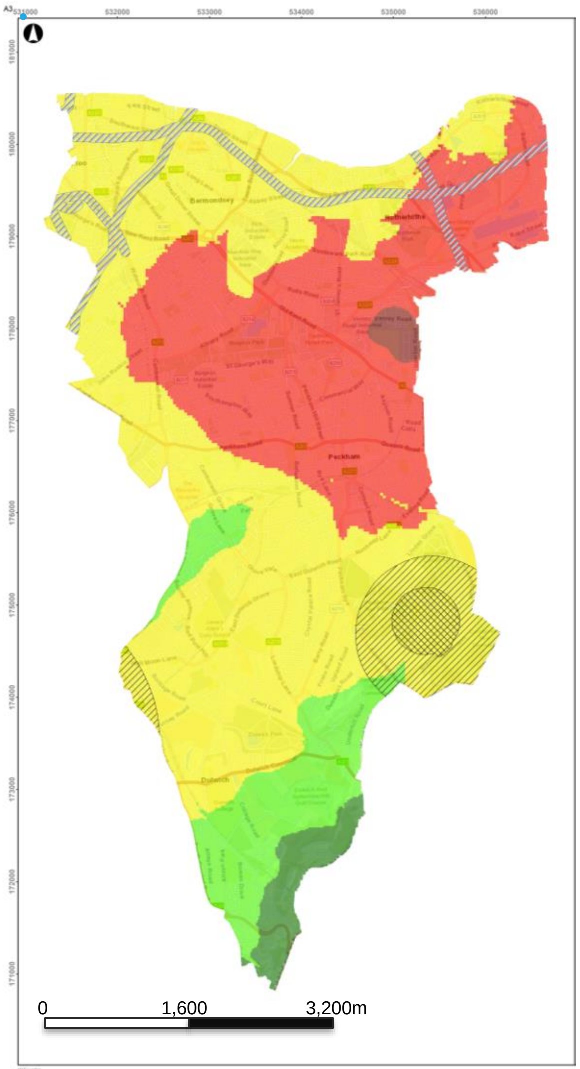
Issued Report, Version 1

Southwark Council
southwark.gov.uk

ARUP

Executive Summary (1/2)

Open and Closed Loop Ground Source Heat Pump system development opportunities have been mapped across Southwark Borough



Legend

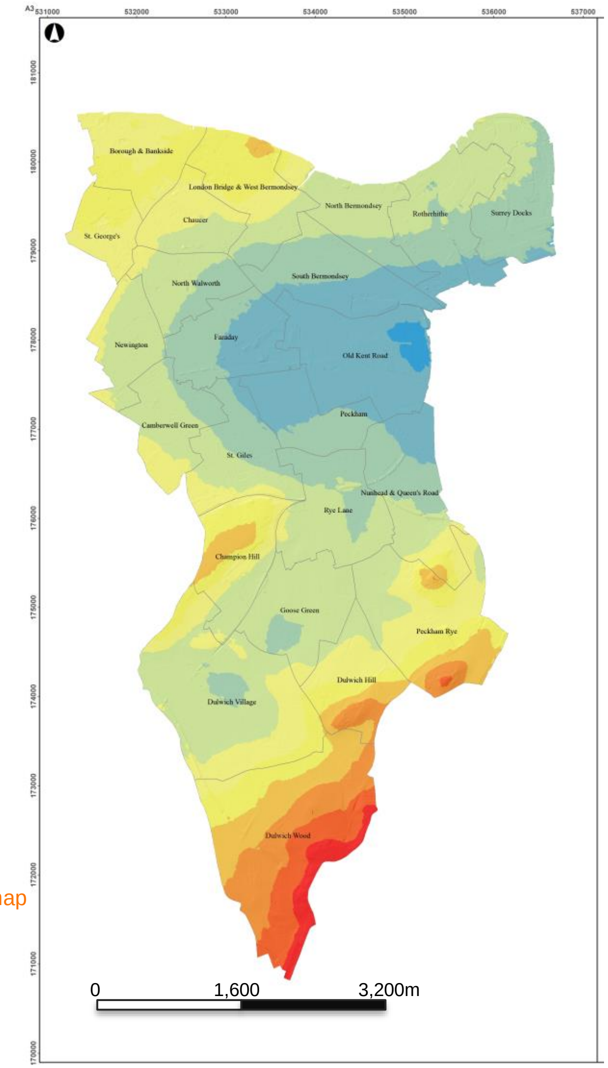
- TfL Safeguarding Zone
- Source Protection Zone 1
- Source Protection Zone 2
- Very low potential
- Low potential
- Medium potential
- High potential
- Uncertain reinjection capacity

Open Loop Potential Map

Legend

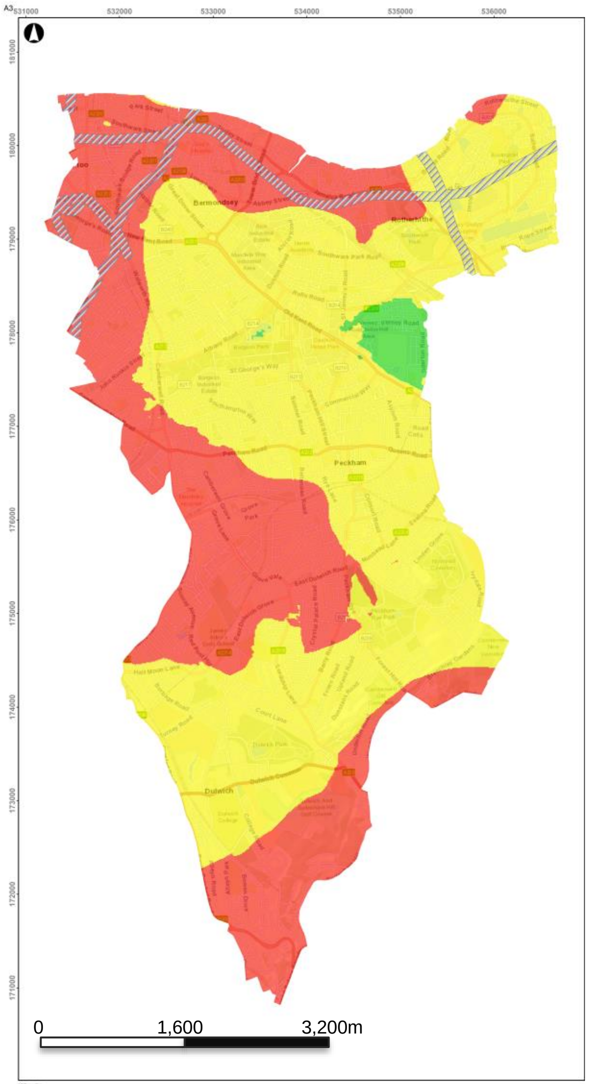
- 8.2 - 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 60
- 60 - 75
- 75 - 100
- 100 - 125
- 125 - 150

Depth to top of Chalk fm map



Executive Summary (1/2)

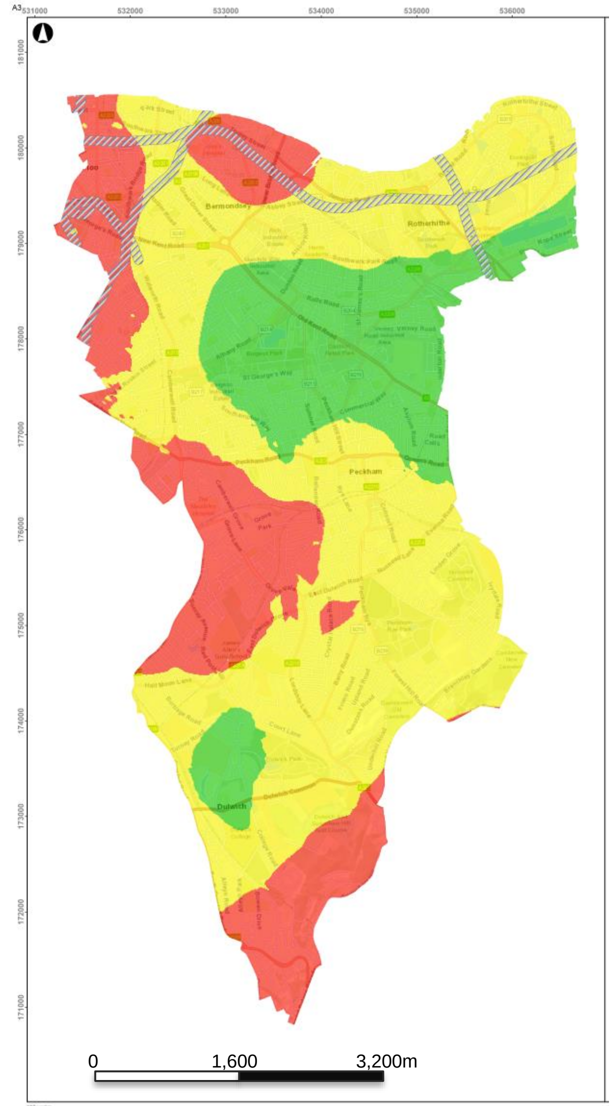
Open and Closed Loop Ground Source Heat Pump system development opportunities have been mapped across Southwark Borough



Legend

- TfL Safeguarding Zone
- Low Potential (40W per m)
- Medium Potential (45W per m)
- High Potential (50W per m)

Closed Loop Potential Map
(50 to 100m deep boreholes)



Legend

- TfL Safeguarding Zone
- Low Potential (6 to 6.5kW per borehole)
- Medium Potential (6.5 to 7kW per borehole)
- High Potential (7 to 7.5kW per borehole)

Closed Loop Potential Map
(150m deep boreholes)

Executive Summary (2/2)

Once planning level assessments have been made using the opportunity maps, specialist GSHP designers should be consulted to confirm the assessment and aid in next steps.

Ground Source Heat Pump (GSHP) Systems

- Ground source heat pumps can provide a low carbon and sustainable source of baseload heating and cooling. There are two types of systems:
  - Open Loop systems: Groundwater is pumped from an aquifer, passed across a heat pump, and reinjected back to the aquifer. In London, the Environment Agency (EA) typically requires open loop systems to be non-consumptive (i.e. all pumped groundwater to be reinjected back to the same aquifer). In London, open loop systems normally target the Chalk formation, within the Lower Aquifer. While the Chalk formation can be very productive, its productivity is also highly variable, leading to uncertainty in planning. Open loop systems are typically more cost effective than closed loop systems, using less boreholes, providing more efficient energy exchange, and allowing for greater thermal imbalance in energy delivery.
  - Closed Loops systems: Closed loops systems utilise a series of piping to be installed into the ground and then a geoexchange fluid (typically water which may have some antifreeze) is circulated through the geoexchange piping. Closed loop systems are less efficient than open loop systems, but are more predictable in performance; but typically require thermal balancing. Closed loop systems typically require greater capital expenditure than open loop systems. However, where structures piles can be fitted with geoexchange piping (energy piles), the capex can be greatly reduced.

Using the Open Loop Map

- Open loop systems are likely to be feasible across the Borough. The opportunity has been evaluated based on formation productivity (i.e. transmissivity / hydraulic conductivity), sufficient headroom to reinject groundwater, high-level assessment of drilling cost, and other factors.
- The ranking are defined based on potential productivity: high, medium, low, and very low (with estimated 'per well' outputs provided in the map).
- One zone has been identified where Chalk fm groundwater levels may be too shallow to allow sustainable reinjection, and should be assessed by an experienced professional (i.e. a hydrogeologist or open loop designer).

Using the Open Loop Map (Continued)

- EA source protection zones (SPZs) and Transport for London (TfL) safe guard zones are indicated. Where sites overly these area, the relevant agency will need to be consulted.
- The depth of the Chalk will influence the overall price of drilling. A separate map has been generated indicated depth to the top of the Chalk formation for reference.

Using the Closed Loop Maps

- Closed loop systems are also likely to be feasible across the Borough. Two maps have been provided to indicate output potential for shallow vertical systems (i.e. energy piles) and deeper systems (i.e. vertical boreholes). Horizontal 'slinky' systems have not been assessed.
- Closed loop system productivity has been evaluated based on weighted thermal conductivity values for the identified geological layers.
- The ranking are defined based on potential productivity: high, medium, low.
- Only TfL safe guard zones are indicated on these maps, as no groundwater pumping and reinjection is required. Where sites overly TfL areas, TfL will need to be consulted.

What next?

- Once a site has been reviewed in the context of these maps, a specialist GSHP designer should be consulted. The designer will provide guidance on how best to progress a GSHP system, including when to advance the collection of critical ground investigations.
- The ground investigation for an open loop system will include the installation of a Chalk production well and testing for pumping and reinjection rates. An application to the EA will be required to for consent for the pumping test.
- The ground investigation for a closed loop system will be a thermal response test (TRT).
- The UK's GSHP Association (GSHPA) provides a useful source of design firms and other information. www.gshp.org.uk

Contents

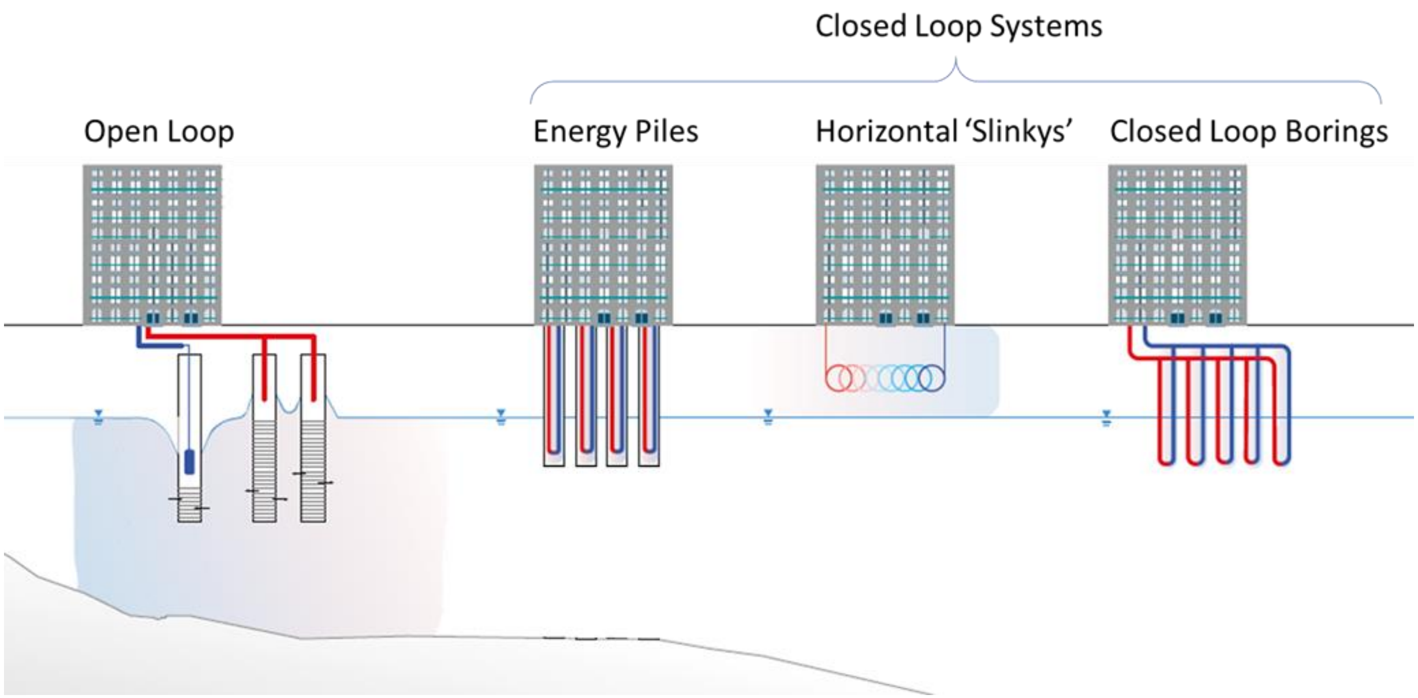


Figure 1: Types of GSHP Systems

1. Introduction

Ground Source Heat Pumps are a viable source of sustainable, low carbon energy for Southwark Borough.

Introduction

- Ove Arup and Partners Limited (Arup) has been providing Southwark Council in London with consulting related to the Council's energy planning.
- Arup's scope of services has been extended to produce maps related to ground sourced energy opportunities.

Scope of Work

- Arup scope of work consisted of the following:
  - General description of ground sourced energy systems, commonly referred to ground source heat pump (GSHP) systems,
  - Production of opportunity maps for Southwark Borough (Figure 1) based on publicly available information,
  - Delivery of the maps in GIS to complement the Council's existing GIS database, and
  - Production of this report to aid in use of the maps.

Project Limitations

- Arup has produced GSHP system opportunity maps for the use of Southwark Council based on publicly available information and using the methodology described in this report.
- Arup takes no responsibility for or provides reliance for the accuracy of the maps produced.
- The intent of the information provided is to provide high-level guidance on the relative opportunities and constraints to develop GSHP systems within the limits of the Borough. As such The information provided in the maps should not be construed as design information. Any GSHP system should be developed based on site specific criteria and information and by a competent and experienced professional.

Figure 2: Southwark Borough within Greater London (source: Wikipedia)

2. Overview of GSHP Systems

There are two primary types of GSHP Systems: Open-loop and Closed loop systems

Closed Loops Systems

Overview

- Closed loop systems run thermal exchange fluids through piping installed in the ground. Where installed horizontally, these systems are often referred to as 'slinky' systems. Where installed in vertical borings, they are referred to as vertical closed loop systems (or just closed loops). Energy piles (or thermal piles) are another type of closed system where the loops are installed within structural piles. Finally, deeper closed loop systems (at depths greater than 800 feet) utilize a coaxial design and are often referred to as standing column wells. Standing column systems are a hybrid between open and closed loop systems (in that they actively extract/inject groundwater, but because it is from the same location, the exchange is similar to a closed loop system).

Vertical Closed Loop Boreholes

- A closed-loop system is comprised of HDPE tubing that is arranged in a loop configuration typically between 200 and 500 feet vertically deep into the ground. There are typically many boreholes in a system of this type (as many as can fit inside the available site area). Water (and often an antifreeze is also used) is pumped through the piping and the thermal exchange occurs within the borings. Where heat to the building is required, the fluid extracts heat from the ground, and where cooling is required, the fluid rejects heat to the ground. For this reason, closed loop systems are run in balance between the annual heating and cooling loads.

Energy Piles

- Energy piles are functionally and operationally identical to vertical closed loop borefields. The difference occurs during the design and installation to ensure that the inclusion of the geo-exchange loops do not reduce the structural capacity and integrity of the piles. The major benefit of thermal piles is the reduced capital cost for the GSHP system (as the drilling and installation costs are most borne by the piles).

Horizontal 'Slinkys'

- A horizontal closed-loop system operates on the same principal as vertical closed loop boreholes, though the HDPE tubing is installed in horizontal trenches typically 1 to 2m below surface. The tubing can either be arranged as straight runs or coiled around in the trenches as slinkys to increase the energy yield. There are typically many trenches installed underneath open areas such as playing fields, grassed areas or car parks (as many as can fit inside the available site area). The major benefits of horizontal systems are that they are technically less challenging and cheaper to install than vertical systems, however the energy yield for the same site area is much lower.

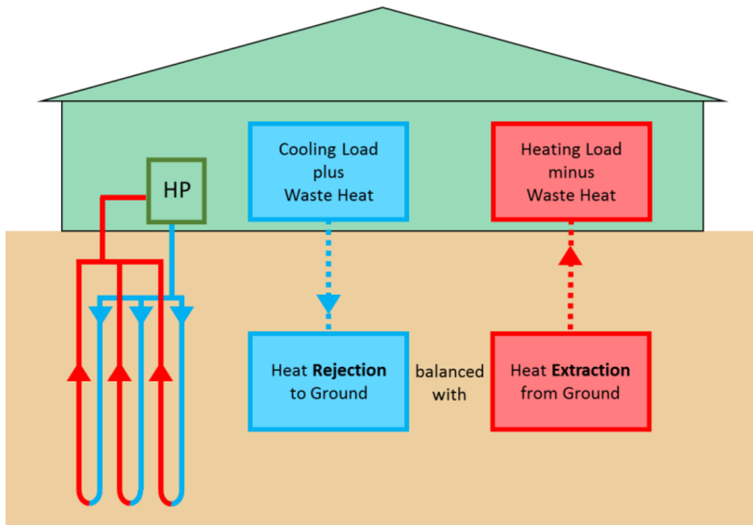


Figure 3: Illustration of energy in closed loop GSHP systems.

2. Overview of GSHP Systems Continued

Open loops systems can utilise the productivity of the aquifer of the Chalk formation.

Open Loops Systems

- Open loop systems are typically more efficient and cost effective than closed loop systems. However open loop systems are only feasible where an aquifer can provide sufficient volumes of groundwater and a site is large enough where the reinjection of groundwater does not cause thermal short-circuiting or breakthrough. A typical rule of thumb for open loop systems is on the order of 250m for abstraction and reinjection well spacing (however this will vary based on a variety of factors).
- An open-loop system requires only a few wellbores, open at the base to a groundwater bearing aquifer. Groundwater is drawn from the aquifer, via supply wells (i.e. pumping wells). The water is then pumped back via injection wells into the same aquifer. The supply and injection wells must be separated sufficiently to minimize thermal breakthrough or short-circuiting.
- Figure 4 at the rights provides a conceptual illustration of the energy flow within an open loop system (on the aquifer / ground side). The concepts are discussed with a bit more detail in the methodology section below.

Hydrogeology of the London Basin and Southwark Borough

- Hydrogeologically, Southwark Borough is fully within the London Basin. The primary aquifer within the London Basin is the 'Lower Basal Sands and Chalk Formation'. The hydrogeological properties of this aquifer are dominated by the secondary porosity (i.e. the fractures and fissures) of the Chalk Formation (fm).
- The productivity of the Chalk fm is dependent on encountering sufficiently conductive fractures. However, the locations of these fractures are highly uncertain features. While the Environment Agency (EA) has produced significant data on the overall productivity of the Chalk fm on a city-wide 'regional' scale, the exact productivity at any specific location must always be proven by drilling and well testing.

- Given the relatively high sustainable productivity of the Chalk fm, open loop system potential mapping was limited only to the Chalk fm. Other secondary aquifers (such as the shallower River Terrace Deposits) are typically not considered to be feasible targets for an open loop system for a variety of reasons (principally due to the limited thickness of the shallow aquifers).

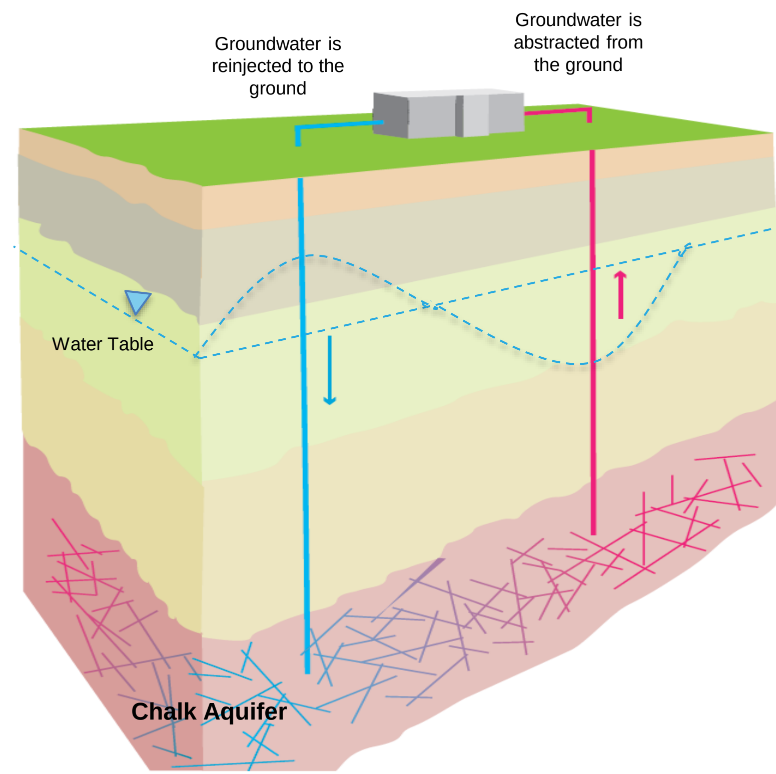


Figure 4: Illustration of energy flow in an open loop system..

3. Methodology

GIS based mapping tools have been coupled with high level evaluations of ground energy potential.

Overview

- Mapping was performed using GIS tools and based on simplified methods to evaluate GSHP system potential capacity. Two types of GSHP systems were evaluated Open Loop and Closed Loop. The mapping methodology different for each system and is thus separately described.
- Within a GIS data environment, a map of Southwark Borough is used as a base map and several supporting map layers are developed. The map layer are digitised to provide a quantitative value within each grid cell of the map. A weighting equation is then used to combine the relevant layers to produce a semi-quantitative ranking of the open loop or closed loop opportunity across the Borough.

Open Loop Mapping Methodology

Open Loop Parameter Selection

- For an open loop system, the following parameters were evaluated and mapped:
  - Depth to top of Chalk fm aquifer (data collected from BGS water wells at http://mapapps.bgs.ac.uk);
  - Depth to top of groundwater within the Chalk fm (which is typically above the top of the Chalk fm, due to the confining nature of overlying clay units (Ref: EA, 2019. Management of the London Basin Chalk Aquifer); and
  - Hydraulic Conductivity and Tranismissivity of the Chalk fm (Ref: NERC 2003. Simulated transmissivity of Chalk Aquifer under typical average conditions).

Evaluation of Open Loop Potential

- Open Loop systems are dependent on the rate of sustainable pumping and reinjection rates and the temperature of the aquifer. The pumping rate is based on aquifer transmissivity and the available thickness of the aquifer to remain saturated during pumping. The reinjection rate is based on the aquifer transmissivity and the available 'head room' between the groundwater surface and the ground surface.
- A simple well yield equation based on Darcy's Law was used to estimate production and reinjection capacity. The inputs to the equation include the hydraulic conductivity and hydraulic gradient. The hydraulic conductivity is a function of transmissivity and aquifer thickness. The hydraulic gradient is based on the draw-down or draw-up which occurs during pumping.

Potential Ranking Method

- A ranking system was developed using the following evaluated parameters:
  - Sustainable well flow (both for pumping and reinjection),
  - Drilling costs (estimated as a function of depth to reach the top of Chalk fm),
- The ranking system employed is as follows:
  - R_{OL} = A x I x C x O
  - Where:
    - R_{OL} = opportunity total ranking for open loop systems,
    - A = aquifer productivity ranking, ,
    - I = reinjection capacity ranking,
    - C = cost ranking, and
    - O = ranking due to other factors.
- Aquifer productivity ranking is based on the assessment by the EA on the distribution of transmissivity in the Borough (Figure 10). Both identified transmissivity ranges would allow for sufficient groundwater production rates, thus the following was selected:
  - Between 50 and 100 m^2/d = 1, and
  - Between 100 and 500 m^2/d = 2.

3. Methodology Continued

Maps are based on semi-quantitative ranking of driving factors for both open-loop and closed-loop systems.

Open Loop Methodology Continued

- Injection capacity ranking is based available difference between the ground surface to the groundwater surface in the chalk to allow for reinjection of groundwater. For the range of transmissivity in the Borough the following was selected:
  - Less than 15 m of thickness = 0, and
  - 15 m or more = 1.
- While the EA has produced an assessment a transmissivity ranges in the Borough (as part of it regional management of the London Basin's principal aquifer), transmissivity ranges are based on the ability to intercept fractures within the Chalk fm. Thus, until a well is drilled and tested, transmissivity should only be seen as planning level estimates. In addition, a sufficient contingency for additional wells should always be including in cost planning.
- On cautionary features such as being within a Source Protection Zone (SPZ) or nearby an existing open loop system. Where a cautionary feature exists, an open loop system may still be feasible, but will require additional evaluation measures to confirm feasibility.

Closed Loop Mapping Methodology

- The driving factor for closed loop systems are the ground thermal parameters of thermal conductivity and thermal diffusivity as well as the depth of the closed loop boreholes. Closed loop boreholes are typically advanced to around 150 m below ground, but energy piles can be much shallower and are dependent on the depth of the structural pile. To evaluate thermal ground parameters, a 3D geologic model was developed across the Borough.
- The 3D model was developed using publicly available borehole logs and then geo-statistically interpreted using the commercial modelling tool, Leapfrog (Figure 11). The output from the 3D model was used to interpret the thicknesses of the geologic formations across the Borough. Thermal conductivity parameters were selected from literature reviews (Table 1) and then weighted across depths of 50 and 150 m, to estimate effective thermal parameters across the Borough.
- A distribution of thermal conductivity was then estimated across the Borough at closed loop systems installed to 50 m and 150 m below ground surface.

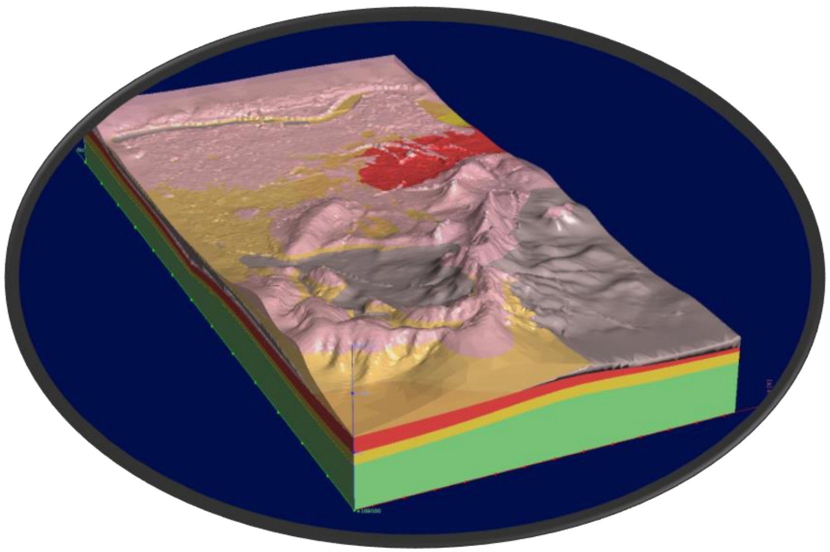
Table 1. Selected literature values of thermal conductivity for geologic units in the Borough.

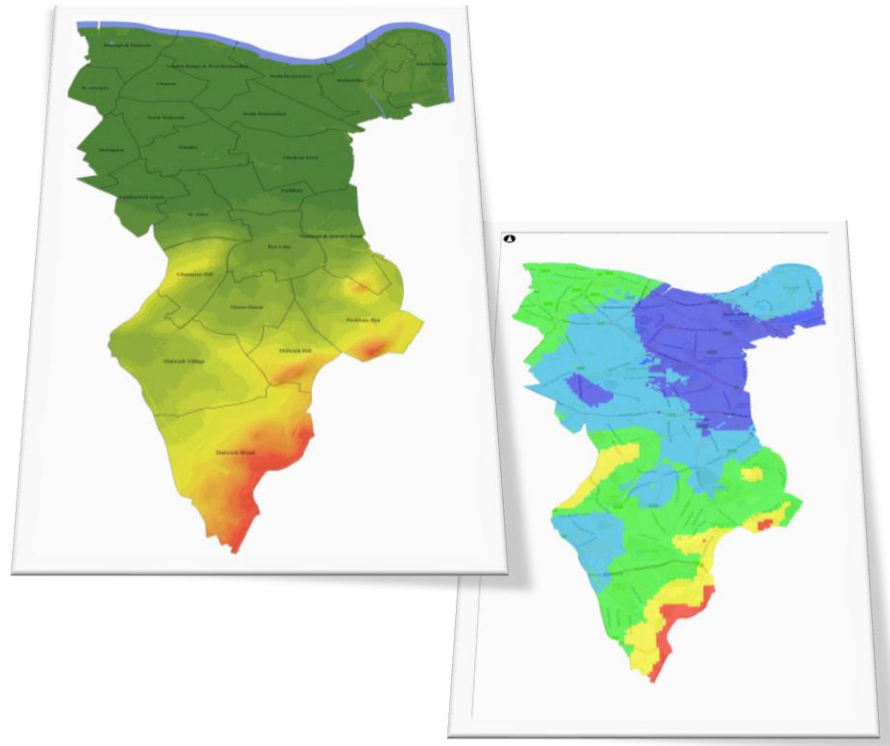
Formation Unit	Thermal Conductivity (W/m-K)
Alluvium	1.67
River Terrace Deposits	2.50
London Clay	1.79
Harwich Formation	2.4
Lambeth Group	2.2
Thanet Sands	2.35
Chalk Group	1.67

4. Inputs

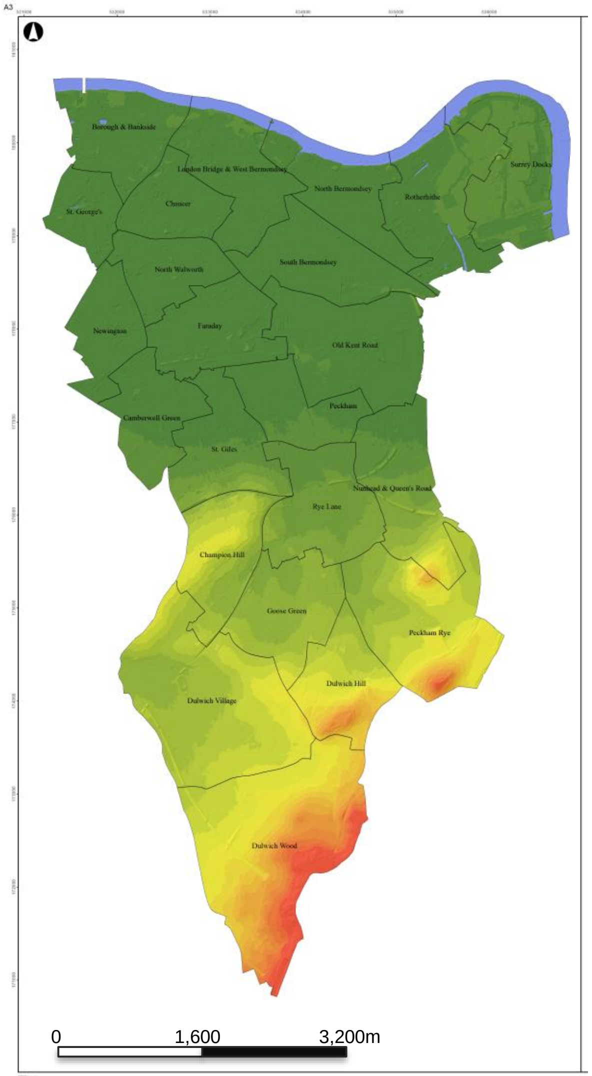
All the input maps rectified and digitalized; and a 3D model has been generated for the geologic layers across the Southwark Borough.

- Maps and models used to generate the opportunity maps are provided as follows:
  - Figure 5: Topographic Map;
  - Figure 6: Depth to top of Chalk fm map;
  - Figure 7: Chalk groundwater level map;
  - Figure 8: Depth to groundwater level map;
  - Figure 9: Source Protection Zones (SPZs);
  - Figure 10: Chalk fm Transmissivity map
  - Figure 11: Extract of 3D Ground Model showing geologic units





Lidar Topography Data and Chalk Depths is crucial to evaluate the depth of source.



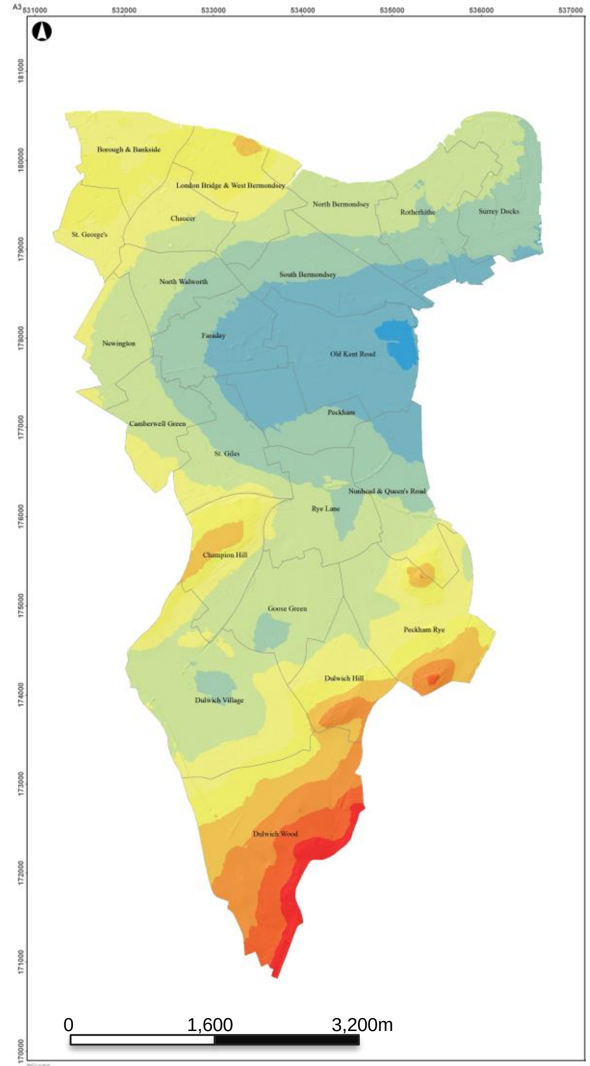
Legend

Lidar Elevation Data (mOD*)

- -13 to 0
- 0 - 5
- 5 - 10
- 10- 15
- 15 - 20
- 20- 25
- 25 - 30
- 30- 35
- 35- 40
- 40- 45
- 45 - 50
- 50- 55
- 55 - 60
- 60 - 65
- 65 - 70
- 70 - 75
- 75 - 80
- 80 - 85
- 85- 90
- 90 - 95

*Note: mOD (metres Ordinance Datum) refers to the survey coordinate system used across London.

Figure 5: Topographic Map



Legend

Depth to Chalk (mbgl)

- 8.2 - 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 60
- 60 - 75
- 75 - 100
- 100 - 125
- 125 - 150

Figure 6: Depth to top of Chalk fm map

Groundwater Data taken by EA Chalk Groundwater Level Map published in 2019.

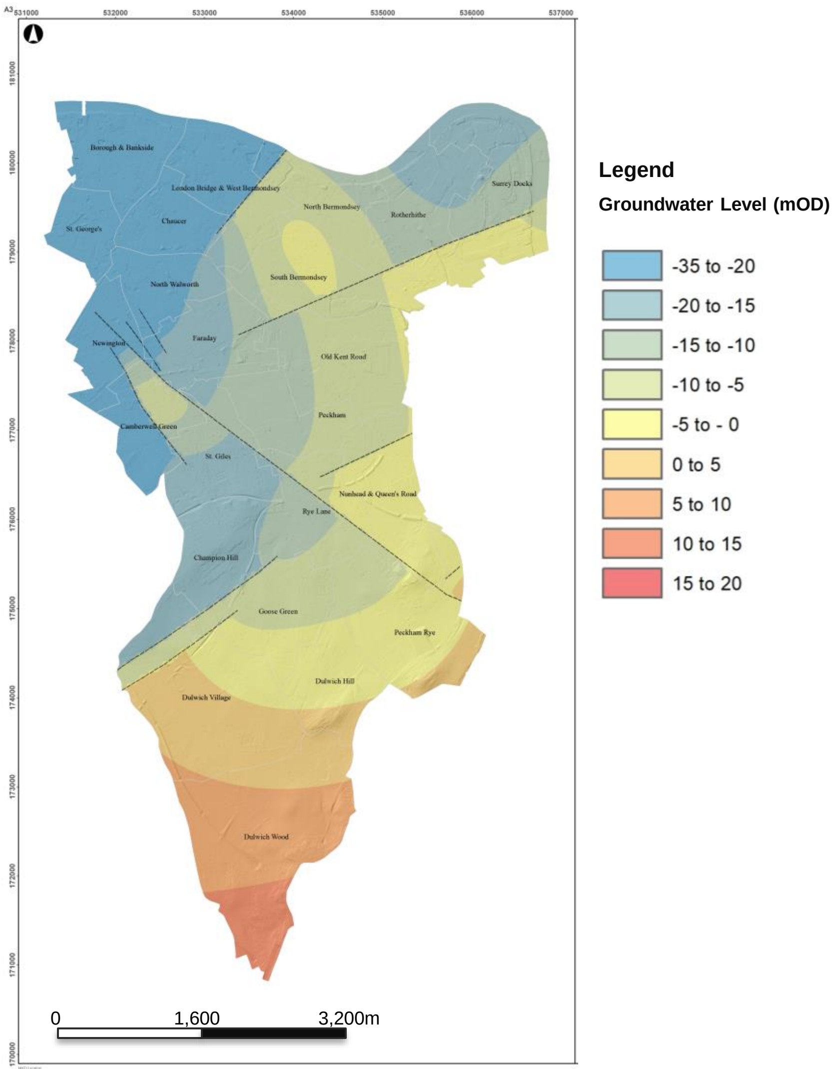


Figure 7: Chalk groundwater level map

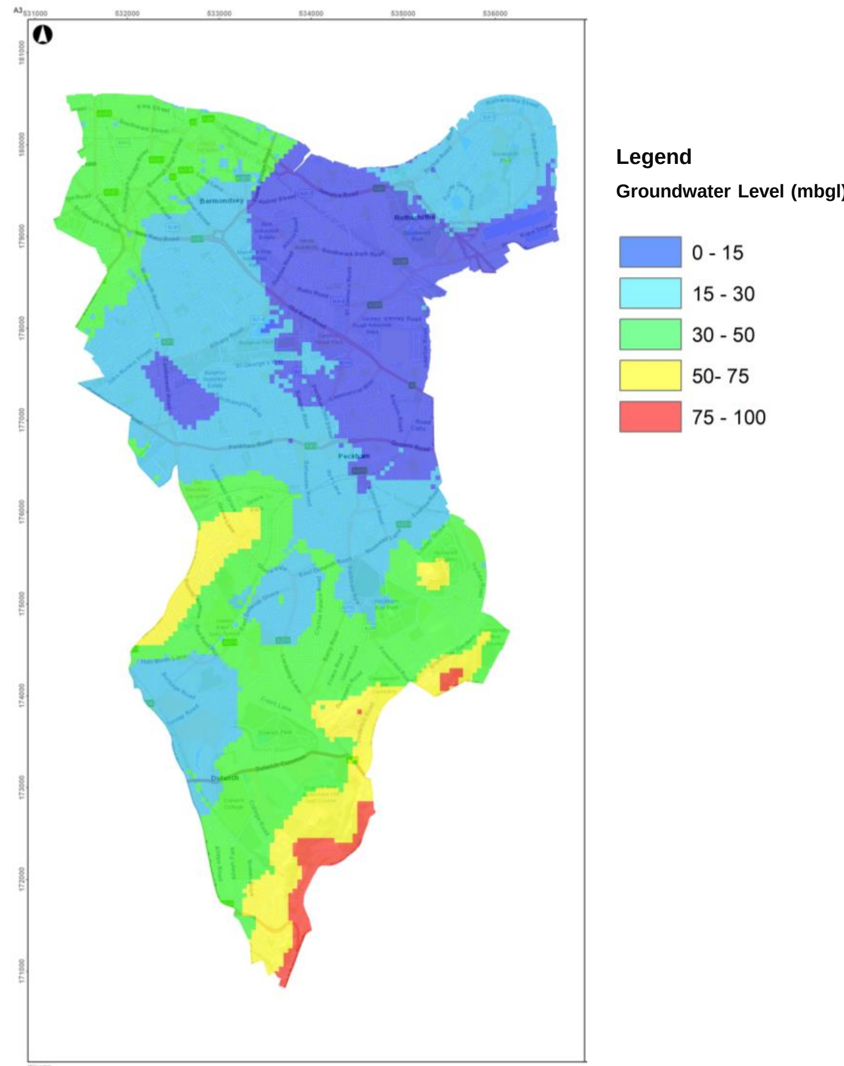


Figure 8: Thickness between ground surface and Chalk (fm) groundwater level

4. Inputs

Transmissivity of Chalk Aquifer is one of the main score parameter to calculate the potential, and SPZs are negative impact for start the project.

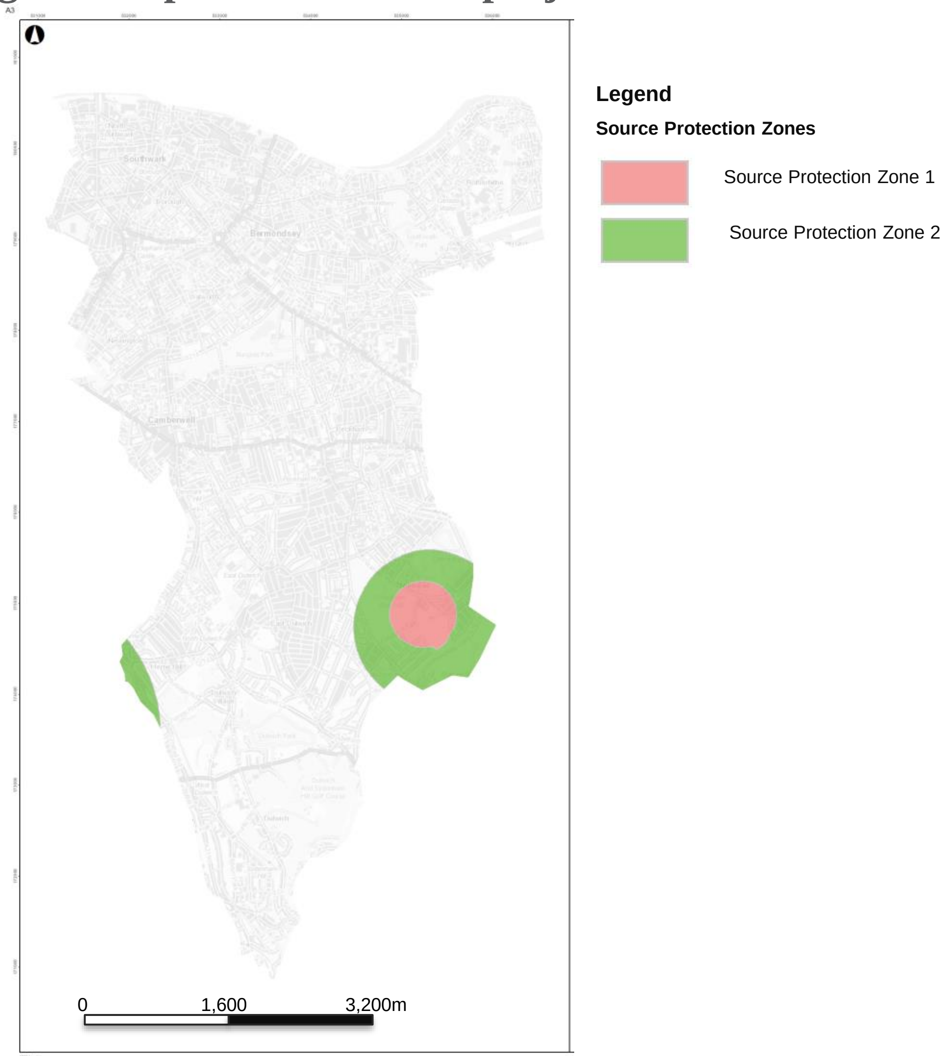


Figure 9: Source Protection Zones (SPZs);

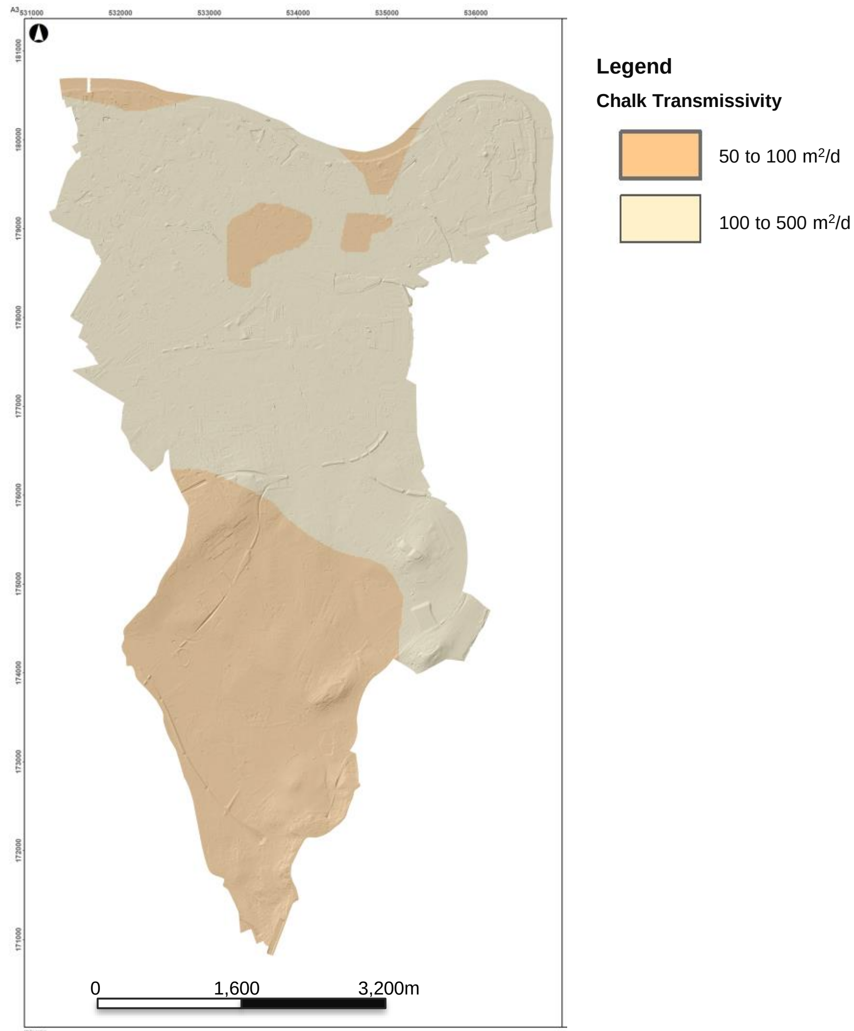


Figure 10: Chalk fm Transmissivity map

4. Inputs

A 3D model has been generated for the geologic layers across the Borough. Formation thicknesses inferred from the 3D model has been used to estimate variation in thermal properties.

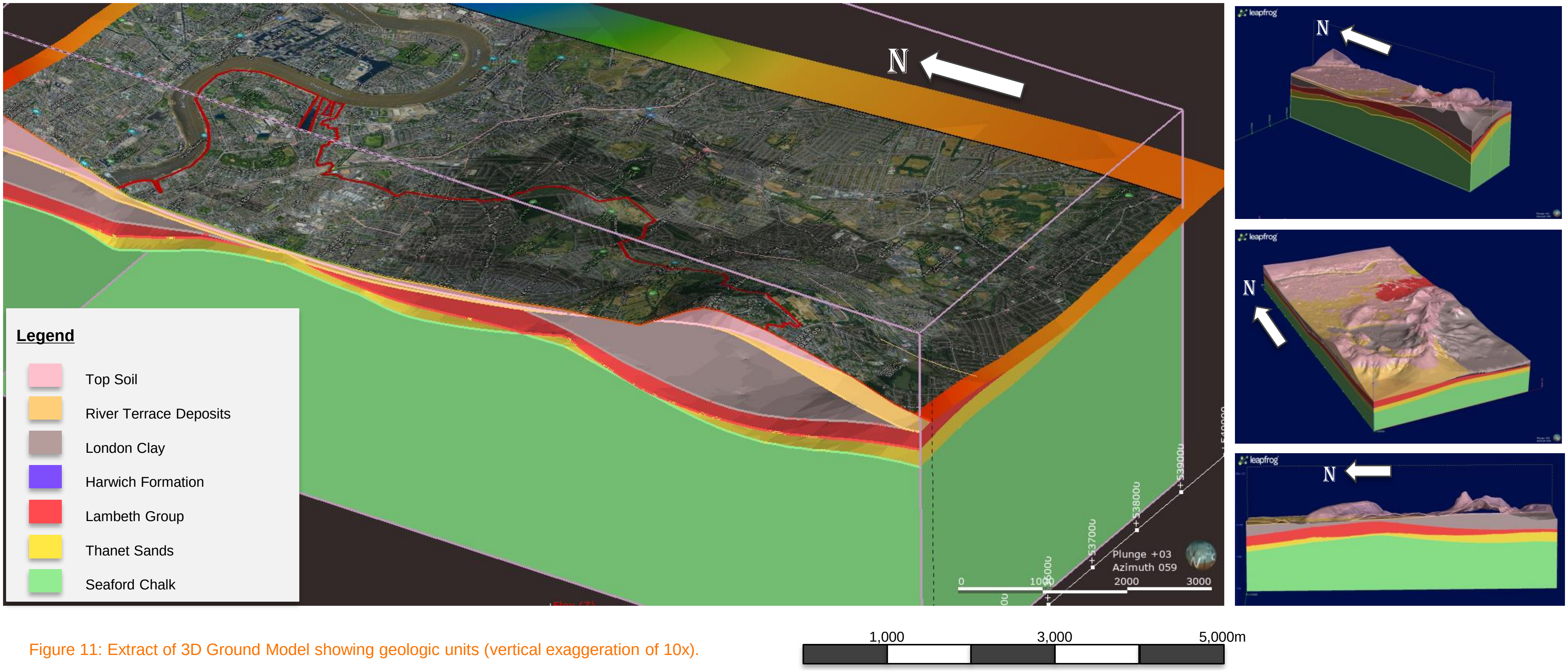
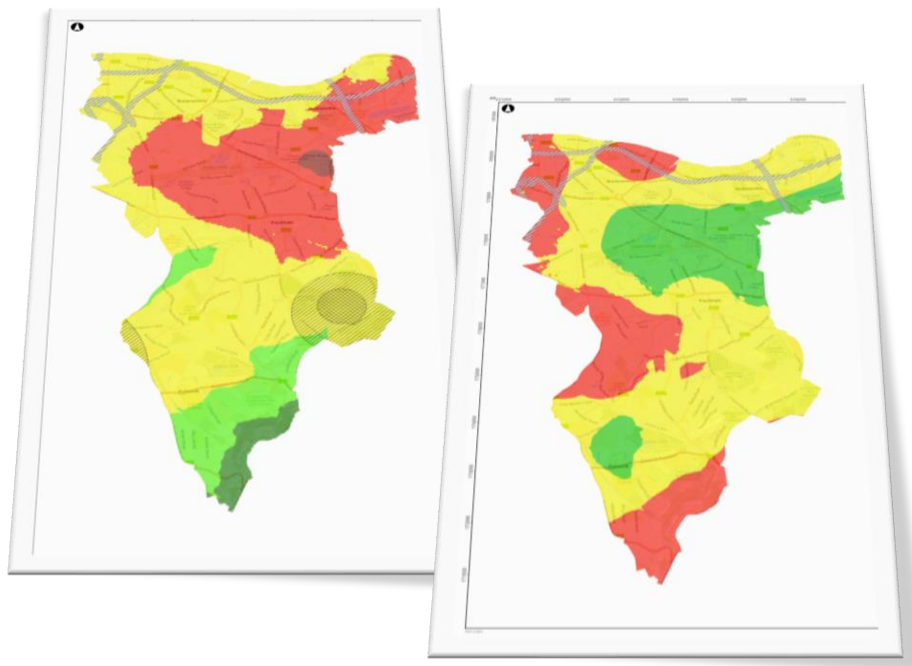


Figure 11: Extract of 3D Ground Model showing geologic units (vertical exaggeration of 10x).

5. Results and Data Validation

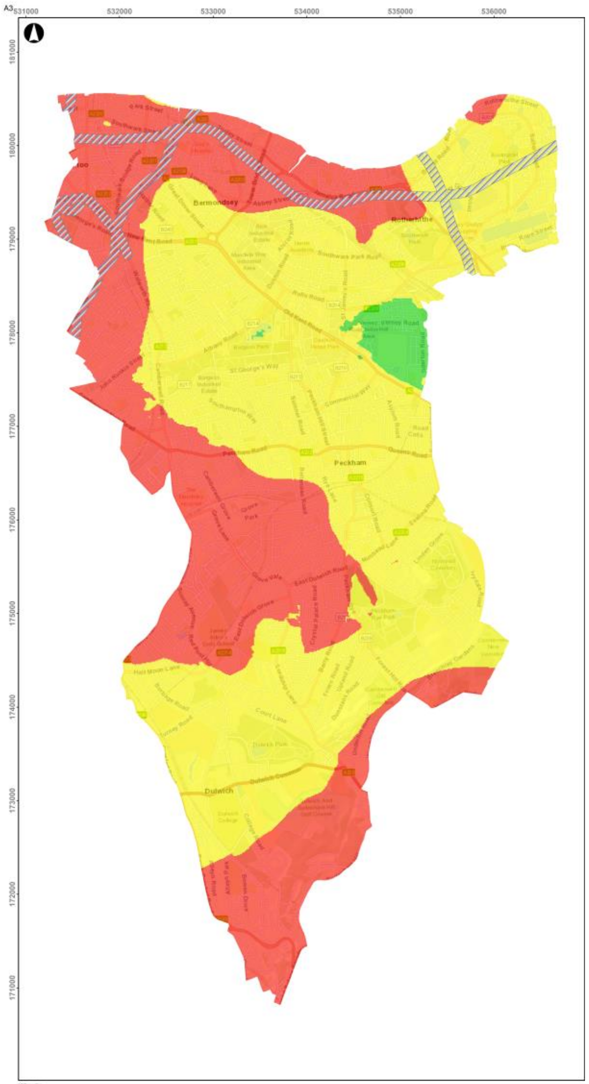
Open Loop and Closed Loop potentials generated for the geologic layers across the Borough.

- Maps and models used to generate the opportunity maps are provided as follows:
  - Figure 12: Closed Loop Potential Map for 50 to 100m depth boreholes
  - Figure 13: Closed Loop Potential Map for 100m depth boreholes
  - Figure 14: Open Loop Potential Map
  - Figure 15: BGS Depth to Source Map from BGS Open Loop Potential Map
  - Figure 16: BGS Bedrock Aquifer Potential Map from BGS Open Loop Potential Map



5. Results: 50 to 100m Closed Loop Potential

Closed Loop systems are mostly suitable all the area in Southwark Council.



Legend

- TfL Safeguarding Zone
- Low Potential (40W per m)
- Medium Potential (45W per m)
- High Potential (50W per m)

- **Assumptions**
  - Borehole Depth: 50 to 100m
  - Minimum well separation distance: 6m

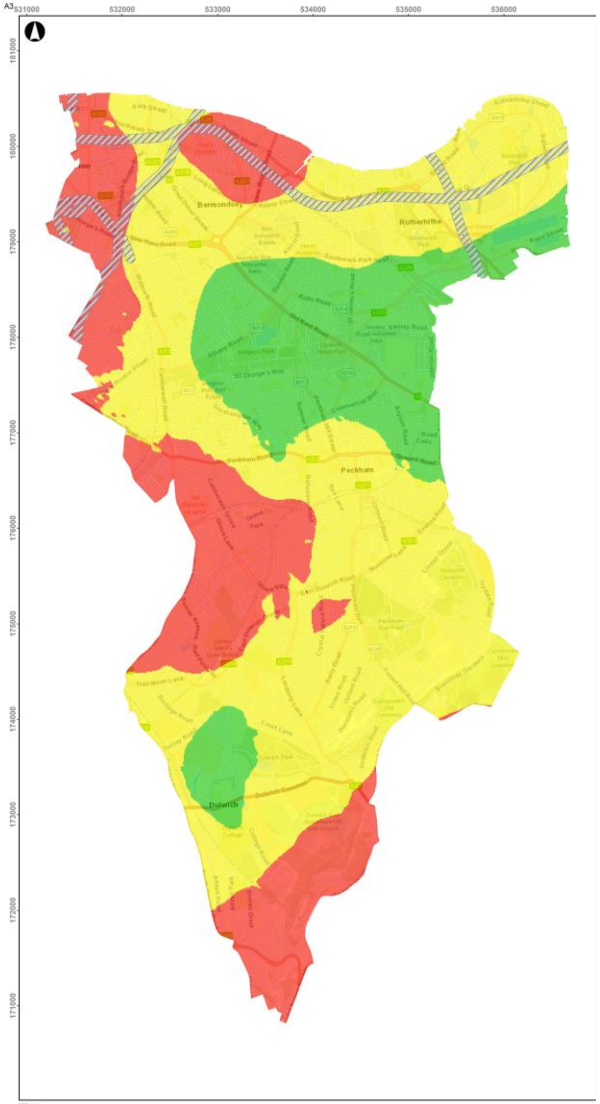
- **Potential Range for Southwark Area**
  - 40w to 50w per meter:
    - 2 kW to 2.5 kW per 50m borehole;
    - 3 kW to 3.7 kW per 75m borehole; and
    - 4 kW to 5 kW per 100m borehole.

0 1,600 3,200m

Figure 12: Closed Loop Potential Map for 50 to 100m depth boreholes

5. Results: 150m Closed Loop Potential

Closed Loop systems are mostly suitable all the area in Southwark Council.



Legend

- TfL Safeguarding Zone
- Low Potential (6 to 6.5kW per borehole)
- Medium Potential (6.5 to 7kW per borehole)
- High Potential (7 to 7.5kW per borehole)

- **Assumptions**
  - Borehole Depth: 150m
  - Minimum well separation distance: 6m

- **Potential Range for Southwark Area**
  - 6 to 7.5kW per 150m vertical borehole

0 1,600 3,200m

Figure 13: Closed Loop Potential Map for 150m depth boreholes

5. Results: Open Loop Potential

Shallow open loop systems are potentially available at the north south part of Southwark.

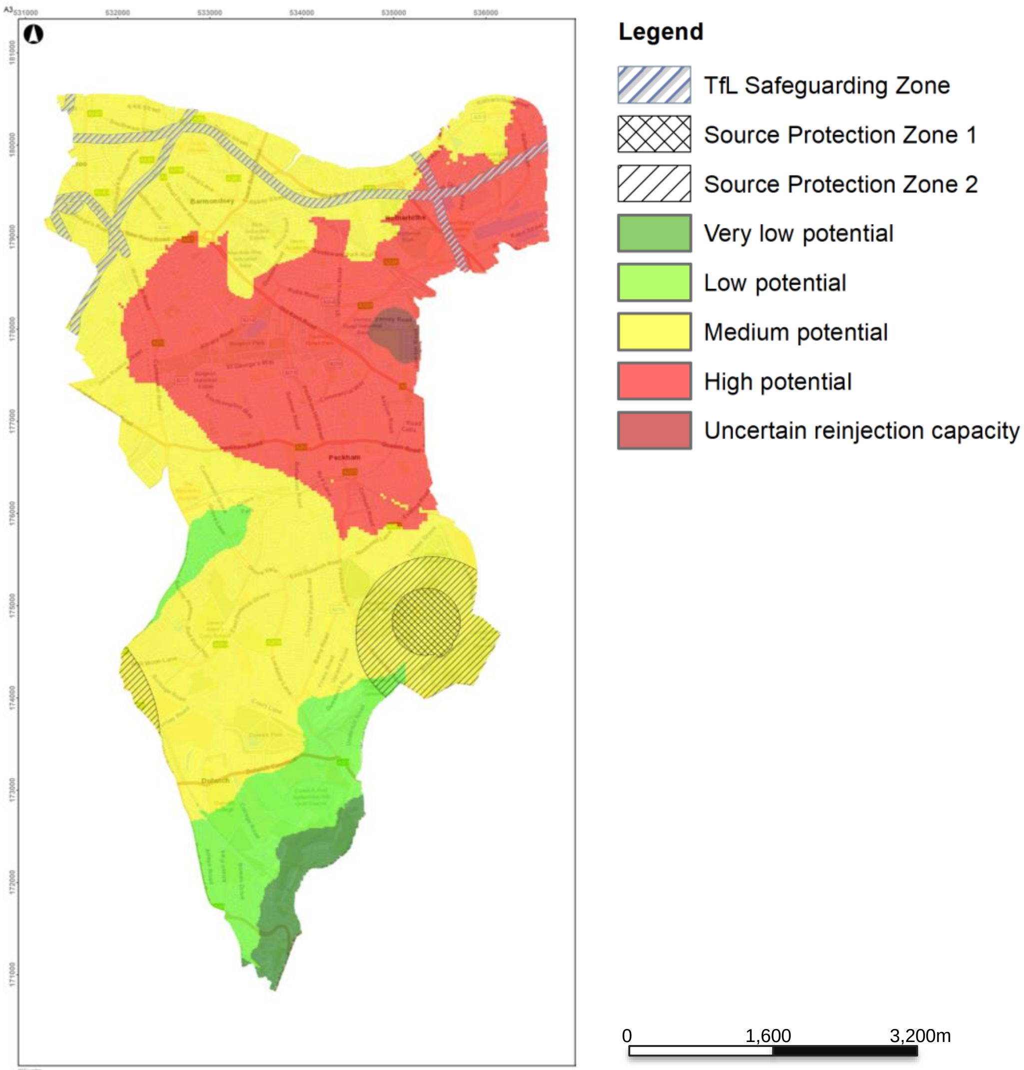


Figure 14: Open Loop Potential Map

- **Assumptions**
  - Well depth: 150m
  - Efficiency Factor: 80%
  - Temperature differences: 5 C
  - Open loop production rate: 16 kW/L/s
  - Minimum well separation distance: 100m

- **Potential Range for Southwark Area**
  - 5 to 400 kW for per 150m well

- **Limitations**
  - Source Protection Zones (SPZ's)
  - TfL Safeguarding Zones (50m to TfL Assets)
  - Existing Open Loops (100m to existing wells)
  - Groundwater Levels taken by 2018 values and can change by the years.

Depth to Chalk results checked with the BGS Depth to Source Map

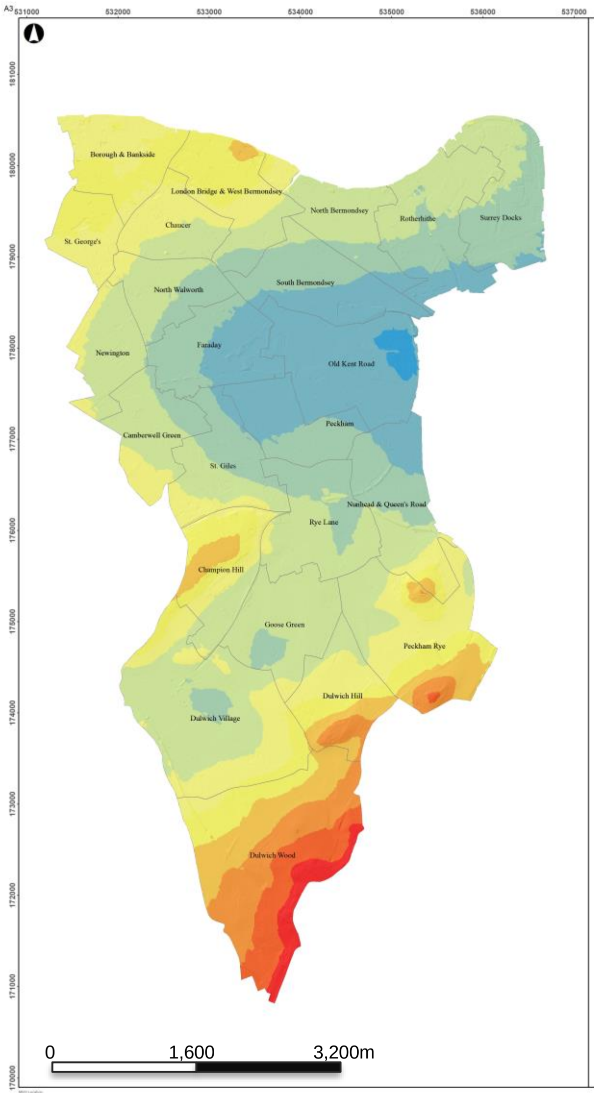


Figure 6: Depth to top of Chalk fm map

Legend

Depth to Chalk (mbgl)

- 8.2 - 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 60
- 60 - 75
- 75 - 100
- 100 - 125
- 125 - 150

Legend

Depth to Source (mbgl)

- <=50m
- 50 - 100m
- >100 - 150m
- >150 - 200m

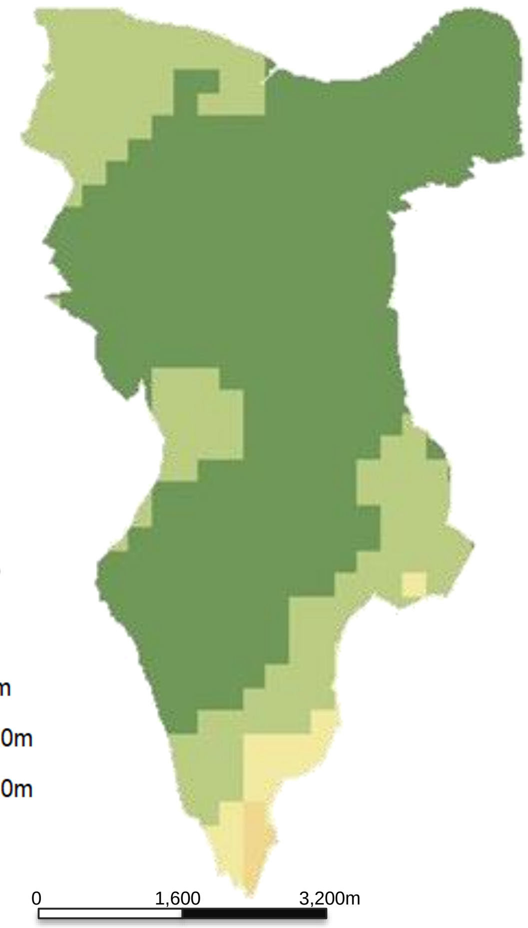


Figure 15: BGS Depth to Source Map from BGS Open Loop Potential Map

Open-loop production capacity results checked with the BGS GSHP Bedrock Aquifer Potential Map

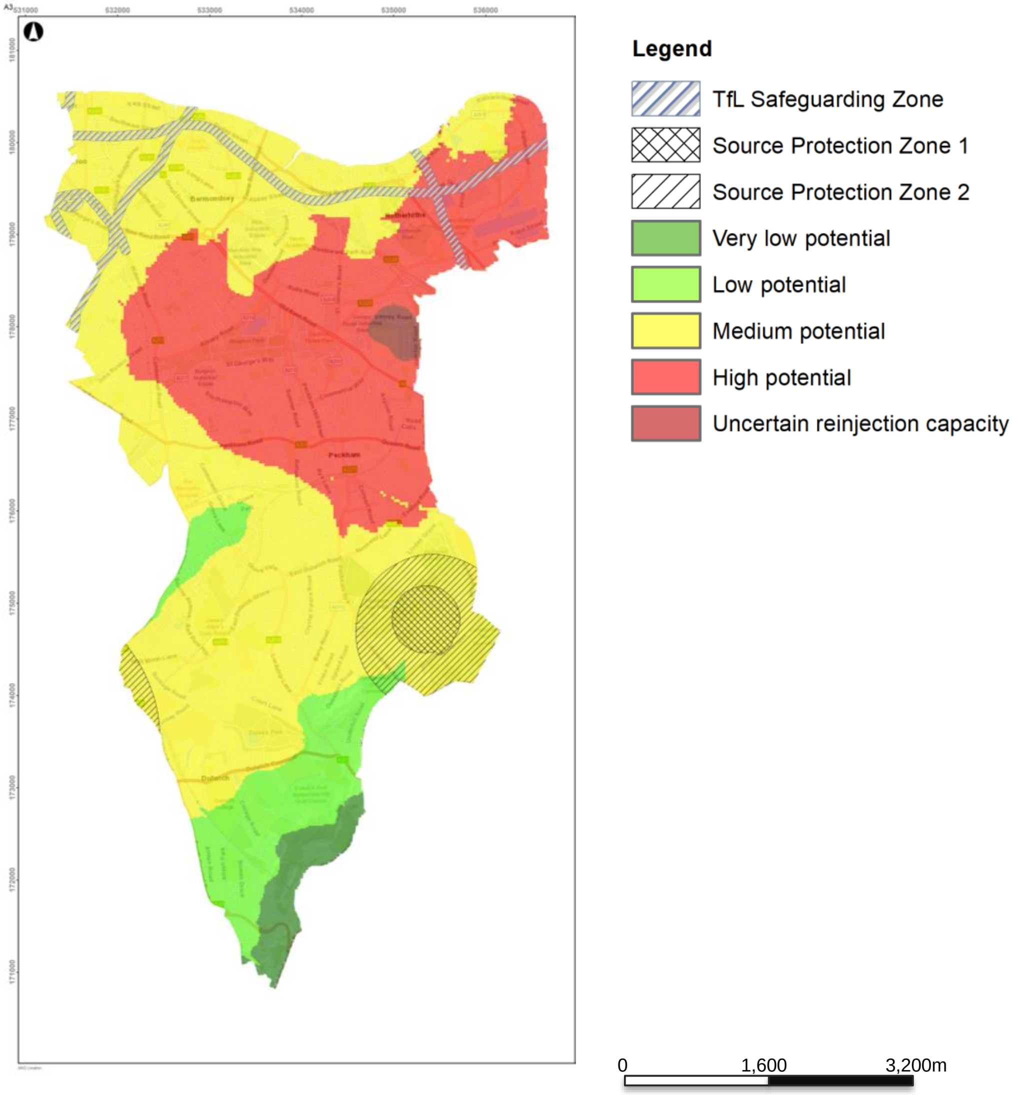


Figure 14: Open Loop Potential Map

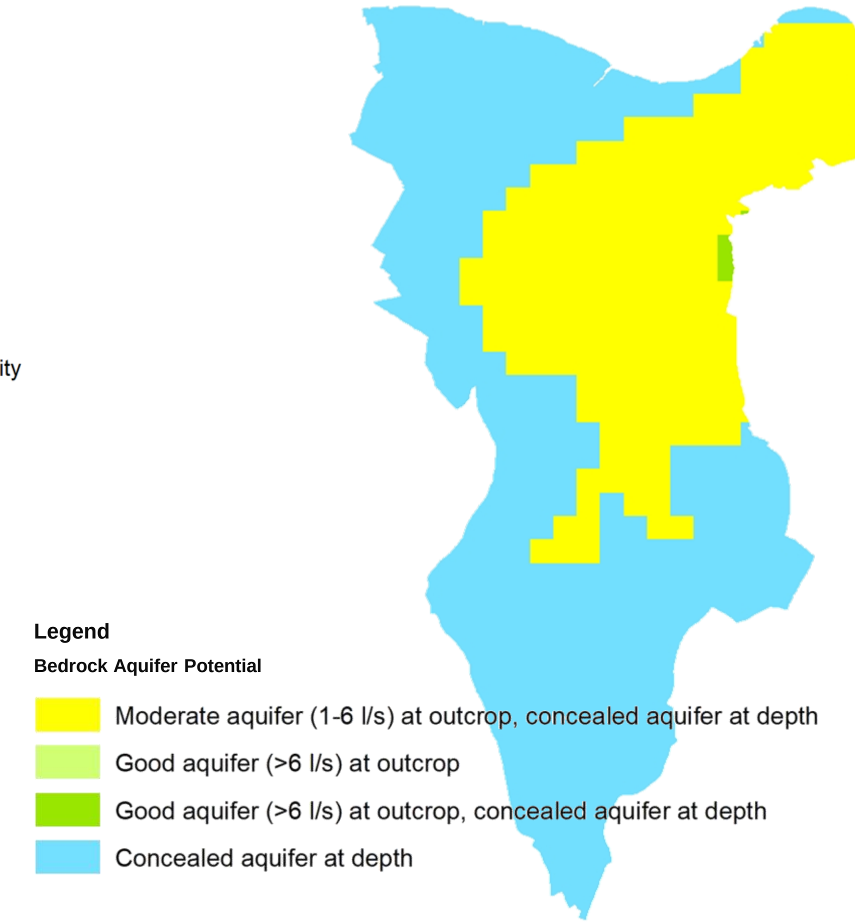


Figure 16: BGS Bedrock Aquifer Potential Map from BGS Open Loop Potential Map