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Abstract

Detailed analysis of potential water chemistry and settlement issues associated with the installation of open loop geothermal systems are infrequently carried out. This has led to the failure of several previously installed systems. Chemical analysis of water extracted from beneath the Cork Docklands has been performed by the authors in order to assess the suitability of the area to exploitation of open loop geothermal energy. The possibility of settlement induced by pumping of groundwater for open loop systems has also been examined.

Current market penetration of ground source heat pumps in Ireland is discussed in order to illustrate the infancy of the technology in Ireland relative to other European countries and to highlight the necessity to approach possible installation of such systems with the care required.

Water extracted from beneath the Docklands shows that significant water chemistry issues exist. Laboratory and field tests confirm that optimal concentration levels of several water chemistry characteristics are significantly exceeded; leading to the conclusion that open loop exploitation in the area may not be suitable. In addition, settlement induced by pumping of water could potentially lead to a consolidation settlement in excess of 30 mm due primarily to the existence of highly compressible alluvium.

Notation:

ε strain

$\delta\sigma'$ change in effective stress

$\delta\varepsilon$ change in strain

ΔH consolidation settlement

σ_v' effective stress

$\mu\text{S/cm}$ micro-siemens per centimetre

CaCO_3 calcium carbonate

CO_2 carbon dioxide

I_d	seismic dilatometer material index
kWh	kilowatt-hours
M	constrained modulus
m	modulus number
mOD	meters above ordinance datum
MW _t	mega watts thermal
°C	degrees centigrade
pH	potential for hydrogen
pH _s	saturation pH
ppm	parts per million
q _t	corrected CPTU end resistance
R _f	ratio of sleeve friction to corrected CPTU end resistance
s _u	undrained shear strength
TDS	total dissolved solids
UU	unconsolidated undrained
V _s	shear wave velocity

Keywords: Renewable Energy; Groundwater; Site Investigation

Introduction to Shallow Geothermal Energy

There are five broad types of shallow geothermal (or ground source) energy exploitation, each of which is represented in Figure 1 and briefly described in Table 1.

Figure 1 Shallow Geothermal Energy Exploitation Categories (Cementation Skanska, 2010)

Table 1 Explanation of Exploitation Categories

Having briefly illustrated the various geothermal exploitation categories, this paper will now focus primarily on settlement and water chemistry issues associated with the exploitation of open loop geothermal systems (with case studies as appropriate), Ireland's fuel import dependency and will give a broad overview of renewable energy statistics applicable to Ireland.

Fuel Import Dependency

A spike in oil prices in the late 70's and early 80's encouraged many countries worldwide to develop programmes to investigate the potential for renewable energy resources and technologies. Many of these programmes were however dramatically scaled back or cancelled altogether as oil prices reverted to their previous lows for much of the two decades which followed. Following the subsequent return of high oil prices in the mid 1990's, countries worldwide are once again forced to investigate the development potential of renewable energy resources and technologies. Driven by the need to secure a more cost-stable energy future, decrease reliance on energy imports and reduce greenhouse gas emissions, Europe is seen by many as leading the way in the reduction of dependence on fossil fuels.

Energy Dependence Rate describes the proportion of energy that an economy must import. It is calculated as net imports divided by gross consumption plus fuel supplied to international bunkers. Ireland was the fourth most energy dependent state in the European Union in 2007, relying on imports for 89% of energy (Energy Policy Statistical Support Unit, 2008a), importing significantly larger proportional quantities compared with the average of the 27 European Union member states (EU-27)

which stands at 53%. By contrast, the United Kingdom had an energy import dependency rate of just 20% (Eurostat, 2009) ranking second in the EU-27. Denmark, a country similar in land area and population to Ireland, was the only EU-27 member state with a negative energy dependency (-25.4%) in 2007.

Ireland's disproportionately high reliance on fossil fuels when compared to other European countries is primarily due to the fact that oil and natural gas alone account for over 80% of the country's energy input (Energy Policy Statistical Support Unit, 2008b). Given the lack of fossil fuel reserves in Ireland (notable exceptions are the Corrib and Kinsale gas fields located off the western and southern coasts respectively) and the existing opposition towards exploring the nuclear option, at least in the short to medium term, renewable energy is sure to be a major focus of energy policy for years to come. All forms of renewable energy (wind, solar, geothermal, biomass, wave and tidal) will have a part to play in the expansion of the renewable energy industry in Ireland.

Renewable Energy in Ireland

In order to achieve a more cost stable and secure energy future, the European Union (EU) has embarked on an ambitious short and medium-term plan to augment the contribution of renewable energy in Europe and remains committed to achieving a renewable energy target of 20% of total final energy usage by 2020. Each EU member state has been allocated an individual national target, the aggregate of which adds up to the overall 20% target. This allocation is based on each country's existing renewable generation capabilities, their Gross Domestic Product and a flat rate increase. Ireland and the UK have been allocated targets of 16% and 15% respectively.

In recent years renewable energy production in Ireland has passed through a rapid phase of development, with renewable energy providing 2.7% of Ireland's Total Primary Energy Requirement (TPER) in 2007, compared to just 1.8% in 1990 (Energy Policy Statistical Support Unit, 2008b). At first glance, this does not appear to be a significant increase, however, it should be noted that Ireland's TPER increased by almost 70% in the period 1990-2007 while renewable energy increased by 182% (Energy Policy Statistical Support Unit, 2008a). This increase in renewable energy is primarily due to the increasing contribution of wind energy which supplied 63% of renewable energy used for electricity generation in 2008 (Energy Policy Statistical Support Unit, 2009). Although the

exact contribution from geothermal energy to this increase in renewable energy generation is not precisely known it is certainly significantly less than one percent. The lack of any regulatory system with regard to geothermal energy, a lack of specialist knowledge in the area among Irish engineering consultants and the consequent low confidence in geothermal energy technologies are some of the primary reasons for the lack of geothermal installations in the country. Nevertheless renewed interest in renewable energy technologies in Ireland evidenced by increasing numbers of renewable energy installations and ambitious renewable energy targets set by government are certain to have an impact on the number of geothermal energy installations going forward.

Ground Source Energy in Ireland

Geothermal heat pumps are one of the fastest growing applications of renewable energy worldwide, with an annual increase in the number of installations of over 10% over the last ten years in approximately 30 countries (Lund et al., 2004). Although installations in Ireland are few, water source heat pumps are regarded as a mature technology in many countries, with estimates of 50,000 installations in the United States alone as far back as 1990 (Lund, 1990).

It is difficult to accurately estimate the number of ground source heat pumps in operation in Ireland. However, the pie chart in Figure 2 shows that 23% of applications for grant aid to the Sustainable Energy Authority of Ireland's Greener Homes Scheme (GHS) are for Heat Pump Applications. While this does not give an indication as to overall number of installations in the country, it gives an idea of the quantity of installations relative to solar and biomass. Almost 5,000 domestic Ground Source Heat Pumps (Open & Closed Loop) have been installed in the Republic of Ireland with Greener Homes Scheme Grant Aid since the scheme began in 2006. The European Commission website shows that by 2006, there were 1,500 geothermal heat pump installations (corresponding to a capacity of 19.6 MWt) in Ireland (EUROSTAT, 2008). This indicates that the total number of installations is currently in excess of 6,500.

Figure 2 Breakdown of Applications to GHS in Ireland by Technology

It has been previously stated that vertical open-loop collectors used in combination with water source heat pumps* are the most commonly used systems in shallow boreholes in Ireland (Goodman et al., 2004). More up to date statistics (provided by the Sustainable Energy Authority of Ireland's Greener Homes Scheme) however suggest that water source heat pumps account for a minority of installations when compared with horizontal or vertical (closed loop) ground source heat pumps (see Figure 3). Water source heat pumps operate by extracting water, removing its heat and returning the water to the aquifer, by discharge into a mains wastewater system, onto the land surface or into a lake, pond or river.

**(Note that Ground Source Heat pumps may refer to both closed and open loop systems, the term 'water source heat pump' refers to open-loop applications only)*

Figure 3 Heat Pump Types Installed in Ireland with GHS Aid

While ground source heat pump systems are initially more expensive than the equivalent air source system, they can benefit from lower operating and maintenance costs and a higher coefficient of performance (COP) (Lund, 1990). Air source heat pumps have the added disadvantage of high variability in air temperatures when compared to ground source heat pumps which benefit from a relatively constant ground temperature throughout the year.

Environmental Benefit of Ground Source Energy

The environmental benefits of heat pump exploitation are somewhat hampered by the fact that electricity used during their operation is drawn from a grid which relies to a large degree on fossil fuels. The current emission factors for Irish and United Kingdom grid electricity are 0.543 (Sustainable Energy Authority of Ireland) and 0.422 (Boennec, 2008) kgCO₂/kWh respectively. It should be noted however, that these emission factors are currently decreasing in tandem with the gradual decarbonisation of national grids, due to the escalating share of electricity generated from renewable sources. This means that the emissions created by the operation of heat pumps, even if there is no

improvement in the technology, will also decrease. Ireland's 'electricity from renewables' generation target is 40% by 2020. In 2008 renewables accounted for only 6.4% of the energy inputs required to produce electricity in Ireland (Energy Policy Statistical Support Unit, 2009) – plainly demonstrating the considerable scope that exists for further de-carbonisation of Irish grid electricity.

Figure 4 (data courtesy of Energy Policy Statistical Support Unit, 2009) shows the decarbonisation of the Irish electricity grid from 1990 to 2008.

Figure 4 Irish Grid Electricity De-Carbonisation

When installed correctly and for an appropriate application, significant emission savings are possible using heat pump technologies when compared to conventional heating systems. This is despite the fact that heat pumps require electricity for their operation.

Cork City Development Plan & Geothermal

The current Cork City Development Plan (Cork City Council, 2009) which outlines the city's development policies and objectives for the period 2009 to 2015 encourages the use of renewable energy in all new buildings and states that renewable energy will be the first choice for all council developments where it is a cost effective solution. In fact, the Development Plan goes a step further by incorporating into policy (Policy 12.40), the continued pursuit of initiatives which promote innovation in the fields of energy conservation and renewable energy resources and research.

The Cork City Docklands are spread over an area three times the size of the existing Cork City Centre. The Docklands are located within walking distance of the established city centre and currently represent the most significant development opportunity for the Greater Cork City area. However, a number of existing issues require resolution in order to allow development of the area to commence in earnest. These issues, identified in the Cork City Development plan include access and service

infrastructure, relocation of existing port activities, ground contamination caused by heavy industry, flooding and energy and telecommunications infrastructure.

Capacity analysis has indicated that the South Docklands area, currently occupied by a mixture of large warehouses and unused sites, is capable of sustaining a population of 20,000 residents in addition to a working population of 25,000 persons. With development potential of this magnitude in the Republic of Ireland's second city, renewable energy technologies should be given detailed consideration at the early stages of any new projects, and shallow geothermal energy can have a part to play. This is reinforced by the following statement extracted from the Cork City Development Plan 2009-2015 *“geothermal research projects carried out to assess the geothermal resources in Cork City have revealed that there is good potential for such an energy source”* (Cork City Council, 2009).

Noteworthy existing geothermal applications sourcing groundwater contained in the Lee buried gravel aquifer in Cork City include the open loop heat pump technology and combined heating and cooling plant (CHCP) used to supply space heating and cooling and grey water to the Glucksman art gallery in University College Cork (UCC), The Lifetime Lab (space heat provided by two geothermal heat pumps and 20m² solar thermal collectors), Cork City Hall Extension and The UCC Environmental Research Institute.

Cork Geological Setting

Water chemistry and settlement parameters may be considered to be primarily influenced by underlying geological conditions. Prior to discussion of water chemistry and settlement issues it is fitting to give a detailed description of geological/geotechnical parameters encountered in the area. The present River Lee floodplain overlies a buried valley or “gorge”, which was formed in the Carboniferous and Devonian rock 15,000 to 18,000 years B.P. during the Pleistocene glaciation. Formation of the buried valley occurred when sea level fell to about -130 mOD in response to a particularly cold spell and a major glacial advance. Pleistocene rivers rapidly cut steep sided gorges to the new base level to meet these low sea-level positions. The result was the creation of a classic U-shaped glacial trough with a base possibly in excess of -100 mOD (Davis et al., 2005, Devoy, 2005), which was subsequently infilled with glaciofluvial sands and gravels. This large aquifer

provides a groundwater source close to the surface, enhancing the potential for open loop geothermal exploration and exploitation in the area at low to medium costs.

Scourse et al. (Scourse et al., 1992) carried out a detailed study of the Eamonn De Valera Bridge / Custom House Quay area, located to the west of Cork Docklands area. This study presented clear evidence of a stiff laminated silt / clay within the sands and gravels corresponding to an interglacial warm period. At this site some organic deposits of Holocene age were also found within the upper layer of sands and gravels. Scourse et al. (Scourse et al., 1992) concluded that the deeper deposits within the buried valley are glaciofluvial outwash valley whilst that above the Holocene lens is glaciofluvial sediment reworked within the valley system by the rising sea level at the end of glaciation (c. 10,000 years B.P.).

The next stage in the formation of the valley was the deposition of estuarine clays, silts and peats, typically 3 m to 4 m thick. Marshes formed the final shape of the upper estuary, after the sea level steadied near its present level about 6,000 years ago. At this time the river was braided, flowing in a large number of channels between a series of marshlands. These marshlands were progressively embanked and reclaimed, the channels culverted and the islands urbanised (O'Flanagan, 2005).

Ground conditions at the old Ford Factory site

Recent site investigations performed by the authors near to the centre of the South Cork Docklands, on the old industrial Ford factory site, confirm probable bedrock at depth of 42.2 m. Previous research confirms that depths of at least 60 m (Long and Roberts, 2008, Allen et al., 2003, Milenic and Allen, 2005) have also been encountered in the buried valley which has a width of approximately 0.5 km to 0.75 km (Long and Roberts, 2008).

Figure 5 Cork City & Docklands Map

Figure 5 (Mapping Re-produced with kind permission of Ordnance Survey Ireland Permit Number APL0001810) shows the sites on the Cork Docklands where investigations were carried out by the authors. Several sites on the Docklands, namely the old ford factory site, Gouldings site, Water Street Bridge site and Eamon De Valera bridge site, are referred to in this paper. The existing city centre consists mainly of the island on the western side of the map. The Docklands area is that enclosed by the Eamon De Valera Bridge to the west, the Lower Glanmire Road to the north and roughly extends to the edge of the map in both the southern and eastern directions. Ground conditions at the old Ford Factory site as revealed by the drilling of a shell and auger borehole are shown on Figure 6. The geology revealed is consistent with that described previously and is similar to that for the Eamonn De Valera Bridge site (Scourse et al., 1992). A thin layer of alluvium overlies the upper sand and gravel stratum. These materials are typical of those found elsewhere in the Cork City area (Long and Roberts, 2008) and are in a loose to medium dense state with an average SPT N of about 20 (SPT N refers to a standard penetration test whereby a 'split spoon' shaped sampler is driven into the ground in order to examine soil stiffness properties. The number of hammer blows required to advance the sampler 300 mm into the ground, following an initial 150mm seating drive, is termed the SPT N value). A relatively thick stratum of very stiff silty clay underlies the upper gravels which is in turn underlain by a second layer of sand and gravel which is in a dense to very dense state with average SPT N of about 85.

Figure 6 Ford Factory Site Ground Conditions

Both the alluvium and stiff clay layers show relatively high water content whereas the corresponding values in the gravels are low. Both cohesive strata have an organic content of some 4.5%. The two sand and gravel layers have somewhat similar particle size distributions and have average sand and gravel contents of 17% and 83% respectively.

The results of in situ CPTU (piezocone) and SDMT (seismic dilatometer) tests are shown in Figure 7. CPTU tests are carried out insitu in order to determine geotechnical properties such as bearing capacity, frictional resistance and porewater pressure. The test is performed by advancing a cone

shaped probe of cross sectional area 10cm^2 into the ground, while continuously recording cone tip resistance, sleeve friction and pore pressure measurements. Seismic dilatometer tests are carried out by advancing a blade containing a circular membrane into the ground. This steel membrane is expanded at the predefined test depths allowing measurements to be taken. Shear wave velocity may also be measured during seismic dilatometer tests through calculation of the ratio between the difference of distance between an energy source (typically a metal plate on the surface energised by a hammer blow) and the two seismic receivers and the measured delay time for the energy pulse between the upper and lower seismic receivers.

Due to difficulties in penetrating the granular material, the CPTU and SDTM tests are confined to the alluvium and upper sand and gravel layers. Shown on the graph are the corrected CPTU end resistance (q_t), the friction ratio (R_f , which is the ratio between the CPTU sleeve friction and q_t), the SDMT material index (I_d), shear wave velocity (V_s) and the constrained modulus (M). These data are generally consistent with the findings of the shell and auger borehole, confirming that about 3 m of alluvium overlies loose to medium dense sand and gravel. An important finding revealed by the CPTU and SDMT tests is the existence of thin lenses of soft clays within the upper gravels. This is evidenced by the high R_f and low q_t , I_d , V_s and M values encountered between 5 m and 6 m depth. These lenses correspond to soft clays and peats deposited during warm periods within the general glaciofluvial deposition.

Figure 7 CPTU and SDMT Results

Groundwater Chemistry

Water chemistry is a vital issue which should be considered prior to proceeding with design and selection of materials for geothermal heat pumps. Regrettably however, it is often overlooked (Rafferty, 2000) as an issue in the early planning stages of such systems, sometimes to the detriment of the projects viability in later stages. In years past water chemistry related problems and excessive pumping power have often characterised open loop systems (Rafferty, 2009). Corrosion and scaling

in particular should be investigated as they can lead to leaks, clogging, increased pressure drop, a reduction in heat transfer properties and failure of a heat pump system.

The Langelier Saturation (LSI) and Ryznar Stability indices (RSI) have long been used as broad indicators of the likelihood of water to cause corrosion and/or scaling. It should be noted however that chemical species such as hydrogen sulphide (H_2S) and ammonia (NH_4) which are not accounted for in the LSI/RSI calculation (Rafferty, 2000) can cause rapid failure of heat pump systems by attacking copper, cupronickel or copper bearing alloys even when in concentrations of less than one part per million (Knipe and Rafferty, 1985). The LSI is calculated using the following formula $LSI = pH - pH_s$ and is used to determine the likelihood and extent to which water will cause scaling and / or corrosion. The RSI is calculated using the following formula $RSI = 2pH_s - pH$ and attempts to associate water chemistry to an empirical database of scale thickness observed in municipal water systems. Guidance on the interpretation of the indices is presented in Table 2.

Table 2 (a) LSI & (b) RSI Interpretation

In addition to the use of the LSI & RSI indices, water with a pH of less than six and hardness greater than 100ppm as $CaCO_3$, or which has a hydrogen sulphide presence should be carefully analysed prior to potential use in a heat pump. In such circumstances a closed loop system can often be a better choice (Rafferty, 2008). Following preliminary testing on water extracted from beneath the Cork Docklands, it was discovered that the broad pre-condition of a low pH in tandem with a high hardness existed, meriting further analysis.

Examination of the chemical characteristics of the water below the Cork Docklands area is an important precursor to the potential future development of structures incorporating open loop geothermal systems in the area. In order to assess water chemistry issues, the authors took samples at a depth of 25m below ground level (lower gravel layer) and tested them both on-site and in the laboratory of the School of Architecture, Landscape and Civil Engineering of University College Dublin. The results from these tests are presented in Table 3.

Table 3 Water Chemistry Results (Comments edited after Rafferty (2009))

Chlorides in groundwater may be either naturally occurring in deep aquifers or caused by sea water intrusion, brine, sewage or industrial & domestic waste. Pitting corrosion of stainless steel materials is likely to occur if water has extremely high chloride content, especially in circumstances where hardness values are high. The water extracted from beneath the Cork Docklands has both high chloride content (5,660 ppm) and hardness values, indicating that heat pump systems where water comes in contact with stainless steel, copper, cupronickel or titanium may not be suitable for exploitation in the area. The very presence of chlorides means that stress corrosion cracking is a possibility.

The measured electrical conductivity of 19,325 $\mu\text{S}/\text{cm}$ far exceeds a threshold of 600 $\mu\text{S}/\text{cm}$ for differentiating background and anomalous values, indicating saline water or anthropogenic contamination (Lee et al., 2008). A total hardness value of greater than 200 ppm as CaCO_3 indicates a very hard water (Rafferty, 2000) (after Carrier Air Conditioning Company, 1965). The water extracted from the Cork Docklands was found to have a total hardness value of 4,540 ppm as CaCO_3 indicating that scaling is highly likely to occur.

A pH below 7.0 gives rise to corrosion of the equipment with which the water comes in contact, whereas when pH is above 7.5 or 8, calcium carbonate scale is deposited more readily (Carrier Air Conditioning Company, 1965). The pH value measured from water extracted from the Cork Docklands is 5.57, indicating that corrosion may present problems for any potential open loop installation. In addition to the previously mentioned water chemistry issues, both the Langelier Saturation and Ryznar Stability indices indicate that serious corrosion is likely to occur.

Any open loop heat pump system installed in the Cork Docklands area would have to be designed against adverse chemical characteristics, in so far as is possible, would require frequent additional maintenance and the requirement for early system replacement would be high. It is possible that the chemical properties of water pumped from the aquifer may improve as large quantities of water are extracted; this is questionable however, given that the evidently perpetual groundwater flow in

existence would have the effect of washing through the area. Conversely, it is also possible that excessive pumping close to the coast could cause some degree of saline intrusion as a result of a lowering of the groundwater table.

Settlement induced by an open loop system

The key material influencing the extent to which settlement induced by the operation of an open loop geothermal system in the Cork Docklands area is the alluvium. This is because groundwater level drawdown due to pumping from the wells will cause consolidation settlement of these layers. The properties of the alluvium layers in the region are discussed in order to 'set the scene' for the sample settlement calculation which follows.

Properties of alluvium layers

A summary of data collected by the authors on the Cork Docklands for the material is shown on Figure 8.

Figure 8 Alluvium Test Results

The alluvium material is relatively uniform with water content of about 45%, plasticity index of 30% and organic content of about 6%. Interestingly there is little difference between the properties of the upper alluvium and the soft layers within the upper gravels (termed lower alluvium here). In addition some unconsolidated undrained (UU) triaxial tests data for the Gouldings Fertiliser site show undrained shear strength (s_u) values in the range of 8.6 kPa to 16.4 kPa with an average value of 15.5 kPa. These values are a little lower than that which would be obtained from the CPTU data, where the average q_t is about 0.4 MPa and are similar to the SDMT data where the average derived s_u value was 12 kPa.

The results of six maintained load oedometer tests from the Water St Bridge site for depths of between 1.8m and 4.5m are shown on Figure 9 (Thompson, 2009). The tests are presented in the form of log stress (σ_v') versus strain (ϵ) and also σ_v' versus constrained modulus (M). It can be seen that the test results are relatively consistent and suggest the material has a preconsolidation stress of approximately 150 kPa. In the overconsolidated zone the average M values is approximately 2 MPa and in the normally consolidated zone the average modulus number (m) is about 13. These values are consistent with published data for soft clays with water content of about 45% (Janbu, 1985).

Figure 9 Water St. Bridge Oedometer Tests

Sample settlement calculation

A typical open loop geothermal system could comprise a nest of 4 to 8 wells each with a pumping capacity of 20 l/s. Wells are typically about 150 mm in diameter and would probably need to extend into the lower gravel layer in order to provide sufficient water. Taking a single well the water table drawdown at a distance 5 m from the well would be in excess of 10 m. This large drawdown is due to the very high permeability of the gravels, which is of the order of 5×10^{-3} m/s (Long et al., 2007). This drawdown would result in an increase in effective stress ($\delta\sigma'$) in the alluvium layers, which on average will equal about 10 kPa and 50 kPa in the upper and lower alluvium respectively. As the new effective stress will remain within the overconsolidated zone the resulting change in strain ($\delta\epsilon$) and consolidation settlement (ΔH) can be obtained directly from the constrained modulus, e.g. for the upper alluvium:

$$M = \frac{\delta\sigma'}{\delta\epsilon} = 2000 = \frac{10}{\delta\epsilon} \Rightarrow \delta\epsilon \approx 0.005 \Rightarrow \Delta H \approx 5mm$$

And for the lower alluvium:

$$M = \frac{\delta\sigma'}{\delta\epsilon} = 2000 = \frac{50}{\delta\epsilon} \Rightarrow \delta\epsilon \approx 0.025 \Rightarrow \Delta H \approx 25mm$$

The radius of influence of this settlement, calculated in accordance with the methodology set out by the Construction Industry Research and Information Association (Somerville, 1986) is of the order of 1 km. This means that, were the geology to extend in a completely uniform and continuous fashion in all directions, a settlement of 30 mm would be encountered at the pumping site, reducing to zero settlement at a distance approximately 1 km from the pumping site. The reality however is that boundaries such as the river Lee to the north and north west of the Cork Docklands and changes in geology with distance would serve to 'cut short' this zone of influence. The latter factor would likely have little effect in the area however; as the geology has shown to be reasonably consistent throughout the Docklands area, meaning that the zone of influence could conceivably extend for up to 1 km. This total consolidation settlement of about 30 mm which would be encountered at a pumping site on the Docklands is unlikely to be acceptable in an urbanised area, particularly as it is due to the effects of one well only and no creep settlements are allowed for.

Conclusions

Ireland's high dependence on imported energy in addition to ever increasing fuel prices means that the cost effectiveness of renewable energy technologies is likely to improve significantly in the coming years. Although heat pumps rely on the consumption of electricity for their operation, the decarbonisation of grid electricity will help reduce the emissions associated with this.

The water extracted from beneath the Cork Docklands area shows that significant water chemistry issues exist. Laboratory and field tests confirm that optimal concentration levels of several water chemistry characteristics are significantly exceeded; leading to the conclusion that open loop exploitation in the area may not be suitable.

Potential consolidation settlement of approximately 30 mm which would be caused by the pumping of excessive amounts of groundwater associated with an open loop geothermal installation is unlikely to be acceptable in an urban area. Selection of an appropriate pumping rate should not only consider the rate required to satisfy the heat load of the building and the abstraction potential of an aquifer, but also geotechnical characteristics of soils such as settlement.

Vertical closed loop, horizontal closed loop and thermal foundation configurations are shallow geothermal alternatives which may be considered in cases where open loop systems are not suitable; however each system must be carefully investigated to ensure suitability to site specific conditions. As a general rule, closed loop systems will require less maintenance over their operating period and are less likely to be susceptible to water chemistry issues as they are sealed and pressurised.

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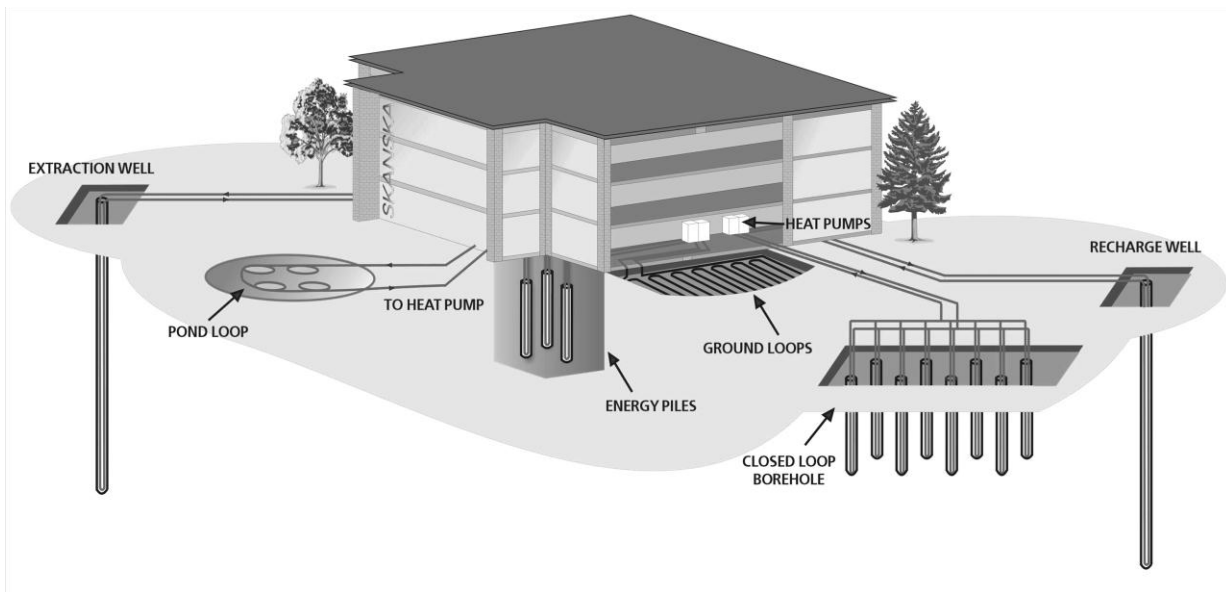


Figure 1 Shallow Geothermal Energy Exploitation Categories (Cementation Skanska, 2010)

Table 1 Explanation of Exploitation Categories

No.	Category	Description
1	Open Loop (via Extraction Well / Recharge Well)	Open loop systems pump water from sources such as lakes, ponds and wells. They generally consist of an extraction well and either a re-injection well or surface discharge system.
2	Pond Loop	Pond loops consist of loops of coiled pipes placed into a pond. Fluid is circulated through the pipes allowing heat to be exchanged between the circulating fluid and the water in the pond.
3	Energy Piles	Energy piles are structural piles equipped with channels (closed loops) through which a heat transfer fluid may circulate. Energy piles benefit from lower installation costs than closed loop boreholes as no 'extra' drilling is required.
4	Ground Loops	Ground Loops (also known as Horizontal Closed Loop) consist of piping laid horizontally below the frost line. Ground loops are generally found in rural areas where there is sufficient space to lay them.
5	Closed Loop Boreholes	Closed Loop Boreholes (a.k.a. Vertical Closed Loops) consist of piping installed vertically in boreholes. Closed loop boreholes are generally used where there is not enough ground space to install a ground loop.

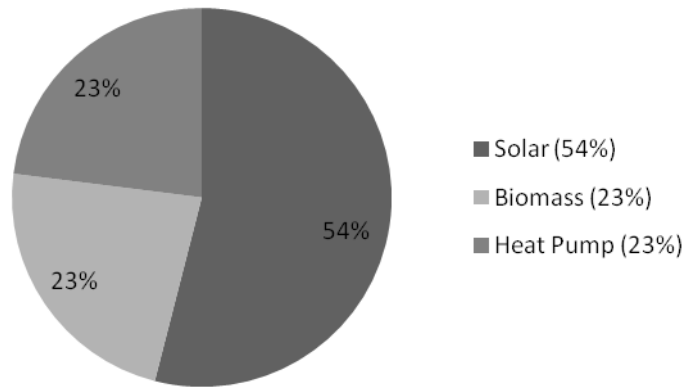


Figure 2 Breakdown of Applications to GHS in Ireland by Technology

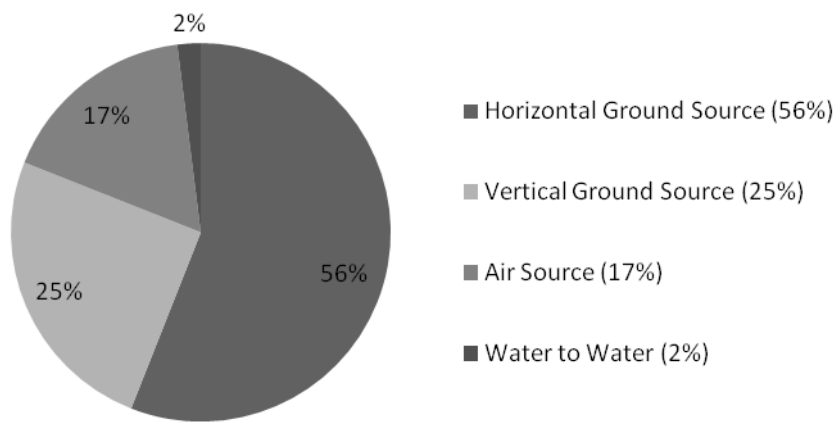


Figure 3 Heat Pump Types Installed in Ireland with GHS Aid

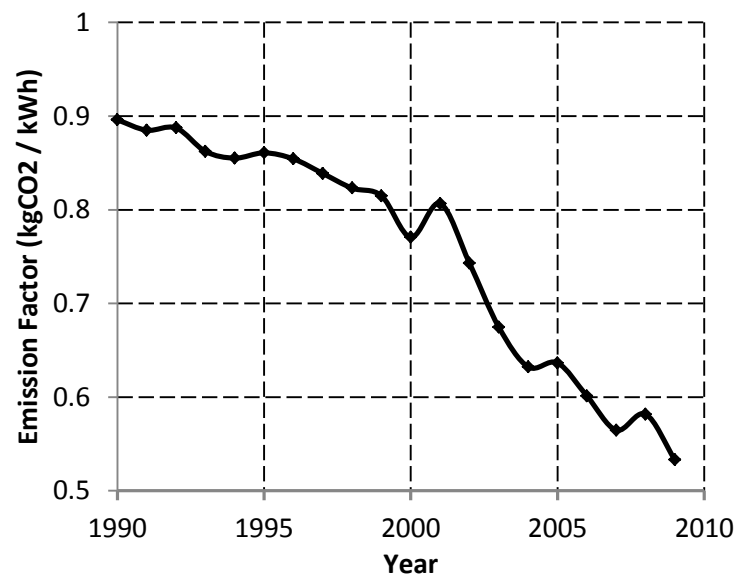


Figure 4 Irish Grid Electricity De-Carbonisation

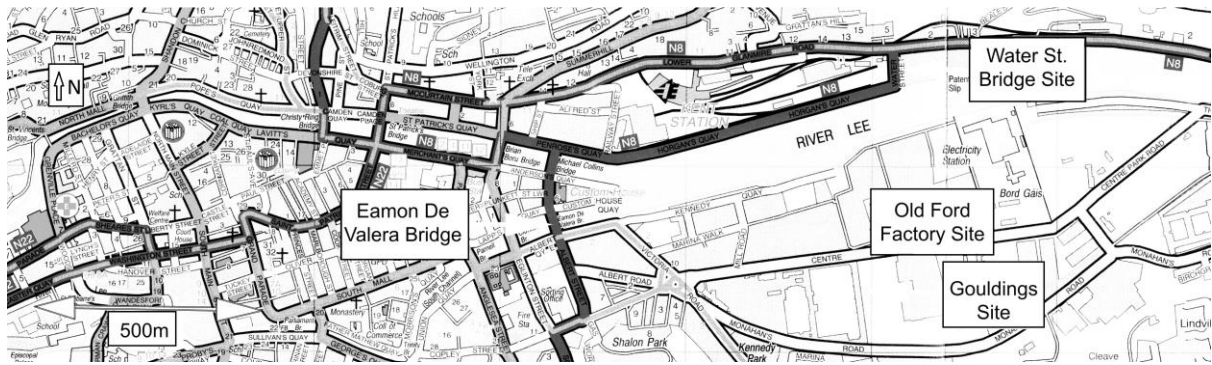


Figure 5 Cork City & Docklands Map

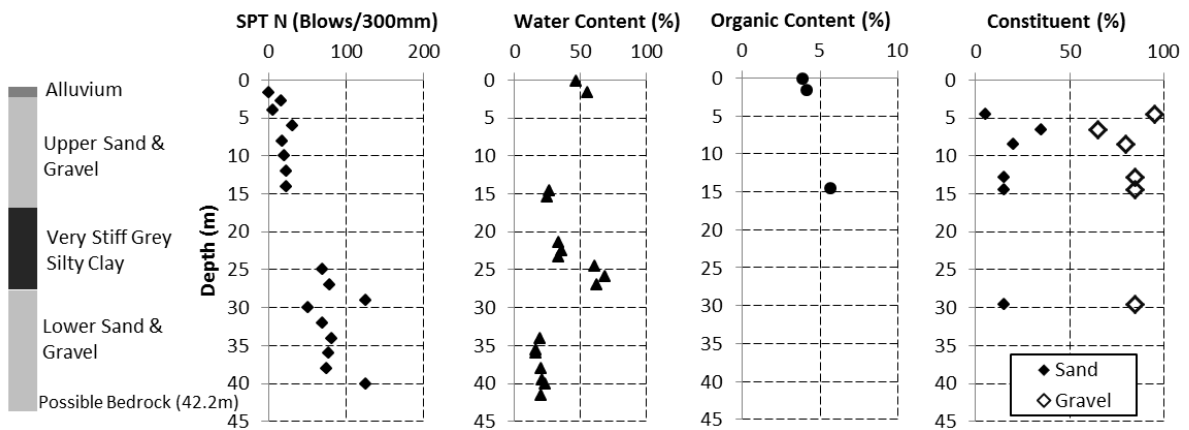


Figure 6 Ford Factory Site Ground Conditions

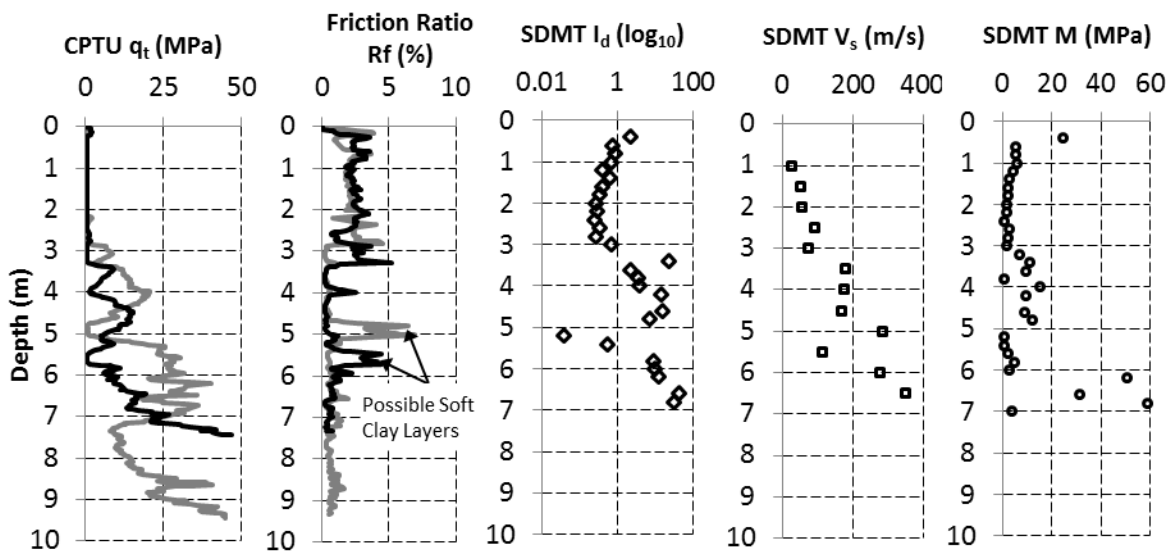


Figure 7 CPTU and SDMT Results

Table 2 (a) LSI & (b) RSI Interpretation

LSI Value	Indication
2.0	Scale Forming but Non-Corrosive
0.5	Slightly Scale Forming and Corrosive
0.02	Balanced but Pitting Corrosion Possible
-0.5	Slightly Corrosive but Non-Scale Forming
-2.0	Serious Corrosion

RSI Value	Indication
4.0 – 5.0	Heavy Scale
5.0 – 6.0	Light Scale
6.0 – 7.0	Little Scale or Corrosion
7.0 – 7.5	Corrosion Significant
7.5 – 9.0	Heavy Corrosion
> 9.0	Corrosion Intolerable

Table 3 Water Chemistry Results (Comments edited after Rafferty (2009))

Constituent	Measured Value	Comment
pH	5.57	Typical range 6.5 to 9.0. Lower Values are typically associated with higher rates of corrosion, higher values scaling. A pH value of lower than 7 gives rise to corrosion of materials with which the water comes in contact
Electrical Conductivity	19,325 $\mu\text{S/cm}$	Higher levels indicate contamination of groundwater. Typical electrical conductivity of drinking water is approximately 5 to 500 $\mu\text{S/cm}$
Total Dissolved Solids	18,348 ppm	Higher Values of Total Dissolved Solids are associated with increased corrosion and/or scaling
Total Alkalinity	125 ppm	Alkalinity is the most important characteristic of water when determining its scale forming tendency. It is used in the calculation of LSI & RSI
Calcium Hardness	2,250 ppm as CaCO_3	Used to calculate LSI & RSI
Total Hardness	4,540 ppm as CaCO_3	Values >100ppm indicate that scaling can occur
Chloride	5,660 ppm	Accelerates corrosion of carbon and stainless steels, may be elevated in coastal areas. High chloride content promotes aggressive corrosion, especially if there is a tendency to lime deposit. Copper not suitable for use with water at high chloride values
Ryznar Stability Index (RSI)	7.9	See Table 2
Langelier Saturation Index (LSI)	-1.1	See Table 2

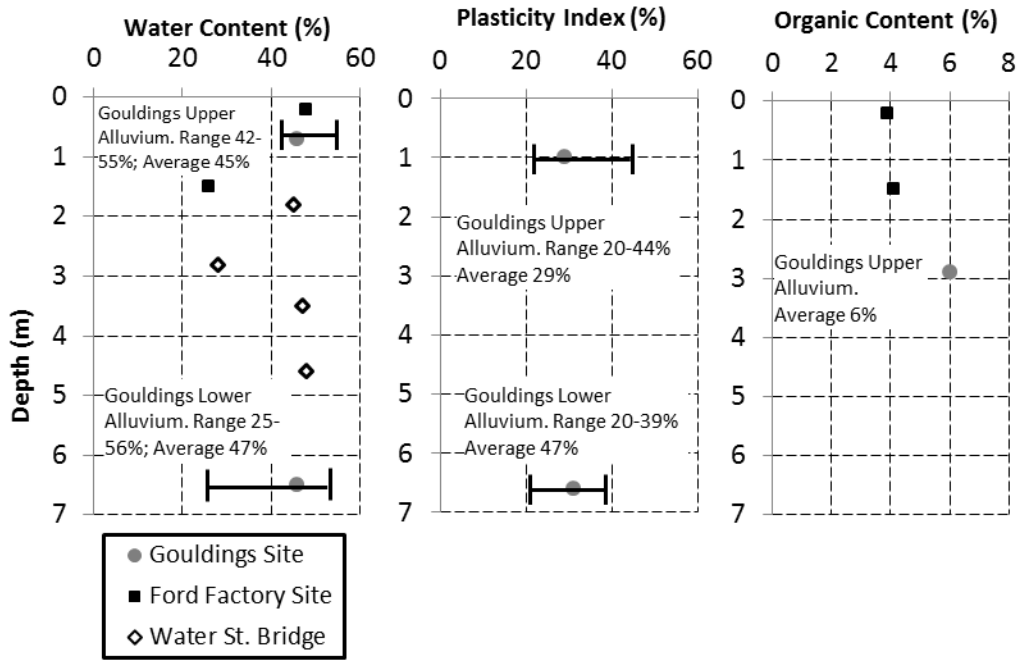


Figure 8 Alluvium Test Results

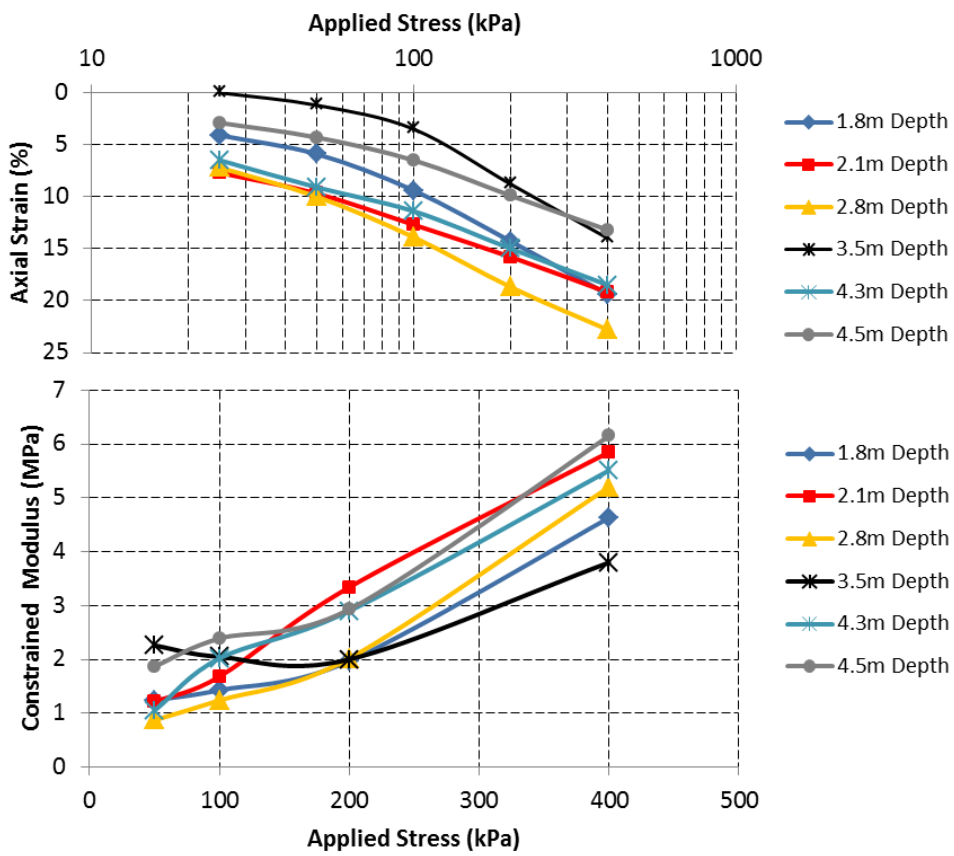


Figure 9 Water St. Bridge Oedometer Tests