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Department of Communications,
Energy & Natural Resources

Geoscience Research
GSI
Suirbhéireacht Gheolaíochta Éireann
Geological Survey of Ireland

Geological Survey of Ireland Research Programme
- Short Call 2015, Final Report -

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Organisation name	Terra GeoServ Ltd. (T/A GeoServ Colutions)
Organisation type:	☐HEI ☐Public Sector (other) ☒Private Sector
Department/section	

Project Title	Irish Soil Thermal Properties Project (ISTP)
Contract No.	2015-sc-030

INFOMAR
Integrated Mapping for the Sustainable Development of Ireland's Marine Resource

Tellus
Understanding Underground

Marine Institute
Foras na Mara

2. Project information:

Title of project	Irish Soil Thermal Properties Project (ISTP)
Did you make any formal amendment to the project workplan / budget?	☒ yes ☐ no If yes, please specify: The overall programme of works and deliverables has remained the same. Some changes have been made to the budget structure. These are further outlined below.

<u>Project Report (*max 1500 words, excluding figures and headings*)</u>:

(i) Objectives and scientific/engineering targets beyond the state of the art

The Irish Soil Thermal Properties Project set out to characterise the geothermal properties of Irish soils and their suitability for deployment of horizontal closed loop collectors. This was done by collecting and testing a number of representative Irish soil types to build a reference database of typical Irish soil thermal conductivities.

The project was carried out in several phases;

- Data review.
- Mapping of representative soil locations
- Collection of selected soil samples
- Thermal properties testing of all samples
- Data compilation and analysis

The information compiled as part of the ISTP database is targeted at government agencies and professionals as a screening tool to understand the amount of energy that can be sustainably extracted from specific soils and the controls on such soils that impact their heat transferring capacity. This information facilitates optimising the performance of ground source heating systems and the design specification of geothermal closed loop horizontal collectors.

(ii) Implementation (including reference to timelines, milestones, management)

The opening task for the ISTP project was to conduct a comprehensive review of mapped Irish Soil data in order to accurately select field work sampling targets. The objective of this project was to target and measure the thermal properties of a representative selection of typical Irish soils. The Soils in Ireland have a hierarchical arrangement used for taxonomical classification. This hierarchical classification is broken down into 11 Great Groups comprised of 58 Sub Groups which are in turn subdivided into 220 Soil Series. For the purpose of this project some of the most common soil series for each of the 58 Sub-Groups were chosen as a comprehensive representation of typical Irish soils whilst also comprising of an achievable number of sampling targets.

The Irish Soil Information System developed by Teagasc and the EPA is a comprehensive database of all Irish soil types and has an accompanying map. The Irish Soil Information System Map is at 1:250,000 scale but at this scale it is impossible to show the individual soil series. In order to map soils across Ireland the soil association concept was developed as a cartographic grouping of local soils. The soil associations are represented in the polygons of the Irish Soils Information System (ISIS).ISIS groups the most frequently occurring soil series and combination of ancillary soil series that appear in the Irish landscape.

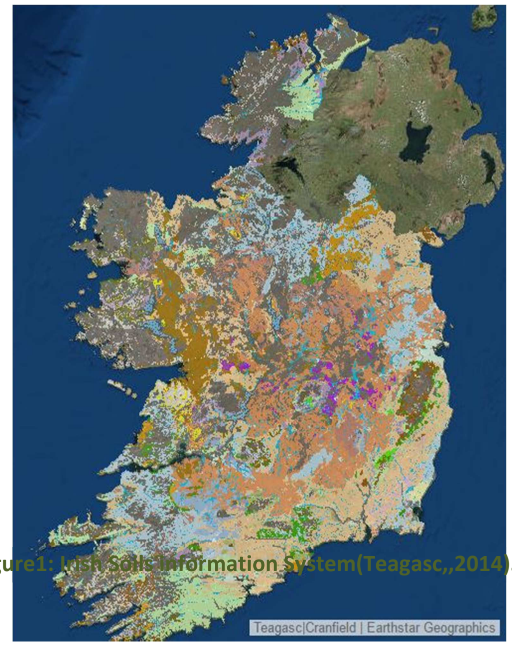

Figure1: Irish Soils Information System(Teagasc,,2014).

In order to select and test specific Soil Series as part of the ISTP project, the mapped Soil Associations from the ISIS Map was not found to be accurate enough as the associations include ancillary soil series that have different diagnostic features and soil forming processes. Therefore, in order to select specific sampling locations, the soil series mapped by the ISIS Map in conjunction with historic county soil maps that mapped individual Soil Series and not Soil Associations were used. A consultation was undertaken with Teagasc as part of the site selections process.

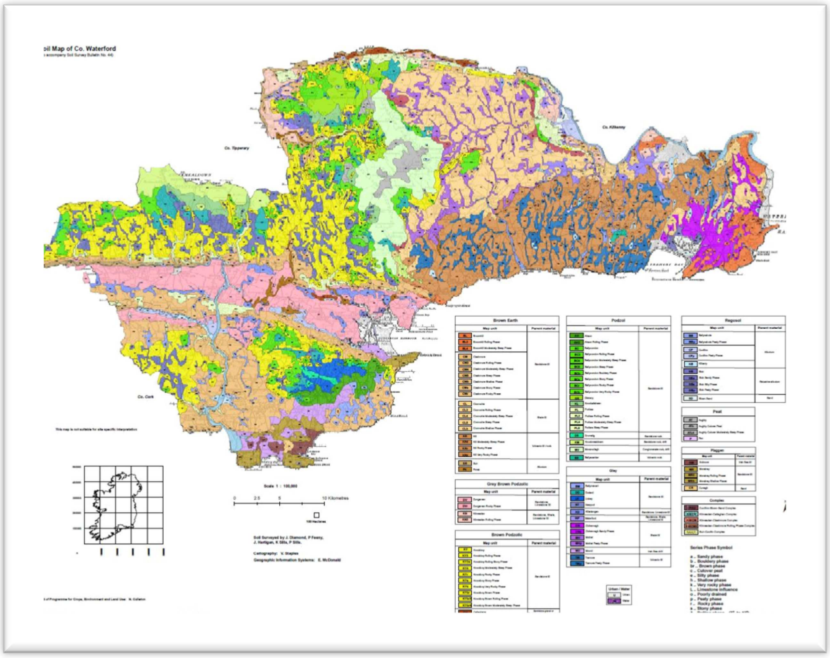

Figure 2: County Soils Map Co. Waterford (Teagasc, OSI,2011).

The soil series maps at 1:100,000 scale accurately represent soil series without the need to group them into the Soil Association system developed for the ISIS Maps. These were used in conjunction with the ISIS Maps to accurately Identify the location of all the targeted soil series. The use of both datasets allowed us to correlate specific soil series with polygon sections of Soil Associations on the Irish Soil Information System Map This process was repeated for all the available historical county soil maps until 33 Soil Sub-Group representative soil series were identified out of a possible 58.

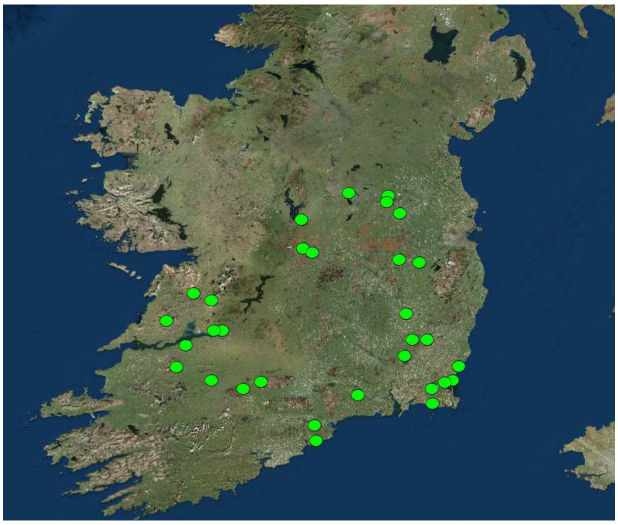

Figure 3: Locations of all sampled soil series locations

Field Work sampling

Soils were sampled using a soil auger and liner sampling kit. The auger was used to penetrate depths up to 100 cm. Once the hole was augured, a sample collection cylinder was then hammered a further 30 cm into the ground, utilising a specialised hammer and bit attachment. This allowed for collection of soil in a non disturbed state. Where ground conditions were permissible a second sample would be taken from below the first. The samples were then labelled with depths and soil types before transportation back for laboratory testing.

Figure 4 Soil auger (left) and use in field (right)

Figure 5: Sample cylinder in both filled and empty state.

Laboratory Testing

Testing was carried out using a Huskeflux needle probe apparatus. This gives the thermal conductivity (TC) in Watts per metre Kelvin (W/mK). The testing involves sending timed pulses of heat into the sample along the 15cm metal probe which is inserted into the material to be tested. Sensors within the probe measure the decay of this heat in the medium over time and thereby calculate the thermal conductivity of the sample.

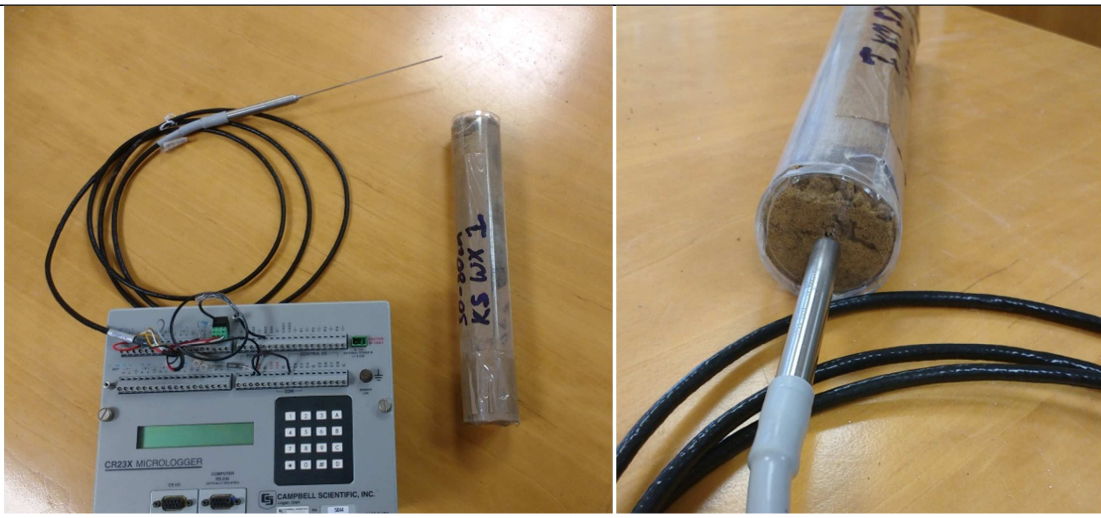

Figure 6: Testing of samples with needle probe system.

The testing methodology involved all samples were tested in their plastic field cylinders. This ensured a measured value as close to in-situ conditions as possible for each soil. Three tests were carried out on each sample and the average value recorded. The mass of each sample was recorded and density calculated from the volume of the cylinder.

Some samples were chosen at random, removed from their cylinders and dried, then tested again to determine the fully dried thermal conductivity. This procedure provides an increase understanding into the control of moisture content on the thermal conductivity value of the soils (see figure 8) Locations where 2 samples were taken were tested separately to give greater confidence to the results.

Results

Location	MC %	weight	bulk density	TC sat	TC dry
Elton 1	14.9	532.1	1664.58	1.7661	n/a
Elton 2	14.5	435.2	1683.57	1.6062	n/a
Rathowen	19.17	366.8	1554.64	1.239	n/a
Ballylanders	15	541.5	1756.18	0.5638	n/a
Moord	11.38	293.6	1329.92	0.4057	**0.16**
Baggotstown	9.01	419.5	1566.88	0.9269	**0.301**
Ashgrove	13.29	519	1699.42	1.27	n/a
Aughty 1	89.23	193.2	867.5	0.4052	n/a
Aughty 2	91.03	217.3	880.04	0.387	n/a
Garynamona 1	88.49	232.9	933.31	0.6144	n/a
Garynamona 2	88.12	236.6	939.21	0.447	n/a
Tubary	12.36	352	1343.56	0.7727	n/a
Clonsast 1	86.68	344.5	942.71	0.6129	n/a
Clonsast 2	86.72	247	1021.42	0.517	n/a
Banagher	78.1	208.2	913.95	0.4664	n/a
Seafield 1	11.29	352.4	1438.77	1.43985	**0.244**
Seafield 2	7.92	544	1877.06	1.742	n/a
Burren	18.22	438.1	1596.19	0.6018	**0.126**
Carrignavanagh	20.96	197	891.29	0.3467	**0.08**
Rienna	16.78	202	1129.41	0.2193	n/a
Lyre	15.81	438.9	1580.52	0.587	n/a
KilmoreSlob 1	20.24	474.3	1803.92	0.907	**0.191**
KilmoreSlob 2	21.93	533.6	1725.41	0.83385	n/a
Wexford Slob	17.03	345.3	1523.75	1.0714	n/a
Clohamon 1	17.13	314.1	1403.2	0.655	**0.13**
Clohamon 2	24.74	260.7	1373.74	0.6892	n/a
Greenane	13.6	219.9	1171.13	0.7643	0.192
Mylerstown 1	9.16	461.7	1965.27	1.2925	n/a
Mylerstown 2	11.92	415.2	1743.09	1.526	n/a
Ballyshear	31.92	210.2	961.94	0.5743	n/a
Puckane	79.96	295.4	1034.51	0.9887	n/a
Macamore 1	13.78	350.4	1741.45	1.1939	n/a
Macamore 2	13.16	421.6	1852.61	1.505	n/a
Howardstown	22	349.1	1499.14	0.6565	n/a
Ballycondon 1	13.81	335.9	1526.14	0.8496	n/a
Ballycondon 2	10.05	377.3	1834.12	1.4906	n/a
Forth Commons	27.46	305.2	1246.31	0.7011	**0.083**
Portlaw 1	16.33	401.8	1509.95	1.006	n/a
Portlaw 2	12.39	311.5	1619.08	0.9707	n/a
Cooga	24.9	389.9	1819.56	1.30085	n/a
Clonegall 1	22.57	433.4	1424.18	0.668	n/a
Clonegall 2	14.6	403.3	1583.09	0.733	n/a
Knockaceol	8.43	225.3	1327.21	0.29	**0.119**

Table 1: Testing of samples with needle probe system

Data Analysis

The TC and soil moisture data was analysed to better understand the controls on Thermal Conductivity.

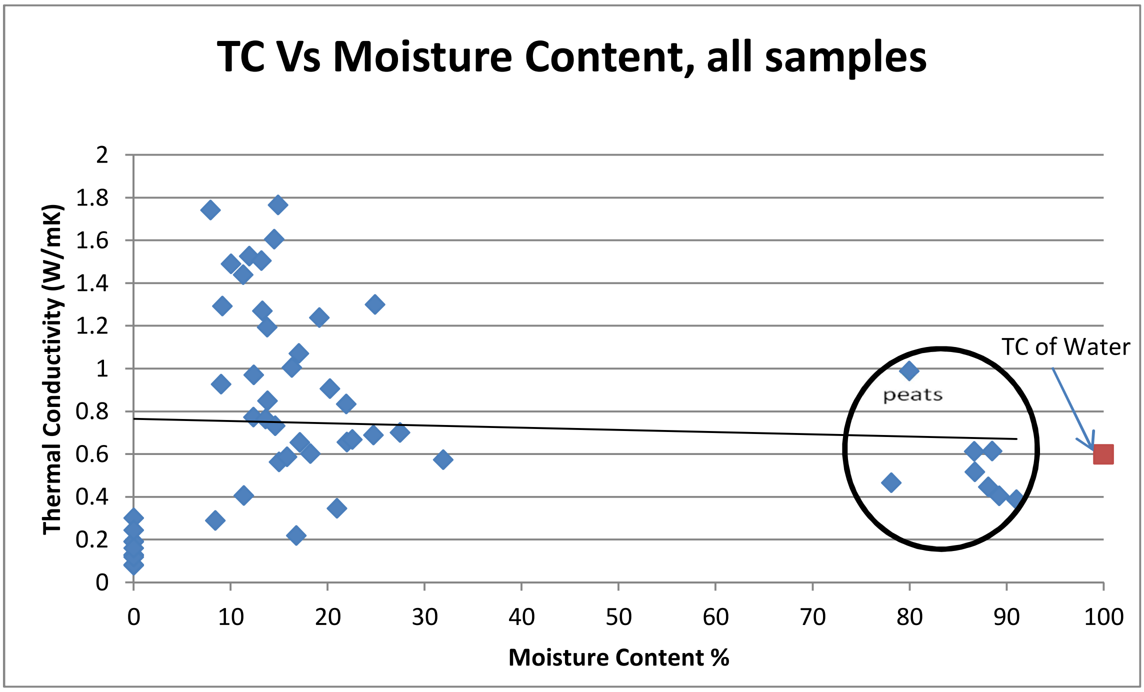

Figure 7: TC Vs Moisture Content

Error! Reference source not found. demonstrates the role that moisture content plays in the transmission of heat. A small moisture content of around 10% -15% seems to be the optimal, with increasing water content tending towards the value of thermal conductivity of water demonstrating heat is transferred less efficiently. This is more clearly seen in **Error! Reference source not found.**, (removing the peats and the dried samples) where the highest conductivity is arrayed around the 10% to 15% moisture content range, and steadily decreasing thereafter.

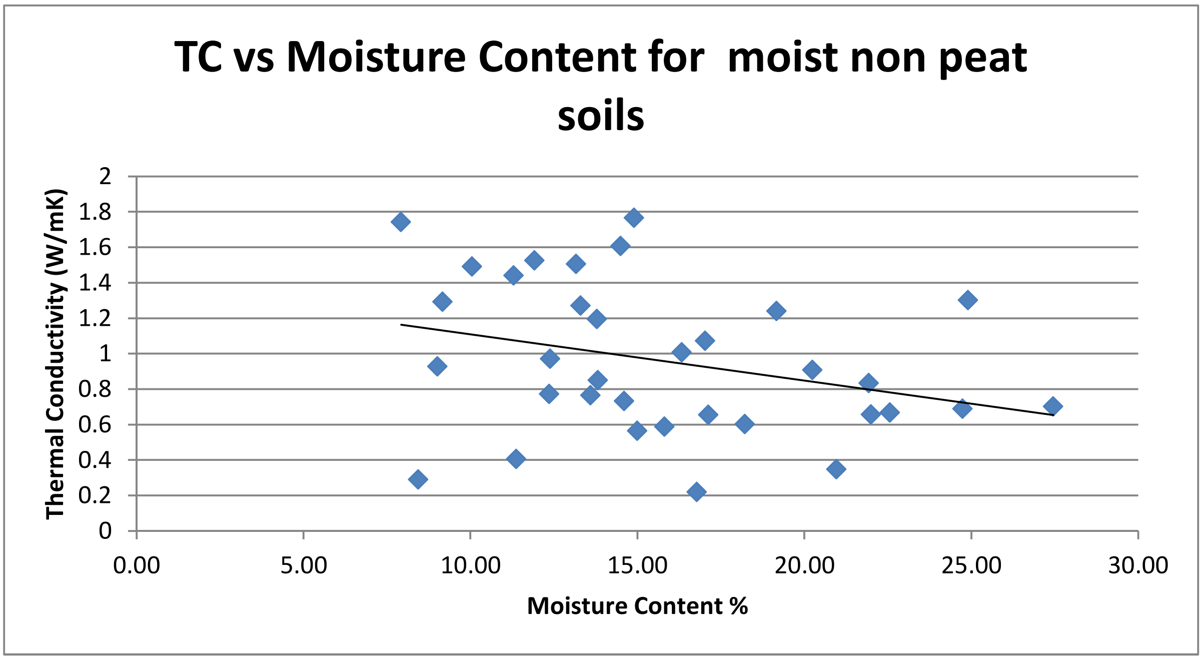

Figure 8: TC vs Moisture Content for moist non peat soils

No water content at all, as indicated by the points sitting upon the y axis at left of **Error! Reference source not found.**, have low thermal conductivity values. This is further shown in **Error! Reference source not found.** where the variation in TC between samples in their saturated (in situ) state and dried state is quite large.

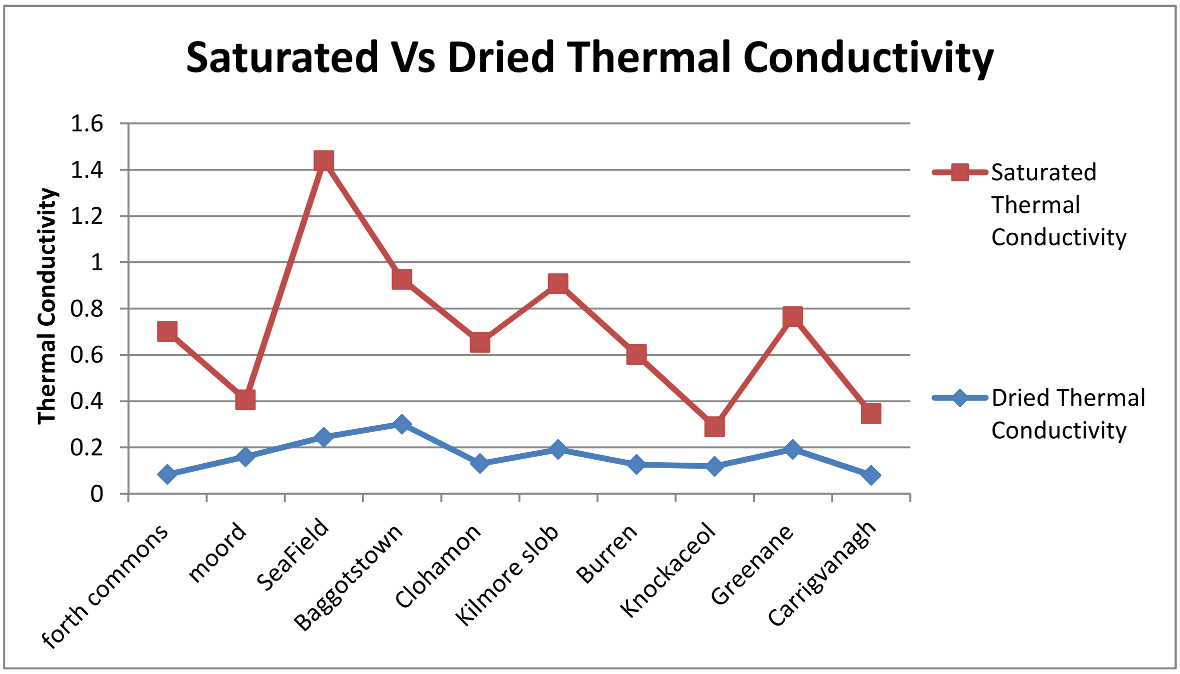

Figure 9: Saturated Vs Dried Thermal Conductivity

Density is an important control on thermal conductivity, with increasing density correlating to a higher conductivity. As density increases, void space within the soil decreases resulting greater compaction of gains resulting in more contact points and therefore increased conductance (**Error! Reference source not found.**).

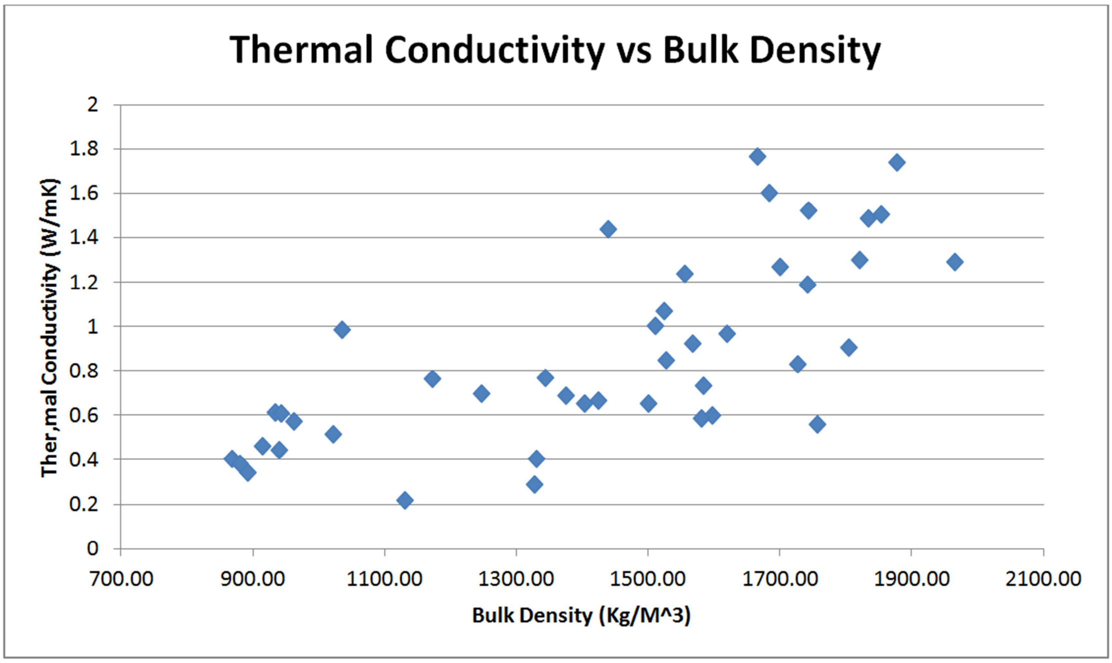

Figure 10: Thermal Conductivity vs Bulk Density

Error! Reference source not found. shows all the sampled soils sub groups demonstrating that there are mineralogical differences within each subgroup.

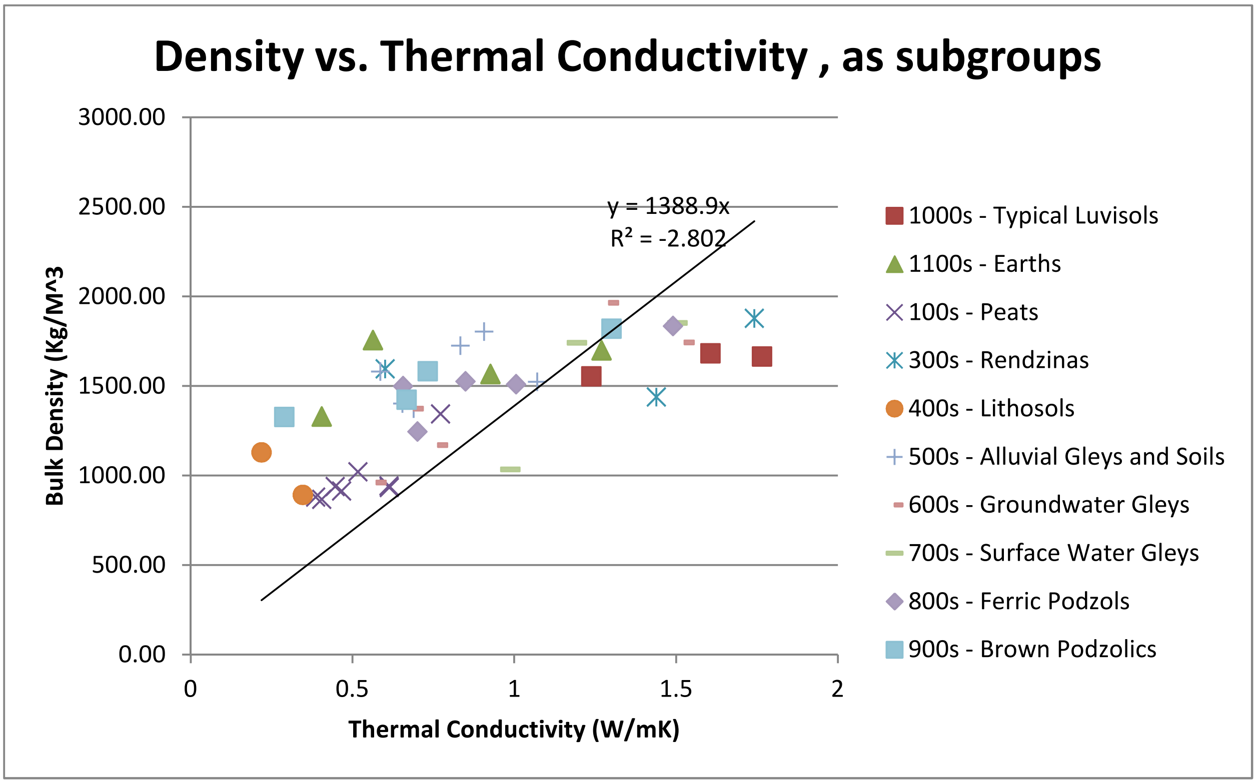

Figure 11: Density vs. Thermal Conductivity, as subgroup.

Conclusions

The results from testing and analysis of 43 soil samples shows that the strongest controls on thermal conductivity are moisture content and density. The soil type and parent material had much less affect on heat transfer than was expected.

Soils with a moisture content of around 10-15% gave the highest thermal conductivity values with any increase in moisture content trending the thermal conductivity towards that of water at 0.60 W/mK. Density also had a significant influence with denser soils resulting in higher thermal conductivity values.

Analysing of the data shows that moderately moist (10-15% MC) dense soils are the most suitable for horizontal closed loop collectors.

Based on the results of the ISTP project, installation of horizontal ground collectors must be considered below a depth of 1m. Shallower depths will have lower density values and an increased potential for saturation, leading to decreased performance and efficiency of a horizontal closed loop collector.

All samples were collected during summer 2016, so it can be expected that moisture contents would be higher during the wetter seasons. This should be considered in the design of horizontal ground loop systems.

(iii) Outputs (please use bullet points)

- Irish Soil Thermal Properties Database – Thermal Conductivity, Moisture Content and Density data.
- European Geothermal Congress 2016 paper - Quantifying Irish Soil Thermal Properties – a reference for improved ground source collector design.
- Final Report

Impact/value of the project (M*ax 500 words*):

The Irish Thermal Soils Project (ISTP) has contributed to the following initiatives:

- Increase the understanding of soil and subsoil properties in Ireland by acquiring new data that can enhance existing national soils datasets. The ISTP database provides new baseline data to EPA/Teagasc and more importantly the Geological Survey on soil density, moisture content and porosity/permeability values at site specific locations.
- ISTP developed a new national dataset of Irish soil thermal conductivity and resistivity values to support the work of the Geological Survey in mapping shallow geothermal energy resources in Ireland and more importantly the potential of different soil and subsoil types at providing heat for ground source systems.
- The project database will allow the Geological Survey that further develop the horizontal closed collector suitability map by addressing existing data gaps. This will ultimately improve the quality of these maps as screening tools for professionals designing and installing shallow geothermal systems.
- Support the development of new training course for the design and installation of shallow geothermal collectors being developed by the Geothermal Association of Ireland (GAI) during the course of 2017. These training initiative will disseminate the importance of site assessment and screening at the design stage which is currently poorly undertaken by professionals. The ISTP data will link directly with this initiative and provide baseline data for Irish conditions.
- Provide data of Irish ground conditions for the new upcoming shallow geothermal energy training initiatives for professionals involved in installation and design of geothermal systems by the Geothermal Association of Ireland. GAI will aim to develop a new training programme in 2017 with the support of SEAI in conjunction with the European Geotrainet initiative. Geotrainet has been in operation since 2007 and is the main platform for training drillers, installers and designers of geothermal systems in Europe

Overall the ISTP project contributed new geoscience data that will support the work of The Geothermal Association of Ireland, The Geological Survey and EPA/Teagasc directly. The results of the ISTP project further promote and quantify shallow geothermal resources in Ireland and allow further dissemination this to decision makers involved in energy planning.

This project will also support the development of a sustainable shallow geothermal sector in Ireland in the context of upcoming support through the Renewable Heat Incentive by ensuring adequate training of professionals and system design is achieved.

Appendix 1 – Publications & Presentations

[Conference Publication] McAteer, J.; Pasquali, R.; Long, M.; Hunter Williams, N. (2016) Quantifying Irish Soil Thermal Properties – a reference for improved ground source collector design. *European Geothermal Congress 2016* –Strasbourg, France, 19th-23rd-SPET-16.

Conference Publication] McAteer, J.; Murray, S; Pasquali,. (2016) Irish Soils Thermal Properties Project. *Final Report* –Dublin, Ireland.

Quantifying Irish Soil Thermal Properties – a reference for improved ground source collector design

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Keywords: Ground Source Heat, Soil Thermal Properties, Horizontal Closed Loop.

ABSTRACT

The Irish Soil Thermal Properties (ISTP) project set out to quantify the thermal properties of Irish soils and subsoils, building on the information of the Irish Soil Information System and further develop a national reference dataset that will facilitate the sizing of ground source collectors. The new data is to include thermal conductivity and thermal resistivity, density, porosity and grain size of soils across Ireland. Horizontal closed loop collector suitability maps developed by Geological Survey of Ireland have shown the need for better characterisation of thermal conductivity and moisture content. These new data, combined with the EPA/Teagasc and GSI datasets can provide guidelines for ground source system installation in soil and improve mapping of shallow geothermal energy resources in Ireland. One of the most common problems in the installation of a ground source collector is the reference values of heat delivered per meter of collector installed. Incorrectly sized ground source collectors can have adverse impacts on the environment and can result in increased running costs and CO2 emissions.

1. GEOTHERMAL IN IRELAND

An increased focus on the development of renewable energy sources for the purpose of space heating and cooling in Ireland, as well as for commercial and industrial applications, has seen an increase in the development of shallow geothermal and ground source technologies since 2007. Despite a steady market uptake between 2007 and 2008 and a moderate increase in installed systems in Ireland from 2010 to present, the shallow geothermal sector and installation of system remains poorly developed. A lack of information on potential resources, lack of detailed data to facilitate design and quantification of resources remains, despite some recent project initiatives focusing on addressing these issues.

Data on subsurface thermal properties in Ireland has been the focus of recent research carried out at UCD (Hemmingway, 2012, McGuiness, 2013, Hemmingway and Long, 2012 and 2013 and Mc Guinness et al, 2014), through the SFI funded IRETHERM project and more recently through the SEAI funded Irish Ground Thermal Properties project (IGTP 2014). These projects are mainly focused on bedrock thermal properties for vertical closed loop collectors as well as deep geothermal targets.

The Geological Survey of Ireland (GSI, *In Press*) has developed draft horizontal closed loop (HCL) collector suitability maps as a first effort in evaluating the widespread potential of Irish soils and subsoils for the use of HCL collectors in ground source systems. The HCL maps were developed using soil thickness and moisture content data to determine a suitability for the installation of a HCL collector.

The aims of the ISTP project are to build on this work by augmenting the suitability map based on the key collector performance controlling factors which include density, porosity and thermal conductivity. These properties determine the amount of linear meters of collector required to ensure the sustainable operation of the ground source heating system and to meet the energy demand of the end user. Incorporating this data with the soil thickness and moisture content datasets will give a comprehensive view of the potential for HCL heating systems across Ireland.

In 2015 the Irish Ground Thermal Properties project produced vertical closed loop sizing tables modelling heat extraction from the ground. Variations in; installed capacity of the system, heat pump full equivalent load hours, ground temperatures and the thermal conductivity of the bedrock were modelled to produce these collector sizing tools. Given the correct parameter values the approximate W/mK in a particular location can be determined.

The ISTP soil thermal properties database will facilitate the production of sizing tables for HCL collectors to give designers an indication of the correct thermal properties reference values.

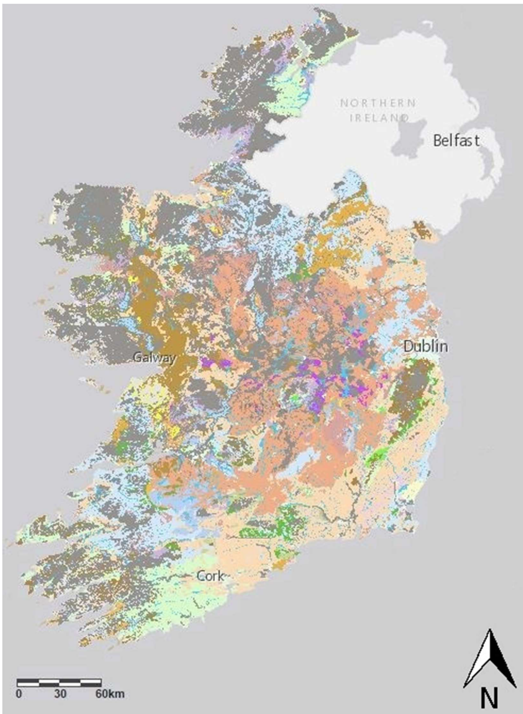

Figure 1: The Irish Soil Information System Map Produced by Teagasc 2014

2. MATERIALS AND METHODS

2.1 Mapping

In this study we investigated and measured a representative body of Irish soils in an effort to quantify all varieties of soil compositions across the country. In order to collect samples for testing from a representative set of soil bodies, a comprehensive review of mapped Irish soil data was carried out. This review focused mainly on the Irish Soil information System developed by the EPA and Teagasc (Figure 1) as well as the more detailed historical counties soil mapping data produced by Teagasc (Figure 2).

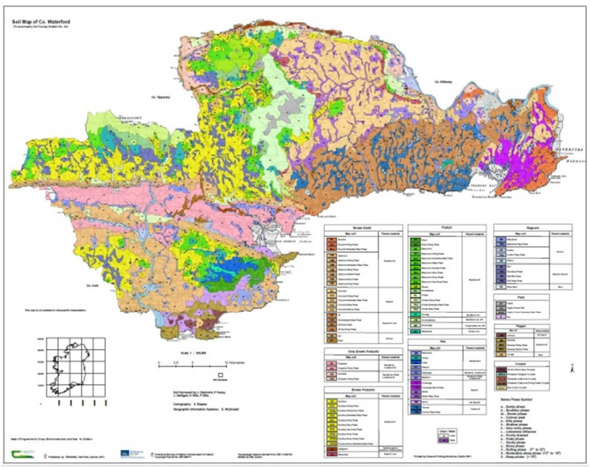

Figure 2: Soil Map of County Waterford, Produced by Teagasc in 2011

These two data sets were used in conjunction with one another to accurately target specific soil formations across the country.

2.2 Sampling and Testing

A field work programme is being implemented based on the selection of representative sites identified through the mapped data review. The ultimate selection of the sites was based on identifying areas where undisturbed soil samples could be collected.

The undisturbed soil sampling is being carried out to ensure the in-situ structure of the soil was intact for more accurate test results as the density of soils can alter the thermal properties (Figure 3).

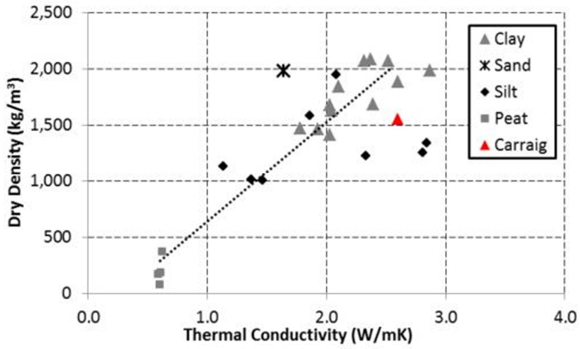

Figure 3: Dry Density vs. Thermal Conductivity (Hemmingway 2012)

A specialised auguring system is used to collect the samples (Figure 4) whereby undisturbed cylinders of soil 30cm in length and 4cm in diameter are collected encased in a plastic lining ready for testing (Figure 5).

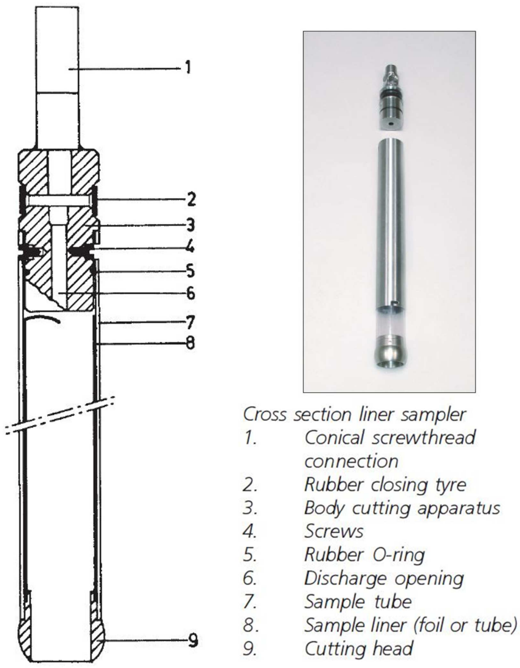

Figure 4: Auger apparatus used to collect 30x4cm undisturbed soil samples (Eijelkamp 2005)

Figure 5: 30x4cm Soil sample encased in plastic lining

The thermal properties tests were performed to the 'ASTM D5334 – 14 Standard Test Method for Determination of Thermal Conductivity of Soil and Soft Rock by Thermal Needle Probe Procedure'. Once collected the samples are stored and transported to the School of Civil, Structural and Environmental Engineering at UCD for laboratory testing.

The laboratory sample testing includes determination of porosity, moisture content, density and thermal properties tests.

Thermal conductivity measurements are measured in the undisturbed samples, fully saturated conditions and at 0% moisture content. A total of three measurements are taken in each case and results averaged for each sample. This testing procedure is adopted to increase the accuracy of the data set whilst also accounting for the seasonal variations in moisture content of each soil and how the thermal properties act in response to changing moisture contents.

3. DISCUSSION

Quantifying the ground thermal properties for the design of ground source heating systems has been the focus of several Irish projects to date, (Hemmingway 2012, McGuinness 2013, IGTP 2014) their work has produced invaluable data for the design of vertical closed loop collectors in Irish bedrock geology.

Uptake of ground source heating systems in Ireland has been slowly growing with HCL systems being preferred, where possible due to lower capital investment over vertical closed loop and the associated drilling costs.

The data currently available on ground thermal properties in Ireland are heavily weighted towards bedrock geology with few data available representing soil formations (Table 1). The lack of soil thermal properties data makes the design of horizontal collector difficult often resulting in inefficient systems.

Accurate soil thermal properties linked to specific soils types will be available for reference from the ISTP dataset following the completion of the field work programme.

Primary Soil Type	Secondary Constituent	Water Content (%)	Dry Density (Kg/m3)	Bulk density (Kg/m3)	TC (W/mK)
Silt		51	1225	1852	2.33
	Sand	28	1344	1720	2.84
		28	1946	2493	2.08
		60	1015	1619	1.37
	Clay	49	1254	1865	2.81
		49	1134	1694	1.13
		42	1547	2201	1.46
	Clay	30	1583	2055	1.86
Peat		666	73	559	0.6
		555	172	1128	0.59
		462	181	1020	0.61
	Silt	233	367	1224	0.62
Clay		18	1680	1974	20.3
		16	1627	1886	20.4
		18	1838	2166	2.1
		20	1415	1691	2.03
		14	1681	1920	2.39
		16	1473	1710	1.78
		15	2082	2320	2.37
		14	2067	2354	2.32
		16	2072	2407	2.52
		18	1988	2342	2.87
	Sand	12	1886	2113	2.6
		18	1464	1743	1.93
Sand		15	1987	2286	1.64

Table 1: Soil Thermal Conductivity Data (Hemmingway 2012)

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