Potential for Groundwater Heating in Cardiff

Thursday 23rd June 2016

Grangetown Nursery, Cardiff

ADEILADU ARBENIGRWYDD YNG NGHYMRU
CONSTRUCTING EXCELLENCE IN WALES

WELCOME

Gordon Brown, Director

Constructing Excellence in Wales

Groundwater

as a Sustainable Energy Resource

Gareth Harcombe

Energy and Sustainability Manager

City of Cardiff Council

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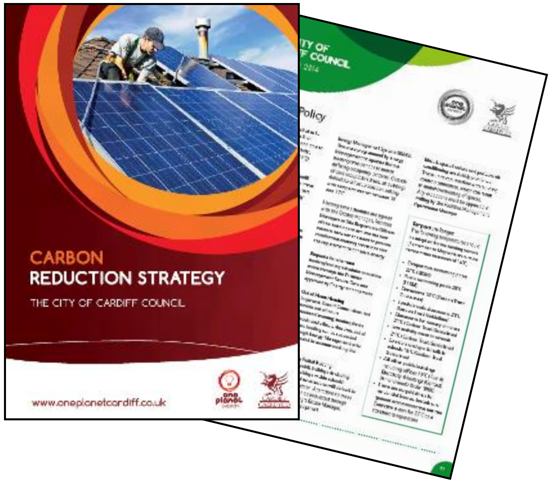
Cardiff Council

Background and Scene Setting

- Cardiff's Energy and Sustainability Agenda
- Overview of live projects
- Introduction to the Groundwater project

Strategy

- Energy
- Waste
- Transport
- Food
- Water
- Place
- People



Increasing, diversifying and localising supply

Reducing demand

Partnership Schemes

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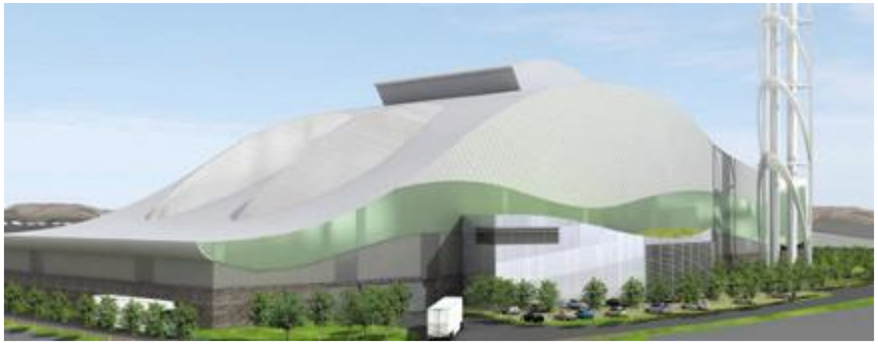
Trident Park Energy from Waste Plant



- 30MW of electricity
- Potential for 20MW of heat?

Anaerobic Digestion Plant

- 1.5 MW of electricity
- Heat?

Landfill Gas Burners

- 4MW of electricity

Council Schemes

Radyr Weir Hydro Electricity Scheme

- 0.4MW electricity
- Anticipated Completion April 2016

Solar

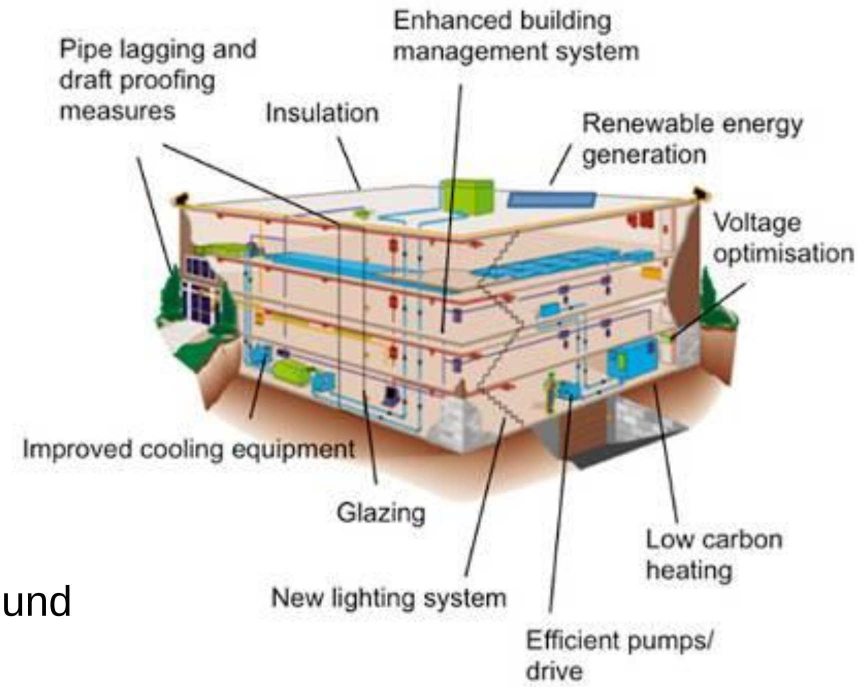
- Almost 0.5 MW roof mounted installed this financial year
- Solar Farm?? – 5-7MW

Energy Efficiency in the Council's Estate

- **£10m energy cost P/A**

- **SALIX** - estate and street lighting

- **Re:Fit**
- Provides guaranteed energy savings
- Wide range of possible measures
- Up to £4m of works
- Incl £2.2m Welsh Government Invest to Save Fund
- In contract with Engie (Cofeley)
- Works start spring 2016



INNOVATION PROJECTS

7 live projects
£2.3m external funding
Over 20 partner organisations

Heritage Retrofit SBRI

The "problem"

- More than 30% of buildings in Wales are over 100 years old
- Mainstream retrofit sometimes conflicts with heritage protection

Response

- 30 applicants, 6 feasibility projects, 3 demonstrators

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Welsh Government

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SBRI Government challenges. Ideas from business. Innovative solutions.

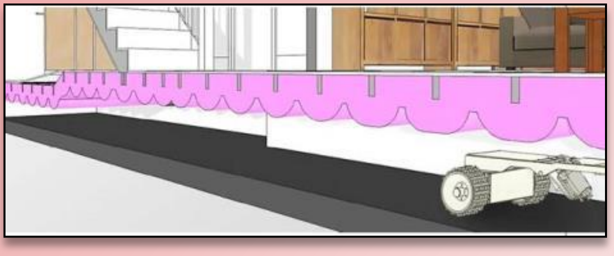
Innovate UK

Vivus Lime

Quick drying lime render and insulation panels

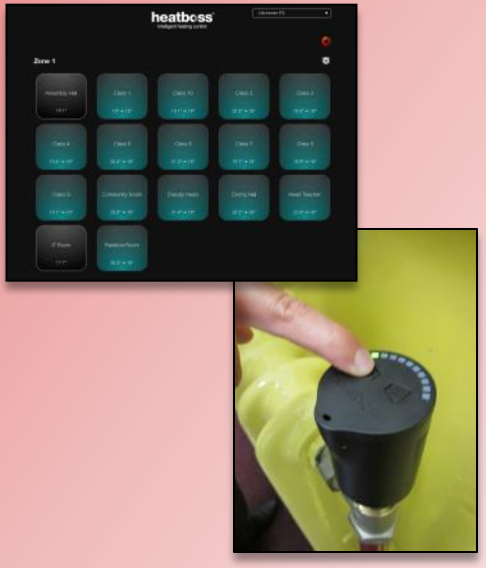
Q-Bot Limited

Underfloor Insulation Robot



Okotech Ltd Heatboss®

wireless zoned heating control solution.



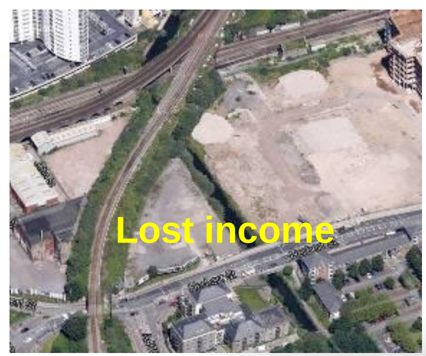
Portable Renewables SBRI

The "problem"

- Vacant and underused land
- Not enough renewable generation in cities
- Can energy be a temporary "meanwhile" use

Response

- 35 applicants, 4 feasibility projects, 2 demonstrators



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SBRI Government challenges. Ideas from business. Innovative solutions.

Department
of Energy &
Climate Change

Innovate UK

Hydrogen Enabled Local Energy

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ITM POWER
Energy Storage | Clean Fuel

Innovate UK

HYDROGEN FUEL H_2

EU FP7 **WISDOM**

Water analytics and Intelligent Sensing for Demand Optimised Management

SEVENTH FRAMEWORK PROGRAMME

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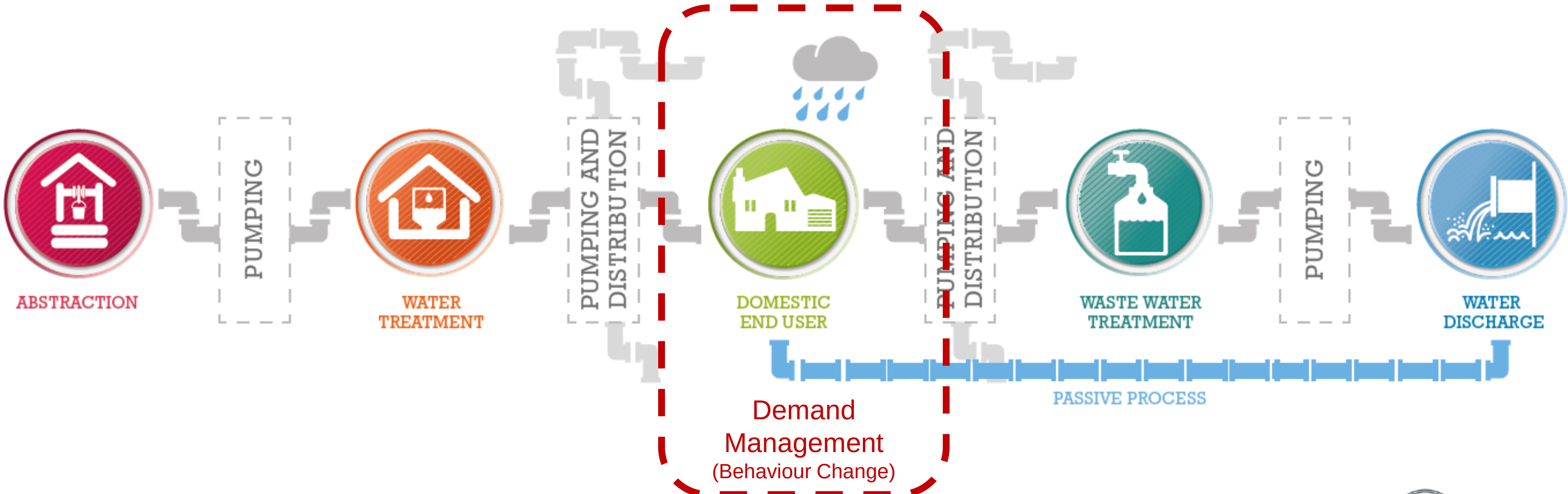

S.A.T. S.p.A. SOCIETA' ACQUEDOTTI TIRRENI

Dŵr Cymru Welsh Water

Imperial College London

D'APPOLONIA

IDRAN ingegneria e tecnologia

PROVINCIA DELLA SPEZIA PROVINCIA D'EUROPA

CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD

intel

CSTB le futur en construction

advanticsys

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EU FP7 PERFORMER

Portable, Exhaustive, reliable, Flexible and Optimized appRoach to Monitoring and Evaluation of building eneRgy performance

- Understand why building actual energy performance is different to building predicted energy performance
- Look to reduce this gap by better management of the buildings HVAC systems through ICT controls

Cardiff Heat Network

H.N.D.U funded feasibility work

- Heat map and masterplan
- Technical delivery study
- Planning Guidance
- Business Planning
- Legal and Governance Issues

Department of Energy & Climate Change

H.N.D.U

GROUNDWATER PROJECT

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Innovate UK Energy Catalyst

Cardiff Bay Barrage

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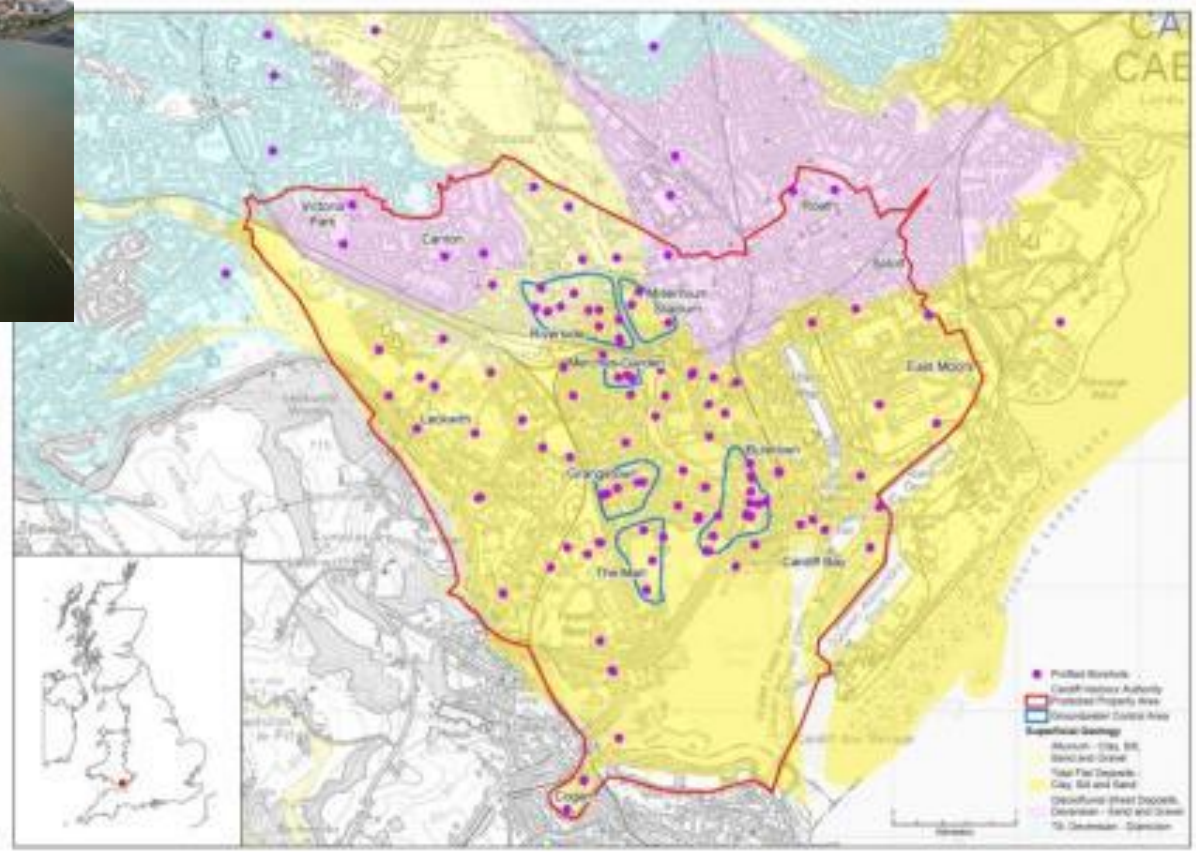

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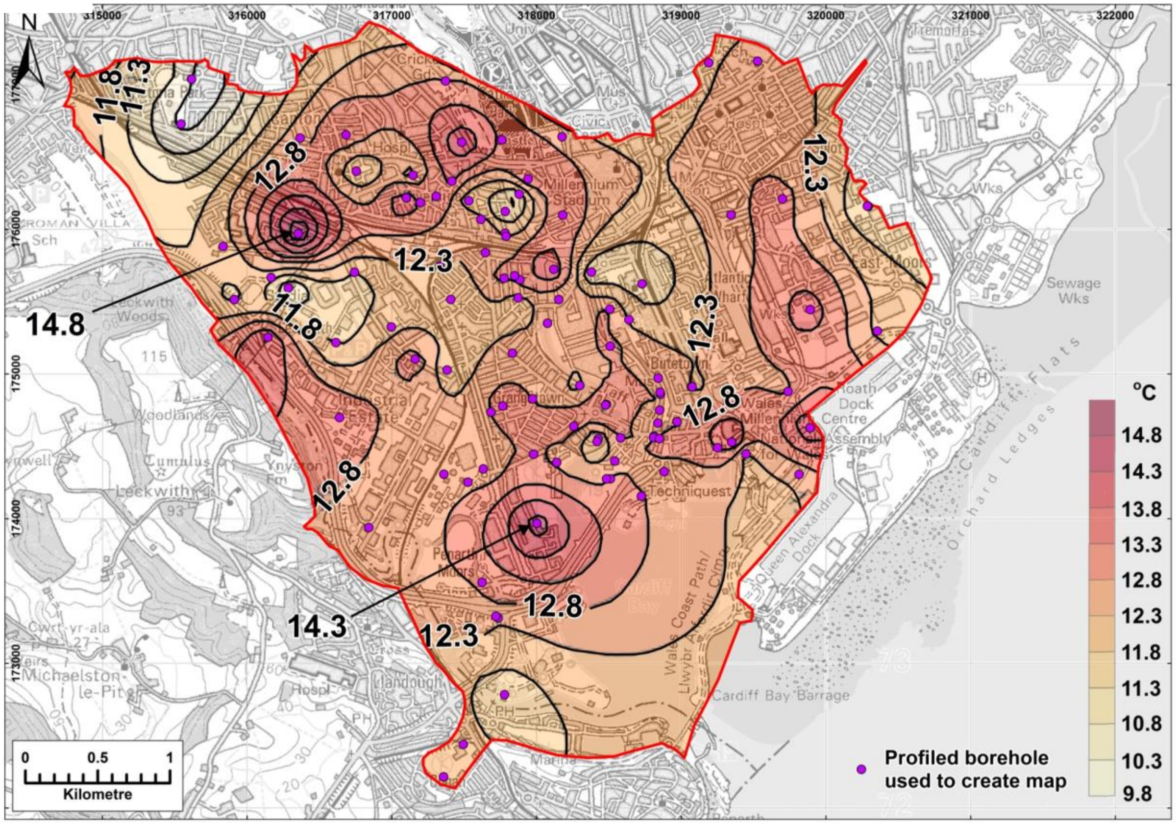

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Questions

- Is the groundwater a viable heat source?
- Is the heat resource sustainable?
- At what scale – building/street/district/city?
- What technology?
- Stand alone or system integration?

Successful “Early Feasibility Stage” funding application

Progress to Date

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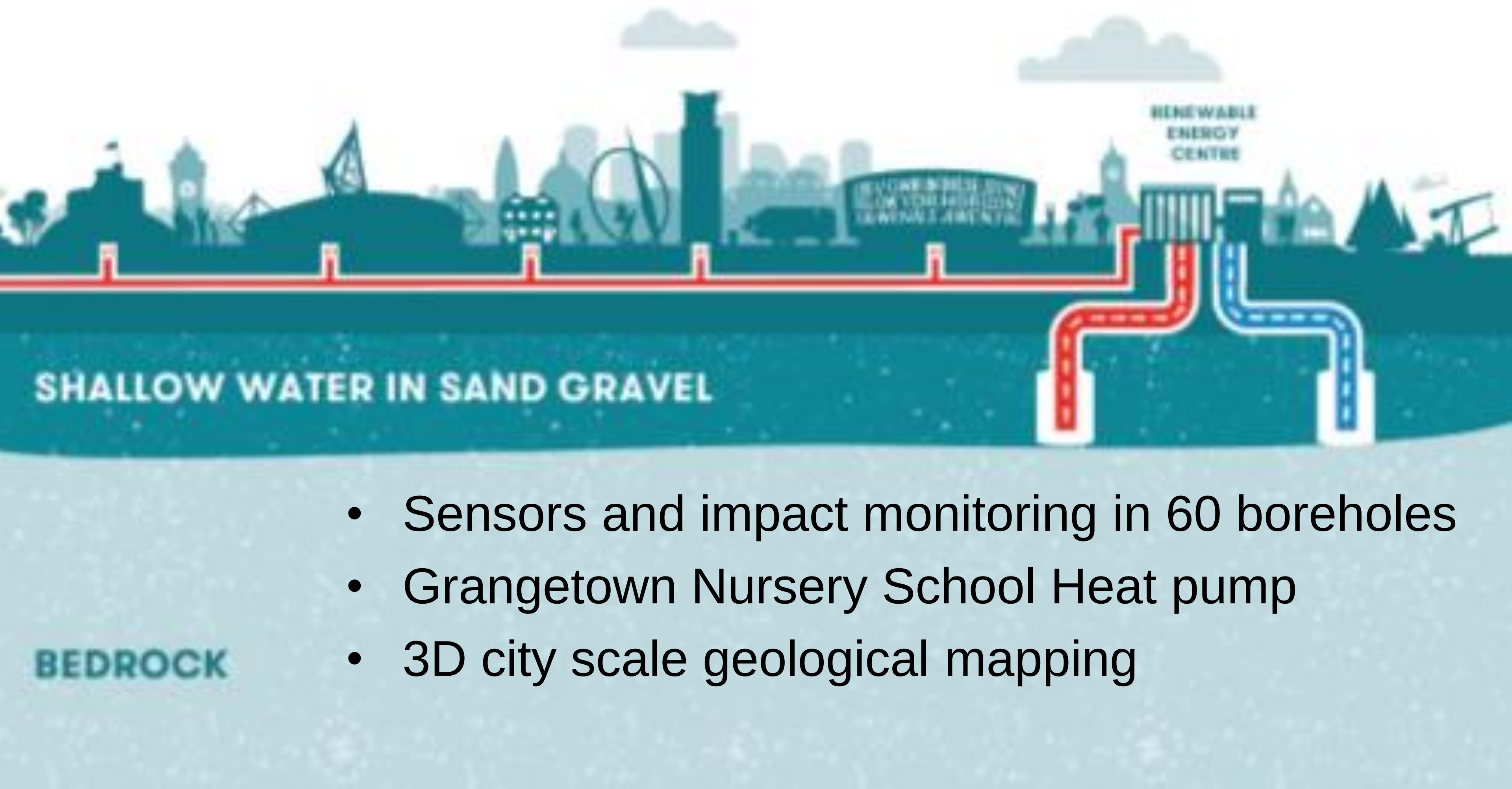
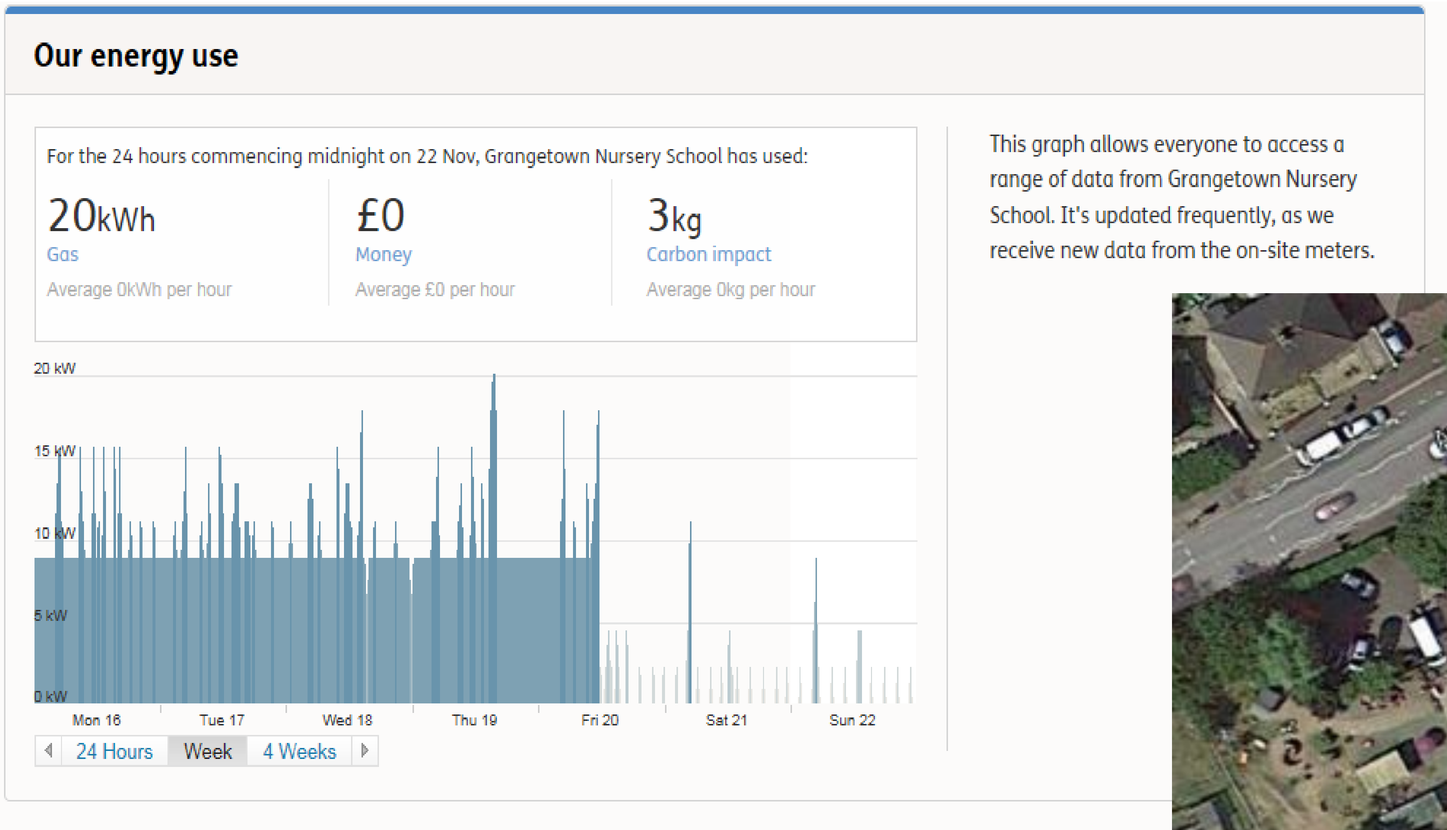


- Sensors and impact monitoring in 60 boreholes
- Grangetown Nursery School Heat pump
- 3D city scale geological mapping

Progress to Date



https://platform.**carbonculture**.net.

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Geological R&D: Feasibility Stage

- Sensor network installed and impact monitoring in 60 boreholes
- 3D city scale geological mapping and long-term heat models

BGS Groundwater Investigations

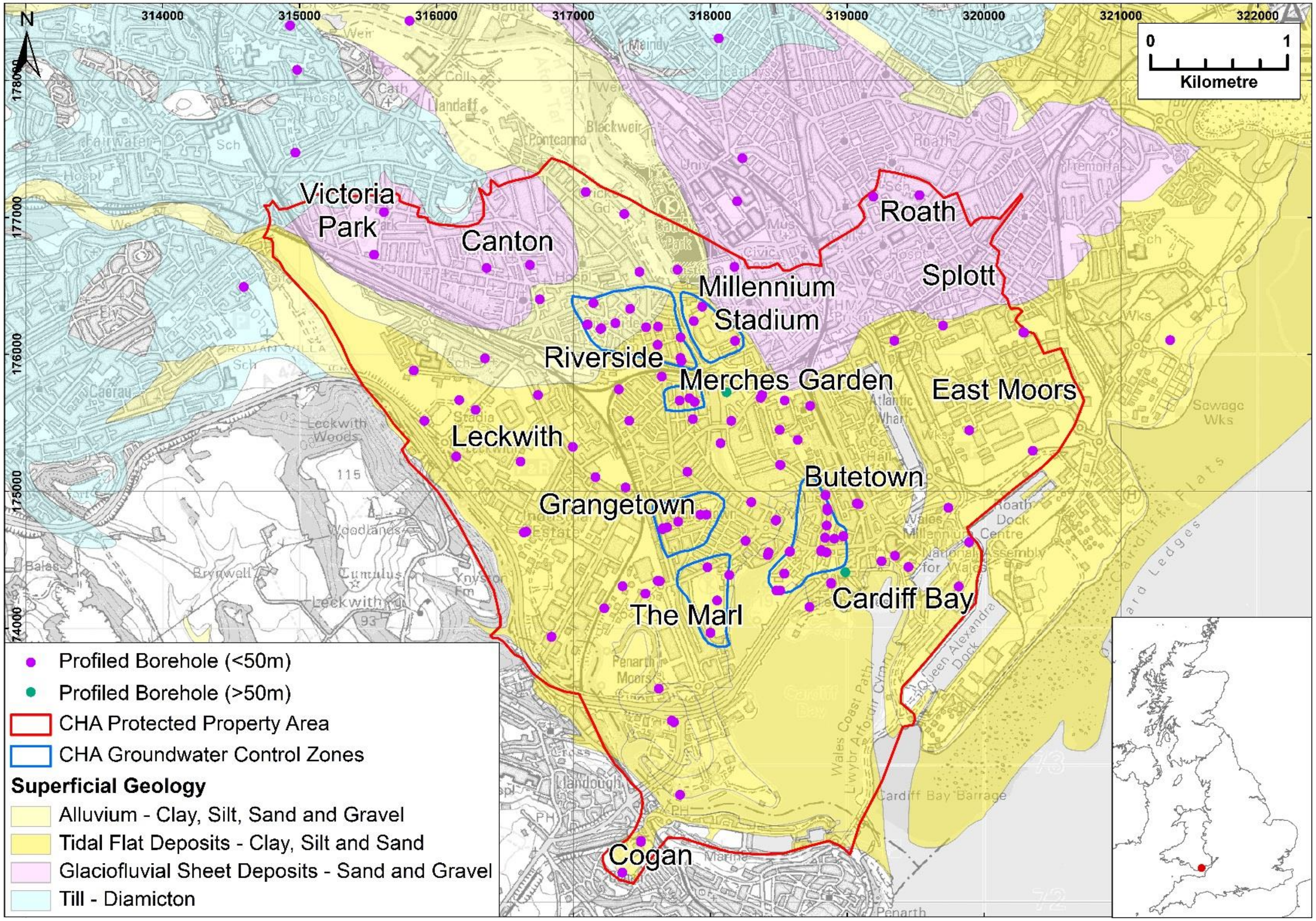
Drivers for research:

- Resource characterisation (volume, yields, temperature)
- Environmental Regulation framework (NRW)
- Need for baseline data and guarantees of performance/Insurance

Research Questions:

- Where is there usable groundwater in the city?
- Are there seasonal temperature trends below ground?
- What is the groundwater and heat flow direction: how does pumping affect natural heat recovery and artificial recharge?
- Will Iron and Manganese oxidation be an issue?

Cardiff Borehole Network



Farr et al. 2016, QJEGH (In Prep)

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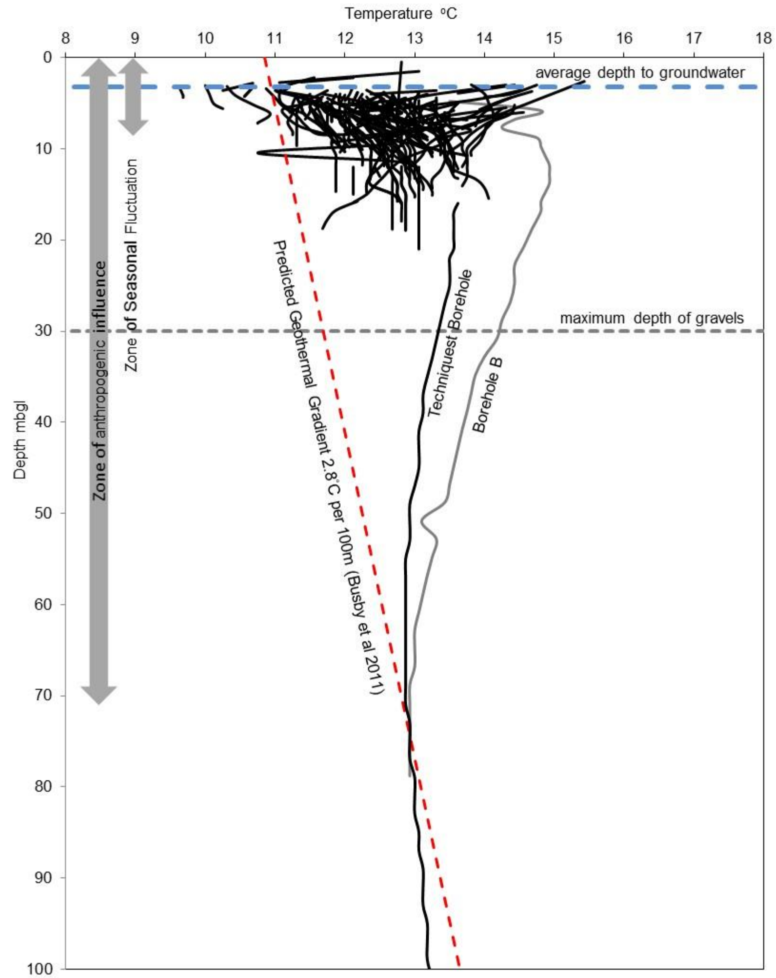
Borehole Temperature Profiling



Farr et al. 2016, QJEGH (In Prep)

- 169 boreholes sampled
- Spring and winter 2014 & 15
- Average temperature is 12.4°C
- Temperatures were 2°C above 'expected' geothermal gradient

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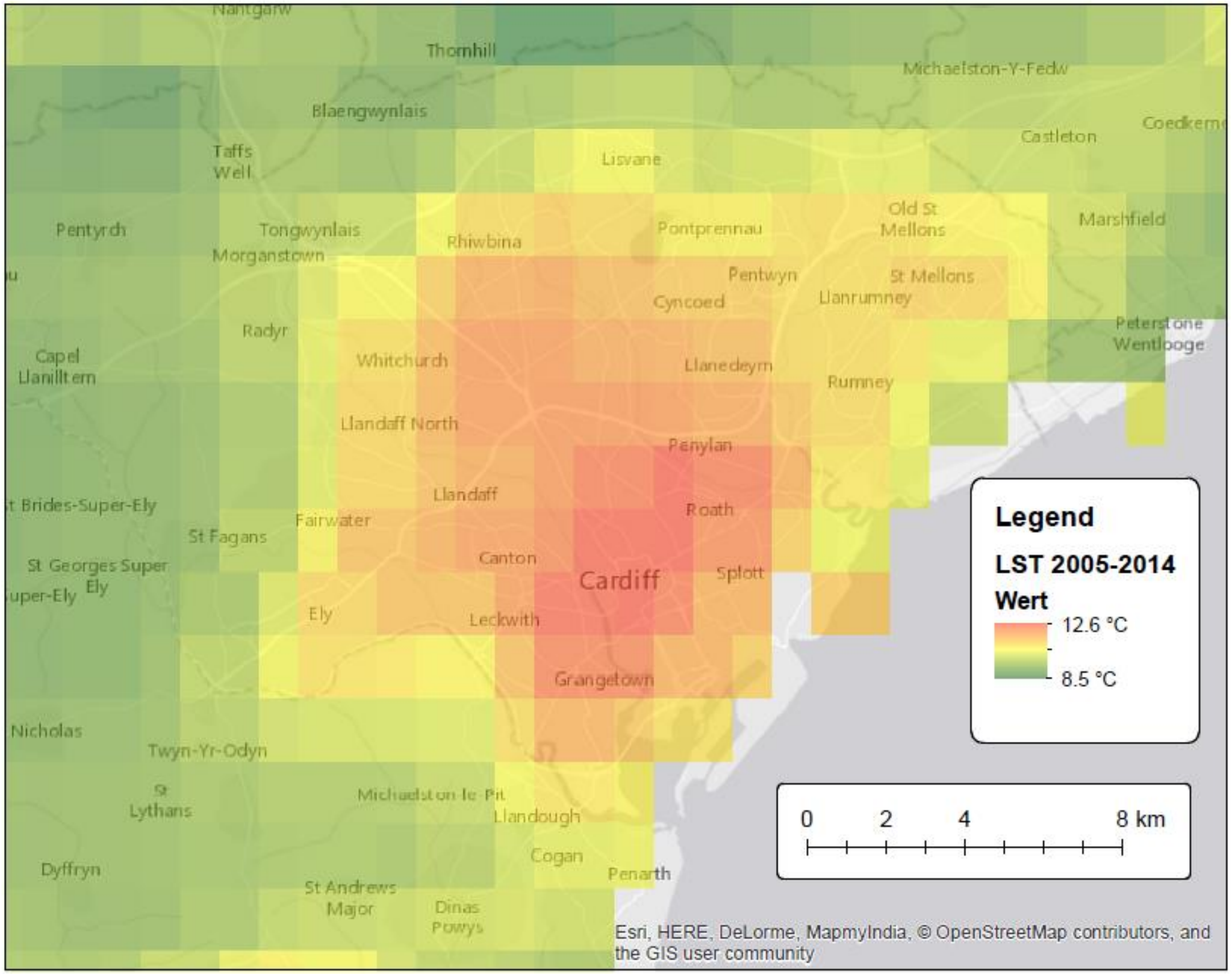
Urban Heat Island Effect (Surface Temperature)



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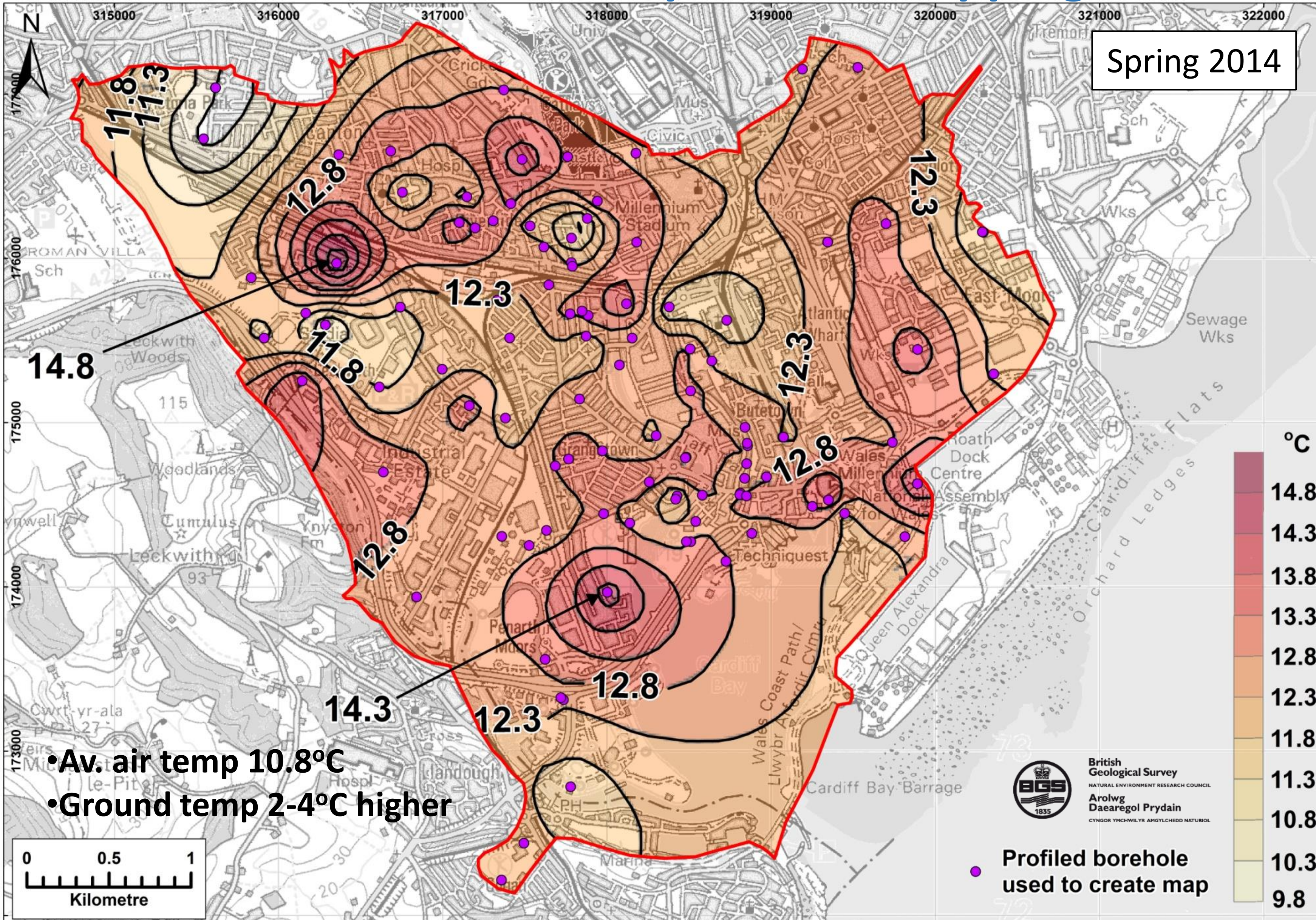
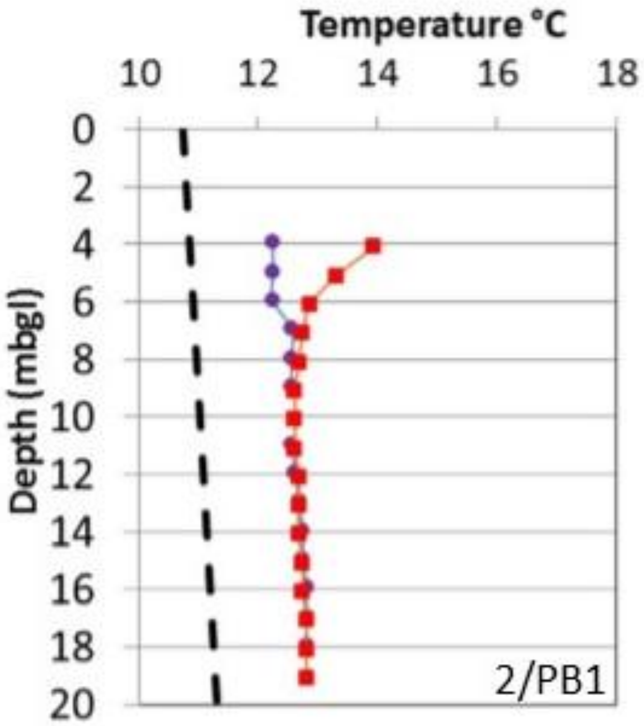
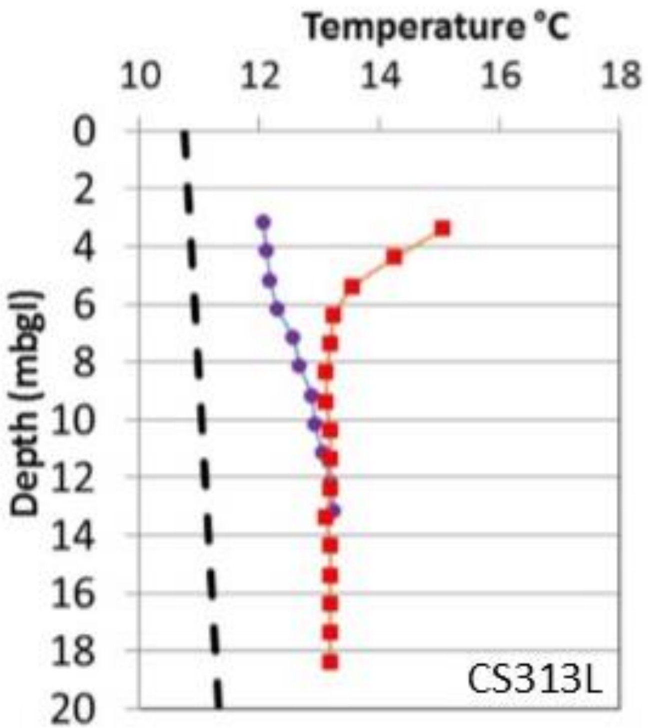
Groundwater Temperature Mapping



Farr et al. 2016, QJEGH (In Prep)

Seasonal GW Temperature Variation Below Ground





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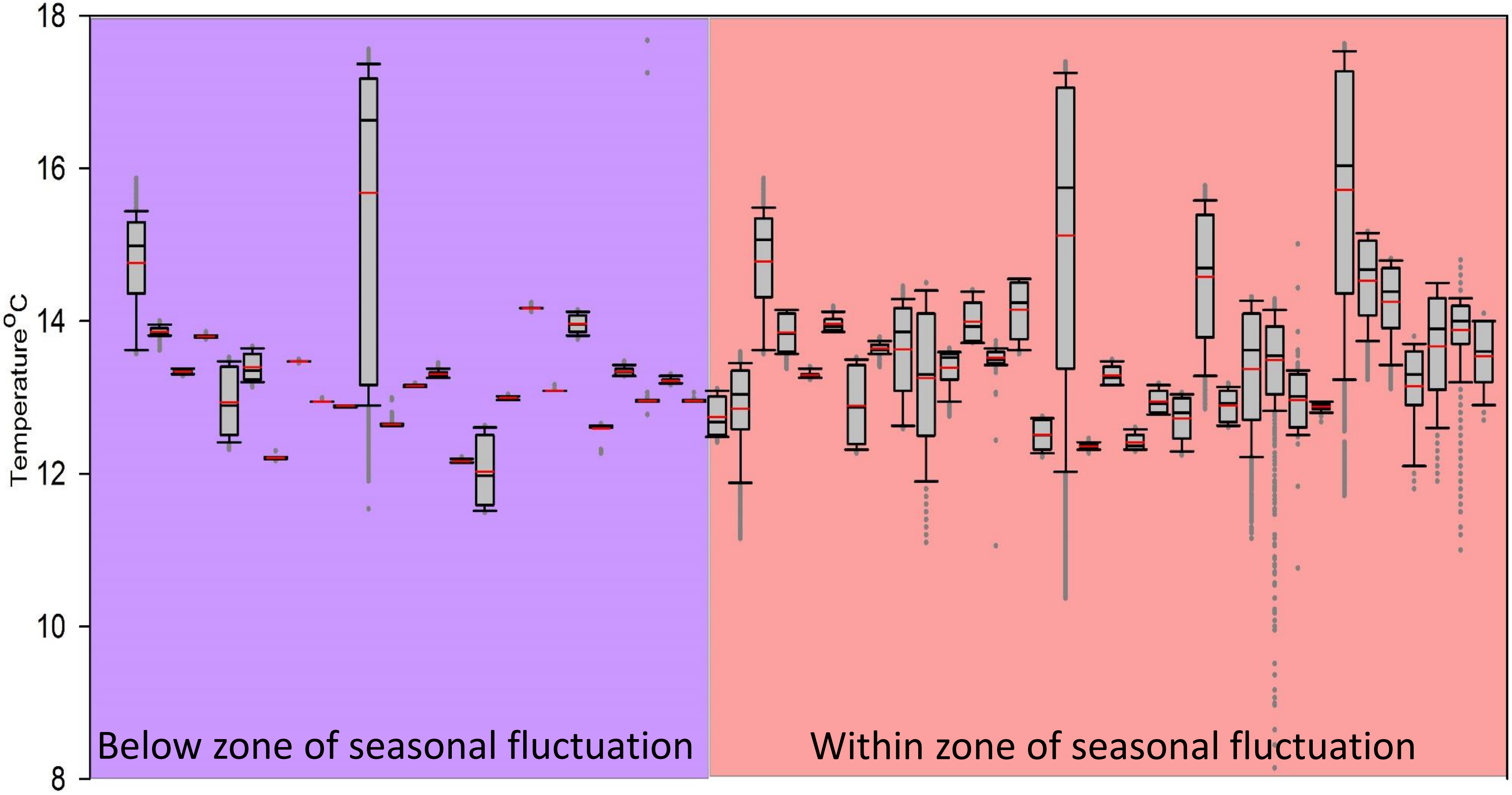
Subsurface Monitoring Network



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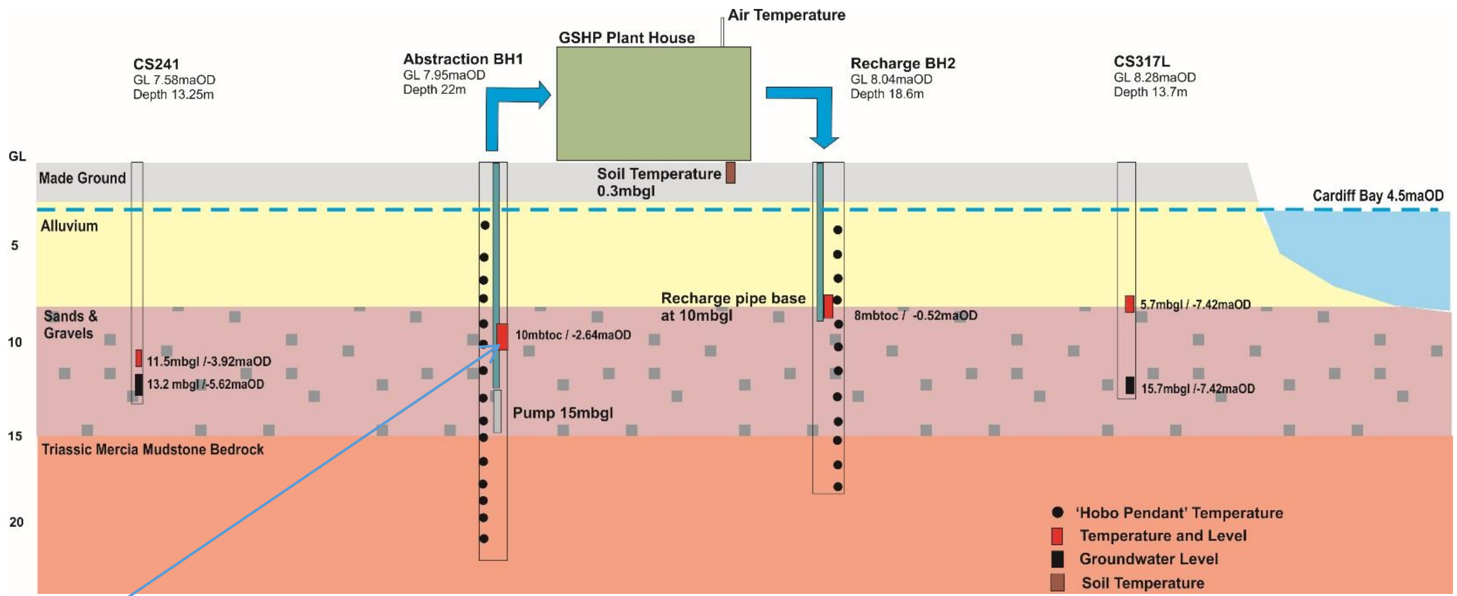
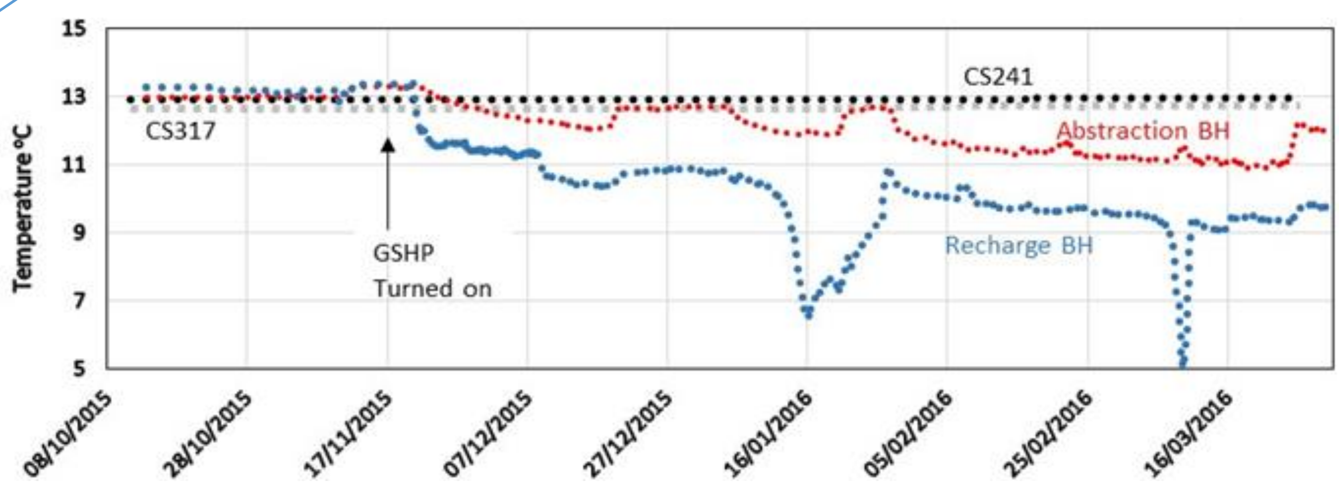
GSHP Test Site: Monitoring





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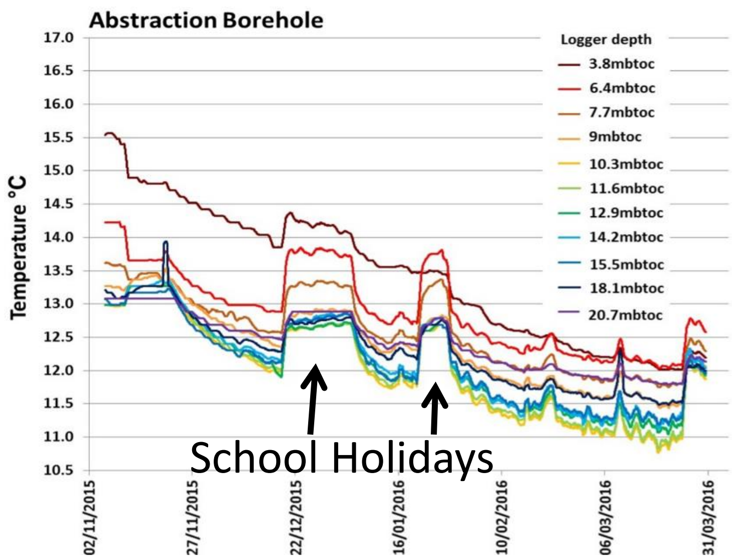
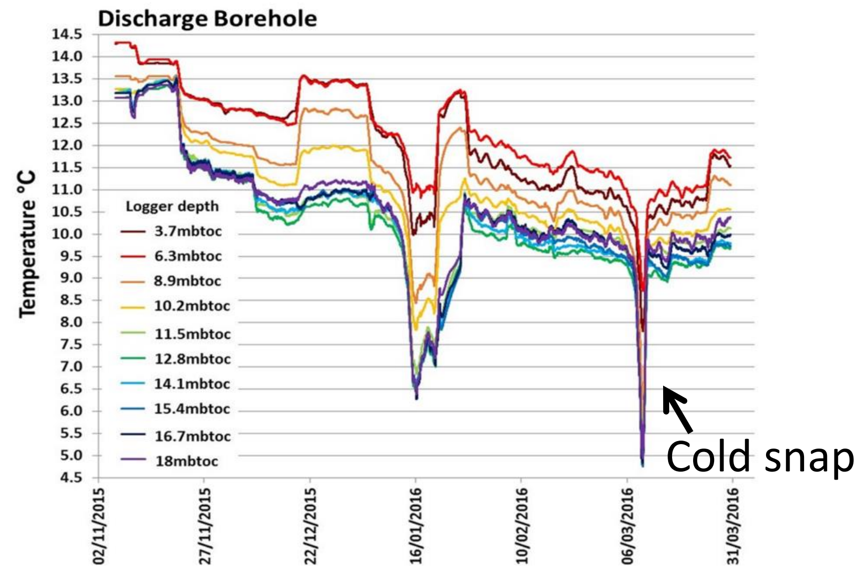
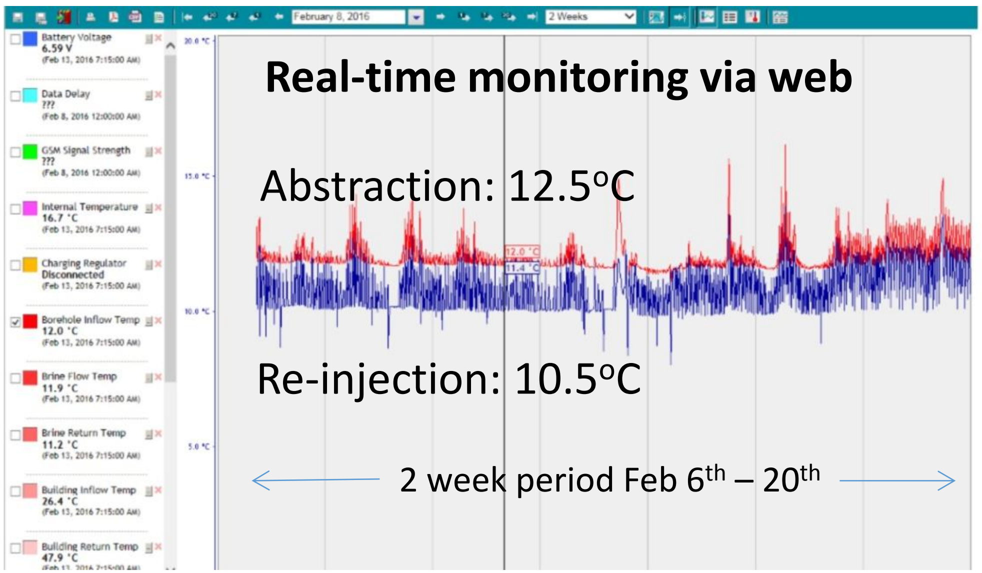
Groundwater Monitoring System: Results







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Iron build-up

Abstraction Borehole (BH1).
No iron build-up after 6 months.

Injection (return) borehole (BH2).
Iron precipitation on the logger device.

Ground Conditions Investigations

Drivers for geological research:

- All development & construction projects face ground 'risk' and a good geological understanding is proven to help reduce costs
- Aim of geological investigations was to provide city-scale baseline information for conceptual ground model development and GSHP feasibility planning

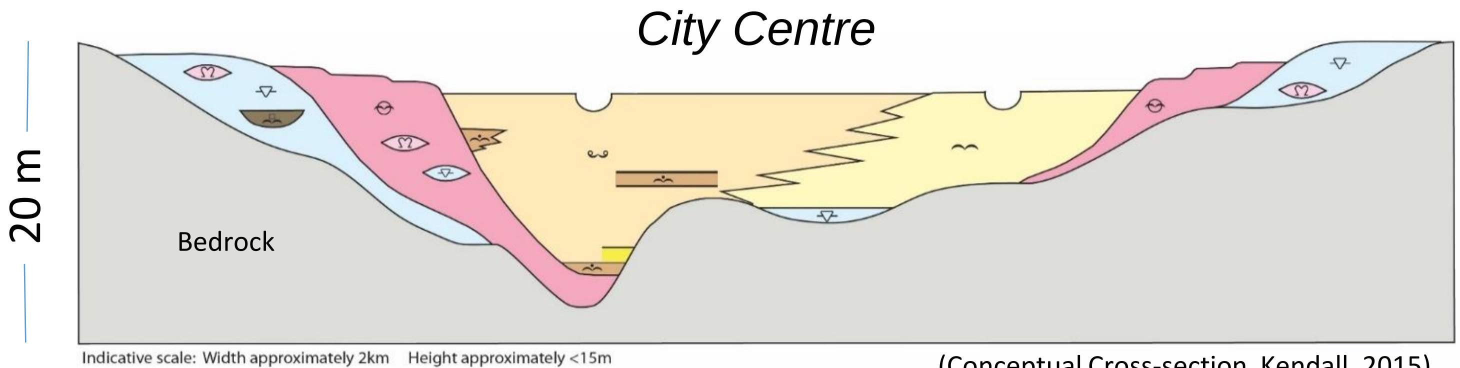
Research Questions: Main issues anticipated were:

- Available groundwater volumes, variable flow direction and quality
- Variable drillability and geotechnical conditions
- Potential to encounter contaminated land, UXO
- Connection to rivers, bay, sewers ground's reaction to pumping

Approach: Develop a 3D geological model and simulate heat flow scenarios


Modern glacial environment, Skaftafell, in Iceland, is similar to Cardiff 15,000 BP

Geo-system Modelling – Cross-sections & 3D Modelling



(Conceptual Cross-section. Kendall, 2015)

Aquifer

TILL (TILL). In the Cardiff district, the dominant type of glacial drift is gravelly till with lenses of sand and gravel. The Tills have a variable composition ranging from stiff, stony, silty clay (CSVLB) to clayey gravel (CLGV). Gravel grade material is usually pebble to cobble sized. The matrix consists of variable mixtures of sand silt and clay. Lenses of sand and gravel (SAGR) are sands and sandy pebble-cobble gravels which are commonly cross bedded.

Hummocky (Moundy) Glacial Deposits (HMGD). Glacial sand and gravel deposits of the Cardiff memoir are here referred to as Hummocky Glacial Deposits. These comprise chaotic sandy pebble-cobble gravel (VSL) with lenses of locally pebbly sand (SAGR), laminated clay (GLD-C) and gravelly till (CLGV).

Glaciofluvial Sheet Deposits (GFSD). Clayey sandy pebble-cobble gravels (CSVLB) with thin beds of gravel which are matrix free (SAGR). GFSD is often overlain by very fine clayey sand/silt (CS). May be cryoturbated in upper parts.

Glaciolacustrine (GLD). Laminated clays (C) occur in lenses throughout the TILL and HMGD

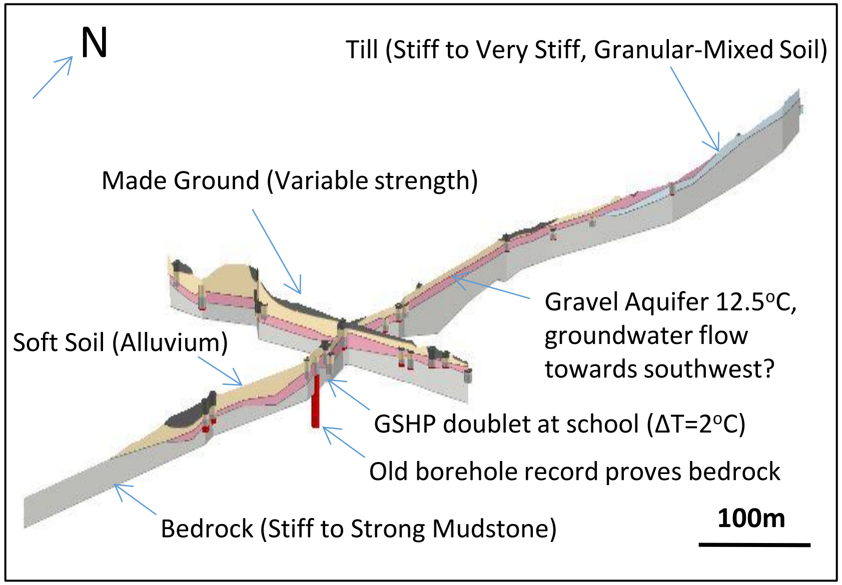
Tidal Flat Deposits (TFD). In the Cardiff district, these deposits are referred to as Estuarine Alluvium. The deposit mainly comprises clay with very subordinate silts, sands and gravels (CZSV). A peat is commonly present at the base (PEAT-PEAT) and scattered thin peats (PEAT-CPS). Interbeds of sand and gravel (SAGR) are noted in borehole logs.

Alluvium (ALV). Variable deposits, commonly clay, sand and gravel (CZSV) and sand and gravel which could be the same deposit with the fines washed away.

Peat (PEAT) A diachronous basal peat is commonly present at the base of the Tidal Flat deposits as well as occurring as scattered thin layers. The basal peat is well developed beneath the former East Moors Steelworks site but rarely present beneath the estuaries. Two other higher peats are also recorded from boreholes. Peat is also recorded as accumulating in kettle-holes on the supragacial till complex.

Basal Gravels occur at or near the base if the Tiadal Flat Deposits and are impossible to distinguish from older fluvioglacial gravels unless separated by a basal peat.

Bedrock, undifferentiated.



Example of 3D ground conditions prognosis, Grangetown, Cardiff

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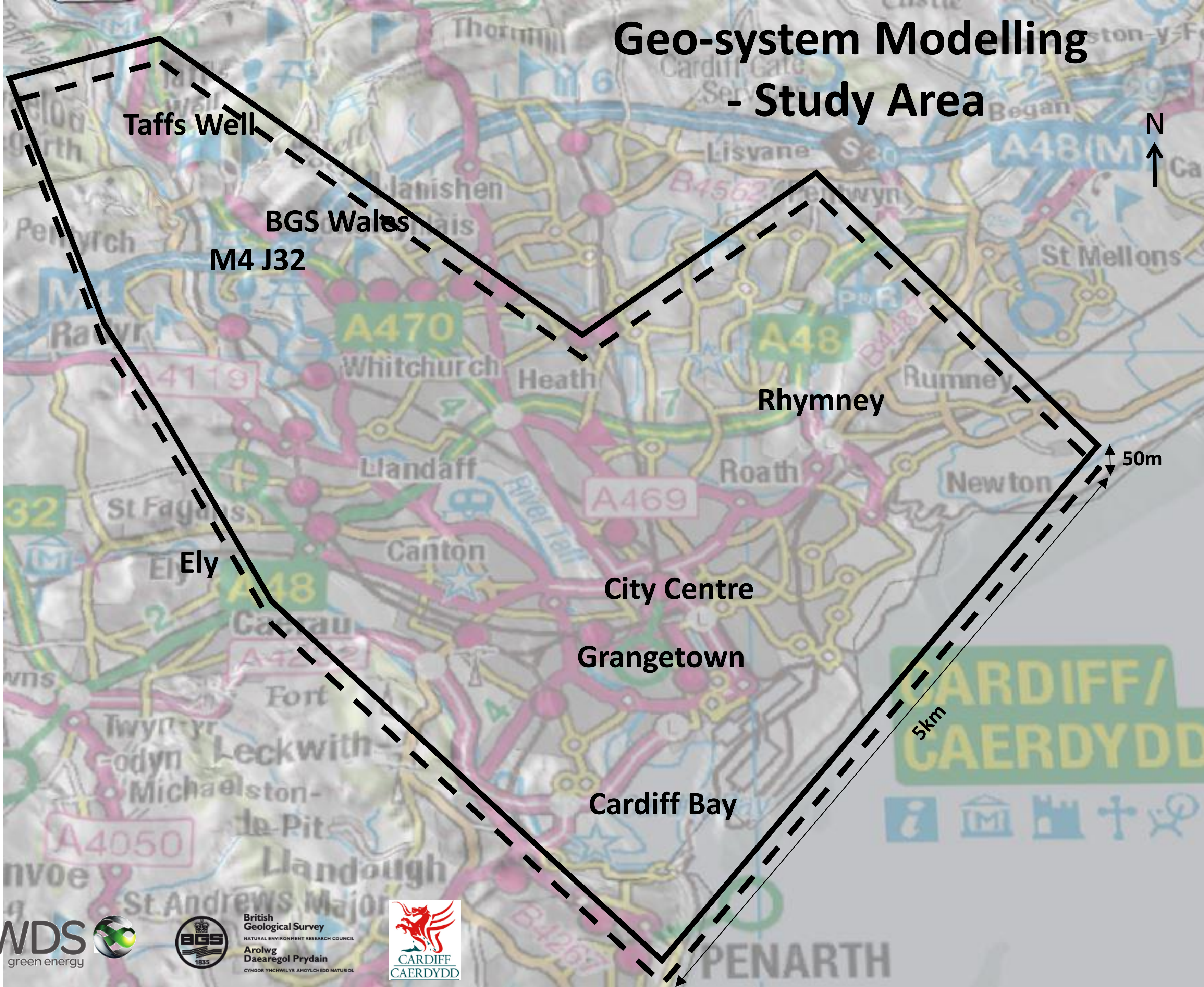
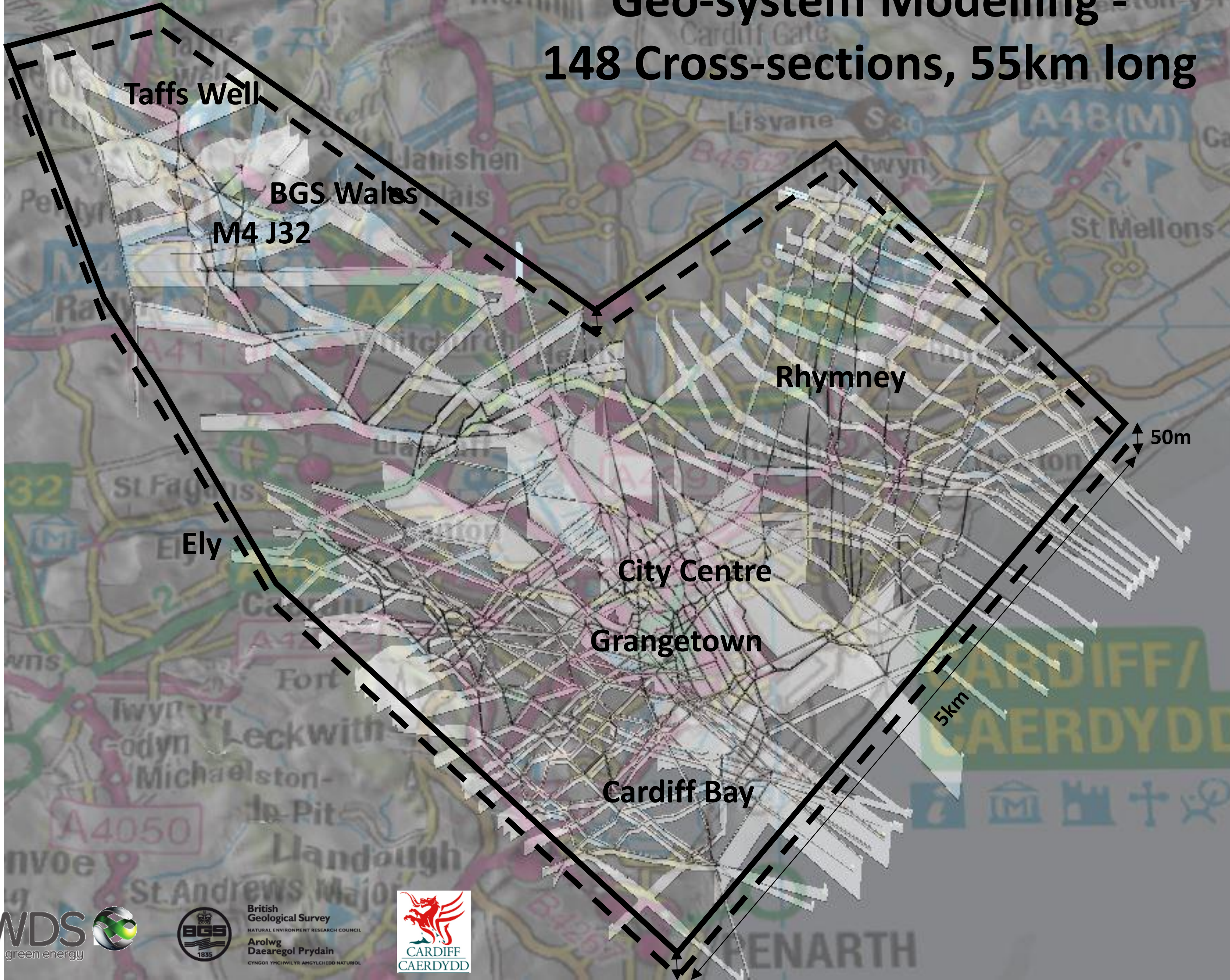
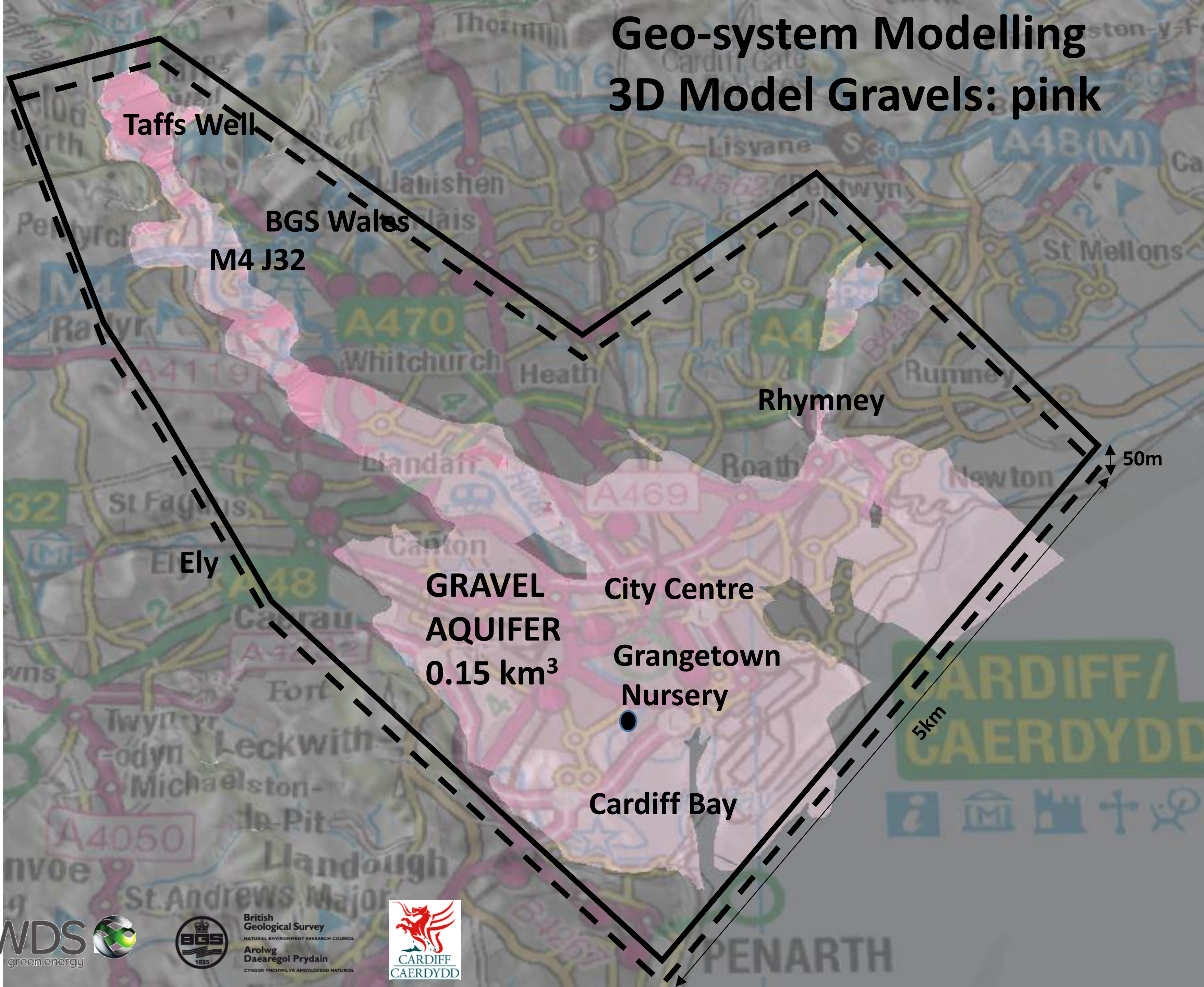
Geo-system Modelling - Study Area



Geo-system Modelling - 148 Cross-sections, 55km long



Geo-system Modelling
3D Model Gravels: pink



Shallow Groundwater Volume Estimate

Fact:

•Our model shows 25% (38km^2) of Cardiff sits on a shallow aquifer* 5m to 10 m thick of sand and gravel

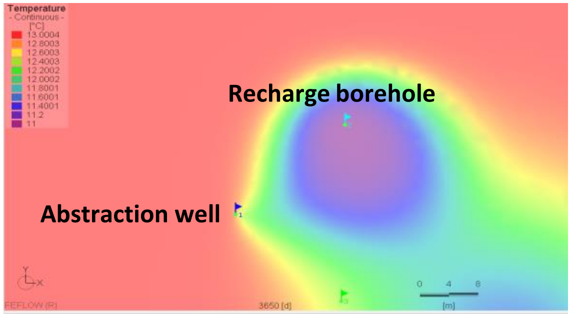
•Volume of the main glacial gravel is approx 0.18km^3

•When we assume it is water-saturated with porosity of 20%, volume of water is 28 Billion Litres at ~12°C **

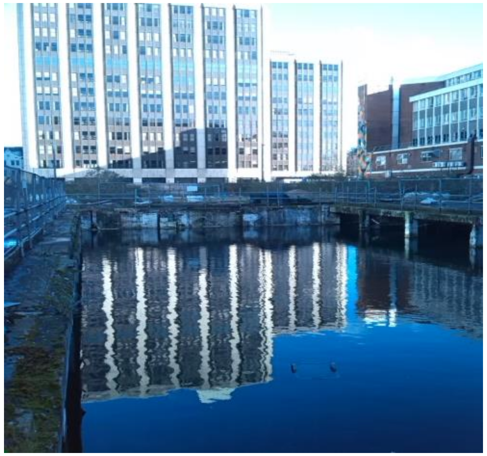
...Initial estimates / don't include deeper groundwater

Questions: (1) How much heat can we abstract? ***

(2) Does heat recharge 'naturally' if we stop pumping?



***Simulated groundwater temperature drop after 10 years of operation is ~1°C



*Flooded Basement in Cardiff showing shallow water table 3m-4m below your feet

** 28 Bn Litres is enough water to fill 11,000 Olympic swimming pools!

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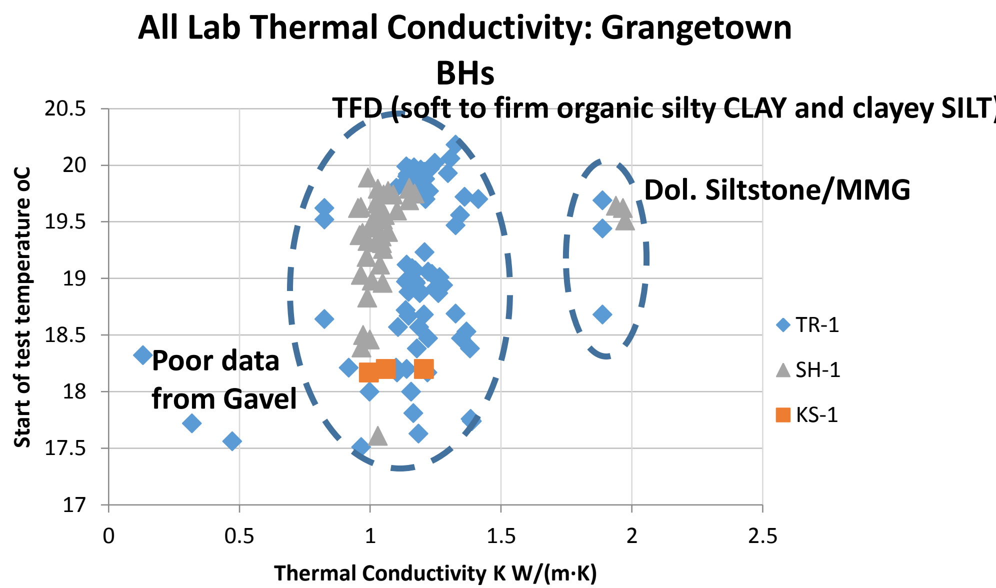
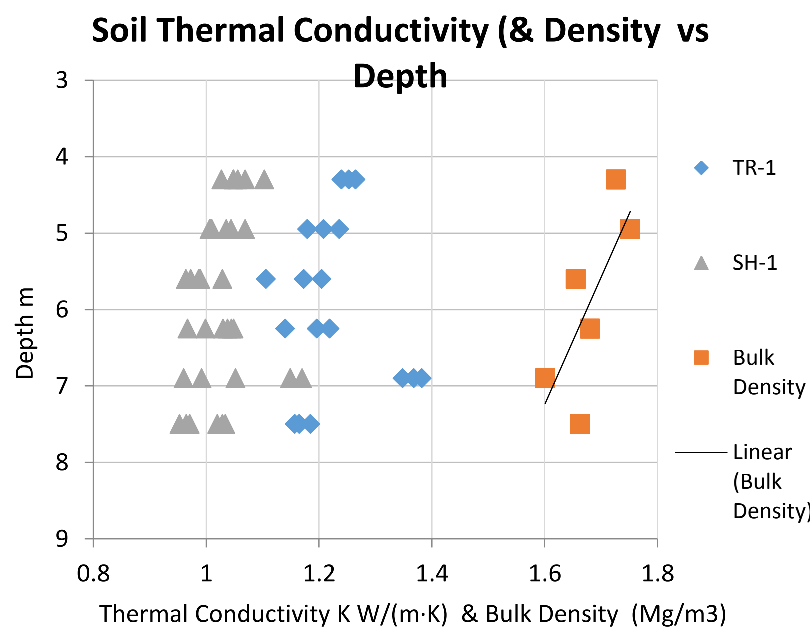
Soil Properties

- Thermal properties of soil and bedrock affect heat flow & transfer below ground
- 186 measurements made on soil and rock cores
- 3 types of probe used to determine *Thermal Conductivity* and *Diffusivity*
- TR-1 needle probe most accurate for soils TC
- SH-1 best for *Thermal Diffusivity*

Deposit	Tidal Flat Deposit (Clay & Silt)	Mercia Mudstone Group (Siltstone)
Thermal Conductivity* K W/(m.K)	1.221 (TD -1) 1.027 (SH -1)	1.2 – 1.9 (Weathered – Fresh)
Thermal Diffusivity m^2/d	0.024 (SH-1)	0.035 – 0.065 (Weathered – Fresh)

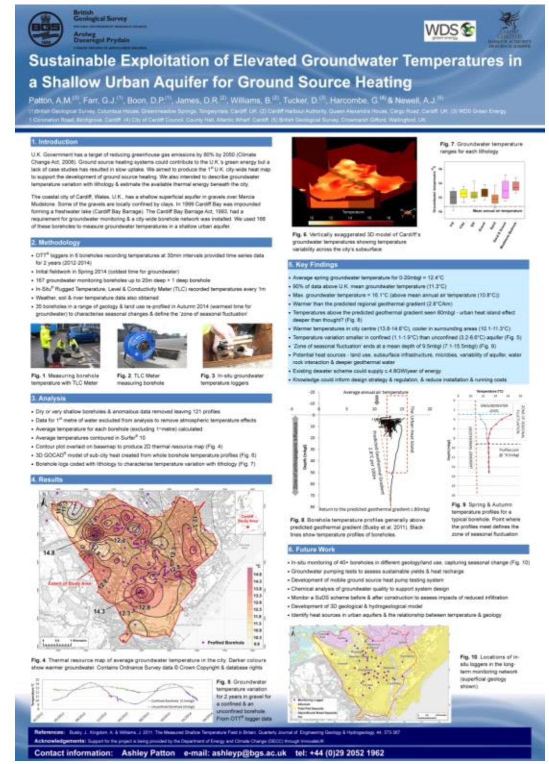
Split U100 core sample of Tidal Flat Deposits with SH-1 probe was inserted both parallel and parallel to bedding plane to measure fabric anisotropy





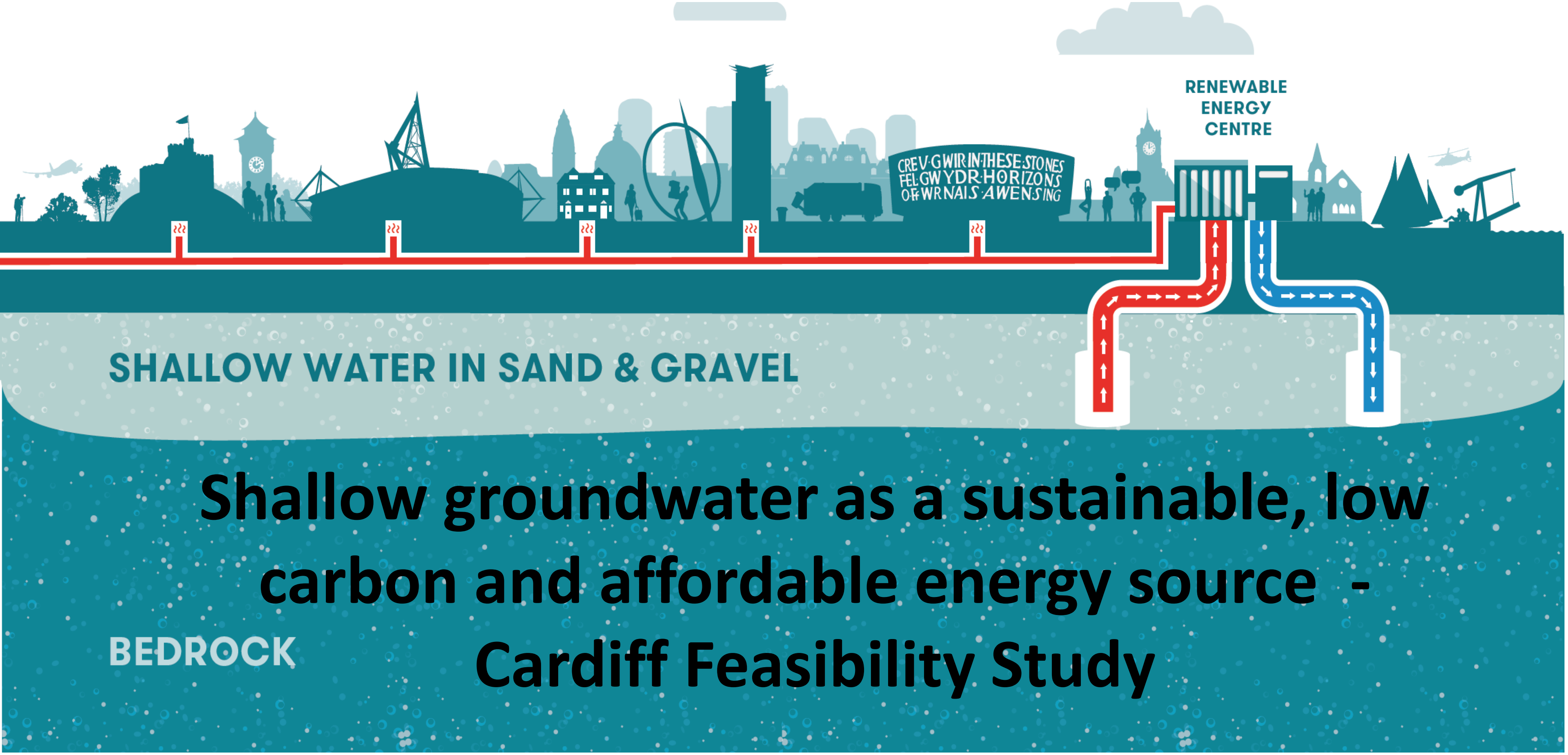
* '*Geometric mean*' value reported as this provides best estimate of 'bulk' Thermal Conductivity (GSHPA Standards 1.0, 2014)

Ground Heat Network Strategy at a City Scale Dissemination



- Press Release via Cardiff Council & Capital Times
- ‘Sustainable Exploitation of Natural Resources’ Conference, London
- BBC Radio Wales interview and tweets
- Online news article www.Walesonline.co.uk
- BGS ‘Geoblogy’ online blog , Twitter, You Tube video (*showing soon!)*
- European Geophyscial Union (EGU) publications 2015 & 2016
- Special Interest Group
- Geological Society of London 2016 (Cardiff & Bristol)
- CEW (June 2016)

ENERGY CATALYST PROJECT
Early Stage Technical Feasibility Study
Ground Heat Network Strategy at a City Scale



Shallow groundwater as a sustainable, low carbon and affordable energy source - Cardiff Feasibility Study

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Ground Heat Network Strategy at a City Scale

WDS Green Energy – Who are we

- A specialist renewable energy company (SME) trading for over 15 years
- Based in Cardiff serving clients in Wales and England
- Over 600 ground and air source heat pump systems installed
- MCS accredited installers
- Projects include:

- Schools	- Social houses
- Arts centres	- New homes
- Offices	- Village halls
- Leisure centres	- Factories
- Retrofitted properties	- Stately Homes

- Developed first mine water heating project in Wales in 2013 under the Seren Project with Cardiff University
- Subsequently short listed in 2014 for a REA award for this mine project (won By Williams F1)

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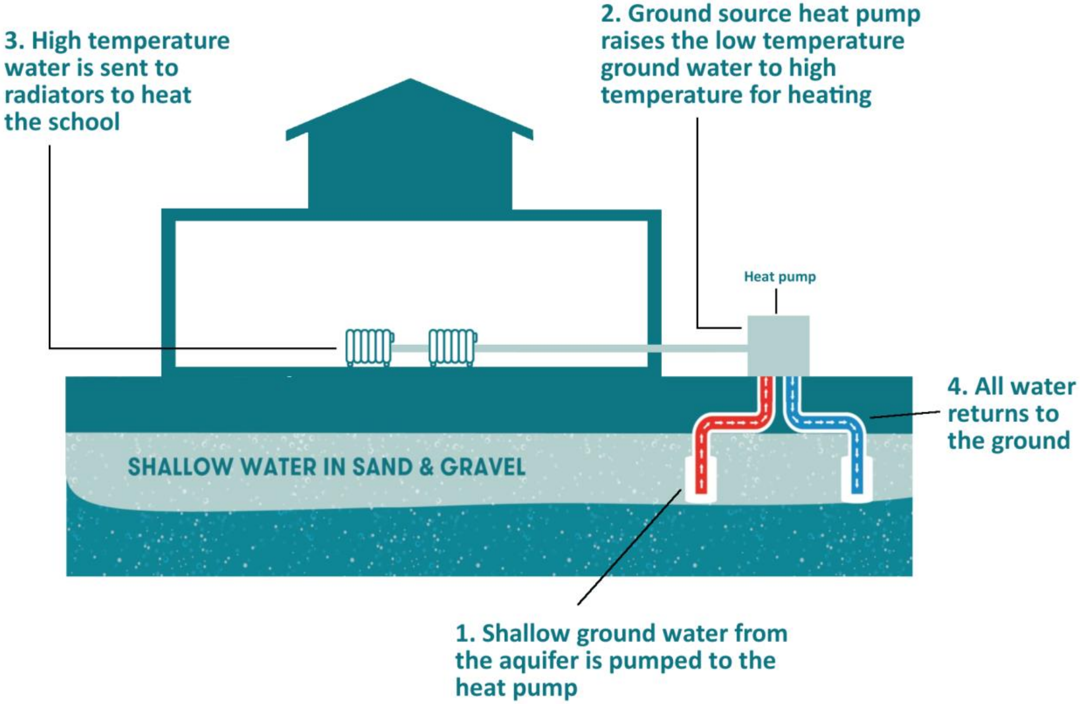
Ground Heat Network Strategy at a City Scale

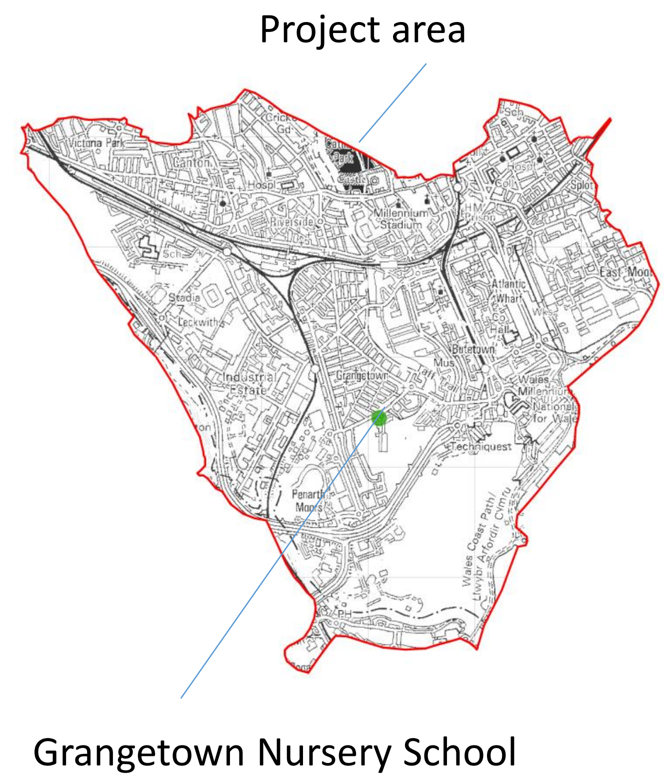
WDS Green Energy – Role in the Project

- Project management – Innovate UK require consortia to be lead by SME's
- **Design and construct an experimental demonstration heat pump system for ground water 'testing' and to provide proof of concept**
- Help change public perception of renewable energy as an alternative to fossil fuels
- Develop an understanding of the infrastructure and restraints that may effect development of heat networks in the City
- Investigate usage of water-to-water heat pumps in the UK and European arena for best practice systems

Ground Heat Network Strategy at a City Scale

Heat Pump project at Grangetown Nursery School





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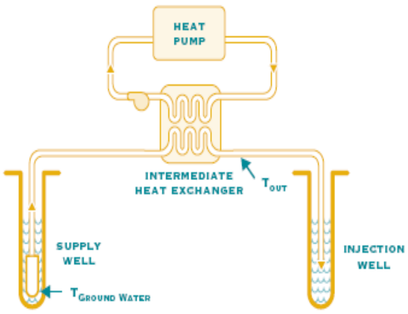
Technology Strategy Board
Energy Catalyst

Ground Heat Network Strategy at a City Scale

Heat Pump System

- Site chosen – Grangetown Nursery School
  - Heating system needed upgrading
  - Sufficient space for 2 boreholes, housing and plant within school boundary
  - Boreholes shallow at 22m and water level at circa 6m
  - Heating demand allows new standalone scheme (22kW @ -3˚C)
  - School head teacher is keen to promote renewables

- Works undertaken :
  - 2 boreholes - one abstraction with borehole pump ; one discharge
  - Heat exchanger
  - 2No – 11kW high temperature heat pumps
  - Buffer tank and all transfer pumps
  - Housing for all equipment
  - Heat and electricity meters and temperature loggers
  - Remote data transmission and collection



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Ground Heat Network Strategy at a City Scale

Heat Pump System - Ground Water Works

Borehole drilling and development

Borehole pump installation

Heat exchanger, filter and flow meter

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Heat Pump System

Housing with heat pump system

Heat pump and buffer tank

Delivery pumps with loggers/metering

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Ground Heat Network Strategy at a City Scale

Why Heat Pumps

- Major alternative to oil and gas fired systems
- Only uses electricity
- Utilise on-site renewable ground energy
- Produces more heat than electricity used (COP's up to 4)
- Reduce CO_2 emissions
- Only renewable technology for 24/7 heating
- Government approved technology attracting Renewable Heat Incentive payments for 20 years on commercial ground source projects and 7 years for domestic air source schemes
- Suitable for new build and retrofitting properties

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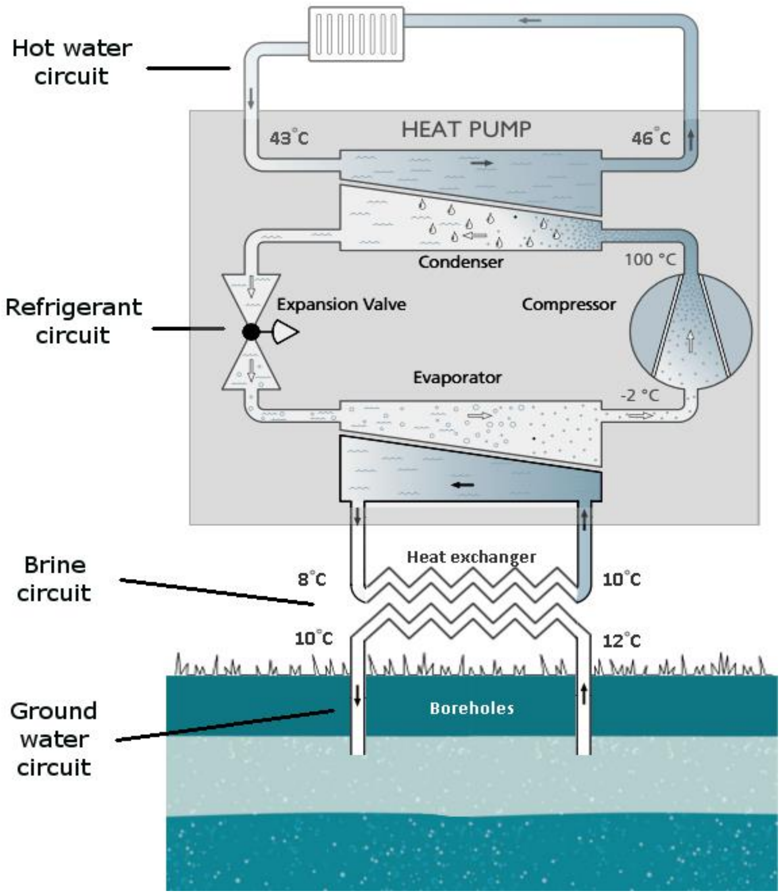
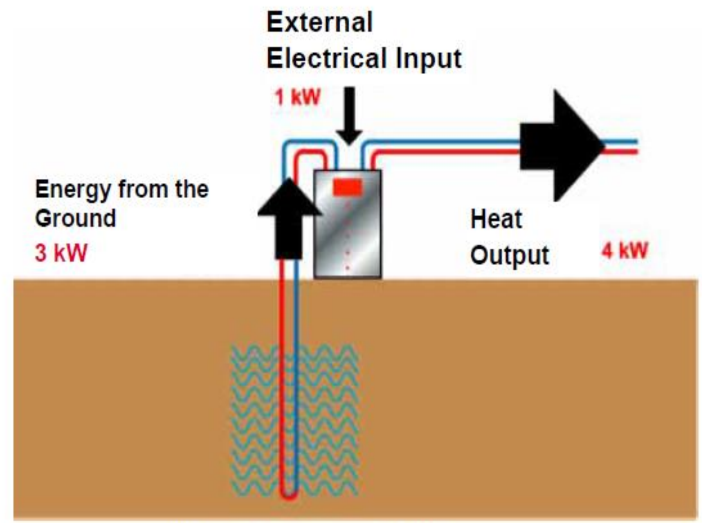
Ground Heat Network Strategy at a City Scale

Energy Collection



Open loop heat pump system



$$CoP = \frac{\text{Heat Output}}{\text{Electrical Input}} = \frac{4\ \text{kW}}{1\ \text{kW}} = 4$$

Ground water yields 75% of energy output

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Ground Heat Network Strategy at a City Scale

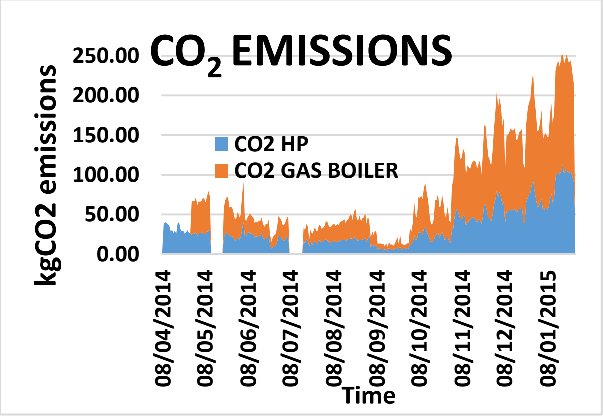
Energy Efficiency and Running Costs

Heavily used Domestic System							
Heating System	CO_2 emissions per kWh of fuel (kgCO2/kwh)	Efficiency %	CO_2 emissions per useful kWh	**Total CO_2 emissions per year Kg**	Cost per kWh	Cost per useful kWh (pence)	**Cost for annual running time of 3000 hours**
LPG boiler (condensing)	0.25	90	0.28	9240	5.63	6.3	£2,063
Off peak electricity	0.41	100	0.41	13530	8	8.0	£2,640
Oil boiler	0.27	80	0.34	11220	5.02	6.3	£2,072
Gas boiler (condensing)	**0.19**	**90**	**0.21**	**6930**	**4**	**4.4**	**£1,467**
Ground source heat pump	**0.41**	**350**	**0.1**	**3300**	**11**	**3.5**	**£1,155**
Air source heat pump	0.41	325	0.12	3960	11	4.9	£1,617
			Heat pump running time (hours)				**3000**
			Heat pump output (kW)				**11**

Ground Heat Network Strategy at a City Scale

Results so far – The School

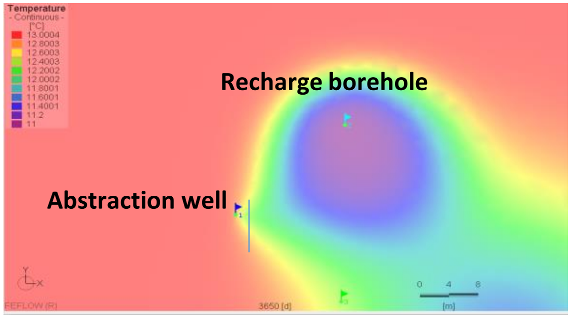
- No alterations made to the radiators in the school
- School environment comfortable for staff and children
- Radiators are safer with lower operating temperatures of circa 43°- 45°C (gas was > 75°C)
- Internal temperature monitoring to optimise flow temperatures and comfort levels
- Heating system fully instrumented with on line data
- No disruption to play activities of the school
- CO_2 footprint of school being reduced by circa 50%
- No gas so no potential carbon monoxide issues



Ground Heat Network Strategy at a City Scale

Results so far – The Engineering

- No drawdown or increase in ground water levels during pumping regime
- Abstracted water temperatures static at circa 12°C (no cooling from discharge well)
- Flow/return delta T only 2°C for each heat pump
- 13kW heat pump output > 75% from warm ground water
- School uses **one** heat pump for most of the time
- Second heat pump only used when air temp < 3°C
- Electricity consumption minimised to 3.5kW (heat pump = 2.7kW)
- Water volume under the city circa 28 million m^3
- Estimated ground water energy at delta T of 3°C > 52MW
- Proof of concept for using ground water to heat the city through networks proven



Predicted groundwater temperature after 10 years

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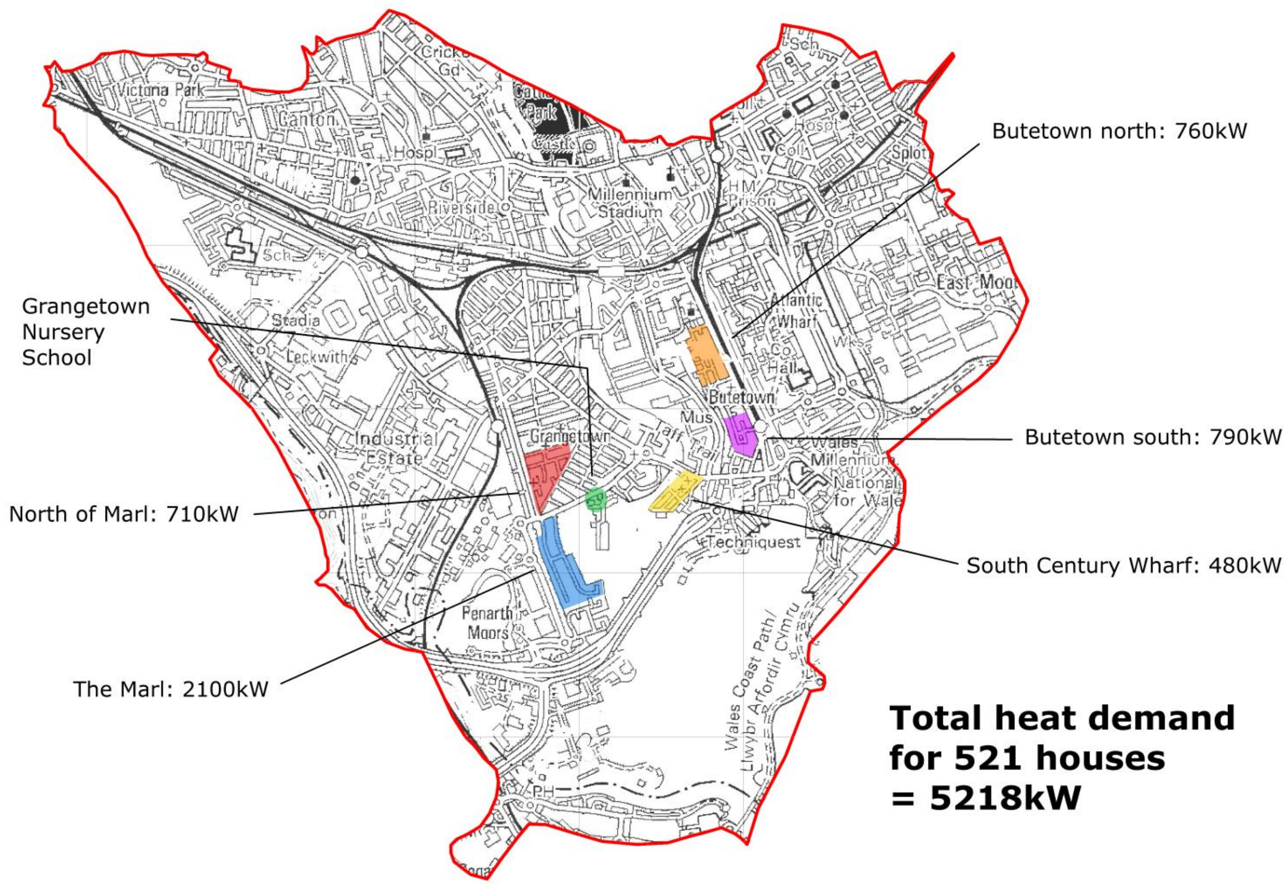
Ground Heat Network Strategy at a City Scale

Heat Demand Mapping



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Ground Heat Network Strategy at a City Scale

Future Works

- More extensive borehole drilling, test pumping and data collection
- Site specific 3D ground water modelling and validation (inter-seasonal storage)
- Investigation thermal storage potential of waste heat into ground water
- Consider open water usage – barrage and rivers
- Undertake heat demand mapping and energy planning across the city
- More detailed network distribution designs at key location
- Address utility issues from new heat networks
- Business model development – partners, funding, detailed costings
- Creation of ESCO with public and private support ?

Ground Heat Network Strategy at a City Scale

Project mascot !

Next Steps?

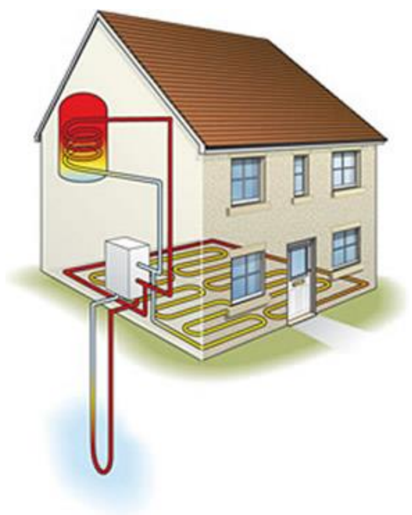
More work needed on…

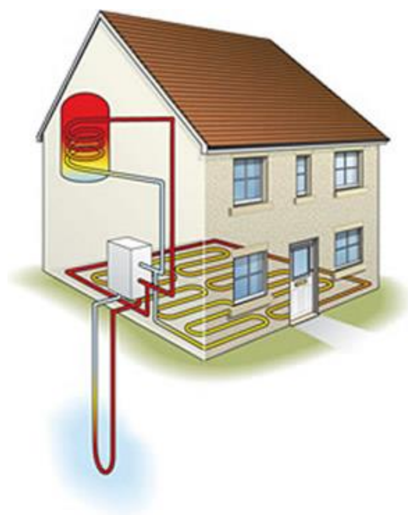
- Maximising efficiency of heat pumps?
- Value of integrating other renewables?
- Understanding customer perspective?
- Regulation and governance?
  - NRW licensing
  - Regulating heat extraction / maintaining resilience
  - Network ownership

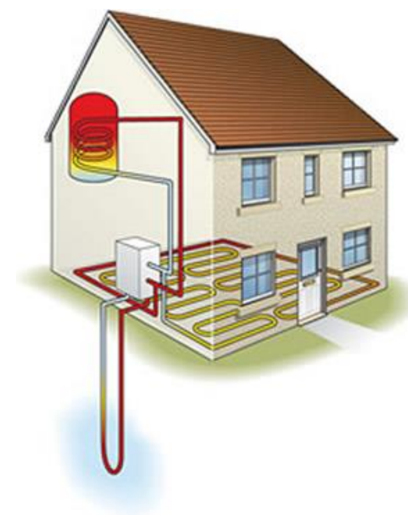
More work needed on…

Best system format?

- Network of stand alone systems?



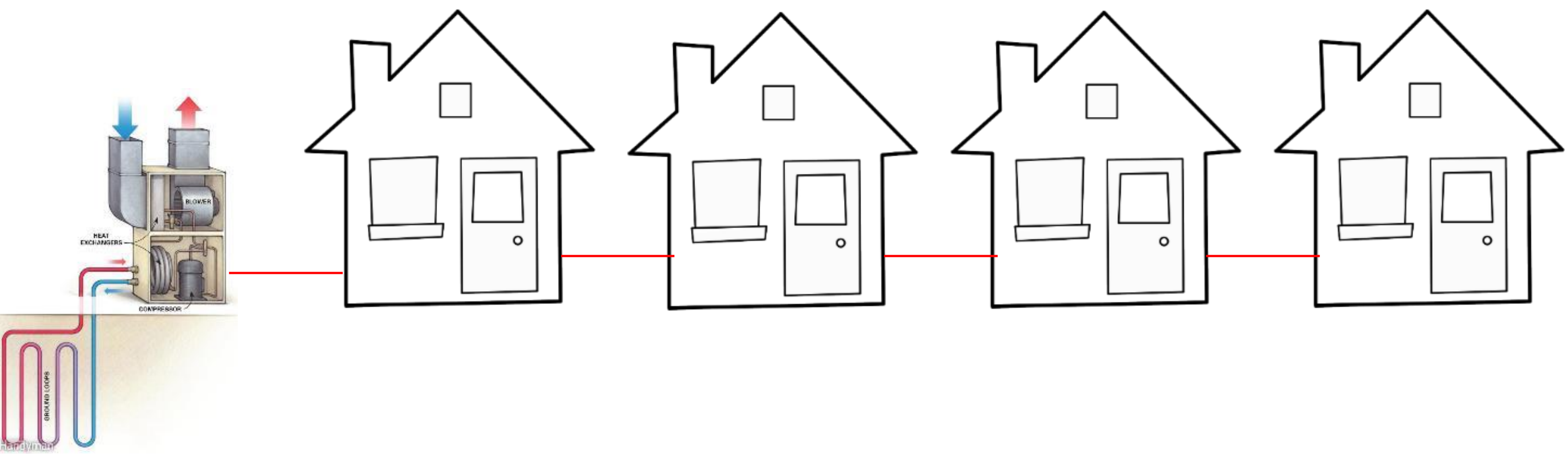




More work needed on…

Best system format?

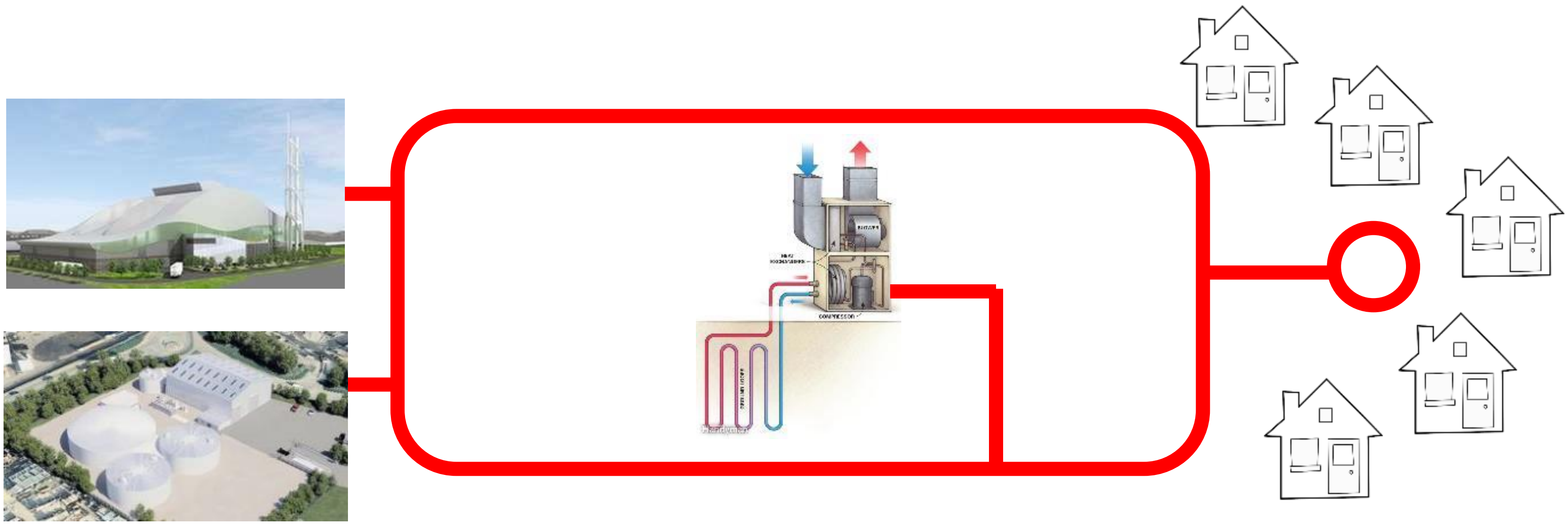
- Street/district distribution?



More work needed on…

Best system format?

- Part of a multi heat source network?



Next Steps

- I-UK funding ends April 2016
- Proposing bid into 2nd 3rd stage of Energy Catalyst
- HNDU – heat mapping and technical integration work packages (Spring/Summer)
- Other support? WG/H2020/etc

Questions & Answers

Tour of Grangetown Nursery School