Case study: Surface/groundwater relations in Cork City, SW Ireland and the response of the salt water/fresh water interface to pump test investigations

Xiang Cheng[1, 2] and Alistair Allen[2]

[1] Cork City Energy Agency, Cork City Council, Cork, Ireland
[2] Department of Geology, University College Cork, Cork, Ireland

ABSTRACT

Cork City is situated in SW Ireland at the mouth of the River Lee, which flows into Cork Harbour, connected by a narrow entrance to the Atlantic Ocean. The River Lee, which flows from west to east through Cork City is estuarine and is subject to semidiurnal tides, reaching as far inland as the western edge of the city.

Cork City Centre is underlain by the Lee Buried Valley gravel aquifer, formed in the late Pleistocene (~30-20kA) when sea level was about 130m lower than at present. This and a number of other buried valleys in the area were excavated into a bedrock sequence of U. Devonian sandstone and L Carboniferous limestone folded into a series of E-W synclines and anticlines.

Boreholes have been drilled in Cork Docklands area to the east of the city to monitor groundwater behaviour with a view to extracting groundwater for geothermal district heating and potential supply of drinking water. The buried valley aquifer in the Docklands area consists of two gravel sections at about 4-16m and below 18m separated by an approximately 2m thick finer-grained sandy horizon, which acts as a localised semi-confining layer. The upper gravel layer is overlain by about 3m alluvium and 2m fill.

Groundwater in the gravel aquifer is hydraulically connected to the River Lee and sea water. The static groundwater level varies over a range of 1.5-2m during a tidal cycle from about 2-4m below the ground surface. It also displays a delay in response of about 1-1.5 hours depending on distance from the river.

Step pump test programmes, run continuously over several weeks have been undertaken in two adjacent boreholes, one to 30m to investigate the behaviour of the lower gravel aquifer and the other to 17m to test the upper aquifer. Dynamic water levels, temperature and electrical conductivity of the groundwater were recorded. Yields of 60lsec^{-1}, the maximum discharge attainable by the 200mm submersible pump can be achieved from the 250mm PVC cased and screened boreholes. However, such large abstractions over significant timescales lead to a gradual deterioration in the water quality of the aquifer.

The variation in electrical conductivity of the groundwater with depth was also determined and analysed. Brackish water with an electrical conductivity of 5mS/cm was identified at a depth of 15m below ground level (~13m below the water table), and increases rapidly to 26mS/cm at a depth of 27m below ground level. Therefore, it is concluded that the fresh/saline water interface occurs in the range of 15-27m below ground level, and that the transition zone is of the order of 12m thick. Continuous pumping test, drawdown, temperature and conductivity for the aquifer are in the process of being modeled using FEFLOW.

INTRODUCTION

This paper focuses on the gravel aquifer affected by the tidal River Lee, which flows into Cork harbour. The groundwater-surface water interaction was studied; pumping tests and monitoring programmes (levels, temperature and electrical conductivity) were carried out with a view to ultilising groundwater for potential low enthalpy geothermal development and drinking water purposes. The depth of the saline water interface and the thickness of the transition zone were also determined to facilitate the next stage of FEFLOW modeling process to assess the most sustainable pumping rate with minimum impact on groundwater quality.

Background

Cork City (Latitude 51^{o}51' North, Longitude 8^{o}29' West) is located in SW Ireland at the mouth of the River Lee, which ends into Cork Harbour, connected by a narrow entrance to the Atlantic Ocean. The River Lee, flowing from west to east through Cork City, is estuarine and subject to semidiurnal tides. The tide can reach as far inland as the western edge of the city. The real time tide data was collected at the Lee Malting Data Station, which is very close to the City Centre on the north channel of the River Lee.

Cork South Docklands to the east of the city, was reclaimed from the marsh which was a floodplain covered by the River Lee at high tide back centuries ago. Due to the nature of historical manufacture and industrial activity at South Docklands, it was presumed that there is a legacy of contaminants in the soil and groundwater. It is consistent with the drilling findings of the upper most layer of the manmade filling material followed by the alluvium layer.

Cork City is underlain by Lee Buried Valley gravel aquifer, formed in the late Pleistocene (~30-20kA) when sea level was about 130m lower than at present. This gravel aquifer and a number of other buried valleys in the area were excavated into a bedrock sequence of U. Devonian sandstone and L Carboniferous limestone folded into a series of E-W synclines and anticlines.

Previous studies on the Lee Buried Valley gravel aquifer have suggested a substantial direct recharge by rainfall infiltration is estimated at a rate of 650mm per annum between Classes and Garryhesta in the Ballincollig-Ovens area toward the west of Cork City. At these locations the Lee Buried Valley is exposed due to the sand and gravel mining activity (Milenic, 2003). The natural infiltrations though fine sand, gravel and soil removes impurities and gives a very good quality of groundwater. This groundwater resource can potentially be used for low enthalpy geothermal development and for future additional drinking water purposes.

METHODS

A number of different depth boreholes have been drilled at South Docklands to monitor groundwater's response to the tidal River Lee. Dynamic water levels, temperature and electrical conductivity of the groundwater were recorded by CTD Diver for months. The recorded real time tide data is used to compare against the monitoring data as reference. The true tidal efficiency of the aquifer and the tidal time lag can then be calculated.

Step pump tests and long term pumping tests were running continuously over several weeks in two adjacent boreholes, one to 30m below ground level (bgl) to investigate the behaviour of the lower gravel aquifer and the other to 17m bgl to test the upper aquifer, in order to estimate the most sustainable pumping rate. In addition the variation in groundwater electrical conductivity with depth was determined to establish the depth of fresh-saline water interface and the thickness of the transition zone.

RESULTS

According to borehole and trial pit logs at Cork South Docklands the local geology can be summarised as follows:

- the uppermost horizon comprises 0.1-0.5m exclusively asphalts and gravels
- this is followed by approximately 1.0-2.0m of fill material
- the fill is then underlain by 1.5-2.5m layer of soft grey alluvial silt
- this in turn is underlain by approximately 11m thick of fine to coarse subangular to subrounded sandstone gravels from about 4.5m bgl
- a layer of fine sand and silt was encountered at 15m bgl, estimated to be 2.0-3.0m thick
- between 18-28m bgl fine to coarse sandy gravels with some silt zones was encountered
- from 28-32m bgl approximately are fine silts, sands with gravels
- borehole drillings did not hit the bedrock which indicates the thickness of the Lee Buried Valley aquifer is in excess of 30m at Cork South Docklands

The particle distribution tests of drilling samples taken at different depths were carried out. When the sample material comprising medium-grain sand with a coefficient uniformity of C<5, hydraulic conductivity can be determined from grain-size data by the widely used United States Bureau of Reclamation (USBR) Formula $K=0.36*(d_{20})^{2.3}$cm/s. The hydraulic conductivity K of the aquifer is calculated in the range of 0.37cm/s to 1.22cm/s.

The groundwater level fluctuates with the tide of River Lee, which is effectively caused by the sea tide. The recorded static groundwater level varies over a range of 1.5-2m during a tidal cycle. It also displays a delay in response of about 1-1.5 hours depending on distance from the River. By employing the Tidal Method (Carr, *et al.* 1969) the true tidal efficiency φ of the aquifer at Cork South Docklands can be described as $\phi = e^{-2.11\times10^{-3}x}$, and the lag time t_L (day) can be described as $t_L = 1.736\times10^{-4}\cdot x$, where *x* (m) is the distance from the River Lee.

Yields of 60lsec^{-1}, the maximum discharge attainable by the 200mm submersible pump can be achieved from 250mm PVC screen cased boreholes. A step pumping test result is shown in Figure 1 below. The local drawdown was in the range of 10m and cone of depression at the pumping test was insignificant. However, such large abstractions over significant timescales will certainly lead to a gradual deterioration in the water quality of the aquifer. In Figure 1 the groundwater electrical conductivity has increased over the time which indicates the existence of saline intrusion. The groundwater samples from BH1 and BH2 was also tested, as shown in Table 1 below.

The variation in electrical conductivity of the groundwater with depth was analysed to establish the depth of fresh-saline water interface and the thickness of the transition zone. Brackish water with an electrical conductivity of 5mS/cm was identified at a depth of 15m bgl (~13m below the water table), and increases rapidly to 26mS/cm at a depth of 27m bgl. Therefore, it can be concluded the fresh/saline water interface occurs in the range of 15-27m bgl and the transition zone is of the order of 12m thick.

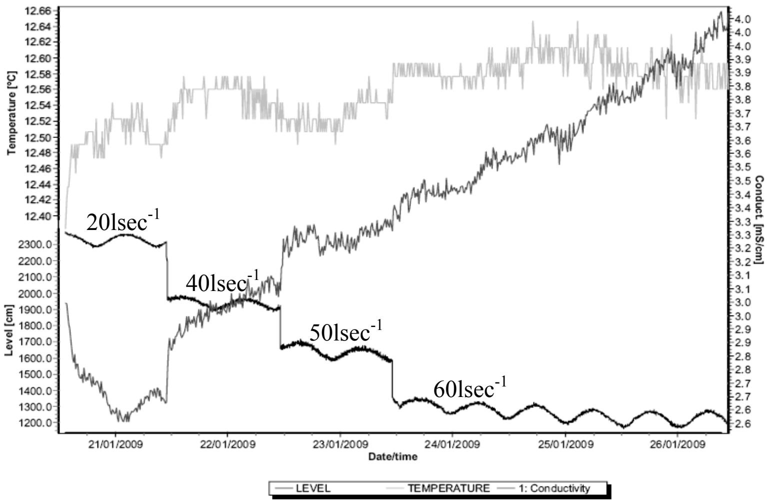

Figure 1. Step Pumping Test at Cork South Docklands from 20/01/2009 – 28/01/2009

Table 1. Quality Analysis of Groundwater Sample from BH1 and BH2

Parameter	Sample BH1	Sample BH2	Parameter	Sample BH1	Sample BH2
pH	6.88	7.9	Total Oxidised Nitrogen as N (mg/l)	<0.3	24.2
Temperature ^{o}C	12.7	12.5	Dissolved Aluminium (ug/l)	4	40
Conductivity (uS/cm)	>3,999	2,590	Arsenic (ug/l)	7	<2.5
Dissolved Oxygen (mg/l)	6.7	10	Dissolved Boron (mg/l)	0.717	<0.012
Total Alkalinity as $CaCO_3$ (mg/l)	240	236	Dissolved Cadmium (ug/l)	<0.4	<0.5
Ammonium (mg/l)	0.3	<0.2	Dissolved Chromium (ug/l)	<1	<1
Total Hardness (mg/l)	2661	550	Dissolved Copper (mg/l)	<0.001	8
Dissolved Calcium (mg/l)	238.2	136.0	Mercury (ug/l)	<0.05	<0.6
Dissolved Manganese (ug/l)	9	14	Nickel (ug/l)	<1	2
Dissolved Iron (ug/l)	<2	<20	Zinc (ug/l)	10	79
Dissolved Magnesium (mg/l)	381.80	50.00	Benzene (ug/l)	<10	<1
Nitrate as NO_3 (mg/l)	1.3	24.2	Toluene (mg/l)	<0.01	<0.002
Nitrite as NO_2 (mg/l)	<0.05	<0.01	Ethylbenzene (mg/l)	<0.01	<0.002
Orthophosphate as PO_4 (mg/l)	0.06	<0.01	Total Xylene (mg/l)	<0.01	<0.003
Potassium (mg/l)	111	12.82	Petrol Range Organics (C5-C9) (mg/l)	<0.01	<0.01
Sodium (mg/l)	3400	286	Petrol Range Organics (C10+) (mg/l)	<0.01	<0.02
Chloride (mg/l)	7492	28.21	Diesel Range Organics (mg/l)	<0.01	<0.03
Sulphate (mg/l)	947	104	Mineral Oils (mg/l)	<0.01	<0.04

DISCUSSION AND CONCLUSIONS

The project is still in progress and next phase is the FEFLOW modeling of Docklands aquifer. This will facilitate the assessment of the most sustainable pumping rate with minimum impact on groundwater quality. The FEFLOW model will then be calibrated by the pumping test results.

REFERENCES

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Contact Information: Xiang Cheng, Cork City Energy Agency, Cork City Council, Lifetime Lab, Lee Road, Cork, Republic of Ireland.Phone: 00353-21-4941509, Fax: 00353-21-4941519, Email: xiang_cheng@corkcity.ie