Characterising the Hydrogeology of Bell Harbour Catchment affected by a saltwater intrusion as a basis for Groundwater Modelling

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Abstract

With the aim of developing a better understanding of the interaction of the freshwater/seawater along the west coast of Ireland, a hydrogeological study focused on the karstic aquifer of a small catchment - Bell Harbour - (~50km^2) located on the south coast of Galway Bay has begun. Discharge from the catchment is entirely through intertidal diffuse springs and submarine groundwater discharges (SGD). Logging of temperature, conductivity and water levels at coastal springs, turloughs and boreholes in the catchment is underway, water samples have been recovered for chemical analysis, water tracing has been undertaken and a pumping test has been completed. Initial results clearly show a tidal influence up to 2.5 kilometres inland and an intrusion of seawater at least up to 1 kilometre inland. These data sets will be subsequently incorporated into HydroGeoSphere, a 3D finite-element model, for which simulations in variably saturated fractured media have been already performed successfully.

Résumé

Afin d’obtenir une meilleure compréhension de l’interaction eau douce/eau salée le long de la côte ouest irlandaise, l’étude hydrogéologique de l’aquifère karstique de Bell Harbour (~50km^2) situé sur la côte sud de la baie de Galway, est en cours. L’écoulement des eaux souterraines de cet aquifère se déverse entièrement par plusieurs sources intertidales et diffuses ainsi que par des sources d’eau douce sous-marines (SGD). Des mesures de températures, conductivités et niveaux piézométriques sont actuellement réalisées sur les sources côtières, les turloughs et plusieurs forages situés à l’intérieur du bassin hydrogéologique. Des analyses hydrochimiques, des traçages d’essais et un pompage d’essai sont également prévus. Les premiers résultats montrent clairement une influence de la marée sur les eaux souterraines visible jusqu’à une distance de 2,5 kilomètres dans les terres et une intrusion d’eau de mer visible jusqu’à au moins 1 kilomètre. Ces données seront utilisées par la suite pour la création d’un modèle hydrogéologique avec le logiciel 3D HydroGeoSphere, qui utilise la méthode des éléments finis, et pour lequel diverses simulations en milieu variablement-saturé et fracturé ont déjà été réalisées avec succès.

1 Introduction

Climate change impacts such as increased flooding frequencies and sea-level rise have been observed recently in karstic areas along the Galway and Clare coasts in the west of Ireland. The Bell Harbour catchment study is the first study in Ireland focused on developing a better understanding of salinity intrusion in a karst aquifer. Bell Harbour was selected due to its small size and its boundaries fairly well defined, Drew (1990).

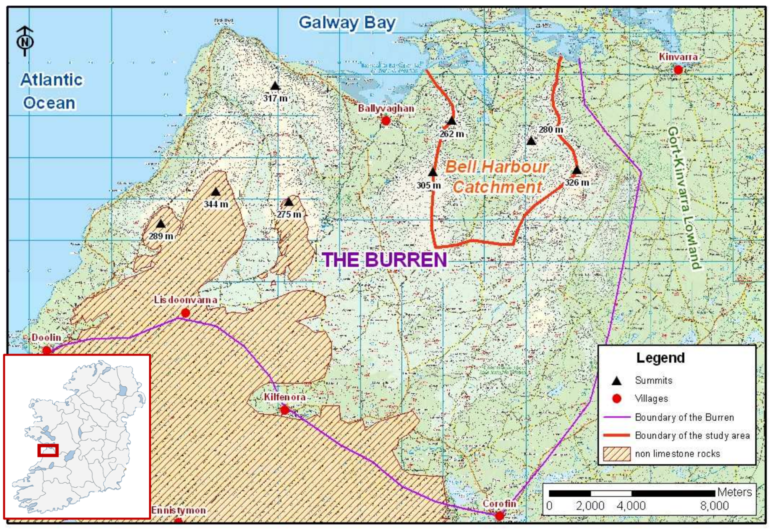

Fig. 1: location of Bell Harbour catchment

The catchment which covers an area of around 50 km^2 is located in a large karstic area called the Burren (Fig. 1) and is defined by upland areas to the west, south and east at an altitude of about 300 meters. The valley drains north to Galway Bay via Bell Harbour. The geology is dominated by massive or bedded Carboniferous limestone of several hundred meters thickness with interbedded chert, shale and dolomite horizons, all dipping gently (2-3 degrees) to the south (Fig 2). Annual precipitation averages approximately 1500 mm with an annual effective rainfall estimated at 980 mm. The rainfall

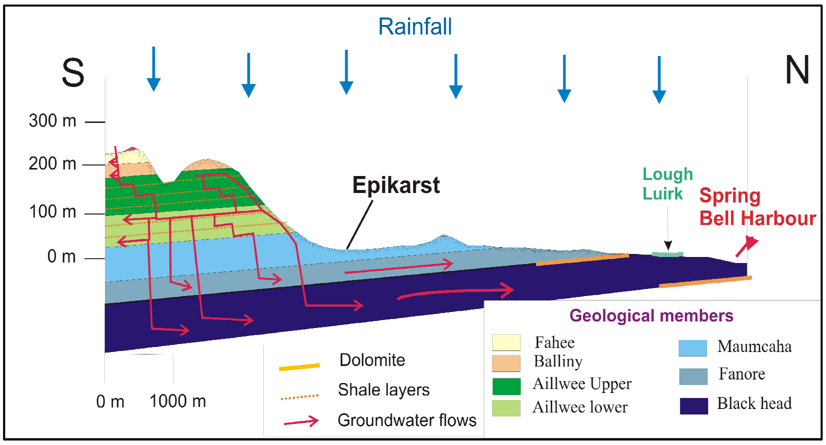

Fig. 2: hydrogeological conceptual model of the catchment.

occurs throughout the year though spring tends to be drier than other months. Recharge in the catchment is mostly diffuse due to a large area of limestone pavement and, as is typical for the region, it drains almost wholly by underground channels directly to the sea via submarine or littoral diffuse springs: five intertidal springs have been located in the eastern edge of Bell Harbour Bay (Fig. 3). The valley is characterised by an almost complete lack of surface drainage, while there are three groundwater-fed and draining seasonal lakes (turloughs), and an extensive underground drainage system whose lower portions may be affected by an intrusion of saltwater.

This salinity intrusion can be influenced spatially by the geology and the topography of the catchment as well by the location, size and shape of the conduits/fractures which carry the groundwater flows. Moreover, it may be affected temporally by the different tide cycles, the occurrence of rainfall events and the presence of turloughs.

2 Materials and methods

This project is the first detailed groundwater study to be undertaken in this catchment and detailed data collections have been completed on the field and are ongoing:

- A karst geomorphological investigation is in progress with the aim of mapping the most important land karst features of the area;
- Discharge measurements of five coastal springs with a current-meter are taken several times through all over the year;
- Water samples from thirteen boreholes, three land springs, seven marine springs, one cave and two turloughs have been collected in March 2011 for chemical analysis.
- Monthly manual measurements are underway in nine boreholes and five intertidal springs for about one year (Fig. 3): temperature and specific conductivity (spC) are taken with a YSI and water level with a dipmeter.
- Automatic loggers have been installed in five of those boreholes (B-03, B-05, B-08, B-57 and B-59), two of the coastal springs, two turloughs and in the middle of Bell Harbour Bay to get continuous measurements of temperature, spC and water level. In Situ *Aqua TROLL 200* loggers are used for boreholes and they are connected with a vented cable to take account for atmospheric pressure. This sensor can resolve pressure level to ± 0.05 % Full Scale, temperature to ±0.01oC and spC to ± 0.1 µS/cm. CTD-Divers are installed for the coastal springs; values recorded at low tide are spring flow and seawater values are recorded at high tide. A Baro-Diver installed adjacent to borehole B-05 allows the compensation of pressure measurements of the springs. These sensors can resolve pressure level to 1 cmH_20, temperature to ±0.01°C and spC to ± 0.1 µS/cm. Two SBE 37-SI MicroCAT have been ballasted at the bottom of the turloughs and two others are hung on mussel float lines in Bell Harbour at 1 and 6 m below the water surface. Pressure readings are not taken for Bell Harbour MicroCats because of tidal movement and fluctuation. This sensor can resolve pressure level to ± 0.1 m, temperature to ±0.0001oC and spC to ± 0.1 µS/cm. Data are recorded every 15 minutes for all of the sensors. An RTK GPS survey has been used to record the X, Y and Z to relate all water levels collected above Mean Sea Level (MSL).
- Water tracing tests using Fluorescein and Rhodamine WT have been completed in the spring of 2011 and additional ones are planned for autumn 2011.

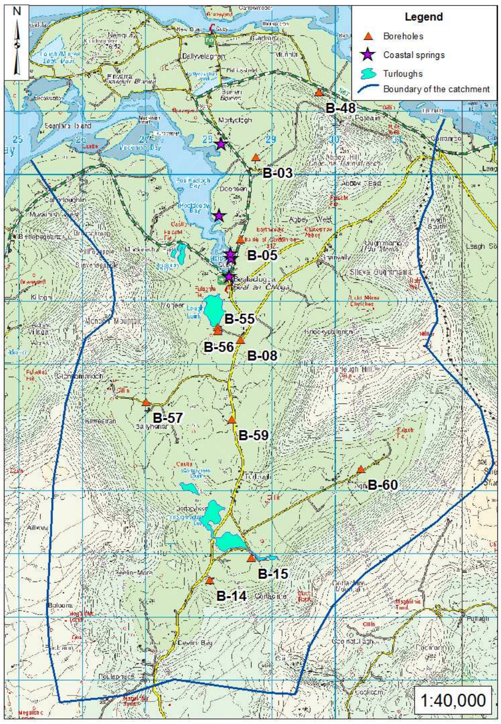

Fig. 3: location of nine boreholes, five coastal springs and several turloughs monitored into Bell Harbour catchment.

- One pumping test (step test and 72-hour test) in borehole B-59 located in the middle of the valley will be completed in May 2011.

3 Results

Firstly, the data are interpreted in the aim to understand the principal characteristics of the aquifer and especially the behaviour of the water levels from loggers installed in the boreholes with rainfall events. Secondly, the influence of the tide and the saltwater intrusion into the aquifer are analysed through all these wide sets of data. The collection of the data is still on-going but already early results can be shown.

3.1 Aquifer water level changes

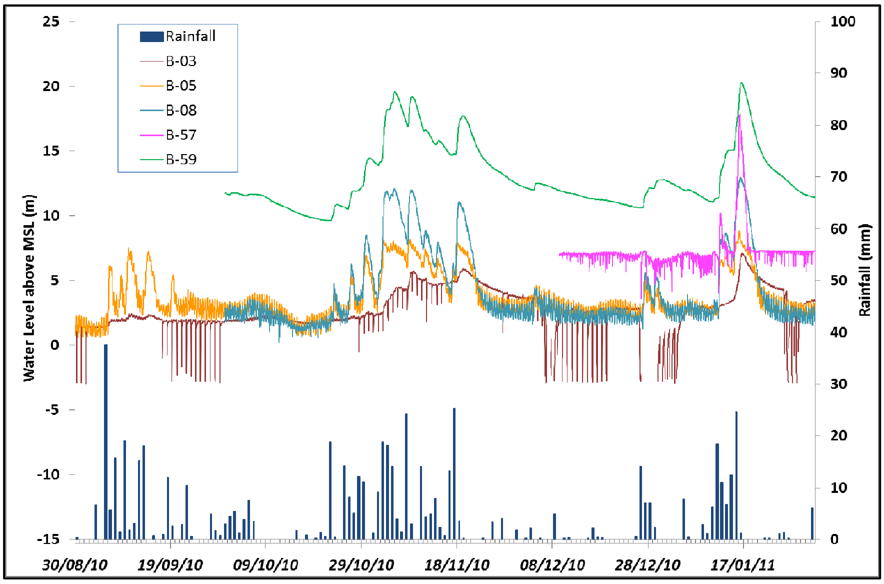

Fig. 4: water levels recorded in five boreholes plotted against rainfall (NUI Galway) from 30/08/2010 to 31/01/2011.

Continuous water level measurements in the five boreholes logged show different behaviours between them (Fig. 4). During a base flow period, boreholes B-03, B-05 and B-08, located at 1 kilometre or less of the seashore, have almost the same level (around 2 m above MSL). The base flows for water levels from boreholes B-57 and B-59 which are 2.4 kilometres from the shore in the middle of the valley, are respectively 7 m and 10 m above MSL.

Rainfall Event	**31th of October to 5th of November 2010**		**10th to 15th of January 2011**	
Intensity of rainfall	11 mm/day		13 mm/day	
Boreholes	***Amplitude***	***Delay***	***Amplitude***	***Delay***
B-03	~ 4 m	~ 48 h	~ 4 m	~ 48 h
B-05	~ 6 m	~18 h	~ 6.5 m	~24 h
B-08	~ 10 m	~ 35 h	~ 10.5 m	~ 35 h
B-57	*N/A*	*N/A*	~ 10.5 m	~ 18 h
B-59	~ 10 m	~ 43 h	~ 9 m	~ 41 h

Table 1: delay and amplitude of the water levels in the five boreholes between the first rainfall input and the maximum of water level rising for two major rainfall events.

The responses after a rainfall event are shown in Tabl. 1. Borehole B-03 is drilled in the matrix system (or in fracture system not well connected with an active conduit), as it shows slow storm responses and small rise levels for the two events. It is also affected periodically by pumping effects with a large drawdown of 5 m. B-05 shows rapid storm responses and fairly large rises in levels which means it is certainly well connected to a conduit system and the recharge reaches it rapidly. B-08, B-57 and B-59 display amplitudes of 10 m each: an important amount of groundwater transits in the valley. B-57 responds quickly, and so it assumed it is near a conduit system which is confirmed to its location close to large mapped NNE-SSW trending fault.

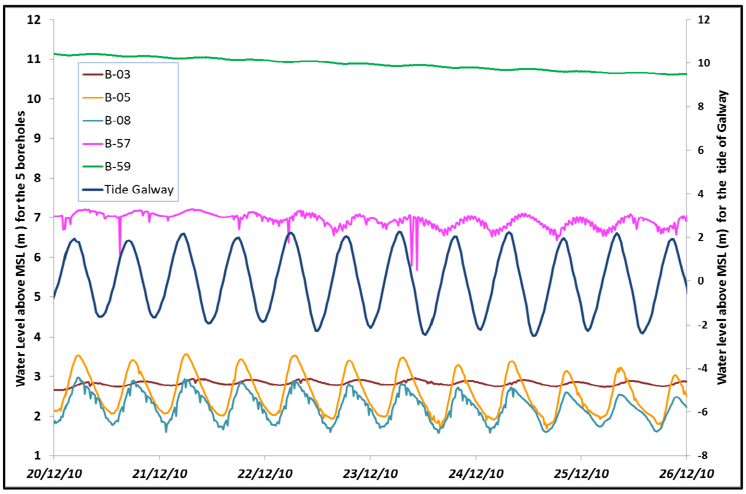

Fig. 5: tidal influences observed in water levels recorded in five boreholes from 20/12/10 to 26/12/10.

3.2 Tidal influence and seawater intrusion

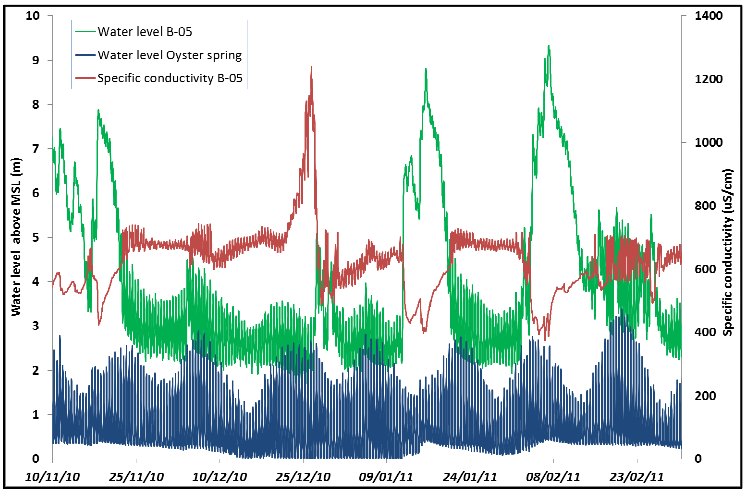

Fig. 6: water levels recorded at Oyster spring with water levels and spC of Borehole B-05 from 10/11/2010 to 02/02/2011.

Water levels recorded in the five boreholes are all influenced by the tide (Fig. 5). Their amplitudes vary from 0.04 m for water levels at B-59 to 1.4 m for water levels at B-05. The lag time observed with the Galway tide is from 1 hour at Borehole B-05 to 5.5 hours at B-59. Small variations observed in water levels of boreholes B-05, B-08 and especially in B-57 are only due to pumping effects.

SpC recorded in borehole B-05 varies with tides (Fig. 6). Fluctuations of spC are stronger during spring tides (generally varies between 60 and 110 µS/cm) than during neap tides (vary between 10 to 40 µS/cm). During base flow periods, the spC is close to 650 µS/cm and can drop to 380 µS/cm during a high rainfall event (during which the water level rises about 6.5 m). A high peak of spC (1227 µs/cm) is observed the 26/12/2010. This occurred during a spring tide and when Oyster spring was completely dry (from 13/12/2010 to 10/01/2011) and precipitation was really low (< 50 mm from 12/12/2010 to 09/01/2011). The water level was the lowest recorded (1.7 m above MSL at low tide) since August 2010 during this same period. This high peak of spC can be associated with a seawater intrusion into the aquifer which occurred during a period of low rainfall and high amplitude of tide. However, it needs to be confirmed with a longer time series data from this borehole.

4 Conclusions

The study of a karst aquifer affected by a saltwater intrusion is complex and requires large amounts of data from different sources to understand the dynamic of the saltwater-freshwater interface. The initial results presented here will be coupled with new data from pumping tests, water geochemical analyses, ongoing monitoring of water levels and spC in turloughs (which reflect local water tables).

It is anticipated that characteristics of the aquifer may be estimated using two different methods based on the logging measurements. First, a comparison of these data with the tide gauging at Galway which allows calculating of lag time and an amplitude factor will give information on the transmissivity of the aquifer, FERRIS AND BRANCH (1952). Secondly, correlation and spectral analysis may be used to better understand the spatial behaviour of the aquifer system.

Ultimately, the data will be incorporated into HydroGeoSphere, THERRIEN *et al.* (2006), a 3D finite-element model for which simulations of variably saturated fractured have been already performed successfully, GRAF & THERRIEN (2008). It is an upgraded version of the FRAC3DVS discrete fracture model where surface water simulation capabilities have been added. It can also takes account the variability-density of the groundwater flows.

Acknowledgement

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