HYDRODYNAMICS OF A COASTAL KARST AQUIFER AFFECTED BY SALTWATER INTRUSION UNDER OCEANIC CLIMATIC INFLUENCE, CO. CLARE, IRELAND

Marie Perriquet[1,2];Tiernan Henry[1];Rachel Cave[1] ;Véronique Leonardi[2] ;Hervé Jourde[2]
Marie.perriquet@univ-montp2.fr
[1]- Biogeoscience Group, Earth and Ocean Sciences, National University of Ireland, Galway, Ireland; [2]- Université de Montpellier 2 (UM2), laboratoire Hydrosciences, France
Université Montpellier 2 - HydroSciences Montpellier - Case MSE
Place Eugène Bataillon - 34095 Montpellier Cedex 5 France

Abstract. *Coastal regions in western parts of Ireland are characterized by karst aquifer systems vulnerable to the contamination of seawater. Bell Harbour catchment (~50km^2) located on the south coast of Galway Bay in County Clare has been selected for this research to better understand the freshwater/seawater interaction into the aquifer. The groundwater circulating into this catchment is drained into Bell Harbour bay via submarine springs and intertidal diffuse springs. Data (temperature, specific conductivity (SpC) and water levels) are being collected at two coastal springs, five boreholes, three lakes, and in the middle and the mouth of the bay using dedicated loggers. The control of aquifer water level and SpC by the seawater is observed visually on the boreholes data and confirmed through time series analysis: water level and SpC fluctuate with the same periodicities as the tide with some spatial difference intensities. Estimations of the groundwater volume discharging into the bay are assessed using salinity data by the method of the simple tidal prism model. These results give an evaluation of the proportion of the aquifer affected by the tidal level and an assessment of the volume of freshwater available through the year.*
Keywords: *coastal karst aquifer, tidal effect, seawater intrusion, time series analysis, submarine groundwater discharge.*

INTRODUCTION

Large karstic areas present along the Galway and Clare coasts in the west of Ireland are subject to climatic changes: increase of flooding frequencies and sea-level rise have been observed recently. The Bell Harbour catchment has been selected for developing a better understanding of the hydrodynamic of the karst aquifer because of its small size (50 km^2) and its fairly well defined boundaries and, therefore, the possibility for detection of a salinity intrusion. This research focus mainly on the relationship between the change of tidal level and groundwater chemistry, using time series analysis on data (groundwater level and specific conductivities) collected in boreholes. Also, a method to evaluate the quantity of freshwater discharging into the bay of Bell harbour from submarine and intertidal groundwater discharge (SiGD) is applied below.

1. HYDROGEOLOGICAL SETTING

1.1 Hydrogeological context

The catchment is located in a large karstic area called the Burren in County Clare and is defined by a valley which drains north to Galway Bay (via Bell Harbour bay) surrounded by upland areas to the west, south and east. The geology is dominated by massive or bedded Carboniferous limestone dipping gently 2-3 degrees to the south. Annual precipitation averages approximately 1500 mm and the rainfall is regularly distributed through the year. The groundwater from the karst aquifer discharges into the bay through intertidal and submarine springs and thus, saltwater intrusions may occur into the lowest lying part of the catchment.

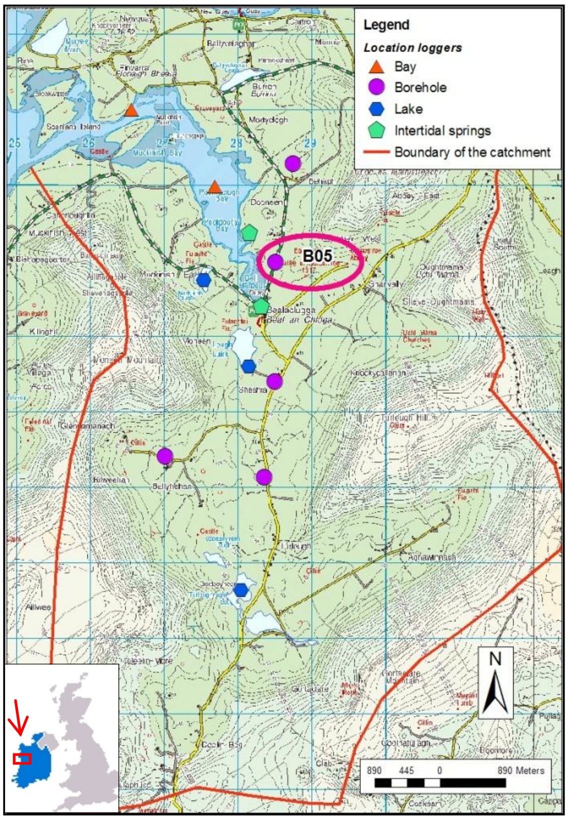

Fig. 1: Location of the loggers in Bell Harbour catchment.

1.2 Data Collection

In Situ *Aqua TROLL 200* loggers have been installed in five boreholes (B03, B05, B08, B57 and B59) and CTD-Divers are sited at three permanent or seasonal lakes and two coastal springs (fig. 1). Measurements of temperature, specific conductivity (SpC) and water level are recorded at 15 minutes intervals. The tide height provided by the Irish Marine Institute is recorded at Galway Port station at 6 minute intervals. For calculating freshwater removed on the ebb tide in Bell Harbour bay, one SBE 37-SI MicroCAT has been ballasted at the bottom of the mouth of the bay and another one is hung on mussel float lines in the middle of the bay at 1 m below the water surface (fig. 1).

Measurements of temperature and SpC are recorded at 15 minute intervals. Rainfall data used are an average of the daily data from Carran (upland) and Ballyvaughan (lowland) stations.

2. METHODS AND RESULTS

2.1 Tidal and saltwater influence: deduction of a transmissivity

Water table levels and SpC data recorded at borehole B05 (Figure 2) have been selected as an example for applying the different methods. The small high frequency fluctuations may be due to the tidal influence while the bigger ones seem to be a response to the rainfall. To assess this hypothesis, we perform cross-correlation and auto-spectral analysis. The theory and mathematical expressions of these functions can be found in Jenkins and Watts (1969) and Mangin (1984).

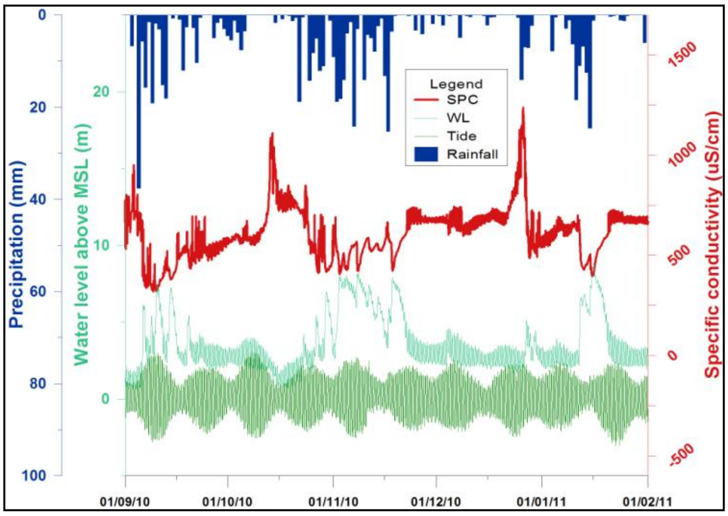

Fig. 2: Precipitation from Galway station, water level and SpC at Borehole B05 and tide from Galway port station from 1st Nov. 2010 to 1st Feb. 2011.

✓ <u>Tidal influence</u>

The auto-spectral analysis, applied on the tidal level and water level series, corresponds to change from a time mode to a frequency mode through a Fourier transformation of the auto-covariance function which projects vectors in sines and cosines. The Tuckey filter, which is a window function, has been selected and used in the power spectral density formulation to smooth the spectral estimates.

The spectrum of the tide (fig. 3 (a)) indicates three distinctive peaks at frequencies of 0.0418, 0.0807 and 0.161 cycle per hour (cph), which relate to the diurnal (23.9 h), semi-diurnal (12.4h) and quarter-diurnal (6.2h) periods, respectively. The two latter tidal components are observed clearly on the water levels at B05 which confirms the tidal influence of the water levels at B05.

✓ <u>Seawater intrusion</u>

Cross-correlation analysis was used to establish a link between the input time series (the tidal level) and the output series (water levels and SpC) and thus, estimate a delay between the two series. First, to get the real time of the tide at Bell Harbour bay, a cross-correlation analysis has been applied between the tidal level recorded at Galway Port station and the water levels from a coastal spring into Bell Harbour bay: a delay of 45 minutes was deduced.

This modified tide was then used as input with SpC and water level at B05 as output. On the cross-correlogram, a positive elapsed time indicates that SpC and water level show retardation of 1h30 and 13h30 respectively (fig. 3 (b)) compared to the change of tidal level. The difference between the two delays is natural, because of the quicker response of the transfer pressure (water level change) in comparison with the transfer of water (SpC change).

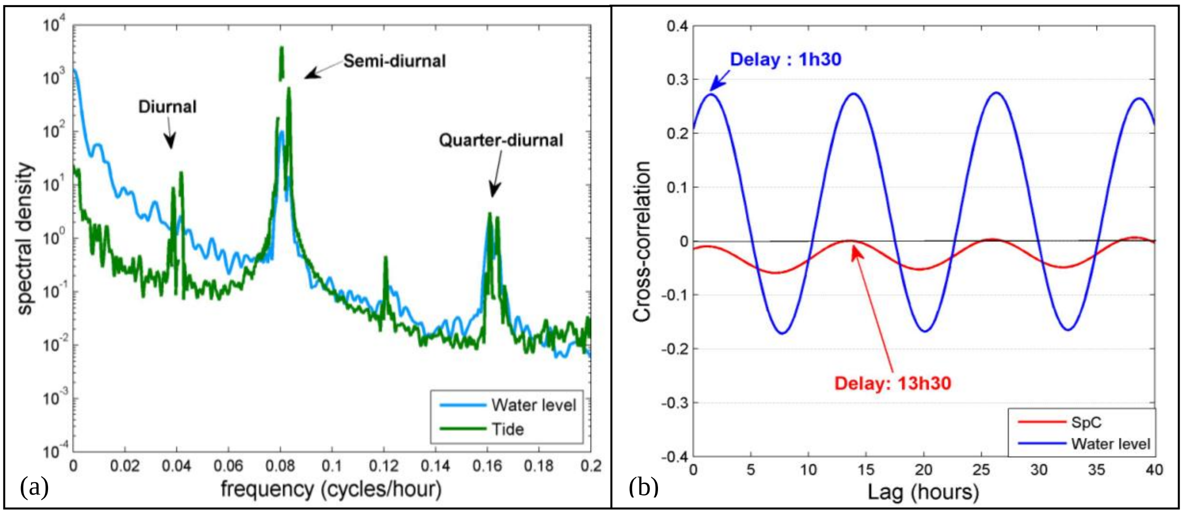

Fig. 3: Time series analysis at borehole B05: (a) auto-spectral density function for water level and the tide modified; (b) cross-correlograms for water level and SpC.

✓ <u>Transmissivity estimation</u>

The hydraulic transmissivity (T) at B05 was estimated using Ferris's method (1952), using the time lag calculated above for the groundwater level change: $T = \frac{x^2 \times S \times P}{4\pi d^2}$ where x is the distance from suboutcrop to observation well (265 m at B05), S the coefficient of storage, P the period (12h30) of a sinusoidal cycle and d the lag time (1h30). For S estimates between 2.10^{-4} and $2.5.10^{-2}$, the estimated transmissivity values range between $1{,}9.10^{-3}$ $m^2.s^{-1}$ and $2{,}8.10^{-1} m^2.s^{-1}$.

2.2 Submarine and intertidal groundwater discharge

An estimation of the groundwater volume discharging into Bell Harbour is assessed using the simple tidal prism model (Eq. 1), after Cave & Henry (2011).

$$\underbrace{1 - (S_{HW} - S_{LW})/\text{max. salinity of flood tide}}_{\text{Proportion of freshwater}} \times \underbrace{(H_{HW} - H_{LW}) \times \text{Surface Area}}_{\text{Volume of water brought out on the ebb tide}} \quad \text{Eq. 1}$$

where S_{HW}–S_{LW} and H_{HW}-H_{LW} are, respectively, the average of salinity and the difference of height between high tide and low tide. The surface area is that calculated for the bay. This formulation was applied for each tidal cycle from the 2nd December 2010 to the 31st of May

2011 (salinity data available from the Microcat located in the middle of the bay). A total volume of freshwater of $7.40.10^7$ m^3 has been assessed for all this period (6 months) with a proportion of freshwater averaged at 3.7% to total water in the bay and a freshwater discharge of 4.7 m^3/s.

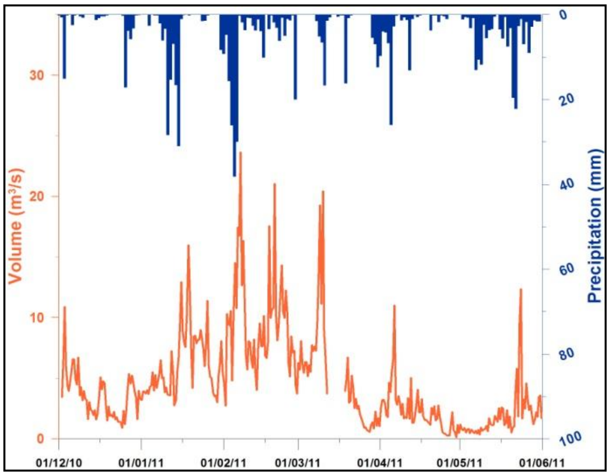

Fig.4: Volume of freshwater estimated discharging into the bay plotted with the rainfall.

3. *DISCUSSIONS AND CONCLUSIONS*

These results at borehole B05 show that tidal effect and saltwater intrusion observed on water levels and SpC data can be confirmed through time series analysis. Moreover, this tool allows calculation of a lag time of the tidal pressure transfer into the aquifer at specific location and thus, an estimation of hydraulic parameters. This method will be repeated for different boreholes in the catchment, allowing for a better understanding of the heterogeneity of the aquifer.

From use of the tidal prism method and using salinity data recorded into Bell Harbour, a volume of freshwater discharging into the bay has been estimated for a period of 6 months. This volume will be subsequently compared to the water available for runoff calculated from the precipitation of the area. This will be further assessed following the compilation of a full year of data from the loggers in the bay and precipitation.

ACKNOWLEDGEMENT

The project is based on research grant-aided by the Department of Communications, Energy and Natural Resources under the National Geoscience Programme 2007-2013.

REFERENCES

Cave, R.R. and Henry, T., 2011. Intertidal and submarine groundwater discharge on the west coast of Ireland. Estuarine, Coastal and Shelf Science, 92(3): 415-423.

Ferris, J. and Branch, G.S.G.W., 1952. Cyclic fluctuations of water level as a basis for determining aquifer transmissibility. US Dept. of the Interior, Geological Survey, Water Resources Division, Ground Water Branch.

Jenkins, G.M. and Watts, D.G., 1969. Spectral analysis and its applications. Holden-Day Series in Time Series Analysis, London: Holden-Day, 1969, 1.

Mangin, A., 1984. Pour une meilleure connaissance des systèmes hydrologiques à partir des analyses corrélatoire et spectrale. Journal of Hydrology, 67(1-4): 25-43.