GROUNDWATER FIELD MEASUREMENTS FOR STREAM SEEPAGE ESTIMATION

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Introduction

The water leakage from gravel riverbeds in high plain areas is one of the most important natural factors contributing to groundwater recharge in Veneto region (Northern Italy).

Along the Brenta river two pilot transversal ramps (permeable check dam) were built in order to reduce the downstream flooding risk and to increase the river seepage. These engineering works represented an useful opportunity to estimate the hydraulic interaction between the aquifer and the stream. In this area, in fact, the river seepage reaches very high values (4 – 5 $m^3/s \cdot km$). The aim of the study is to compare the stream seepage before and after the realization of the artificial ramps, by means of several field investigations and a groundwater monitoring activity, carried out since 2007. For this purpose, groundwater head and temperature data were used as calibration targets for numerical modeling of flow and heat transport.

Material and Methods

Boreholes and monitoring wells were drilled to obtain the geotechnical classification of sediments and the hydraulic parametrization of the unconfined aquifer. Automatic probes and level data loggers were also used to monitor temperature and pressure head both in river and in the piezometric network. The experimental dataset was therefore analyzed to build the site specific conceptual model. Numerical finite difference (FDM) and finite element (FEM) models were developed to obtain respectively the flow field distribution and heat transport simulations, concerning mixing processes of shallow water into the aquifer. In particular a transient two-dimensional groundwater model was realized to determine the equivalent hydraulic conductivity of the streambed. A specific 3D transport model was finally set up to estimate the river leakage rate, considering the thermal monitoring time series as calibration target.

Results

Field measurements confirmed that the pilot ramps realized in Brenta riverbed have locally increased the stream seepage rates. After the completion of hydraulics works persistent rises of water table (of about 4 meters) have been detected in near monitoring wells. Up to now this condition seems to be stable, after a long-term monitoring period which includes all the different phases of the hydrogeological regime.

Thermal datasets proved to be useful to validate the artificial groundwater recharge effectiveness. For example, in monitoring well Pz1, that was at first barely influenced by the stream leakage because of the greater distance from Brenta river, a marked head and temperature variation was identified after the realization of ramp S1.

The groundwater temperature resulted heavily conditioned by the streambed seepage, even in the furthest monitoring point.

The modeling process considered different saturation conditions of the gravel bed material and the hydraulic conductivity computed values well agree with borehole field tests. The computed increase of stream seepage rate related to artificial recharge in check dam S1 is about 1.0 m^3/s.

HEAD AND TEMPERATURE GW-MONITORING : ANTE / POST OPERAM COMPARISON

The site is located in the north - east of Italy (Veneto Region), about 30 km north of the city of Vicenza.

The local hydrogeology is characterized by a single unconfined unit: this is the typical structure in the entire high alluvial plain of the region.

The aquifer is composed by gravel deposits with an high hydraulic conductivity value and has a direct connection with the Brenta River, the most important stream in the basin.

In the study area the river shows a seepage behavior; the stream represents the principal natural recharge factor in terms of groundwater balance.

This study is focused in the area near the transversal ramp S1, a permeable check dam realized in Brenta streambed between October 2008 and February 2009.

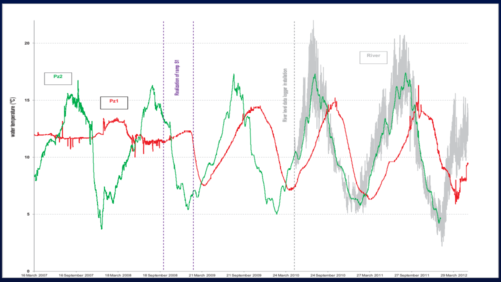
Two groundwater monitoring wells (Pz1 and Pz2) were drilled along the river banks; these points have been monitored with automatic head and temperature data loggers since March 2007. A river stage data logger has also been installed near the permeable check dam in April 2010, in order to obtain hydraulic head and temperature values of the stream.

GW-head in monitoring wells is strictly related to the Brenta river: some statistical data are useful to explain the differential recharge effects connected with the recent hydraulic works.

The temperature distribution is different: Pz2 is nearer to the streambed and the observed values revealed a direct relation with river leakage also in ante-operam period.

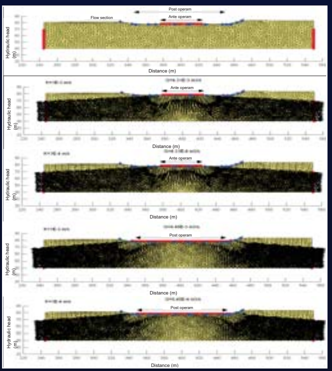
The further well Pz1 starts to show the stream seepage influence only in post-operam condition, after the realization of ramp S1.

HYDRAULIC HEAD OBSERVATIONS STATISTICS	Pz1		Pz2	
	Ante operam	Post operam	Ante operam	Post operam
min (m a.s.l.)	59.42	60.86	59.76	60.92
medium (m a.s.l.)	63.14	68.55	63.56	69.42
max (m a.s.l.)	67.64	73.78	68.90	73.80



The effects of the permeable barrier S1 consist of:
(A) - the enlargement of the leakage zone upgradient the ramp; (B) - the increasing of the streambed seepage rate.
The first aspect is confirmed by the qualitative analysis of the groundwater monitoring data series, demonstrating a clear variation in the hydrogeological regime after the realization of S1.
The leaking buffer extension reached Pz1 well, at about 500 m from the streambed, as shown by the groundwater temperature trend in this position.
To evaluate the amount of seepage discharge due to the permeable check dam, it has been necessary to use a numerical approach.

NUMERICAL MODELS RESULTS: DISCUSSION



A bidimensional finite elements numerical model, based on Richards equation (flow estimation in variable saturated porous media), was initially setup to determine the streambed leakage rate respectively in ante operam and post operam conditions.

The modeling process was based on a three steps analysis:

1) hydraulic conductivity "trial and error" evaluation, simulating river flood transient events with parameter calibration based on observed values in monitoring well;

2) hydraulic conductivity experimental evaluation in ante operam condition, using a field dataset aquired before the realization of S1 ramp;

3) seepage rate increasing value calculations.

The results have been determined for two different conductivity scenarios, in a reasonable variation range, obtaining the ante operam and post operam stream seepage rates in the modeled flow section.

The artificial specific leakage can be calculated as follows:

a) k = 1E-3 m/s → $Q_{seepage}$ = 6.45E-3 – 4.31E-3 = 2.14E-3 m^3/s

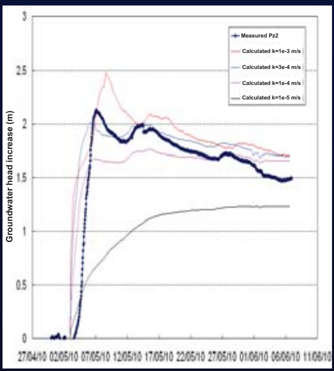
b) k = 1E-4 m/s → $Q_{seepage}$ = 6.45E-4 – 4.31E-4 = 2.14E-4 m^3/s

Multiplying these values for the dimension of the stream seepage buffer, of about 500 m, the leakage rates related to ramp S1 are:

a) k =1.0E-3 m/s → $Q_{seepage}$ =2.14E-3 • 500 = 1.07 m^3/s

b) k =1.0E-4 m/s → $Q_{seepage}$ = 2.14E-4 • 500 = 0.11 m^3/s

The first result (a) is more representative of the local hydrogeology (k_{eq}).



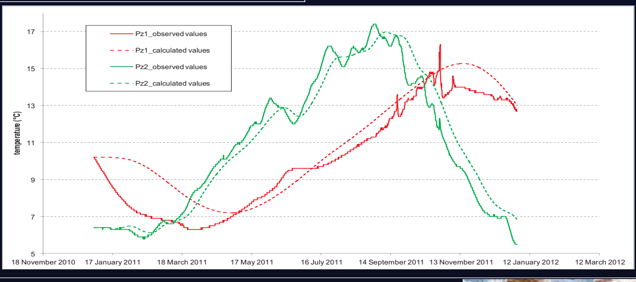
Then a 3D finite elements model, based on MODFLOW 2000 code, has been developed in order to optimize the seepage estimation in a larger domain and to simulate, as a robust calibration, the thermal trends observed in Pz1 and Pz2. This way it was possible to calculate the streambed leakage value, calibrating the flow rate from the river to the aquifer.

The mathematical model results have been also compared to previous field experiences (1972) and to the experimental discharge measures realized along some sections in the streambed with an acoustic digital current meter.

The calibration dataset referred to the thermal values collected during 2011 in Pz1 and Pz2: the streambed discharge parameter in the model area has been modified until the best fit was obtained.

The temperature of the modeled stream has been determined using field values recorded by the hydrometric station during the same period.

The final simulation considered a medium leakage discharge of 6.3 m^3/s in the whole river segment (about 1.7 km). This value is perfectly comparable with other scientific references and with the field measurements results, confirming the numerical tool validity for river seepage evaluation.



CONCLUSIONS

The purpose of this study was to provide a quantitative analysis of the complex interaction between leaking river and unconfined aquifer. An analytic approach was used during the initial stages of the work to estimate the incremental leakage rate from stream to aquifer, consequent to the realization of hydraulic works in the riverbed.

Numerical model results confirmed the field measurements of hydraulic parameters and allowed to estimate the increase of stream discharge connected to the artificial ramp S1 (about 1 m^3/s).

In the hydrographic context of the researches (braided system) the stream seepage estimation, based on groundwater measurements and performed by means of a numerical modeling approach, seems to be more representative than the experimental field sessions, conducted along stream sections with an acoustic digital current meter.

In this site, strategic because of the drinkable resources supply, long-term hydrogeological monitoring activities are planned for the next years, in order to assure the maintenance of actual vertical leakance relationship between aquifer and river.

Included in a project of compensatory actions, stream seepage estimations are aimed to support the development in the next future of new sustainable waterworks in Brenta river basin.

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