Water–budget as a tool to evaluate the sustainable use of groundwater resources (Isonzo Plain, NE Italy)

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ABSTRACT

Climate change and the necessity to preserve and provide good quality freshwater for human consumption has led researchers to study the aquifers of the Friuli Venezia Giulia Region (NE Italy) in more detail. Of particular interest is the cross-border Soča/Isonzo River, which contributed to the creation of a remarkable alluvial aquifer. Today more than 300.000 inhabitants are supplied by water withdrawals from water wells which are located in the southern part of the aforementioned aquifer. Taking into consideration the importance of this area for the inhabitants, a groundwater balance was computed also to guarantee the sustainability of the actual use of the water resource.

The sustainability of the actual use of the resource comes from the consistency and ratio between recharge and withdrawals. The more detailed and precise the input values in the water balance are, the more conscious is the management and safeguarding of this precious resource, avoiding pauperisation in terms of quantity but especially quality.

KEY WORDS: water budget, hydrogeology, Soča/Isonzo River, climate change, Italy.

INTRODUCTION

Most of the liquid freshwater resources are stored as groundwater (99%) (Bäumle & Siemon, 2017). Their regional distribution on earth is dependent on climatic conditions as well as the geology of the subsurface. Detailed knowledge of groundwater resources enables its sustainable use. In this framework, the awareness of the regional distribution of resources, the hydraulic characteristics of the aquifers as well as the regional and temporal variations of the water quantity results are fundamental in order to evaluate the amount of the resource.

As de Vries & Simmers (2002) report, in the mid-1980s, groundwater-recharge studies exploded in number. There were few studies dealing explicitly with groundwater recharge as a component of the water balance. But even if water is a circulating, naturally recharged resource, the climate system puts an upper limit on the circulation rate of available Renewable Fresh Water Resources (RFWR). Although actual world global withdrawals are below the upper limit, many people live in highly water-stressed areas because of the uneven distribution of RFWR in time and space (Corbatto et al., 2016). As reported by Oki & Kanae (2006), climate change is expected to accelerate water cycles. This means that there will be a change in seasonal patterns and a continuous increase in extreme events as testified also by the data collected and analysed by Calligaris et al. (2016) for the study area.

Whether the concept expressed by Oki & Kanae (2006) is right or wrong, a detailed study of the territories in which we live represents a preliminary insight leading to a broader knowledge, understood as a first step to the conscious use of the groundwater resource.

The Friuli Venezia Giulia Region (NE Italy) is a small territory (7.845 km²) where surface fresh waters, springs and groundwaters are abundant (fig.1) and the area is reported as the rainiest in Italy. The waters are an important natural wealth in terms of quantity, quality and ease of supply. This optimal condition, however, is thought to allow for irrational and poorly controlled exploitation. This inevitably produced tangible consequences on the water resources availability. In the last twenty years, a lowering in the phreatic groundwater levels of the High Plain and a lowering of pressure in the confined aquifers of the Low Plain has been noted (Cucchi et al., 1999; Martelli & Granati, 2010; Bezzi et al., 2016; Calligaris et al., 2016). These phenomena are accompanied by the gradual amplitude range reduction of the spring belt (Vella, 2013), resulting in a decrease of the amount of available water to the naturalness of the lowlands, in an impact on ecosystems and related loss of traditional habitats such as wet meadows.

Unless appropriate measures are taken at a regional level, the intense human pressure will probably cause the persistence or the increase of the previously described phenomena.

The recharge, the natural runoff and groundwater exploitation rates have also to be known in light of a sustainable groundwater management.

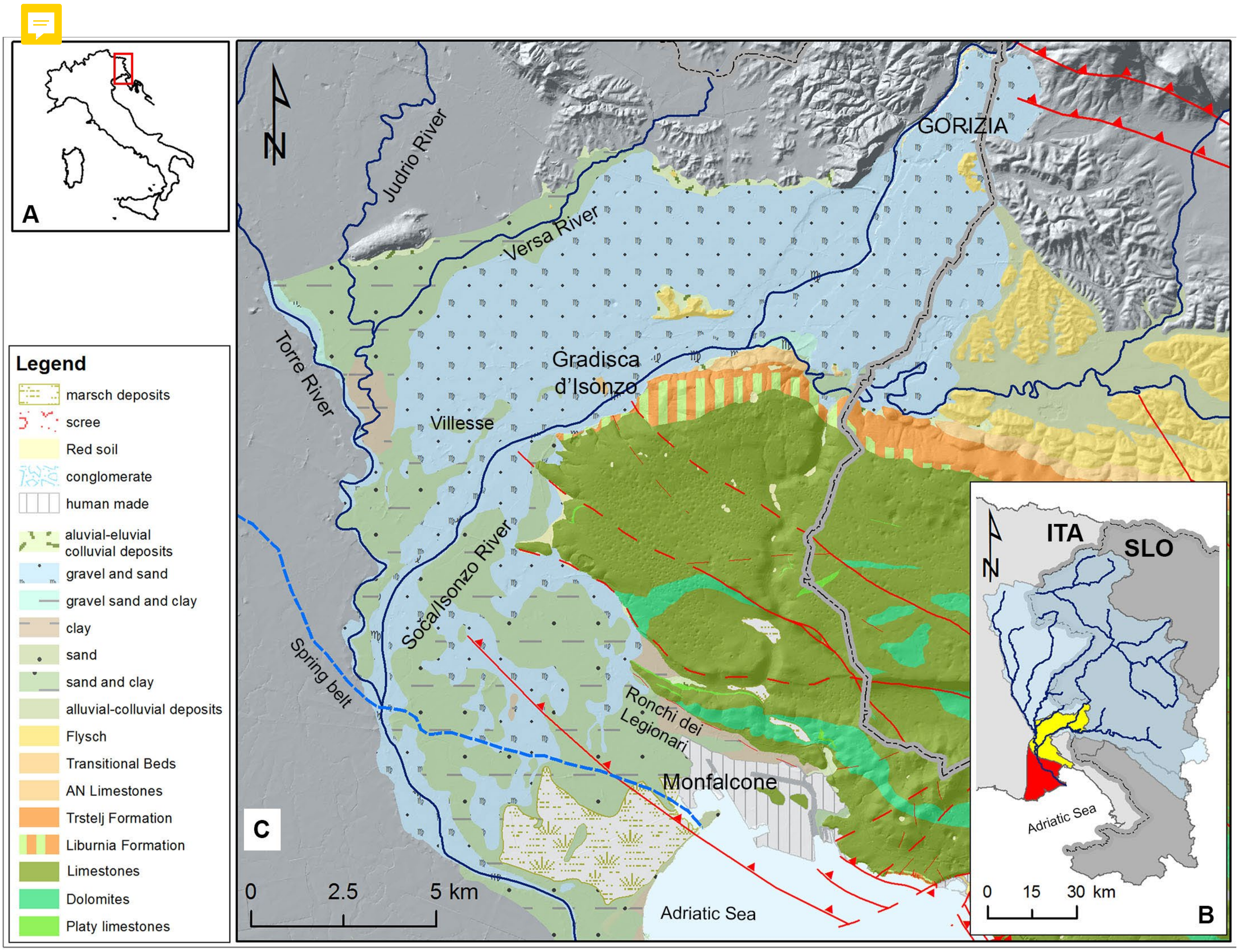

Fig. 1. - Study area location and geological map (C). A) Overview of the Italian peninsula and the location of the study area in the red rectangle; B) In pale blue the Soča/Isonzo cross-border watershed. In bright colours, the Groundwater bodies used to compute the water budget. The High Plain in yellow and the Low Plain in red.

GEOLOGICAL AND HYDROGEOLOGICAL SETTING

The Soča/Isonzo Plain is located in the north-eastern corner of Italy, on the eastern side of the Friuli Venezia Giulia Region bordering Slovenia (Fig. 1).

The karst spring of the Soča/Isonzo River originates under the glaciated Julian Alps in Slovenia. The river crosses the Italian border after a path of about 100 km, flowing into the Adriatic Sea. It is the second largest river of the region. Its average annual discharge, measured at the entrance in Italy (Solkan gauging station, SLO) was estimated to be 90 m^3/s (Bat et al., 2008; Siché & Arnaud-Fassetta, 2014), the average discharge at the river mouth is estimated to be about 170 m^3/s.

The plain area, subject of the present study, is the result of a significant sediment transport which occurred during the Quaternary. It is enough to consider the period after the Wùrmian glacial age when from the frontal side of the alpine glacier, the glacial outlets flowed, modifying the environment and building up the actual morphology (Venturini, 2003). The Soča/Isonzo River modified its flow path. During the Roman age it flowed bordering the Karst hydrostructure near the small town of Ronchi dei Legionari. During the Middle Ages, that river branch was abandoned and the river moved to its current location (Venturini, 2003).

Quaternary deposits forming the plain are characterised by a variable thickness: from 100 m in a depression sited S of Gorizia, up to 350 m in the Villesse area (Treu et al., 2017). The thickness gradually decreases towards the NE at the border with Slovenia where it is between 20 - 30 m (Zini et al., 2011).

These deposits are characterised by the presence of an extensive alluvial unconfined aquifer, which evolves southward into a multi-layered confined/semiconfined aquifer. The aquifers greatly differ from a textural viewpoint: the northern part of the plain, the so-called High Plain (fig.1, in yellow), is more gravelly, while the Low Plain (Fig. 1, in red) in the southern part, mainly consists of finer deposits sizing from gravel to sand and silty-sand. From the ground level to the pre-Quaternary bedrock, six aquifer systems are recognised and referred to using a letter of the alphabet.

Aquifer A, generally positioned between 10 m and 40 m b.s.l., is widely present in the Low Plain and is characterised by permeable layers from sandy to sandy-gravelly deposits. Their total thickness is around 30 m.

Aquifer B is a permeable gravelly and sandy layer, fairly constant with the top at about 70/80 m ~~depth~~ b.s.l. with an average thickness of 15 m.

Aquifer C can be identified at depths of around 110 m b.s.l. and consists of mainly sandy permeable layers with an average thickness of 15 m.

Aquifer D is made up of a set of thin layers (sandy-gravelly deposits). The top of this system stands at about 140 b.s.l., with an average thickness of about 10 m.

Aquifer E is an interval consisting of clean and coarse gravel in the northern part shifting into gravel with sand and silt to the south with a thickness of only few meters. It is not always continuous with a top identifiable at approximately 180 m b.s.l.

Aquifer F is made up of a set of different permeable complex levels of gravelly-sand deposits. The top of this system is present at 190 m b.s.l. The average thickness is about 15 m.

In the Low Plain a shallow and not continuous phreatic aquifer is also present.

Slovene waters flowing in the Soča/Isonzo mountain basin recharge the river. Prior to its course reaching the Italian border its flow is intercepted by the Solkan dam. Once in Italy, the Soča/Isonzo waters contribute to the aquifer recharge which, in turn, also partially contribute to the recharge of the Classical Karst hydrostructure with about 10 m^3/s (Zini et al., 2013a).

METHODOLOGICAL APPROACH

WELL WITHDRAWALS

To obtain the budget in non-natural conditions, the groundwater withdrawals were evaluated for each type of use and for each aquifer system. Data were analysed starting from 2 Geodatabase: one for the domestic use, not subject to withdrawal license referred to as “domestic withdrawals” (1077 wells and 4244 estimated users in the High Plain, and 2068 wells and 7345 estimated users in the confined aquifers of the Low Plain) and one concerning industrial, agricultural, fish breeding, hygienic, geothermal and other minor uses, referred to as “licensed withdrawals”, instead subjected to a required license for withdrawing. The domestic withdrawals were estimated based on the number of declared wells and the number of people supplied (ISTAT, 2001), while the “licenced well” withdrawals were estimated based on the real water consumption recorded via ~~the~~ counter meters.

The well withdrawal amounts were evaluated on an annual basis and are expressed as m^3/s. The withdrawal quantity is calculated for the year 2016 (which is considered to be a mean year).

In the High Plain, considering the use of 290 l/d for a single person, there is a withdrawal of 0.01 m^3/s for domestic use from the phreatic aquifer. The total licensed withdrawal amount was calculated to be 0.70 m^3/s with a prevalence for the use of drinking water (42%) industrial uses (34%) and the agricultural requirements (8%) (tab. 1).

In the Low Plain, downstream from the spring belt, most part of the withdrawals are related to a shallow aquifer system (A+B) with a withdrawal volume of about 2.60 m^3/s (1.11 m^3/s licensed and 1.49 m^3/s domestic) mainly due to domestic (57%) and drinking (29%) uses over the others.

In the Aquifer C system, the domestic withdrawals are few, only 0.02 m^3/s, 6% of the total amount in that aquifer system compared to that for drinking water (which reaches 0.49 m^3/s, the 94%). Increasing the depth, the situation is similar, from D to F. In these deep aquifers, 81% of the waters are used for drinking, and the rest is used for other purposes. These numbers are linked to the good quality waters present in these aquifers and to the withdrawals due to the water supply systems for drinking purposes.

Analysing the quantities, from the phreatic aquifer of the High Plain there is a total withdrawn volume of water of 0.71 m^3/s. The amount of water withdrawn from the system of aquifers in the Low Plain is instead of 3.95 m^3/s (tab 1).

TABLE 1

Withdrawals in [m3/s] calculated for the phreatic and confined aquifers of the High and Low Plain.

	Licensed withdrawals [m3/s]	Domestic withdrawals [m3/s]	TOTAL
High Plain Phreatic aquifer	0,70	0,01	0,71
Low Plain Phreatic aquifer	0,16	0,00	0,16
Low Plain confined A+B	1,11	1,49	3,95
Low Plain confined C	0,49	0,02	
Low Plain deep aquifers	0,72	0,12	

WATER HYDROGEOLOGICAL BUDGET

The considerable water withdrawals and the rapid deterioration of the groundwaters have highlighted the necessity for an assessment of its sustainable consumption and future use. In order to complete this assessment, hydrogeological balance can be considered a useful tool in the evaluation of available resources.

The orography of the study area is extremely favourable for the computation of the water budget, being a bounded basin with limited water sharing. To compute the budget, we used the groundwater bodies defined in the plain areas according to the hydrogeological provinces (Cucchi et al., 2008) based on the hydrogeological and geochemical characteristics of the groundwaters (Fig. 1B, the High Plain in yellow and the Low Plain in red).

The budget was computed solving the equation $P=ET+R+I$ on a 500 m regular grid.

The terms of the equation are respectively:

P, which represents the precipitation;
ET, which is the crop evapotranspiration;
R, being the run-off;
I, which is the effective infiltration.

To compute the budget, well withdrawals in the phreatic and confined aquifers must be subtracted.

In the budget computation, the precipitation amount (P) was summarised using the daily rainfall data; the process of snow accumulation and snow melting was taken into account.

The evapotranspiration (ET) was quantified as "crop evapotranspiration" and calculated using the two step approach as a product between reference evapotranspiration, calculated using a modified Hargreaves-Samani formula (Hargreaves, 1994; Allen et al., 1998; Carobin, 2008) and crop coefficient (Kc). The formula was chosen according to the results obtained by Carobin (2008) which modified the Hergaves-Samani formula to obtain results similar to that of the Penman-Montheith FAO-56 formula. The Hergaves-Samani was site-specific calibrated to reduce overestimation.

The run - off component (R) was calculated using the curve number methodology modified by Kannan et al. (2008) for continuous analysis.

The effective infiltration was calculated subtracting from P, R and ET seeing that the data regarding the soil characteristics were not always available and homogeneously distributed over the territory. We assumed I=0 in case of negative values.

RESULTS

For the Judrio and Versa rivers, the mountain basin discharge was calculated to be 7.6 m^3/s taking into consideration the run-off and the effective infiltration. During the wet months, 90% of the discharge infiltrates, while during the dry season all the waters infiltrate and the riverbed is dry. For this reason, the infiltration was calculated on a monthly basis and then summed obtaining a value of 7.4 m^3/s.

For the Soča/Isonzo River basin, run-off (R) and infiltration (I) not being available, we used the total river discharge. For the reconstruction of the discharges and leakages we used data coming from several hydrological and hydrogeological surveys carried out in the framework of the ITA-SLO 2007-2013 Camis Project (A.A.V.V., 2015). The main difficulties in measuring the discharge were due to the hydropicking at the Solkan dam (SLO), which seldom allows for discharge measurement in stationary conditions. The subsequent elaboration of the H/Q rating curve had to take into account the changing discharge effect (with the same hydrometric stage, the river can show different discharges) and the derivations for agricultural purposes.

These effects were overcome thanks to the huge amount of measurements made and a multi-section approach (4 discharge sections along 14 km of river flow):

- different single measurements (not contemporary through different sections) were done in different hydrologic conditions (about 40 measures per section);
- continuous discharge measurements (1 discharge measure every 30 minutes for a 4-5 hour hydropeaking cycle) during hydropeaking were carried for entire loading/unloading cycles and for different cycles. According to the river base flow, the cycle generally starts at discharges of 30-40 m^3/s (base flow) up to 120-140 m^3/s (peak discharge);
- during the stationary phases, contemporary discharge measurements (1 measure per section every hour, for 5-6 hours) were carried out in correspondence of cross-sections spaced 5 to 10 km apart.

The result was the evaluation of a mean daily discharge river for the 2014-2016 period. The mean annual discharge was found to be 141 m^3/s for the 2014, 55 m^3/s during 2015 and 101 m^3/s in 2016. The differences in the resulted river discharges are in agreement with the differences in the precipitation regime recorded in the mountain basin during the study period.

The reliability of the discharge measures corresponds to the 5% of the measured discharge (referred to a single measure which is the mean of 4 values), which is due to the limit of the instrument and to the measurement and validation approach.

The river leakages were also defined thanks to:

- contemporary flow rate measurements in different but close river sections (2-3 km away one from each other);
- the drilling of 6 piezometers in 2 different backswamps of the flood plain where the water level, temperature and electrical conductivity were measured continuously.

The natural variations of these parameters, jointly with the grain size analyses and the geophysical investigations, allowed for the estimation of the quantities of the Soča/Isonzo leakages as 0.2 $m^3/s/km$ during low flow conditions up to 1.6 $m^3/s/km$ during high flow conditions (Casagrande & Avon, 2016).

The approach with discharge measurements on close sections and the computation of the average monthly discharge rate at the sections, confirmed the magnitude of the leakages which corresponds to the estimation of 15% of the annual discharge measured at Gorizia.

For the Vipacco River, as for the Soča/Isonzo, the available discharges measured at Miren, close to the ITA-SLO border, were used in order to estimate the value of the leakages which were considered to be 10% of the measured discharge.

For the Torre River, discharge values were available in the regional archives (Regione Autonoma Friuli Venezia Giulia, 2012) and an infiltration value was calculated to be 1.3 m^3/s.

For the High Plain area, the effective infiltration (I) was 3.6 m^3/s, to which the contribution of the irrigation return flow (0.5 m^3/s) was added.

In order to compute the groundwater balance from all the input which contributes to the High Plain it is necessary to subtract the waters which contribute to the recharge of the karst hydrostructure valued at 10.0 m^3/s. The number corresponds to the discharge measured at the Timavo springs area in low flow conditions (after a very dry period) when it has been demonstrated (Doctor, 2008; Zini et al., 2013b) that the drained waters are mainly due to the leakage from the Soča/Isonzo River which, in turn, recharges the western part of the Classical Karst.

In the High Plain area, it is necessary to subtract the component due to the discharge in correspondence with the spring belt, estimated at around 16.0 m^3/s (Zini et al., 2011).

Only a modest amount of water remains (3.4 m^3/s) to recharge the systems of aquifers of the Low Plain once all the withdrawals have been subtracted. To this volume, we added the contribution to the recharge coming from the karst aquifer (estimated at about 1.0 m³/s), proven by the presence of springs bordering the karst hydrostructure in contact with the alluvial plain (in the Ronchi dei Legionari area). When these numbers are applied the balance is positive, with a value of 0.5 m³/s (Fig. 2).

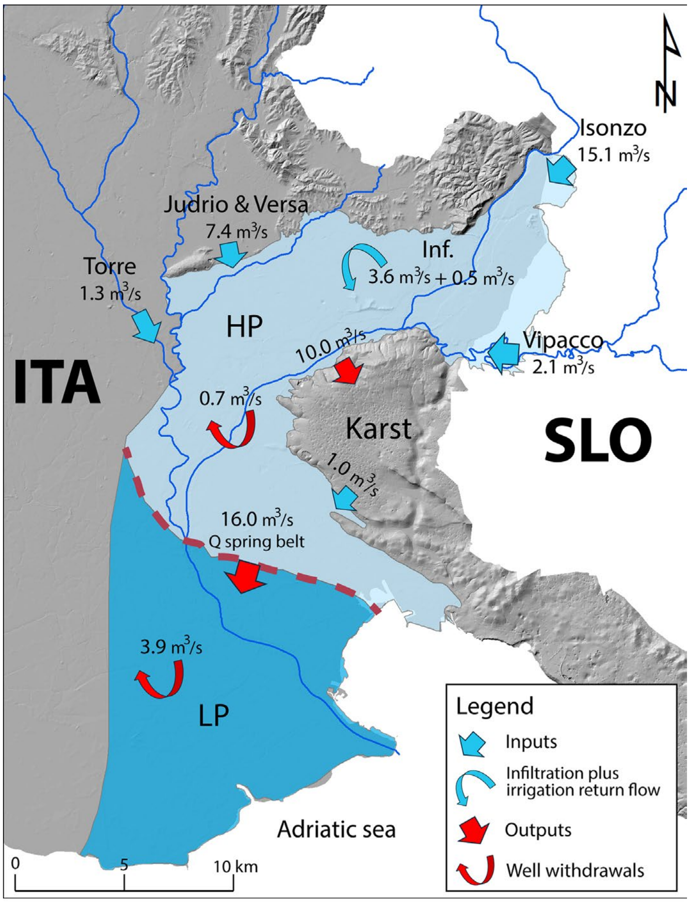

Fig. 2. - Groundwater budget computed in the Soča/Isonzo Plain. HP is the High Plain, LP is the Low Plain. All the numbers have been rounded to a single digit after the decimal.

CONCLUSIONS

The proof of the sustainable use of the resource derives from the congruity between recharge and withdrawals, whereas discharge measured in correspondence with the spring belt is an indirect indicator of the balance of the system. Its decrease could dramatically compromise these delicate wet ecosystems with an irreparable loss of the present environment.

At the current state of knowledge of the study site, it is possible to assert that the groundwater budget indicates that the balance is fragile. The calculated values are the expression of detailed work carried out over years in order to reduce uncertainties (Zini et al., 2011; Cucchi et al., 2015). The discharge values measured have an accuracy of +/-5%, due to the methodological approach, the validation of the measures and the limits of the instruments used. The uncertainty of the input received from the karst is mainly due to two factors: the discharge estimation (Gemiti, 1984; Casagrande, 2015) and the current lack of knowledge regarding the submerged springs discharge which has been well estimated (Gemiti, 1984; Gemiti 1995) but never measured. These considerations adduce to a+/-5-10% of uncertainty to add to the final water balance which means that in a world where climate change is a reality with periods of very dry seasons which alternate with extremely wet periods, the priority is to continue to measure all the factors which contribute to the balance in order to guarantee the ~~sustainability~~ of the water resource for present and future generations.

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