Water hydrogeological balance in the FVG Plain

CHIARA CALLIGARIS[1], FRANCO CUCCHI[1], ALBERTO DEANA[2], FRANCESCO TREU[1], ENRICO ZAVAGNO[1], LUCA ZINI[1], DANIELA IERVOLINO[2] & FEDERICA LIPPI[2]

1 *Geoscience Department, Trieste University, via Weiss, 2 - Trieste, Italy*
calligar@units.it; cucchi@units.it, franzaldo@libero.it, cutizav@alice.it, zini@units.it

2 *Servizio Idraulica, Regione Friuli Venezia Giulia, via Giulia, 78 – Trieste, Italy*
alberto.deana@regione.fvg.it, daniela.iervolino@regione.fvg.it, federica.lippi@regione.fvg.it

Abstract One of the objectives of the European Directive 2000/60 and the Legislative Decree 152/06 is the sustainability of water-balance in a reference area with the aim of protecting water resources. Thorough verification of the water-balance it will be possible to obtain the consumption sustainable water value and, together with other protective measures planned, the achievement of environmental quality. The constantly increasing water demand for human consumptions and the constant use of water resources induced to study deeply the Friuli Venezia Giulia Plain (north eastern part of Italy) where all the water resources of the Region are stored. The aim of the present research is to realize a water-balance in order to understand the amount of the water resource and its use. To reach this aim, the Geosciences Department from Trieste University has been engaged by the Hydraulic Survey of the FVG Region in order to coordinate an integrated study finalized to the Friuli Venezia Giulia Plain confined and unconfined aquifer geometries reconstruction and to provide guide-lines for water rational exploitation (Agreement D.G.R. n. 1827 dd. 27.07.2007). Water-balance means the comparison between the water resources (available or obtainable) in the reference area. In order to define water consumption, 2 Data Base: one for the domestic use (47709 extimated water-wells), and the other one for all the other uses (7930 water-wells) have been analyzed. Domestic, potable, agricultural, industrial, hygienic and sanitary, fish breeding and geothermal uses have been considered. Precipitation, evapotraspiration, runoff, infiltration and river discharge were used to obtain input and output water values from the regional system. As result, the High Plain recharge from the mountain basins in the Friuli Venezia Giulia Plain are abundant (233,5 m^3/s) but the water extractions become consistent if summarizing the values from the High Plain and the Low Plain (59,3 m^3/s). The balance is critical, some waters are really old and precious (19.000 LGM years old – Cucchi et al., 2008), water table is subsiding 0,1-0,4 m/yr (Cucchi et al., 1999), the pressure of the confined aquifers is dropping and this imply a different policy geared towards a conscious use of the resource.
Keywords aquifer; hydrogeology; Friuli Venezia Giulia

HYDROGEOLOGICAL CONTEST

The Friuli Venezia Giulia Plain extends south Carnic and Giulian Prealps between Livenza and Isonzo Rivers (Fig 1). The powerful thickness of sediments composing the plain are mainly Quaternary, with a bedrock, near Latisana, more than 600m depth rising gradually to the east (reaches -250m in Grado) where rises sharply towards the north joining with the slopes of the Carnian and Giulian Prealps. From a hydrogeological point of view, it is possible to divide the entire plain into two parts: the High Plain and the Low Plain separated from the resurgence belt, a narrow band WNW-ESE oriented from the base of Cansiglio, until Timavo. In the underground of the High Plain, characterized by a high permeability, a phreatic continuous aquifer is recognized that gradually reaches the surface while approaching the resurgence belt. This is due to the permeability decreasing of the deposits. In the Low Plain, enclosed in aquitard or aquiclude layers, has been recognized a dozen artesian aquifers of which the deepest are spas characterized. The phreatic aquifer in the High Plain, is characterized by loose coarse deposits. Deep wells highlighted the presence, about 100m below ground level, of mainly conglomeratic deposits, fractured, containing water up to considerable depth. There are still few wells that draw from these levels apparently confined and distinct by the overlying water table; for this reason, at present, does not seem to be necessary to distinguish, in the High Plain, artesian groundwater from the phreatic ones.

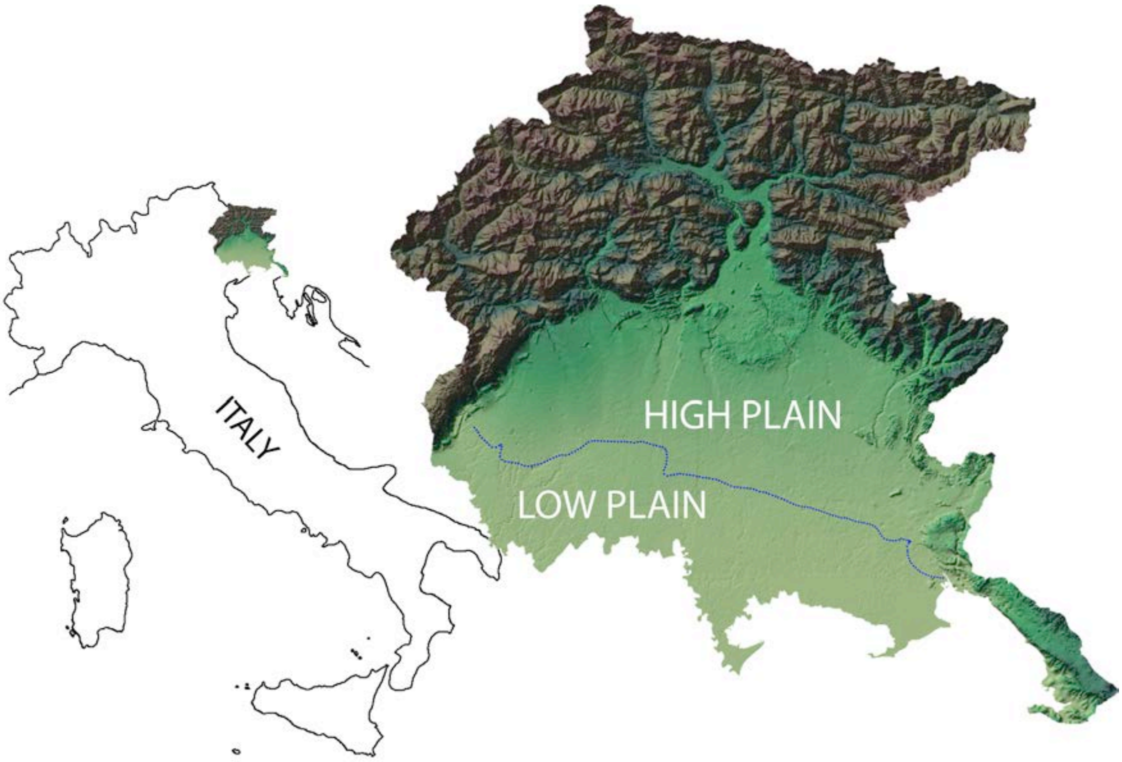

Fig 1 Location of the investigated area.

The supply processes for the phreatic aquifer of the High Plain, crucially depend from the major losses occurring along the gravely riverbeds at the mouth in the plain, while the precipitations cover a much more modest role. Unquantifiable, but certainly important are surely also the contributions due to the buried relief. Moving south towards, the phreatic aquifer joins in a complex layered aquifer characterized by gravel-sand deposits variously interspersed with clay ones more frequent and more powerful. In almost all the Low Plain, wherever outcrop discontinuously gravelly-sandy horizons, at shallow depth from the ground level, is present a sort of suspended aquifer that has some relevance for issues related to land (use, pollution, etc.).

The adopted scheme to describe the subsoil of the Low Friuli Plain, requires the presence of seven “cold” artesian aquifers (designated as A, B, C, D, E, F, G in the direction of increasing depth) between 10 and 400 m deep, and, as known at the time, four aquifers affected by geothermal water (called H, I, L and M).

The aquifer A, generally positioned between 30 and 80 m from ground level, is always present. It is contained in enough permeable layers from sandy to sandy-gravelly deposits. The thickness of the horizons sometimes has value even higher than 10 m, but more often the aquifer is variously divided into weak permeable horizons intercalated by clay-silt impermeable layers with a medium thickness of 10 m.

The aquifer B, is a permeable gravelly (northern areas) and sandy (southern areas) interval, fairly constant at about 80-100 m depth from ground level. The average thickness of this

system is about 15m.
The C aquifer, while developing unevenly, is positioned on average deep between 110 and 135 m from the ground level and is well developed in the area close to the lagoon and in the behind zone. The average thickness of this interval is about 5-7 m. Sometimes, though not uniformly in the investigated territory, are clearly distinguishable two permeable horizons referred to as “C high” and “C low”.
The aquifer D is a set of thin permeable layers made by predominantly sandy-gravelly deposits, which are generally divided in two main groupings often clearly visible, interpreted as aquifers “D high” and “D low”. This system stands at a depth indicative of 150-175 m from ground level and the two levels succeed one from another a few meters up and then join in a single layer indistinct at high permeability, thus forming a hydraulic complex circuit locally intercom.The named range “D high” has an average thickness of 10 m, while the thickness of "D Low", if present, is about 8-10 m.
The E aquifer is a permeable interval consisting of clean and coarse gravel passing to gravel with sand and silt in the southern part. The average thickness is less than 10 m. The top of the permeable E aquifer is approximately 180 m below the ground level.
F aquifer is constituted by a set of different permeable complex levels of gravelly-sand deposits, sometimes cemented, interbedded discontinuously by thin layers of silt and clay. This system stands at a depth of 220-260 m from the ground level.
The G system consists of sandy intervals, sometimes with gravel or with weakly cemented sands. The top is about 270-290 m depth from the ground level.
The H aquifer is located below a clay-silt thick and continuous aquitard in the Low Plain and it is one of the most thin gravel level, sometimes weakly cemented containing a percentage of sand. It is possible to distinguish two permeable horizons called “high H” and “low H” having an average thickness of 15 m and positioned between 320 and 370 m from the ground level.
Regarding the deeper aquifers, the available informations are scarce and discontinuous, and this does not allow realizing a full characterization: they are freshwaters aquifer with a strong thermal component (>25°C).
The aquifer I is at a depth ranging from 450 to more than 490 m and is mainly contained in sandy and discontinuous lenticular bodies. Sometimes the deposits are sandy-gravelly present in weakly cemented sand and cemented Pliocene deposits. This aquifer has a discontinuous thickness that varies widely from 5 to 15 m.
The aquifer L is located in a low range of sandstone cement or sand cement from Tortonian Fm., whose top is detected at depths exceeding 500 m to about 540 m. The thickness varies between 10 and 30 m and it is recognized only along the Tagliamento River.
The aquifer M consists of sand deposits inside the Sup. Miocene, the top of this system can be roughly placed at depths exceeding 590 m.

WATER RESOURCES, USES AND CONSUMPTIONS: COMPARISON AND SUSTAINABILITY

In the present paper we try to quantify the total water resources available in Friuli Venezia Giulia considering the components of flow (effective precipitation) and runoff (surface runoff and infiltration). To compare the available water resources with the estimated consumption is necessary to aggregate the results by creating a conceptual model of physical reality. The scheme has been realized dividing the FVG Region into five homogeneous areas: the mountains, High Plain (Tagliamento in right and left) and Low Plain (Tagliamento in right and left) as shown in Fig 2. The five macro-areas can be compared to communicating tanks: the mountain groundwater supplies through direct contributions or through the dispersion of the rivers the High Plain which, in turns, supports both resurgences belt and aquifers in the Low Plain (Servizio Idraulica, Regione Friuli Venezia Giulia, 2010).

Fig 2 Friuli Venezia Giulia Region divided into five homogeneous macro-areas: in orange the mountain areas, in different blue the High Plain and in different green the Low Plain.

The variables used are:

$\mathbf{R_M}$: ***Mountain recharge*** – the computation was made from effective precipitation consisting in the contribute of precipitation (P) subtracting the evapotraspiration component (ET) assuming that all the mountain contribute to recharge the High Plain. In the case of the Cellina mountain basin, the discharge has been reduced subtracting the ones coming from Ravedis used for hydroelectric purposes. The total amount of the available water is 233,5 m^3/s.

$\mathbf{R_{AP}}$: ***High Plain recharge*** – is calculated as the sum of the mountain recharge ($\mathbf{R_M}$) and the effective precipitation insisting on the High Plain. The total amount of the available water is 294 m^3/s.

$\mathbf{Q_S}$: ***discharge of the resurgence belt*** – All the discharges of the several rivers flowing in the High Plain summed with the resurgence ones have been evaluated at the resurgence belt (AA.VV., 1982). The total discharge is 227 m^3/s.

$\mathbf{R_{BP}}$: ***Low Plain recharge*** – the effective precipitation (26 m^3/s) on the Low Plain is recharging only the phreatic unconfined aquifer and not the confined one (multistrata artesian aquifer system).

For the present paper, were estimated the total of withdrawal points present on the territory of Friuli Venezia Giulia Region (55639 water-wells). The results obtained are expressed in Table 1 (Fig 3) where is possible to appreciate the withdrawals calculated for every single aquifer. The total withdrawal amount is 59,342 m^3/s. Of this total 10,22 m^3/s are due to Low Plain unconfined aquifer. The comparison between water availability and withdrawals plus river discharges is 66,5 m^3/s that is an estimation of the consumption. The difference between the consumption value calculated as withdrawals and the one obtained through the water balance permit to evaluate the withdrawals value in Portogruaro area (SW of FVG Low Plain). For this zone there are not enough data to estimate the withdrawals but what can be obtained is comparable with the consumptions of the closer northern territories (about 20 m^3/s).
The increasing withdrawals tend to decrease the resurgence belt discharge, and in an idea of sustainable development, this is not acceptable. It is instead necessary to pay attention not to undermine the superficial hydraulic system in the respect of the available resources.

AQUIFERS	WHITDRAWALS	
	[Mm^3/year]	[m^3/s]
FAP	226.7	7.187
FBP	322.3	10.219
A	918.1	29.097
B	156.9	4.973
C	38.3	1.213
D	84.8	2.689
E	77.4	2.453
F	21.2	0.673
G	10.5	0.332
Ha	2.8	0.088
Hb	4.4	0.140
I	3.2	0.102
L	0.7	0.023
M	0.5	0.015
ND	2.0	0.063
ND deep confined	2.3	0.074
TOTAL	1872.1	59.342

Table 1 Withdrawals divided for single aquifer.

RESULTS AND DISCUSSION

From the realized analysis, it is clearly evident how the current use of the artesian aquifers in the Low Plain is not sustainable in the long run; this fact, however, was highlighted by progressive lowering of the phreatic aquifer of the High Plain, loss of pressure by the artesian aquifers and by the advances of the resurgence belt with a consequent loss of traditional habitats such as wet meadows (Cucchi et al., 1999). This situation is even more pronounced in the Low Plain in the right side of Tagliamento River, where besides the usual recourse to domestic gushing wells, recharge from the Cellina basin, derived for hydroelectric purposes, is returned only downstream the resurgence belt and thus did not contribute any more to recharge the aquifer in the Low Plain. The enormous artesian aquifer withdrawals also cause more recalls from the High Plain waters, that as is known, is very vulnerable to pollutants, particularly areas in left and right Tagliamento are subjected to significant contamination by nitrates and herbicides. This clearly implies a depletion of artesian aquifers not only in quantitative but also qualitative, fact that is more relevant seen that the withdrawn water is used for drinkable purposes. To increase the risk of mixing water from the deeper artesian aquifers with the shallow ones contributes also the gradual increase in depth of the new drilled wells and therefore the number of potentially interconnected aquifers. The prevalent uses of artesian aquifers in the Low Plain are in order: domestic, fish breeding and agricultural. With regard to water saving in agriculture, much has been achieved or is planned to be a structural point in areas managed by Consortium of drainage (conversion of irrigation systems from scroll to rain), while still so few has been done to raise awareness of the farmer to the choice of crops that does not need too match water for a more conscious use of water resources. It is also desirable that the saved water due to the increased efficiency of the equipment is properly "reinvested" to improve the ecological status of rivers and to balance the water budget by reducing groundwater extraction for irrigation and streamlining the irrigation system if not present. Emblematic is the case of fish breeding along the resurgence rivers: such systems were born to take advantage of the abundant and excellent water quality resurgent. Over the years the discharge of these rivers has been reduced and it was noted a deterioration in quality, forcing the operators of these facilities to drill new wells to offset the decrease in both scale and qualitative. Today, the drawing from groundwater for fish breeding use is equal to 11.7 m^3/s on a total of 494 wells. It is therefore necessary a rationalization of water use through the use of oxygenators and also limiting the discharge withdrawn in order to limit the withdrawal to the real requirements.

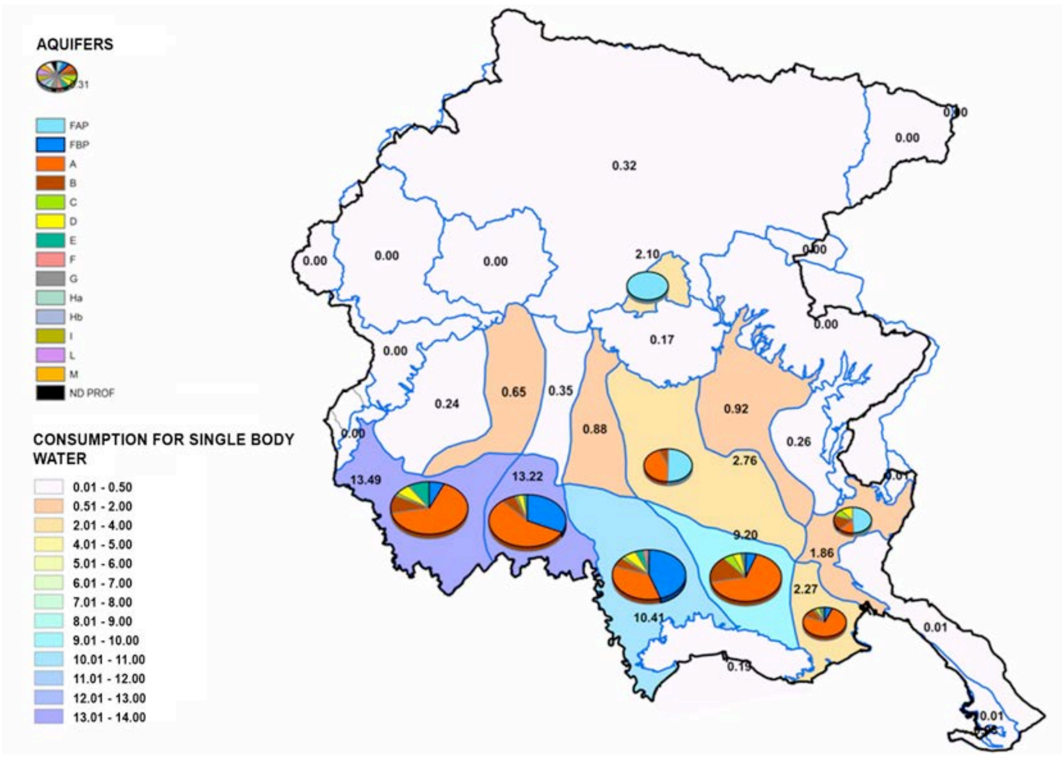

Fig 3 Water withdrawals divided on single different body water. Diagrams are on logarithmic scale.

Finally, with regard to the domestic use, the analysis concludes that the water taken from private wells is 51.88 %, according to estimates, withdrawn from groundwater. This value is over three times, in the best assumptions, of the amount allocated for aqueduct purposes. While, therefore, fountains and sinks in the Lower Plain have been part of the landscape forever and culture of our region, it is necessary to reflect on the sustainability of this use and how it is processed in time. Even if the domestic use, is already the case for other types of use, should be limited to the actual needs and therefore each well must be equipped with a device for regulating/restricting the discharge.

REFERENCES

AA.VV. (1982). Studio per la determinazione del bilancio idrologico dell'alta pianura friulana compresa tra i fiumi Isonzo e Tagliamento (High Friuli Plain water balance calculated between Isonzo and Tagliamento Rivers). *Report no. 2641, Consorzio di Bonifica Ledra Tagliamento.* 1-45.

Cucchi F., Massari G., Oberti S. (1999) Water table fluctuations in the northern Friuli Plain. *Gortania. Vol.* ***21****, 39–51.*

Cucchi F., Franceschini G., Zini L. (2008) Hydrogeochemical investigations and groundwater provinces of the Friuli Venezia Giulia Plain aquifers, northeastern Italy. *Env.Geol. Res.* ***55****, 985-999.*

Servizio Idraulica, Regione Friuli Venezia Giulia (2010) Piano Regionale di Tutela delle Acque, Allegato 1 alla Relazione istruttoria: Bilancio Idrogeologico. [Online] Available from: http://www.regione.fvg.it/rafvg/export/sites/default/RAFVG/AT9/ARG1/Foglia20/allegati/allegato1_bilancio.pdf [Accessed 3rd June 2010].