

## Groundwater sustainability in the Friuli Plain

*La sostenibilità dell'utilizzo delle acque sotterranee nella pianura friulana*Luca ZINI<sup>a</sup>, Chiara CALLIGARIS<sup>a</sup> , Francesco TREU<sup>b1</sup>, Enrico ZAVAGNO<sup>c2</sup>, Daniela IERVOLINO<sup>d</sup>, Federica LIPPI<sup>d</sup><sup>a</sup> Dipartimento di Matematica e Geoscienze - Università degli Studi di Trieste - email: [zini@units.it](mailto:zini@units.it); email  : [calligar@units.it](mailto:calligar@units.it)<sup>b</sup> Geologo libero professionista, Via Mazzini, 12 - 33017 Tarcento (UD), Italy - email: [franzaldo@libero.it](mailto:franzaldo@libero.it)<sup>c</sup> IC Meduna Cosa Arzino, Via Roma, 12A - 33090 Travesio, Italy - email: [enrico.zavagno@gmail.com](mailto:enrico.zavagno@gmail.com)<sup>d</sup> Servizio gestione risorse idriche-Regione Autonoma Friuli Venezia Giulia, Via Sant'Anastasio 3 - 34132 Trieste, Italy- email: [daniela.iervolino@regione.fvg.it](mailto:daniela.iervolino@regione.fvg.it); [federica.lippi@regione.fvg.it](mailto:federica.lippi@regione.fvg.it)<sup>1</sup> Francesco Treu was working at Dipartimento di matematica e Geoscienze University of Trieste at the time of the study presented in this paper.<sup>2</sup> Enrico Zavagno was working at Dipartimento di matematica e Geoscienze University of Trieste at the time of the study presented in this paper.

**Publication Note** - This paper has been published previously (DOI 10.4409/Am-058-13-0051), in the international journal "AQUA mundi". AQUA mundi closed in 2015 and published papers officially disappeared, being available only in secondary, personal or organizations' repositories. However, the contents of this paper are still considered of interest for readers, who suggested that Acque Sotterranee - Italian Journal of Groundwater reprint it, so here it is republished in its original form, with minor updates limited to references and data, provided in footnotes.

## ARTICLE INFO

Ricevuto/Received: 04 April 2013

Accettato/Accepted: 07 May 2013

Pubblicato online/Published online:

30 August/2013

Ripubblicato online/Republished online:

30 September 2023

## Citation:

Zini, L., Calligaris, C., Treu, F., Zavagno E., Iervolino, D., Lippi, F. (2023) Groundwater sustainability in the Friuli Plain. *Acque Sotterranee - Italian Journal of Groundwater*, 12(3), 77 - 92  
<https://doi.org/10.7343/as-2023-713>

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**Keywords:** groundwater, sustainability, water-budget, Friuli Venezia Giulia Plain.

**Parole chiave:** acque sotterranee, sostenibilità, bilancio idrogeologico, pianura della regione Friuli Venezia Giulia

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## Abstract

Groundwater resources in the Friuli Venezia Giulia (FVG) Region (northeast Italy) are an important natural wealth in terms of quantity, quality and ease of supply. This optimal condition, however, has long believed that it allowed an irrational and uncontrolled exploitation that inevitably produced tangible consequences on the water resources availability. The goal of the present research is the evaluation of the sustainable use of the groundwater in the Friuli Venezia Giulia Region aimed at providing guide-lines for its rational use. The study area belongs to the hydrogeological basin of the Friuli Plain and includes part of Veneto Region and Slovenia. The plain area is divided in two parts: the High Plain (HP) characterized by a phreatic aquifer and the Low Plain (LP) where eleven confined aquifer systems were identified. The two physiographic zones are separated by the spring belt. In order to evaluate the groundwater availability, a 3D model of the Low Friuli Plain aquifer systems was realized using Rockworks R14 software, starting from 603 lithostratigraphic wells data. Isobath and isopach maps were elaborated using kriging geostatistical method. Precipitation, evapotranspiration, runoff and infiltration were calculated to evaluate the inflow and outflow groundwater budget terms (109 rainfall and 46 thermometric stations, time series 1979-2008). To better define the river influences and the outflows at sea, a series of recent surveys on river discharges and surface withdrawals were considered. To obtain the water-budget in non-natural conditions, as the currents, were taken into account the groundwater withdrawals that were evaluated for each type of use and for each aquifer systems, starting from 2 geodatabases: one for the domestic uses (50101 estimated wells) and one for the industrial, agricultural, fish breeding, hygienic, geothermal and other minor uses (7594 wells). Well withdrawals amount were evaluated on annual base for recent periods and expressed as  $m^3/s$ . The total current estimated groundwater withdrawals reach  $62.4 m^3/s$ , of which  $41.1 m^3/s$  from the confined aquifer systems in the LP area. More than 52% of the withdrawals are due to the domestic wells. For the water-budget, the studied territory was considered a "semi-closed box" in which groundwater sharings with the neighboring areas are not relevant and where the recharge is mainly due to the influent character of the river, infiltration, rainfall and irrigation practices. As result, the water-budget for the confined LP is equal to  $+2.6 m^3/s$  representing the accuracy, fairly acceptable for the scale of the research. Withdrawal entity, spring belt discharge, phreatic levels and confined aquifer's pressure are closely interdependent and in dynamic equilibrium. The sustainability comes from the consistency and ratio between recharge and withdrawals. The confined aquifer withdrawals in the LP represent the 23.1% of the groundwater recharge coming from the HP and the 30.6% of the spring belt discharge. Seen that this last one can not further decrease, unless loss of important ecosystems, is likely to think that the present situation can be defined of limit equilibrium.

## Riassunto

Le risorse idriche sotterranee della Regione Friuli Venezia Giulia (Italia nord-orientale) rappresentano un'importante ricchezza naturale in termini di quantità, qualità e facilità di approvvigionamento. Questa condizione ottimale, tuttavia, ha consentito uno sfruttamento irrazionale e incontrollato che ha inevitabilmente prodotto tangibili conseguenze sulla disponibilità della risorsa stessa. L'obiettivo della presente ricerca è quello di valutare la sostenibilità dell'attuale utilizzo delle acque sotterranee regionali, al fine di fornire delle linee guida che ne permettano uno sfruttamento razionale. L'area di studio appartiene al bacino idrogeologico della Pianura Friulana e comprende parte della Regione Veneto e della Slovenia. La pianura è suddivisa in due parti: l'Alta Pianura a nord, caratterizzata dalla presenza di un acquifero freatico e la Bassa Pianura, più a sud, dove sono stati identificati undici sistemi di acquiferi confinati. Le due zone fisiografiche sono separate dalla fascia delle risorgive. Al fine di valutare la disponibilità delle risorse idriche sotterranee, a partire da 603 litostratigrafie corrispondenti ad altrettanti pozzi, è stato possibile realizzare un modello 3D dei sistemi di acquiferi della Bassa Pianura Friulana. Il modello è stato realizzato utilizzando il software Rockworks R14. Le mappe delle isobate e delle isopache relative a ciascun singolo acquifero, sono state elaborate utilizzando l'interpolatore *kriging*. I dati di 109 stazioni pluviometriche e 46 termometriche disponibili per l'arco temporale 1979-2008, hanno permesso di stimare l'entità delle precipitazioni, dell'evapotraspirazione, del deflusso e dell'infiltrazione e quindi di determinare il bilancio idrogeologico.

Per definire accuratamente gli apporti derivanti dalle aste fluviali e torrentizie, nonché i deflussi verso mare, si sono integrati i dati storici con i risultati delle recenti campagne di indagini, tenendo in considerazione anche i prelievi superficiali. Per ottenere il bilancio idrogeologico in condizioni non naturali, come quelle attuali, si sono presi in considerazione anche i prelievi da pozzo e ne è stata quantificata l'entità. Le tecniche di calcolo adottate hanno fornito le aliquote dei volumi emunti pertinenti ad ogni sistema di acquiferi e a ciascuna tipologia di utilizzo delle acque e quindi hanno consentito la stima dei "tempi di esaurimento" della riserva idrica di ogni singolo sistema di acquiferi. I prelievi sono stati calcolati a partire da 2 geodatabase distinti: uno inerente gli usi domestici (50101 pozzi stimati) e un secondo inerente gli usi industriali, agricoli, di allevamento ittico, igienici, geotermici e altri usi minori (7594 pozzi).

I prelievi da pozzo sono stati valutati su base annuale ed espressi in  $\text{m}^3/\text{s}$ . I prelievi totali di acqua sotterranea attualmente stimati raggiungono i  $62,4 \text{ m}^3/\text{s}$ , di cui  $41,1 \text{ m}^3/\text{s}$  prelevati dai sistemi acquiferi confinati della Bassa Pianura. Oltre il 52% dei prelievi è dovuto ai pozzi domestici. Per il bilancio idrogeologico, il territorio è stato suddiviso in settori paragonabili a serbatoi intercomunicanti: i bacini montani alimentano, tramite apporti sotterranei diretti oppure attraverso le dispersioni dei corsi d'acqua, l'Alta Pianura che, a sua volta, alimenta sia la fascia delle risorgive sia i sistemi di acquiferi artesiani della Bassa Pianura. Premesso ciò, il bilancio per la Bassa Pianura è risultato essere pari a  $+2,6 \text{ m}^3/\text{s}$ , valore nei limiti di un'accuratezza accettabile per la scala della ricerca svolta.

L'entità dei prelievi, la portata della fascia delle risorgive, i livelli freatici e la pressione degli acquiferi confinati sono strettamente interdipendenti e in equilibrio dinamico tra loro. La sostenibilità deriva dalla coerenza e dal rapporto tra ricarica e prelievi. I prelievi dagli acquiferi confinati nella Bassa Pianura rappresentano il 23,1% della ricarica delle acque sotterranee provenienti dall'Alta Pianura e il 30,6% della portata della fascia delle risorgive. Considerato che quest'ultima non può ulteriormente diminuire, a meno di perdite di importanti ecosistemi, si può pensare che la situazione attuale possa essere definita di equilibrio limite.

## Introduction

Groundwater resources in the Friuli Venezia Giulia Region (northeast Italy) are an important natural wealth in terms of quantity, quality and ease of supply. This optimal condition, however, has long been believed that it allowed an irrational and uncontrolled exploitation. This inevitably produced tangible consequences on the water resources availability. Since ten years ago, has been noted a lowering in the phreatic groundwater levels of the HP and a lowering of pressure in the confined aquifers of the LP. These phenomena are accompanied by the gradual amplitude range reduction of the spring belt, resulting in a decrease of the amount of available water to the naturalness of the lowlands, its impact on ecosystems and related loss of traditional habitats such as wet meadows. In light of this, it is easy to predict that, unless appropriate measures will be taken at a regional level, the intense human pressure will cause the persistence, if not the increase, of the just described phenomena.

The goal of the presented research is the evaluation of groundwater sustainability in the Friuli Venezia Giulia Region aimed at providing guide-lines for rational exploitation.

One of the objectives of the European Directive 2000/60 and the Legislative Decree 152/06 is the sustainable use of groundwater resources that needs to guarantee its maintenance avoiding the overuse and the depletion preserving the natural environment. In this framework, the water-balance become a tool to obtain the consumption sustainable water value and, together with other protective planned measures, the achievement of environmental quality (Alley et al., 1999). And so, the proper management of the groundwater goes through an accurate knowledge of the parameters involved in the balance: the inputs (recharge) and outputs (pumpage and natural discharges) (Alley et al., 1999; Elsheikh Abdalla E. M. et al., 2009; Sophocleous, 2005).

For this reason, a deep investigation into the groundwaters of the Friuli Venezia Giulia Region has been realized (Zini et al., 2011).

Human activities and the gradually increasing necessity of waters, for industrial, hydroelectricity, agricultural, farming and household purposes have produced inevitably tangible impacts on the quantity and quality of groundwater availability.

Although, on a global scale, the situation can be considered not yet alarming, even if are increasingly frequent reports of water pollution and increasingly manifest indicators of the progressive groundwater depletion. In light of this, it is easy to predict that unless appropriate measures will be taken at the regional level, the intense human pressure will cause the persistence, if not the increase, of the phenomena so far claimed. It is indisputable fact that any well withdrawals have now created a disruption of the normal cycle, the natural way of flow and the groundwater residence time.

To worsen the situation contribute also the considerable river discharges captured for hydroelectric and irrigation purposes, subtracted from the mountain basins and returned back to the river courses only downstream the spring belt

causing a depletion in the active recharge of the HP and indirectly of the LP. In this context the knowledge of the water volume amounts subtracted to the normal water cycle assumes a higher importance.

Closely regarding groundwaters, the knowledge of the well withdrawal's amount and the type of uses is necessary not only to support and verify the water-budget but also for the evaluation of anthropic pressures on aquifer systems, the identification of the local critical situations and, in the different areas, the assessment of the withdrawals sustainability and the identification of current usage patterns to derive useful guidelines for the optimal water uses. This is even truer in the Friuli Venezia Giulia Region, where well withdrawals dissolve a significant amount of groundwater and now constitute the regulating force of groundwater flow.

They, moreover, are currently the only reliable and predictable outflow from the confined aquifer systems in the LP. In fact there is a data lack concerning significant losses into the sea while, at the state of knowledge, it is not possible to quantify meaningful shearing among neighboring aquifer systems.

With this very simple schematization the withdrawals amount from the confined systems can indirectly be an evaluation of the mean recharge from the aquifers of the HP.

Other parameters of strategic interest, closely related to withdrawals, are represented by the ratio of withdrawal volumes and availability of groundwater and by the prevailing water uses. The first is an excellent indicator of sustainability able to provide information on the degree of water renewals. The type of use, however, is very useful for the identification of the critical sectors and future rationalization of the different water uses.

In order to characterize the aquifer systems of the Friuli Plain, the researchers of the Trieste University in jointly with the functionaries of the Hydraulic and Geological Surveys of the Friuli Venezia Giulia Region collaborated towards a GIS implementation as collector of information concerning the wells drilled in the region. This GIS can be considered a strategic tool to preserve the sustainability of the actual activities (Alley et al, 1999; Zini et al., 2011). During the three years project, were input in the geodatabases data concerning technical characteristics (as litho-stratigraphies, screens...) and uses (well discharges, type of uses, pumping rates). The homogenization, validation and data entry, guaranteed a geodatabase with 57,914 water wells and geognostic investigations. All these data were later used to evaluate the water-budget in order to define the groundwater sustainability in the Friuli Venezia Giulia Plain.

## Hydrogeological Settings

The study area, located in the north eastern side of Italy, belongs to the hydrogeological basin of the Friuli Plain and includes part of Veneto Region and Slovenia. It extends from the Alps to N, to the Adriatic coastline to S, bounded by the Livenza River to the W and the Isonzo River watershed to the E. From N to S is possible to find the Mountain Basins, the HP and the LP up to the Adriatic Sea and the Classical Karst

(Fig. 1). The surface and groundwater flow directions mainly are from N to S. The HP is characterized by a phreatic aquifer, while the LP consists of several confined aquifer systems. The two physiographic zones are divided by the spring belt, that represent a kind of “overflow” for the HP into the LP.

The mountain part presents very complex characteristics from the lithologic and structural point of view (Carulli et al., 1980; Carulli, 2006). To North, along the border with Austria, mainly outcrops the more ancient Palaeozoic units where clastic lithotypes (claystones, marls, sandstones often in facies of Flysch) are prevailing on the platform carbonate lithotypes weakly metamorphosed.

The central part is characterized by Mesozoic sediments as calcareous and dolomitic rocks. In the piedmont belt considered as the connector between mountains and plains, are mainly present the Flysch silico-clastic lithotypes, the Cenozoic Molasse and the moraine amphitheatre of the Tagliamento River.

The Friuli Plain extends south Carnic and Giulian Prealps between Livenza and Isonzo Rivers and the Classical Karst. Administratively it mainly belongs to Friuli Venezia Giulia Region and only the western south is part of Veneto Region. It represents the eastern edge of the Po Valley Plain, although its characteristics must be considered marginal compared to the evolution of the latter being characterized by greater steepness and coarser sediments. Its highest elevation is about 250 m a.s.l., on a north-south length of about 90 km (Antonelli et al., 1981).

Quaternary sediments are widely present in the Plain reaching thickness, near Latisana, of more than 600 m gradually decreasing towards east till 250 m near Grado (Cimolino et al., 2010; Della Vedova et al., 2008; Nicolich et al., 2004). From a hydrogeological point of view, it is possible to divide the entire Plain into two parts: the HP and the LP divided by the spring belt, a narrow band WNW-ESE oriented from the base of Cellina-Meduna watershed, until Classical Karst. In this area the waters emerge through a myriad of springs that give rise to a series of rivers. Its amplitude is in the order of several hundred meters, variable in space and time as a function of the water power supply conditions.

In the HP, characterized by a high permeability of the loose coarse deposits, a phreatic continuous aquifer is recognized that gradually reaches the surface while approaching the spring belt.

During the year the water table excursions are very different from place to place: from the lowest values reached along the southern side of the spring belt with few meters of oscillation, it switches to more than 50 meters close to the pre-Alpine mountains arc (Cucchi et al., 1999).

Moving towards the LP, the phreatic aquifer joins in a complex layered aquifer systems characterized by gravel-sand deposits variously interspersed with clay and silt increasingly frequent and powerful. In almost all the LP wherever outcrop discontinuously gravelly-sandy horizons, at shallow depth, is present a discontinuous phreatic aquifer that has some relevance for the issues related to land (use, pollution, etc.).

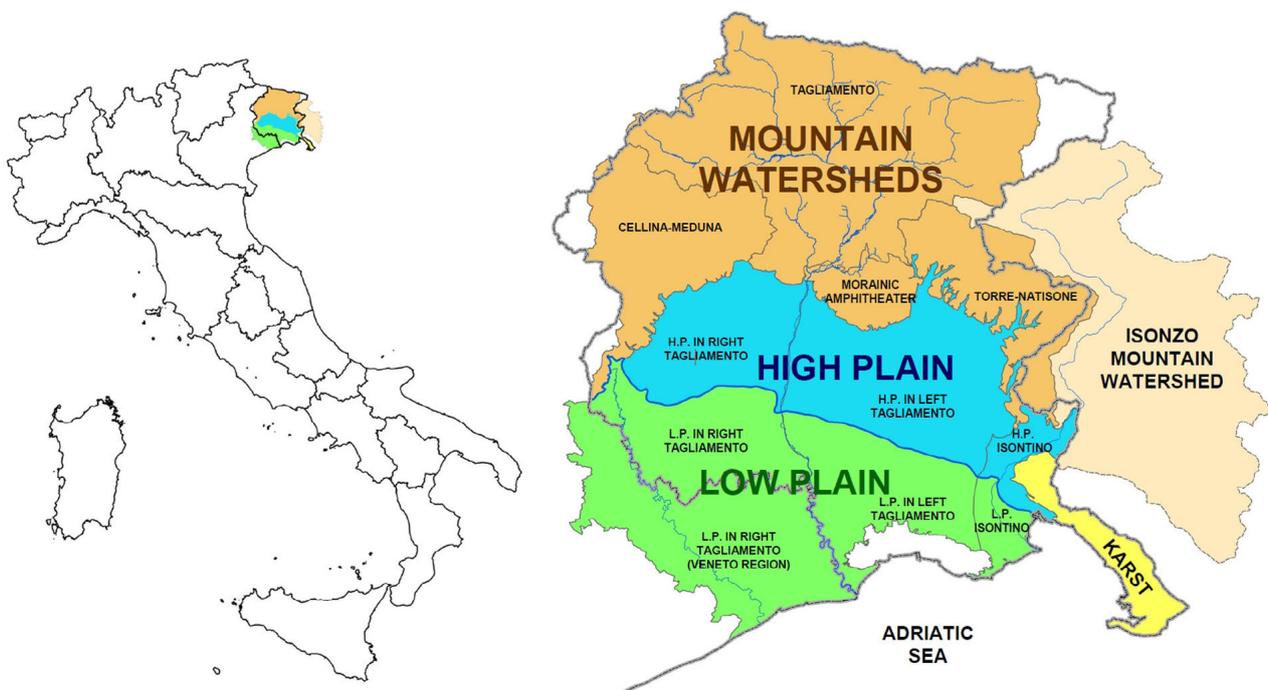


Fig. 1: Location of the study area and the main physiographic units. In light brown and in sandy colour the mountain watersheds and the Isonzo River one, in light blue the HP, in light green the LP; these last two are divided by the spring belt (blue). In yellow the Karst area.

Fig. 1: Ubicazione dell'area di studio e delle principali unità fisiografiche. In marrone chiaro e in color sabbia i bacini idrografici montani compreso quello del fiume Isonzo, in azzurro l'Alta Pianura, in verde chiaro la Bassa Pianura; queste ultime due sono divise dalla fascia delle risorgive (blu). In giallo il Carso Classico.

Here, enclosed in aquitard or aquiclude layers have been recognized eleven confined aquifer systems of which the deeper have a geothermal character (Stefanini et al., 1976; Stefanini et al., 1977a, 1977b; Stefanini, 1978). To describe the subsoil of the Low Friuli Plain, has been adopted a scheme which provides the presence of seven “cold” confined aquifer systems (designated as A, B, C, D, E, F, G in the direction of increasing depth) between 10 and 400 m of depth, and, as known at the time, four aquifer systems characterized by geothermal waters (called H, I, L and M) (Cucchi et al., 2008a, 2008b; Della Vedova et al., 1994; Martelli et al., 2007a, 2007b; Martelli et al., 2010; Nicolich et al., 2008; Stefanini et al., 1976; Stefanini et al., 1977a, 1977b; Stefanini, 1978; Stefanini et al., 1978).

## Materials and Methods

In order to evaluate the groundwater amount, a 3D model of the Low Friuli Plain aquifer systems was realized using Rockworks R14 software, starting from 603 lithostratigraphic well data, chosen among 3258 available and seismic sections. Isobath and isopach maps were elaborated too, using kriging as geostatistical interpolation method.

Precipitation, evapotranspiration, runoff and infiltration were calculated to evaluate the inflow and outflow groundwater budget terms, using data recorded by 109 rainfall and 46 thermometric stations during 1979-2008. For the precipitations the interpolating algorithms Natural Neighbor was used, instead for the temperatures experimental elevation gradients were used. The evapotranspiration was quantified as “crop evapotranspiration” calculated with the two-step approach. The surface runoff was defined using the Curve Number methodology modified by Williams. To better define the river influences and the river effluences at sea, a series of recent surveys on river discharges and surface withdrawals data were considered too.

To obtain the budget in non-natural conditions, as the currents, were taken into account also the groundwater withdrawals. These were evaluated for each type of use and for each aquifer system, starting from 2 geodatabases: one regarding the domestic use (50101 estimated wells) and one concerning industrial, agricultural, fish breeding, hygienic, geothermal and other minor uses (7594 wells, 7930 extraction points considering the screens). The well withdrawals amount were evaluated, on annual base for recent periods and expressed as  $m^3/s$ , for specific areas taking into account the number of wells, the discharges, the screen depths, the water meter data and other useful parameters.

For the water-budget, the studied territory was considered as a “semi-closed box” in which the groundwater sharings with the neighboring areas are not relevant and recharging groundwater is mainly due to the river influences, infiltration, rainfall and irrigation practices.

## The dataset

For the realized research, a Geographic Information System on an ESRI platform was implemented. It is a

specific Oracle Geodatabase in which the alphanumeric information are integrated with the geographical ones and where data interoperability towards the other used platforms is guaranteed. Data query and management are possible thanks to the ESRI ArcGIS interface. In the geographic platform converged six different databases having information regarding wells, springs and litho-stratigraphies (“DERIVAZIONI” and “DENUNCE” by the FVG Hydraulic Survey, “GEOTERMIA”, “CGT” and “CARG” by the FVG Geological Survey and AdB realized by the Autorità di Bacino dell’Alto Adriatico). During the data assembly has been necessary a polishing operation on the duplicates. The homogenization, validation and implementation of the collected data reaching the number of 59260 points of which 1346 are springs and 57914 (28902 domestic) are wells (Zini et al., 2011) permitted to obtain the final geodatabase.

## The confined aquifers

In order to characterize the confined aquifer systems a 3D model, having a cell of  $400 \times 400 \times 1$  m, was realized using Rockworks R14 release software starting from 603 lithostratigraphic and wells data chosen among 3258 available (Zini et al., 2011). The set of available data allowed the elaboration of the separation surfaces, expressed as grid files, between the different hydrostratigraphic units being these last ones the structure of the realized model. First of all were realized hundred lithostratigraphic cross sections passing through the lithostratigraphic data, in order to verify the conceptual model proposed; later the three-dimensional analysis on the lithostratigraphies was done according to the chosen permeability classes. This allowed a semi-automatic construction of the model taking into account the hydraulically connected domains and the etropic interdigitations. A “picking” operation made on the top and bottom of each tapped aquifer system allowed a hydrostratigraphic reconstruction. From the geostatistical elaboration (kriging interpolator) was derived the model defining the domains of existence and/or the limits of the investigated areas, the depth of the top and the bottom (a.s.l.) and the thicknesses of the recognized aquifer systems as isobath and isopach maps (Fig. 2 and at the next page Fig. 3).

The aquifer A, generally positioned between 10/20 and -80 m a.s.l., is widely present in the LP. Permeable layers from sandy to sandy-gravelly deposits are characterizing it. The thickness of the layers sometimes reach value even higher than 10 m, but more often the aquifer is variously divided into weak permeable layers interspersed by clay-silty impermeable ones with an average thickness of 31 m.

The aquifer B, is a permeable gravelly (northern areas) and sandy (southern areas) layer, fairly constant with the top at about -30/ -40 m depth a.s.l. and the bottom at -100 m a.s.l. The average thickness of this system is about 13 m.

The C aquifer is on average depth between -60/70 and -130 m a.s.l. and is well developed in the lagoon and hinterland areas. It mainly consists of two almost always clearly distinguishable permeable layers identified as “C<sub>high</sub>” and

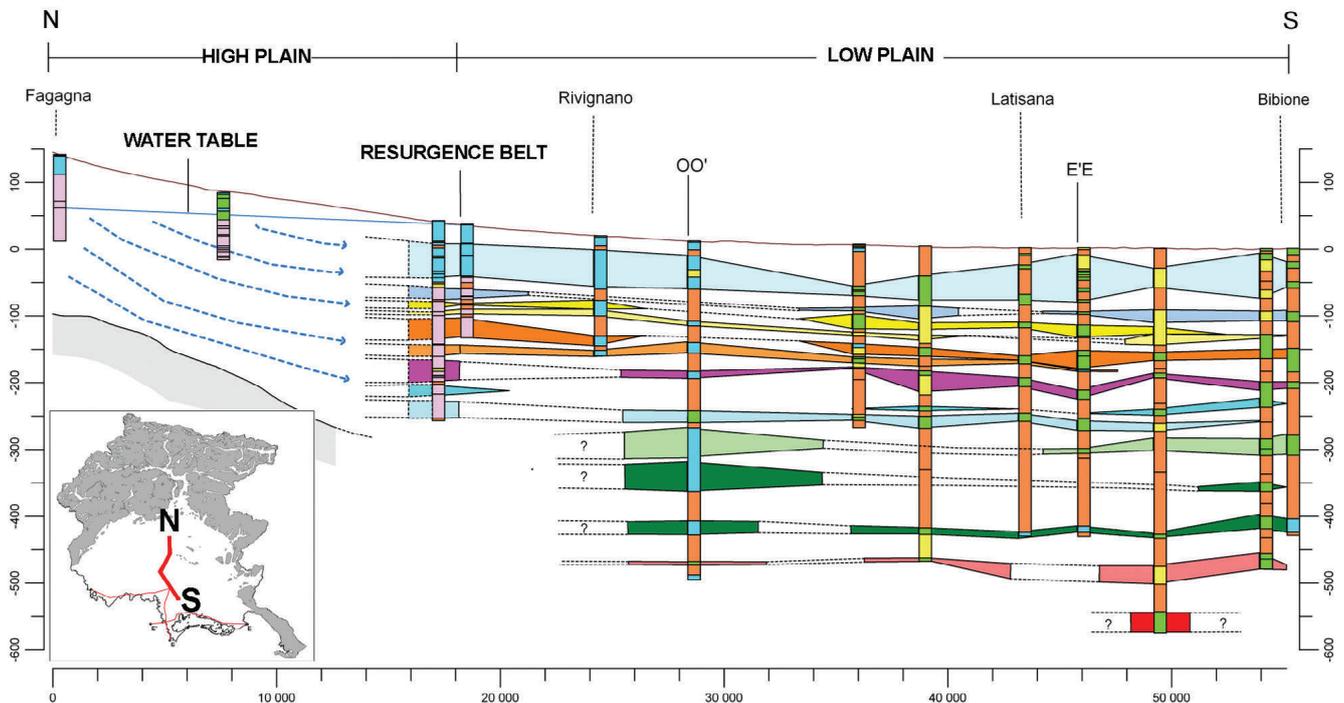


Fig. 2: Schematic North-South hydrostratigraphic cross section; each different color is representing a single different aquifer system. The question marks are identifying the unknown correlations due to the lack of data (depth not reached by the drilled well).

Fig. 2: Sezione idrostratigrafica schematica Nord-Sud; a colore diverso corrisponde un diverso acquifero. I punti interrogativi identificano le correlazioni non note a causa della mancanza di dati (profondità non raggiunta dal pozzo).

“C<sub>low</sub>” which average thickness is 14.5 m (“C<sub>high</sub>” + “C<sub>low</sub>”).

The aquifer D comprises a set of thin permeable layers of predominantly sandy-gravelly deposits, which are generally divided in two main groups interpreted as aquifers “D<sub>high</sub>” and “D<sub>low</sub>”. The top of this system stands at indicative quotes of -110/-120 and -155 m a.s.l. and the two levels succeed one from another at few meters of distance joining in a single indistinct layer at high permeability, thus forming a hydraulic complex circuit with local vertical sharings. The average thickness is around 15 m (“D<sub>high</sub>” + “D<sub>low</sub>”).

The E aquifer is a permeable interval consisting of clean and coarse gravel in the northern part shifting into gravel with sand and silt to the south. The average thickness is about 14 m. The top of the permeable E aquifer is approximately -150/-200 m and the bottom at -170/-215 m a.s.l. The waters are of geothermal interest reaching temperatures of 29 °C.

A set of different permeable complex levels of gravelly-sand deposits, sometimes cemented, interbedded discontinuously by thin layers of silt and clay constitute the aquifer F. The top of this system is present between -190 and -250 m a.s.l. depending from the location. Overall it can be considered quite well distributed mainly in the southern part of the plain where sometimes it is splitted into two different layers. The average thickness is about 17 m.

The G system consists of sandy intervals, sometimes with gravel or with weakly cemented sands. The top is about -260/-300 m a.s.l. Its average thickness is about 11 m.

The H aquifer is a composite system located below a clay-silt thick and continuous aquitard and it is one of the thinnest

gravel level, sometimes weakly cemented containing a percentage of sand. It is possible to distinguish two permeable horizons named “H<sub>high</sub>” and “H<sub>low</sub>” having an average thickness of 13-15 m and the top at a depth of -320/-370 and -380/-420 m a.s.l. respectively.

Regarding the deeper aquifers, the available information are scarce and discontinuous, and this does not allow a full characterization (Cimolino et al., 2010; Nicolich et al., 2008; Regione Autonoma Friuli Venezia Giulia, 2007). They are contained in porous horizons with variable thickness and extension where freshwaters have a high content in solutes and a strong thermal component with temperatures higher than 35°C.

The aquifer I is tapped at a depth ranging from -450 to -470 m a.s.l. and is mainly characterized by sandy and discontinuous lenticular bodies. Sometimes the deposits are sandy-gravelly present in weakly cemented sand and Pliocene deposits. This aquifer has a discontinuous thickness that varies widely from 5 to 20 m.

The aquifer L is located in a low range of sandstone or cemented sand from Tortonian age, whose top is tapped at depths exceeding -500 m to about -540 m a.s.l. The thickness varies between 10 and 30 m and it is recognized only along the Tagliamento River.

The aquifer M consists of sand deposits of the Upper Miocene, has the top that can be roughly placed at depths exceeding -590 m a.s.l.

In the LP all the confined aquifers are artesian, having pressure values that can reach more than 1 bar. The seasonal variations mainly affect the shallower aquifers but are

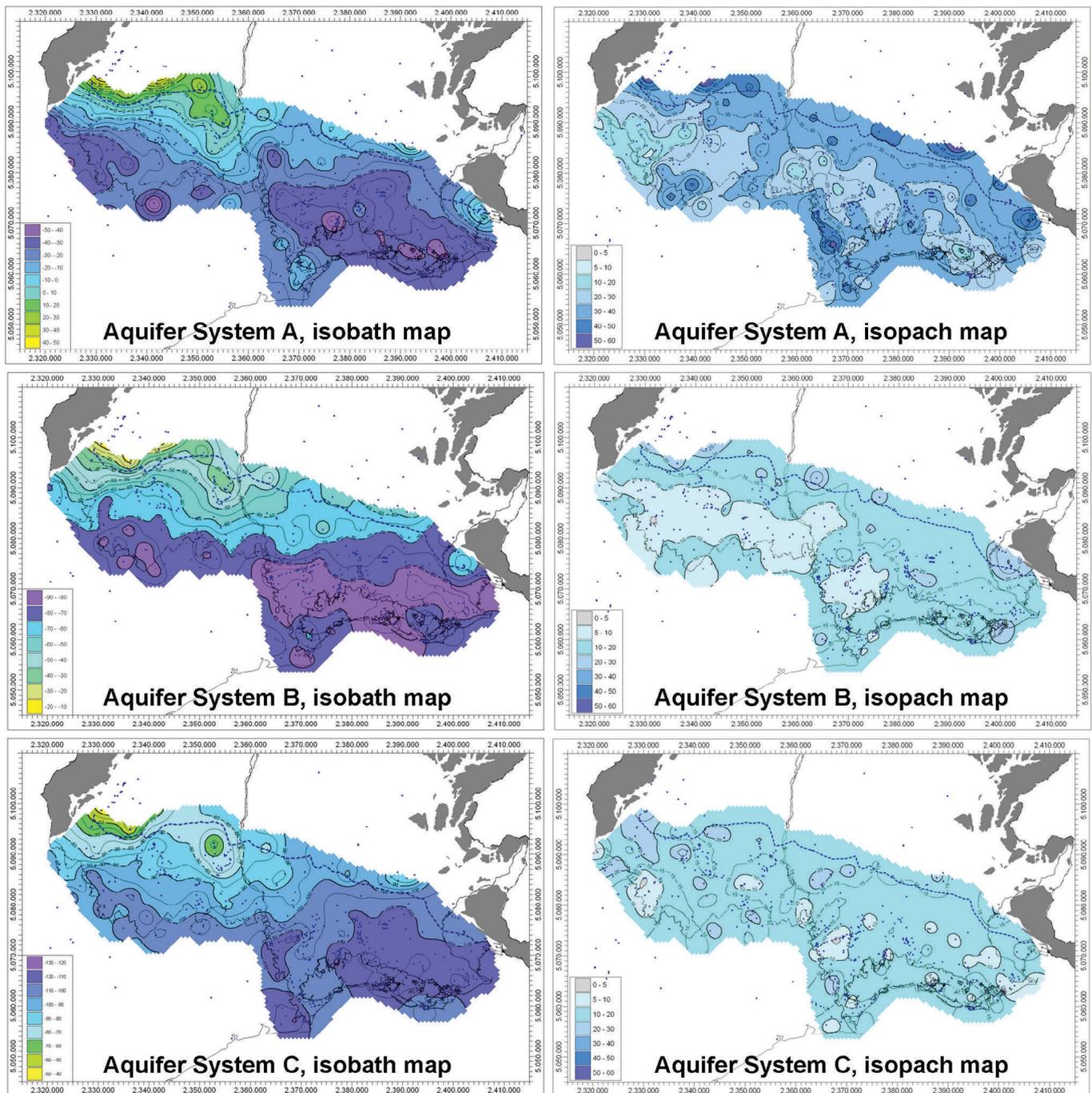


Fig. 3: Isobath (left) and isopach (right) maps for the aquifer systems "A", "B" and "C". The maps are in m a.s.l., in blue the well points used for the construction of each map. Isobaths are the result of the top depth values interpolation through the *kriging* algorithm. Different variograms, iterations and filters were applied on each dataset. Isopach maps are the interpolated result of the thickness values computed for each single aquifer system; different variograms, iterations and filters were applied on each dataset also for these maps (Zini et al., 2011).

Fig. 3: Carte delle isobate (a sinistra) e delle isopache (a destra) relative ai sistemi di acquiferi confinati "A", "B" e "C". Le carte sono in m s.l.m., in blu i pozzi utilizzati per la realizzazione di ciascuna carta. Le isobate sono il risultato dell'interpolazione realizzata utilizzando il *kriging*, dei valori del tetto dei singoli acquiferi. Su ogni set di dati sono stati applicati diversi variogrammi, iterazioni e filtri. Le carte delle isopache invece sono il risultato interpolato dei valori di spessore calcolati per ogni singolo sistema di acquiferi; su ogni dataset sono stati applicati diversi variogrammi, iterazioni e filtri (Zini et al., 2011).

generally less than 0.5 bar (Martelli et al., 2007a, 2007b).

From the data present in the international literature, to each aquifer systems has been assigned a value of effective porosity and hydraulic conductivity (Castany 1985; Civita, 2005; Fetter, 2001) taking into account the lithological data, the hardness degree, cementation or fracturing. The volumes and the average thicknesses of the aquifer systems were calculated starting from the 3D model (Tab. 1).

Starting from volumes and effective average porosity has been calculated the amount of the water storage contained in each aquifer systems (Tab. 2). The water storage, expressed as volume [ $\text{km}^3$ ] and as equivalent water column average height  $H_w$  [m], is here interpreted as the drainable storage, that is the amount of mobilizable water contained in the sediment's pores. In the computation was not taken into account, being an order of magnitude lower, the compressible storage due to the compression of the aquifer and the water itself. All these studies are useful to reconstruct the groundwater availability and to evaluate the sustainable exploitation.

### Wells withdrawals evaluation

For the present paper, were developed procedures that permitted to reach an adequate estimation of the wells withdrawals and their quotes divided among the different

aquifer systems and for each different type of use and then compared to the available literature (Granati et al., 2000). In particular on the available datasets two different protocols were adopted: one for the 7594 wells subjected to licence (drinking, agricultural, fish breeding, industrial, hygienic, geothermal and other minor uses) and one for the 50101 estimated domestic wells (Treu, 2011).

For these purposes has been necessary to identify and evaluate the following characteristics: number of captures and their distribution on the territory, tapped aquifers, main uses and the effective consumptions. In order to define for each well the tapped aquifer systems were used the intersection between the depth of the screens, or the total depth, and the 3D model of the aquifers. The well withdrawals amount were evaluated on annual base for recent periods and expressed as  $\text{m}^3/\text{s}$ , as million  $\text{m}^3/\text{year}$  and as water column height (m/year) with reference to specific areas.

As regard the 7594 wells subjected to license (7930 extraction points considering the screens), useful information has been derived from a informatic census done in Friuli Venezia Giulia Region starting from 2004. It permitted to have good quality data on location, total depth, screen depth and licensed discharges. Using the screen depth when available or the total depth, it has been possible to assign the

Tab 1: Geometrical characteristics of the confined aquifer systems recognized and tapped in the Friuli LP.

Tab 1: Caratteristiche geometriche degli acquiferi confinati della Bassa Pianura.

Aquifer systems	Area	Volume	Top - Depth	Domains of existence	Average thickness
	A [ $\text{km}^2$ ]	V [ $\text{km}^3$ ]	(a.s.l.) [m]	(a.s.l.) [m]	$b_{\text{mean}} = 1000 \cdot V/A$ [m]
A	2294	71.2	+10 / -50	+10 / -80	31.0
B	2294	30.6	-30 / -90	-30 / -100	13.3
C	2294	33.3	-60 / -120	-60 / -130	14.5
D	2294	35.1	-110 / -155	-110 / -170	15.3
E	2294	32.5	-150 / -200	-150 / -215	14.2
F	2294	39.5	-190 / -250	-190 / -265	17.2
G	2124	23.1	-260 / -300	-260 / -320	10.9
$H_{\text{high}}$	1135	15.2	-320 / -370	-320 / -380	13.4
$H_{\text{low}}$	852	12.5	-380 / -420	-380 / -440	14.7

Tab 2: Hydrogeological parameters and water storage, expressed both as volume and as equivalent water column height ( $H_w$ ), calculated for each confined aquifer systems of the Friuli LP.

Tab 2: Quadro sinottico delle caratteristiche idrogeologiche dei sistemi di acquiferi confinati della Bassa Pianura. Le riserve vengono espresse sia in termine di volume che di altezza della colonna d'acqua ( $H_w$ ).

Aquifer systems	Hydraulic Conductivity		Effective porosity	Storage	$H_w$
	$K_{\text{min}}$ [m/s]	$K_{\text{max}}$ [m/s]	$n_{\text{e mean}}$ [%]	$V \cdot n_{\text{e mean}}$ [ $\text{Km}^3$ ]	$b_{\text{mean}} \cdot n_{\text{e mean}}$ [m]
A	1.0E-05	5.0E-02	20.0	14.2	6.2
B	1.0E-05	5.0E-02	20.0	6.1	2.7
C	1.0E-05	5.0E-03	22.5	7.5	3.3
D	1.0E-05	5.0E-02	24.0	8.4	3.7
E	1.0E-04	1.0E-02	20.0	6.5	2.8
F	1.0E-04	5.0E-03	20.0	7.9	3.4
G	1.0E-05	5.0E-02	20.0	4.6	2.2
$H_{\text{alto}}$	1.0E-05	5.0E-02	20.0	3.0	2.7
$H_{\text{basso}}$	1.0E-05	5.0E-02	20.0	2.5	2.9

tapped aquifer. Additional information from water-meter consumption has been collected for 553 wells (648 extraction points). All the data collected, even if of good quality, were anyway subjected to a validation protocol in order to verify their effective value. The known wells are almost all the existing ones and therefore the analyzed number can be considered representative of the real situation.

Only for the wells without water-meter attributes, a reducing coefficient was assigned to the licensed discharge in order to estimate the real consumption. For each use the coefficient value was evaluated according to the available water-meter data.

For the agricultural use a value of 10% of the licensed discharge was assigned. This corresponds to 37 day of use per year and represents the irrigation period concentrated in summertime.

For the drinking use, a value of 56% was assigned corresponding to an effective use of 13.5 hours per day.

The fish breeding are active during all the year to maintain the correct water recharge and freshness, for this reason a value of 100% was assigned.

For the industrial use, a value of 26% was assigned corresponding to 6.5 hours/day at full discharge.

Concerning the hygienic use several uses are converging into this item (e.g. antifire). The estimation assigned a value of 7%.

Geothermal wells are active all over the year and so was considered a value of 100 % of the licensed discharge.

Concerning the other minor uses, the estimation assigned a value of 100 %.

For the LP area in Veneto Region, there were no available data and so an evaluation of the withdrawals has been done by analogy with the near municipalities located in the Friuli Venezia Giulia.

Knowing the licensed discharges, the percentage of effective use of each well and the corresponding tapped aquifer, it has been possible to estimate the withdrawals amount divided by type of use and aquifer systems.

As regard domestic wells, in the Friuli Plain are widely present private wells being part of the local culture. Their density and withdrawals vary from area to area function of the geographical distributions of the settlements, of the type of aquifer (phreatic or artesian), the depth of the water table, the groundwater quality, the distance to the coast or the development of the pipe aqueduct network. Several are, in fact, the municipalities unprovided by an aqueduct net.

In particular, a huge amount of domestic wells characterize the LP. Withdrawals are mainly interesting the shallower artesian aquifer systems (A, B and C) and have continuous flow seen that are naturally gushing wells and generally not equipped with discharge reducers. Accordingly, the withdrawals are far higher than the real demands of the population. The flow freely waters, as a rule, discharges to the sea, through the irrigation canals drainage network or are influent for the shallow phreatic waters.

North of the spring belt instead, the water well withdrawals for strictly domestic use have always been not widespread seen that the depth to water is higher and the water might be extracted only using submersible pumps. In recent years, this practice has further mainly reduced due to the depletion over time of the water quality and due to the realization of a widespread aqueduct network. The use is therefore discontinuous and withdrawals are closely linked to the real water demand.

For the evaluation of the withdrawals, has been necessary to estimate and determine the following variables:

- the total number of wells and their widespread on the territory;
- the coefficients (concerning consumptions for the phreatic wells and discharge for the artesian ones) to be adopted for the withdrawals calculation;
- the sharing volume rates of the water withdrawals among the different aquifer systems.

The domestic wells data present in the geodatabase (28902 wells) are a close underestimation of the real situation representing the best knowledge framework. To fill the gap were used also data of the XIV general census of population and houses (ISTAT, 2001) from which were abstracted information on houses served by domestic wells in order to compensate the lack of information. Through appropriate data processing and integrated analysis of the gathered information, to each municipality was assigned its number of domestic wells.

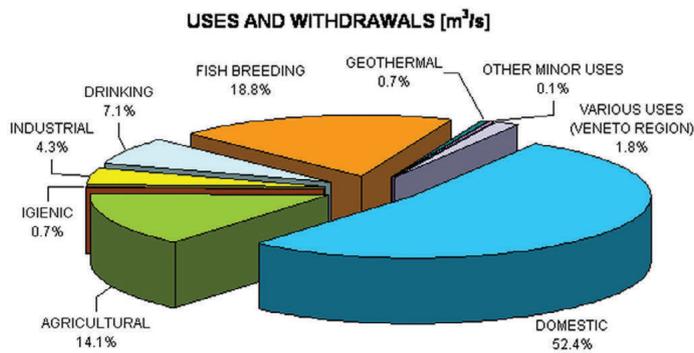
In total were estimated 50101 wells for domestic or similar uses: 9376 in the HP and 40725 in the LP. With regard to the administrative boundaries, 47709 wells are in the Friuli Venezia Giulia Region and 2392 are in the part of the LP located in the Veneto Region.

For the withdrawals evaluation, first it was necessary to distinguish between wells located at north of the spring belt, considered all phreatic, and the ones located at south of it, considered all confined. Of course, these assumptions are partially forced, but necessary to simplify the calculation.

With regard to phreatic wells were considered the number of persons using a domestic well with an average *per capita* consumption, set equal to 290 liters per day.

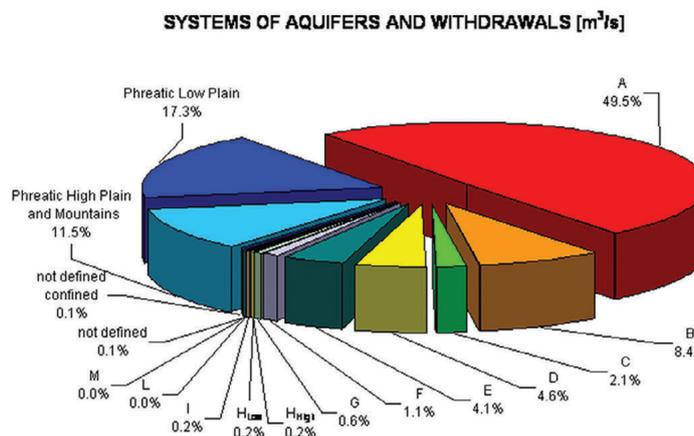
With regard to the artesian wells, to compute the withdrawn amount were used the mean discharge seen that withdrawals are completely independent from the actual water demand. Based on the data surveyed in the last decades by the Servizio gestione risorse idriche of the FVG Region and from bibliography (GEOS, 1994; Granati et al., 2000) has been estimated a mean discharge per artesian well of 0.8 l/s. From the data present in the geodatabase (28902 domestic wells), using the screen depth when available or the total depth, it has been possible to assign the withdrawal rate for each artesian aquifer. From the realized analysis it came out that 80% of the wells present in the database are tapping the aquifer A, 10% the aquifer B, 2% the C, 4% the D, 2% the E, 1% the F and 1% the G.

The total amount of groundwater withdrawals in the Friuli Plain basin was obtained by adding the one coming from the



WELLS TYPE	USE	n° OF WELLS	WITHDRAWALS	
			m³/s	%
SUBJECTED TO LICENSE	AGRICULTURAL	4517	8.788	14.1
	IGIENIC	1354	0.408	0.7
	INDUSTRIAL	662	2.666	4.3
	DRINKING	457	4.458	7.1
	FISH BREEDING	478	11.702	18.8
	GEOTHERMAL	106	0.449	0.7
	OTHER MINOR USES	20	0.084	0.1
	VARIOUS USES (VENETO REGION)		1.141	1.8
NOT SUBJECTED TO LICENSE	DOMESTIC	50101	32.7	52.4
<b>TOTAL</b>		<b>57695*</b>	<b>62.40</b>	<b>100.0</b>

\* wells subjected to license in Veneto Region are not included



SYSTEM OF AQUIFERS	WITHDRAWALS		
	million of m³/year	m³/s	%
Phreatic High Plain and Mountains	226.9	7.19	11.52
Phreatic Low Plain	339.7	10.77	17.25
A	974.3	30.88	49.48
B	166.1	5.26	8.43
C	40.4	1.28	2.05
D	89.8	2.85	4.56
E	81.6	2.59	4.15
F	22.4	0.71	1.14
G	11.1	0.35	0.56
H <sub>high</sub>	3.0	0.10	0.15
H <sub>low</sub>	4.6	0.15	0.24
I	3.1	0.11	0.17
L	0.7	0.03	0.04
M	0.6	0.02	0.03
not defined	2.2	0.07	0.11
not defined confined	2.2	0.07	0.12
<b>TOTAL</b>	<b>1968.8</b>	<b>62.40</b>	<b>100.0</b>

Fig. 4: Withdrawals in the Friuli Venezia Giulia Region subdivided by aquifer systems and by type of use.

Fig. 4: I prelievi nella Regione Friuli Venezia Giulia suddivisi per sistema di acquifero e tipologia di utilizzo.

wells subjected to license with the domestic ones. More than 50% of the withdrawals are due to the domestic wells.

The total withdrawals are 62.4 m³/s. Withdrawals from the mountains areas are 2.6 m³/s while 4.54 m³/s are from the phreatic aquifer of the HP, for a total value of 7.19 m³/s. The total withdrawals amount from the confined aquifer systems are 44.4 m³/s, of wich 3.3 in the HP and 41.1 in the LP areas (38.6 in Friuli Venezia Giulia Region and 2.5 in Veneto Region). Almost 50% of the withdrawals are in the aquifer systems A (Fig.4).

**Water hydrogeological budget**

The considerable water withdrawals and the rapid deterioration of groundwater highlighted the necessity of an integrated approach for the assessment of sustainable consumption and for planning of future uses. The water-balance looks like the tool used to evaluate the available water resources and the future demand (Calligaris et al., 2010a, 2010b; Henriksen et al. 2008; Kalf et al., 2005; Jukic’ et al., 2009; Sophocleous et al., 2004; Sorek et al., 2010; Zhou, 2009).

The orography of the studied area is extremely favorable

for the computation of the water-budget as it is a bounded basin with limited water sharing with neighboring aquifers.

The analysis extended to the whole region was focused on the Plain where the withdrawals are mainly concentrated. Evaluating the budget input components it was used what already carried out by the Friuli Venezia Giulia Region (2010) in the formulation of the Water Protection Plan (Regione Autonoma Friuli Venezia Giulia, 2010).

With regard to precipitation were used data from 109 rainfall stations and 46 regional thermometric stations (Hydrographic Region Unit and ARPA Osmer) recorded in the period between 1979-2008. Any missing data were reconstructed using linear regression techniques (stepwise or multiregression) (Cicogna, 2008) (Fig. 5).

The daily rainfall and temperature data spatialized on a 50 m grid were overlapped to the DEM. For the Precipitations (P) were used interpolating algorithms as Natural Neighbor, while for the temperatures were used experimental elevation gradients obtained correlating the thermometric daily data with the elevation of the stations (Cicogna, 2008; Castrignanò et al., 2005).

The Evapotranspiration (ET) was quantified as “crop

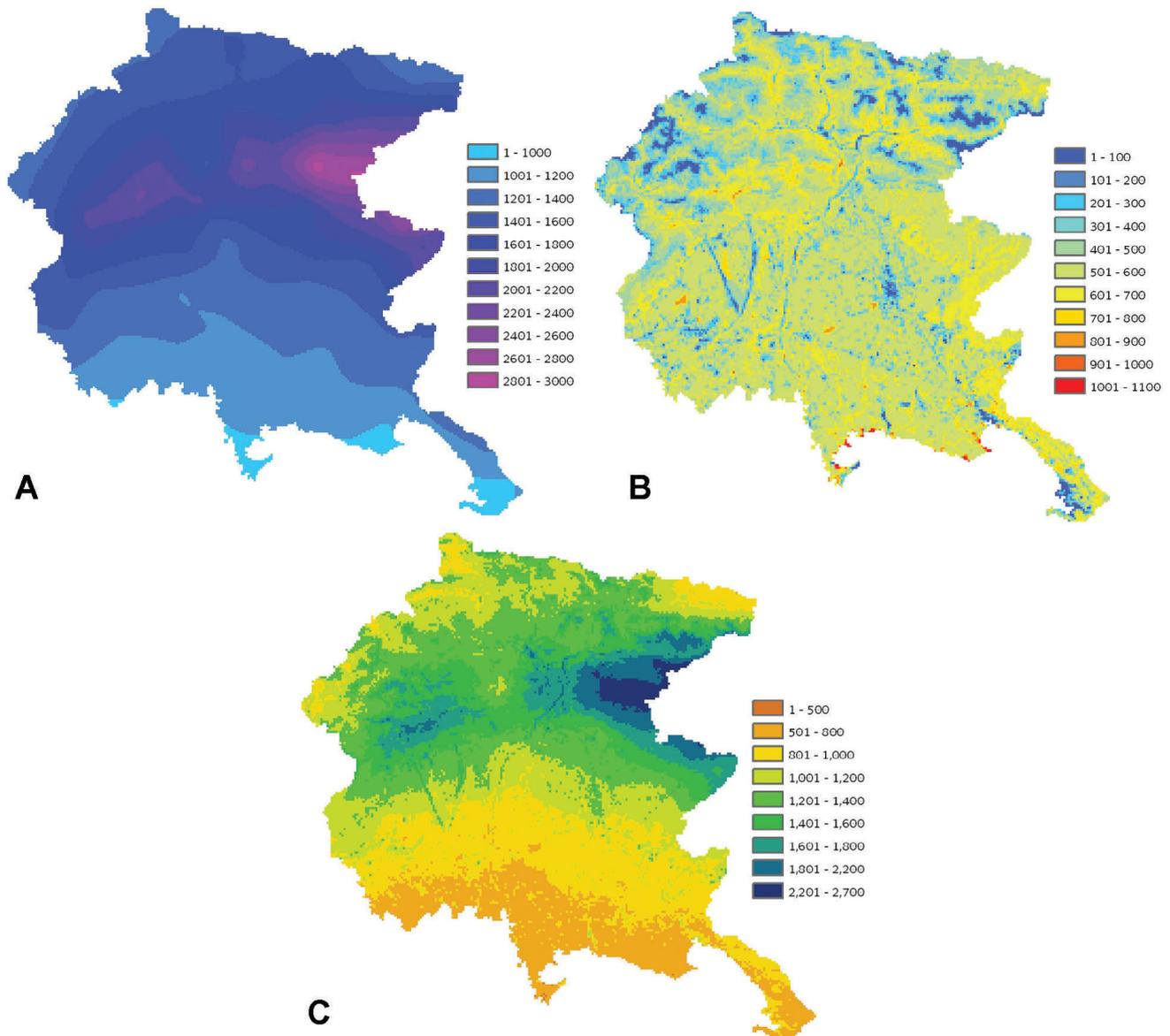


Fig. 5: Thematic maps concerning P - Precipitation (A) in mm/y, ET - Evapotranspiration (B) in mm/y and R+I map realized for the surface Runoff and Infiltration (C) in mm/a.

Fig. 5: Carte tematiche relative a P - Precipitazione (A) in mm/a, ET - Evapotraspirazione (B) in mm/a e mappa R+I realizzata per il deflusso superficiale e l'infiltrazione (C) in mm/a.

evapotranspiration" calculated with the two-step approach as the product between the reference evapotranspiration and the crop coefficient  $K_c$  that incorporates and synthesizes all the effects on evapotranspiration due to the morfophysiological characteristics of the different cultural species from phenological stage to the soil cover degree (Zini et al., 2011).  $K_c$ , depending from the type of vegetation and from the stage of plant development, was evaluated for each land use Moland class and for each decade of the year and associated to each cell of the grid. The reference evapotranspiration is a typical climate parameter expressing the tendency to perspire of a given plant. To calculate it, it was used the Hargreaves formula (Allen et al., 1998), described in the notebook 56 of the FAO (Food and Agriculture Organization). The average crop evapotranspiration for the Friuli Venezia Giulia Region is equal to 489 mm/y.

Surface Runoff (R) and effective Infiltration (I) components were used for the Plain, while for the whole mountain basins was considered the sum R+I. The surface runoff has been defined using the Curve Number (CN) methodology modified by Williams (1995) to fit the long-term analysis. CN was defined for the whole regional territory combining on a 50x50 m grid the map of the hydrological groups, the land use map and the slope map extracted by DEM. From CN the retention parameter was calculated varying from a minimum, corresponding to a saturated soil, to a maximum, coincident with a dry soil depending from potential evapotranspiration of the computed day, from the precipitation and run off of the previous day (Zini et al., 2011). The mean annual runoff over the Plain is equal to 216 mm/y. The effective infiltration component was calculated as the difference between precipitation, evapotranspiration

and runoff. The annual mean effective infiltration over the Plain is equal to 718 mm/y.

The mountain basins discharge (R+I) analysis allows quantifying the mean annual active recharge of the HP (Tab. 3). If we consider the average R+I values, purged from the quantity of water outflowing to sea, they represent the average quantity that normally feed the aquifers of the HP.

The analysis was conducted dividing the area into four main hydrological basins and in the area of moraine amphitheater. The effluent character of the main watercourses in the HP represents the main component of the recharge in these areas.

Based on a series of measurement surveys carried out in recent years (Consorzio di Bonifica Ledra Tagliamento, 1982; Cimolino et al., 2011) and on river discharge data surveyed by the “Servizio gestione risorse idriche della Direzione centrale ambiente, energia e politiche per la montagna” of the FVG Region were evaluated the percentages of river losses of each single water course. These values in conjunction with the shallow capture of waters for irrigation and industrial purposes and with the groundwater withdrawals permitted to compute the mean outflows at sea and, as difference, the effluences in the HP (Tab.4).

The discharge of the Cellina Meduna basin has an average value of 28.5 m<sup>3</sup>/s of which 25.1 m<sup>3</sup>/s is captured mainly for irrigation and hydroelectric purposes. It follows that the useful influent discharge into the phreatic aquifer of the HP is 3.4 m<sup>3</sup>/s being the 12% of the total amount of the Cellina Meduna mountain basin rate.

In the mountain basin of the Tagliamento River, the discharge has an average value of 100.7 m<sup>3</sup>/s. Of these, 2.4 m<sup>3</sup>/s are well withdrawals, 23.0 m<sup>3</sup>/s are captured for

irrigation purposes, 21.2 m<sup>3</sup>/s directly outflow to sea and 54.1 m<sup>3</sup>/s supply the HP.

In the mountain basin of Torre-Natisone rivers the discharge has an average value of 32.8 m<sup>3</sup>/s, of which 2.5 m<sup>3</sup>/s are captured for drinking, irrigation and hydropower purposes. Seen that the component flowing directly to the sea has been estimated to be around 3.0 m<sup>3</sup>/s, the influence on the HP is equal to 27.3 m<sup>3</sup>/s.

For the Isonzo River basin, seen that are not available the run-off and infiltration data for the slovenian side of the mountain basin, it has been decided to use the river discharge measured at the border (Gorizia - Ponte Piuma site). In this point, the discharge has an average value of 170.8 m<sup>3</sup>/s of which 26.3 m<sup>3</sup>/s are captured for irrigation and hydropower purposes, 107.1 m<sup>3</sup>/s directly flow out to sea and 37.4 m<sup>3</sup>/s are influent into the aquifers of the HP.

In the moraine amphitheater the estimated outflow is of 8.5 m<sup>3</sup>/s with well withdrawals of 0.2 m<sup>3</sup>/s, which implies that the amphitheater has an influent character with respect to the HP with a volume of 8.3 m<sup>3</sup>/s.

The HP is average fed by 130.5 m<sup>3</sup>/s of waters from mountain basins and by 65.3 m<sup>3</sup>/s due to effective infiltration and irrigation return flow (Zini et al., 2011).

The withdrawals are 7.9 m<sup>3</sup>/s (4.54 m<sup>3</sup>/s tapped from the phreatic aquifers and 3.36 m<sup>3</sup>/s from the confined aquifer northern of the spring belt) and 10 m<sup>3</sup>/s are the waters drained by Classical Karst aquifer (Cucchi et al., 2007; Urbanč et al., 2012).

An estimation was made on the spring rivers discharges that overall drain 134.2 m<sup>3</sup>/s (Zini et al. 2011). From the difference between the inputs of the HP and the spring rivers discharges, was estimated the input of the LP as 43.7 m<sup>3</sup>/s.

Tab 3: Mountain watersheds contribution to the HP aquifer recharge (m<sup>3</sup>/s).

Tab. 3: Il contributo dei bacini montani alla ricarica degli acquiferi dell’Alta Pianura [m<sup>3</sup>/s].

MOUNTAIN WATERSHED	OUTFLOW R+I	WITHDRAWALS IN THE MOUNTAIN WATERSHED	DIFFERENCE OUTFLOW -WITHDRAWALS	% RIVER INFLUENCES IN THE HP ACQUIFERS	CONTRIBUTION TO THE HP AQUIFERS RECHARGE R <sub>M</sub>
Cellina-Meduna	28.5	25.1	3.4	100%	3.4
Tagliamento	100.7	25.4	75.3	72%	54.1
Torre-Natisone	32.8	2.5	30.3	90%	27.3
Moraine Amphitheater	8.5	0.2	8.3	100%	8.3
Isonzo	170.8	26.3	144.5	26%	37.4
TOTAL	341.3	79.5	261.8		130.5

Tab. 4: HP aquifers groundwater recharge and discharge (m<sup>3</sup>/s).

Tab. 4: : Il bilancio nell’Alta Pianura [m<sup>3</sup>/s].

INPUT		OUTPUT		IN-OUT
R <sub>M</sub> recharge coming from the mountain watersheds	I+Ii infiltration in the HP due to effective precipitation and irrigation return flow (Ii)	well withdrawals in the HP	Karst drainage	R <sub>HP</sub>
+130.5	+65.3	-7.9	-10.0	+177.9
	+195.8		-17.9	+177.9

The obtained result is validated by the estimated value of the calculated withdrawals 41.1 m<sup>3</sup>/s in the aquifer systems in the LP area (Tab. 5).

Considering that the mean annual active recharge coming from the HP is equal to 43.7 m<sup>3</sup>/s, and that the well withdrawals in the LP for the confined aquifers are 41.1 m<sup>3</sup>/s, the water budget is equal to +2.6 m<sup>3</sup>/s. This value is in the range of acceptance seen also the regional scale of the research (Tab. 6).

### Discussion and Conclusions

The research presented in this paper has as aim the quantification of the water resources available and the identification of the groundwater withdrawals in Friuli Venezia Giulia Region in order to define, through the water-budget, the sustainability of the actual use of the resource. 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

adopted scheme divides the studied area into homogeneous zones: the mountains, the Isonzo mountain watershed, the HP (HP) and the LP (LP) as shown in Fig 1. Each single area can be compared to communicating tanks: the mountain groundwater supplies, through direct contributions or through the rivers influences, the HP which, that in turns, supports both springs belt and LP aquifer systems.

From the realized analysis, emerges how the current use of the confined aquifers in the LP is not sustainable in the long run, that means that the amount of water withdrawals in the HP affects the spring belt discharge, reducing its amplitude with a consequent loss of traditional habitats such as wet meadows. The effect just mentioned, in the LP, is highlighted on the artesian aquifers where the lowering of their pressures is fully monitored (Cucchi et. al, 1999; Martelli et al., 2007a, 2007b). Seen that in the water-budget the balance definition itself is resuming the concept of equilibrium, the final result obtained for the present research (+2.6 m<sup>3</sup>/s) is in the range of acceptance of a computation realized in a wide area like the

Tab. 5: LP confined aquifers groundwater recharge (m<sup>3</sup>/s).

Tab. 5: La ricarica degli acquiferi confinati della Bassa Pianura [m<sup>3</sup>/s].

INPUT	OUTPUT	IN-OUT
R <sub>HP</sub> recharge coming from the HP	Q <sub>s</sub> spring belt discharge	R <sub>LPA</sub> recharge of the LP confined aquifers
+177.9	-134.2	+43.7

Tab. 6: LP confined aquifers hydrogeological groundwater budget (m<sup>3</sup>/s).

Tab. 6: Il bilancio idrogeologico negli acquiferi confinati della Bassa Pianura [m<sup>3</sup>/s].

INPUT	OUTPUT	IN-OUT
R <sub>LPA</sub> recharge of the LP confined aquifers	well withdrawals in the LP confined aquifers	groundwater balance
+43.7	-41.1	+2.6

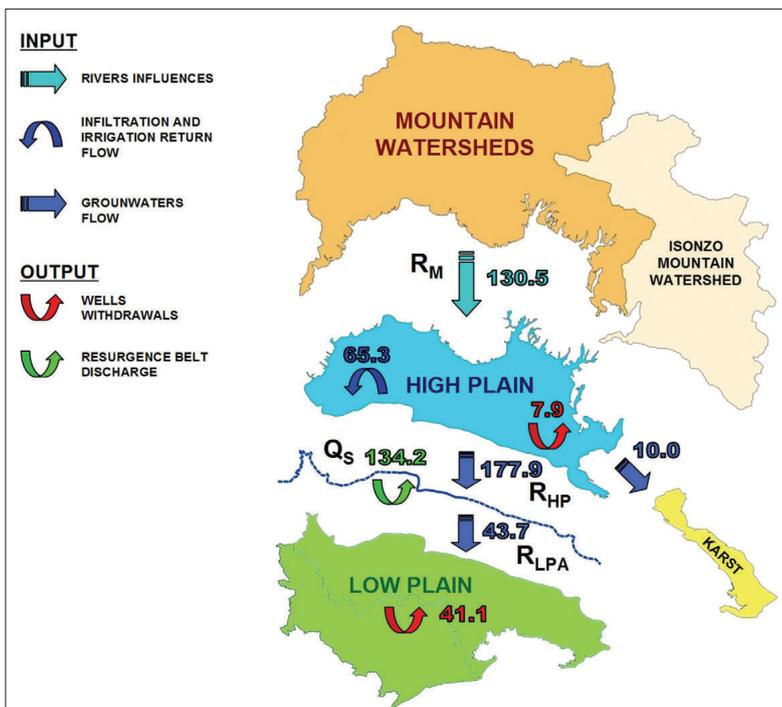


Fig. 6: Water-budget scheme. Mountain Watersbeds (light brown) and Isonzo River mountain watershed (in sandy colour) to the North, the HP (HP) area (light blue) separated from the LP (LP) (light green) by the spring belt (blue dashed line). In yellow the Karst area. Blue arrows are related to the influences and water flows, while red and green arrows represents the well withdrawals and the spring belt discharges.

Fig. 6: Il bilancio idrogeologico schematizzato. Gli spartiacque montani (marrone chiaro) e lo spartiacque montano del fiume Isonzo (color sabbia) a nord. Più a sud, l'Alta Pianura (blu chiaro) separata dalla Bassa Pianura (verde chiaro) dalla fascia delle risorgive (linea blu tratteggiata). In giallo il Carso Classico. Le frecce blu sono indicative dei flussi, mentre le frecce rosse e verdi rappresentano i prelievi dai pozzi e la portata calcolata in corrispondenza della fascia delle risorgive.

Friuli Region. But even if the result is positive, the criticism of the actual withdrawal rate is mainly highlighted if the attention is focused on specific areas seen the heterogeneous distribution of the wells. For example, in the right side of Tagliamento River, in the LP, the withdrawals are 21.7 m<sup>3</sup>/s with a withdrawal intensity of 35.5 L/s on Km<sup>2</sup>. In the left side of Tagliamento River instead, always for the LP, the withdrawals are 14.8 m<sup>3</sup>/s with a withdrawal intensity of 22.9 L/s on Km<sup>2</sup>. If we consider the Isonzo LP, the withdrawals are 2.1 m<sup>3</sup>/s with a withdrawal intensity of 14.9 L/s on Km<sup>2</sup>. For this reason it is necessary to focus the attention on the artesian aquifer withdrawals that can also cause water recalls from the HP, more vulnerable to pollutants. In this framework of wild withdrawals, it is not possible to forget the massive hydroelectric withdrawals from mountain basins and from irrigation that gradually increase in time and determine nowadays a strong decrease of the HP recharge, with direct impact on feeding of the confined aquifers in the LP.

The enormous vulnerability of the water quality emerges also if we look at the analysis conducted on the age of waters that indicate that most of the waters deeper than 110 meters, belonging to the systems "C" and above, are older than 15000 years. Deep waters have an extreme high quality but have a very low turnover (Cucchi et al., 2008a, 2008b).

An hypothetical computation of the "exhaustion time" for different aquifer systems - defined as the time required to extract, with the current withdrawal rate, all the water contained in them (without recharging) - will give very variable values, sometimes short. For shallower aquifers as "A" and "B" systems, the depletion time ranges from a minimum of 6 years in the LP in the right Tagliamento to a maximum of 66 years in the LP in the left Tagliamento.

For the system "C", the depletion time ranges from a minimum of 51 years in the Low Central East Plain to a maximum of 349 years in the Low Isonzo Plain. For the system "E", the depletion time ranges from a minimum of 23 years in the LP around Pordenone in the right side of Tagliamento river to a maximum of 153 years in the Low Isonzo Plain.

Deeper aquifer systems are still not much used and so the depletion time greatly increase: for the system "F" the mean depletion time is equal to 274 years.

Shorter are the depletion time higher is the replacement rate of water of the aquifer systems. Seen that the water supply mainly derives from the phreatic groundwaters of the HP, having worse quality, this clearly implies a depletion of artesian aquifers not only in quantitative but also qualitative (Zini et al., 2008), fact that is more relevant seen that the withdrawn water is used also 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 LP 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 much 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 spring rivers: such systems were born to take advantage of the abundant and excellent water quality. Over the years the discharge of these rivers has been reduced and it was noted a quality deterioration, forcing the operators to drill new wells to offset the decrease in both scale and quality. Today, the groundwater withdrawals for fish breeding use are equal to 11.7 m<sup>3</sup>/s on a total of 478 wells. Even if the main part comes from the shallow phreatic aquifers of the LP, it is therefore necessary a water rationalization through the use of oxygenators limiting the discharge withdrawn to the real requirements.

Finally, with regard to the domestic use, in Friuli Venezia Giulia Region was estimated that each person is consuming 17000 l/day that, compared to the European consumptions (about 250 l/day *pro capite*) are about 70 times higher. Even if fountains and sinks in the LP have always been part of the landscape and cultural heritage, it is necessary to reflect on the sustainability of this practice applying for example a discharge reducer, infact withdrawal entity, spring belt discharge, phreatic levels and confined aquifers pressure are closely interdependent and in dynamic equilibrium. The sustainability comes from the consistency and ratio between recharge and withdrawals. The confined aquifers withdrawals in the LP represents the 23.1% of the groundwater recharge coming from the HP and the 30.6% of the spring belt discharge. Seen that the spring belt discharge cannot further decrease, unless loss of important ecosystems, it seems that the present situation can be defined of limit equilibrium.

## Acknowledgments

Project founded by Direzione Centrale Ambiente, Energia e Politiche per la Montagna, Servizio idraulica of the Friuli Venezia Giulia Region in the framework of the Agreement prot. n. 36037 dd 27.11.07 among Servizio idraulica and Trieste University (Departments of Mathematics and Geosciences – D.M.G. and Department of Civil and Environmental Engineering – D.I.C.A.).

The authors would like to thank all the researchers who contribute to the project: Alzetta S., Barison E., Burelli G., Catanese G., Cicogna A., Cimolino A., Cleva S., Deana A., Della Vedova B., Franceschini G., Massari G., Mereu A., Nicolich R., Oberti di Valnera S., Olivo P., Piano C., Pocecco G., Ramani M., Riccamboni R., Schak R. and Turpaud P.

Moreover Prof. Franco Cucchi, head of the project, for his precious advices, corrections and management.

## Additional information

Supplementary information is available for this paper at

<https://doi.org/10.7343/as-2022-713>

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