# The contribution of recharge in mountain area to groundwater in the Lombardy plain aquifer (Northern Italy)

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*Abstract:* - This study purposes to define the quantitative relationship between recharge from mountain aquifers and water availability in plain aquifers of Lombardy (Northern Italy), which is one of the most important areas in Italy for both water resources and industrial activities. To obtain this, a hydrogeological balance for mountains and piedmont areas has been calculated at two different scales: the first regional, the second more detailed for Serio River basin. The results show how important is the contribution of the mountain discharge to the recharge of the plain aquifers.

*Keywords:* - Hydrogeological balance, recharge, basin of Serio River, C. I. P. model, Italy

## 1. Introduction

Lombardy (Fig. 1) is one of the most important Italian Regions for availability of water resources, both on surface and underground. However, urban growth, industrial and agricultural spread caused a change in these resources, both in terms of quality and quantity. In particular, the Lombardy plain, characterized by Pleistocenic – Holocenic glacio-fluvial and alluvial deposits, hosts a multiplayer alluvial aquifer, constituted by gravels and sands interbedded with clays. The plain supports most of the agricultural and industrial activities of Northern Italy, which are associated with groundwater exploitation and pollution. A correct management of water resources in the plain area assumes a correct comprehension of the recharge processes, in particular the relationship with Prealpine aquifers. There are two possible ways to define these relations: one is geochemical and isotopic, which allows to identify the zones where waters come from, quantifying the contributes in percent [8], [9], and the other is an hydrogeological balance-based method [1], [3]. Specifying for Lombardy, the interaction between mountain aquifer system and plain groundwater system has been ignored by literature because of the complexity of the problem and the absence of an adequate monitoring network. However, a correct evaluation of water flows from fractured and karstic systems is necessary to quantify water resources of the Lombardy plain.


*Fig. 1 – Geographical context of study zone*

The purpose of this study[1] is to improve the knowledge about recharge due to groundwater circulation in mountain and piedmont areas of Lombardy, in order to define the inputs of hydrogeological plain system. Actually, groundwater flowing from mountain and piedmont area constitutes the boundary upstream conditions of the plain aquifer system: knowing it is very important to improve the precision in hydrogeological balance and modeling.

[1] Developed within the PRIN Project 2008 "Water resources management and policy in Po Valley"

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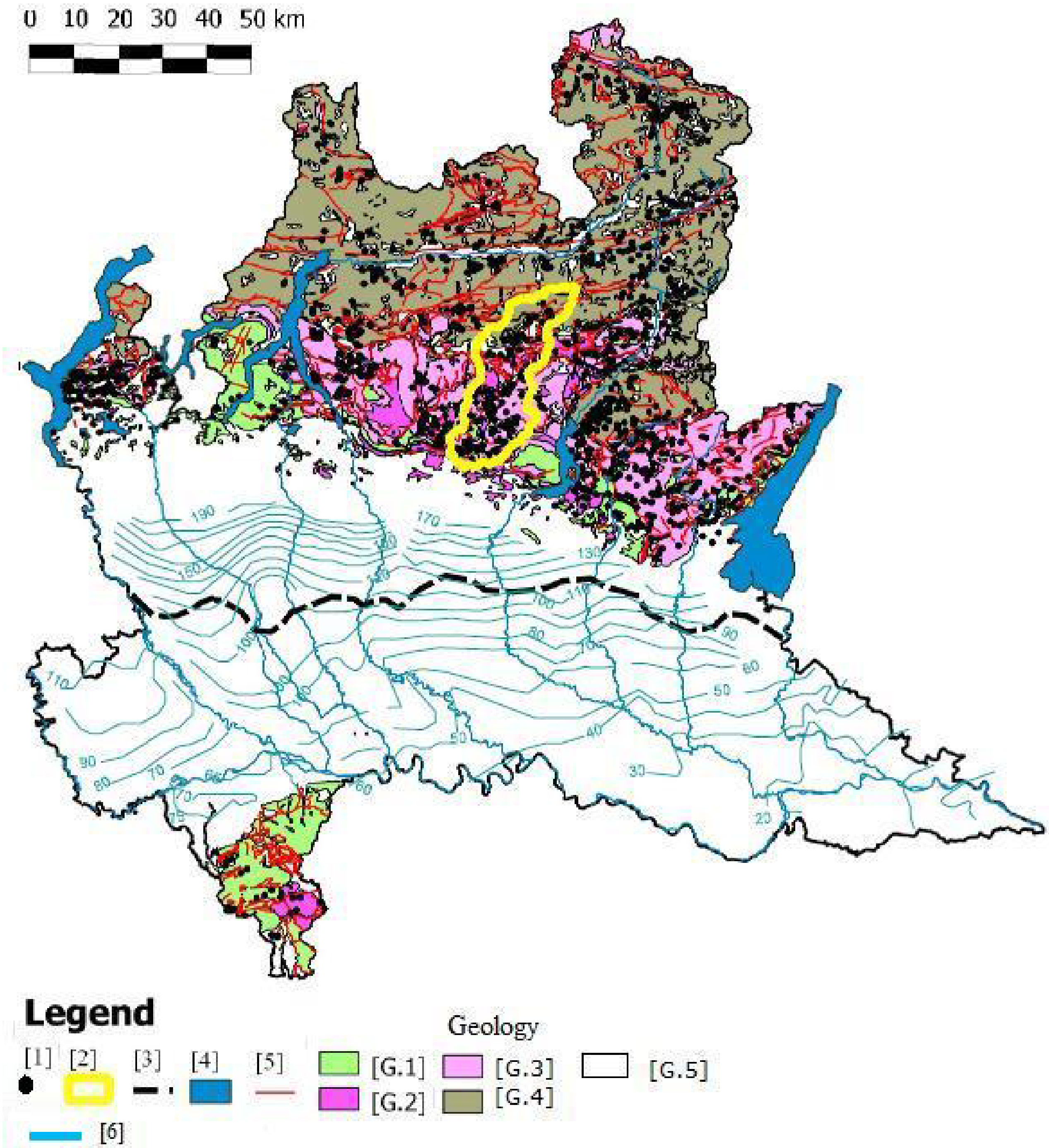


*Fig. 2 – Hydro – geological map of Lombardy with the River Serio basin; legend: [1] – Springs, [2] – the Serio River basin, [3] – Resurgences line, [4] – Lakes and rivers, [5] – Faults, [6] – Piezometric lines in m a.s.l.; Geology: [G.1] – Low permeability sedimentary rocks (marls and clays), [G.2] – Middle permeability sedimentary rocks (marly limestones and flysch), [G.3] – High permeability sedimentary rocks (limestones and dolomites), [G.4] – Magmatic/metamorphic rocks, [G.5] – Alluvial deposits*

For this reason, using different databases, heterogeneous for origin and type of data, an accurate assessment of the amount of recharge from mountains and piedmont aquifers has been computed. In this study, there are two scales of analysis: one, general, focused on the entire Lombardy mountain area, the other, more detailed, focused on the Serio River basin (Fig. 2).

## 2. Hydrogeological setting

The geological outcrops in Lombardy are part of a more complex system which belongs to the Alps and the Apennines and the Lombardy Plain (Pianura Padana). This complex structure can be divided in four main sections (Fig. 2) [11]:

- The Alpine zone: there are mainly crystalline rocks (magmatic and metamorphic) interbedded

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with limestones and dolomites; even if there are few volumes of groundwaters, these rocks can release important flows, due to climatic factors (high rainfall) and geostructural factors (fracture and alteration zones);

- The Prealpine zone: carbonate rocks primarily constitute an important groundwater reservoir, connected to the presence of karstic structures, despite the presence of marl levels;
- The Apennines placed to the South of the Po River: the stratigraphic series is constituted by marls and limestones, sandstones and conglomerates, with flysch and clays, called Argille Scagliose, generally characterized by low hydraulic permeability;
- The Pianura Padana: this plain area is constituted by a bedrock with low permeability, superimposed by glacial and alluvial deposits. These sediments are usually gravels, sands, silt and clays, and are characterized by frequent vertical and horizontal transitions.

More in detail, in the plain area an unconfined shallow aquifer is underlain by deeper semi – confined and confined aquifers. Inside the stratigraphic sequence of Pleistocene and Quaternary deposits it is possible to single out four Aquifer Groups [10], called A, B, C and D (from the youngest to the oldest). The aquifers traditionally exploited in the plain area (A and B) consist of a hydrogeological system of unconfined and semi-confined aquifers within a system of very heterogeneous layers. As far as the deep aquifers are concerned (groups B, C and D), the water sources are located along the foot hills areas of the Alps and Apennines which correspond with the direct recharge areas of these aquifers [5]. Even if nowadays there is no detailed evaluation regarding the yield of the different geological units of the Lombard hydrogeological series, previous researches [7] have evidenced a well differentiated productivity in term of the yearly average discharge of the springs per km$^2$.

## 3. Hydrogeological balance at regional scale

The purpose of this study is to calculate and solve at a regional scale the following balance equation:

$$\begin{cases} P - ET = PE \\ PE = PN + INF \\ PE - INF = PN \\ R = INF - PT \end{cases} \quad (1)$$

where $P$ is rainfall, $ET$ evapotranspiration, $PE$ effective rainfall, $INF$ infiltration, $PN$ surface runoff, $PT$ spring discharge, and $R$ recharge to alluvial plain aquifers.

Based on available thermometric and pluviometric stations, an interpolation of rainfall ($P$, Fig. 3) and temperature data has been done for all the basin area. To that aim the *nearest neighborhood-method*, based on Thiessen Polygons [14] and that utilizes data from the nearest $n$ points, where $n$ is an arbitrary integer, has been used.

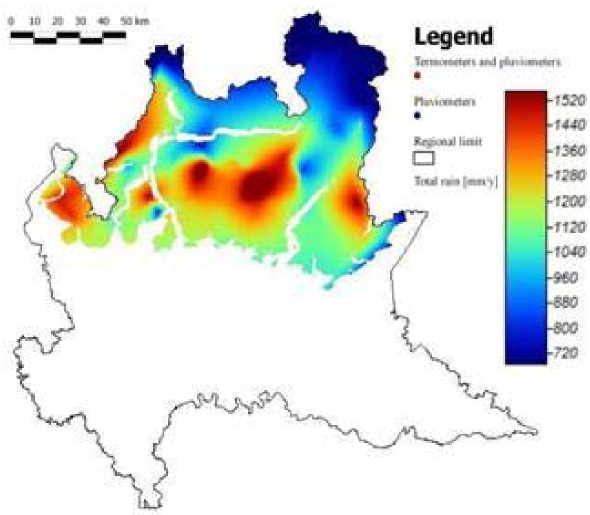


*Fig. 3 – Interpolation of rainfall data in Northern Lombardy*

Applying Turc's Model [15], an estimation of evapotranspiration (*ET*) has been done, and then, by difference, the effective rainfall (*PE*) has been computed.

Then, the Italian C.I.P. Model (*Potential Infiltration Coefficient*) [4] has been used to estimate infiltration (*INF*) (Fig. 4). This model is based on coefficients, determined from experimental observations of soil covers and geological structure, which multiply *PE* to calculate *INF*. Yet recharge (*R*) is only a part of the water which infiltrates, whereas an another part (*PT*) supplies springs.

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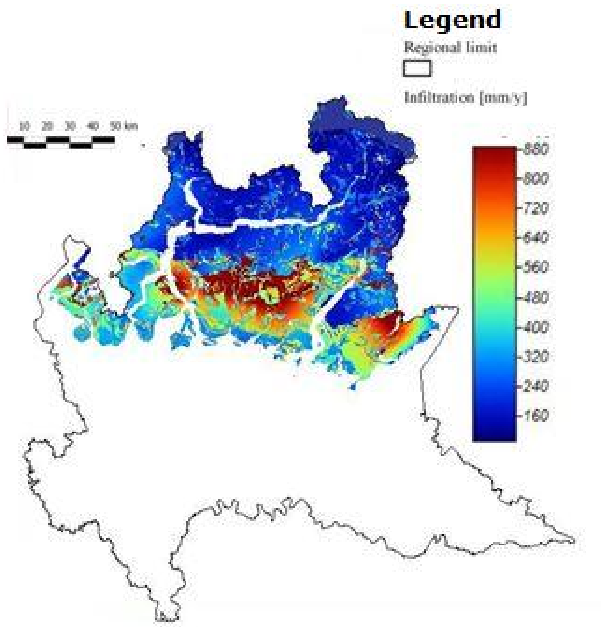


*Fig. 4 – Yearly infiltration rate for Northern Lombardy.*

The resulting recharge to plain aquifers could be underestimated as a consequence of the lack of data in spring discharge (Fig. 5).

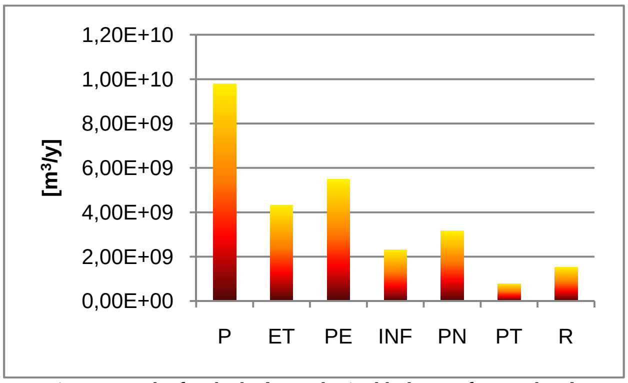


*Fig. 5 . Results for the hydrogeological balances for Lombardy*

On the basis of the results obtained, the ratios among the different balance elements has been considered (Tab. 1).

*Tab. 1 – Ratio between the different balance elements at regional scale*

| | | |
|---|---|---|
| $[R_1]$ = | R / INF = | 65,95% |
| $[R_2]$ = | R / PE = | 27,87% |
| $[R_3]$ = | R / P = | 15,60% |
| $[R_4]$ = | INF / PE = | 42,26% |
| $[R_5]$ = | INF / P = | 23,65% |

The amount which contributes to recharge plain aquifers is about *66%* of infiltration, whereas the ratio of recharge on total rainfall is about 1*5%*.
The flow which contributes to recharge plain aquifer is *48.5* $m^3/s$, considerably bigger than the flow extracted from groundwater plain aquifer for human uses, equal to *34.1* $m^3/s$. This result allows to consider that the recharge is important to maintain and preserve the plain groundwater availability.

## 4. Hydrogeological balance for the Serio River basin

The studied area has an extension of about *450* $km^2$ and it is characterized by great difference in altitude (from *361* m a.s.l. in Cene to about *2900* m a.s.l.). The Serio River basin mainly consists of carbonate rocks, where large fractured-karst aquifers developed. The presence of a well organized epikarst layer on surface brings about an important infiltration capacity in all the basin. A number of springs are supplied by this hydrogeological system, among them the two most important are the Nossana Spring [5] and the Ponte del Costone Spring, having an average discharge of more than *3.8* $m^3/s$. The waters coming from the Serio River basin supply the plain area enclosed between the Adda and Oglio rivers.
In the balance, two different portions of Serio River basin have been considered: the mountain basin, and the piedmont basin, which extends towards the valley (the two areas are identified by the black line in Figs. 7 – 8), in order to analyze how much each portion contributes to the recharge. The results have been afterwards aggregated, to obtain a global hydrogeological balance.

Thanks to detailed knowledge of springs in Serio Valley, the estimate of the recharge (*R*) is more accurate than the previous regional analysis (Section 3). Results are resumed in following Figures 6, 7 and 8, and Table 2.

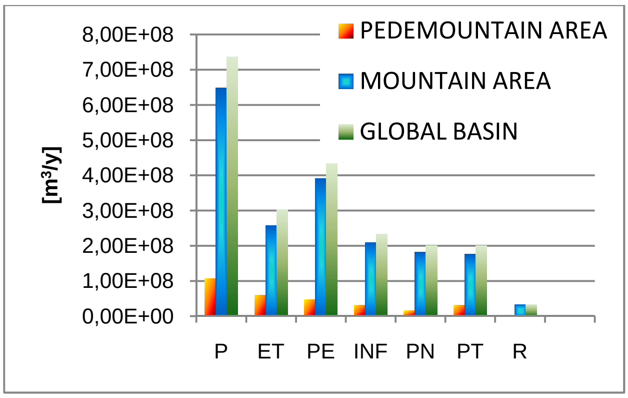


*Fig. 6 – Results for hydrogeological balance of Serio River basin*

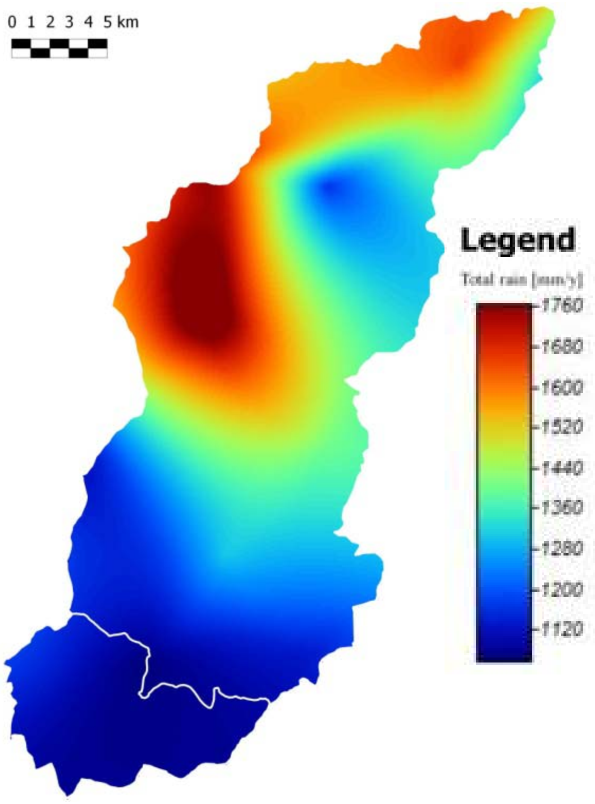


*Fig. 7 – Interpolated rain for all the Serio River basin; the white line identifies the separation between mountain (upper area) and piedmont area (lower area)*

*Tab. 2 – Ratios between volumes in Serio River balance*

| | PIEDMONT | MOUNTAIN | GLOBAL |
|---|---|---|---|
| $R_1$=R/INF | 0,95% | 15,79% | 14,16% |
| $R_2$=R/PE | 0,64% | 8,44% | 7,60% |
| $R_3$=R/P | 0,28% | 5,08% | 4,48% |
| $R_4$=INF/PE | 67,88% | 53,45% | 53,69% |
| $R_5$=INF/P | 29,63% | 32,20% | 31,61% |

The results underline how the contribute to recharge from piedmont area is very small, whereas the recharge from the mountains is more consistent. Total recharge is about *6.5* $m^3/s$ corresponding to about *5%* of total rainfall and 14% of infiltration. Considering the flow drawn from the groundwater aquifer in plain area (Adda – Oglio system), equal to *5,78* $m^3/s$ [13], the recharge coming from mountain is quite equivalent to the drawings in alluvial aquifer.

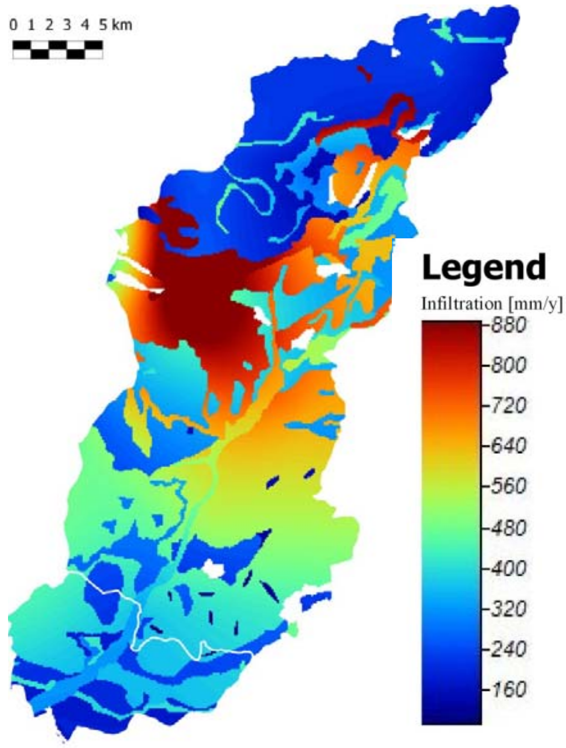


*Fig. 8 – Infiltration for the Serio River basin; the white line identifies the separation between the mountain (upper area) and piedmont area (lower area).*

## 5. Conclusions

At a regional scale, the amount of groundwater flowing from mountain aquifer contributes to recharge the plain aquifers in Lombardy sufficient to satisfy the human water needs (in fact, the recharge is about *140*% of consumptions).

Considering the Serio River basin, the recharge amount is smaller than at regional scale (at about *14%* of infiltration), due to the high number of springs. Nevertheless, the amount of recharge is sufficient to satisfy the human water consumptions, because the recharge is about *112*% of drawings.

The hydrogeological balance presented in this study can be the first important step to implement numerical models capable of simulating water exchanges between the plain and the mountain areas. By doing this it is possible to obtain quantitative informations on outflows and relationship between surface and groundwater aquifers.

Another possible improvement is to use these models like provisional instruments.

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