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Deliverable summary

This document provides an accurate description of provision of storage and curation of data carried out in the first part of the project. Here, we summarize all available geological and hydrological data collected for the two field sites analysed within the project: the Bologna and the Cremona Aquifer systems, located in the Po Plain, Northern Italy. The Bologna and Cremona sites are archetypal of two distinct realities of alluvial aquifers, and can be considered representative of diverse environmental settings of Europe-wide interest. Both sites are heavily exploited, but associated with different degrees of knowledge, monitoring and even processes involved. For each type of data we report: data source, number and location of measurement points and monitoring period and frequency. This deliverable will be continuously updated as soon as new data become available.

D1.1

Provision of storage and curation of data

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1. Introduction

WE-NEED considers direct pilot application to two field sites representing different but complementary realities: the Bologna and the Cremona Aquifer systems, located in the Po Plain, Northern Italy (Figure 1.1). The *Bologna* and *Cremona* sites are archetypal of two distinct realities of alluvial aquifers, and can be considered representative of diverse environmental settings of Europe-wide interest. Both sites are heavily exploited, but associated with different degrees of knowledge, monitoring and even processes involved. In this document we summarize all the available data that we collected during the first year of the project for the two areas.

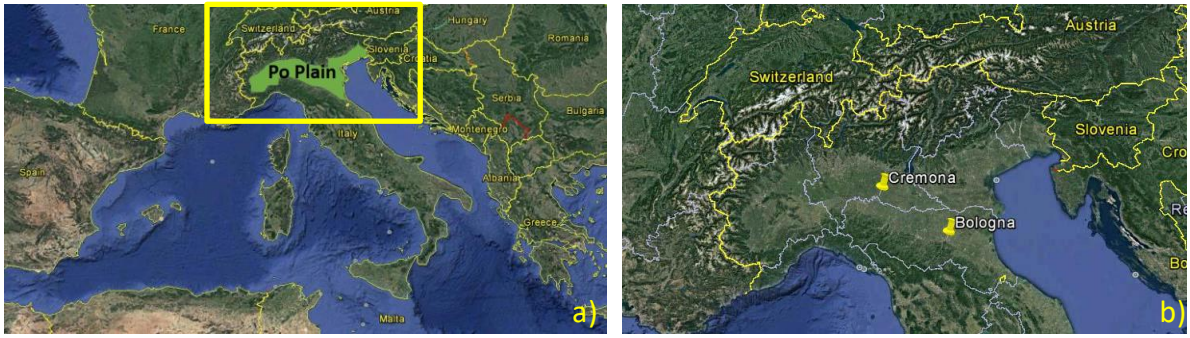

Figure. 1.1. Geographical framework of the study area. (a) Location of Po Plain; (b) Location of Cremona and Bologna cities.

2. Cremona site

The study area lies in the Lombardia region (northern Italy), inside the territory called "Po Plain", between the cities of Bergamo and Lodi. Its location within the Lombardia region is shown in Figure 2.1. The western-southern boundary of the area of interest is formed by the Adda river, flowing from North to South until it joins the Po river; the eastern boundary is the Serio river, flowing from North to South until it flows into Adda river. The northern side lacks of a defined hydrological limit. We adopt as northern bound the same limit indicated in a previous work (Rametta, 2008) collocated in correspondence of the UTM coordinate 5060180 North. The surface area of the domain investigated is about 785 km^2. The selected territory includes portions of three administrative provinces (Cremona, CR, Bergamo, BG, and Lodi, LO). A key feature of the study area is the occurrence of natural high-quality water springs which are the main supply to agriculture and a key environmental driver. These natural springs (and the associated historical buildings and hydraulic works) have remarkable social, historical and touristic value. Concerning this site we have collected a large amount of geological and hydrological data summarized in Table 2.1 and described in the following subsections.

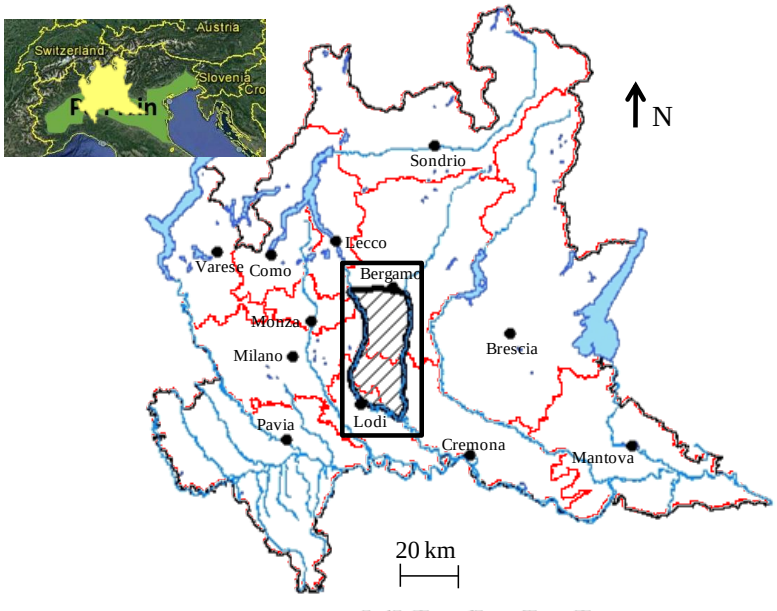

Figure 2.1. Lombardia region. Dashed area highlights the Cremona site. Red lines depict boundaries of administrative provinces.

	Data Type	N points	Monitoring Period	Monitoring Frequency	Sources
Geological Data	**Lithostratigraphic-cross sections**	15	-	-	CMPB[1] - Maione et al. (1991)
	Geological stratigraphies	553	-	-	Geoportale Lombardia
Hydrological Data	**Precipitation and temperature**	7	2010-2016	Daily	ARPA[2] Lombardia
	Groundwater quality	41	2011-2014	Twice a year	ARPA Lombardia
	Surface water quality	22	2011-2014	Once a year	ARPA Lombardia
	Piezometric level	26	2010-2015	Monthly	ARPA Lombardia
		20	2005-2015	Bimonthly	CMPB
	Hydrometric level	3	2010-2015	Hourly	ARPA Lombardia
	Pumping wells	81	-	-	Catasto utenze idriche
	Natural springs	125	-	-	Geoportale Lombardia

Table 2.1. List of available data collected for the Cremona site.

[1] CMPB: Consorzio Media Pianura Bergamasca

[2] ARPA: Regional Agency for Environmental Protection

2.1 Geological data

Data source: CMPB; Maione et al. (1991); Geoportale Lombardia.

Link: http://www.geoportale.regione.lombardia.it/download-dati#

Geological data located within and in the surrounding of the study area include:

(i) 15 lithostratigraphic cross sections, named from S1 to S15 (Figure 2.2) provided by CMPB and by Maione et al. (1991). As an example, the lithostratigraphic cross section S3 is shown in Figure 2.2.

(ii) 553 geological stratigraphies collected from the database of Regione Lombardia (Geoportale Lombardia). The depth of the wells b.g.l. ranges between 1 to 320 m (Figure 2.2). As an example of the information available at each location, the geological stratigraphy at well C6A267426178 (UTM coordinates x = 546795 m, y = 5036360 m, close to the intersection between section S3 and S14 in Figure 2.2) is reported in Table 2.2.

On the basis of this geological information, we identify the following main lithostratigraphic units:

(i) deposits of gravel and sand locally interrupted by silt and clay lenses;

(ii) alternation of lithotypes formed by gravel and sand and by silt and clay;

(iii) deposits mainly formed by silt and clay (with occasional sand inclusions);

(iv) deposits of silt and sand (Asti sand).

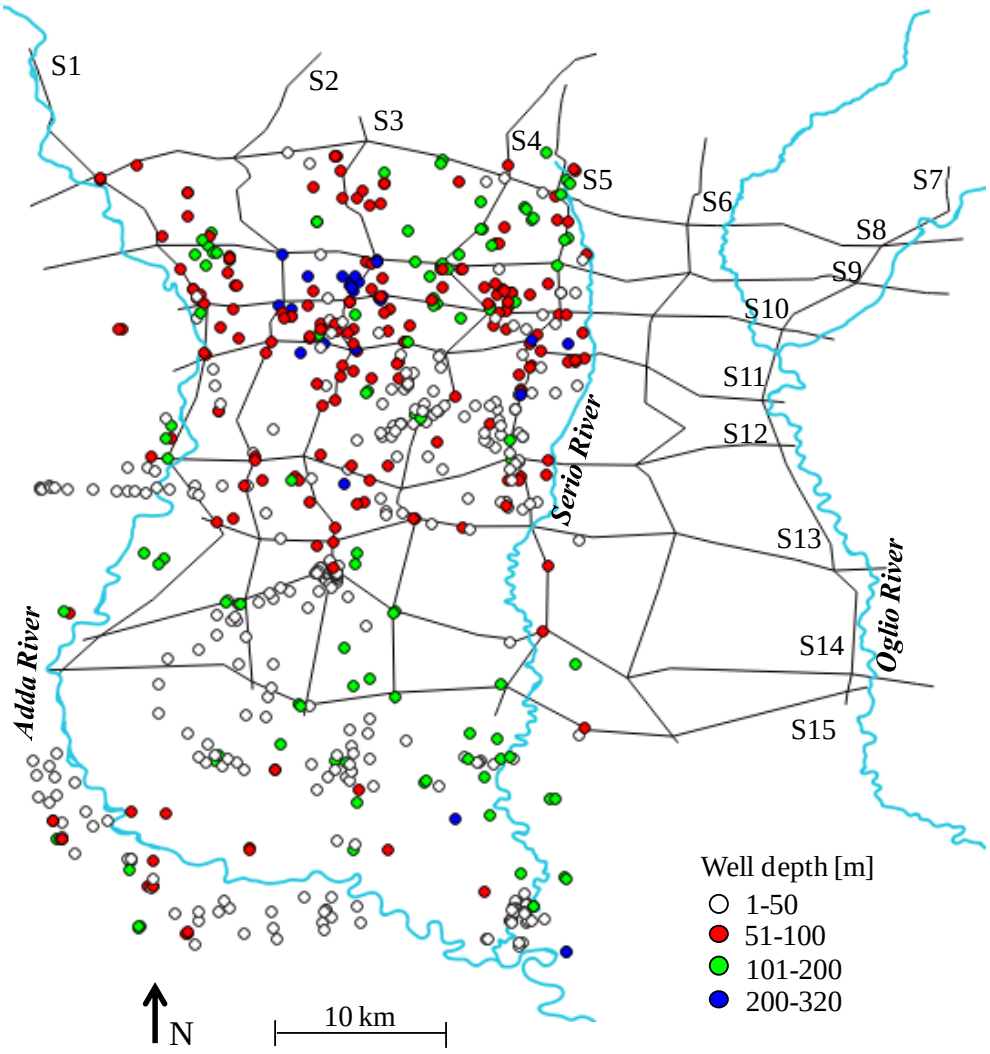

Figure. 2.2. Location of lithostratigraphic cross sections and geological stratigraphies within the study area. Wells are depicted with different colors depending on their depth b.g.l.

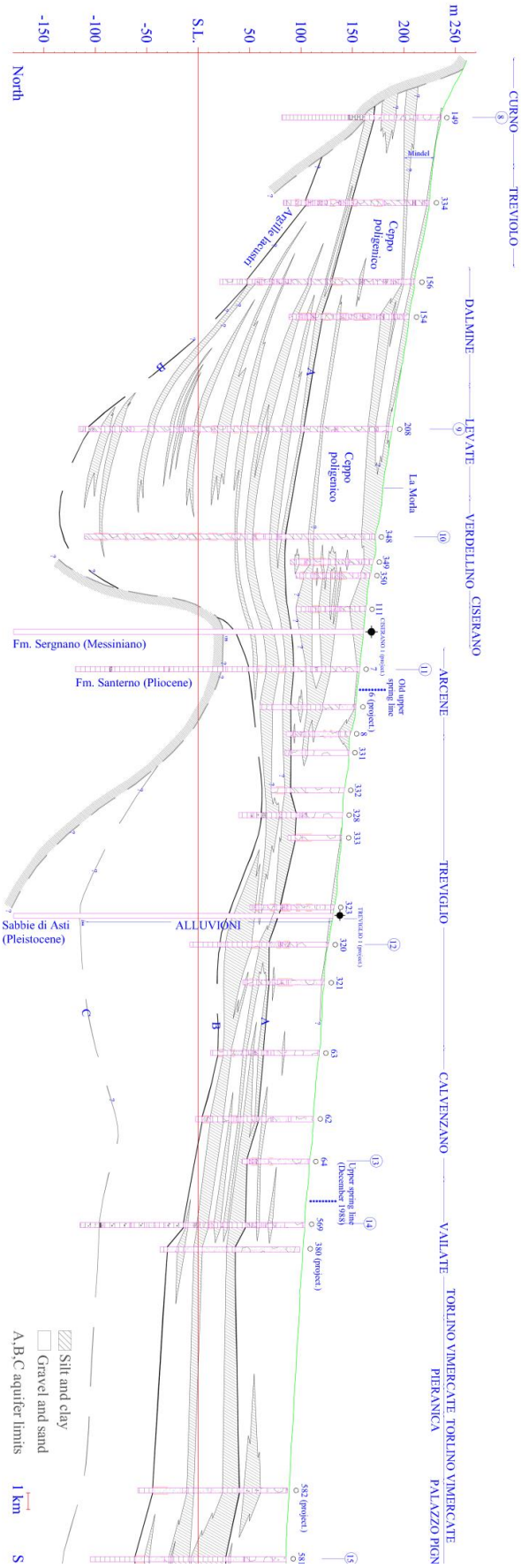

Figure. 2.3. Cross section S3 (see location in Figure 2.2).

Ground level (m a.s.l.)	Depth (m b.g.l)	Level	Top (m b.g.l.)	Bottom (m b.g.l.)	Top (m a.s.l.)	Bottom (m a.s.l.)	Thickness (m)	Lithology
106	64.5	1	0	29	106	77	29	Coarse gravel with few sand inclusions
		2	29	35	77	71	6	Clay sand with few inclusions of gravel and conglomerate
		3	35	39	71	67	4	Gravel
		4	39	46.5	67	59.5	7.5	Sand
		5	46.5	49.5	59.5	56.5	3	Clay with sandstone
		6	49.5	57	56.5	49	7.5	Gravel and sand with conglomerate
		7	57	60	49	46	3	Sand with sandstone
		8	60	64.5	46	41.5	4.5	Clay

Table 2.2. Lithology of well C6A267426178, UTM coordinates x = 546795 m, y = 5036360 m.

2.2 Precipitation and temperature

Data source: ARPA Lombardia

Link: http://www2.arpalombardia.it/siti/arpalombardia/meteo/richiesta-dati-misurati/Pagine/RichiestaDatiMisurati.aspx

Meteorological measurements are available from year 2010 to year 2016 at 7 meteorological stations located within and around the area of interest as illustrated in Figure 2.4. Data include measurements of temperature and precipitation on a daily basis. As an example Figure 2.5 depicts the monthly mean temperature and precipitation recorded at the station Rivolta D'Adda for the period 2010 - 2015.

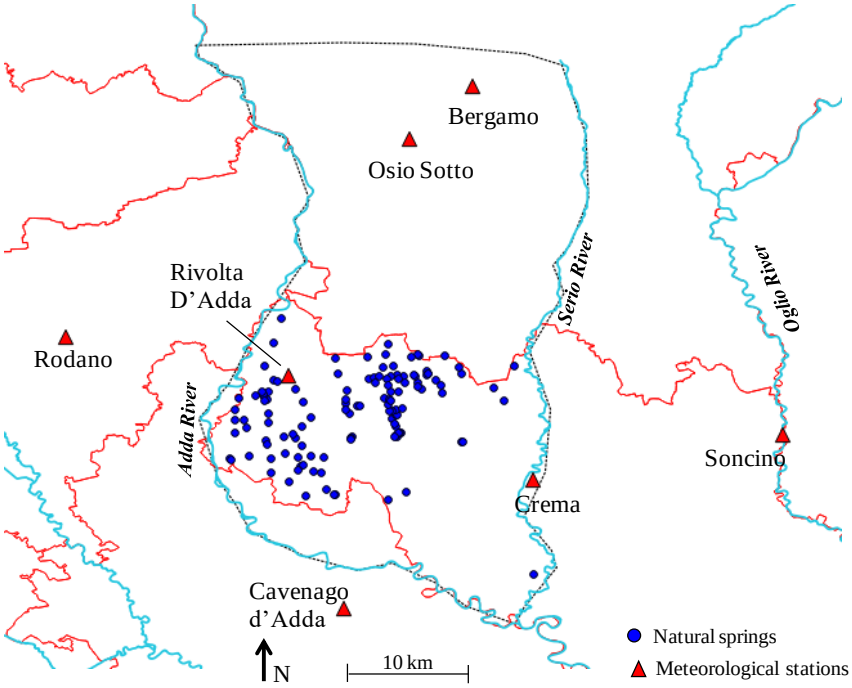

Figure 2.4. Location of meteorological stations (triangle-shaped symbols) and natural springs (circle-shaped symbols). Red lines depict boundaries of provinces.

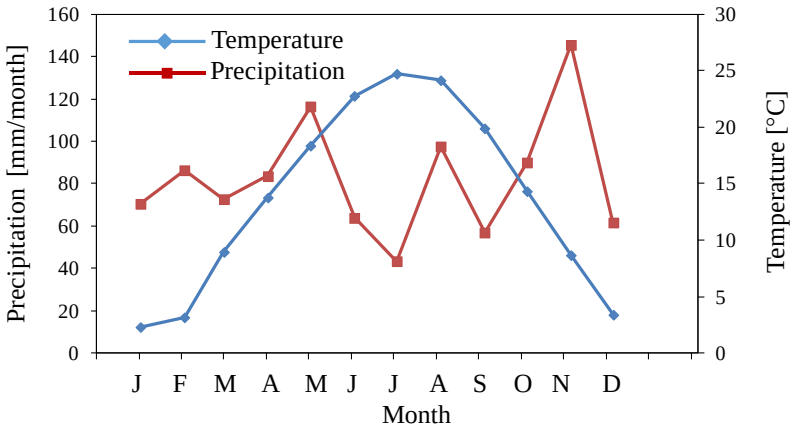

Figure 2.5. Monthly averages of temperature and precipitation recorded at Rivolta d'Adda station, period 2010 – 2015.

2.3 Groundwater/surface water quality

Data source: ARPA Lombardia

Link: http://shp.arpalombardia.it/sites/arpalombardia2013/RSA/Pagine/indicatori.aspx?p1=2

Groundwater. Chemical analyses of groundwater quality are available from year 2011 to year 2014 at 41 points within and in the surrounding the area of interest. Location of monitoring stations is shown in Figure 2.6. Samples for chemical analyses are usually collected twice a year (during spring and autumn). Available data include measurements of

water temperature; pH; 1,2,4-Trichlorobenzene; 1,2-Dichloroethylene; 1,4-ichlorobenzene; Alachlor; Aldrin; Antimony; Arsenic; Atrazina; Atrazina-desetil; Atrazina-desisopropil; Bentazone; Benzene; Benzo (a) pyrene; Benzo (b) fluoranthene; Benzo (g,h,i) perylene; Benzo (k) fluoranthene; Beta-Esachlorocycloexane; Boron;Bromacil; Bromine-dichloro-methane; Cadmium; Calcium; Carbon tetrachloride; Chlorides; ChromiumVI; Cyanides; Electric conductivity 20°C; DDT,DDD,DDE; Dibenzo (a,h)anthracene; Dibromo-chloro-methano; Dicamba; Dichlorobenzamide 2,6; Dicloroethane 1,2; Dicloroethylene cis; Dicloroethylene trans; Dichloromethane; Dieldrin; Dissolved Oxygen; Endrin; Ethylbenzene; Fluorides; Glyphosate; Hardness; Hexachlorobenzene; Hexachlorobutadiene; Indeno (1,2,3,cd) pyrene; Ion Ammonium (NH4+); Isodrin; Isopropilbenzene; Iron; Lead; Linuron; Magnesium; Manganese; Mercury; Metolachlor; Molinate; Monochlorobenzene; Nikel; Nitrates; Nitrites; Nitrobenzene; Organic Nitrogen; Pentachlorobenzene; Potassium; Propanil; Selenium; Simazine; Sodium; Styrene; Sulphates; Sum (aldrin, dieldrin, endrin, isodrin); Summation of phytopharmaceuticals; Summation organhalogen; Terbuthylazine; Terbuthylazine desetil; Tetrachloroethane 1,1,2,2; Tetrachloroethylene; Toluene; Total Chromium; Total Hydrocarbons (n-esano); Total Nitrogen; Trichlorobenzene; Trichloroethane 1,1,1; Triclhoroethane 1,1,2; Trichloroethylene; Trichloromethane; Vanadium; Vinyl Chloride; Zinc; Xilene (sum isomers); Xilene meta; Xilene orto; Xilene para. As an example, distribution of Nitrates and Pesticides for year 2014 (autumn campaign) is shown in Figure 2.6a and 2.6b, respectively.

Surface water. Chemical analyses of surface water quality are available from year 2011 to year 2014 at 22 points within and in the surrounding of the area of interest. Location of sampling points is depicted in Figure 2.7. Samples for chemical analyses are collected once a year. Data include a qualitative indicator of water quality based on the LIMeco Index. This index describes the trophic level of the water sample considering four parameters: ammonia nitrogen, nitric nitrogen, total phosphorus and the level of dissolved oxygen expressed as percentage of saturation. LIMeco Index gives five qualitative values (Excellent, Good, Sufficient, Scarce) for decreasing quality of the sample. Figure 2.7 shows the distribution of LIMeco Indeces measured in 2014 for the area of interest.

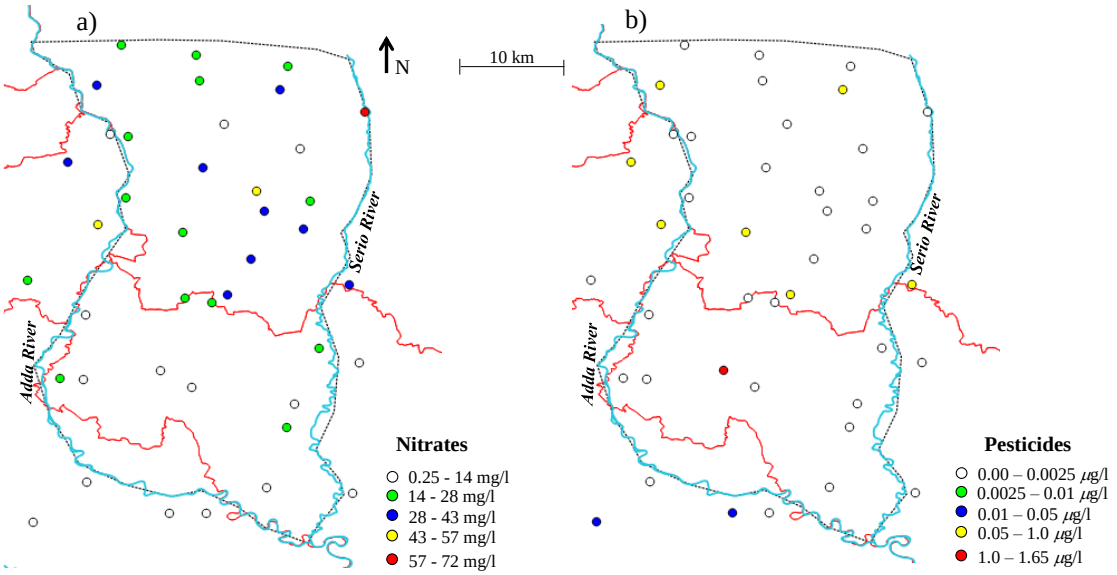

Figure 2.6. Location of groundwater quality measurement stations in the area of interest. a) Distribution of Nitrates (autumn 2014); b) Distribution of Pesticides, i.e. summation of Phytopharmaceuticals (autumn 2014). Red lines depict boundaries of provinces.

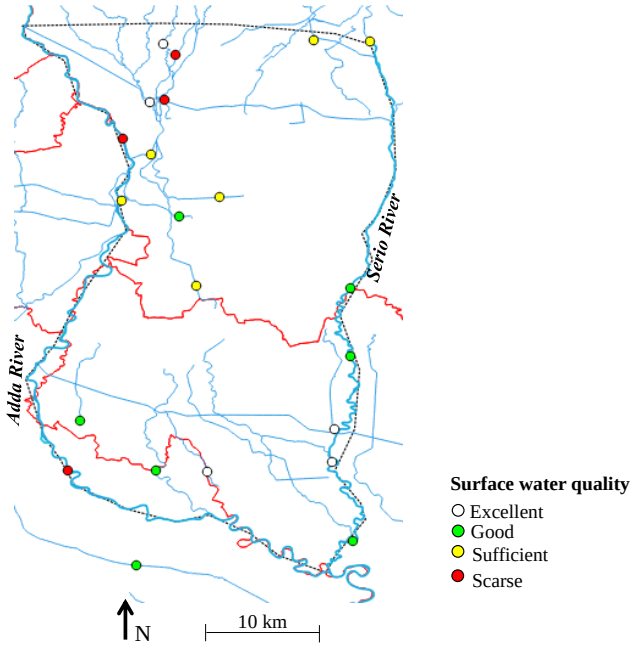

Figure 2.7. Location of the surface water quality measurement stations in the area of interest and associated LIMeco Indeces (year 2014). Red lines depict boundaries of provinces.

2.4 Piezometric levels

Data source: ARPA Lombardia, CMPB.

ARPA Lombardia. Piezometric level measurements are available from year 2010 to year 2015 at 26 observation wells located within the area of interest. The depth of the monitoring wells ranges from 9 to 249 m b.g.s.. Piezometric data are usually collected on a monthly basis. Based on sedimentological and hydrogeological analyses, ARPA Lombardia (PdGPo, 2015) identified in the area three main aquifer systems: the Superficial aquifer system of high and medium plain (ISS), the Intermediate aquifer system of medium plain (ISI) and the Deep aquifer system of high and medium plain (ISP). The location of ARPA observation wells is shown in Figure 2.8 (circle-shaped symbols) with diverse colours depending on the monitored aquifer system (ISS, ISI or ISP). As an example, piezometric measurements recorded at the observation well PO019035NRA001 (UTM coordinates x = 552725; y = 5023133) during 2015 are shown in Figure 2.9 together with the cumulated monthly precipitation measured at a close meteorological station (Crema station, see Figure 2.4).

CMPB. Piezometric level measurements are available from year 2005 to year 2015 at 20 observation wells located within the area of interest (see squared-shaped symbol in Figure 2.8). Depth of the monitoring wells is not available. Piezometric data are usually collected on a bi-monthly basis.

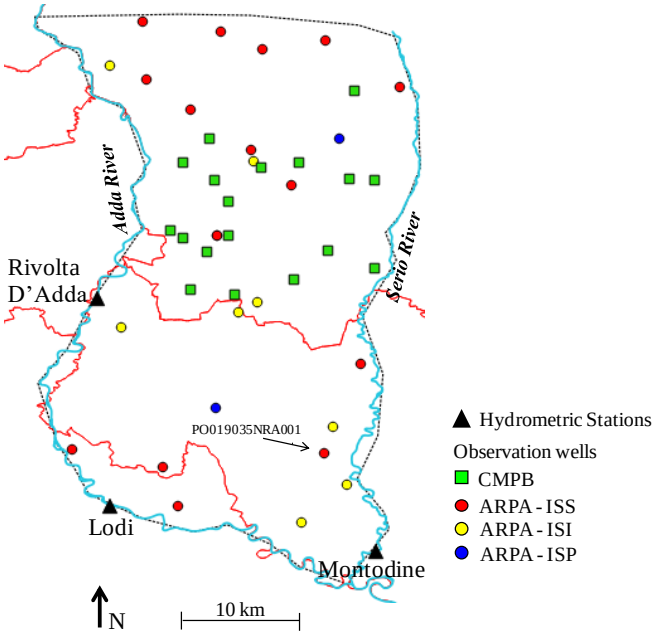

Figure 2.8. Location of ARPA (circle-shaped symbols) and CMPB (square-shaped symbols) wells within the area of interest. ARPA wells are reported with diverse colours depending on the monitored aquifer system. The location of well PO019035NRA001 and of hydrometric stations (triangle-shaped symbol) are also shown. Red lines depict boundaries of provinces.

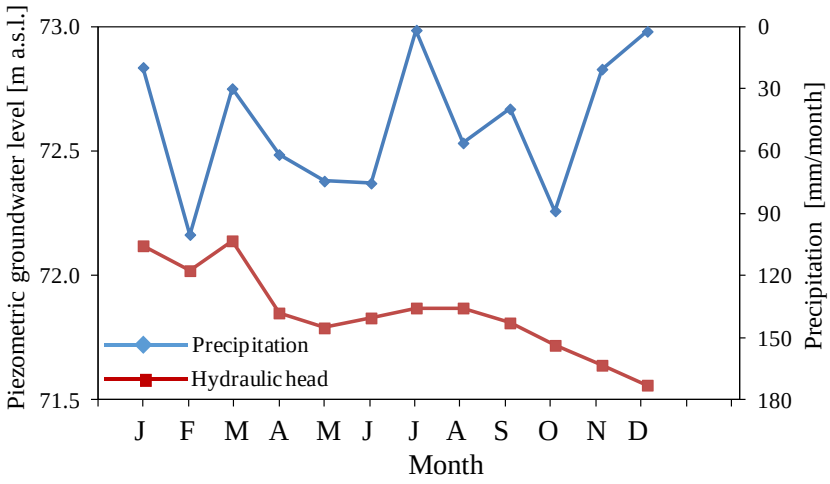

Figure 2.9. Piezometric level at well PO019035NRA001 (UTM coordinates x = 552725; y = 5023133) and monthly precipitation at the meteorological station of Crema, year 2015.

2.5 Hydrometric levels

Data source: ARPA Lombardia.

Link: http://www2.arpalombardia.it/siti/arpalombardia/meteo/richiesta-dati-misurati/Pagine/RichiestaDatiMisurati.aspx

Hydrometric measurements are available from year 2001 to year 2015 within the area of interest at 2 locations along the Adda river and at 1 locations along the Serio river as illustrated in Figure 2.8. For each station topological characteristics are available, including location and hydrometric zero. Data include measurements of water level on hourly basis. Minimum, maximum and average daily water levels are also available. Figure 2.10 depicts an example of average daily hydrometric measurements at the Rivolta d'Adda station (see its location in Figure 2.8) for year 2015.

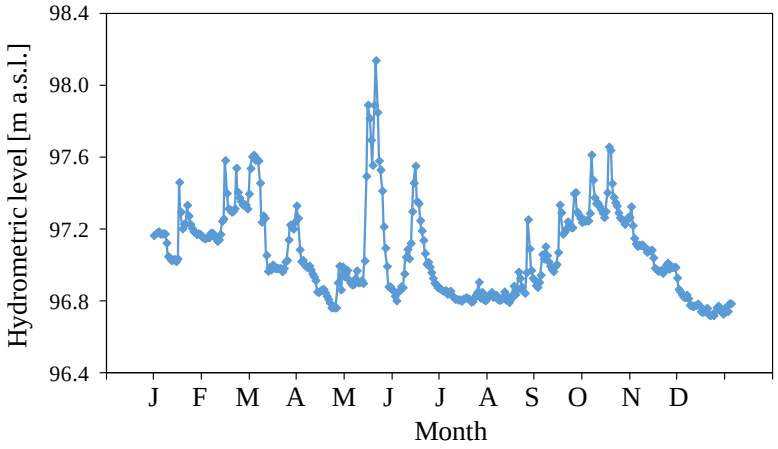

Figure 2.10.Hydrometric measurements at the Rivolta d'Adda station, year 2015.

2.6 Pumping wells

Data source: Catasto Regionale delle Utenze Idriche.

Link:http://www.cittametropolitana.mi.it/ambiente_old/acqua/acque_superficiali/info_tecniche/catasto_utenze_idriche.html

Withdrawals from the aquifer system for agricultural, industrial and drinking purposes are regulated by the local public administration. Values of water concessions are available at 194 pumping wells in the area of interest (60, 80 and 54 wells, respectively for agricultural, industrial and drinking purposes). The location of all wells is not available. For this reason, we localized each well at the baricentrum of the corresponding municipality as illustrated in Figure 2.11. Figure 2.12 depicts the cumulated value of water concessions subdivided by the

use updated at 2016. The screen of pumping wells is located (on average) at depth 60÷80 m b.g.l. (withdrawals for drinking purposes), 40÷50 m b.g.l. (withdrawals for industrial use) or 20÷30 m b.g.l. (withdrawals for agricultural activities).

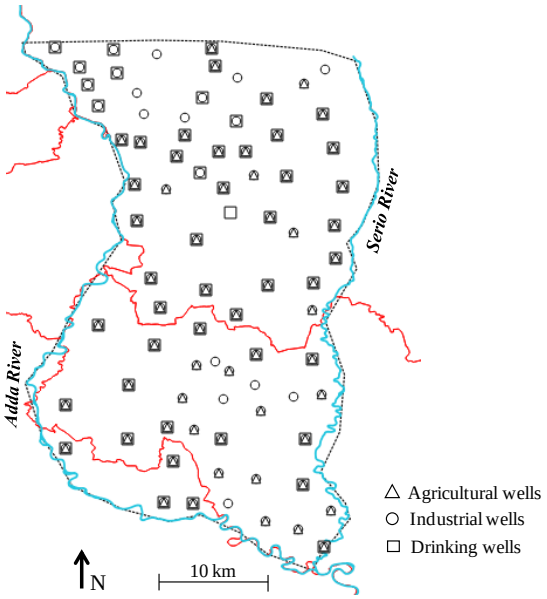

Figure 2.11. Location of pumping wells in the study area. Square-, circle- and triangle-shaped symbols represent wells used for drinking, industrial and agricultural, respectively. Red lines depict boundaries of provinces.

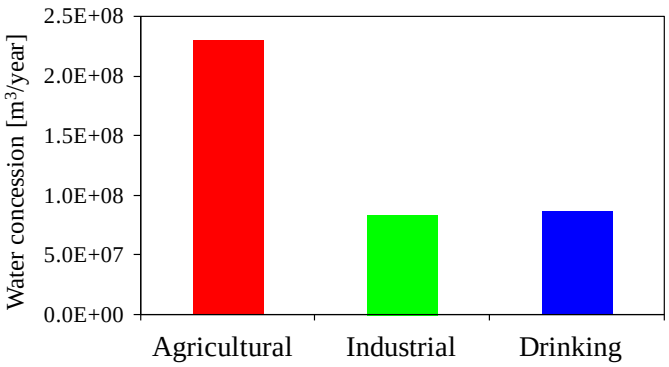

Figure 2.12. Water concession for the wells located within the study area, year 2016.

2.7. Natural springs

Data source: Geoportale Lombardia

Link: http://www.geoportale.regione.lombardia.it/download-dati#

A total of 125 springs are located within the area of interest (see circle-shaped symbol in Figure 2.4). The available database reports the exact location of each spring, while discharge measurements are not available.

3. Bologna site

The Bologna site is part of a high-medium alluvial plain in the Emilia Romagna region (close to the city of Bologna). The study area, of about 400 km^2, is located within the Reno alluvial fan. Two major well fields (Borgo Panigale and Tiro a Segno. managed by Hera S.p.A.) are located within the area of interest (Figure 3.1).

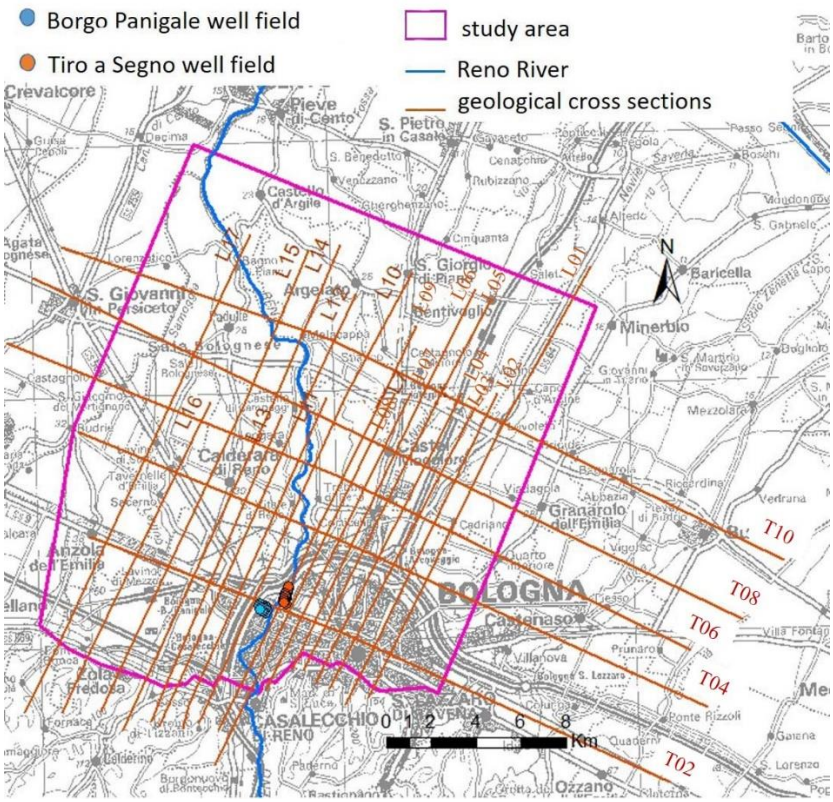

Figure 3.1. Limits of the study area together with the location of the well fields and traces of geological cross sections provided by the Geological, Seismic and Soil Survey of the Emilia Romagna Region.

The plain around Bologna is part of the Po Basin fill, which is a syntectonic sedimentary wedge (Ricci Lucchi, 1984) forming the infill of the Pliocene–Pleistocene foredeep. The sedimentary evolution of the basin is characterized by an overall regressive trend from Pliocene open marine facies to Quaternary marginal marine and alluvial deposits, respectively indicated as cycle Qm and Qc by Ricci Lucchi et al. (1982). According to previews studies (Regione Emilia–Romagna and ENI, 1998) cycle Qc is subdivided into two coarse units, respectively denominated Cycle A and Cycle B. The lower portion of these units, whose thickness is about 100–150 m, is formed by clayey deposits. The latter lies on Cycle C, which, in turn, is the upper portion of Cycle Qm. Cycle Qc is essentially composed of coarse deposits with subordinate clay, while sand deposits are scarce. The alluvial deposits form large and productive aquifer systems. Three Plio-Pleistocene aged fresh water aquifers have been identified: Aquifer Group A (between 0 and 150-200 m b.g.l.), Aquifer Group B (between 150 and 300-350 m b.g.l.) and Aquifer Group C (more than 300-350 m b.g.l.). These correspond to Cycle A, B, and C respectively. Aquifer groups A and B are essentially composed of alluvial deposits. Aquifer group C is formed by sea deposits (Regione Emilia Romagna- Eni 1998). Coarse deposits are essentially related to the fluvial activity of the Apennine streams and of the Po River. Generally, these aquifers are separated by discontinuous horizons (aquitards) of variable thickness and lithology.

Based on sedimentological and hydrogeological analyses, three main hydrogeological complexes, i.e., Apennine alluvial fans, Apennine alluvial plain and alluvial and deltaic Po plains, are identified within the Emilia Romagna region. The Apennine alluvial fan complex characterizes the uppermost portion of the Po basin at its southern border (Apennine Piedmont area). It is formed by an array of coalescent fans. The mainly coarse deposits are related to the fluvial activity of the Apennine streams. In areas close to the alluvial fans, where recharge boundary conditions can be identified for the plain aquifers, the ground water is essentially unconfined. Multilayered confined or semiconfined aquifers can be recognized in the distal portions, due to the occurrence of interbedded fine deposits. Gravel is gradually replaced by sand deposits in the northern part of the plain and the thickness of fine deposits increases (Regione Emilia–Romagna, 2010). These depositional units become mainly silty-clayey with local inter-bedding of coarser material. Four confined hydrogeological units, indicated as A1, A2, A3, and A4 in Figure 3.2, are identified within aquifer group A. A free surface layer A0 (with average thickness of about 10 m and discontinuous sand deposits) overlies these units (Figure 3.2). An upper confined portion including A1 and A2 and a lower

confined portion including A3, A4. Aquifer group B and aquifer group C have been distinguished within the aquifer system in a series of studies aimed to delineate ground water bodies for the implementation of Directive 2000/60/CE (Regione Emilia–Romagna, 2010). The study area lies partly within the Apennine alluvial fans complex and partly within the Apennine alluvial plain. The geological and hydrogeological data collected within the study area are summarized in Table 3.1 and described in the following subsections.

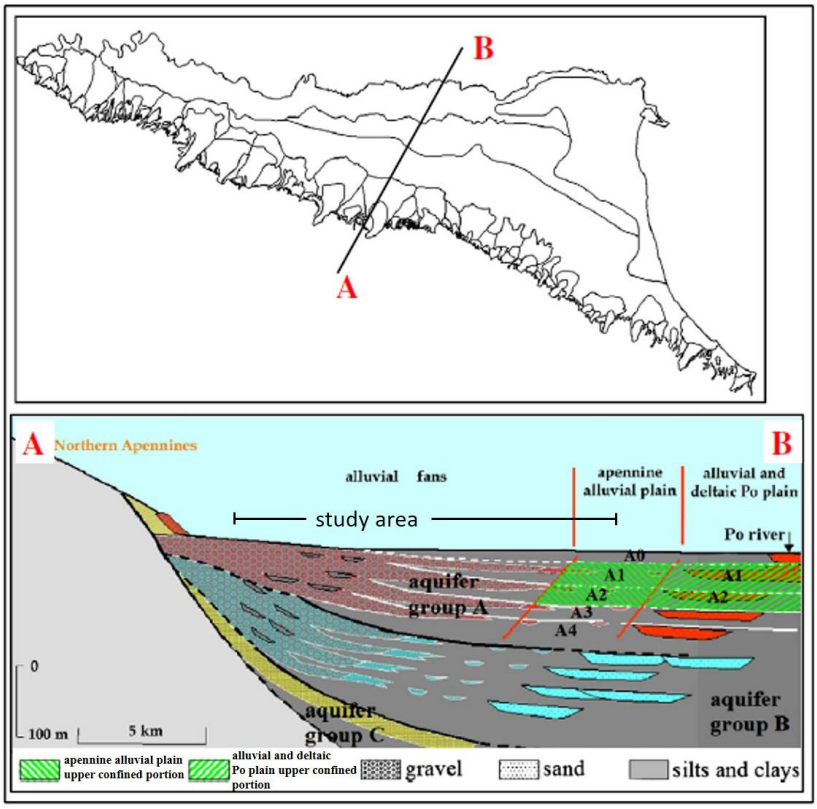

Figure 3.2. Planar extension of the groundwater bodies identified within the Emilia Romagna region and simplified schematic hydrostratigraphic cross-section AB (modified from Molinari et al., 2012).

	Data Type	N points	Monitoring Period	Monitoring Frequency	Sources
Geological Data	**Lithostratigraphic-cross sections**	22	-	-	G.S.S. Regione Emilia Romagna[1]
	Geological stratigraphies	>1000	-	-	G.S.S. Regione Emilia Romagna[1]
Hydrological Data	**Precipitation/ temperature**	19/13	2005-2016	Daily	Arpae[2]
	Groundwater quality	72	2001-2015	From monthly to twice a year	Arpae[2]
	Surface water quality	9	2010-2015	From monthly to four-monthly	Arpae[2]
	Piezometric level	66	2001-2015	From monthly to twice a year	Arpae[2]
	Hydrometric level	8	2001-2016	Hourly	Arpae[2]
	Pumping wells	820	2002-2011	Quarterly	Arpae[2]
	Wells in Borgo Panigale and Tiro a Segno fields	26	2002-2016	Monthly	Arpae[2]

Table 3.1. List of available data collected for the Bologna site.

[1]G.S.S. Regione Emilia Romagna: Geological, Seismic and Soil Survey -Regione Emilia Romagna.
[2]Arpae: Emilia Romagna Regional Agency for Environmental Protection.

3.1 Geological data

Data source: Geological, Seismic and Soil Survey of the Regione Emilia Romagna.

Link:https://applicazioni.regione.emilia-romagna.it/cartografia_sgss/user/viewer.jsp?service=geologia

Geological data located within and in the surrounding of the Bologna site include:

(i) 22 lithostratigraphic cross sections provided by G.S.S., as illustrated in Figure 3.1. As an example, the lithostratigraphic cross section L09 is shown in Figure 3.3.

(ii) more than 1,000 geological stratigraphies collected from the database of G.S.S.. Locations of available well logs are depicted in Figure 3.4. The depth of the well logs ranges from 10 to 560 m. Among the available data, 1879 geological stratigraphies intersect the bottom of Aquifer A1 (in blue in Figure 3.4a), 622 the bottom of A2 (in red in Figure 3.4a), 400 the bottom of A3 (in green in Figure 3.4b), 304 the bottom of A4 (in blue in Figure 3.4b) and 223 reach the bottom of Aquifer group B (in red in Figure 3.4b). As an example of the information available at each location, the geological stratigraphy at well 220080P651 (located at UTM coordinates x = 680283 m, y = 4931830 m) is reported in Table 3.2.

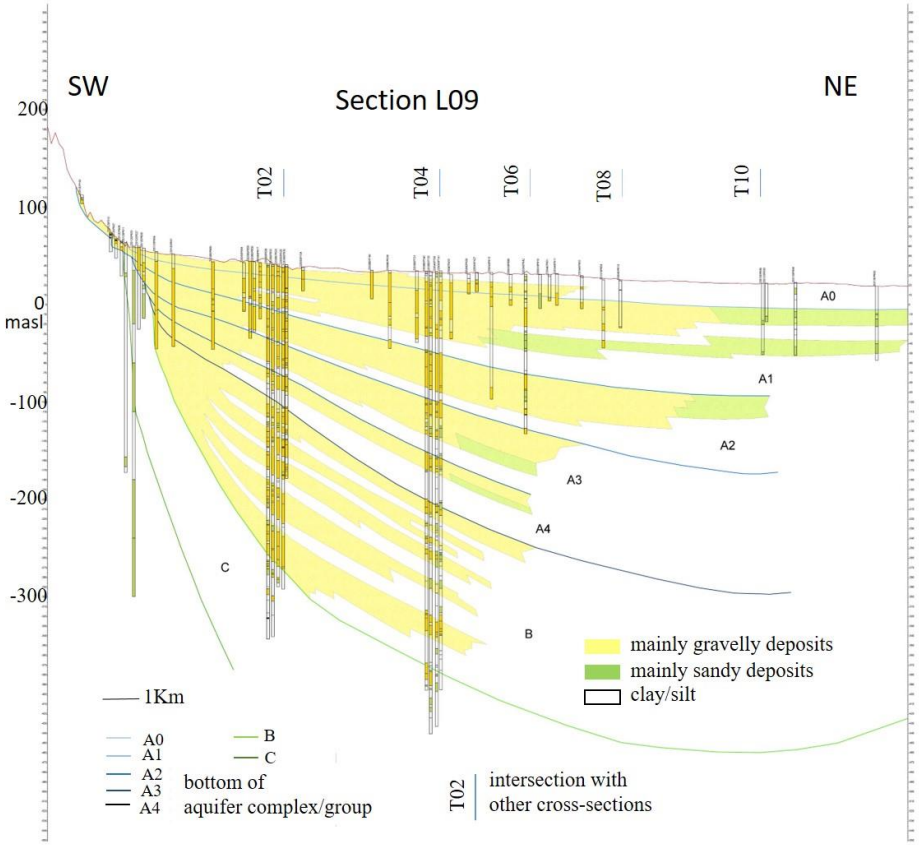

Figure 3.3. Cross section L09 (see location in Figure 3.1).

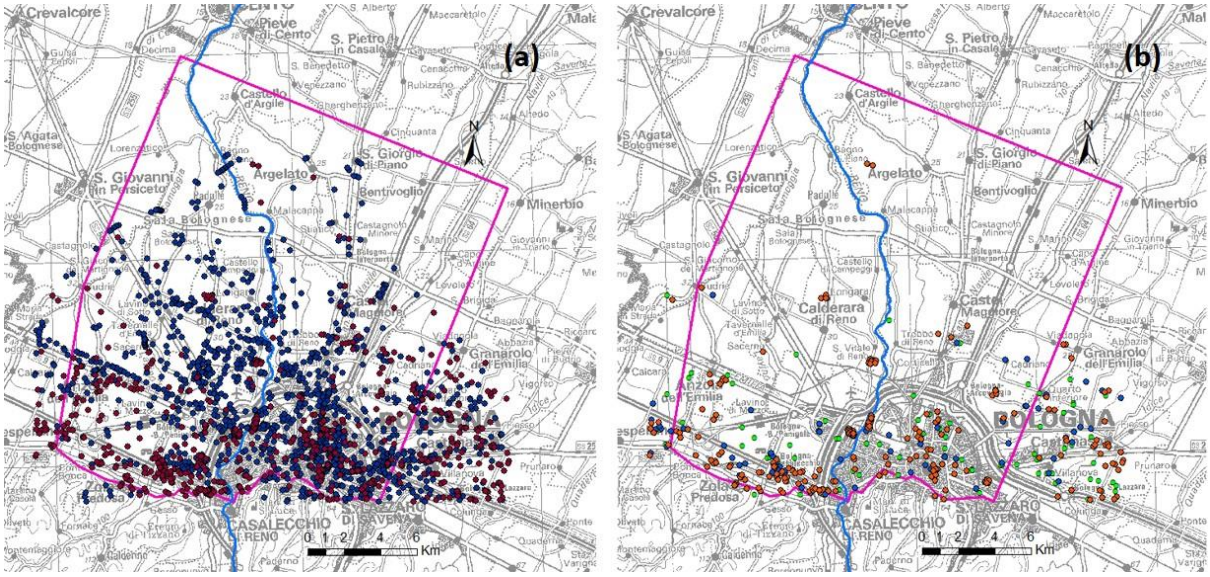

Figure. 3.4. (a) Well logs intersecting the bottom of Aquifer A1 (blue) and A2 (red). (b) Well logs intersecting the bottom of Aquifer A3 (green), A4 (blue) and B (red).

Ground level (m a.s.l.)	depth (m)	Level	Top (m b.g.l.)	Bottom (m b.g.l.)	Top (m a.s.l.)	Bottom (m a.s.l.)	Thickness (m)	Lithology
47	131	1	0	10	47	37	10	Fill material
		2	10	45.5	37	1.5	35.5	Coarse gravel
		3	45.5	51	1.5	-4	5.5	Clay
		4	51	65	-4	-18	14	Coarse gravel
		5	65	76.5	-18	-29.5	11.5	Gravel
		6	76.5	92.5	-29.5	-45.5	16	Clay
		7	92.5	103	-45.5	-56	10.5	Gravel
		8	103	115	-56	-68	12	Gravel
		9	115	127.5	-68	-80.5	12.5	Gravel
		10	127.5	131	-80.5	-84	3.5	Not determined

Table 3.2. Lithology of well 220080P651, UTM coordinates x = 680283 m, y = 4931830m.

3.2 Precipitation and temperature

Data source: Arpae Emilia Romagna (Regional Agency for Environmental Protection)

Link: https://www.arpae.it/dettaglio_generale.asp?id=2897&idlivello=1625

Nineteen meteorological stations have been (till now) selected among the meteorological stations managed by Arpae Emilia Romagna within and around the area of interest as illustrated in Figure 3.5. Precipitation (available at all stations) and temperature (available at 13 stations) data are available from year 2005 to year 2016 on a daily basis.

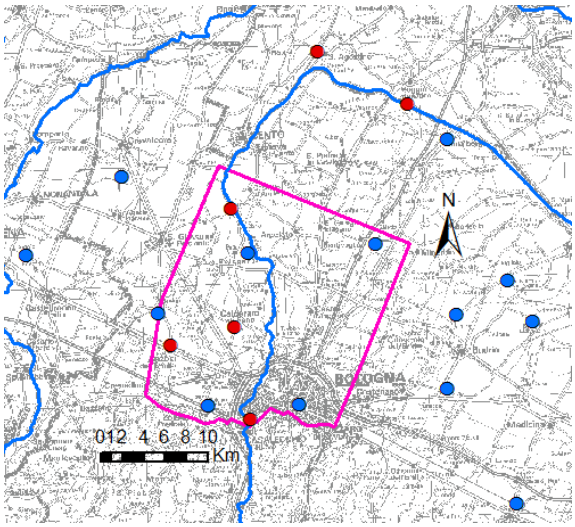

Figure. 3.5. Location of meteorological stations at which precipitation (red) and both precipitation and temperature (blue) data are available between 2005 and 2016.

3.3 Groundwater/surface water quality

Data source: Arpae Emilia Romagna (Regional Agency for Environmental Protection)
Link: https://www.arpae.it/elenchi_dinamici.asp?tipo=dati_acqua&idlivello=2020

Groundwater. Chemical analyses of groundwater quality are available from year 2001 to year 2015 at 72 points located within and in the surrounding of the area of interest. The depth of the monitoring wells ranges from 4 m to more than 400 m below ground surface. Samples for chemical analyses are usually collected twice a year (during spring and autumn). In some cases, e.g. due to pollution detection, sampling frequency can be higher. Groundwater samples at the well fields are analysed at least monthly. Table 3.3 reports the number of wells monitoring the aquifer systems previously described.

N. of wells	Aquifer
11	Unconfined portion of the alluvial fans
15	Upper confined portion of the alluvial fans
15	Lower confined portion of the alluvial fans
15	Upper confined portion of the Apennine alluvial plain
2	Lower confined portion of the Apennine alluvial plain
6	Phreatic aquifer A0
8	Uncertain

Table 3.3. Location of the hydrochemical monitoring points within the aquifer system.

Data usually include measurements of water temperature; pH; 1,2,4-Trichlorobenzene; 1,2-Dichloroethylene; 1,4-ichlorobenzene; Alachlor; Aldrin; Antimony; Arsenic; Atrazina; Atrazina-desetil; Atrazina-desisopropil; Bentazone; Benzene; Benzo (a) pyrene; Benzo (b) fluoranthene; Benzo (g,h,i) perylene; Benzo (k) fluoranthene; Beta-Esachlorocycloexane; Boron; Bromacil; Bromine-dichloro-methane; Cadmium; Calcium; Carbon tetrachloride; Chlorides; ChromiumVI; Cyanides; Electric conductivity 20°C; DDT,DDD,DDE; Dibenzo (a,h)anthracene; Dibromo-chloro-methano; Dicamba; Dichlorobenzamide 2,6; Dicloroethane 1,2; Dicloroethylene cis; Dicloroethylene trans; Dichloromethane; Dieldrin; Dissolved Oxygen; Endrin; Ethylbenzene; Fluorides; Glyphosate; Hardness; Hexachlorobenzene; Hexachlorobutadiene; Indeno (1,2,3,cd) pyrene; Ammonium (NH4+); Isodrin; Isopropilbenzene; Iron; Lead; Linuron; Magnesium; Manganese; Mercury; Metolachlor; Molinate; Monochlorobenzene; Nikel; Nitrates; Nitrites; Nitrobenzene; Organic Nitrogen; Pentachlorobenzene; Potassium; Propanil; Selenium; Simazine; Sodium; Styrene; Sulphates; Sum (aldrin, dieldrin, endrin, isodrin); Summation of phytopharmaceuticals; Summation of

organhalogen; Terbuthylazine; Terbuthylazine desetil; Tetrachloroethane 1,1,2,2; Tetrachloroethylene; Toluene; Total Chromium; Total Hydrocarbons (n-esano); Total Nitrogen; Trichlorobenzene; Trichloroethane 1,1,1; Triclhoroethane 1,1,2; Trichloroethylene; Trichloromethane; Vanadium; Vinyl Chloride; Zinc; Xilene (sum isomers); Xilene meta; Xilene orto; Xilene para.

Figure 3.6 depicts the location of piezometric and hydrochemical measurement points available between 2001 and 2016. Colour code denotes the location of the monitoring wells within the aquifer system. Concentration values of halogenated compounds detected in autumn 2013 are shown in Figure 3.7.

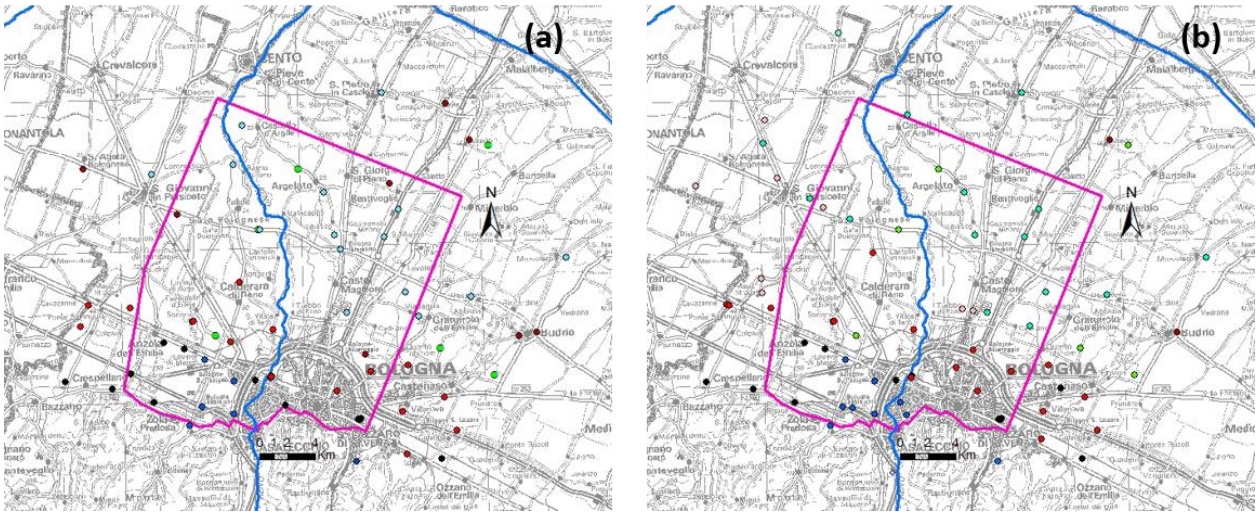

Figure 3.6. Locations at which (a) piezometric and (b) hydrochemical data are available between 2001 and 2015. Color code denotes the location of the monitoring wells within the aquifer system, i.e., unconfined (blue), upper confined-alluvial fans (red), lower confined-alluvial fans (black); upper confined-alluvial plain (light blue), lower confined-alluvial plain (brown), phreatic aquifer A0 (green); uncertain data (pink).

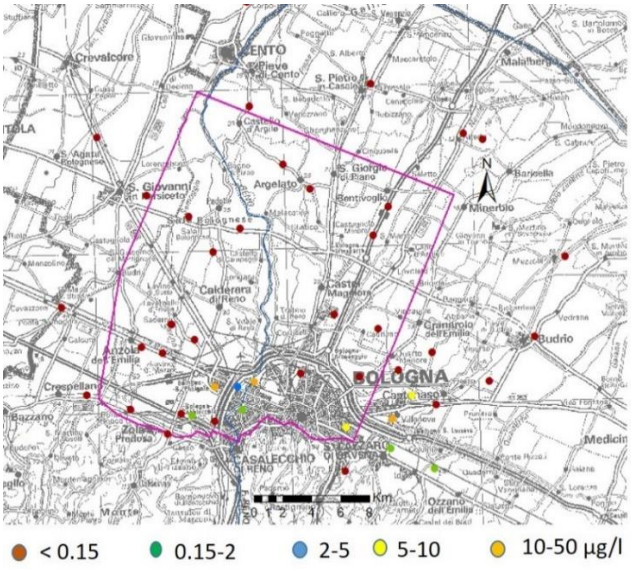

Figure 3.7. Distribution of the halogenated compounds, autumn 2013.

Surface water. Chemical analyses of surface water quality are available from year 2010 to year 2015 at 9 points within and in the surrounding of the area of interest. Location of sampling points, together with their code, is depicted in Figure 3.8. Sampling frequency varies from monthly to four-monthly. Sampling points 6002150 and 6002480 have been monitored only during 2014-2015 and 2015, respectively.

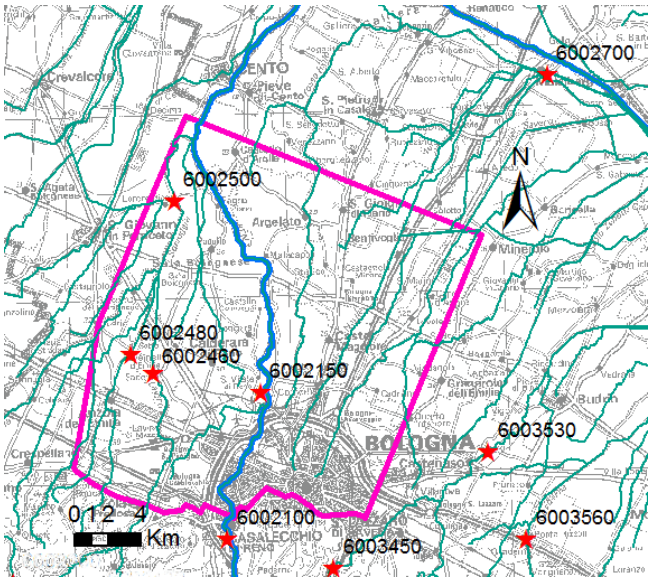

Figure 3.8. Location of surface water quality monitoring stations in the area of interest (2010-2015).

3.4 Piezometric levels

Data source: Arpae Emilia Romagna (Regional Agency for Environmental Protection).
Link: https://www.arpae.it/elenchi_dinamici.asp?tipo=dati_acqua&idlivello=2020

Piezometric levels measurements are available from year 2001 to year 2015 at 66 observation wells located within and in the surrounding of the area of interest (see Figure 3.6). The depth of the monitoring wells ranges from 6 to more than 500 m b.g.l.. Available data include well depth, screens depth and type of screen. Piezometric data are usually collected twice a year (during spring and autumn). Groundwater levels at selected locations within the two well fields are monitored using a continuous acquisition system. Table 3.4 reports the number of wells monitoring the aquifer systems previously described.

N. of wells	Aquifer
6	Unconfined portion of the alluvial fans
15	Upper confined portion of the alluvial fans
16	Lower confined portion of the alluvial fans
15	Upper confined portion of the Apennine alluvial plain
8	Lower confined portion of the Apennine alluvial plain
6	Phreatic aquifer A0

Table 3.4. Location of monitoring wells within the aquifer systems.

Figure 3.9 shows the contour lines of mean hydraulic head measured in the upper confined and in the lower confined portions of the aquifer system for the period 2010-2014. It can be noticed a deep depression located within the Reno alluvial fan. This is mainly due to the activities of the two well fields.

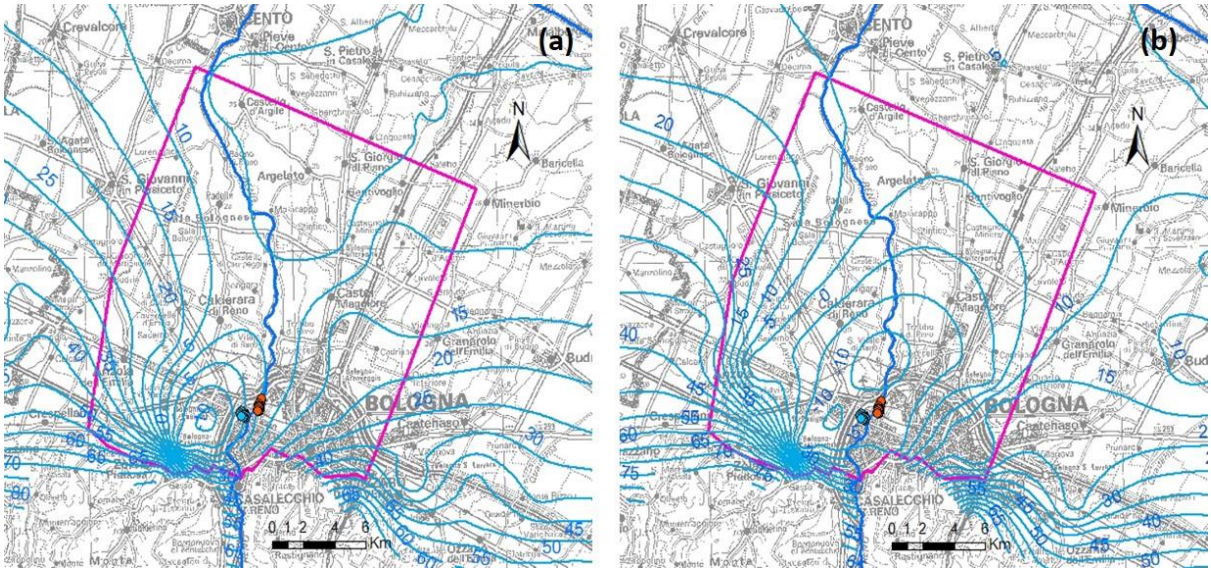

Figure 3.9. Contour lines of hydraulic head for the upper confined (a) and the lower (b) portions of the aquifer system (mean values in m a.s.l., period 2010-2014).

3.5 Hydrometric levels

Data source: Arpae Emilia Romagna (Regional Agency for Environmental Protection).

Link: https://www.arpae.it/dettaglio_generale.asp?id=2897&idlivello=1625

Hydrometric measurements of water level are available from year 2001 to year 2016 within the area of interest at 8 locations along the Reno river as illustrated in Figure 3.10. For each station topological characteristics are available. Data usually include measurements of water level (with respect to the hydrometric zero) on an hourly basis.

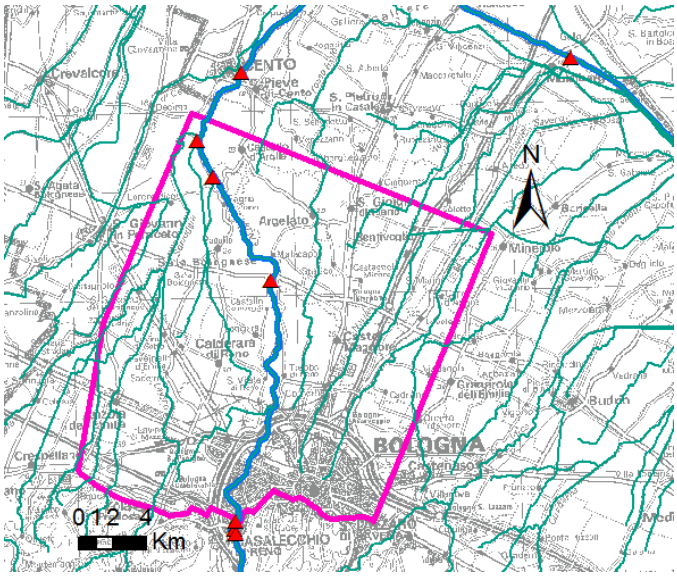

Figure 3.10. Location of hydrometric stations (monitoring period 2001-2016).

3.6 Pumping wells

Data source: Arpae Emilia Romagna (Regional Agency for Environmental Protection).

Quantitative information about withdrawals from the aquifer system are provided by Arpae Emilia Romagna. Data are available on a quarterly basis across the window between 2002 and 2011. Groundwater is used for civil (drinking water), industrial, agricultural and zootechnical purposes. Figure 3.11 shows the location of available withdrawal data. The pumping well stratigraphy and their screen depths are known at Borgo Panigale (13 pumping wells) and Tiro a Segno (13 pumping wells). The depth of the 26 wells ranges between 220 and 380 m b.g.l.. Pumping wells are mainly screened within Aquifer group B. Volume of groundwater extracted from each well on a monthly basis is available in the period 2002 - 2016. Figure 3.12 depicts the total annual volume extracted from each well field during the period 2006-2016.

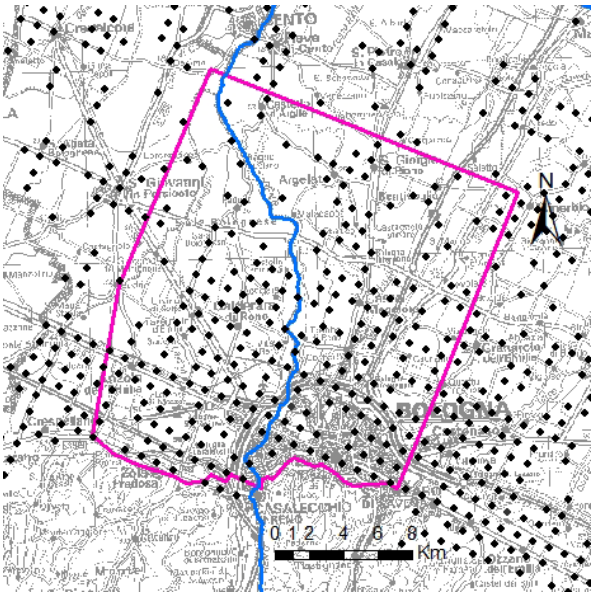

Figure 3.11. Location of pumping wells within and in the surrounding of the study of interest.

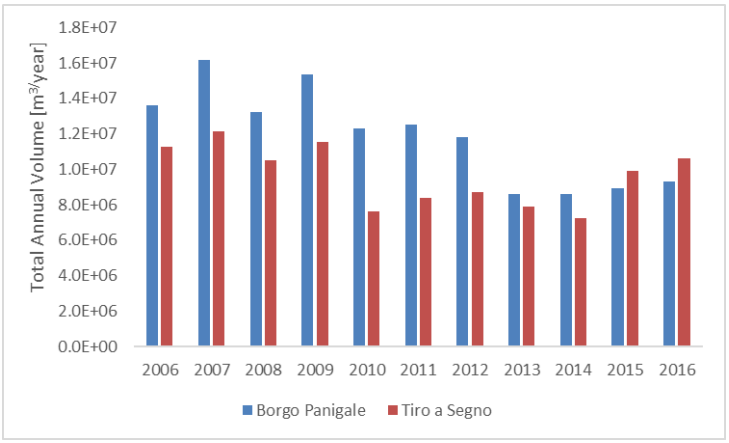

Figure 3.12. Total annual volume extracted from the well fields of Borgo Panigale and Tiro a Segno.

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