MAURICE

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D.2.1.1 - Joint report for pilot actions design in Stuttgart-Feuerbach and Lombardy

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Joint report for pilot actions design in Stuttgart-Feuerbach and Lombardy

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A. Introduction - Gaps and goals of the two Pilot Actions

The Pilot Actions outlined in this document face common issues and are aimed to achieve common goals. Since the geographical context of the two Pilot Areas are different, differences in their conditions are present, but the actions share a common way to go towards their goals.

The gaps faced in the Italian context start from the uncertainty in climate change impacts that the region will face, and how they'll modify the relationship between surface and groundwater. Linked to this uncertainty, the lack of a sufficiently detailed existing monitoring network in the Italian Pilot Area made it necessary to form one merging existing networks and building new points. The losses along the irrigation channels network and the subsequent irrigation practices followed by farmers along with the presence and consideration of lowland springs opens a field with lots of uncertainty in their behaviour and monitoring. Thus, modelling both the groundwater and agricultural systems is a necessity to be able to represent and understand climate change scenarios. In Stuttgart's Pilot Area, it needs to be clarified whether the falling groundwater levels are due to climate change and what influence climate change will have on groundwater conditions in the future. The factors and processes responsible for the falling groundwater levels must thus be identified. This lack of knowledge requires a monitoring network to record groundwater levels and meteorological data. Furthermore, the processes between groundwater recharge, runoff via the Feuerbach creek and complex hydrogeological conditions in the Pilot Area and groundwater levels must be understood. This makes it necessary to set up a complex system model in which the hydrological model, the hydrogeological model and the climate model for Stuttgart are integrated.

So, the Pilot Actions goals merge in the common task of increasing the understanding of the future dynamics related to groundwater, creating a monitoring network which can sustain assessment and analyses and finally use both these achievements to model the systems and assess the feasibility of climate change adaptation measures.

To reach a shared development of the Pilot Actions, Politecnico di Milano and Stuttgart met to agree on the activities to carry out and propose changes or upgrades to each plan. The meetings were participated also by other MAURICE partners, which contributed to the plurality of information shared and permitted to have a broad view on the two actions.

B. Pilot Action Milan

1. Description of the Pilot Area

1.1. Introduction to the Pilot Area

The Italian Pilot Action area is enclosed between the Ticino River and the West administrative boundaries of Milan mainly including the following municipalities: Vanzago, Bareggio, Cornaredo, Sedriano and Cusago. The area falls within the Ticino-Adda underground basin which is characterised by one of the highest levels of urbanisation in Europe, but also by the coexistence of the urban area of Milan with a vast agricultural area intensively irrigated with furrows and flooding irrigation methods through a dense network of canals built since the XIII century. This irrigation system has a close relationship with groundwater as it seasonally influences groundwater levels through abundant flows of percolation from irrigated fields and permeable canals. PP7 partner Consorzio di Bonifica Est Ticino Villoresi (ETV) manages a great part of irrigation canals around Milan, Pilot Area included. The network directly managed by ETV originates from Canale Villoresi (Villoresi Canal), a paved channels which derivates from river Ticino and runs North of Milan for 86 km ending up in Adda river. The network then branches out from the main canal with multiple orders of derivations. The Pilot Area will thus get the water needed to perform the Pilot Action from this network, specifically from Derivatore di Parabiago which is then derived by Derivatore di Bareggio. The southern part of the Pilot Area is characterized by the presence of a great quantity of lowland springs, a typical occurrence in southern Lombardy. These springs are usually constituted of a “head”, where water emerges from the ground, and a channel which conveys water downstream. They are in close relationship with both groundwater and irrigation, since they receive water from the former and provide water which is used for the latter. However, some of their recharge can come horizontally from irrigated fields around them.

1.2. Reasons for the choice of the Pilot Area

Milan’s Pilot Action aims to test climate change adaption measures involving groundwater. Lombardy’s diffused irrigation network is an already available infrastructure to be harnessed to increase groundwater recharge. Thus, the Pilot Area was defined based on several decision-making steps, primarily driven by management considerations, territorial peculiarities and positive collaboration from landowners or farmers. An effort was made to locate the Pilot Area within the irrigated territories depending by Consorzio Est-Ticino Villoresi’s main channel (Canale Villoresi), in areas subjected to flow and submersion irrigation (maize and rice growing areas) and located inside the flow-nets shown in Figure 1. A flow-net shows the direction of groundwater flow in an area and this choice ensures that the groundwater recharge enhanced by the Pilot Action will remain inside the Pilot Area and its monitoring network. In this way the Pilot Action can also aim to demonstrate the importance of groundwater infiltration in the northern part of the ETV district in order to ensure irrigation supply in the southern territories. The adaptation measures experimentation fields were selected in terms of available water supply and willingness of landowners and farmers to adhere and implement innovative water management techniques has been verified. So, from the combined analysis conducted between PP7 and PP6 technicians, it emerged that the ideal territory to ensure the success of the Pilot Action measures envisioned in MAURICE is an approximately 340 km^2 area West of Milan, shown in Figure 1, and it is the area referred here and in the future as Pilot Area. This area will coincide with the groundwater and agricultural model boundaries, and in Figure 1 and the following figures will referred as the groundwater model boundaries.

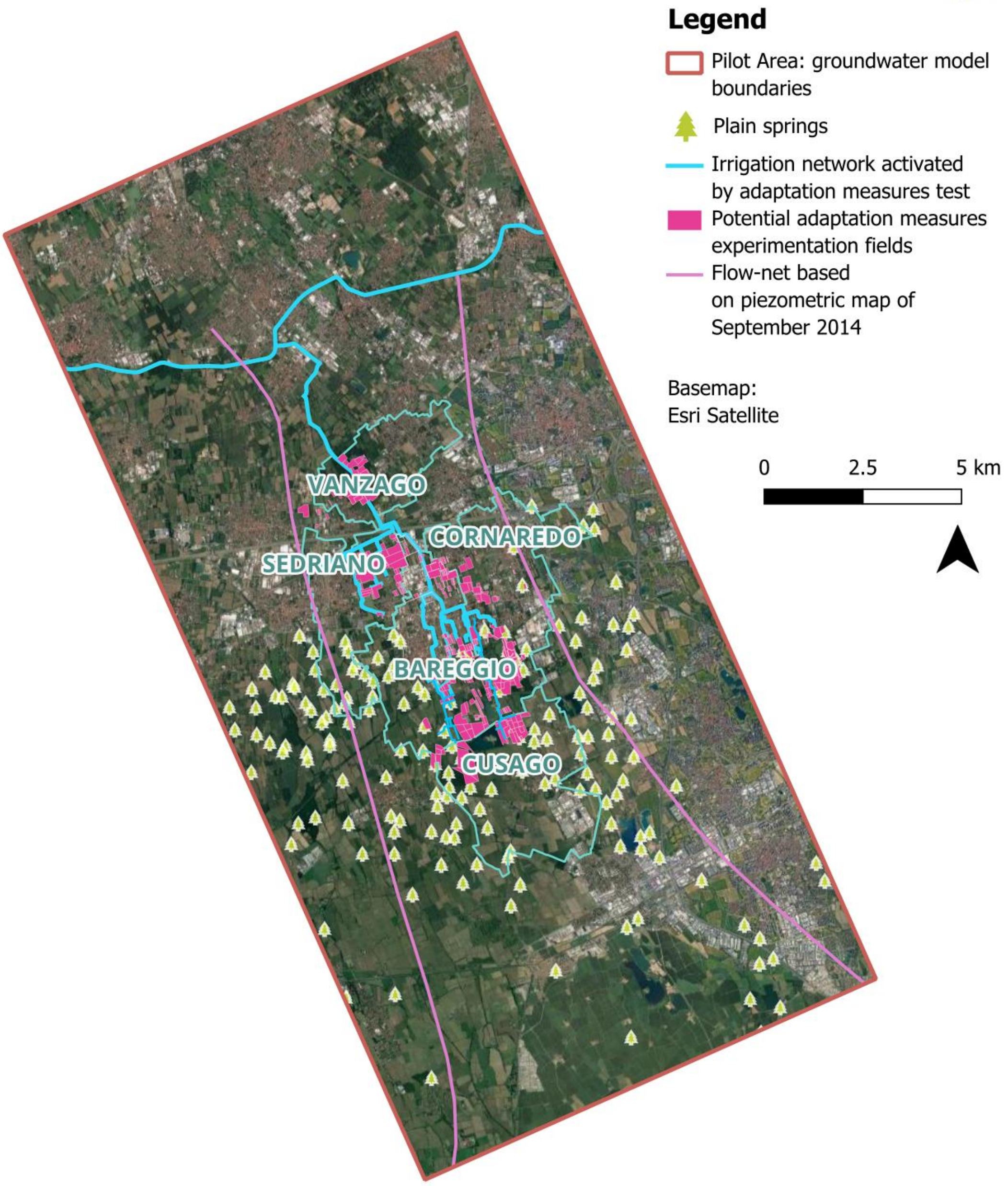

Figure 1. Pilot Area domain having and extension of about 340 Km^2.

1.3. Geographical and climatic framework

Milan's Pilot Area is located in west-central Lombardy, in a richly irrigated stretch of the upper Po Valley between the Ticino River to the west and the Adda river to the east. Land use data over the years have shown a progressive increase in urbanised areas at the expense of a steady decrease in agricultural land. Milan is in the centre of the Po Valley, enclosed on three sides by high mountain ranges: the Alps to the north and west, the Apennines to the south. The presence of the mountain ranges affects the general circulation, blocking disturbances from the North Atlantic and preventing the mixing of air masses. The climate can be defined as humid temperate with some continental features due to distance from the sea. The region's climate is characterised by precipitation between 700 and 1500 mm/year and by a significant annual and daily temperature difference. This means hot summer and cold winter and a temperature range between day and night of about 10°C in summer. The wettest months are the spring months (April and May) and the autumn months (October and November). In winter, the temperatures drop to average lows of around 0°C, while in summer the average maximums exceed 30°C (Cornes et al., 2018). The winter months are the driest period of the year; with humidity often appearing in the form of dense fog, which can, however, give way to precipitation events, even snowfall, or strong north winds (Föhn).

1.4. Basin scale description: geological and hydrogeological framework

The Pilot Area is located in the largest hydrological basin in Italy: the Po plain. To better understand its genesis, the genesis of the Alpine arc and the Apennines has to be considered. This important process resulted in the concave morphology of the Po plain, currently divided in two by the most important water element: the Po River. Subsequently, as a result of climatic phenomena and the action of atmospheric agents, this container was filled more and more with material derived from the two important reliefs, the Alps and the Apennines, correspondingly from rocks of different lithotypes. In extreme synthesis, the plain is characterised by a convergence of surface and groundwater initially in the direction of the Po River and later towards the Adriatic Sea. Successive glacial periods have played a fundamental role in the current configuration of the subsoil characterised by expanses of aquifers separated by aquitards/aquicludes. Currently, the aquifers play a central role in the territory's water reserves together with the large water flows provided by the large Alpine lakes (Lake Como, Lake Maggiore, Lake Iseo and Lake Garda). These, together with the main rivers, guarantee the territory's water requirements for agricultural, industrial and civil use. From a hydrogeological point of view, the Po River Basin is extremely influenced by the sedimentological and stratigraphic features that have determined the progressive filling of the Basin. There is substantial asymmetry between the Alpine and Apennine sides, reflecting the substantial differences in the geological evolution of the two ranges: the sediments from the Alpine zone derive from predominantly calcareous crystalline rocks-arenaceous that in dry and glacial periods produce a large gravelly input. For the hydrogeological component and the related subdivision of the Po Valley aquifers, reference is made to the publication "Geology of the Po Valley Aquifers of the Lombardy Region" (Carcano et al. 2001) a series of groups are recognized in the Lombardy sector of the Po Valley Basin aquifers separated by discontinuity surfaces. The aquifer groups found in the study area are as follows:

- Aquifer Group A corresponds to the most superficial portion of the traditional aquifer, which is generally free and is currently intensively exploited, although often affected by pollution phenomena due to the reduced thickness and low preservation potential of the clay levels present, which cannot determine, except at a local scale, aquifer confinements. Coarser lithologies fall here: predominantly coarse gravels and gravels, polygenic with medium to very coarse sand; sandy intervals are subordinate, with yellowish, medium to very coarse sands, often pebbly. However, moving away from the alpine feeding areas the succession of the group shows a clear lateral variation of facies, with gradual increase toward the South of sandy lithologies at the expense of gravelly ones. (Carcano et al. 2001);
- Aquifer Group B, which in the areas of the upper Lombardy plain appears instead in outcrop, corresponds to the deeper portion of the traditional aquifer, generally confined or semi-confined. This Aquifer Group has thicknesses between 40 and 50 m and is represented by a succession consisting of sediments, such as medium coarse sands and gravels with a sandy matrix, characterized by high porosity and permeability. Fine, highly subordinate sediments are limited to the lower part of the succession, where intercalations of silty clay and silt, decimetric to metric in thickness, appear. At the base of Aquifer Group B it is also possible to identify, locally, levels of poorly cemented to well-cemented conglomerates, likely referable to the Auct "Stump." The base of Aquifer Group B corresponds to the base of the Lower Lombard Supersytem (SLI);
- Aquifer Group C, attributed to the Calabrian (Middle Pleistocene of the old scale chronostratigraphic scale) shows an alternation of silicoclastic platform marine sediments (silty clay sandy fossiliferous), deltaic and littoral transitional deposits (predominantly fine to medium, bioturbated, laminated or

massive), continental floodplain deposits with meandering fluvial systems (alternating sand and green or marshy clay rich in organic matter);

- Aquifer Group D, attributed to the Calabrian (Lower Pleistocene of the old chronostratigraphic scale) consists of predominantly silty clays and silt with intercalations of fine and very fine sands in thin layers at the base, bioturbated fine and medium sand in the middle part, and polygenic grey gravel alternating with sand in the upper part defining sequences with negative facies.

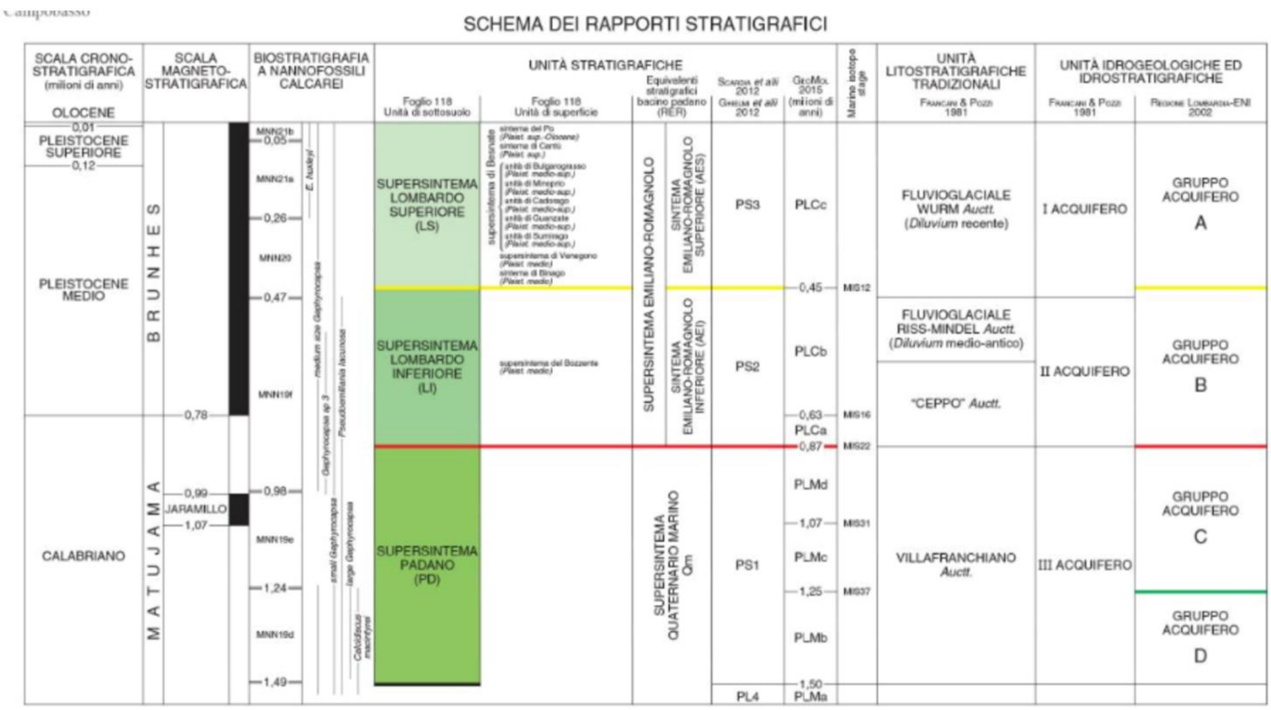

Figure 2. Outline of stratigraphic relationships in the Po Valley Basin (Francani et al. 2010)

The hydrostructures present in the Pilot Area according to the nomenclature used in "Piano di Tutela delle Acque" (PTA) 2016 in accordance with the standard European denomination, are:

- For the shallow hydrostructure (Idrostruttura Sotterranea Superficiale, ISS): IT03GWBISSAPTA, IT03GWBISSMPTLN
- For the intermediate hydrostructure (Idrostruttura Sotterranea Intermedia, ISI): IT03GWBISIMPTM
- For the deep hydrostructure (Idrostruttura Sotterranea Profonda, ISP): IT03GWBISPAMPLO

1.5. Hydrographic and pedological framework

The hydrography of the Milan area is rather complex mainly due to the numerous interventions carried out over the centuries. The main watercourses, shown in Figure 3, are connected to a dense network of secondary and tertiary artificial canals that span through the territory both collecting and channelling rainfall and for irrigation purposes. Milan area is crossed by the course of many watercourses (Ticino, Olona, Seveso, Lambro and Adda), roughly parallel to each other, and with a direction of flow from North-West to South-East, corresponding to the direction of the slope of the Po plain.

The main watercourses surrounding the Pilot Area are both natural and artificial. River Ticino flows on the West side, at a short distance from its outlet at Lake Maggiore, showing bumps that can be interpreted as residues of moraine deposits. It continues its course towards the sub, digging deep valleys and creating terraces in the oldest sedimentary bodies. The Olona river, which has its source in the Varese foothills of the Alps, reaches Milan near the current Gallaratese district. It runs underground for a great portion of its course, but it used to flow directly into the Porta Ticinese dockyard. It currently crosses the Naviglio Grande and gives rise to the Colatore Lambro Meridionale. The Naviglio Grande derives its waters from the Ticino, near Tornavento, and flows into the city at the dock of Porta Ticinese. To remedy the frequent flooding of the Seveso and Olona rivers, there is also the North-West spillway, which has, however, often proved insufficient to prevent flooding in the city. The Pilot Area is characterised by the presence of an artificial or semi-natural hydrographic network, represented by a network of primary and secondary irrigation canals, irrigation ditches, with a prevalent North-South trend in the southern sector. It is crossed in its Northern part by the Villoresi Canal together with the network of irrigation ditches and canals belonging to the Consorzio Est Ticino Villoresi.

Pedologic contribution is fundamental to the knowledge of the Quaternary deposits that most characterise the Po Valley. In Billard, 1973 the upper Milanese plain is subdivided into three topographical units linked to three different glaciations: the valley floor alluvium, which derives upstream from the moraine arches (Wurm), the intermediate terraces at Riss and the upper terraces at Mindel. More specifically, the pedological conditions are characterised by alluvial sediments, through deposition from watercourses, and glacial origin (where moraine hills are present). By the term 'fluvioglacial', the authors mean alluvial Pleistocene alluvial deposits, contemporary with the phases of ice advance and retreat. From a more strictly pedogenetic point of view, it recognises the systematic presence of bleached A horizons, superimposed on B or BC horizons of leached soils, organised in cycles (IA/IB; IIA/IIB; IIIA/IIIB), whose number decreases from the oldest to the most recent terrace; the B soils in the III horizons also have a fragipan character (hardened horizons of pedogenetic origin).

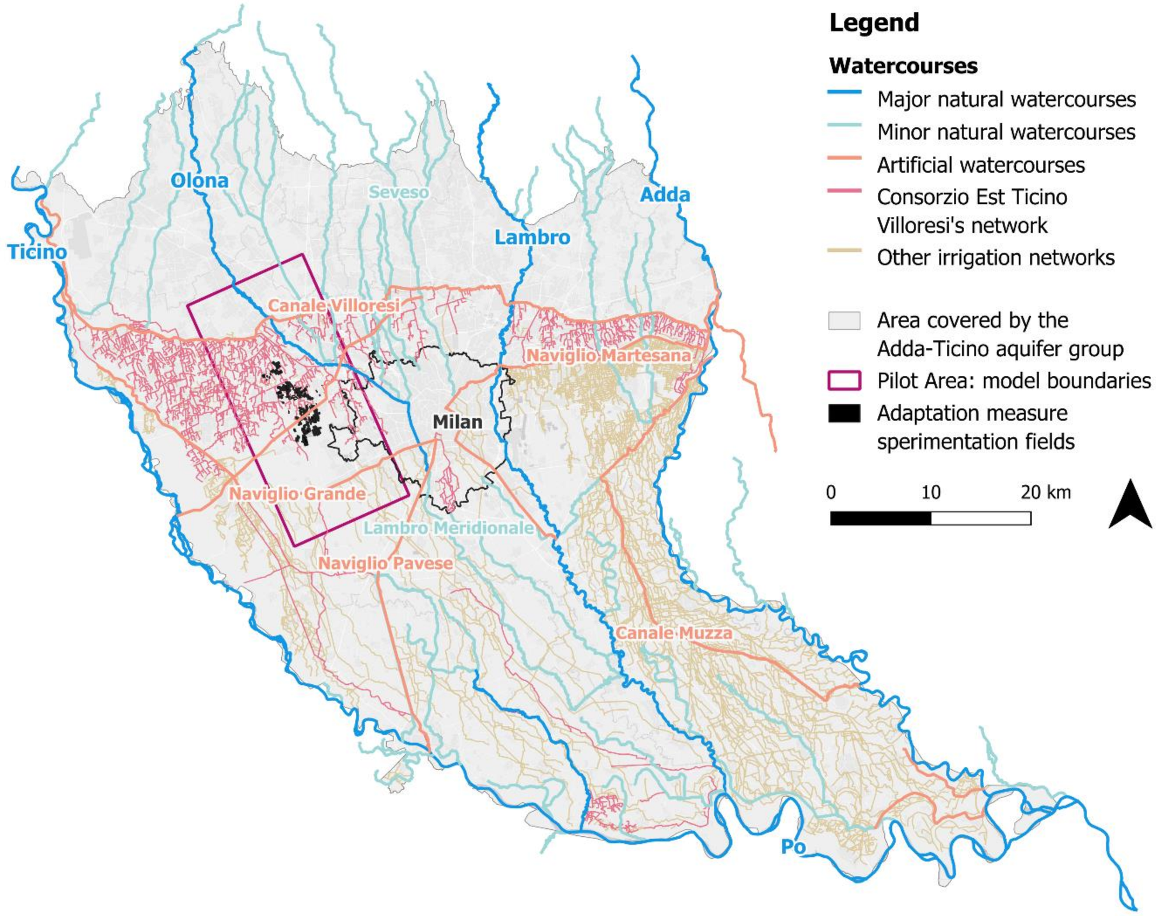

Figure 3.Watercourses surrounding the Pilot Area and Milan, over the area covered by Adda-Ticino aquifer group.

1.6. Geomorphological, geological and hydrogeological framework

The surface geomorphology of the Po Plain is shaped by fluvial dynamics and geomorphological agents. High, medium and low plains are the bands with which the Po Valley is divided according to slope differences that vary from being greater than 4% and directed North-South in the high plain to being less than 1% in the low plain, dipping towards East (Castiglioni and Pellegrini 2001). In terms of elevation, the Pilot Area has gradually decreasing topographic elevations towards the south ranging between the maximum elevation of 180 m above sea level in the northern sector and the minimum elevation of about 130 m above sea level at the southern sector. The vast agricultural area is characterized by a dense irrigation network that draws its water partly from the Canale Villoresi and partly from numbers of plain springs located in the central northern belt. The high plain on the Alpine side is characterised by the presence of glacial deposits and forms such as frontal and terminus moraines generally arranged to form typical amphitheatre shapes, and fluvioglacial deposits such as conoids, sandurs and proglacial plains that extend to the low plain. These deposits have been intensely reshaped by fluvial dynamics that, together with the tectonic evolutions of glacial-isostatic release and rebound tectonics linked to the advance of the Apennine trusts, have determined their progressive erosion and terracing. Regarding the geological component of the Pilot Area, reference will be made to the characterisation carried out in the CARG project by ISPRA. The CARG Project envisages the realisation and computerisation of the 636 geological and geothematic sheets at the scale 1:50,000 that make up the puzzle of the 50,000 coverage of the entire national territory. Given the morphological uniformity of the territory investigated and its contiguity, it is considered consistent to use sheet n°118 (Milan) to describe the geological characteristics of the area, despite the fact that part of it falls under sheet n°117 (Legnano) which is still unpublished.

Within the report, the authors describe the Holo-Pleistocene successions which are attributed to the Upper Lombard Supersystem (LS). This newly introduced unit is bounded at the base by an unconformity surface (Scardia et al, 2012) as well as the base of Aquifer Group A defined in Regione Lombardia & ENI, 2002. This subsurface unit likely includes all the following surface geologic units: Binago synthema (BIN), Venegono supersynthema (VE), Besnate supersynthema (BE), which in turn includes the units of Sumirago (SUM), Guanzate (BEZ), Cadorago (BEE), Minoprio (BMI) and Bulgarograsso (BXE); synthema of Cantù (LCN) and subsynthema Ronchetto delle Rane (LCN4); Po synthema (POI). The unit just described is about 60 m thick and is predominantly characterized by coarse and medium gravels with frequent pebbles, often poorly sorted, locally cemented, in medium to thick layers, with subordinate levels of medium and coarse sands and gravelly sands. To further detail the stratigraphic characteristics reported in the "*Basin scale: Geological and hydrogeological framework*" section, reference was made to the Territorial Governance Plan (orig. PGT – Piani del Governo del Territorio) of the municipalities mentioned in the Pilot Area section. The stratigraphic characteristics can be described through their lithological characteristics and thus refer to the classification of lithostratigraphic units. The three hydrogeological units envied in the central-northern sector of the Po Valley are described below:

- Gravelly-sandy unit (autochthonous Wurm): it is characterised by an alternation of gravels and sands and by rare clay intercalations; it can be differentiated up to three superimposed aquifers, gradually less separable proceeding northwards, in relation to the progressive decrease in the presence of impermeable septa, which act as separators of the circulation. This is the so-called 'traditional aquifer', containing the free water table, which is very productive due to the high permeability of its constituent deposits of alluvial and fluvioglacial origin. The permeability of this aquifer increases especially where the "Ceppo" gives way to gravels and loose sands. The thickness of this first lithozone tends to increase from north to south in the Milanese plain, varying from 20 m in the northern sector to 120 m south of Milan; in the examined area averages around 50 metri (A. Cavallin., V. Francani, S. Mazzarella, 1983). According to the scheme of stratigraphic relationships, this unit mostly constitutes the Upper Lombardy Supersytem (LS) corresponding to Aquifer Group A. The unconfined superficial aquifer body presents variable grain sizes from S to G, with few fractions silty fractions, with high conductivity values greater than 10^{-5} m/s.
- Gravelly-sandy-silt unit (native Riss-Mindel): this is below the previous one and is in correspondence with the transition deposits attributed to the "Villafranchian" (Curioni G., 1877). It consists of clays and silts with sandy and/or gravelly levels and lenses. There may be also present peaty levels, indicating marsh-type sedimentation environments, and fossils. The permeable levels within this second unit are locally interconnected and the aquifer present is of the pressure type, with generally limited productivity. According to the scheme of stratigraphic relationships, this unit mostly constitutes the Lower Lombardy Supersytem (LI) corresponding to Aquifer Group B. The fine matrix in the sediments increases moving southwards and the aquifer tends to subdivide into several compartments called Aquifer Complexes B1, B2, B3 and B4. This Aquifer System has variable grain sizes from mfS to GB, which are attributed a high-to-high hydraulic conductivity (>10^{-5} m/s). The aquifer levels in this complex are thin and do not border aquifers within the aquifer, they have clayey grain sizes that result in a conductivity hydraulic conductivity of less than 10^{-7} m/s.
- Sandy-clay unit: this is generally found beyond a depth of 120 m and is characterised by facies of both continental and transitional (sandy-clay unit) and marine (clay unit) origin from the Lower Pleistocene and Calabrian. These sediments host the deepest, hydraulically separated aquifer of the traditional aquifer. According to the scheme of stratigraphic relationships, this unit mostly constitutes the Padanian Supersytem (PD) corresponding to Aquifer Group C. In the System deep aquifer below the maximum hierarchical discontinuity (0.87 Ma), the grain sizes vary from S to SL. The estimated hydraulic conductivity is medium to high in the range of 10^{-3} and 10^{-7} m/s. The aquitards in the marine environment vary from silty grains to clays and peats, which are attributed a low hydraulic conductivity in the order of 10^{-9}.

Figure 4 shows the thickness of the different aquifers in the subsoil. The two aquifer groups are hydraulically separated by low permeable levels (aquitards), which, however, are not present with continuity throughout the study area. A fairly constant thickness is noted for Aquifer A while Aquifer B presents different thicknesses according to its specific portions. Aquifer B1 presents an offlap termination on the subsequent aquifer B2, which presents a constant thickness throughout its extension. This indicates that in the northernmost portion of the Po Valley, aquifer B1 will not be found in the stratigraphic sequence. Continuing in depth, aquifer B3 presents variable thicknesses while aquifer B4 presents a constant thickness throughout its extension except in its northernmost part.

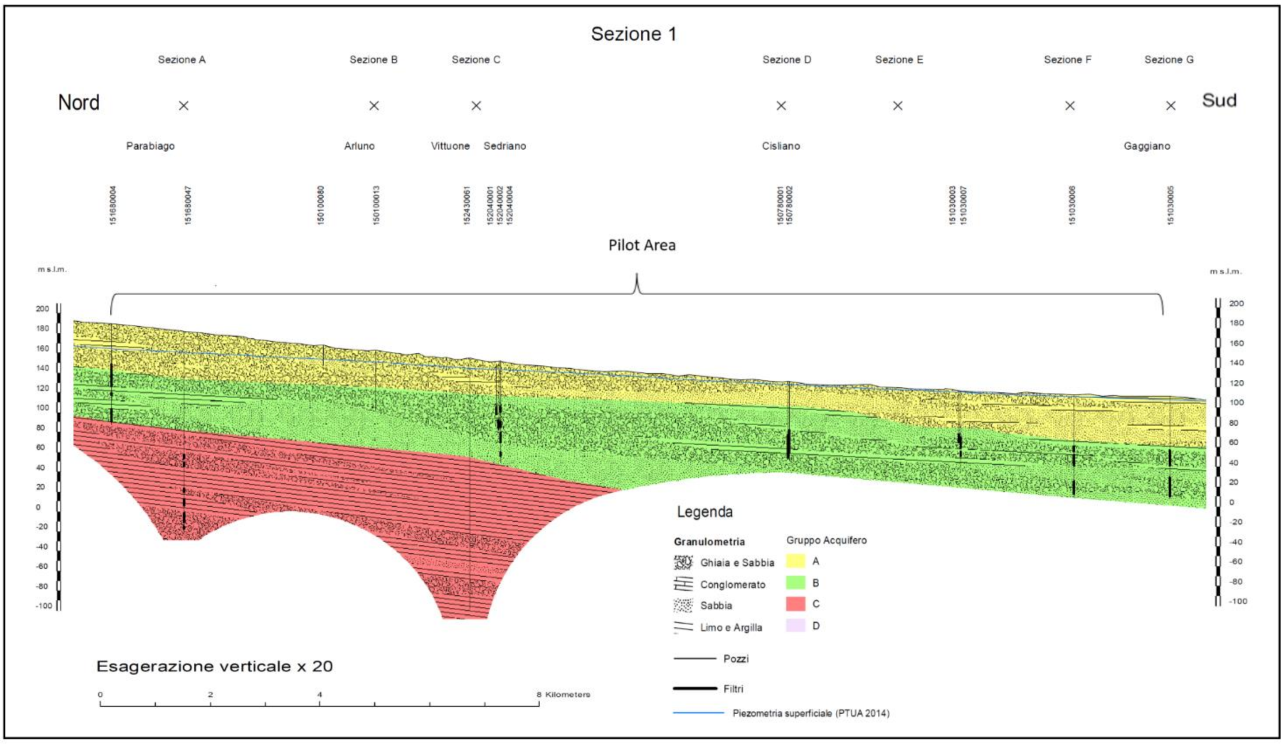

Figure 4. Extrapolation of hydrogeological section 1 (N-S) of the study area.

2. Characterization activities design

To be able to build the necessary agricultural and groundwater models, additional information on the Pilot Area characteristics are needed, especially on irrigation channels and lowland springs. To collect this information, a characterization activities plan has been defined over time, consisting in measures with infiltrometers, filling tests of channels, irrigation discharge measures and pumping tests in the planned piezometers or available wells. The list of activities, their investigated characteristics and the number and date of the tests are listed in Table 1 and explained below. The, the agricultural and groundwater usage characterization activities are explained.

Table 1. Characterization activities' investigated characteristics, scheduled dates and number

Activity	Investigated characteristic	Scheduled date of the activity	N° of activities
Infiltrometer measurements	Vertical hydraulic conductivity of the channels bed (K)	March 23, March 24	10-20
Ponding tests	Leakage rate of the channel	November 24	2-5
Pumping tests	Aquifer hydraulic parameters (e.g. hydraulic conductivity)	March-June 24	4-6
Discharge measurements	Irrigation discharge at field level; irrigation channels' losses; lowland spings flow	December 23, January 24, then one for each irrigation season	5-10

Hydraulic conductivity

Infiltrometer measurements are field tests performed with an infiltrometer and two concentric steel rings, consisting in registering the time it takes for a column of water to infiltrate into the soil, then estimating the vertical hydraulic conductivity by fitting a time-water column height curve.

Pumping tests consist of pumping groundwater from a well, usually at a constant rate, and measuring the change in water level (drawdown) in the pumping well and in nearby wells (if present) to estimate hydraulic parameters such as the hydraulic conductivity.

Leakage rates of channels

Ponding tests involve the filling of a section of an irrigation channel registering the time it takes for it to empty to estimate the leakage rate of the channel. Also, by measuring the discharge between two points along the channel, the difference can be used to find the leakage rate of the channel' segment. Since the channel filling method has many uncertainties both on the realization of the method itself and the results it can produce, the test will be made only in case there would be discrepancies between leakage rates obtained by discharge difference and leakage rates derived from channel's bed hydraulic conductivity.

Discharge: lowland springs, irrigation channels

Discharge will be measured using three methods:

1. Weirs: Weirs are systems which enables the computation of discharge by reading the water height when the water crosses it. Consorzio Est Ticino Villoresi owns weirs at each branch of its irrigation network. A weir will be installed in a lowland spring with the possibility to extend the installation considering the limitations that these unique springs pose.
2. Flowmeters: flowmeters measure water velocity which, coupled with the knowledge of the water section permits the calculation of the discharge by the simple relationship $Q = v*A$, where Q is the discharge, v is the velocity and A is the water section. The measure with this method is more dependent on the channel or spring condition than with the weirs. The presence of vegetation along the borders or the variation of the channel bed can influence the velocity measurement, resulting in a distorted discharge.

3. Tracers: measuring discharge with tracers consists in introducing a solution of water and a tracer at a point in the channel and measuring the electrical conductivity in a point downstream. Then, the resulting conductivity curve is purified from the baseline conductivity and converted to concentration. By dividing the mass of the tracer by the integral of the curve the discharge is obtained. This method is subject to variations from one test to another, due to the dependence of the grade of mixing of the tracer in the water. The tracer which will be used is salt (NaCl).

These methods will be used in parallel, and their results will be compared during the project lifetime to contribute to the final guidelines on good practices related to the adaptation measures implementation (Deliverable 2.4.2 “Guidelines for water resource management approaches”).

Agricultural characterization of the study area

The importance of the agricultural sector in the study area is undisputable. During the project, it is planned to conduct a characterization of the study area regarding the agricultural crops cultivated and the irrigation practices employed. The aim is to provide the IdrAgra[1] model with data that reflect local practices, enabling a more precise modelling of both the vegetated area and the unsaturated soil zone.

The characterization process will be particularly comprehensive for the experimental area, benefitting from ongoing dialogue with participating farmers that provides detailed knowledge of the crops used during the simulation period, the timing of sowing and harvesting, as well as the timing and duration of irrigation practices. For areas outside the experimental zone, where winter irrigation isn't part of the project scope, land use information will be obtained from regional databases. Reference will be made to the maps produced by the Lombardy Region Agriculture Information System (SIARL) for the years 2017-2020 and to the Graphical Crop Plan (GCP) for the years from 2021 onwards. SIARL provides a 20 m x 20 m regular mesh land use map based on cadastral parcels and is available until 2020. The GCP, is instead a polygonal map, based on information provided directly by the farmers, whose elements trace the actual agricultural plots and thus allows for greater detail, providing a better correspondence between the map and the current state of agricultural activity.

It is planned to integrate the information on local irrigation practices collected from the farmers directly involved with the information shared by Consozio Est-Ticino Villoresi, and, if deemed necessary, to involve other farmers not directly involved through surveys. Since 2023, spatialized information with a high level of detail inherent to the irrigation methods used has been available and collected through Common Agricultural Policy applications. Despite expectations of traditional methods prevailing in the study area, an audit will be carried out to confirm this assumption.

The results of the characterization activities will be outlined in greater detail in Deliverable 2.3.1 “Adaptation measure field test and hydraulic & agricultural characterisation of the pilot area”, scheduled for Period 4.

Groundwater usage and piezometric levels data reception

The most important variable to build the groundwater model is the piezometric levels, which permit to represent the conditions in the study area. This information is gathered through the monitoring during the project lifetime, but for the previous periods data is provided by the regional environmental authority, ARPA Lombardia, also for points outside the Pilot Area, to be able to reconstruct the boundary conditions. This data will then be updated during the project lifetime.

Another important variable is the pumped volume. For the Pilot Area, public wells’ pumping rates will be provided by water utilities (MM S.p.A., Associated Partner in this project, being one of them). Private volumes are only available in form of concessions and declared volumes by individuals. This data is

[1] IdrAgra (Idraulica Agraria) model is a distributed-parameter conceptual model, which allows the simulation of the irrigation water distribution in agricultural areas and the estimation of the hydrological balance. Website: https://idragra.unimi.it/

available in the SIPIUI database[2], which will be made available by Regione Lombardia, Associated Partner in this project.

3. Monitoring design

The Pilot Area monitoring network has been created in order to assess the effects of irrigation on the groundwater table and, consequently, on the lowland springs fed by it. For this purpose three datasets will be collected: one of piezometric measurements taken in wells/piezometers and one concerning the related surface waters: lowland springs water height at the spring ponds or deriving water courses and water flow speed will be measured, where feasible, to estimate discharge coming from the aquifer to the spring; the third one will contain irrigation discharge measurements and finally the fourth dataset will contain hydrometeorological data. The monitoring plan aims to understand how groundwater levels and hydrometric levels/flow rates of the lowland springs vary over time, to numerically quantify the extent of contributions that irrigation provides to underground water resources and to groundwater reuse through the lowland spring courses downstream.

The quantitative understanding of water exchange between groundwater and surface water is still unknown and represents one of the important goals of the project, of fundamental relevance for the future management and planning of the exploitation of water resources in Milan, now that climate change effects are beginning to be commonly noticed by the public opinion.

Piezometric network

The piezometric network will be made up from 2 different sets of monitoring points:

- Already existing piezometers/wells, to be used also for MAURICE;
- New piezometers specifically built for the MAURICE project purposes.

The actions carried out for the monitoring network constituted by existing piezometers and wells can be divided in two macro-activities:

- Bibliographic data collection and consultation of existing databases in the area;
- Assessment of water level measurement possibility in identified piezometers and wells.

The first phase was characterized by existing piezometers research in the Pilot Area. In order to collect as much piezometric data as possible, homogeneously covering the entire extent of the area, the following databases were consulted and merged:

- Città Metropolitana di Milano, made available by Regione Lombardia[3,4]
- Ambiente Comune (project by Gruppo CAP[5] and Città Metropolitana di Milano)[6]
- Resulting database from Interreg CE project AMIGA[7]

[2] Sistema integrato di polizia idraulica e utenze idriche (SIPIUI)
[3] Città Metropolitana di Milano is the public authority entitled to grant groundwater exploitation and piezometers permits
[4] https://www.dati.lombardia.it/Ambiente/CITTA-METROPOLITANA-MILANO-Pozzi-piezometrici/dwdr-paz2/data
[5] CAP Holding S.p.A. is the water utility company operating in Milan's hinterland
[6] https://ambientecomune.eu
[7] https://programme2014-20.interreg-central.eu/Content.Node/AMIIGA.html

In Figure 5 all the points contained in the databases are shown, for a total of 1897 potential monitoring points across shallow and deep aquifers. Once this collection process had been achieved, monitoring points were identified and chosen according to the following criteria:

- Homogeneous spatial localisation of monitoring points;
- Proximity to irrigated areas or falling inside the modelling domain;
- Physical accessibility to the measuring site;
- Possibility of consulting and measuring piezometric levels (e.g. private piezometers);
- Inspection depth and monitored aquifer[8].

The points at which the aforementioned criteria were satisfied were selected to constitute the monitoring network which will be utilized during the Pilot Action monitoring phase.

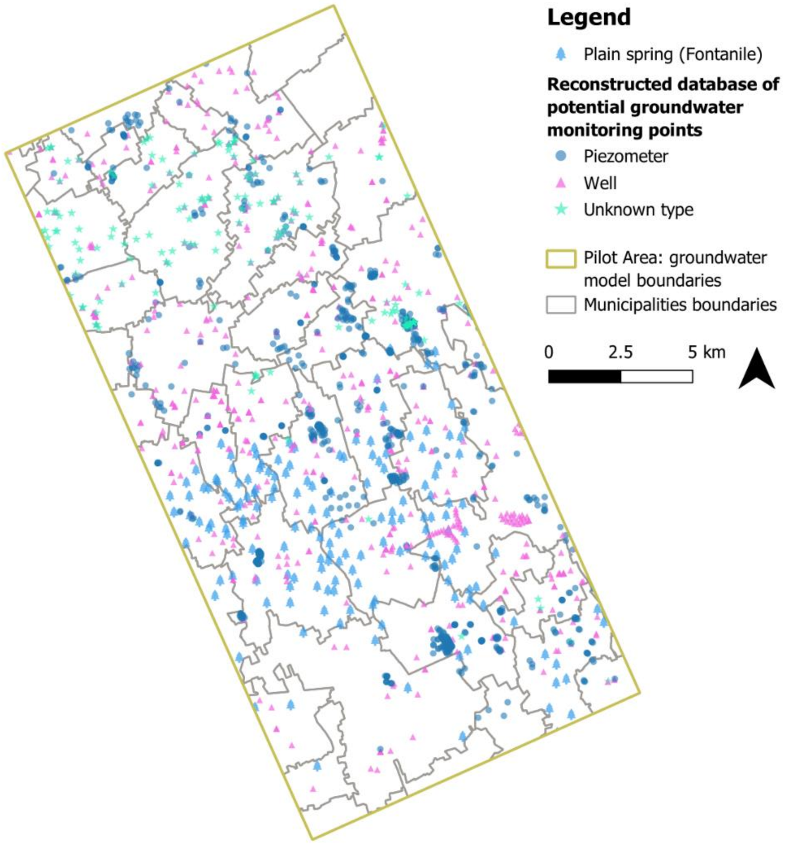

Figure 5. Potential monitoring points reconstruction over the Pilot Area, merge of databases from Città Metropolitana di Milano, Ambiente Comune and AMIIGA projects

Besides the existing piezometers, four new piezometers are currently being installed in strategic places inside the pilot area to deeply examine water exchanges between groundwater and surface water. Because the existing piezometers cover the pilot area with a certain homogeneity, except for the southern part which presents less information, it was decided to locate the new four piezometers within or close to those fields which, based on preliminary interviews with landowners & farmers, will be affected by winter

[8] The interesting aquifer for the project purposes is the most superficial one in the multilevel aquifer below Milan, named "ISS" (Idrostruttura Sotterranea Superficiale - Superficial Underground Hydrostructure), or Acquifero A in previous documents

irrigation practices. To decide where to install the new monitoring points the following general criteria where used to determine land suitability:

1. Existence of significant irrigated areas, by means of annual distributed water and field extension.
2. Presence of relevant downstream lowland springs canals.
3. Expected cooperation from landowners & farmers, among those interested in new approaches application for future water management.
4. Crop suitability for winter irrigation.
5. Existence of winter irrigated areas upstream.

Based on a GIS territorial analysis and specific in-field surveys, it was decided to drill four piezometers in locations strategically chosen to ensure the success of the experimentation, particularly in response to winter irrigation practices that are being conducted in specific areas with the involvement of the concerned landowners and farmers. Three piezometers will be installed on land owned by private individuals, whilst one on public terrain; all of landowners and managers have been interviewed, whilst consent and authorization has been achieved to carry on the needed field activities. The locations of the piezometers are detailed in Table 2 and Figure 6.

Table 2. Coordinates and information of the four piezometers to be built.

Piezometer	Municipality	Cadastral map sheet & parcel	UTM-WGS84 coordinates	Landowner
PZETVMI-01	Sedriano	Sheet 6 parcel 66	32T 498662.3 m E 5037958.0 m N	Private
PZETVMI-02	Bareggio	Sheet. 3 parcel 532	32T 499448.0 m E 5037290.1 m N	Bareggio municipality
PZETVMI-03	Cornaredo	Sheet. 13 parcel 201	32T 501868.94 m E 5035338.1 m N	Private
PZETVMI-04	Cusago	Sheet. 4 parcel 13	32T 502281.7 m E 5034088.4 m N	Private

Lowland springs

Lowland springs represent an important water resource in the Milan area, because the irrigation activities take place mainly in the northern part of the province, whilst in the southern areas water supply for agricultural use is relevantly carried out by the lowland springs network, together with other channels that are directly fed by the Navigli system network. Moreover, groundwater recharge occurs upstream whereas the water transfer between the upper and lower lands is mainly attained by means of this relevant stream network, existing since the XIV century. The Pilot Area includes 209 lowland springs, located in the municipalities of Sedriano, Bareggio and Cornaredo to the north and Gaggiano, Buccinasco and Cusago to the South.

To design the lowland springs monitoring network, dedicated field inspections were carried out to evaluate, among others, the following matters:

- Accessibility to the lowland spring head or deriving water course: useful to evaluate the feasiblity to carry out level measurements on the water resource.
- Activity of the spring: to attain relevant data, the presence of running or still water must be addressed differently.
- Water origin: it is of chief importance to collect solid and consistent data in order to fully understand the water balance, avoiding the evaluation of water flows directly coming from anthropic activities, such as other channel networks, pumping wells, etc.
- Location of the spring in relation to the areas irrigated in the winter.
- Once the above-mentioned requirements were met, 10 lowland springs were chosen.

At all lowland spring will be monitored by measuring their water level, 2 of which will be measured continuously. Six lowland springs, the ones with a discharge, will also have their discharge measured.

Final monitoring network

The resulting monitoring network is shown in Figure 6. The groundwater monitoring network has been sub-divided in three groups:

- Network “Modellistica”: 14 points sampled with lower frequency (4 times a year);
- Network “Irrigua”: 11 points sampled at higher frequency (once a month), plus 4 points, which will be built in the context of MAURICE, continuously monitored through automatic dataloggers;
- Network “NS” (North-South): 3 points monitored during summer months to control the water table northernly and southernly to the fields irrigated during wintertime and to favour solid piezometric trend comparison. It is also included in the “Modellistica” network.

The groundwater monitoring network is complemented by the lowland spring monitoring network illustrated before, for a total of 39 monitoring points across the Pilot Area. In Table 3, the monitoring plan for the groundwater and lowland springs networks is shown.

An additional number of monitoring points are considered to monitor the discharge provided to irrigated fields. In Figure 6, the Consortium monitoring points are shown. For these points, daily data is collected. To complement these, a set of other points has been defined to measure the discharge that actually arrives at the fields irrigated by the farmers involved in the project. These measures will be performed at least once a season, to assess the losses from the main measuring points to the fields. A summary of discharge data collection is provided in Table 4.

Hydrometeorological data will be collected by gathering the nearby hydrometeorological stations of the regional environmental authority.

Table 3. Monitoring plan for the piezometric levels and lowland springs monitoring networks. “Mod.”: network “Modellistica”, L.S.: lowland springs network.

	2023				2024				2025			
Month	"Irrigua"	"Mod."	"NS"	L. S.	"Irrigua"	"Mod."	"NS"	L. S.	"Irrigua"	"Mod."	"NS"	L. S.
J												
F												
M												
A												
M												
J												
J												
A												
S												
O												
N												
D												

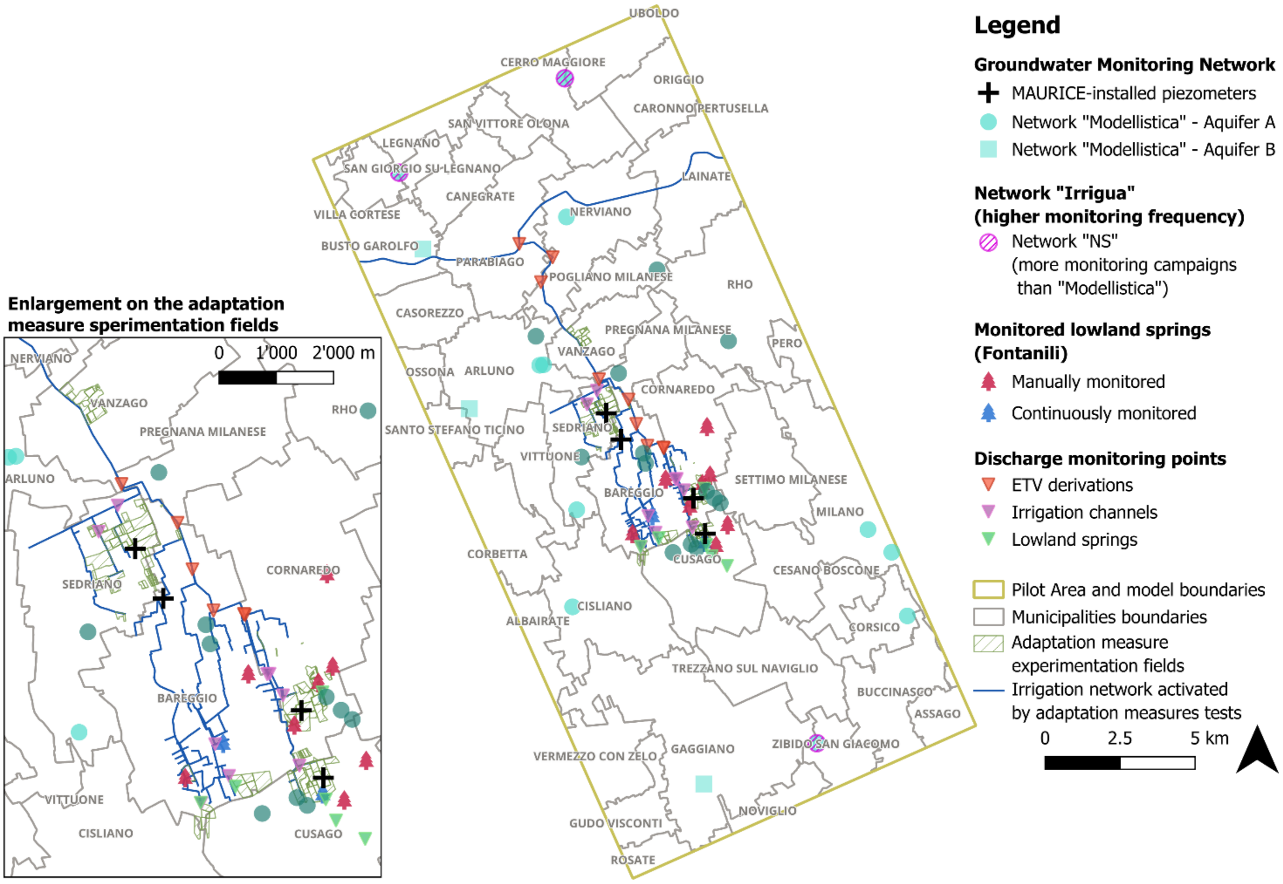

Figure 6. Resulting monitoring networks (groundwater, lowland springs and irrigation channels monitoring network) mapped alongside the adaptation measure experimentation fields and channels.

Table 4. Discharge data collection summary

Type of point	N° of measuring points	Measuring frequency
Consorzio ETV monitoring points along their main channels	7	daily
Irrigation channel at field level	6	monthly
Lowland springs	6	monthly

4. Coordination Activities & Investments

Pilot Action Milan plans to test adaptation measures to climate change by increasing winter groundwater recharge. To do so, cooperation with farmers is crucial, since the adaptation measures will involve the utilization of irrigation channels and irrigated fields, directly managed by farmers in the Pilot Area described in the previous Sections. So, several coordination activities are planned, and some have already taken place:

- Meeting with farmers involved. The first was held on the 25th of October, contacts have been kept frequent since then.
- Coordination of discharge measures arriving at the field: positioning of measuring instruments and involvement of farmers in actual measurements.
- Coordination of the actual measure implementation: definition of the fields to be irrigated, development of a continuous exchange of information between farmers and partners on the fields irrigated.
- Coordination of stakeholders: in compliance with WP1, the Regional Implementation Group has been established and cooperation among different stakeholders is being fostered.

The investments covered by MAURICE useful to achieve the Pilot Action include:

- The construction of 4 boreholes with continuous monitoring of groundwater levels though dataloggers. More details on this can be found in section "Monitoring network design".
- The implementation of measures to improve the water discharge in the irrigation network, by:
    - The positioning of two idrometers and the substitution of an additional one.
    - The refurbishment of the banks and bottom of irrigation channels in two locations.
    - The refurbishment of a measuring weir.
    - The installation of two datalogger to continuously monitor the water level in two lowland springs.

C. Pilot Action Stuttgart

5. Description of the Pilot Area

5.1. Introduction to the Pilot Area

The project area is situated in the northern part of Stuttgart, encompassing both urban territories (districts Feuerbach and Botnang) and the Feuerbach creek valley.

The urban part is distinguished by residential zones alongside high concentration of industrial and commercial sites. A mix of global players and small enterprises that play a leading role in supporting the local economy. Many of the industrial sites in the area have a long and rich history of diverse usage. However, there has been a trend since the 1980s of smaller companies either relocating or shutting down productions. This long-term tradition of industrial and commercial use has led to considerable soil and groundwater contamination in some regions of the district Feuerbach.

Nowadays, only the eastern part of the district Feuerbach is still heavily industrialised and commercial. In contrast, its western and central areas are predominantly residential and densely populated. Moreover, there has been a recent trend of rebuilding commercial areas into residential ones.

The Feuerbach creek has no typical spring. Instead, its formation is attributed to the confluence of multiple smaller streams, each originating from various locations within the catchment area. Its meandering through the Feuerbach valley and flowing into the River Neckar, adds a natural charm to the area. Bordered by the hills Krähenwald and Heukopf, the valley is a popular recreational destination for Stuttgart’s residents, offering extensive forests, beautiful meadow landscapes and notable wetlands for exploration and enjoyment.

5.2. Reasons for the choice of the Pilot Area

Since the goal of the pilot project is to assess and understand the impact of climate change on groundwater levels in Stuttgart, various aspects were decisive for the selection of the pilot area.

In the district Feuerbach, a concerning trend of declining groundwater levels over several years has been observed in numerous groundwater monitoring wells. These observations have been continuously documented, providing a substantial data set. In addition, extensive groundwater data are available in district Feuerbach gained from many years of extensive groundwater investigations and significant construction activities over several years. This provides a solid basis for correlating the groundwater fluctuations with climate data. The hydrogeological conditions in Feuerbach have been intensively researched in recent years, resulting in a relatively comprehensive understanding of the groundwater system.

The delineation of the pilot area primarily considers the surface catchment area of the creek Feuerbach. Toward the north, the boundary of the pilot area is aligned perpendicular to the groundwater flow-isolines of the Gipskeuper aquifer, extending to the major fault zone known as the Nördliche Fildergrabenrandverwerfung, near the district Zuffenhausen. The demarcation is strategically chosen to comprise the entire groundwater recharge zone within the pilot area.

For the purposes of numerical modelling, it is crucial to integrate the delineation of the existing large-scale numerical groundwater model of Stuttgart. This integration is essential due to the connection of the pilot area with the regional Muschelkalk aquifer.

Such a methodical approach to define the pilot area allows the usage of hydrological modelling to investigate potential changes in groundwater recharge patterns as a direct consequence of climatic variations. Subsequently, the numerical modelling applied in the pilot area enables the determination of the extent to which the observed changes in groundwater levels can be attributed to climate change effects. The pilot area spans roughly 22 km^2, see Figure 7.

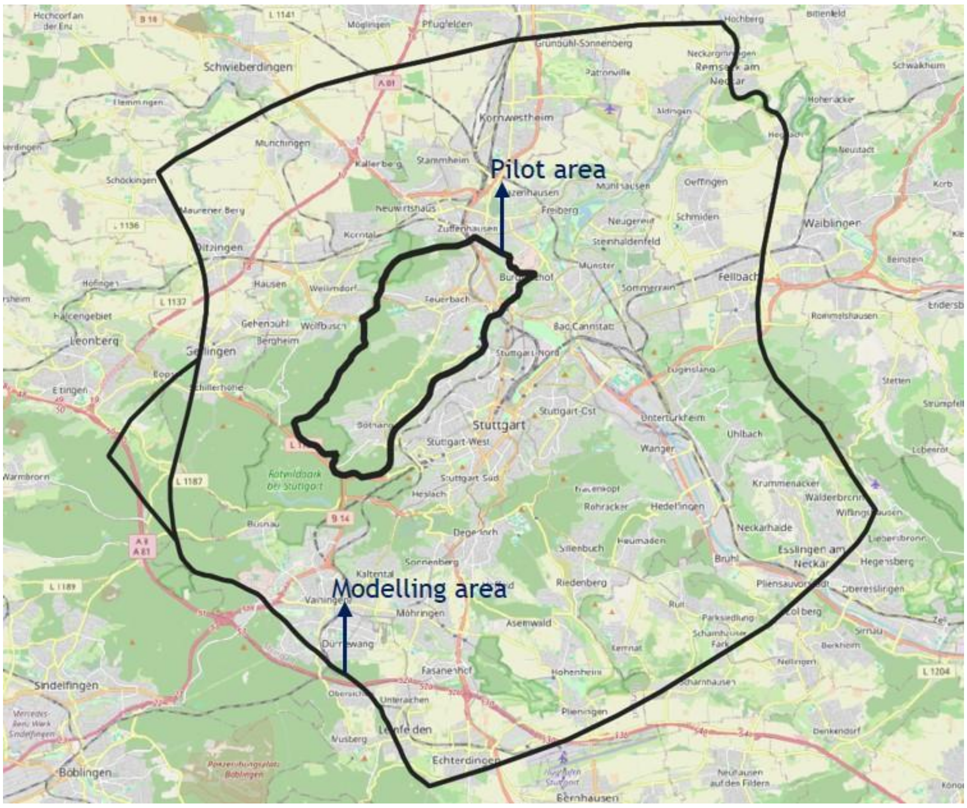

Figure 7. Pilot area and modelling area of Stuttgart-Feuerbach

5.3. Geomorphological, geological and hydrogeological framework

The bedrock outcrops in the Stuttgart area comprise an approximately 500 meter thick section of the overburden in the South German stratigraphic landscape. Stratigraphically, this layer package ranges from the Middle Muschelkalk to the Lower Jurassic, see Figure 8.

The base is formed by the Upper Muschelkalk (brown in Figure 8), which is around 80 metres thick. This is dominated by a sequence of micritic blue limestones and bioclastic shell debris beds, which are interspersed with subordinate clay marlstones alternating with limestone beds.

Above this section is the Lower Keuper (green in Figure 8), which is around 20 metres thick and consists of an alternating sequence of dolomite and mudstone. The uppermost layer of the Lower Keuper, the Grenzdolomit (GD), which is hydrogeologically combined with the gypsum layer known as Grundgipsschichten (GGS) to form a single unit (GGS/GD).

The Lower Keuper is followed by the Gypsum Keuper, which is up to 110 metres thick and consists of mudstones with individual carbonate, mostly dolomitic beds and sulphate rocks (gypsum and anhydrite). The formation subdivisions of the Gypsum Keuper are as follows:

- The up to 22 m thick gypsum layers known as Grundgipsschichten (GGS) with a sulphate rock content (unleached) of up to 80 %; when leached, they are only 9 m thick (blue in Figure 8).

- The 5 m thick mudstones of the Bochinger Horizon (BH), which include a dolomite bench up to 15 cm thick, so-called Bochinger Bank (yellow in Figure 8).
- The reddish-brown to purple mudstones of the Dunkelrote Mergel (DRM), up to 18 m thick (red in Figure 8).
- The claystone of the Middle Gypsum Horizon (MGH), which are up to 38 m thick and contain sulphate rocks in thin beds and nodules when unleached or partially leached in the hilly areas around the Feuerbach valley (violet in Figure 8). On the top there are Estherian layers.
- Residues of erosion from Schilfsandstein and stratigraphically higher layers occur still on the hill peaks (dark green in Figure 8).

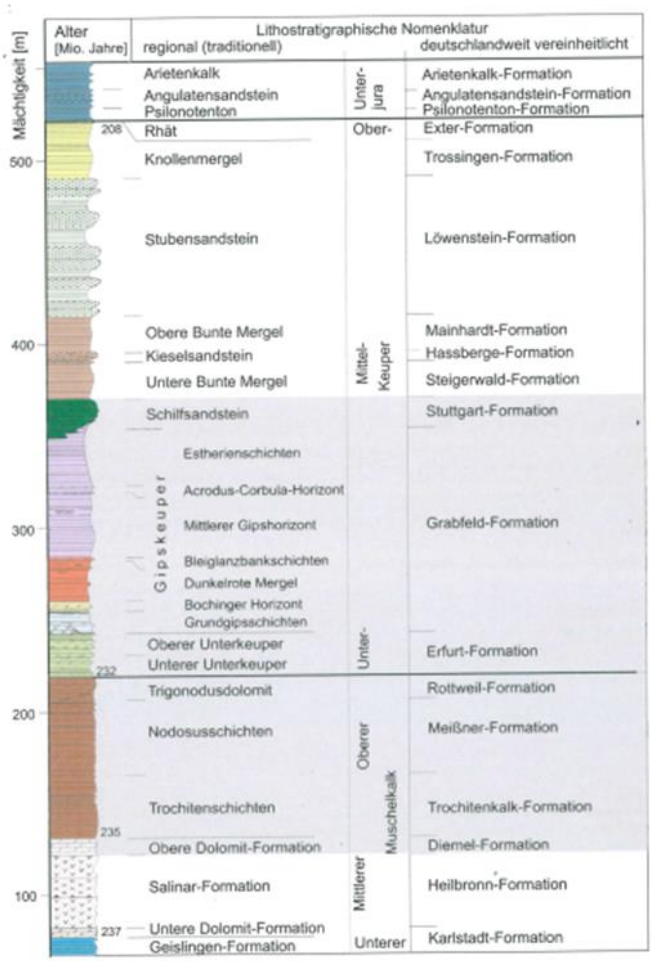

Figure 8. Overview profile of Germanic Triassic and Lower Jurassic

Depending on the stratification and fracture tectonics, the aforementioned sequence of layers in the project area has been eroded down to the basal Gipskeuper or Lower Keuper in some areas, whereas along valleys even down to the Upper Muschelkalk. This is the case in the western part of the project area along the creek Glems and its tributaries, as well as in the northeast in the lower areas of the district Feuerbach. The latter already lies on the plateau of the so-called Fildergraben, whose eastern edge fault in a NW-SE direction from the district Zuffenhausen via Feuerbach to Bad Cannstatt vertically displaces the layer sequence by 60 to more than 100 metres. Numerous faults with a small step-over amount cross the project area parallel or transverse to the Fildergraben east-strand fault, see Figure 9.

The solid rocks are covered by quaternary formations: on the slopes by slope loam and debris, in the valley lowlands by deposits of the creek Feuerbach (stream, shifting debris, alluvial loam and marsh clay).

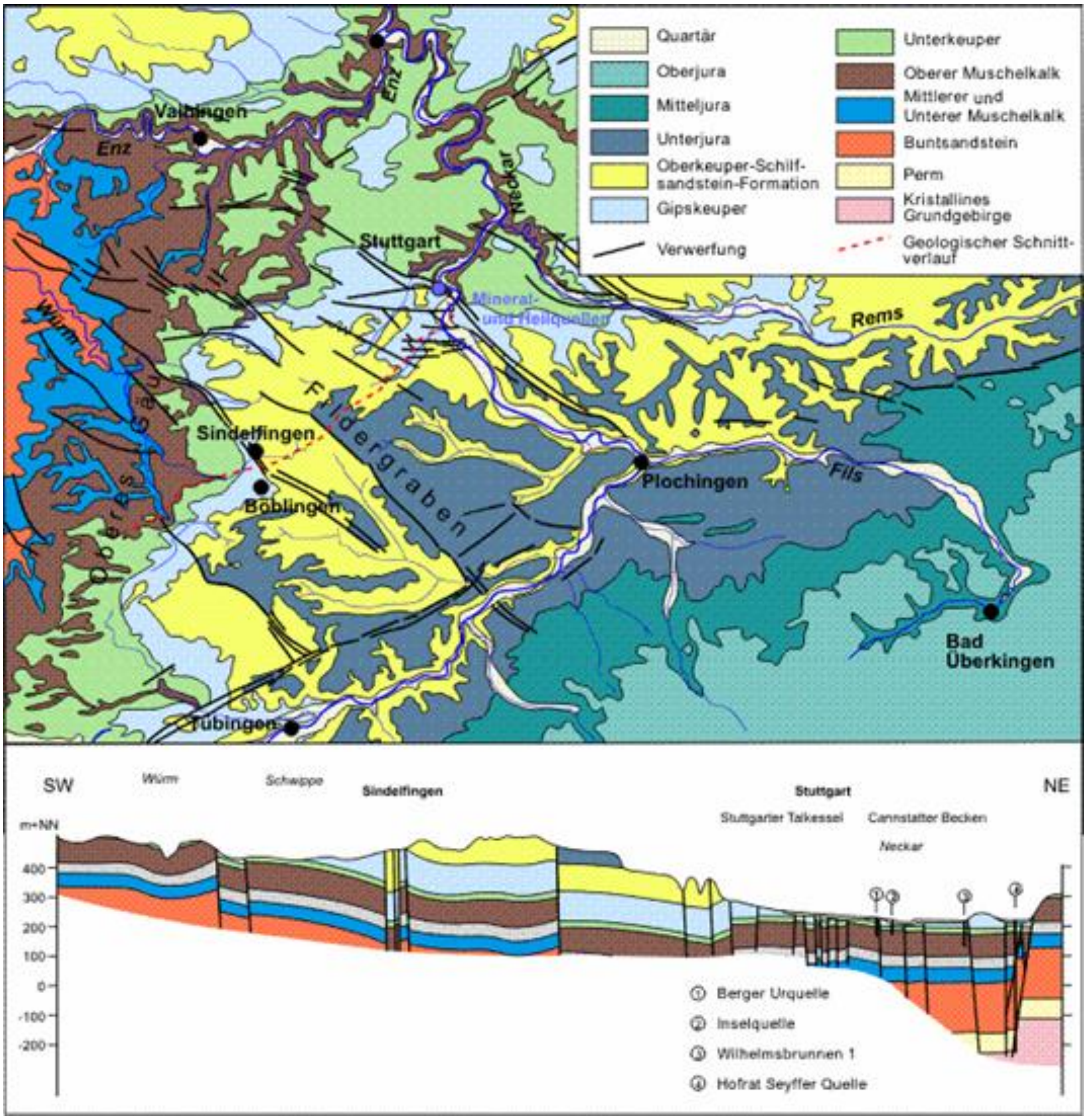

Figure 9. Geological overview for the region Stuttgart, as well as geological longitudinal section from the Upper Gäu to the Stuttgart Neckar Valley (Cannstatt Basin). The main faults of the Fildergraben are highlighted. Kirchholtes and Ufrecht, 2015

The hydrogeology of the project area is characterised by a multi-layered aquifer system, which is divided into the Quaternary of the valley lowlands, the Gypsum Keuper (with partial levels) and - from a depth of around 50 metres below ground level - the Lower Keuper and the Upper Muschelkalk. Within the Gypsum Keuper, four additional horizons are hydrogeologically differentiated (from top to bottom), provided they have not already been removed: Middle Gypsum Horizon (MGH), Dunkelrote Mergel (DRM), Bochinger Horizon (BH) and

Grundgipsschichten/Grenzdolomit (GGS/GD). The lowest layer GGS/GD has a special position, as the Grenzdolomit is stratigraphically assigned to the Lower Keuper, but hydraulically to the Grundgipsschichten (Spitzberg and Ufrecht 2008).

The groundwater flow conditions in Feuerbach are very complex due to the differentiated, highly structured geological stratigraphy and numerous faults (see Figure 10). In the Gipskeuper, the permeability and therefore the groundwater flow is heavily dependent on the lithological structure (fissured dolomite beds) and gypsum leaching (subrosion) (Ufrecht 2017).

Today, gypsum leaching is only active in the core area of the project area, namely in the Feuerbach urban area along the slopes and near Wiener Platz (Ufrecht 2019). If the gypsum is leached out in all sublevels of the Gypsum Keuper, vertical connections (so-called hydraulic windows) to the Lower Keuper and Upper Muschelkalk are created. At such hydraulic windows, depending on pressure conditions, a vertical groundwater or mass exchange can occur, recognisable in a concentration of groundwater in the Lower Keuper and Upper Muschelkalk with dissolved sulphate. Such processes are increasingly possible along tectonic faults.

Based on their hydraulic properties, the aquifers in the project area can be summarised in two aquifer units:

- Local aquifers (Upper Aquifer System): Quaternary (non-extensive) and partial stockworks of the Gypsum Keuper
- Regional aquifers (lower aquifer system): Lower Keuper and Upper Muschelkalk

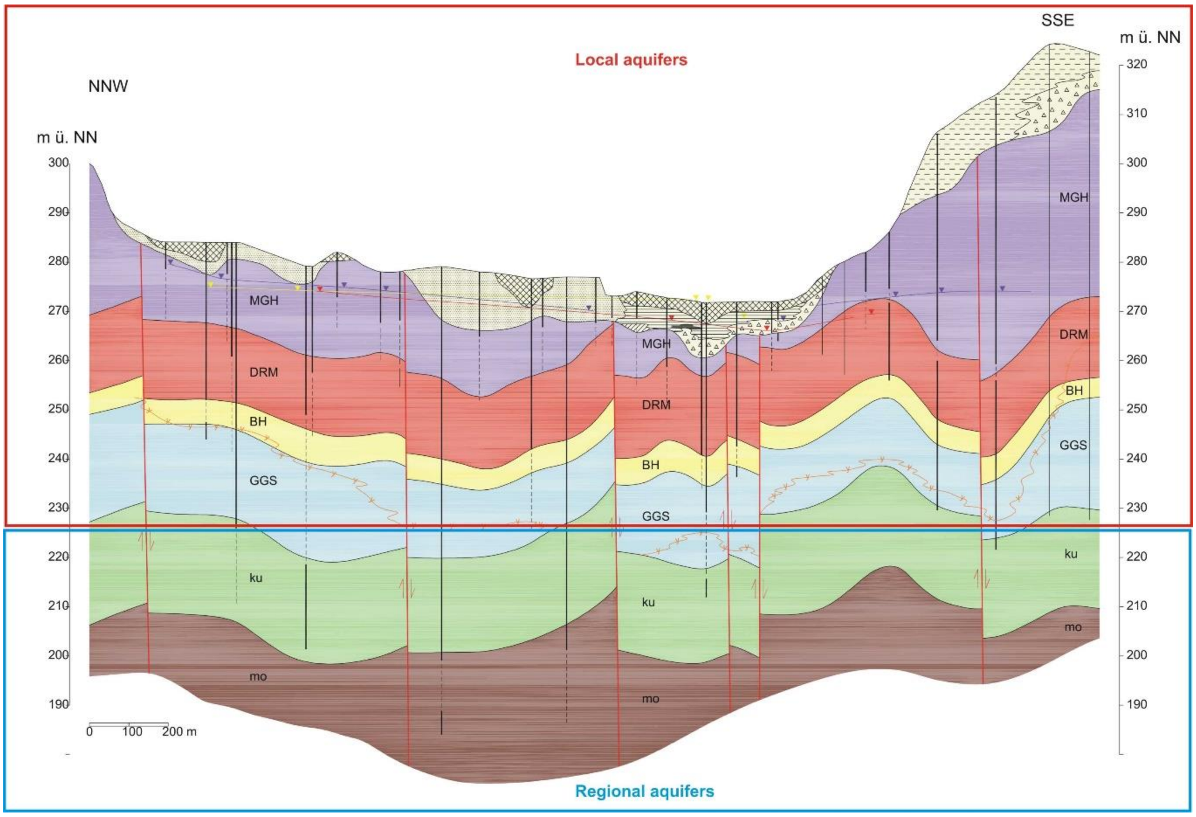

Figure 10. Geological cross section Stuttgart-Feuerbach

5.4. Geographical and climatic framework

Stuttgart's climate is marked by its geographical position in the wide Neckar basin, shielded by the Black Forest in the West, the Swabian Alb in the South, the Schurwald in the East as well as the Stromberg and Heuchelberg region in the Northwest. The city's position has a significant influence on all climatic elements like radiation, temperature, humidity, precipitation and wind.

Stuttgart's climate is mild with an average annual temperature of about 50 °F (10 °C) in the basin of the city and about 47 °F (8.4 °C) in the more elevated outskirts situated about 400 m a. s. l. Besides the Upper Rhine Valley, Greater Stuttgart is one of the warmest regions in Germany. The month of July is the hottest month with an average temperature of 65.9 °F (18.8 °C), while temperature in January averages only 34.3 °F (1.3 °C). Stuttgart's centre has about 150 days above freezing. Thanks to the generally mild climate, wine growing has been important here for a long time. Until the administrative reform in 1972, Stuttgart had been Baden-Württemberg's biggest wine growing region. Long-term measurements show that the Filder region has an annual average of 91 to 94 frost days, whereas Stuttgart's city centre has only 70. This phenomenon is called the heat island effect. There are 28 to 32 summer days in the Filder region, as compared with 40 to 47 summer days in the Neckar Valley and the Stuttgart bight. A combination of high temperature and humidity turns Stuttgart into a region with higher heat stress (about 30 days) and only occasional cold stress.

The region of Stuttgart has very little precipitation compared to other regions in Germany. This is mostly due to Stuttgart's above-mentioned position on the lee side of the Black Forest and the Swabian Alb. The average annual amount of precipitation in the city centre is 679 mm. The biggest amount of precipitation falls, like in the rest of Southern Germany, in summer, mostly in the months of June and August. The little amount of precipitation and the rapidly growing population in the Stuttgart region led to the necessity of fresh water supply from other regions. Fresh water is mostly provided from the Swabian Alb (by the State Association Landeswasserversorgung) as well as from Lake Constance (by the Association Bodenseewasserversorgung).

A major element of Stuttgart's climate is the light wind, a fact which is not only the result of the city's position between two bights of the Keuper plains. The whole Neckar Valley is known for low wind speeds and very frequent lulls. This is the result of small air pressure differences common to Southern Germany and of Stuttgart's sheltered position mentioned above.

6. Characterization activities design

In order to build the hydrological and hydrogeological numerical model and to achieve the link with the climate data, we need additional information to characterize the pilot area, in particular continuous groundwater measurements, discharge measurements from the Feuerbach as well as precipitation data, groundwater extraction rates and investigation of building damages. The following table summarizes the activities, investigated characteristic, number of activities and their duration.

Table 5. Characterization activities' investigated characteristics, scheduled dates and number

Activity	Investigated characteristic	Scheduled date of the activity	N° of activities
Data logger measurements	Current groundwater levels	11/2023 to 10/2024	hourly recording
Collection of data	Historical development of GW-levels	04/2023 to 05/2024	more than 100 monitoring wells
Collection of data	Extraction rates	04/2023 to 05/2024	around 50 wells
Discharge measurements	Discharge of the creek Feuerbach	04/2024 to 09/2024	4
Collection of data	Groundwater recharge	04/2023 to 05/2024	-
Collection of data	Sealing areas	04/2023 to 05/2024	-
Collection of data	Building damages	05/2024	-
Evaluation of data	Development of GW-levels	04 to 09/2024	-
Current climate data	Current climate data: precipitation, temperature, evaporation	02/2024 to 02/2025	daily data

Current groundwater levels

Data loggers shall be installed in the selected monitoring wells to continuously measure the groundwater levels. They will record the groundwater levels on hourly bases. The data shall be read out every 2 months and their function shall be checked.

Historical development of groundwater levels

In order to check the plausibility of the falling groundwater trend, the current measurements must be correlated with the historical measurements as well as with the climate data of the last 20 years. Furthermore, in order to understand the declining trend, the historical data are essential.

Groundwater extraction rates

In the pilot area, the groundwater extractions have been recorded separately for each aquifer for the last 20 years. Since groundwater extractions have an influence on the groundwater levels, it has to be investigated if decreased groundwater levels occur due to excessive extractions of the groundwater. The groundwater extraction rates shall be incorporated into the hydrogeological numerical model.

Discharge measurements

The discharge measurements shall be carried out either by using a water level meter, which will be installed in the underground tube of the creek Feuerbach, or manually by using a velocity meter. For the manual measurement, the creek-bed must firstly be measured in order to calculate the discharge via the cross-section area and the measured flow velocity.

Discharge measurement can be carried out using the following methods:

- Seba FlowSens: Mobile device that registers the discharge by using the magnetic-inductive measuring principle. The measuring device records point velocities. Following the discharge can be calculated according to the measured velocities and the cross-section area.
- Water level meter: The water level is measured via a measuring cell that measures the hydrostatic pressure of the water column. The data are transmitted remotely and are therefore available on a daily basis.

Groundwater recharge

Groundwater recharge is determined for the past decades (1980-2023). The observation over the long period provides information on whether groundwater recharge differs significantly depending on, for example, dry years or wet years. Groundwater recharge influences the groundwater supply and thus also the groundwater levels. These aspects shall be incorporated into the hydrogeological model.

Survey of sealing areas

Historical sealing maps are designed for the groundwater recharge area and compared with the current sealing map. If relevant areas in the recharge area have been sealed in the meantime, this has an influence on groundwater recharge.

Damage of buildings

In the pilot area, a number of building damages have been observed. These are recorded in detail, whereby the quaternary aquifer and the surrounding vegetation are mapped. In order to establish a correlation with the groundwater levels, data loggers shall be installed in this area to monitor the groundwater levels. In addition, building cracks outside the pilot area are also recorded.

Current climate data

Current climate data shall be measured using a measuring station in the pilot area to continuously record precipitation, temperature and evaporation. The data shall be transmitted remotely directly to the Climatology Department's server so that the data are available all the time.

7. Monitoring design

The cause of the falling groundwater levels in the pilot area is not yet understood. However, for future groundwater management in the pilot area and the careful use of groundwater, it is essential to determine the cause of declined groundwater levels and its possible correlation with changing climate conditions. To investigate the influence of climate change on the groundwater levels, the following data are necessary to be measured:

Groundwater levels

Continuous groundwater level measurements shall be performed by data loggers installed in about 20 groundwater wells in the various aquifers (Quaternary, Gypsum Keuper, Lower Keuper). The groundwater levels shall be measured on an hourly basis over at least one year. The monitoring wells shall be regularly distributed over the pilot area, whereby groups of wells shall be selected. Each group of wells enables that the groundwater level is measured simultaneously in the different aquifers. The data shall be read out every 2 months and evaluated together with the precipitation data.

In addition, the groundwater levels shall be compiled from existing documents in the pilot area and from earlier projects, e.g. AMIIGA, and correlated with the climate data. Unfortunately, the data basis varies greatly. In some cases, continuous data from groundwater remediation projects over the last 10 to 15 years are available, but generally only individual measurements of groundwater levels are available. Furthermore, long-term groundwater levels outside the pilot area shall be collected, in order to compare this information with that in the pilot area.

Measurements of climate data

A weather station shall be set up in the pilot area, in particular in the area of groundwater recharge. The goal is to record climate data such as precipitation and air temperature. The weather data shall be recorded continuously over 1 year and correlated with the weather data from the German Weather Service.

For the pilot area, climate data for the last few decades are available from the Schnarrenberg weather station, a station of the German Weather Service. In addition, the climatology department of the City of Stuttgart can also provide long-term climate data for Stuttgart. This weather data shall be used to determine groundwater recharge, which is a key factor in the hydrological and hydrogeological numerical model.

Discharge measurements

The discharge measurements of the Feuerbach shall be carried out either continuously over several months by using a water level meter or several times manually. The discharge measurements are required to record the water balance in the area of groundwater recharge.

D. References

Billard, 1973, Paleosols quaternaires de l'Alta Pianura Milan, interpretation stratigraphique et paleoclimatique. Bollettino A.F.E.Q., 37: 276-286, Paris
Carcano et al., 2001, Geology of the Padanian Aquifers of the Lombardy Region. Eni Agip Division
Castiglioni et al., 1999, Geomorphological map of the Po plain, Italy at a scale of 1:250 000
Cavallin. A., Francani V., Mazzarella S., 1983, Hydrogeological study of the plain between the Adda and Ticino
Cornes et al., 2018, EU-FP6 UERRA (https://www.uerra.eu) and ECA&D (https://www.ecad.eu) from Copernicus Climate Change Service Curioni G. et al., 1877, Geologia applicata alle Provincie Lombarde. Ed. Heopli, Milano, 714p.
Ingenieurbüro Winkler und Partner GmbH (2022): Landeshauptstadt Stuttgart, Flussgebietsabgrenzung Feuerbach, Erläuterungsbericht
ISPRA Progetto CARG - https://www.isprambiente.gov.it/Media/carg/note_illustrative/118_Milano.pdf
Kirchholtes H.J. und Ufrecht W. Hrsg. (2015): Chlorierte Kohlenwasserstoffe im Grundwasser: Untersuchungsmethoden, Modelle und ein Managementplan für Stuttgart. Springer Vieweg. Wiesbaden.
Regione Lombardia & ENI, 2002 Geologia degli Acquiferi Padani della Regione LombardiaScardia et al, 2012, Stratigraphic evidence of a Middle Pleistocene climate driven flexural uplift in the Alps (Tectonics, 31, TC6004)

E. Annex list

- Annex 1: Minutes of meetings and list of participants to the project partners' discussions
- Annex 2: List of participants at the Pilot Area Visit in Milan
- Annex 3: List of participants at the WP2 partners' meeting and Pilot Area Visit in Stuttgart
- Annex 4: Registry of monitored lowland springs in Pilot Action Milan