D5.3 Summary of the conceptual understanding of the natural system in the case study

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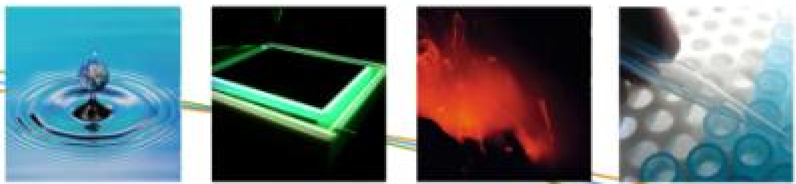

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List of abbreviations & acronyms

PPP	Plant protection product
VMM	Flanders Environment Agency
WFD	Water Framework Directive
DMI	Danish Meteorological Institute
ERT	Electrical Resistivity Tomography
TEM	Transient Electro-Magnetic
GEUS	Geological Survey of Denmark and Greenland
DHI	Danish Hydraulic Institute
CBDH	Central Hydrogeological Data Base (Hydro Bank).

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1 Introduction

The overall objective of WaterProtect is to contribute to the protection of drinking water from farming activities through an effective uptake and implementation of innovative farming systems. The work is realized through studies in seven action labs covering a variety of farming system and pedo-climatic conditions throughout Europe, Table 1.1. Each case is unique with respect to the physical system, crop schemes and farming practice, as are the sources of drinking water and possible treatment of drinking water. Hence, the threat towards the drinking water will be unique for the seven action labs. A prerequisite for the formulation of optimal solutions, including efficient mitigation measures and best management practices, is a thorough understanding of the physical system, from which the major critical pathways that need to be targeted can be identified.

Table 1.1 Summary of the seven WaterProtect action labs

	BE	IE	PL	DK	IT	ES	RO
Environmental Zone*	ATC	ATC	CON	ATN	MDN	MDS	ALS
Land use	mixed urb/rur	rural	rural	rural	mixed urb/rur	mixed urb/rur	rural
Farming system	field crops	grass & field crops	field crops	field crops	vineyards	minor fruit & veg	extensive grassland/ subsistence
Size	small ~40 km^2	small ~10 km^2	interm ~60 km^2	interm ~27 km^2	small to large	interm ~120 km^2	Small ~20 km^2
Drinking water**	SW	GW private & public	SW	GW public	GW private	SW& GW private	GW private
Pollutant	pesticide	nitrate and pesticide	nitrate	nitrate	nitrate and pesticide	pesticide and nitrate	nitrate
Irrigation	no	no	yes	no	yes	yes	yes

*ATC Atlantic Central; CON Continental; ATN Atlantic North; MDN Mediterranean North; MDS Mediterranean South; ALS Alpine South
** SW surface water, GW groundwater

During the WaterProtect project data on farming practice and observations from the physical system has been collected. These data are represented in the present report supplemented by a description of the system data. Based on these data and prior knowledge, a conceptual model is developed for each action lab. The conceptual model summarises the relevant sources threatening the drinking water and the main physical processes important for the transport and possible degradation/removal of the pollutant during transport.

As the challenges in the seven action labs are all unique, no "one-size" solution to target the different challenges exists. Depending on whether surface water or groundwater is in focus different transport processes need to be considered. Similarly, nitrate and pesticides, and even different groups of pesticides, have different physiochemical properties, and thus require different approaches in the analyses. The level of knowledge, i.e. the level of system understanding, as well as the data availability also has to be considered in the selection of appropriate models and/or tools. Working with stakeholders in a multi-actor approach adds yet another aspect to be considered, namely the

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stakeholders trust in models/tools. Such trust, or mistrust, may arise from previous experiences with modelling tools as well as the stakeholders perception towards the model complexity, which may be deemed either too complex to understand or too simplistic to represent the actual processes. Finally, the choice of models/tools must also be guided by the type of mitigation measures to consider in the individual action labs, and the level to which the effect of these mitigation measures need to be quantified prior to their implementation,

All those aspects implies that it is not feasible to use the same tools or models for all action labs. The purpose of developing a conceptual model (the present deliverable) is thus to understand the physiochemical system. Such understanding, combined with knowledge on the stakeholder communities, will then guide in the selection of the most appropriate tools/models to analyse the system and the effect of the proposed mitigation measures. Hence, the different action labs have selected different tools/models for the further assessments in the action labs. This is also reflected in the descriptions below, where some action labs have, or are in progress of, developing complex numerical models, while others type of challenges in other action labs can be targeted by the use of analytical approaches.

The main objective of Work Package 5 in WaterProtect is the development of collaborative tools to be used in the action labs. Deliverable D5.1 focus on the requirements to the collaborative tool with focus on using the functionalities of the tool as dialogue platform with local stakeholders, which was followed up by a functional analysis (D5.2) detailing the required code development. In the present deliverable focus is on understanding the physical system, and what and how to analyse this. Results from the assessments with the tools/models from the individual action labs, will provide input to the collaborative tools, and thus provide additional information to utilise during the discussion and decision making with local stakeholders.

A thorough understanding of the physical system is a prerequisite for the identification of optimal solutions, but is in itself not sufficient. In addition to the physiochemical conditions, the local conditions need to be considered as well, e.g. what is possible and acceptable and how will potential costs be covered. Hence, the physical possibilities need to be combined with an understanding of the social aspects and governance system. In this respect, the present deliverable on the physiochemical understanding provide one of the vital components that need to be combined with other results from WaterProtect, especially Work Package 2, in order to identify optimal and long lasting solutions.

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Action lab: Bollaertbeek (Belgium)

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2 Bollaertbeek (Belgium)

2.1 Executive summary

The Belgian study area is the Bollaertbeek catchment just south of the city of Ieper. The Bollaertbeek and Haringsebeek spring north of the Kemmelberg and join south of the village of Voormezele to continue to the north towards the city of Ieper. The southern part of the catchment is highly vulnerable for erosion while the northern part has a rather flat topography and is not vulnerable to erosion. The landuse in the area is dominated by agriculture (81%). The catchment is relatively small (23 km^2) and 167 farmers are active in the area on one or more fields.

The catchment outflow is located at Stuw 8 (a weir on the river). Here the drinking water company de Watergroep has an intake of surface water and collects it in the Verdronken Vijver to produce drinking water for the city of Ieper. During periods of the year the company suspends the intake of surface water because of the high concentrations of plant protection products which would cause excessive purification costs to make drinking water. During these periods the Bollaertbeek is disconnected from the Verdronken Vijver and redirected and other water sources are needed to produce drinking water.

Water quality and concentrations of plant protection products have been monitored for a long time by de Watergroep and VMM (Flanders Environment Agency). VMM takes bimonthly samples at 4 locations in the area and de Watergroep monitors weekly at Stuw 8. In the WaterProtect project in 2017 a more extensive monitoring campaign was conducted at 8 locations in the area. The measurements show a lot of exceedances of the drinking water limit and the environmental limits with most of the exceedances occurring in the main stretch of the river. In order to better assess the importace of the different pathways of plant protection products to the river and design targeted measures, in 2018 a continuous monitoring campaign at two locations was set up: one upstream location in the erosion sensitive area and one location close to the outflow of the catchment. This monitoring is continued in 2019. The historical data on pesticide concentrations as well as the new measurements and relevant maps for the area (land-use, erosion sensitivity) are made available in the WaterProtect app. This way all actors in the area have access to this information.

Based on the monitoring results and on results from previous study we concluded that the main routes for plant protection products to the Bollaertbeek are direct losses (point sources) and diffuse losses from runoff and erosion. The strong seasonal signature of the exceedances supports the hypothesis that other processes such as groundwater contribution or interaction with river sediment are of minor importance in the Bollaertbeek catchment. To target the two main routes, risk maps have been constructed for direct losses (based on location of farmyards, size of the farm and spraying by the farmer) and for runoff and erosion (based on land-use, topography and erosion sensitivity). These maps will be used to propose suitable mitigation measures and discuss implementation of these measures with all actors involved.

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2.2 Executive summary in Dutch

Het Belgische studiegebied is het afstroomgebied van de Bollaertbeek ten zuiden van Ieper (West-Vlaanderen). De Bollaertbeek en Haringsebeek ontspringen ten noorden van de Kemmelberg en vloeien samen ten zuiden van Voormezele om dan in noordelijke richting naar Ieper te stromen. Het zuidelijk deel van het stroomgebied is gekenmerkt door een hoge gevoeligheid voor erosie terwijl het noordelijk deel eerder vlak is en weinig gevoelig voor erosie. Het gebied is voor het grootste deel (81%) ingenomen door landbouw. Het stroomgebied is relatief klein (23 km^2) en er zijn 167 landbouwers actief op één of meerdere velden.

De uitstroom van het gebied is gelegen aan Stuw 8. Op dit punt neemt de Watergroep het water van de Bollaertbeek in in de Verdronken Vijver voor drinkwaterproductie voor de stad Ieper. Gedurende periodes van het jaar is het niet mogelijk voor het drinkwaterbedrijf om het water in te nemen omwille van de hoge concentraties gewasbeschermingsmiddelen waardoor de kosten voor zuivering te hoog zouden oplopen. Op die momenten wordt het water van de Bollaertbeek voorbij de Verdronken Vijver geleid en moet beroep gedaan worden op andere bronnen voor drinkwaterproductie.

De waterkwaliteit en concentraties aan gewasbeschermingsmiddelen worden al gedurende lange tijd opgevolgd door VMM en de Watergroep. VMM heeft 4 meetpunten in het gebied waar elke 2 maanden stalen genomen worden en de Watergroep meet wekelijks ter hoogte van Stuw 8. Binnen het WaterProtect project is er in 2017 een uitgebreidere meetcampagne opgezet in 8 locaties in het gebied. Uit de metingen bleek dat er heel wat normoverschrijdingen van de drinkwaternorm en milieunormen worden vastgesteld en dat de meeste overschrijdingen in de hoofdloop van de beek voorkomen. Om meer duidelijkheid te krijgen over het belang van verschillende routes van pesticide aanvoer naar de Bollaertbeek en zo gerichte maatregelen te kunnen nemen, is in 2018 gekozen voor een continue staalname op 2 locaties in het gebied, één stroomopwaarts waar het risico op erosie hoog is en één stroomafwaarts aan de uitstroom van het gebied. Deze staalnamecampagne wordt ook nog in 2019 verdergezet. Zowel de historische metingen in het gebied als de nieuwe metingen en relevante kaarten van landgebruik en erosiegevoeligheid worden ter beschikking gesteld via de WaterProtect app zodat de verschillende partijen in het gebied allemaal toegang hebben tot deze informatie.

Op basis van een gedeeltelijk analyse van de metingen en kennis uit andere studies kunnen we concluderen dat de belangrijkste routes voor PPPs naar de Bollaertbeek directe verliezen en diffuse verliezen door afstroming en erosie zijn. Het sterk seizoensgebonden karakter van de overschrijdingen in de Bollaertbeek duidt er ook op dat andere processen zoals bijdrage door grondwater of interactie met sediment hier van minder belang zijn. Om deze twee routes op een gerichte manier aan te pakken, zijn er risicokaarten opgesteld voor directe verliezen enerzijds (op basis van ligging van het erf, grootte van het bedrijf en al dan niet zelf sproeien) en verliezen door afspoeling en erosie anderzijds (op basis van landgebruik, topografie en erosiegevoeligheid). Deze kaarten worden gebruikt om geschikte maatregelen in het gebied voor te stellen en de implementatie ervan te bespreken met betrokken partijen.

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2.3 Introduction

The Belgian Action Lab is a small agricultural catchment (23 km^2) in SW-Flanders, the Bollaertbeek catchment. In this area we focus on concentrations of PPPs (Plant Protection Products) in surface water. In the Bollaertbeek there are many exceedances of environmental quality standards for PPPs. The water from the Bollaertbeek is stored in reservoirs ('Verdronken Weide' and 'Zillebeke pond') and used for drinking water production for the city of Ieper. During some periods of the year the drinking water company cannot use the water of the Bollaertbeek because of too high concentrations of PPPs which would lead to too high costs of purification.

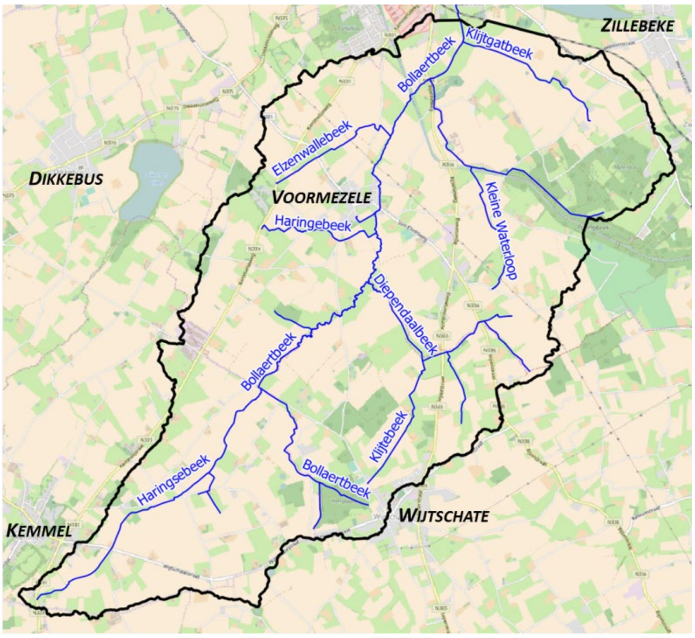

Figure 2.1: The catchment of the Bollaertbeek and its tributaries with the intake of the drinking water company located in the north.

2.4 System description

2.4.1 Water quality monitoring in the catchment

The water quality in the Bollaertbeek has been monitored in routine campaigns of the Flemish Environment Agency (VMM) and the drinking water company de Watergroep. The VMM collects grab samples at 4 locations (948010, 949000, 949040, 949060) in the catchment on a monthly basis. De Watergroep collects weekly samples for water quality analysis at one location (948010) downstream in the catchment. The monitoring location is upstream of the intake point of surface water from the river for drinking water production and the analyses at this point are used to decide whether the surface water is suitable for drinking water production or if it will be diverted downstream of the reservoirs.

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During the WaterProtect project a more extensive monitoring campaign has been set up with monitoring of the river water quality at 8 locations spread over the catchment in a bi-weekly collection of grab samples for water quality analysis in 2017 (see Figure 2.2).

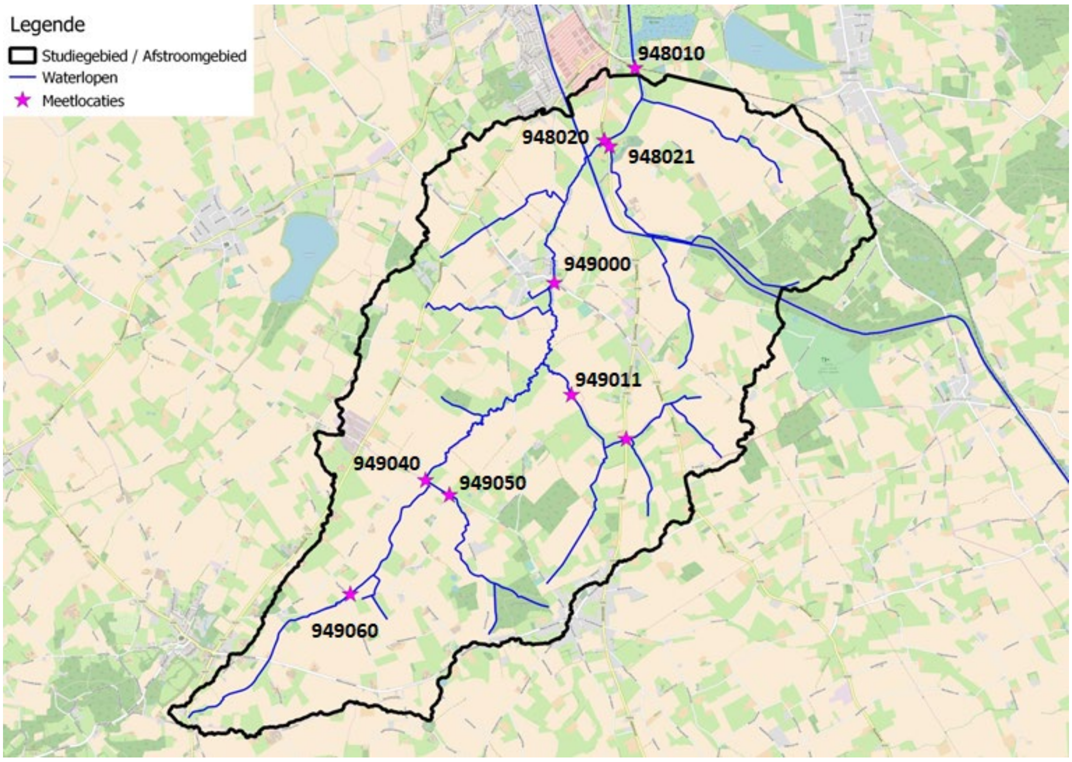

Figure 2.2: Map with water quality monitoring locations.

The results of this campaign show exceedances of both the drinking water limit and of the environmental quality standards (Maximum Allowable Concentration or MAC) for a range of herbicides such as metolachlor, dimethenamid, terbutylazin, metazachlor, MCPA, linuron and metobromuron. Additionally for a range of herbicides concentrations above the drinking water limit (but not exceeding the environmental standard) were measured. The results for the 2017 campaign are shown in Figure 2.3 with for each monitoring location the number of active ingredients exceeding the environmental limit and exceeding the drinking water limit.

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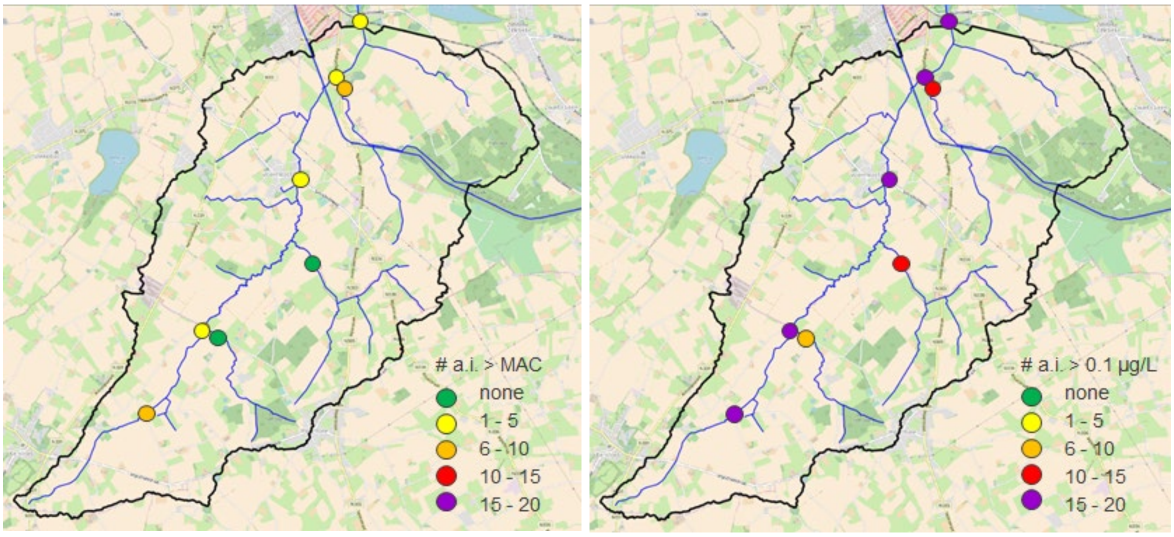

Figure 2.3: Number of active ingredients exceeding the environmental Maximum Allowable Concentration (left) and exceeding the drinking water limit of 0.1 µg/l (right) in the period June-September 2017.

From the 2017 results it was concluded that the main pesticide load is in the main stretch of the river and less in the tributaries and secondly, that already in the upstream part of the catchment a considerable pesticide load is present. Based on these results in 2018 a permanent monitoring of the river water quality has been set up at 2 locations in the catchment, upstream (close to 948020) and downstream (close to 949040). At the two locations there is a combination of automated collection of time-integrated samples over a 24 hours interval and automated sampling from the river upon a rainfall event (triggered by the exceedance of a set threshold on water level and/or flow velocity). Water level and flow velocity are recorded every 5 minutes. The goal of the additional sampling is to better assess the importance of the different pathways (point losses, runoff or erosion) of pesticides to the river.

2.4.2 Agricultural land-use in the catchment

The pilot area has mainly agricultural land-use, with 81% of the area in use for agricultural activities. In Figure 2.4 the map of the different agricultural crops at the parcel scale for 2016 is given. The main agricultural land-use in the catchment is grassland, followed by field crops such as corn, potatoes and cereals (percentages given in Table 2.1).

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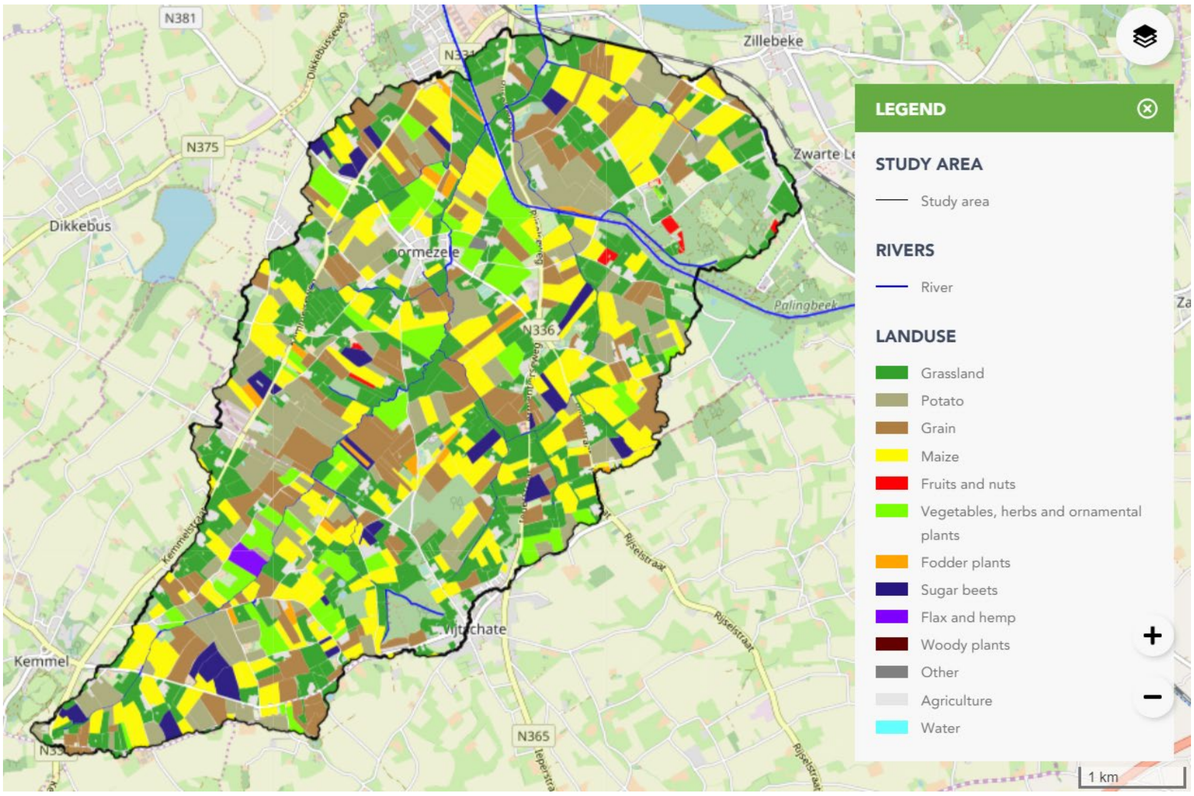

Figure 2.4: Map of the agricultural land-use (2016) in the Bollaertbeek catchment.

Table 2.1: Coverage of the different agricultural crops in the Bollaertbeek catchment.

Land-use		**Area (ha)**	**% of total area**
Crop	Potatoes	332.1	14.7
	Fruits and nuts	6.5	0.3
	Cereals, seeds and legumes	302.9	13.4
	Grassland	512.0	22.6
	Vegetables, herbs and ornamental plants	126.9	5.6
	Woody crops	0.1	0.0
	Corn	420.4	18.6
	Sugar beets	66.1	2.9
	Flax and hemp	6.0	0.3
	Fodder crops	19.8	0.9
	Other	2.2	0.1
Other	Agricultural infrastructure	45.8	2.0
	Water	1.5	0.1
Total	Agricultural land-use (total)	1842.1	81.4

2.4.3 Potential erosion

The area has a variation in topography, with the south part bordering the ‘Kemmelberg’ hill and the northern part more flat. This is reflected in the potential erosion calculated with the RUSLE equation.

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The resulting erosion sensitivity classes are shown in Figure 2.5 with the coverage of each class in Table 2.2. Overall, almost 19% of the area is in a medium to very high erosion class but there are large differences within the catchment: in the upstream area (subcatchment associated with location 949040) this percentage is over 40% of the area.

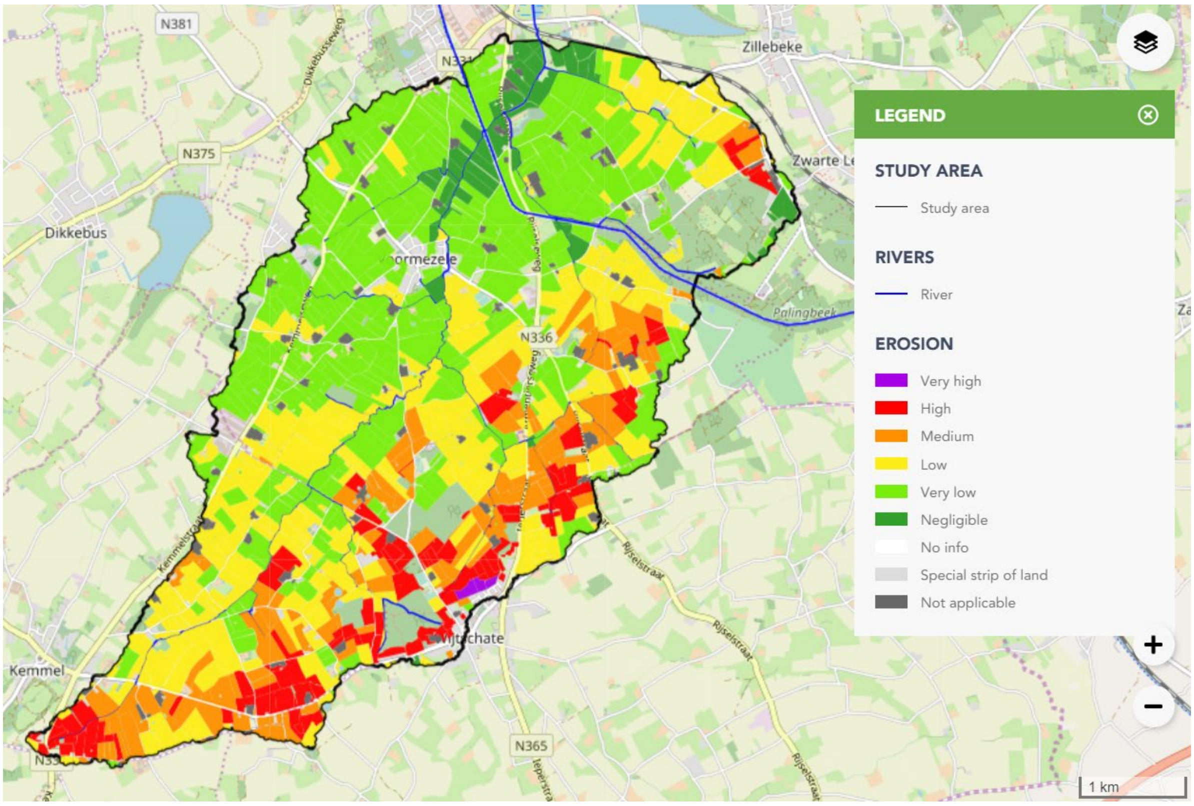

Figure 2.5: Map of the erosion sensitivity (2017) in the Bollaertbeek catchment.

Table 2.2: Coverage of the erosion sensitivity classes in the Bollaertbeek catchment.

Erosion sensitivity	Area (ha)	% of total catchment area
Very high	3.9	0.2
High	167.0	7.4
Medium	255.6	11.3
Low	570.8	25.2
Very low	721.1	31.9
Negligible	82.5	3.6

2.4.4 Climate

North of the catchment a VMM weather station is located in Ieper. The recorded rainfall in the period 2005 to 2017 in this station is given in Figure 2.6. Total yearly rainfall in the area is on average 765 mm over this period and varies between 600 and 955 mm with the highest amount recorded in 2012.

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In the Figure 2.6 also a distinction is made between rainfall in summer (April to September) and in winter (January to March and October to December). From this it can be seen that the distribution of rainfall over the year also varies with for instance a wet year in 2013 and a dry year in 2014 but the opposite trend when looking at the summer rainfall (which is more critical in triggering runoff of PPPs to surface water).

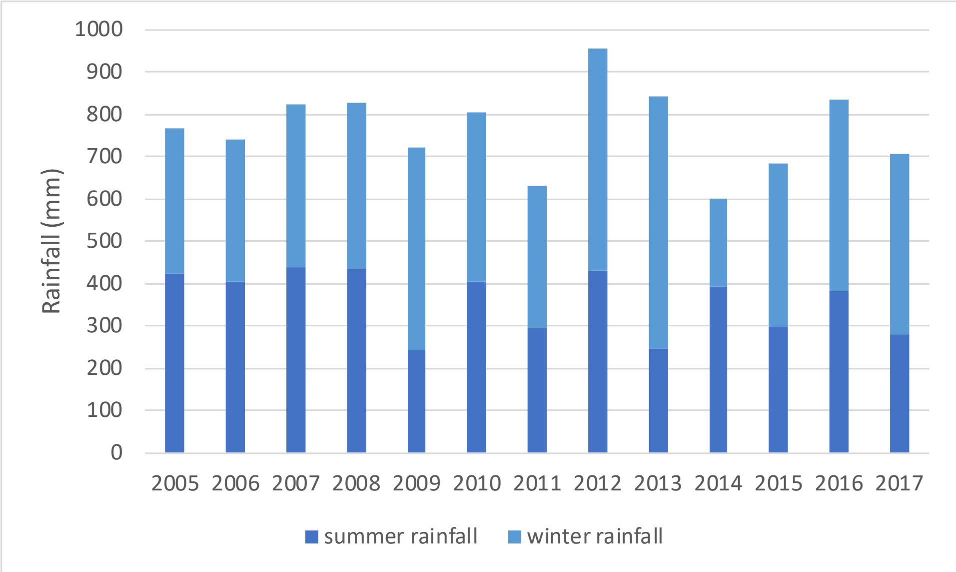

Figure 2.6: Yearly rainfall, summer rainfall (Apr-Sep) and winter rainfall (Jan-Mar, Oct-Dec) recorded in Ieper.

2.4.5 Groundwater system

In the catchment there are 6 groundwater wells from VMM with the location given in Figure 2.7 and the characteristics in Table 2.3. Groundwater levels are rather shallow in the catchment with average levels between 0.9 and 1.7 meters below ground level and an amplitude of 2 meters (1.7 to 2.5 m).

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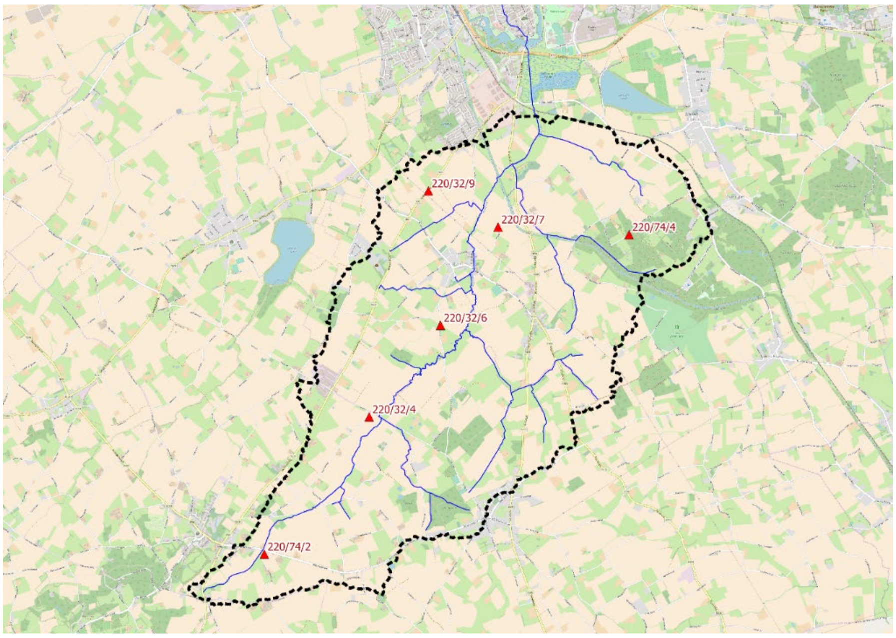

Figure 2.7: Location of VMM groundwater wells in the catchment.

Table 2.3: Characteristics of groundwater wells in the area.

ID	Filter	Aquifer	Surface level (m TAW)	Filter bottom (mblg)	Filter length (m)	Groundwater depth (mblg)			Periodic dry
						avg	min	max	
220/32/4	1	0100 - Quartaire aquifersystemen	33,86	2,5	1,0	1,34	0,55	3,00	Y
	2			5,0	1,0	1,37	0,54	2,68	N
	3			7,0	1,0	1,37	0,62	2,68	N
220/32/6	1	0100 - Quartaire aquifersystemen	31,94	3,0	1,0	1,42	0,76	2,52	N
220/32/7	1	0100 - Quartaire aquifersystemen	28,15	4,0	1,0	1,72	0,82	3,05	N
	2			8,3	1,0	1,73	0,89	3,03	N
	3			13,0	1,0	1,72	1,06	3,03	N
220/32/9	1	0100 - Quartaire aquifersystemen	31,18	1,5	0,5	1,33	0,36	2,00	Y
	2	0921 - Klei van Aalbeke		3,0	1,0	1,38	0,38	3,50	Y
220/74/2	1	0910 - Silt van Kortemark	51,18	2,5	1,0	0,91	0,16	2,17	N
	2			4,5	1,0	0,92	0,21	2,12	N
	3			7,5	1,0	0,92	0,23	2,13	N
220/74/4	1	0800 - Ieperiaan Aquifer (Egem and/or Mont-Panisel)	44,8	2,5	0,5	0,87	0,16	2,13	N
	2			4,0	0,5	0,97	0,21	2,13	N
	3			6,5	0,5	1,00	0,32	2,17	N

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2.5 Conceptual model for pesticide losses to surface water

2.5.1 Pathways of pesticides to surface water

Pesticide concentrations in rivers generally have a very dynamic signature and are strongly dependent on time and space. The dynamic time course is due to the time- and space-variant input conditions resulting from fast overland (runoff and erosion, direct losses) and subsurface flow (artificial drainage), directly connecting surfaces and/or agricultural fields where pesticides are applied, to receiving rivers. A thorough understanding of pesticide behaviour at the watershed scale is needed to increase the effectiveness of mitigation measures.

Figure 2.8 shows a schematic representation of possible pathways for PPPs to enter the river (from TOPPS-Life, 2007, www.topps-life.org). For the total load of PPPs to the river, it is estimated that in general point losses contribute for >50 %, drift for 5 % and runoff and erosion for 30 % (TOPSS-Life, 2007). The order of magnitude of these numbers has been confirmed in other studies in Belgium such as the detailed monitoring of the Kleine Kemmelbeek.

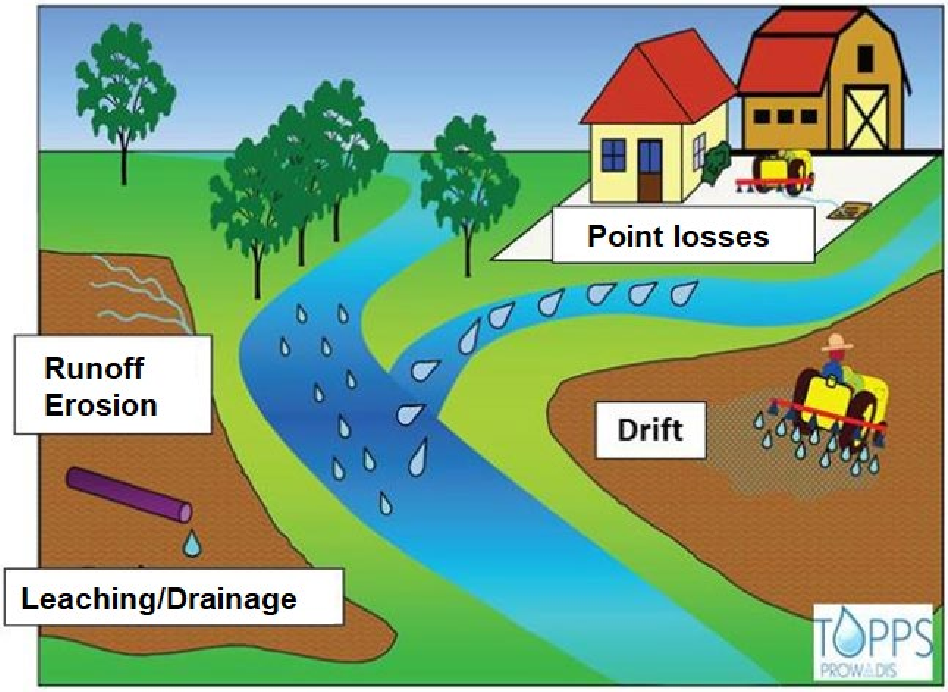

Figure 2.8: Main transport routes for plant protection products to surface water (TOPPS-Life, 2007).

From the measurements of concentration of PPPs at the outflow of the catchment (in location 948010) it can be seen that the concentrations have a strong seasonal dynamics with high concentrations in summer (approximately from May to October) and much lower concentrations in winter (see Figure 2.9). This indicates that possible contributions from groundwater inflow or interaction with river sediments are of minor importance in this catchment and that the main pathways are point losses and runoff and erosion with a possible contribution from drift.

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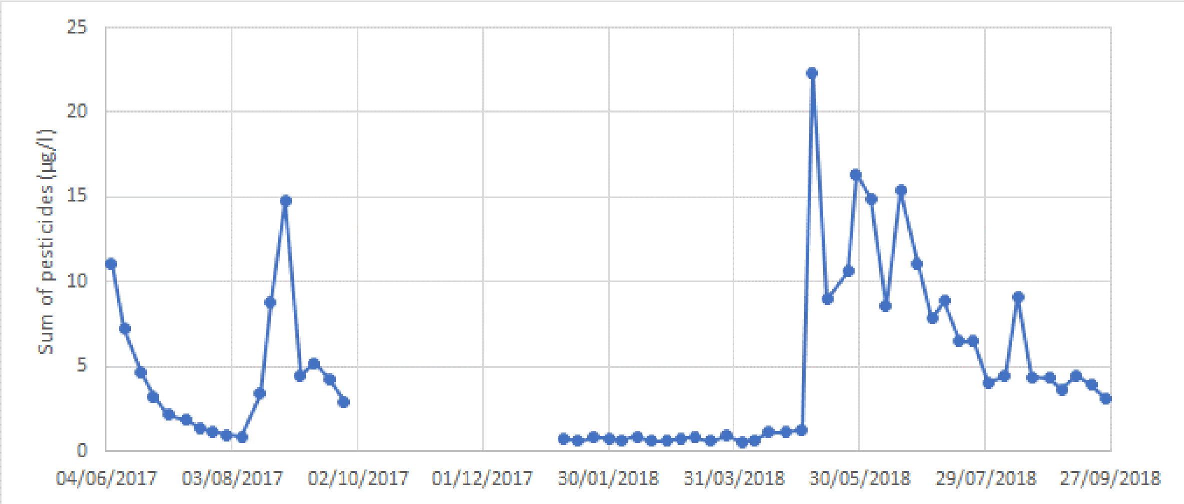

Figure 2.9: Evolution over time of sum of concentrations of 35 active substances and metabolites at the outflow of the catchment.

In the Bollaertbeek catchment, we find a combination of intensive agricultural use and high erosion risk in the upstream part of the catchment. In order to evaluate the importance of runoff as a pathway of pesticides to the river, we installed a high-resolution monitoring set-up from 2018 on to better quantify the loads of pesticides entering the river during rainfall events. While 2018 was a very dry year with few rainfall events during summer, in Figure 2.10 it can be seen that there is a direct effect of rainfall on the concentrations in the Bollaertbeek at the upstream continuous monitoring station. Further monitoring and analysis of data should allow to better assess the relative importance of this process on the loads of pesticides in the river.

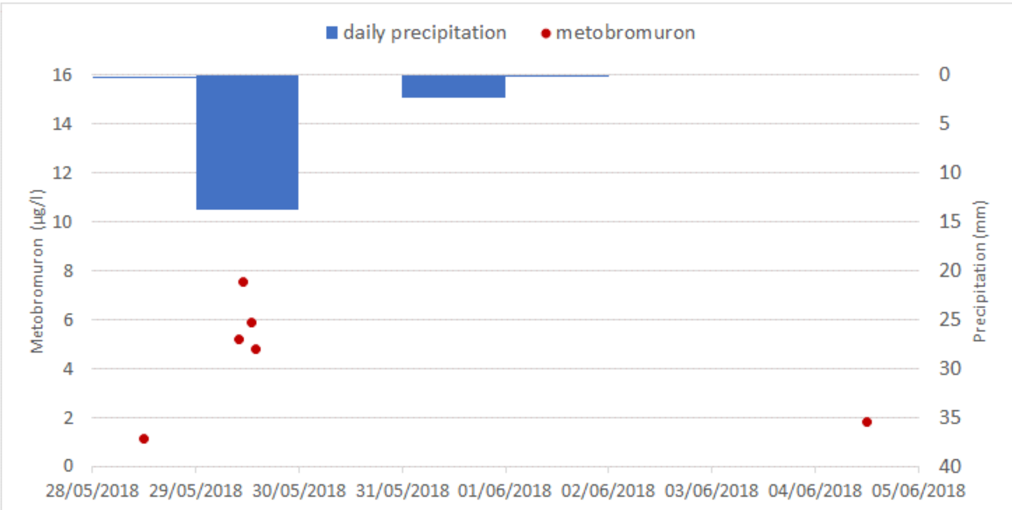

Figure 2.10: Daily precipitation in Ieper and concentration of metobromuron in the upstream continuous monitoring location during a rainfall episode.

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2.5.2 Risk mapping

In order to derive priority zones for applying mitigation measures for pesticide runoff and point losses, risk maps for the catchment have been developed both for the risk of direct losses (related to agricultural practices and to location of farmyards/size of farms in the catchment) and for diffuse losses (related to erosion, connectivity of fields to the river and crops).

The risk map for diffuse losses to the river is constructed from the potential emission of pesticides to the river and the connectivity of each field to the river as derived from topography. The potential emission of pesticides is calculated for the top 10 herbicides detected in the 2017 monitoring campaign. For each of these substances it was assumed that the recommended dose for the most common use of the substance was applied over all fields in the catchment expect grassland. The fraction of the dose reaching the soil and being potentially emitted to surface water through drainage or erosion was calculated and based on this the fields were ranked with an emission index. This index in combination with an index for the connectivity of the field to the river resulted in a risk index for the field for a specific crop. These indices were then summed for the 10 most occurring PPPs in the Bollaertbeek to give an integrated risk map for diffuse losses of PPPs to the river (see Figure 2.11).

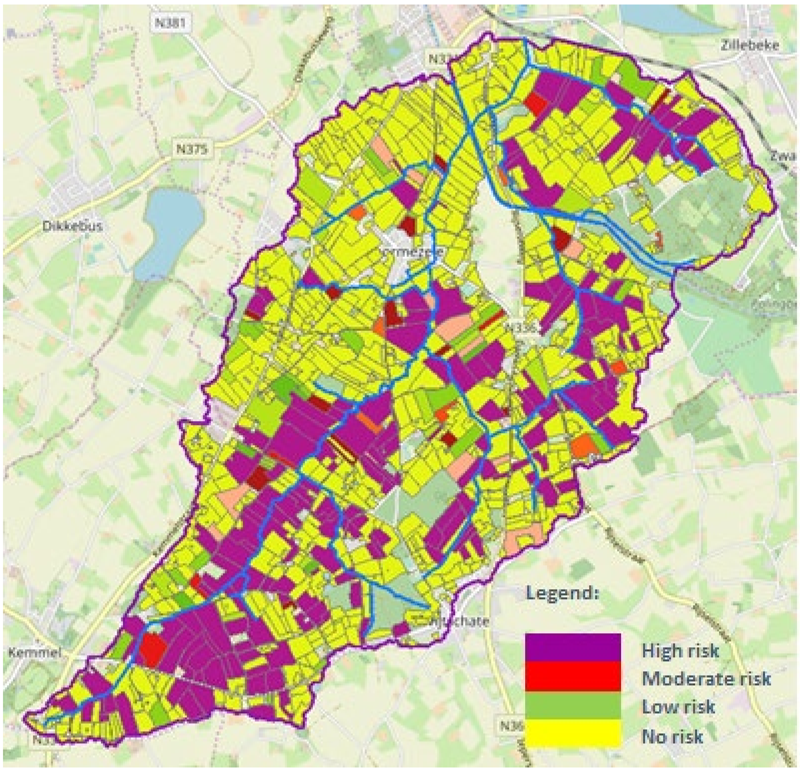

Figure 2.11: Risk map for losses of PPPs to the river through runoff and erosion.

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2.5.3 Conclusion

The Bollaertbeek catchment is a small catchment with intensive agriculture in a source area and a landscape sensitive to erosion. Monitoring data show the presence of plant protection products mainly during summer. From the measurements and previous studies we can conclude the main pathways for plant protection products to the river are point losses and runoff and erosion. We developed risk maps indicating the fields with potentially a large contribution to the load in the river based on crop type, potential erosion and connectivity to the river. Similarly we developed a risk approach indicating farms in the catchment where potentially point losses can occur. These maps will be used in targeting measures and communicating to farmers on effective mitigation measures and best management practices.

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Action lab: Val Tidone (Italy)

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3 Val Tidone (Italy)

3.1 Executive summary

In the Italian Action Lab, Province of Piacenza, the viticulture is particularly developed in a hilly area located in Val Tidone, which covers the Municipalities of Ziano Piacentino, Borgonovo Val Tidone, Castel San Giovanni, Alta Val Tidone and Pianello Val Tidone. In particular, in the Ziano Municipality the area cultivated with vineyards exceeds 56% of the entire Municipality's surface. This vocation of the territory has an impact on environmental resources, which is specifically investigated in the WaterProtect project. As for grape cultivation both nitrogen fertilizers and plant protection products are used, their residues can be found in both surface and groundwater, at concentrations even above the environmental or drinking water quality standard limits. The water used for human consumption comes from aquifers "protected" from potential sources of contamination, through impermeable layers, naturally present in the subsoil of this territory. However, the pollution could penetrate deeply through lenses of permeable material, interdigitate to the waterproof ones.

The groundwater in the Action Lab, starting from 2010, is partly identified, characterized and monitored in accordance with Water Framework Directive (2000/60/EC) by ARPAE (Regional Agency for Energy Environment Prevention), which operates on behalf of the Emilia-Romagna Region. Indeed, every six months, a network of wells, appropriately distributed throughout the territory and representative for the existing aquifers, are monitored both from a qualitative and a quantitative point of view. The results are published annually on the Agency's website. ARPAE monitors the environmental quality of groundwater, regardless of the end use that will be made of it. Drinking water is instead controlled by the AUSL and guaranteed by the Drinking Water Supplier IRETI.

Since the ARPAE's wells in the project area were covering just partially the viticulture area and therefore would not have highlighted any impact of it on the groundwater, selection of new wells was necessary. The new wells are all located inside the viticulture area, some in a "downstream" position with respect to the prevailing flow of groundwater, in order to collect the residues of wine-making activities. Most of the wells intercept a very superficial aquifer, recognized as "phreatic" according to the hydrogeological criteria defined for the aquifers of the Emilia-Romagna region, about 5-6 meters deep, up to a maximum of 10. This aquifer is not used for drinking purposes, but for agricultural practices (preparation of pesticide mixtures). Finally 26 wells were sampled, three of which are used for drinking purposes, 21 for irrigation and 2 for domestic use.

Three monitoring campaigns were carried out, of the six planned, and the first results confirmed that the prevailing direction of the water table is from SW to NE, comparable to that established for Piacenza province. This suggests a basic homogeneity in the groundwater circulation compared to the other aquifers present in the territory, studied and monitored by the Regional Network of groundwater.

To characterise the conceptual model of "phreatic" aquifer and its interaction with the contaminants, additional information are necessary. Data for soil type, temperature, precipitation, wind speed, evapotranspiration, soil-grape interaction, crop development, etc, will be collected and

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implemented in CRITERIA – 3D hydrological model. This will allow to evaluate the water drainage at the bottom of soil layer, the lateral water flow movement in the subsoil, the field capacity and other relevant information for the characterisation of the Action Lab area hydrology. Finally, the hydrological data together with the chemical analysis data for groundwater (presence of pesticides and nitrates, etc) will be use to evaluate the risk of contamination of groundwater by pesticide and nitrates. All the needed data will be collected by the end of February 2019 while the results of the simulations with CRITERIA - 3D are expected by the end of May 2019.

3.2 Executive summary in Italian

La viticoltura è particolarmente sviluppata in una zona collinare della Provincia di Piacenza, situata in Val Tidone, nei Comuni di Ziano, Borgonovo, Castel San Giovanni, Nibbiano e Pianello; in particolare nel territorio di Ziano l'area coltivata a vigneto supera il 56% dell'intero Comune. Questa vocazione del territorio comporta un impatto sulle risorse ambientali, che viene appositamente indagato nel progetto: dato che in viticoltura vengono utilizzati fertilizzanti azotati e prodotti fitosanitari, si possono ritrovare nelle acque circolanti nel territorio, sia superficiali che sotterranee, residui di pesticidi e nitrati in concentrazione elevata, anche al di sopra dei limiti di qualità ambientale o di potabilità. Tuttavia le acque utilizzate per il consumo umano provengono da acquiferi "protetti" dalle potenziali fonti di contaminazione, tramite strati impermeabili, naturalmente presenti nel sottosuolo di questo territorio. L'inquinamento però potrebbe comunque penetrare in profondità attraverso lenti di materiale permeabile, interdigitate a quello impermeabile.

Le acque sotterranee dell'area progetto sono state in parte identificate, caratterizzate e monitorate ai sensi della Dir. 2000/60/CE, Direttiva Quadro sulle Acque, a partire dal 2010, a cura di ARPAE (Agenzia Regionale Prevenzione Ambiente Energia), che opera per conto della Regione Emilia-Romagna; con cadenza semestrale una rete di pozzi, opportunamente distribuiti sul territorio e rappresentativi degli acquiferi sottesi, vengono monitorati sia dal punto di vista qualitativo, sia da quello quantitativo; i risultati vengono pubblicati annualmente sul sito internet dell'Agenzia. ARPAE controlla la qualità ambientale delle acque sotterranee, a prescindere dall'uso finale che di queste verrà fatto; la potabilità invece viene controllata dalla AUSL e garantita dal Gestore (IRETI).

Poiché la Rete di pozzi esistente nell'area-progetto non avrebbe evidenziato eventuali impatti della viticoltura sulle acque circolanti, è stato necessario cercare pozzi differenti, localizzati a stretto contatto con le sorgenti di inquinanti, in posizione di "valle" rispetto al flusso prevalente della falda, in modo da raccogliere i residui delle attività vitivinicole: i pozzi trovati intercettano un acquifero molto superficiale, riconosciuto come "freatico" secondo i criteri idrogeologici definiti per gli acquiferi della Regione Emilia-Romagna, profondo circa 5-6 metri, fino ad un massimo di 10. Questo acquifero non viene utilizzato per usi potabili, ma per pratiche agricole (preparazione miscela fitofarmaci). I pozzi campionati sono in totale 26, di cui 3 ad uso potabile, 21 irrigui, 2 domestici. Sono state effettuate 3 campagne di monitoraggio sulle 6 previste e come primo risultato hanno confermato l'ipotesi della direzione prevalente della falda (SW-NE), paragonabile a quella rilevata in tutta la provincia: questo fa ipotizzare una omogeneità di fondo nella circolazione idrica sotterranea

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rispetto agli altri acquiferi presenti nel territorio, studiati e monitorati dalla Rete Regionale delle Acque Sotterranee.

Per identificare il modello concettuale dell'acquifero ARPAE necessita ancora di dati e di monitoraggi, che verranno implementati con l'applicazione del programma CRITERIA.

3.3 General description

In Italy the volume of water withdrawn for drinking use amounts to 9.5 billion cubic meters in 2012. Compared to the 2008 urban water census, it had an increase of 3.8%, confirming the steady, however slight, upward trend observed since several years. The daily output production of drinking water from the treatment plants is about eight million cubic meters, which corresponds to an annual total of 2.9 billion cubic meters, that is the 30.6% of the water withdrawn. **Water input in public water supply:** 8.4 billion of cubic meters of water for drinking use are placed in municipal distribution networks: 385 liters per capita per day, with an increase of 2.6% comparing with 2008. **Water delivered:** Water delivered to the users corresponds to 5.2 billion cubic meters: 241 liters per capita per day (12 liters less than 2008). **Water losses:** Water lost by leaky pipes in the distribution system - calculated as the percentage difference between the volumes input in the public water supply and the delivered water - amounts to 37.4%, indicating a deterioration compared to what happened in the previous census when it was of 32.1%. More than 3.1 billion cubic meters are, then, lost in the journey along the pipes. Compared to 2008, the regional dispersion of network shows the most critical situations in the Islands and in the Center-south, with the exception of Abruzzo and Puglia, which in recent years have restored some situations of strong losses. Although with lower levels, also the northern regions indicate a general deterioration of the losses level in the water supply network, with the exception of Valle d'Aosta. **Wastewater treatment plants:** Urban wastewater treatment plants (UWWTP) are, in 2012, 18.786, of which 18.162 in operation. In the North Italy there is the biggest number of plants. UWWTP with advanced treatment, even if represent only the 10.0% of the total plants, process more than 60% of pollutant loads. In most cases, these plants are at the service of big urban areas. In the South Italy and in the Islands there is the major ratio of plants with an at least secondary treatment. Comparing with 2008 result, the load of pollutants from industry that flows to the UWWTP with secondary or advanced treatment, is reduced of 27.8%. A little increase in the percentage of civil pollution loads treated by secondary or advanced UWWTP has been observed, shifting from the 56.5% in 2008 to the 57.6% in 2012 (ISTAT, 2014).

The Italian Action lab is located in the Tidone Valley and comprises part of the Tidone catchment, Lora-Carogna catchment and Carona-Boriacco catchment for an area of 206.72 km^2. The Tidone Valley is placed in the north-west of Italy in Emilia Romagna region, Province of Piacenza, and is characterized by a mix of urban, peri-urban and rural areas. The area covers five municipalities: Ziano Piacentino, Castel San Giovanni, Nibbiano, Pianello, and Borgonovo for 28 548 inhabitants (see Figure 3.1).

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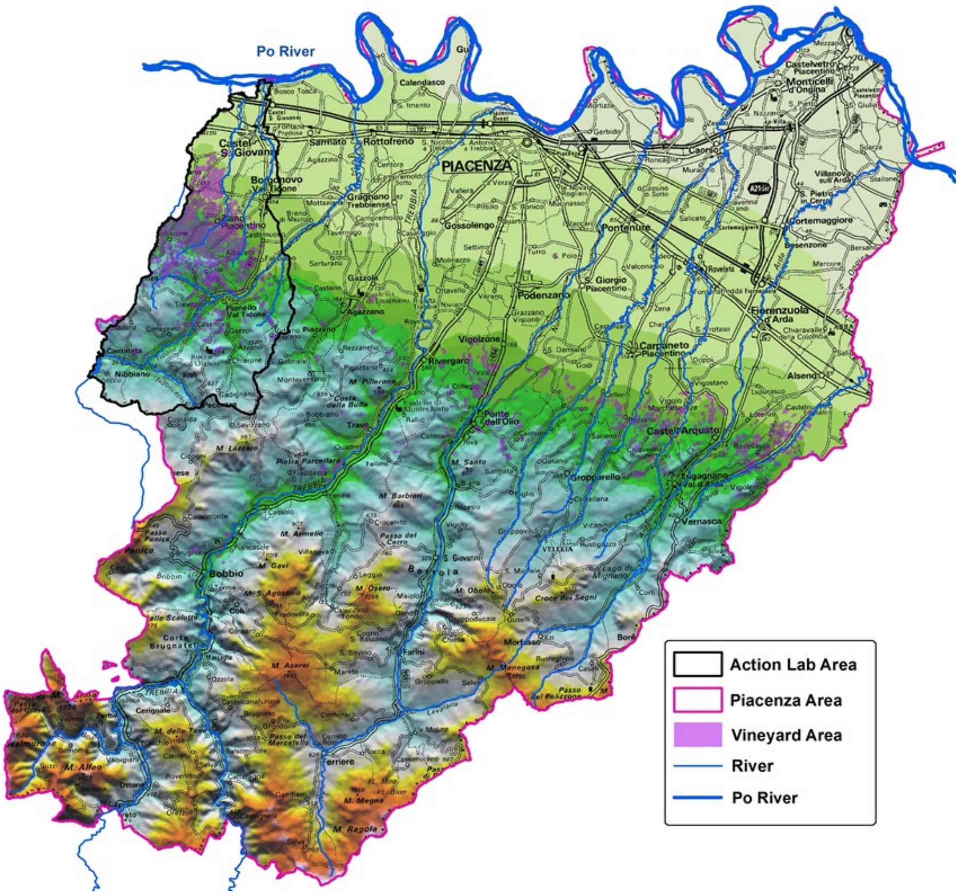

Figure 3.1 - Italian Action Lab in Piacenza Province.

Inhabitants of rural villages are mainly involved in grape and wine production, organised as private farms or as social wineries. 455 farmers are present in the 5 municipalities part of the Action Lab. Two types of farm structure are present:

1. Vineyard with a cellar. In this case, grape transformation to wine and wine retail is self-made. This is the case of 25% of the total vineyards present on the investigated area.

2. Vineyard without a cellar. In this case, farmers deliver their grapes to social wineries. This is the case of 75% of the total vineyards present on the investigated area.

The peculiar orographic features of the territory have determined the development and adoption of agricultural/hydraulic plumbing systems called "rittochino" that already represent a sort of mitigation measures applied in order to limit the erosion and control water speed, slowing down the water flow and that shapes hills, turning them into an orderly sequence of longitudinal line.

3.4 Previous investigation

By now, although the groundwater quality in Tidone valley was investigated for environmental and healthy monitoring purposes, the impact of the grape cultivation on pesticides and nitrates groundwater contamination was never investigated. Indeed, the evaluation of the impact of the grape cultivation on pesticides and nitrates groundwater contamination is one of the scope of WaterProtect Project in our Action Lab. ARPAE, the local Environmental Agency and partner of the project, highlighted the presence of pesticides and nitrates in the groundwater at levels greater than the environmental standards. However, the available data of the monitoring network and campaigns of Healthy agency (AUSL), water supplier company (IRETI) and ARPAE do not completely satisfy the goals of Waterprotect project. The groundwater wells part of the monitoring network of ARPAE are located downstream to the area under investigation in the action lab, as can be observed in the Figure 3.2. The historical data from 2006 to 2016 for nitrates presence in groundwater of these wells, highlighted in red in the Figure 3.2, shows that the nitrates concentration in the groundwater was very often above the groundwater quality limit of 50 mg/L. For this reason, starting with 2014 the water supplier in the area, IRETI, closed the wells PC 41- 01 and PC 83-00 that were used for drinking water, after potabilization treatment. The well PC43-00 is used for irrigation purposes.

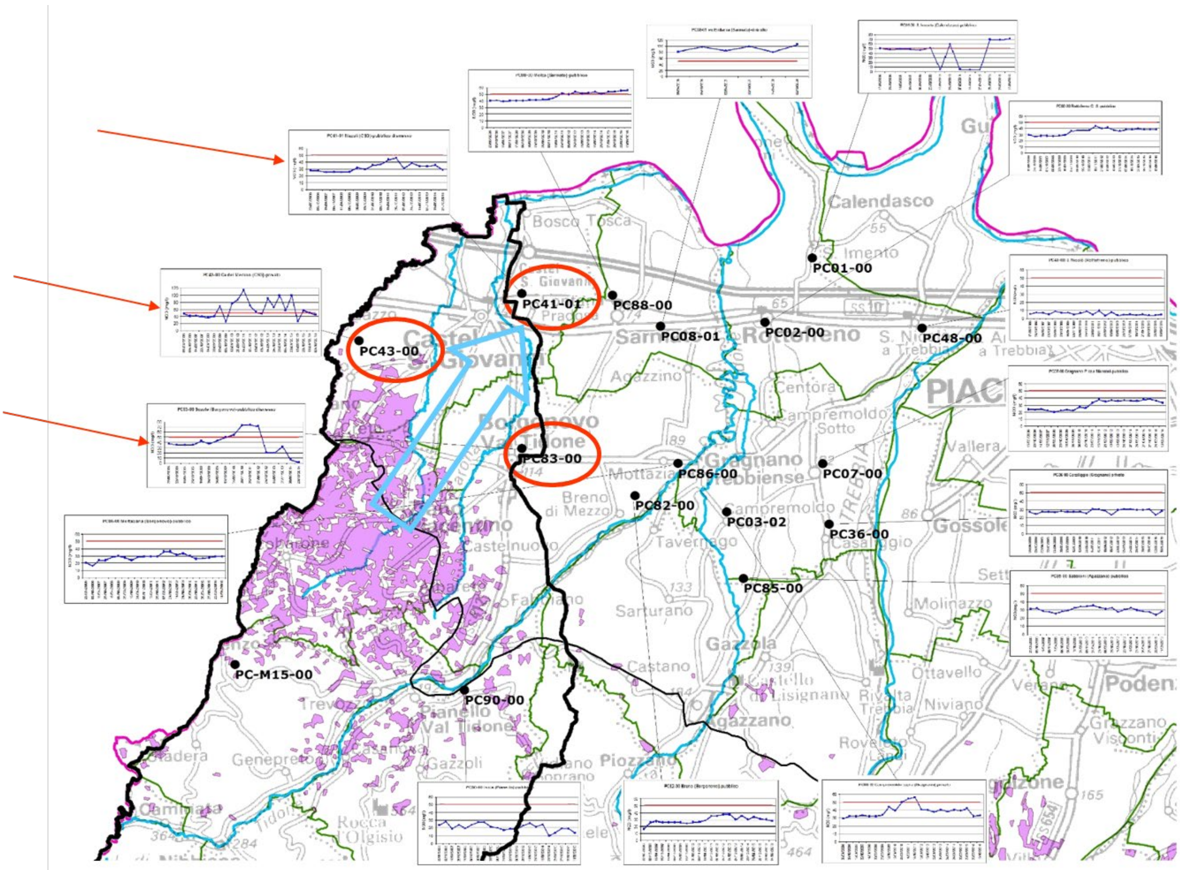

Figure 3.2 - ARPAE sampling wells network and historical data for nitrate concentrations.

The climate change effects have a high impact on water availability in our area: in 2017 the temperature increase and the changes in the precipitation typology, characterized by large downpours occurring in short periods, determinate a decrease of water infiltrating from soil surface to groundwater and, therefore, a decrease of the surface groundwater table. In particular Figure 3.3 shows how the average surface ground water table, of Piacenza and Parma provinces, in spring is lower than the average in the autumn of the previous year.

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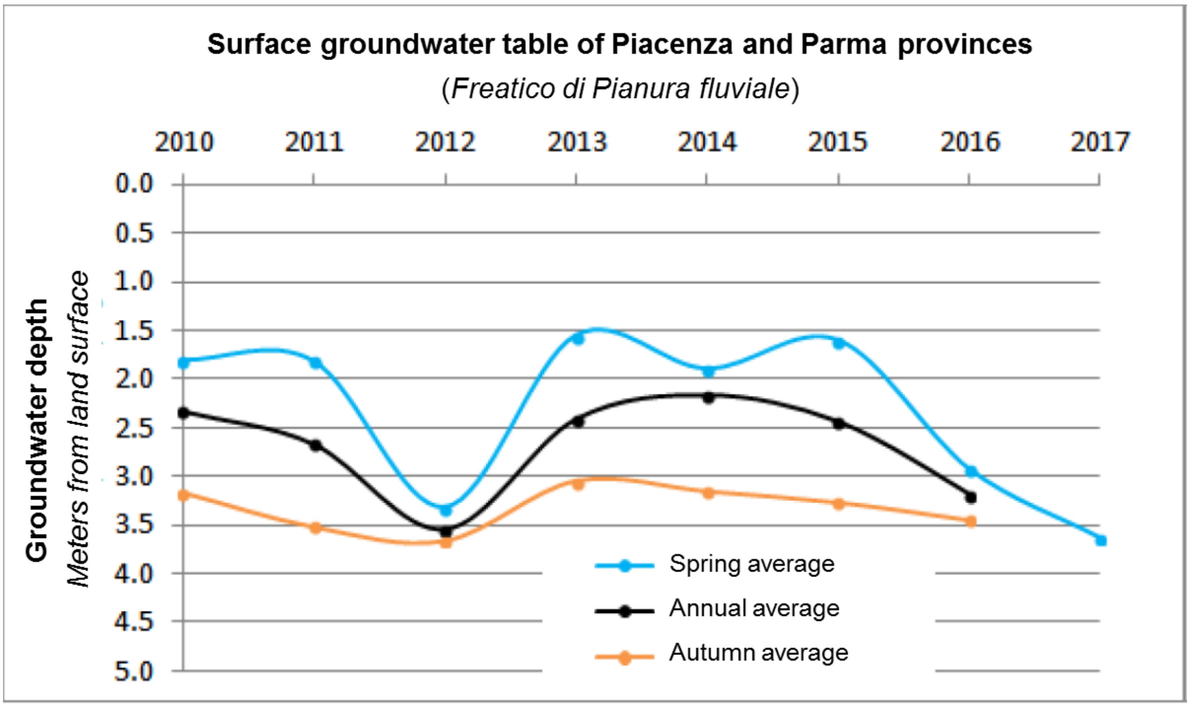

Figure 3.3 - Trend of surface groundwater table

3.5 System Description

In our Action Lab pollutants under investigation are nitrates and pesticides, both used in vineyards. Focus of the study is on groundwater. The groundwater direction in the Action Lab is from SW to NE, following the direction of groundwater table monitored by ARPAE in the Province of Piacenza. The entire area of the Italian Action Lab is considered with a low level of intrinsic vulnerability (see Figure 3.4) and part of it within the zone sensitive to nitrates (see Figure 3.5). Concerning sensitivity to pesticides, the regional map/assessment is under development and therefore, no information is yet available. In the present section the existing data relevant to the drainage of water in the action lab is present and discussed.

Concerning nitrates presence in groundwater, part of it is naturally occurring, while an important part is produced by fertilization of agricultural lands. During a preliminary survey it was revealed that 70% of 175 farmers interviewed use nitrogen fertilizers in their vineyards, however they adhere to voluntary integrated production specifications that prescribe nitrogen doses according to the estimated production, and do not exceed specific values set by competent authorities. Therefore, in the Italian Action Lab fertilization is an important source of possible pollution. Human activities, outside the agricultural sector, are considered having a very low impact on groundwater pollution. Concerning groundwater pollution by pesticides, their use outside the agricultural sector is considered having an insignificant impact on ground water pollution. The groundwater contamination by pesticides and nitrates is caused by both diffuse and point sources. However, the most prevalent source of contamination is the diffuse contamination, while the point source contamination is mostly accidentally.

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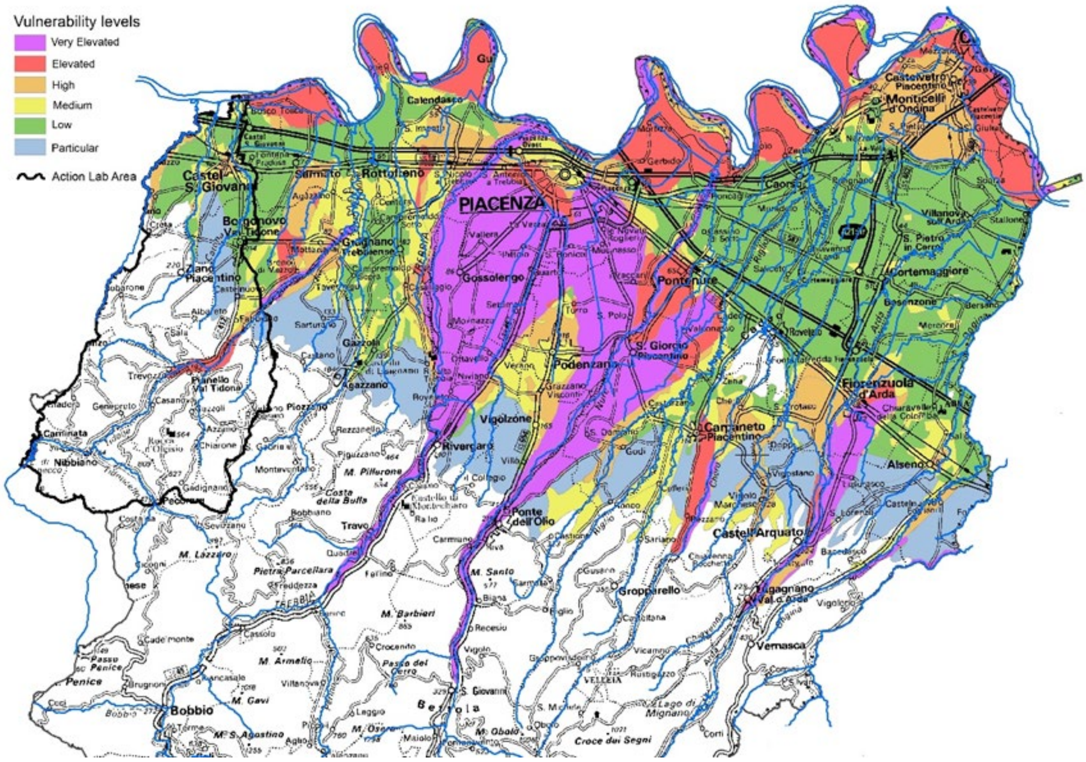

Figure 3.4 - Piacenza Province and Action Lab - intrinsic vulnerability

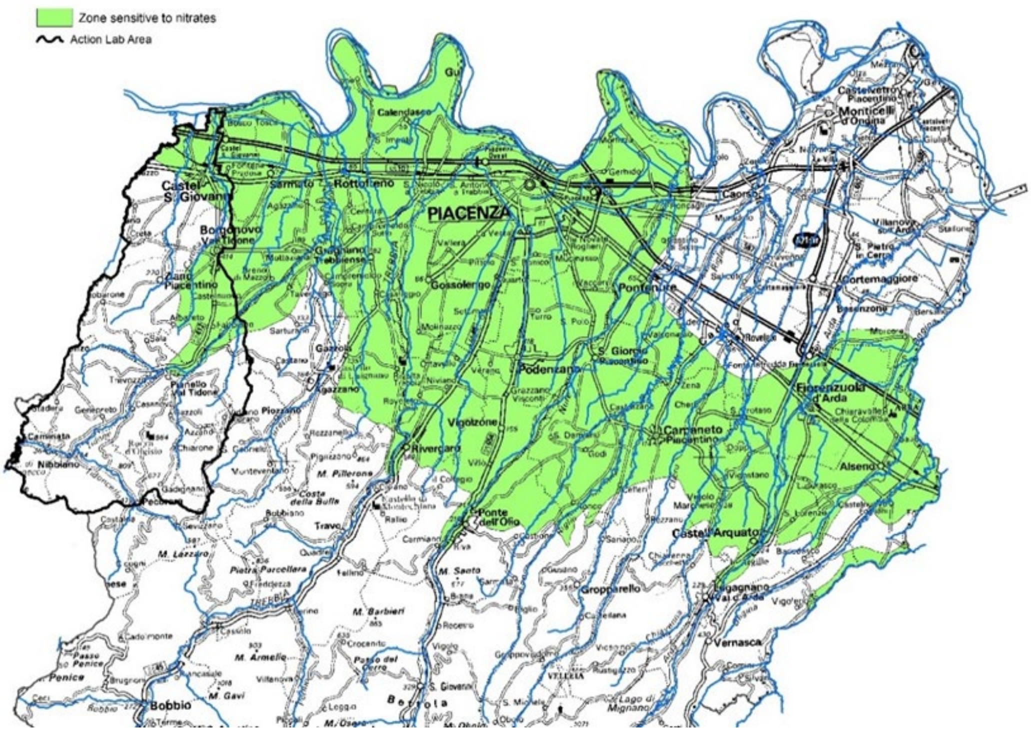

Figure 3.5 - Piacenza province and Action Lab – zone sensitive to nitrates

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3.5.1 Topography and soil type

The area of the Action Lab is a hilly area with elevations ranging between 100 and 350 m above sea level, which is known for deeply rooted tradition and vocation to viticulture. The main culture is the vineyard, with 2941 ha in 2016. The soil lithology is given by the geological surface map (geo250. shape) and is formed by: 57,67% marls, shales and limestone, 17,95 % gravel, sand, silt and clayey silt- unselected alluvial deposits, 9.40 % sandstone and shales, 4.74 % silt and clayey silt- fan and terrace deposits, 4.28 % clay, shale and clayey breccia, marl, sandstone and ophiolite, 3.60 % gravel and sand- fan and terrace deposits and 2,35 % clay and marl (see Figure 3.6).

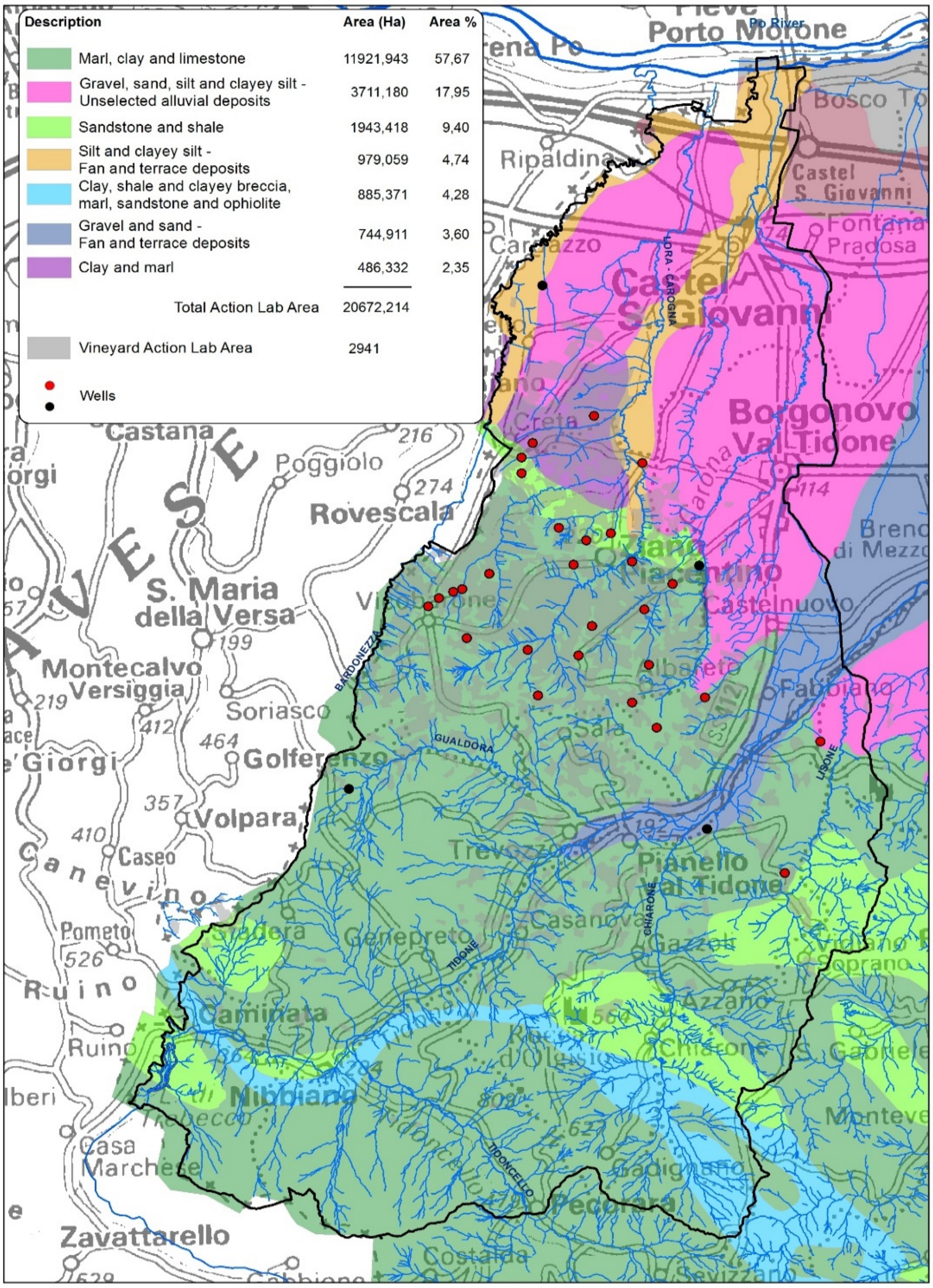

Figure 3.6 - Action lab Area- soil lithology and vineyards distribution (Ha)

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The wells network developed for the WaterProtect sampling campaign contains 26 wells located for 7.5 % on the clay and marl area, for 7.5% on the silt and clayey silt-fan and terrace deposit area, for 19% on sandstone and shale area, for 4% on the gravel and sand –fan and terrace deposits area, for 4% at the border between the gravel, sand, silt and clay silt-unselected alluvial deposits area and marl clay and limestone area and for 58% on the marl clay and limestone area (see Figure 3.6).

3.5.2 Hydrogeology

Due to the fact that no data was available for the direction of the groundwater flow in the Action Lab area, the first step in developing of the WaterProtect sampling campaign network was the selection of the wells taking into consideration the territorial characteristics. For this a upstream-downstream criterium was developed: the wells were selected taking into consideration the upstream-downstream of the valley crossed by tributaries of Tidone River (Figure 3.7), where the vineyards are treated with fertilizers and pesticides.

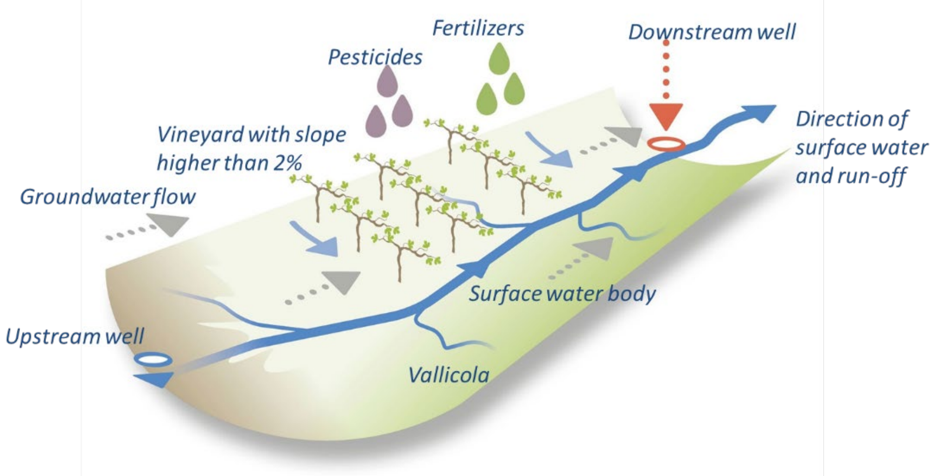

Figure 3.7 - Monitoring scheme – upstream-downstream criteria.

During the sampling campaigns the groundwater level in the wells was measured (see Figure 3.8) and the data were used to develop the groundwater piezometric map. Three sampling campaign were undertaken by date, November 2017, July 2018 and September 2018, and maps were developed (see Figure 3.9)

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Figure 3.8 - Groundwater sampling

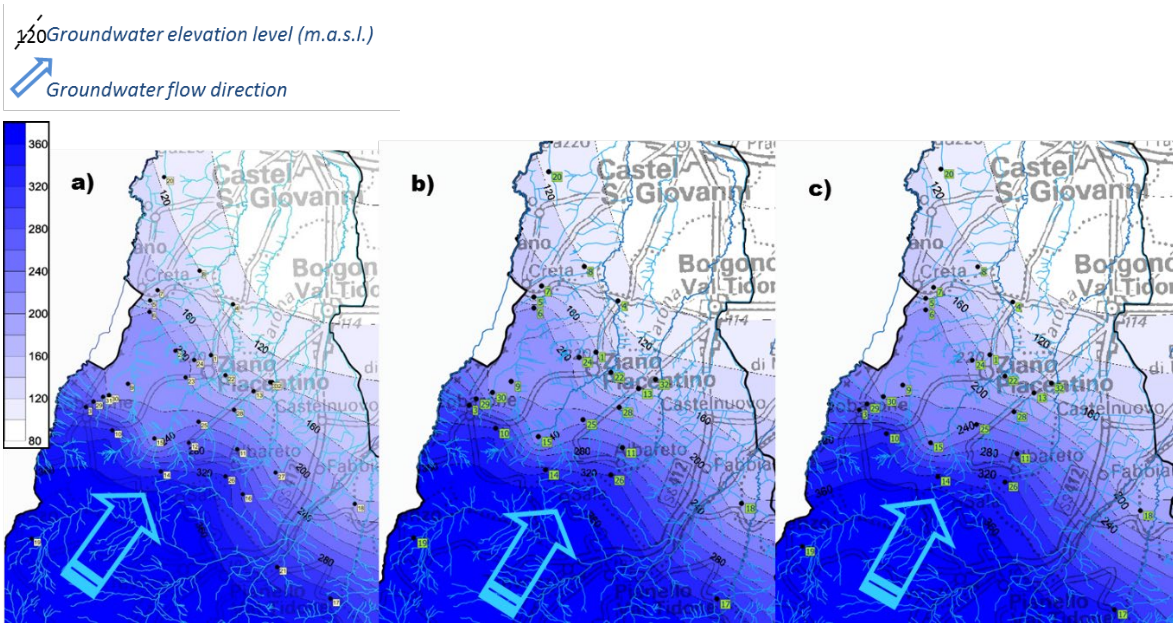

Figure 3.9 -Piezometric maps for groundwater; a) 1st sampling campaign - November 2017, 2nd sampling campaign – July 2018, 3rd sampling campaign – September 2018.

The piezometric maps allowed us to establish that the groundwater flow direction is south west-north east, as groundwater table monitored by ARPAE in the Province of Piacenza.

3.5.3 Climate

The climate in Piacenza Province is warm and temperate. This climate is considered to be ***Cfa*** according to the Köppen-Geiger climate classification. The annual average temperature in Piacenza Province is 13.1 °C. In the Action Lab area, based on the rainfall data for the period 2001-20017, the annual average rainfall is 765 mm (Figure 3.10). It varies between 471 and 1326 mm, with the lowest value recorded in 2017 and the highest value recorded in 2014.

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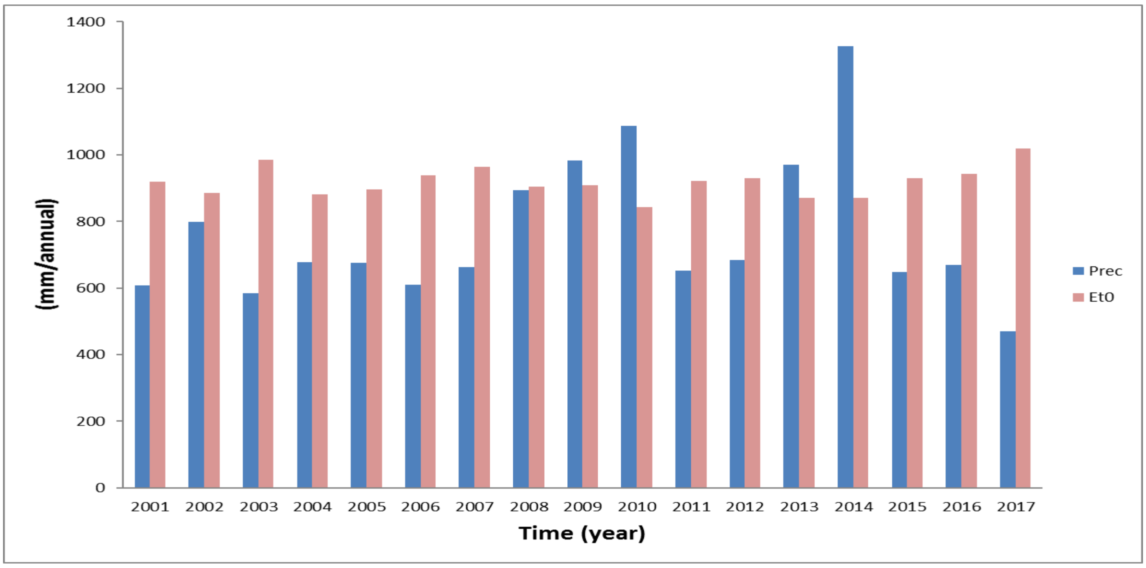

Figure 3.10 - Annual precipitation and evapotranspiration averages in the Action Lab area. The numbers are derived from ARPAE's 5X5 km^2 grid.

3.5.4 Land use

In the Action Lab area in 2016 14,2 % of the land was covered by vineyards (see Figure 3.11). Downstream the vineyard area the land is mostly covered with annual rotation crops (ex: maize, tomatoes, potatoes, strawberry, etc) and extra crops (ex: nursery, etc) while upstream the vineyard area the land is mostly covered by forages (ex: alfalfa, grassland, etc), arboreal and extra crops.

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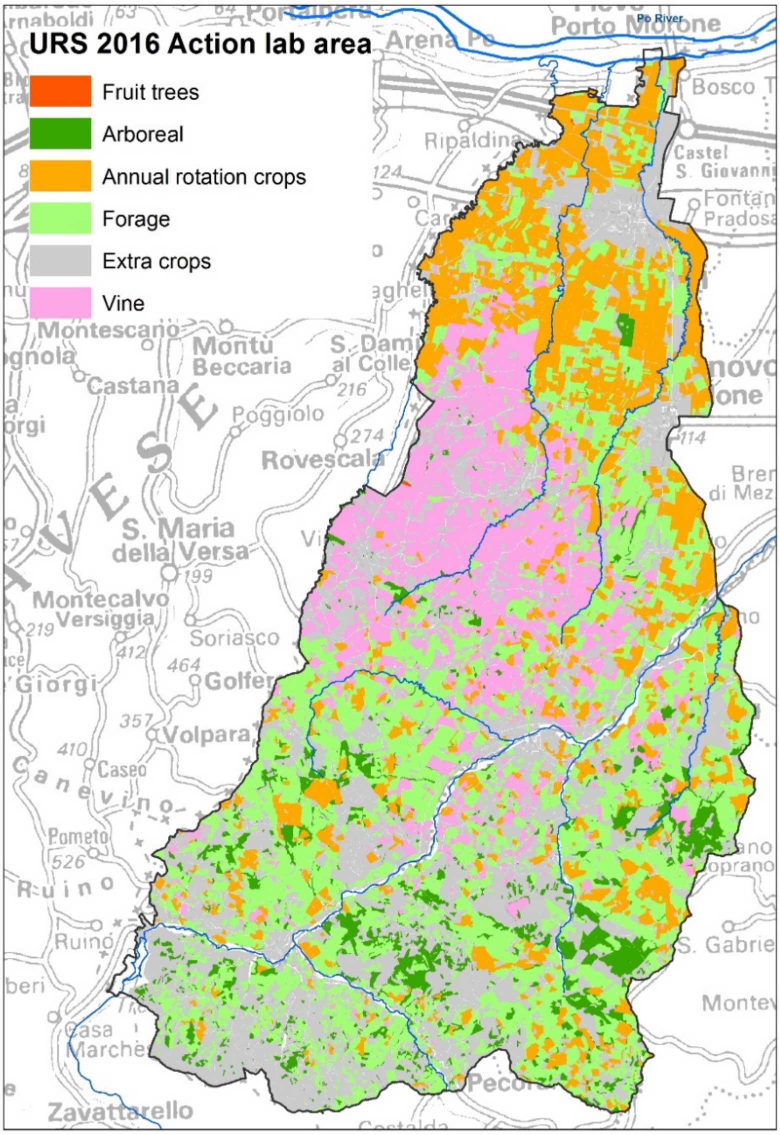

Figure 3.11 - Land use in Action Lab in 2016

3.6 Conceptual and numerical model

As already specified before, no data about the hydrology and the water balance and its components in the Action Lab area were available at the beginning of WaterProtect Project. Therefore, based on the piezometric maps developed after three sampling campaigns, the rainfall and evapotranspiration data, the atmospheric temperature data and the land use and topography data, available from ARPAE, Bologna Unit, the CRITERIA 3D model will be adapted and used in the action lab in order to develop drainage maps, that could represent the first step on understanding the water movement and di consequence possible contaminants movement in reaching the groundwater.

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3.6.1 General description of the model

The model is based on the integrated finite difference (also called cell-centered finite volume scheme) method (Bittelli et al., 2010). The model accounts for saturated water flow, unsaturated water flow and surface runoff, and it is coupled with conceptual models for soil evaporation, snow accumulation and melt, plant water uptake, and topography-dependent solar radiation. Spatial information needed for the hydrological model is provided by a DTM, a soil map with parameters for hydraulic properties and a land use map with the Manning's parameters. Criteria-3D needs hourly sink–source data (precipitation, snow melt, soil evaporation, plant water uptake), which are generated by the conceptual models included in the software that require hourly data of precipitation, temperature, relative humidity, wind velocity and solar radiation. Moreover, land use maps and crop parameters are needed. Soil mapping units are represented by reference soil profiles with specific hydraulic properties for individual soil layers. The model allows for including both horizontal and vertical soil variability. It is therefore possible to use spatially distributed soil profiles, with different horizon depths and total depths of the profile. The model allows coupling with raster data sets from GIS, although it is equipped with an interface for 3D visualization, and data management. All soil and topographic information are provided as Arcview Binary Raster format (.flt). The spatially resolved results (soil moisture, hydraulic heads, flow fields) are also produced as Binary Raster format (.flt) or ASCII grid format readable by most GIS packages. A catchment is simulated as an integrated three-dimensional system, and the whole hydrologically active geometry (i.e., the surface and subsoil down to an impervious layer) should be provided as input to the model. The boundary condition at the catchment bottom is either a no flow or a free drainage condition. Atmospheric boundary conditions are either positive flux (precipitation) assigned to the surface, or negative flux (potential evapotranspiration) to the upper soil layer and rooting depth, respectively. Potential evaporation and transpiration are limited to their actual values by actual soil water availability. The model does not simulate preferential flow, solute transport, and channel flow. Preferential flow can be emulated by using ''effective" soil properties (e.g., increased porosity and hydraulic conductivity), if such data are available. Channel flow plays an increasingly important role as the stream network becomes more and more complex. However, for small catchments it can be argued that the modification of hydrographs occurring in the stream network is less important than the formation of the hydrograph from overland and lateral sub surface flow (Bittelli et al., 2011).

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Action lab: Mara Catchment (Romania)

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4 Mara (Breboaia) Catchment (Romania)

4.1 Executive summary

Mara catchment, Maramureş County, Romania, is representative for the semi-subsistence farming systems in the Carpathian Mountains - cattle and sheep breeding. The study area is a typical cultural landscape modelled by traditional practices. The water supply in the area (Breb village) is provided by the centralized system and the private wells used by more than half of the households in the village. In addition, Mara River is a nature protected area of local interest due to the presence of important protected species: Salmon trutta (brown trout), Thymallus thymallus (grayling), whose survival depends on good water quality.

Breeding of cattle and sheep in the catchment area affects the quality of drinking water but also the quality of surface water, as manure is used as a fertilizer and there are leaks from the barns of most of the households. Nitrates and nutrient levels are monitored by authorities only in downstream surface waters in two sections of the Mara River (located outside the project area). There is no functional centralized sewage system in Breb village, which raises major problems for the quality of surface and groundwater.

Within the project, a database has been developed including: administrative elements, land use categories, vegetation structure, geology, soils, hydrology of the area, climate, rainfall, infrastructure elements such as roads, constructions, economic (touristic) objectives, the drinking water catchment area for Ocna Şugatag commune and the established water protection areas, the drinking water treatment plant area, existing treatment plants in the target area, protected areas, monitoring points for water quality, location of the monitored wells in Breb village.

Within the context of the project, we encourage the construction of simple and improved manure storage facilities that would significantly reduce the risk of water pollution, also contributing to improving the quality of the environment (water quality) and living conditions in numerous households. We also work to identify financial means to facilitate the implementation of manure management systems (covered impermeable manure storage platforms).

4.2 Executive summary in Romania

Bazinul Văii Mara, județul Maramureş, România, este reprezentativ pentru sistemele agricole de subzistență din Munții Carpați - creșterea vitelor și ovinelor. Zona de studiu este un peisaj cultural tipic, modelat de practicile tradiționale. Aprovizionarea cu apă în zona (satul Breb) este asigurată de sistemul centralizat și de puțurile private utilizate de mai mult de jumătate din gospodăriile din sat; în plus, râul Mara este o zonă protejată de interes local datorită prezenței unor specii protejate importante: păstrăvul (Salmo trutta), graylingul (Thymallus thymallus) a cărui supraviețuire depinde de calitatea apei.

Creșterea bovinelor și a ovinelor în bazinul hidrografic afectează calitatea apei potabile, dar și calitatea apei de suprafață, deoarece gunoiul de grajd este folosit ca îngrășământ la scară largă și exista scurgeri din hambarele majorității gospodăriilor. Nitrații și nivelurile nutrienților sunt

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monitorizate de către autorităţi numai în apele de suprafață din aval pe două secțiuni ale râului Mara (în afara zonei de proiect). Nu există un sistem centralizat de canalizare în regiunea zonei pilot din Maramures, cee ace ridică probleme majore pentru calitatea apei de suprafață și subterane.

În cadrul proiectului, pentru realizarea unei baze de date au fost colectate date cu privire la: elemente administrative, categoriile de folosinţă ale terenurilor, structura vegetaţiei, geologie, soluri, hidrologia zonei, clima, precipitaţiile, elementele de infrastructura: drumuri, construcţii, obiective economice pensiuni, zona de captare a apei potabile pentru comuna Ocna Şugatag şi zonele de protecţie stabilite, zona staţiei de tratare a apei potabile, staţii de epurare existente în zona ţintă, arii protejate, punctele de monitorizare pentru calitatea apei, localizarea fântânile din Breb (cele utilizate).

În contextul proiectului încurajăm construirea unor facilități simple și îmbunătățite pentru depozitarea gunoiului de grajd, care ar reduce în mod semnificativ riscul de poluare a apei, contribuind, de asemenea, la îmbunătățirea calității mediului (inclusiv a calității apei) și a condițiilor de viață în numeroase gospodării. Lucrăm şi în scopul identificării mijloacelor financiare pentru a facilita implementarea sistemelor de management al gunoiului de grajd (platforme acoperite, impermeabile).

4.3 General description

The area of interest is located in the alpine and continental biogeographical region, in the volcanic area of the Eastern Carpathians, more precisely in the Gutai Mountains, and it is limited to the West by the Hopsia River, to the East by Rausor Valley, the villages of Mara and Hoteni, to the south by national road DN 18 and to the north by the ridge of the Gutai Mountains. The area is included in N2000 sites ROSPA0134 Munții Gutâi, ROSCI0089 Gutâi - Creasta Cocoșului and ROSCI0092 Igniș.

Maramures action lab is a rural region from North Western part of Romania, including a typical cultural landscape shaped by traditional practices, representative for small scale/ subsistence farming systems in the Carpathian Mountains – cattle and sheep breeding. The core area of the action lab is Breb village which is located in the central-northern part of the Maramures depression, in the upper part of the Mara river basin on the northern piedmont of the volcanic Gutâi massif, 25 km from Sighetu Marmatiei and 52 km from the Baia Mare county capital. (Figure 4.1 location of Breboaia action lab, core region Breb Village).

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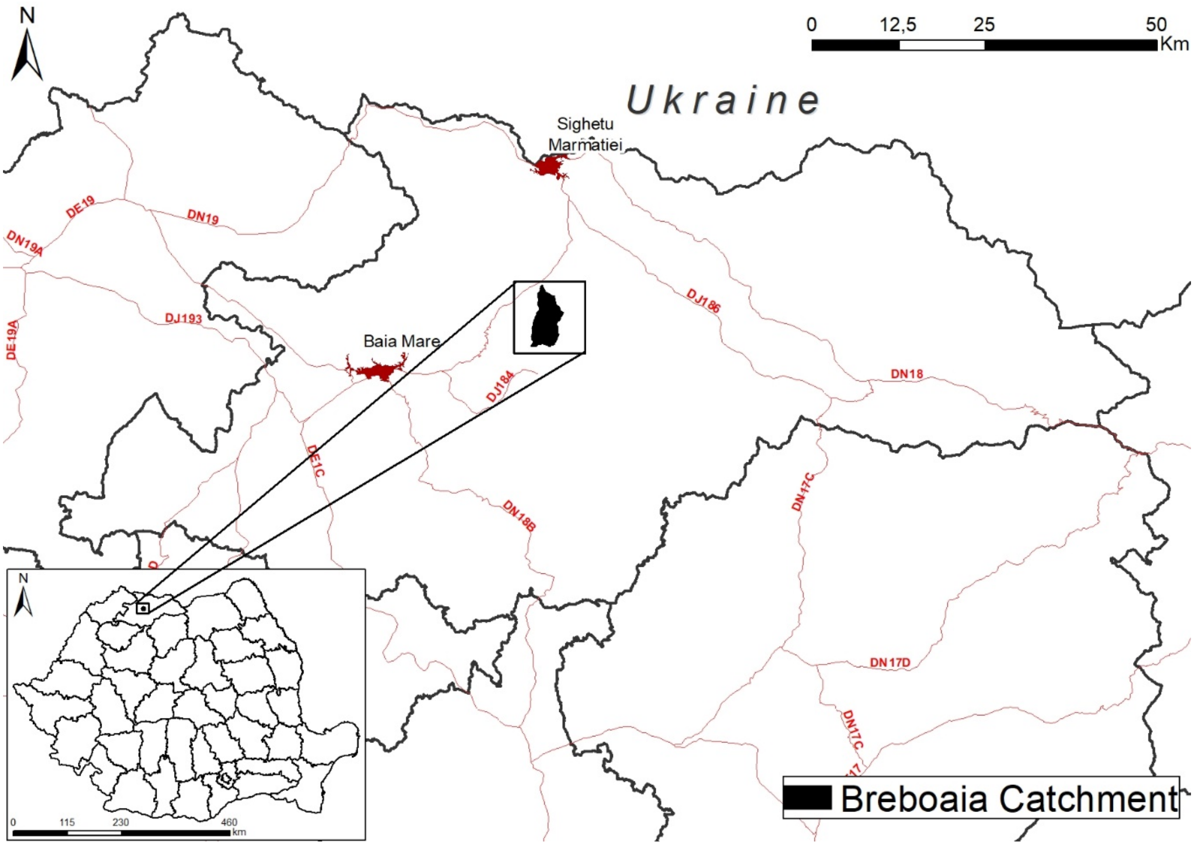

Figure 4.1 location of Breboaia action lab (Romania)

Breb village belongs to Breboaia river catchment (27,1 km^2). Breboaia River is a tributary of the Mara River and an important natural resource which also supports high biodiversity, including many protected species. Mara river is a protected area of local interest due to the presence of important protected species: trout (Salmo trutta), grayling (Thymallus thymallus) whose survival depends on the water quality.

Water coming from the action lab area enters Mara River. The quality of the water is considered good, according to official data. Source of the creeks from action lab is not considered nitrate sensitive. Destination of the water courses has a concentration of nitrates due to crossing of the village where farmers use manure as fertilizer. The water quality of the Mara River is affected by the diffuse pollution sources originating from the agricultural and forestry sector, even if the effect is moderate. In rural households located in the Mara River Basin, traditional agriculture is practiced on small areas, and the fertilization of crops is done only with organic fertilizers. There is a risk of contamination with nitrates but its impact is not significant on the aquatic life.

90% of the population is using the current public drinking water system, managed by Ocna Sugatag Mayor House as for the rest there are some wells and individual water systems in use. The public water system uses water from the mountainous area (Gutai Mountains) and has a good quality

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(according to official data from Ocna Sugatag Mayor House). As part of Maramures depression, Breb village has some mineral springs, but they are not used anymore.

4.4 Previous investigations

The monitoring of the water quality from the basin of the Mara river is performed by the National Water Authority, Maramures Directorate, namely by the Laboratory for the Chemical Analyses in two reference control sections: the upstream of the river Mara (reference section) and the river Mara at Vadu Izei. (these 2 sections are at the boundaries of action lab area, and not included in WaterProtect lab case area). According to available public data for these 2 sections (2007, 2010 the indexes categories range within the first and the second quality classes (the quality categories for the surface waters are stipulated in the Order no.161/2006 of the Ministry of Environment and Waters & Forest Ministry.

Within the framework of Water Protect, a small scale area was investigated and 5 monitoring stations for surface waters were selected: 1. Upstream of Valea Sunătoare, 2. Valea Brebului upstream of Breb; 3. Valea Brebului downstream of the confluence of the Valea Sunatoare 4. Valea Brebului, downstream of Breb) and 5. Mara River – the Harniceşti sector (Figure 4.1).

There has not been additional local data collection or surveys in the area, and therefore many general data and maps have been collected and developed within the context of WaterProtect project. These data are described further in the next section.

4.5 System description

In Mara (Breboaia) action lab (Romania), the present threat to the water quality (especially surface water) is nitrate from agriculture, i.e. cattle and sheep breading in the catchment area affects the drinking water quality but also the surface water quality since manure is used as a large scale fertilizer and leaks from the barns of most of the households; there is no centralized sewage system in this case study (Breb village), which poses major problems for surface and underground water quality. In the present section the existing data relevant to the transport and fate of nitrate in the action lab is presented and discussed.

4.5.1 Topography

Mara (Breboaia) Catchment has an elevation that ranges from 395 m to 1413 m. The Gutâi Mountains cover the southern part of the Breboaia Catchment covering all the area situated above the 800 contour line. The central and north parts of the catchment represents a hilly area with numerous river valleys that belongs to Maramureș Depression. Breb Village is situated in the north central part of the action lab, in an area with mild to moderate slopes.

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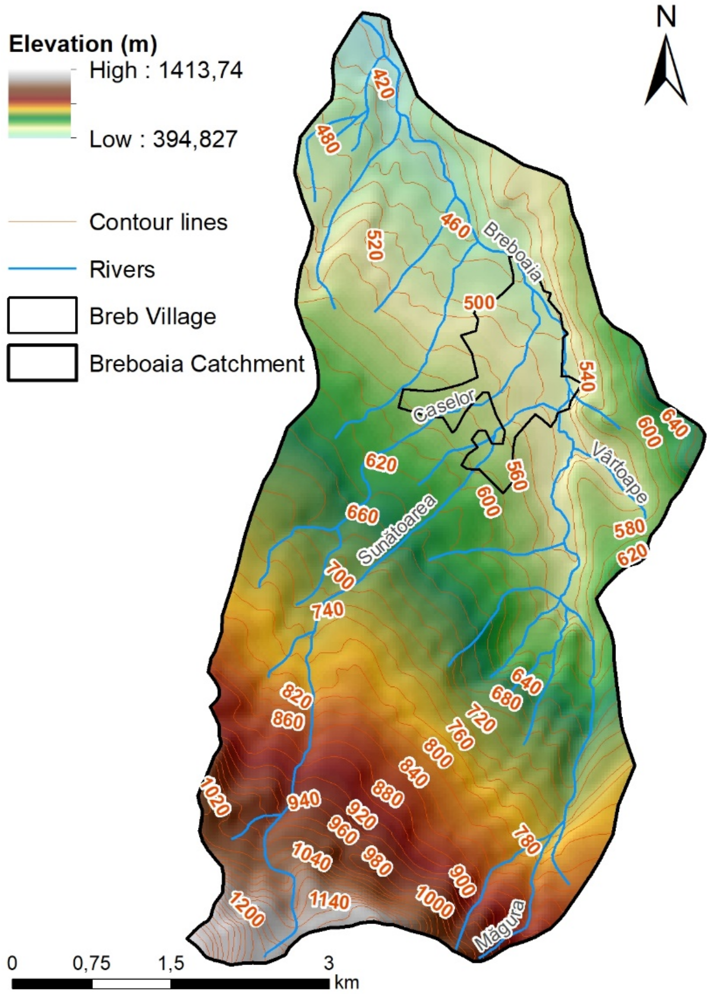

Figure 4.2 Topographical map of Breboaia Catchment

4.5.2 Land use / Land cover

Most of the agricultural land in Mara (Breboaia) Catchment consists of meadows and pastures. In and around Breb Village arable land and orchards (consisting of mostly plum trees) occupy the largest areas (Figure 4.3).

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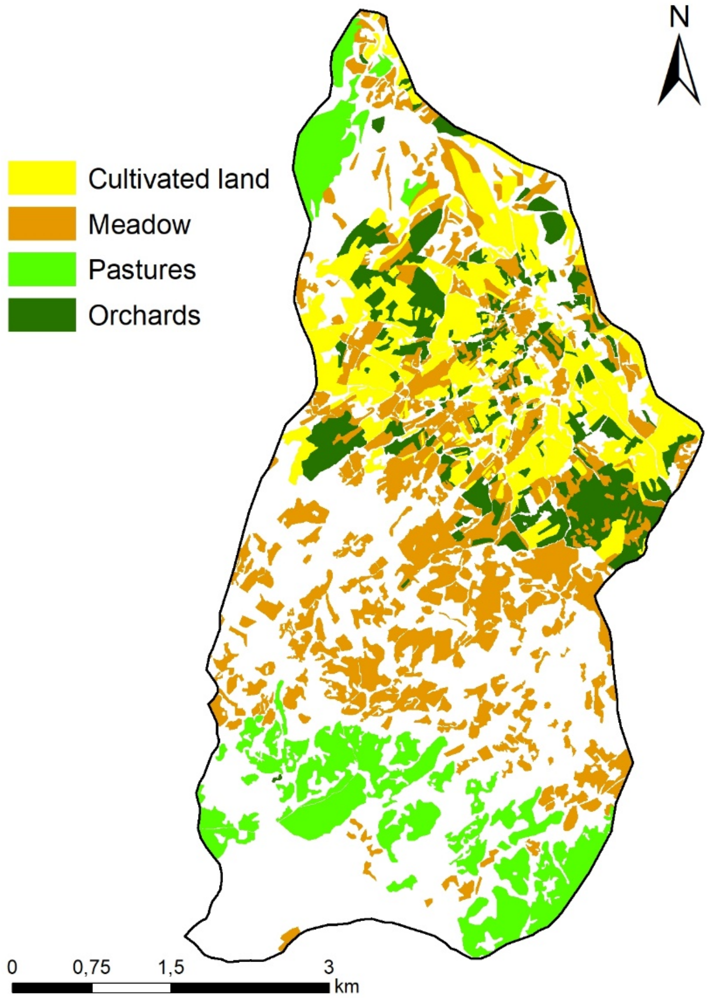

Figure 4.3 Agricultural land use map of Breboaia Catchment

4.5.3 Climate and hydrology (precipitation, evaporation and net precipitation)

The climate in Mara (Breboaia) action lab is typical for temperate continental climate with annual air temperatures values (Figure 4.4) ranging from 4^0C and 8^0C. During the May- September interval it's most likely to experience good weather with pleasant average temperatures. On average, the warmest month is August. On average, the coolest month is January.

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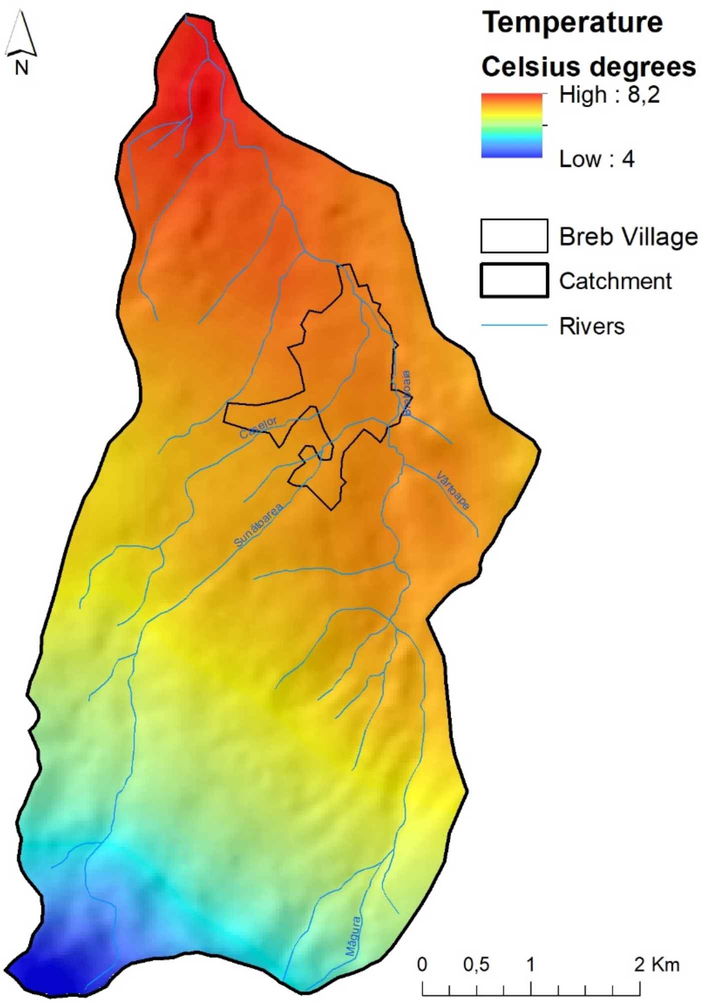

Figure 4.4 Temperature distribution map of Breboaia Catchment

The annual amount of precipitation (Figure 4.5) fluctuates between 750 mm (in the north of the catchment) and 900 mm in Gutâi Mountains. June is the wettest month. February is the driest month. The months with the most abundant rainfall are June, July and October, the poorest being recorded in September, February and March, but with significant annual variations. The average number of precipitation days is 170 in the mountain area, down to 150 in the rest of the catchment.

The first snowflakes that lay a continuous layer of snow in the mountain range occur at the end of November, but they can appear in October as well. The snow is kept in the mountains and on the northern slopes until April, the month of the last snowfalls. There are frequent years in which, at the end of April, the late snow are present on the subalpine pastures, while vegetation in forests at lower altitude are already blooming.

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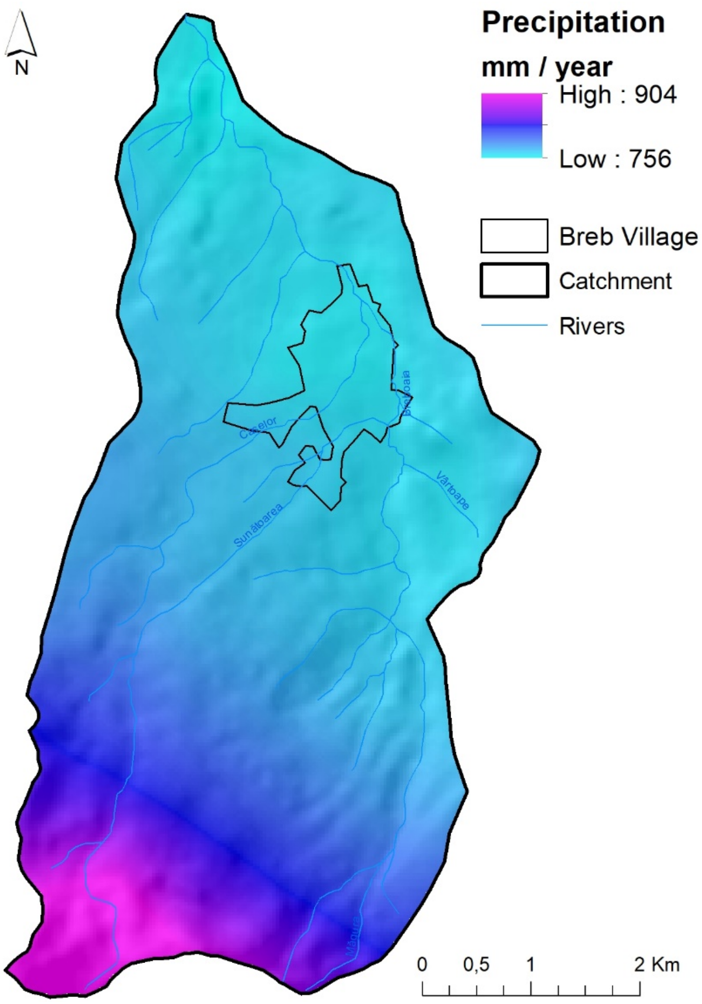

Figure 4.5 Precipitation distribution map of Breboaia Catchment

The potential evapotranspiration distribution map (Figure 4.6) shows high values (over 800 mm/year) in the northern areas of the action lab, and lower values (in the southern parts of the catchment.

The annual water availability values (precipitation minus evapotranspiration) vary between +240 mm/year in the mountainous areas to -67 mm/year in the northern parts of the catchment.

Wind. The calm weather (no wind) varies between 40-54% in the surrounding depressions, which is lower in the subalpine area. The predominant winds are west, northwest and southern direction, at an average speed not exceeding 4 m / s (except for the high peaks). In the Gutâi and Ignis Mountains the eastern and northeast winds are not felt. There are some storms (rare), with disastrous effects on forests due to extensive deforestation, and under the threat of climate change effects.

Cloud. The number of serene days does not exceed 40 in the mountain area, being over 50 in depressions. The relative humidity reaches 84% in the high mountain area, decreasing to 72-76% in December (7.2 tenths), and the minimum in July and September (4.7 tenths) in the Baia Mare area.

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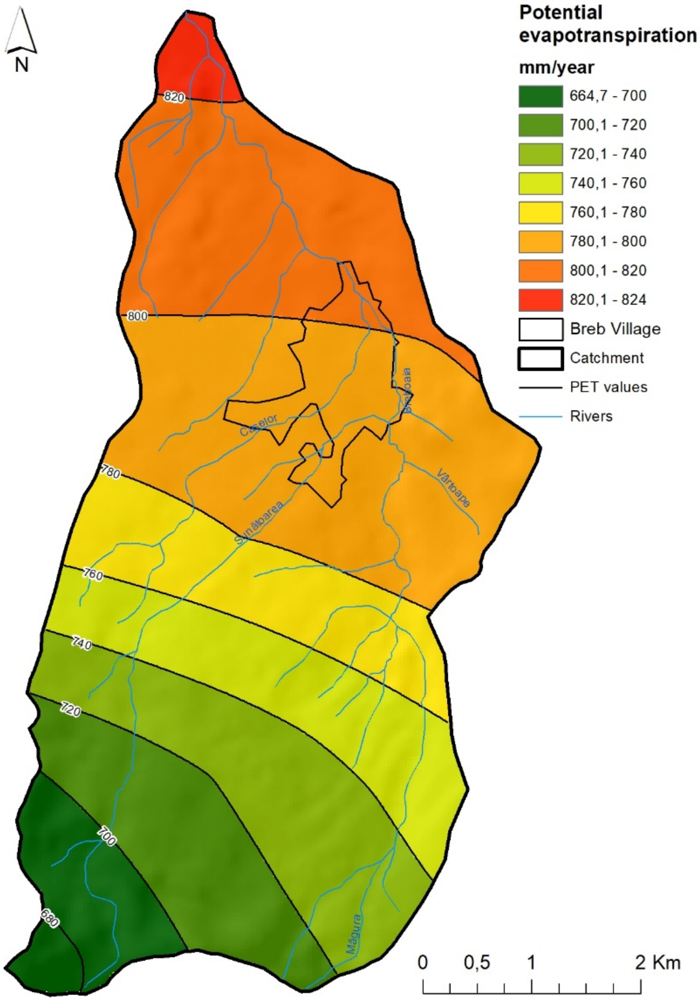

Figure 4.6 Potential evapotranspiration distribution map of Breboaia Catchment

The territory of Breb village is crossed by a rich hydrographic network (Figure 4.7). In the local toponymy, the main watercourses that spring from the Gutâi Mountains and flow into Mara are known under the following names: Valea Breboaia, Valea Mare, Valea Sunatoarei and Valea Caselor.

The depth of phreatic waters ranges from a few centimeters to a few meters and it is used for drinking water from dug wells in Breb Village.

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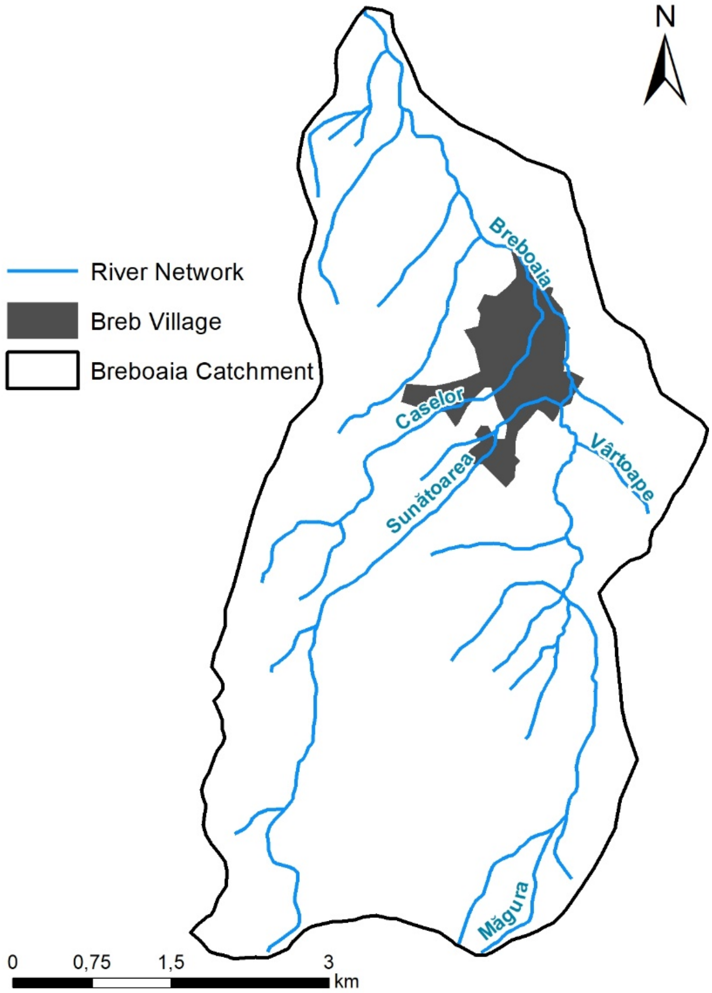

Figure 4.7 River network of Breboaia Catchment

4.5.4 Soil types and drainage

Leptosols and andosols characterize the mountainous areas (Figure 4.8). Fluvisols are found in the lower parts of the Breboaia River. Dystric cambisols dominate the hilly areas from the catchment, while haplic podzols are found in a small area in the north-west.

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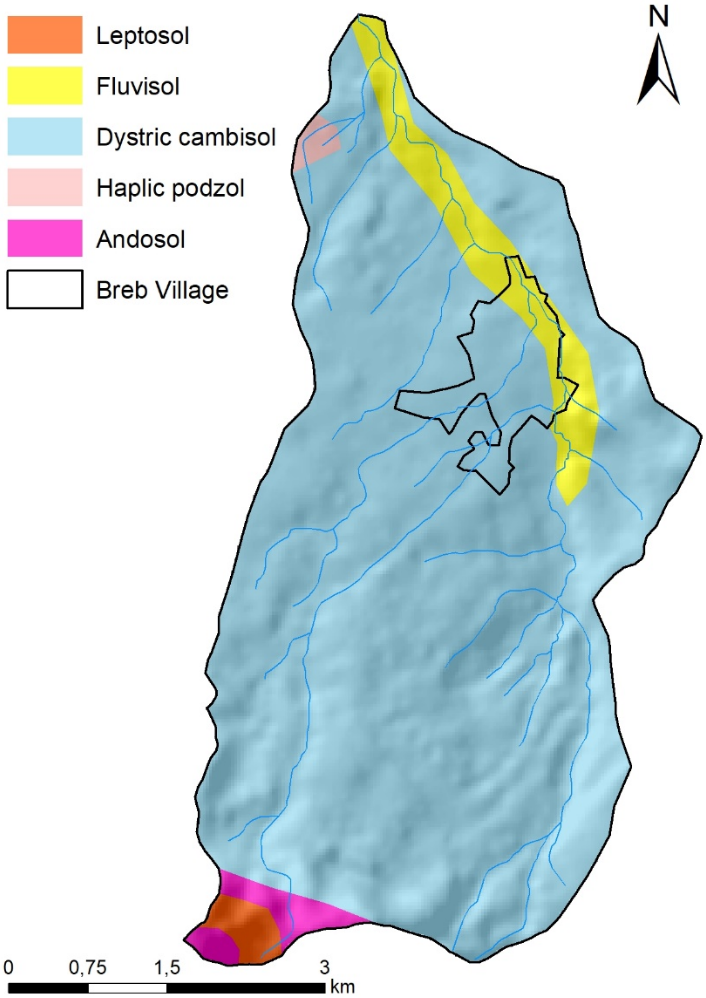

Figure 4.8 Soil types map in Breboaia action lab

4.5.5 Geology

The geological structure of the Gutâi Mountains (Figure 4.9), where volcanism was predominant, determines the present aspect of the morphology. They are composed almost exclusively of volcanic andesitic rocks, formed from Neogene-Quaternary lava eruptions. Tortonian deposits were later covered by delluvial deposits in the upper Pleistocene, mostly mixed with volcanic conglomerates from the surrounding volcanoes. Holocene fluvial deposits occur only in the lower part of the Breboaia River.

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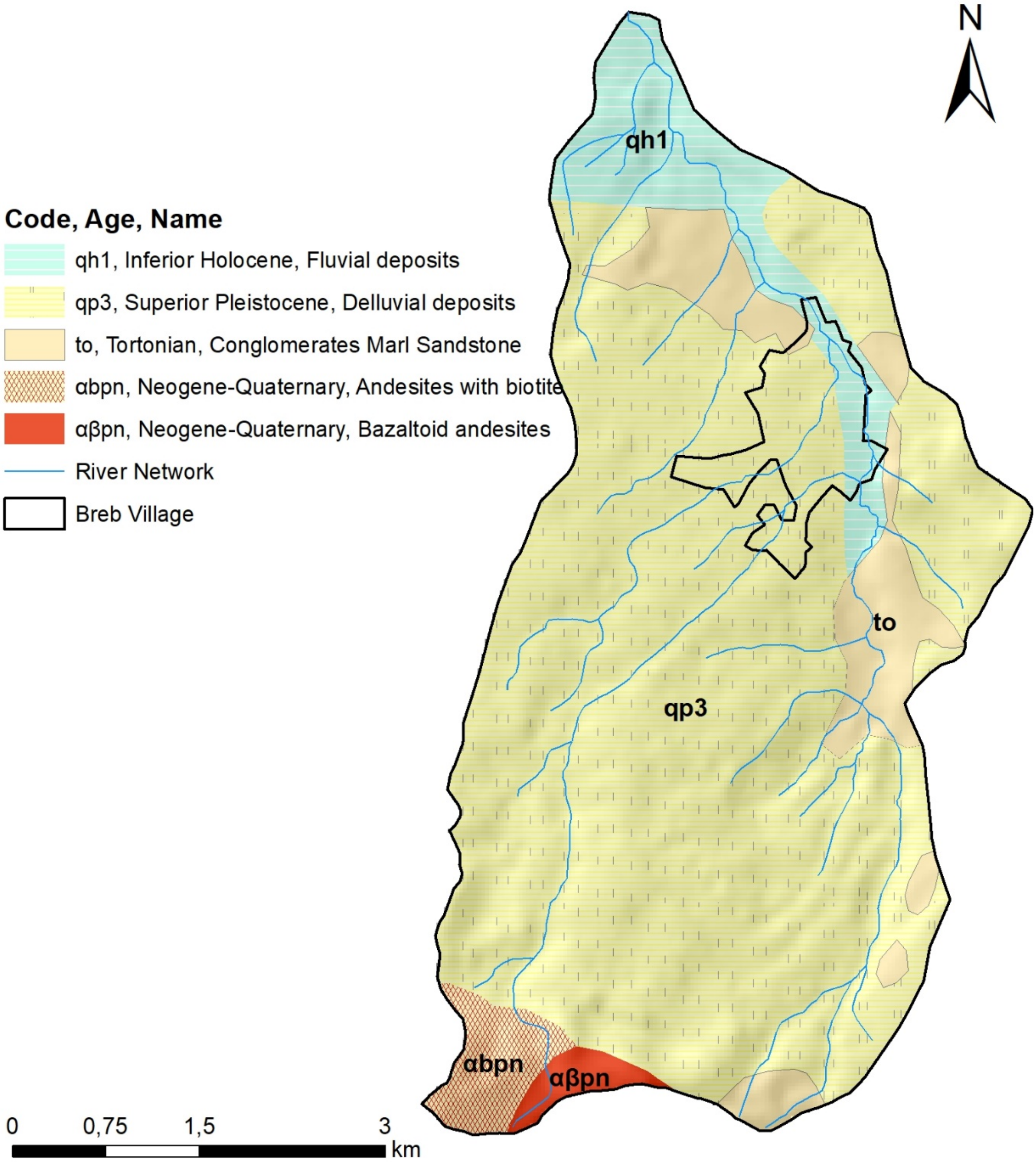

Figure 4.9 Geological map of Breboaia Catchment

4.5.6 Nutrients monitoring

According to official information, the water quality of the Breboaia River is good, and the vulnerabilities are recorded only at the nutrient regime, but at a moderate level.

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In the study area located in the Breboaia river basin, the rural type communities practice traditional semi-subsistence agriculture. Thus, hand labor and animal energy are widely used on small fields, along with natural fertilization and simple rotation of crops. As a result, pesticides or chemical fertilizers are not used in the region. Thus, there is a moderate impact on the environment, including on the aquatic life.

Problems only occur due to household waste, due to the use and storage of manure, due to their defective management. Monitoring from official authorities is performed on larger scale and thus not include study area of Breb.

Potential pressures on the water resource in the area could only be generated by the non-conforming use and storage of manure. As a result, the main objective of the research is to monitor the nutrients in the surface waters that drain the Breb area and to assess the riverside nitrofile vegetation. Seasonal water samplings were carried out during the vegetation period from 5 stations, for which the acidity regime, the oxygen regime and the nutrients were analyzed during the period from 2017 to 2018. Quantitative and qualitative samples of macrozoobenthos were taken from the same stations too. Macrozoobenthos, made up of a wide variety of invertebrates (dominant insect larvae) with varying degrees of tolerance to the anthropic pollution, operates as a real tool for assessing the biological quality of the aquatic environment.

Thus, the physical-chemical analysis of water, substantiated with the biological analysis, much more accurately reflects the ecological status of the analyzed water section and implicitly the magnitude of the anthropic impact.

Table 3.1 Values of the oxygen and nutrients regime in the monitored stations for the water courses in the Breb area, during 2017-2018.

No	Quality indices	U/M	Determined value/Stations														
			Upstream of Valea Sunătoare			Valea Breb – upstream of Breb			Valea Breb downstream of the confluence of Valea Sunatoare			Valea Breb, downstream of Breb			Mara River – the Harnicești sector		
			Summer	Autumn	Spring	Summer	Autumn	Spring	Summer	Autumn	Spring	Summer	Autumn	Spring	Summer	Autumn	Spring
1	pH	pH units	-	6,66	-	7.40	-	-	6.97	5.30	7.39	7.19	7.87	7.40	7.58	-	-
Regimul oxigenului																	
2	Dissolved oxygen	$mgO2/l$	-	11.31	-	12.31	-	-	10.89	8.82	11.20	9.18	8.24	10.5	11.89	-	-
3	CBO_5	mgO_2/l	-	2,23	-	1.23	-	-	4.12	5.20	3.20	3.47	4.23	2.80	1.06	-	-
Nutrienți																	
4	Nitrites ($N\text{-}NO_2^-$)	mgN/l	-	0.020	-	0,017	-	-	0.060	0.060	0.010	0.022	0.010	0.020	0.077	-	-
5	Nitrates ($N\text{-}NO_3^-$)	mgN/l	-	1.200	-	1.225	-	-	1.341	1.100	2.620	0,671	0,900	2.100	1.328	-	-

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The monitoring of surface water, groundwater (wells) and drinking water will be carried out on nutrient contamination during 2018 to 2019 as well. Thus the assessment of nitrofile vegetation in the area of interest will be completed.

Values of the oxygen and nutrients regime in the monitored stations for the water courses in the Breb area, during 2017-2018, are presented in Table 3.1 and Figure 4.10.

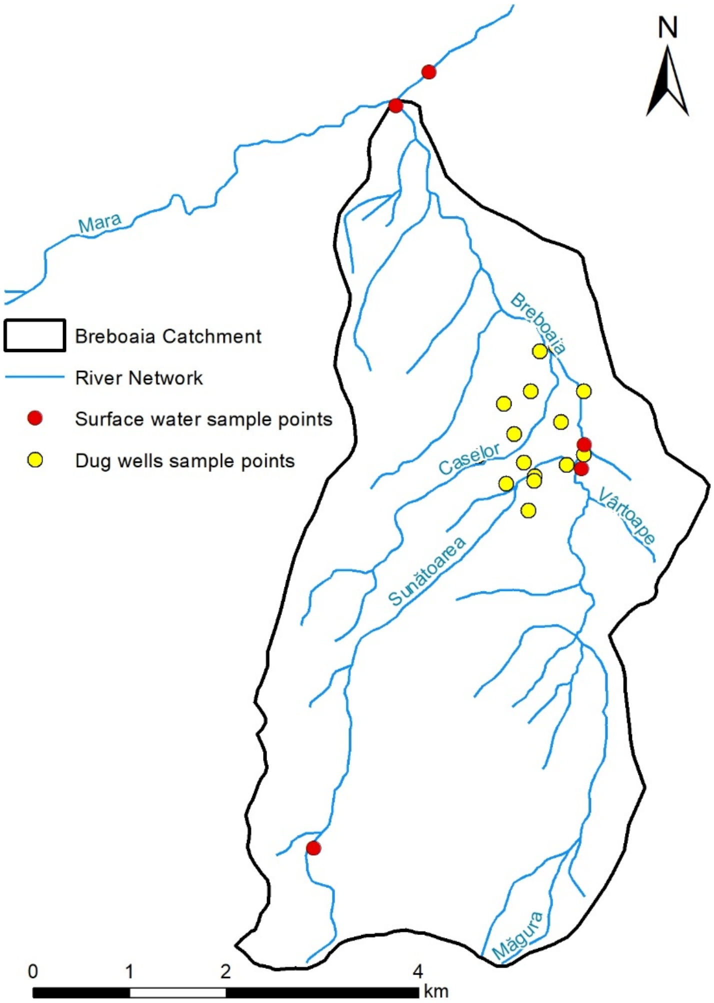

Figure 4.10 Water sampling locations in Breboaia action lab

Complementary, analysis of microbacteriological data were provided by Ocna Sugatag municipality (July 2017) based on analysis of water from central pipeline made by Maramures Sanitary Veterinary Directorate.

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4.6 Conceptual model

4.6.1 Landscape Analysis

The Mara catchment (20 km^2), Maramures County, Romania, is representative for small scale/ subsistence farming systems in the Carpathian Mountains – cattle and sheep breeding. The study area is a typical cultural landscape shaped by traditional practices.

Most of the agricultural land in Breboaia Catchment consists of meadows and pastures. In and around Breb Village arable land (agro-terraces with grass slopes) and orchards (consisting of mostly plum trees) occupy the largest areas.

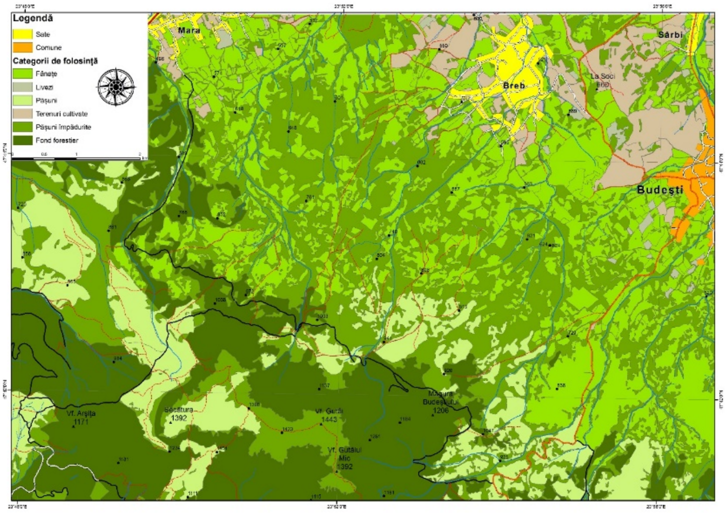

Figure 4.11 Land use in Mara catchment

The area is dominated by animal husbandry (poultry, cows, pigs, sheep, horses, rabbits) and cereal production; many households own hayfields and orchards in the proximity of the village. Farmers usually have 2-4 cattle (left grazing on the fields in summer time during day), some sheep, 2-3 pigs and poultry, horses. The farmers having sheep take their animals to communal sheepfolds (there are 4 sheepfolds in Breb in 2018).

Farmers use organic fertilizers from their farms on their agricultural fields; the use of organic manure is a traditional practice for small scale mountain farms in Romania in Maramures. Farm animals are kept in barns close to households for most of the year. For example, pigs are usually permanently housed, cows graze during summer months but return to barns at night, and sheep spend 4-5 months away whilst grazing at pastures. At some point manure from all types of livestock that are kept in barns accumulates. This is regularly cleaned out (often daily) into a "store" located close to barns where it usually remains for 6-12 months – sometimes for a shorter period of time (1-6 months). Majority of households apply manure to hay fields, orchards and crops. 84% of households surveyed had manure "stores" which consisted of a carefully constructed heap adjacent to buildings, in which farm animals are kept. Less than 5% of manure stores in the survey have a hard base, but approximately 10% do have some form of a retaining wall – most commonly made of stone or brick, but also wooden. Unfortunately, the combination of human and animal waste is a common problem

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that was observed in over half of the households surveyed – commonly due to the construction of households' toilets directly next to the manure stores.

Picture 1 typical landscape in Mara catchment

4.6.2 Nitrate transport pathways

Due to the medium slope morphology of the catchment and the close to surface water table, the phreatic nitrate transport pathways follow the ones on land surface, and the nitrate transport pathway has been defined by digital terrain model (DTM) (Figure 4.12). Due to its positioning within the catchment, Breb Village is susceptible to increased nitrate values as more than half of the catchment pathways concentrate in the village perimeter.

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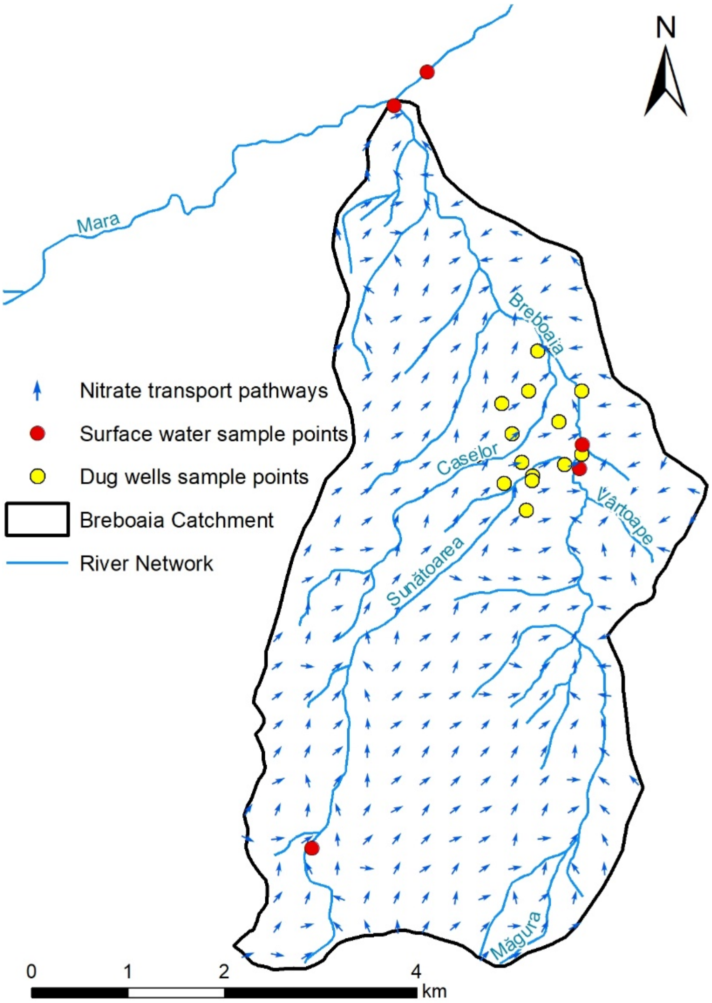

Figure 4.12 Nitrate transport pathways in Mara (Breboaia) Catchment

Assessment of water quality was done based on the following indicator groups: pH, oxygen regimen (O_2, CBO_5), nutrients ($N\text{-}NO_2^-$, $N\text{-}NO_3^-$).
Participatory monitoring for water quality is currently performed on surface waters (5 sections) and underground waters (14 wells) and results show concentrations of nitrates in the vicinity of the village. Nevertheless, monitoring results indicate moderate concentrations of nutrients that do not exceed the standard limits (certain exceptions are present for surface waters, please see below). In the current framework, it is a consequence of existing capacity of the ecosystem to naturally filter pollutants.

The most important anthropogenic threats have been identified along the Valea Sunatoarei, where a large proportion of the Breb households are located and they realte to:

- the non-compliant storage of manure and seasonal excess nutrient inputs in aquatic systems. As a rule residues and manure generated by livestock are stored directly on the soil. Under the influence of environmental factors and the activity of microorganisms, organic matter resulting from fermentation generates bad odorous substances. The livestock manure in individual households in the Breb area is stored under improper conditions,

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without measures against leakage and infiltration of liquid fractions (urine and rainwater) with a major risk to the environment and health. It is recommended to apply a sustainable manure management system for each household having livestock. An example from a monitoring station showing high NO2 concentrations is monitoring section 3 (Breboaia River, after the confluence with Sunătoarea River, Map 2, stations in RO action lab for monitoring of surface waters): April 2018 monitoring campaign, indicate 0.76 mg/l NO2, when maximum admitted limit is 0.5 mg/l). We assume that the high NO2 concentration is due to location of monitoring station in a place where there are many households with livestock and no manure management systems in place and there was reduced rain in the season).

- the abandonment of the residues resulting from the brandy distillation in the autumn season. After obtaining the brandy (traditional Maramures alcoholic drink obtained from fruit from orchards) there is a risk that large amounts of waste (fruit that underwent fermentation) will reach the bed of the Breb Valley. Such a problem was registered during monitoring campaign in the autumn of 2017 (NO2 concentration of 0.66 mg.l, when maximum admitted limit is 0.5 mg/l). Thus, in monitoring station 2 (Breboaia Valley before the confluence with Sunătoarea Valley on Map 2, stations in RO action lab for monitoring of surface waters), the water had a bad smell, it was cloudy and dark.
- lack of functional centralized domestic waste water evacuation system.

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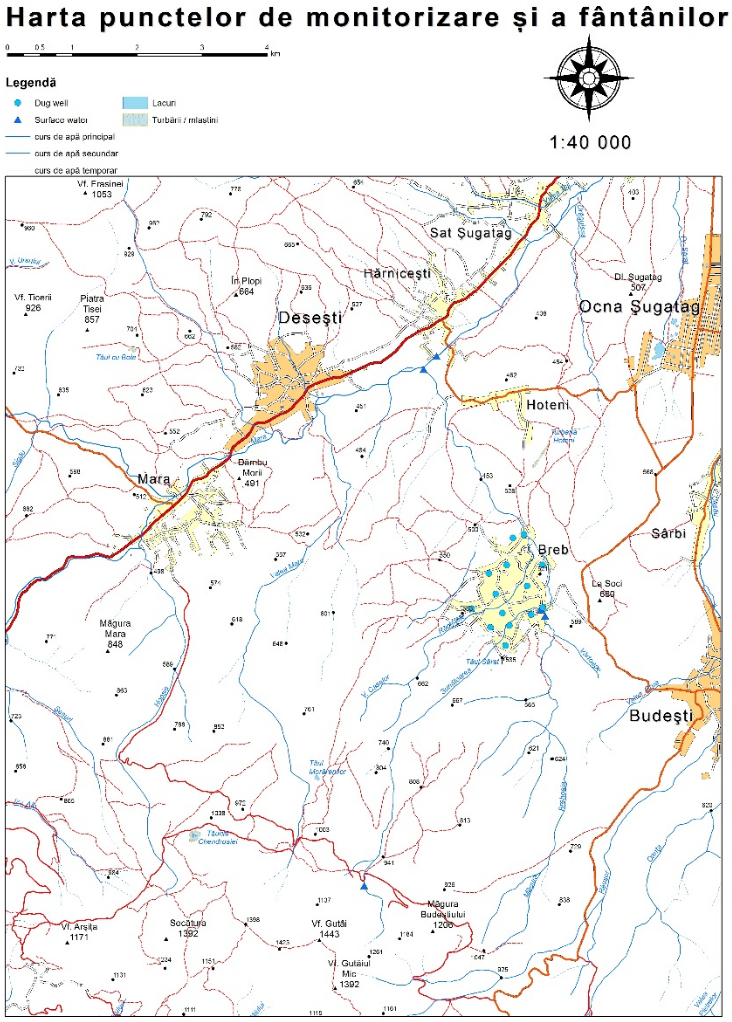

Figure 4.13 Stations in RO action lab for monitoring of surface and underground waters (wells)

The surface water monitoring stations display the following characteristics:

1) Station of Valea Brebului River – upstream of Breb. The analysed site is located upstream of Breb, in an area free of significant pollution sources. Its shores are fully covered with vegetation. The global chemical status for this station is I. Thus, the water quality conditions for the analysed plant undergo changes to the unmodified natural conditions but to a low level. The water is of good quality, the anthropogenic alterations coming from the agricultural sector (animal husbandry, use of fertilizers) are of low intensity.
2) Upstream of Valea Sunătoare the station: the analysed site is located upstream of Breb, in an area free of significant pollution sources. Its shores are fully covered with vegetation. The structure of the riverbed is dominated by the boulders, the width of the riverbed being of 1m with a depth of 20-30 cm. In July 2017, the station is in the 1st grade of quality at the oxygen regime and the nutrient regime. Thus, the water quality conditions for the analysed plant undergo changes to the unmodified natural conditions but to a low level.

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3) The Valea Brebului river downstream of the confluence of Valea Sunătoare river located in the Breb village, at a distance of about 15m downstream confluence with the Valea Sunătoare. The river bed structure is dominated by boulders of large diameters and gravel, the width of the bed being 3m, with a depth of 20-30cm. In the shore area and in the low-speed locations, there is a sandy matrix where large amounts of organic deposits are observed. In connection with these deposits, possible explanations can be: loading of cultivated land near the valley with manure and domestic / animal manure from individual households. In July 2017, with regard to the oxygen regime, the station range in the first grade of quality. In the nutrient regime, the first class quality has been found on the nitrate indicator and the third class quality for the nitrite indicator. High nitrogen content may reflect a recent contamination with animal manure or with runoff from cultivated lands fertilized with nitrogen-based substances. The high values of the total phosphorus indicator may be due to the inappropriate management of manure.
4) Valea Brebului station downstream of Breb: the width of the riverbed is between 6-8 m, the substrate being generally made of gravel and boulder, with a depth of 40-50 cm. Oxygen consumption indicators show the dissolved oxygen content and the chemical oxygen consumption proving the good water quality, corresponding to the first class I quality. The nutrient regime shows first class I quality for the both monitoring campaigns (July and September, 2017). The global chemical status for this station is the first – I for the both monitoring campaigns (July and September, 2017). Water quality is good.
5) Mara River – the Harniceşti sector Station: the water quality of the Mara River is affected by the diffuse pollution sources originating from the agricultural and forestry sector, even if the effect is moderate. In rural households located in the Mara River Basin, traditional agriculture is practiced on small areas, and the fertilization of crops is done only with organic fertilizers. There is a risk of contamination with nitrates but its impact is not significant on the aquatic life. In July 2017, the Mara River – the Harniceşti sector station ranges within the first class quality for the oxygen regime. Nutrient regimes show exceedances of the first class quality for the nitrite indicators (third quality class – III)).

In Maramures action lab, Romania, all farmers use primarily animal manure (solid manure, which comprises material from animal houses and consists of excreta mixed with the bedding materials e.g. straw) as fertilizer for their agricultural fields. In addition, there may also be varying amounts of slurry, which consists of liquid or semi-liquid excreta produced by livestock in a yard or areas of a building where there is little bedding used (e.g. passageways).

4.6.3 Additional field data and improving the conceptual model

Additional data collection is planned in the area for the coming months, which will continue improving the understanding of the system.

4.7 References

Raport baza de date GIS zona Vaii Mara, SC Montan Explore SRL

PROFILUL DE MEDIU AL JUDEŢULUI MARAMUREŞ

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Action lab: Wexford catchments (Ireland)

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5 Wexford catchments (Ireland)

5.1 Executive summary

Work in the Irish Action lab is centred upon two established study catchments, Ballycanew and Castledockrell, located in the south east of the country in County Wexford. Both catchments have been extensively studied since 2009 as part of the on-going Teagasc Agricultural Catchments Programme (ACP). To date, this research has yielded in-depth knowledge surrounding the physical properties of the catchments, including water and soil quality, as well as farming practices and behaviours.

While in relative proximity, both study catchments are distinct in terms of their geological settings. These dissimilarities give rise to important differences in terms of agricultural land use and, hence, contaminant types and sources. Castledockrell is characteristic of mostly free draining soils overlaying fissured slate bedrock and is dominated by arable land while Ballycanew has mostly poorly drained soils overlaying volcanic rhyolite and is dominated by grassland for beef and dairy production.

Drinking water sources in both catchments are vulnerable to contamination from microorganisms, nutrients (from inorganic/organic fertilisers as well as point sources such as farmyards and domestic wastewater treatment systems), pesticides and metabolites from crop production and emerging organic contaminants. However, the distinct hydrogeological settings greatly influence contaminant pathways. The transfer pathways of contaminants in Ballycanew are highly reflective of the distribution of the two dominant soils. The lowland of the catchment is dominated by poorly draining surface water gleys while on the elevated land to the south well drained brown earth soils dominate. There are risks of nitrate and pesticide leaching to groundwater in this upland area which may be transferred to potable water in the lowland, or discharged to the river. Nitrate is, however, largely denitrified along pathway. Due to the poorly permeable nature of the lowland areas the hydrology is “flashy” with a large component of quick and erosive surface runoff. An extensive artificial drainage network further increases the hydrological connectivity. Acid herbicides, and MCPA in particular, are of concern due to its use in controlling rushes, which are typical of the poorly drained soils, and secondly due to its highly mobile and soluble nature. In contrast, in Castledockrell, nitrogen is the main nutrient at risk of loss from the catchment. This is mostly via leaching in the freely drained soils and with relatively little denitrification along the transfer pathways to the groundwater and river due to high hydrological conductivity in the dominating pathways (Mellander et al. 2012; 2014). There is also a risk of pesticide loss through leaching across the catchment.

Facilitated by the ACP, WaterProtect is building upon this knowledge base by utilising existing data while also carrying out a new monitoring programme via a multi-actor approach. In Ireland, while MCPA has been responsible for several breaches of the EU quality standard (0.1 µg/l) in drinking water supplies a paucity of understanding still surrounds the occurrence and fate of pesticides and their metabolites in the environment. The monitoring programme being implemented by WaterProtect is investigating the prevalence of a suite of acid herbicides and their metabolites in private drinking water wells. The programme is also investigating the use of passive samplers as a

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novel method to identify average MCPA concentrations in the study catchments. This method has the potential to overcome the time-specific limitation of one-off grab samples. This improved monitoring will identify MCPA occurrence and transport pathways and therefore guide future actions.

5.2 Introduction

In Ireland 82% of drinking source water is supplied from surface water bodies (rivers and lakes) and 18% from groundwater and abstraction for human use is 2% of water resources. In 2016, there were 904 public water supplies serving 1.3 million households (CSO, Census 2016). There is a large agricultural sector (56% of the land area) which can act as a pressure to water quality and therefore a potential risk to drinking water source. National agri-food targets are to further increase the value of agricultural productivity and export while simultaneously meeting environmental objectives (Food Harvest 2020; Food Wise 2025). To achieve this it is important to implement a strategy for preventing pollution loss from agriculture, including efficient and targeted measures to mitigate pollutant loss to water. Knowledge transfer is also considered important for improved uptake and implementation of the measures.

In rural areas it is common for small scale abstraction of groundwater to supply individual farms and households. Drinking water sources are typically under pressure from inorganic/organic nutrient fertilisers as well as point sources (e.g. farmyards and domestic wastewater treatment systems (DWWTS)), pesticides (herbicides, insecticides and fungicides) and metabolites from crop production and weed control, microbials and emerging organic contaminants from organic fertilisers and DWWTS. Monitoring of drinking water resources has shown that, despite legislative steps to govern the control and use of pesticides, the number of public water supplies that are failing to meet the legislative standards has increased. At the end of 2016, sixty-three supplies serving over 900,000 people had open investigations due to failures to meet the acceptable pesticide quality standard stipulated by the legislation (EPA, 2017). While these observed failures relate to all pesticides, monitoring has illustrated that MCPA is mostly responsible for the exceedances.

The Irish Action lab is focused on farmland within County Wexford, in the south-east of Ireland and will assess both surface water and groundwater. The Irish Action lab consists of two data-rich catchments (Ballycanew and Castledockerell), both extensively monitored in terms of water and soil quality since 2009 within the Agricultural Catchments Programme (ACP, www.teagasc.ie/agcatchments). These catchments are placed in the context of larger river basins; Ballycanew (11.9 km^2) in the Brackan sub-basin of the Owenavoragh (36 km^2) WFD catchment and Castledockerell (11.2 km^2) in the Scarawalsh subsection catchment of the Slaney river WFD catchment (25 km^2), which are monitored as part of the Irish national monitoring programme and by local authorities (Figure 5.1). While the Ballycanew catchment has a large proportion of heavy and poorly-drained soils giving rise to a “flashy hydrology” and surface pathways largely contributing to

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the river flow, the Castledockerell catchment has mostly well-drained soils and is largely groundwater fed with dominating belowground transfer pathways (Mellander et al., 2015). The housing densities within the catchments are low and, similar to large parts of rural Ireland, waste water is commonly treated by DWWTS. However, within the Castledockerell catchment there is a small waste water treatment plant serving part (75 PE) of the catchment population.

Monitoring within these two catchments is as follows:

- hydro-chemical data (river discharge, TON, TP and TRP concentrations, turbidity, EC and temperature (and TOC since June 2018)) collected sub-hourly from the river outlets
- synoptical hydro-chemical data are collected monthly on multiple places along the river
- groundwater is sampled for concentrations of N, P and metals on multiple sites and in different strata in piezometers and multilevel monitoring wells
- standard weather parameters are monitored within the catchment. Soil chemistry is sampled at field scale and information on farm management is recorded.

Within WaterProtect new monitoring of herbicides and metabolites (in particular MCPA) has started from summer 2018. This will include an initial sampling campaign of water from approximately 100 private drinking water wells to map the presence of herbicides, metabolites and nitrate in groundwater. Herbicides will also be analysed from biweekly sampling using passive samplers (Chemcatchers–Tellabs Tullow) placed in the river outlet. Additionally, a focused study site has been selected in the Ballycanew catchment for monitoring the transfer of MCPA to water *via* different pathways during storm events.

Previous studies within the Castledockerell catchment, where N is considered a risk for water pollution, have found that five year spatiotemporal mean (2010-2015) NO_3- concentrations were below the Irish drinking water standard thresholds (8.5 mg N/L) for Castledockerell catchments (McAleer et al., 2017). It was suggested that for WFD (and drinking water) objectives, targeted mitigation measures must both consider and protect denitrifying zones to reduce nitrate leaching to groundwater or losses to surface waters. McManus et al. (2017) found that pesticide and metabolite concentrations exceeded the EU drinking water parametric value of 0.1 µg/L on several occasions in the two catchments. There was an effect of subsoil geology on the occurrence of pesticides and metabolites detections with most frequent detections in sites with well drained soils underlain by gravel and limestone aquifers and within gravel lenses in lower permeability subsoil.

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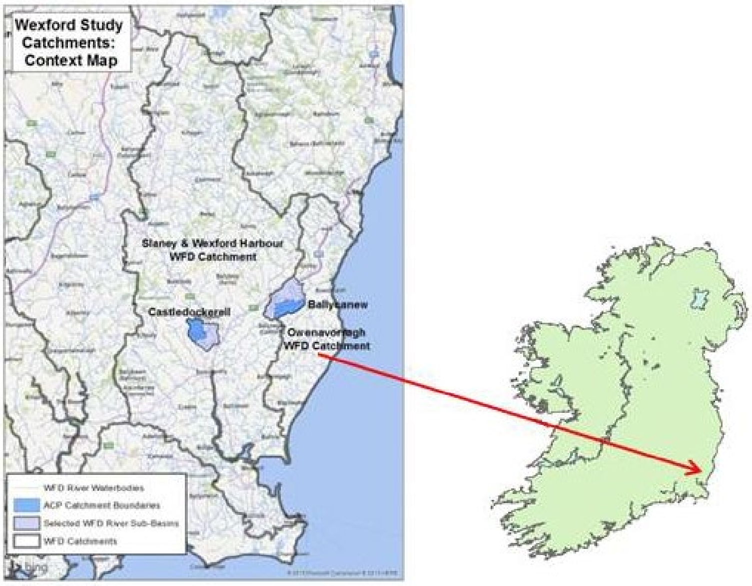

Figure 5.1. Context maps of the two study catchments Ballycanew and Castledockerell placed within the larger Water Framework Directive catchments Slaney/Wexford Harbour and Owenavoragh, County Wexford.

5.3 System description

5.3.1 Topography

The Ballycanew catchment is located just north of the village of Ballycanew, near Gorey in Co. Wexford. The catchment is 11.9 km^2 and drained by a 2nd Strahler order stream draining in an easterly direction and has an altitudinal range of 25 – 230 m a.s.l. over (Figures 5.2 and 5.3). Thirty-seven percent of the land has slopes greater than 5% (mostly within the south and south-west of the catchment).

The Castledockerell catchment is situated between Enniscorthy and Bunclody in Co. Wexford. The catchment is 11.2 km^2 and drained by a 3rd Strahler order stream in an easterly direction and has an altitudinal range of 20 – 210 m a.s.l. (Figure 5.2 and 5.3). Eighteen percent of the land has slopes greater than 5% (mostly in the north-west of the catchment).

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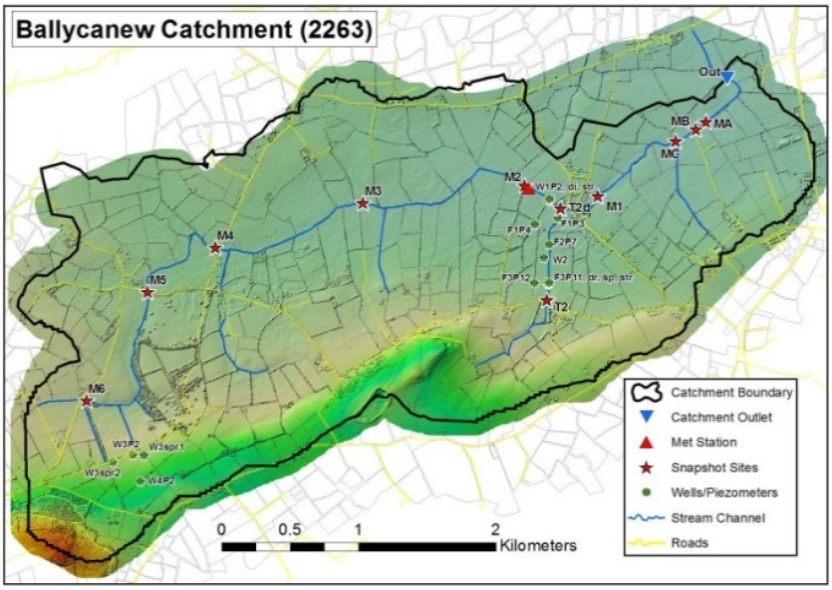

Figure 5.2. Digital elevation model of the Ballycanew catchment in County Wexford.

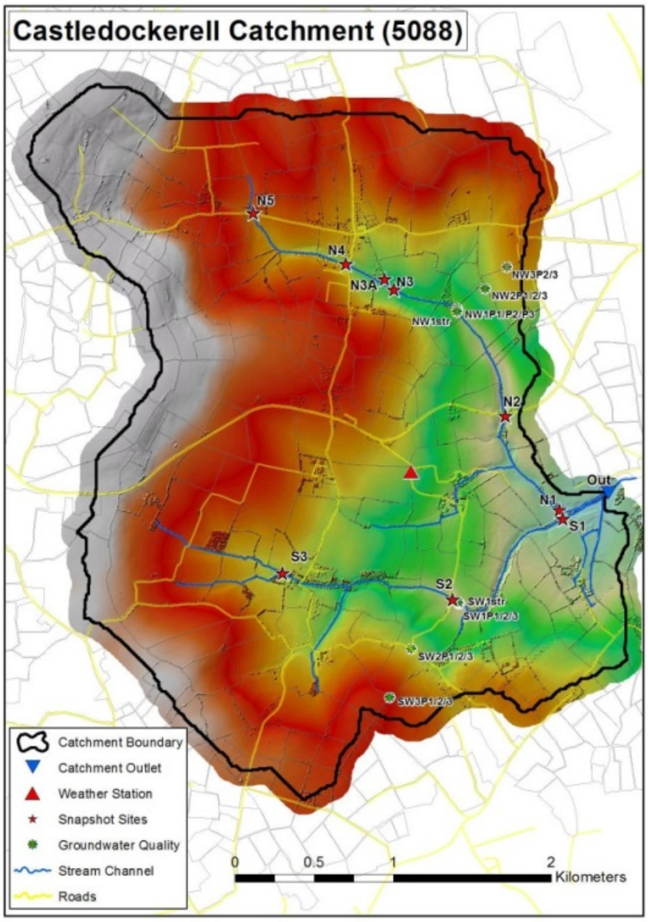

Figure 5.3. Digital elevation model of the Castledockerell catchment in County Wexford.

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5.3.2 Hydrogeology

The geology of Ballycanew catchment consists of rhyolitic volcanic and grey/black slates of the Campile formation. A number of northwest-southwest trending foldings and faults are present in the catchment. Two main soil associations are found, the Macamore and the Clonroche. The poorly drained Macamore soils are found across most of the catchment in the lowlands. These consist of thick gravelly clay deposits and some lenses of more sandy or gravelly material closer to the surface. There are some localised zones of gravel rich material. Well drained Clonroche soils are found in the uplands, southeast of the catchment. Below these is strong rock and zones of highly to moderately weathered rock. There may also be weathering of different rock types. Typically rock/weathered rock is found close to the surface. Clay-rich zones within the rock or increased amounts of weathering products may also occur. Where the two soils meet, in the break of the slope, there is a spring line. Belowground water transport pathways are likely to be concentrated through high permeability layers (i.e. gravel or weathered rock) or along the contact between different layer types.

In the Castldockerell catchment the high ground to the north-west is typically overlain by the Black Rock Mountain soil association (loamy over gneiss and schist bedrock). The bedrock is Ordovician slate and silt stone of the Oakland formation. The soils/subsoils consists of gravelly clay and gravel. The bedrock varies in strength from highly weathered rock to very strong rock. Water and contaminant transfer pathways are likely to be concentrated through the high permeability layers (i.e. gravel or weathered rock) or along the contact between different layer types. The water contribution from the unconfined aquifer is poor. However, the stratified zones of highly weathered and fissured rock connects groundwater to the river with relatively quick responses to rainfall.

5.3.3 Climate

The south-east of Ireland has a cool maritime temperate climate with an annual mean temperature of 10.6^{o}C (mean daily max 13.1^{o}C and mean daily min 8.1^{o}C) and a mean annual total rainfall of 906 mm (Met Éireann, Rosslare – Figure 5.4, 1978-2007 average).

The mean annual total rainfall monitored within the Ballycanew catchment is 1031 mm and the mean annual total potential evapotranspiration is 547 mm, leading to a net rainfall of 484 mm. The river discharge is 472 mm and the runoff coefficient is 0.46 (Oct 2010 – Oct 2017). The hydrology is "flashy" (high ratio of storm flow to base flow magnitudes) due to soil sensitivity to surface runoff and quick shifts in weather.

The mean annual total rainfall within the Castledockerell catchment is 990 mm and the mean annual total potential evapotranspiration is 548 mm, leading to an annual net rainfall of 442 mm. The annual river discharge is 497 mm and the runoff coefficient is 0.50 (2010 – 2017).

Data summaries for each catchment for the 2010-2017 period are shown in Figure 5.4.

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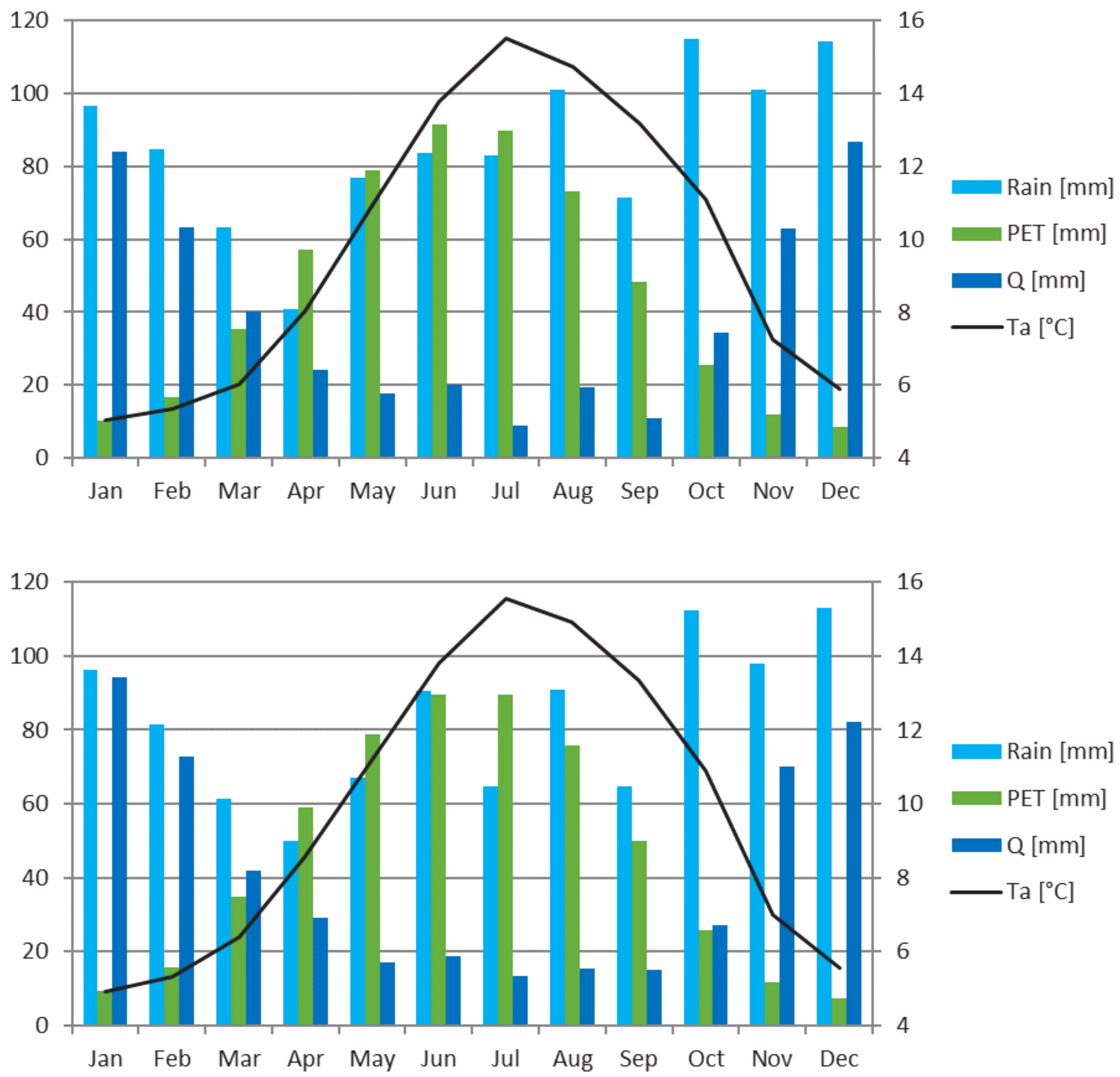

Figure 5.4. Mean monthly total rainfall, potential evapotranspiration (PET), river discharge (Q) and monthly average air temperature (Ta) of the Ballycanew catchment (top panel) and Castledockerell catchment (lower panel) in 2010-2017.

5.3.4 Soil types, land use and drainage

Approximately two thirds of the Ballycanew catchment has poorly-drained gleyic soils (both groundwater and surface water gleys) due to its location on the edge of the Macamore soil association (fine loamy over clayey calcareous Irish Sea till). One third of the catchment, on the elevated land to the southern catchment boundary, are well-drained Cambisols (Figure 5.5). Where the two soils meet, there is a spring line with numerous small springs feeding tributaries to the main stream.

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The catchment is dominated by agricultural land with 77% grassland and 20% arable land (Figure 5.5). The main farm enterprises are beef and dairying (mean livestock unit of 1.28 ha^{-1}) and spring barley as the main tillage crop. The average organic N and P loading was 88 and 13 kg ha^{-1} yr^{-1} respectively based on livestock numbers in 2014. The chemical N loading is estimated to be 132 kg ha^{-1} yr^{-1} (average 2010-2013). Herbicides, MCPA in particular, are used for weed control on the poorly drained and wet fields in the lowlands. Pesticides and herbicides are also used for crop production in the uplands.

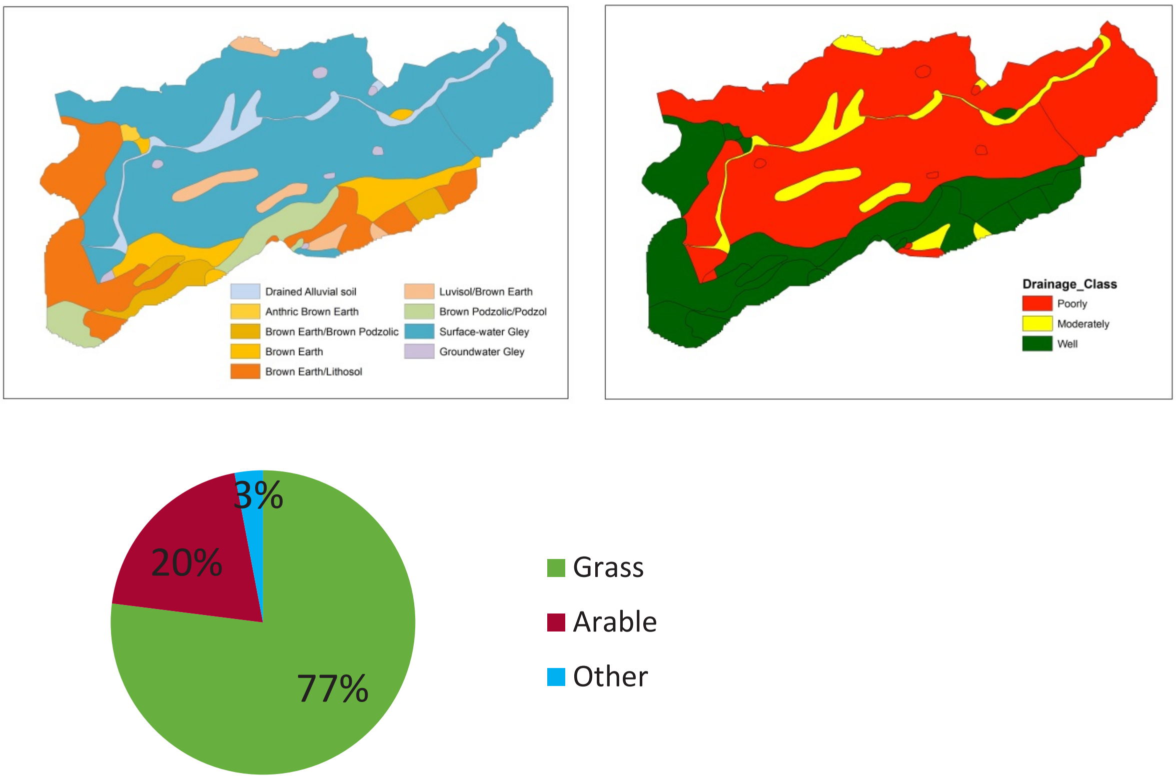

Figure 5.5. Soil types and drainage maps, and percentage of land use in the Ballycanew catchment.

Approximately 80% of the Castledockerell catchment is well-drained acid brown earth (Cambisols) due to the predominance of the Clonroche soil association (fine loamy drift with siliceous stones). The remaining 20% is poorly drained Gleysols mostly due to the River Alluvium soil association (silty) and the Kilpearce (fine loamy drift with siliceous stones) soil association adjacent to alluviums (Figure 5.6).

The catchment is dominated by agricultural land with 39% grassland and 54% arable land (Figure 5.6). The arable land is mostly used for spring barley production, while beef, sheep and some dairy production are the main grass-based enterprises. The average organic N and P loading was 34 and 5 kg ha^{-1} yr^{-1} respectively based on livestock numbers in 2014. The chemical N loading is estimated at 155 kg ha^{-1} yr^{-1} (2010-2013 average). Pesticides including herbicides and fungicides are used during crop production.

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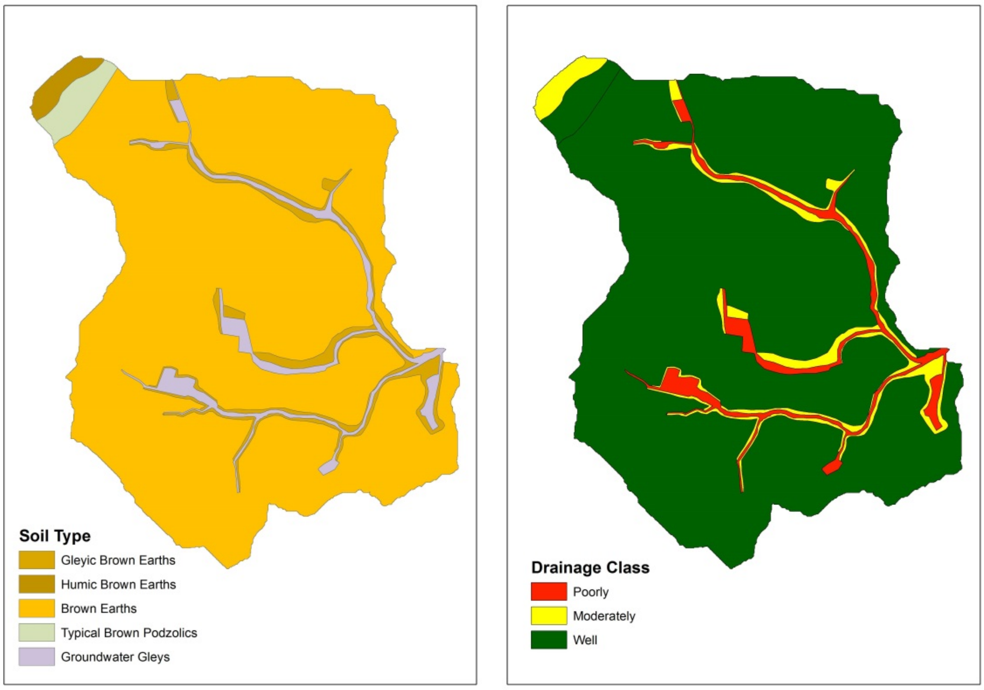

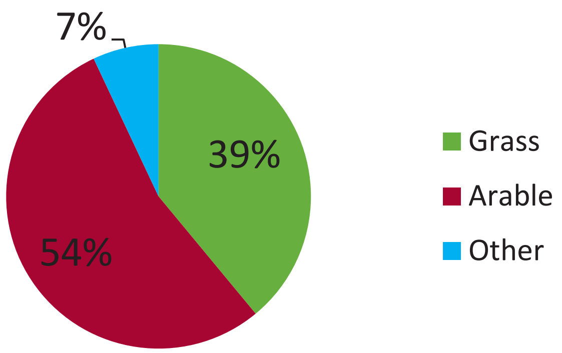

Figure 5.6. Soil types and drainage maps, and percentage of land use in the Castledockerell catchment.

5.4 Conceptual model

5.4.1 Ballycanew catchment

The transfer pathways of contaminants in the catchment are highly reflective of the distribution of the two dominant soils in the catchment. The lowland of this catchment is dominated by surface water gleys, mostly belonging to the Kilrush and Macamore soil series. These soils are derived from end-morainic and marine deposits of heavy muds giving them poor drainage characteristics. The drainage in this area has been improved somewhat by the owners through tile and mole drainage.

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The soils on the elevated land to the southern catchment boundary are well drained non calcarious brown earths over slate and shale geology.

Of the total annual rainfall 46% contributes to the river discharge and only 1% to deeper storage. In some years there is a negative storage. The flow regime is 'flashy' indicating large surface runoff contributions. The large fraction of poorly drained soils, with drainage, present in this catchment likely indicates that annual soil water storage is small.

Grassland and tillage accounts for approximately 77% and 20% of the landuse in the catchment, respectively. The remaining 3% is woodland and other uses. The main grassland-based farm enterprises are beef production and dairying with some sheep production. Spring barley is the main tillage crop with small areas of other cereals. While tillage in the catchment is limited to the southern upland area with well drained soils the dairying is expanding by drainage and nutrient management of the heavier soils.

Drinking water sources are under pressure by nutrients from inorganic/organic fertilisers as well as point sources (e.g. farmyards and DWWTS), pesticides and metabolites from weed control and crop production, and microbials and emerging organic contaminants from organic fertilisers and DWWTS. Based on the type of soil and subsoil in this catchment the main pathway for herbicide loss (mostly MCPA for weed control) would be through direct transport in lateral and vertical pathways (MCPA has a low sorption affinity with soil) and erosive overland flow during heavy rain events with a relatively short transit time. The most vulnerable time would be in spring and also autumn, after application to suppress rush (*Juncus* spp.) on grassland and during frequently occurring large rain events. Since the grasslands have been extensively improved by artificial drainage, other important quick flow pathways of MCPA to the river are via tile drains and ditches. Herbicides, and MCPA in particular, is commonly used in the area and poses a potential threat to drinking water due to its properties of being highly mobile, soluble and with a low soil sorption capacity. The soil type and structure, subsoil geology, pH of the soil, soil microbial community, soil moisture, pesticide application mode and application timing are all factors determining the fate and movement of pesticides. MCPA may also be leached to groundwater in the well-drained soils of the uplands especially where herbicide decay rates are slowed in anaerobic strata. The water recharged in the uplands, that does not emerge in springs, where the well-drained soils meet the poorly drained soils, will move in the fissured rhyolite and slate under the thick confining clay layer in the lowlands. This conceptualization was strengthened by an artesian monitoring well consisting of a piezometer screening the weathered rock below the clay layer at 12 m where pesticide metabolites have been detected (McManus et al. 2017). There is also a risk of N loss through leaching on the more freely drained soils to the west and covering approximately one third of the catchment. However, by the time water has emerged along the spring-line, or below the confining clay layer, this nitrate will be largely denitrified. While both MCPA and nitrate in the lowlands may leach to the perched shallow groundwater, on top of the clay layer, the confined groundwater is effectively protected. Contaminants in this lowland perched groundwater may slowly transfer to the river via interflow pathways after rain events have elevated the hydrological gradient, or quickly via the improved drain network.

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In summary, Ballycanew catchment has intensively managed grassland on mostly poorly drained soils. There are risks of nitrate and MCPA leaching to groundwater in the upland area with well drained soils which may be transferred to potable water in the confounded groundwater of the lowland, or discharged via springs feeding the river. Nitrate is largely denitrified along the transfer to the river. The hydrology is "flashy" with a large component of temporal quick and erosive surface pathways connecting a large proportion of land. An extensive ditch and subsurface drainage network increases the hydrological connectivity all year round. These pathways have a large potential in quickly and temporarily transferring MCPA to the river.

5.4.2 Cactledockerell catchment

The stream that drains the catchment is a tributary of the Slaney River which drains much of the south-east region. The majority of the land in the catchment has free draining typical brown earth soils, belonging to the Ballylanders and Clonroche Soil Series. These soils which are underlain by slate and shale geology are ideal for spring barley growing. In the low lying areas near the stream there are some poorly-drained groundwater gley soils most of which are artificially drained.

Of the total annual rainfall 50% contributes to the river discharge and the storage was -5%. Discharge is mostly generated by groundwater in the thick layers of highly permeable weathered slate on top of competent slate. Here, there is a consistent small surplus in the annual water balance, indicating that regional groundwater may contribute additional flow to the catchment outlet. This catchment has a higher runoff coefficient and 11% more runoff than the Ballycanew catchment owing to its considerably higher baseflow contribution.

In a typical year tillage makes up 54% of the catchment area, with 39% in grass with the remaining 7% in non-agricultural uses. The type of farming in the catchment is typical of the tillage/drystock mix that is found in much of the south-east and south of Ireland on well-drained soils. The main tillage enterprise is spring barley production with some other cereals such as winter barley as well as some oil-seed rape and potatoes. Sheep production is traditional in the area and is still carried on by many farmers as well as beef production.

Drinking water sources in the catchment are also under pressure by nutrients from inorganic/organic fertilisers as well as point sources (e.g. farmyards and DWWTS), pesticides, herbicides and metabolites mainly from the crop production, and microbials and emerging organic contaminants from organic fertilisers and DWWTS. There is a small waste water treatment plant serving up to 75 people, with the remaining catchment population (ca. 208) using domestic wastewater treatment systems. Nitrogen is the main nutrient at risk of loss from this catchment throughout the year. This is mostly via leaching in the freely drained soils and with relatively little denitrification along the transfer pathways to the groundwater and river due to high hydrological conductivity in the dominating pathways (Mellander et al. 2012; 2014). There is also a risk of MCPA loss through leaching on the freely draining soils across the catchments. The dominant flow pathways contributing to river discharge are expected to be subsurface within the layers of permeable weathered rock with a relatively low hydrological and chemical buffering capacity. Stream water dynamics and quality are

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thus highly reflective of groundwater conditions. In winter there is usually a low soil moisture deficit and large rain events will produce substantial quick surface flow pathways.

In summary, the Castledockerell catchment has intensively managed arable land underlain by well drained soils. There are risks of nitrate and MCPA leaching to potable groundwater and which may be transferred, with little attenuation, to the river. The river is mostly groundwater-driven with relatively quick belowground pathways within highly permeable layers of weathered slate bedrock. During large rain events, mostly occurring in autumn and winter, there is also a large influence of quick surface pathways connecting a large proportion of land in winter when soils are saturated.

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Action lab: Vester Hjerk (Denmark)

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6 Vester Hjerk (Denmark)

6.1 Executive summary

In Denmark the drinking water resource rely entirely on groundwater, which only undergoes simple treatment (aeration and filtration). The groundwater quality is generally high, but nitrate, primarily from agriculture praxis, poses a risk for contamination in many parts of the country. The WaterProtect action lab in Denmark is the local waterworks at Vester Hjerk, where rising nitrate concentrations have been found during the last decades, Figure 6.1, with few measurements above the drinking water standards of 50 mg/l and since 2007 the concentration have generally been above 37.5 mg/l.

Vester Hjerk is a small private waterworks on the peninsula Salling, Figure 6.2. Water is abstracted from a shallow depth in a sandy aquifer located in a buried valley. The aquifer is only partly protected by a capping clay layer. The local redox condition in the subsurface is of high importance, as nitrate is reduced only under anoxic conditions. Only sparse data are available for interpreting the subsurface redox conditions in the area. From the two abstraction wells the colour changes in the sediments indicates that change in redox conditions from oxic to anoxic conditions takes place around 7 to 18 m below terrain.

The waterworks supplies ca. 80 households in the local area, which includes a few farms that have significantly higher and variable consumption compared to the remaining ordinary households in the area. The land use is dominated by agriculture, roughly 85% of the area, and the primary source of nitrate is fertilizers and, to a less degree, manure. Point sources, such as septic tanks, may similarly contribute to nitrate pollution, as the nearby village is not connected to a central wastewater treatment plan. However, the point sources are not expected to contribute significantly to the nitrate loss to groundwater.

The local authority, Skive municipality, are responsible for developing local action plans for the waterworks. Model simulations have been used to delineate the capture zone, and thus the area in focus for mitigation measure in order to protect the groundwater resource abstracted at the waterworks. Two model version have been utilized, resulting in different capture zones, Figure 6.2. The alternative capture zones has nourished debate among local stakeholders. The uncertainty in the capture zone can partly be ascribed insufficient data, but is complicated by the complex geology in the area, where the buried valley plays a major, but uncertain, role as an aquifer. Evaluating the uncertainty of the delineation of the capture zone is thus of high priority in WaterProtect.

Existing data from the area have been collected and supplemented by new local data collected as part of WaterProtect, such as geological boreholes, geophysics, and water quality samples from groundwater, drains and streams. The data are analysed to improve the physical understanding of the area, and developed a coherent conceptual understanding of the local physiochemical system. The conceptual understanding of the system is illustrated in the sketch in Figure 6.16, while the major transport pathways and their respective importance is summarised in Table 6.3.

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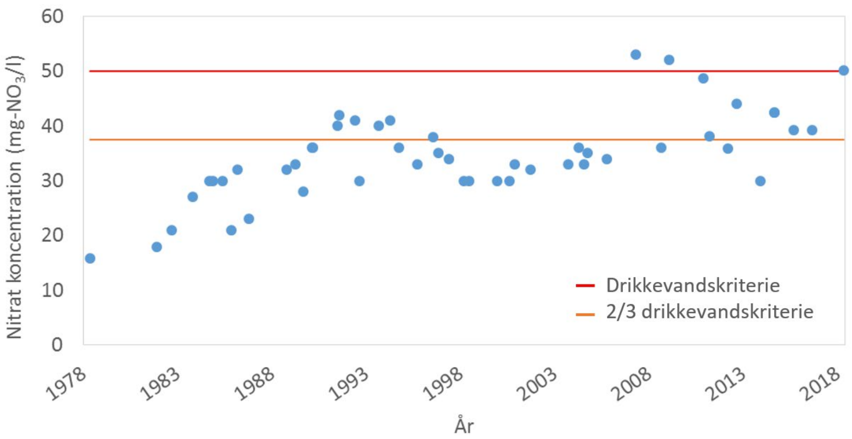
Based on the conceptual model, at detail hydrogeological and hydrological model has been constructed to simulate the nitrate transport pathways to Vester Hjerk Waterworks. Results from the model application will provide input to the collaborative tool in order to provide estimates of the efficiency of different on-field mitigation measures.

6.2 Executive summary in Danish

Den danske drikkevandsforsyning er udelukkende baseret på grundvand, som kun gennemgår en simpel vandbehandling (iltning og filtrering), inden det sendes ud til forbrugerne. Grundvandskvaliteten har generelt en høj kvalitet, men er flere steder i landet truet af stoffer såsom nitrat, som ikke fjernes ved behandlingen. Nitrat kommer hovedsageligt fra landbrugsproduktionen.

I projektet Waterprotect fokuserer vi på Vester Hjerk vandværk, hvor der er fundet stigende nitratkoncentrationer i det indvundne vand gennem de sidste årtier (Figur 6.1). Enkelte målinger overstiger drikkevandskriteriet på 50 mg/l og siden 2007 har målingerne overvejende ligget over 37.5 mg/l, hvilket er grænsen for, hvornår myndighederne er forpligtiget til at tage aktion ifølge EU's vandrammedirektiv.



Figur 6.1. Nitrat koncentration målt i det indvundne drikkevand fra Vester Hjerk vandværk.

Vester Hjerk er et lille privat vandværk på Salling (Figur 6.2), som udvinder drikkevand fra et relativt terrænnært og sårbart grundvandsmagasin, der kun er moderat beskyttet af et lerlag over magasinet. Geologien på Salling er domineret af begravede dale, som har stor betydning for grundvandsressourcens udbredelse og sårbarhed. Vester Hjerk vandværk indvinder vand fra et sandmagasin, der delvist udgøres af en begravet dal. I forhold til transport af nitrat er redox forholdene i undergrunden af stor betydning, idet nitrat omsættes under anoxiske forhold, men ikke under oxiske forhold. Der er imidlertid meget lidt data omkring redoxforholdene i området. Baseret på farveskiftet i sedimenterne rapporteret i boringsloggene til indvindingsboringerne, er redoxgrænsen, hvor forholdene ændrer sig fra oxiske til anoxiske, placeret 7 til 18 m.u.t.

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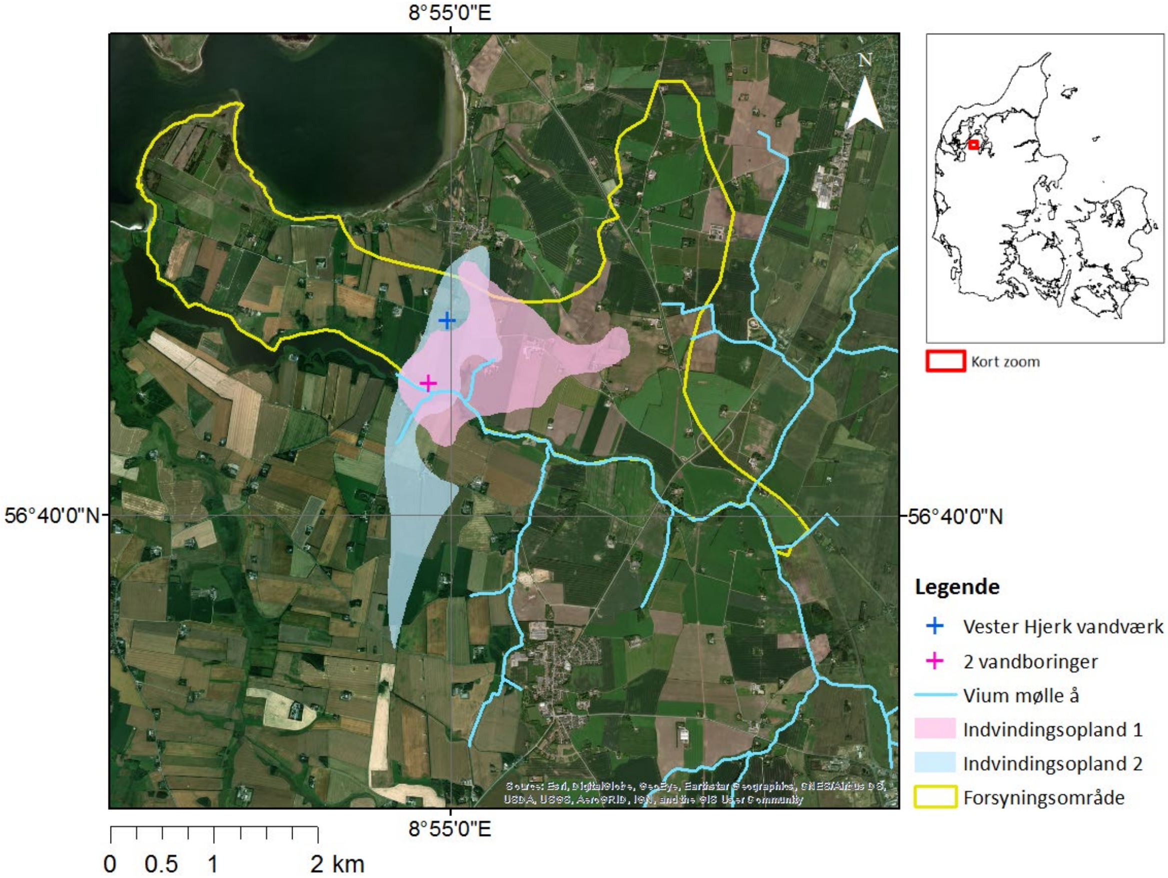
Vandværket forsyner omkring 80 husholdninger, hvoraf størstedelen er almindelige husholdninger, men området omfatter også store landbrugsejendomme, der har et væsentligt større og varierende forbrug. Den primære kilde til nitrat i drikkevandet er brug af gødning, eftersom den dominerende arealanvendelse er intensivt landbrug, svarende til 85% af forsyningsområdet til Vester Hjerk vandværk. Punktkilder (f.eks. septik tanke) kan også have indflydelse på nitratbelastningen, men de betragtes som værende af mindre betydning end den diffuse forurening fra landbruget.



Figur 6.2. Kort over området omkring Vester Hjerk vandværk og de beregnede indvindingsoplande.

I forbindelse med Skive Kommunes indsatsplaner er der præsenteret to forskellige indvindingsoplande for Vester Hjerk vandværk (Figur 6.2). Da afgrænsningen af indvindingsoplandet er bestemmende for, hvor myndighederne vil målrette deres indsats for grundvandsbeskyttelse, har dette vakt debat ifm. den offentlige høring af indsatsplanen. Usikkerheden omkring indvindingsoplandet til vandværket kan delvis tilskrives manglende data og kompliceres yderligere af de lokale geologiske forhold, hvor de begravede dale spiller en afgørende rolle for korrekt kortlægning af grundvandsressourcen. Det er derfor af høj prioritet i WaterProtect, at forsøge at klarlægge placeringen af indvindingsoplandet og usikkerheden forbundet med dette.

For at forstå de fysiske forhold, er der indsamlet mest mulig viden om området, hvilket bl.a. inkluderer nationale data i form af undersøgelser af undergrundens geologiske opbygning samt målinger af nitratkoncentrationen under marken og i dræn, grundvand og vandløb. I projektet

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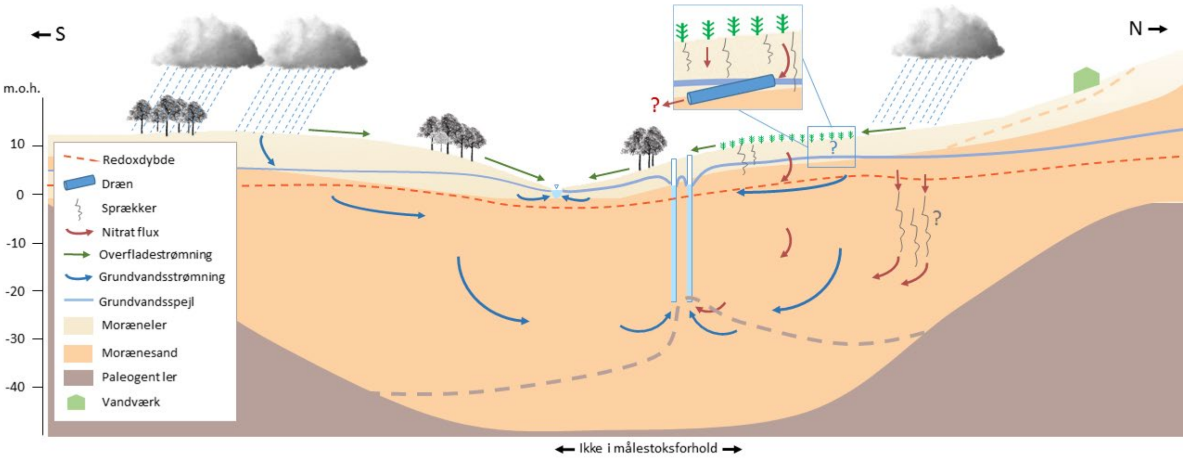
WaterProtect er der indsamlet data i felten; geofysiske målinger og gammalog af boringer til kortlægning af undergrundens geologiske opbygning samt udtagelse af grundvandsprøver. Disse data er efterfølgende blevet brugt til at forbedre den konceptuelle forståelse af området, som illustreret i Figur 6.3. Spørgsmålstegn og stiplede linjer indikerer centrale områder med høj usikkerhed. Figuren viser en simpel geologisk skitse i en profil langs med boringerne og vandværket, samt strømningsveje for vand og hvad der forventes at være de dominerende transportveje for nitrat.



Figur 6.3. Konceptuel model for området omkring Vester Hjerk vandværk.

Disse transportveje er opsummeret i Tabel 4.1**Fejl! Henvisningskilde ikke fundet.**. Den dominerende transportvej til drikkevandsboringerne antages at være via vand, der infiltrerer fra rodzonen udenom drænene, og dermed ender i grundvandet.

Tabel 4.1. Transportveje og omsætning af nitrat og deres relative betydning for Vester Hjerk vandværk.

Transportvej	**Relative betydning**	**Nitratomsætning**	**Vigtighed**
Overfladestrømning	Generelt lille, men kan være betydende under ekstreme nedbørshændelser.	Ingen omsætning/reduktion finder sted.	Generelt lav. Kun vigtig under ekstreme nedbørshændelser og hvis nitraten transporteres til en utæt boring.
Preferential flow gennem sprækker I de øvre jordlag	Størrelsen afhænger af klimavariabilitet og jordtype. Antages ikke at	Ingen eller kun meget begrænset omsætning/reduktion finder sted.	Antages ikke at være en vigtig faktor under evaluering af langtidseffekter.

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	have betydning på lang sigt.		
Dræning	Afhængigt af dræningsintensiteten forventes mellem ca. 10 og 70% af det infiltrerede vand at kunne transporteres via dræn direkte til overfladevandssystemet.	Lokalt kan dele af nitraten blive reduceret, men overvejende vil der ikke ske omsætning af nitrat.	Meget vigtigt. Pålidelig information om dræningsforholdene i området er en forudsætning for at vurdere nitratbelastningen til overfladevand og grundvand, og data skal indsamles fra de lokale landmænd.
Grundvandsstrømning	Infiltreret vand, der ikke løber i dræn, vil generere grundvand.	Afhænger af redoxforholdene.	Meget vigtig. Grundvandets strømning er afgørende for, hvor vandet der indvindes fra boringerne oprindeligt kommer fra, og dermed hvor på landjorden at grundvandsbeskyttelse er påkrævet.

På baggrund af den konceptuelle model er der opstillet en detaljeret hydrologisk model til at simulere grundvandets strømning med særlig fokus på Vester Hjerk. Modellen er lavet med henblik på at kunne udvikle løsninger og værktøjer til at sikre drikkevandet i Vester Hjerk og mere generelt i områder med moderne landbrugsproduktion.

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6.3 General description

Drinking water supply in Denmark is purely based on groundwater (99%) treated only through aeration and filtration. The widespread availability of high-quality groundwater allows for a very decentralised supply system meaning that the drinking water typically is produced at local waterworks. The 2600 water companies in Denmark have very different sizes, the biggest supplying up to several hundred thousand people and the smallest down to 10 households. 97% of the water companies in Denmark are privately owned, mainly by the consumers, and they account for about 1/3 of the total drinking water production (Miljøstyrelsen, u.d.). The small waterworks often abstract groundwater from shallow aquifers, which are more susceptible to pollution.

The Danish action lab forms a microcosm of groundwater problems in Denmark. Vester Hjerk waterworks is located on the Salling Peninsula in the north-western part of Denmark in the municipality of Skive (Figure 6.4). It is privately owned by the consumers and it supplies water for approximately 80 households with an abstraction license of 35,000 m^3/year. The waterworks does not have a tank for storage of clean water to buffer the peak hours, but has to produce water as it is needed by the consumers. Most of the water is supplied to ordinary households, for which 100 m^3/year is the average use in Denmark, but the area also includes farms, where the water consumption is significantly higher and varies throughout the day.

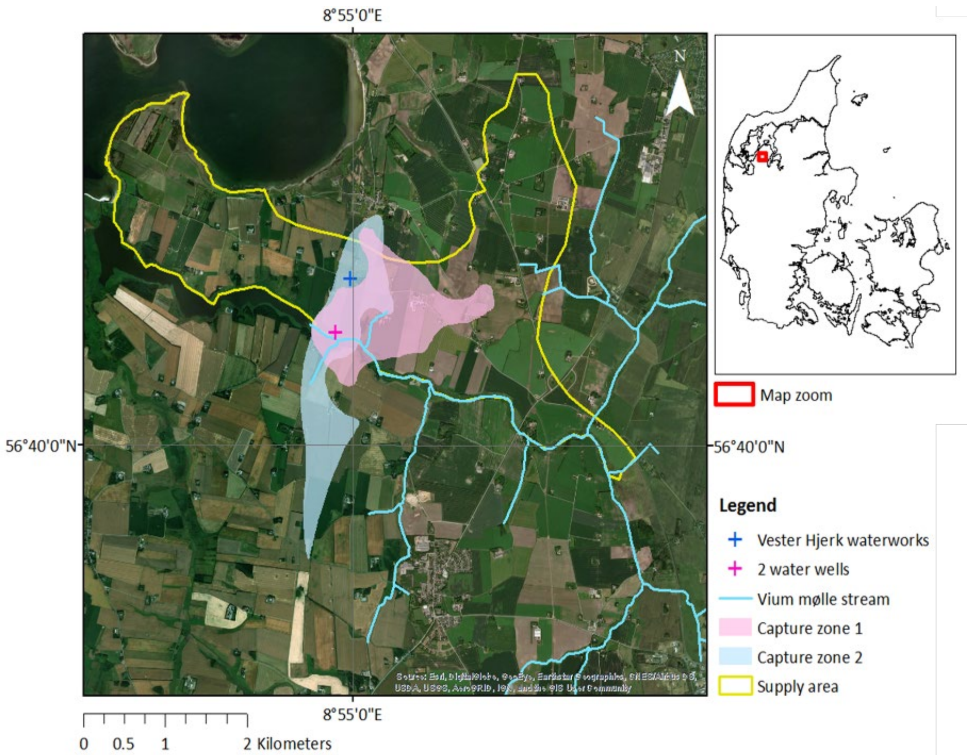

Figure 6.4. Location of Vester Hjerk action lab, with delineation of the water supply area and the two capture zones.

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Groundwater is abstracted from two wells with a filter depth of 24-30 m.u.t. The two abstraction wells are screened in a shallow sandy aquifer, which is only moderately protected by a capping clay layer. Since the 1980's the nitrate concentration in the drinking water has been steadily increasing (Figure 6.5). In recent years, the nitrate concentration has exceeded 50 mg NO_3^-/l in a few samples and in the past 10 years it has generally been above 37.5 mg NO_3^-/l, which is the limit at which actions must be taken according to the Water Framework Directive (WFD).

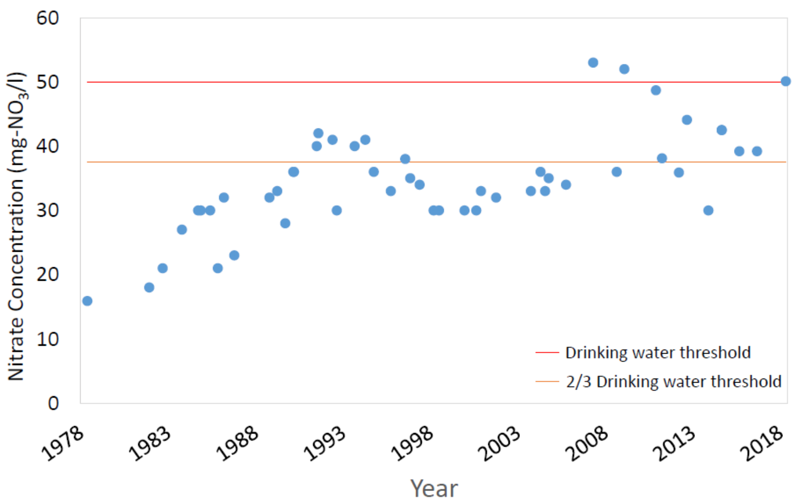

Figure 6.5. Development in nitrate concentration at Vester Hjerk waterworks (all samples).

In the case of Vester Hjerk waterworks, nitrate from fertilizers is the main concern in relation to drinking water as the dominating land use is intensively managed agriculture. Point sources (e.g. septic tanks) may also influence nitrate loads, however they are considered less important than the diffuse pollution. With the intensive agricultural praxis in the area, both nitrate and pesticides pose a potential risk in, however, pesticides and metabolites have not been detected in the wells. Furthermore, the catchment includes a local stream, Vium Mølle Å (Figure 6.4), which discharges to an estuary and bay that is vulnerable towards nutrients, and the surface water quality therefore cannot be disregarded.

Skive municipality is responsible for designing and enforcing local action plans for the protection of the drinking water. By June 2018 the action plan was approved after a hearing process, where all stakeholders were invited to comment on the plan. The plan describes that if the waterworks is to be maintained, there is a need for reducing the nitrate leaching from the root zone to maximum 37.5 mg NO_3^-/l as a mean for the capture zone for the waterworks, and for avoiding the usage of pesticides on agricultural land. In an area of 50 m around the wells use of pesticides and fertilizers/manure is banned, which is part of the general national drinking water protection strategy and imposed on all wells used for drinking water production.

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6.4 Previous investigations

In the Danish national groundwater mapping programme from 1999 to 2015 approx. 40% of the country has been studied with focus on evaluating groundwater vulnerability towards nitrate. Areas identified as areas of special drinking water interest (OSD) and capture zones to existing waterworks have been included in the study. As part of the groundwater mapping programme, a groundwater model has been developed for the entire Salling Peninsula. The first version was developed in 2010 and used to delineate the capture zone for the waterworks (capture zone 2 in Figure 6.4). The model was extended in 2013 by inclusion of four local models developed for four major waterworks on Salling. Utilising the updated model resulted in the delineation of capture zone 1 in Figure 6.4. The origin of the water abstracted is thus uncertain, which poses a major challenge in designing a local protection plan that can be accepted by all actors.

The study carried out in the national groundwater mapping programme included several new geophysical surveys. However, Vester Hjerk is a minor waterworks and not located in the centre of Salling, and the data colletion in the area is thus less dense. The uncertainty in the capture zone can thus to a large extent be attributed to the limited knowledge of the geological structure and the hydrogeological properties in the vicinity of Vester Hjerk waterworks.

Water quality data are collected in the area by two actors: 1) the waterworks and 2) the state. The monitoring programme by the waterworks is defined in the national legislation with respect to substances included and sampling frequencies. In the standard monitoring programme, water quality is measured in tap water at selected households and in the abstraction wells at the waterworks. The waterworks may supplement the monitoring by installing additional monitoring wells, but this option is normally only used in the case of risk of contamination from point sources and not in the case of diffuse sources, such as pesticides and nitrate from agricultural practice, and no such supplemental monitoring exists in the area. The state is responsible for water quality monitoring of surface- and groundwater at the national level as part of the Danish National Monitoring and Assessment Programme for the Aquatic and Terrestrial Environment (NOVANA). The monitoring is designed to fulfil the monitoring requirements in the EU WFD, i.e. provide knowledge at the level of water bodies or group of water bodies. The national monitoring programme does not include groundwater sampling points in the local area, but a surface water monitoring station is installed in the local stream.

There has not been additional local data collection or surveys in the area until present research project, but many general data and maps have been collected and developed at national scale and are thus accessible for Vester Hjerk. These data are described further in the next section.

6.5 System description

In Vester Hjerk, the current threat to groundwater quality is nitrate from agricultural praxis, i.e. a diffuse source. In the present section the existing data relevant to the transport and fate of nitrate in the action lab is presented and discussed.

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6.5.1 Topography

The Salling Peninsula is characterized by relatively irregular, moderately hilly terrain from 0 and up to 50 m.a.t. Throughout time the landscape has been dominated by erosion and seabed formations. Since the last ice age, the landscape has been broken up into a number of smaller areas by late and postglacial erosion that has led to the formation of many and relatively large erosion valleys and ravines. These valleys and gorges often provide a sharp border to low-lying and flat areas, which is the case around Vester Hjerk (Figure 6.6) where the hills have an East-West orientation (Grontmij , 2010).

With an elevation level of 44 m, a local topographical divide is found approximately 1.4 km north of the abstraction wells sloping evenly down to 8.5 m, where the wells are located. To the south of the wells is a steep drop in the elevation down to 2 m in the bottom of the stream valley, where Vium Mølle stream is situated.

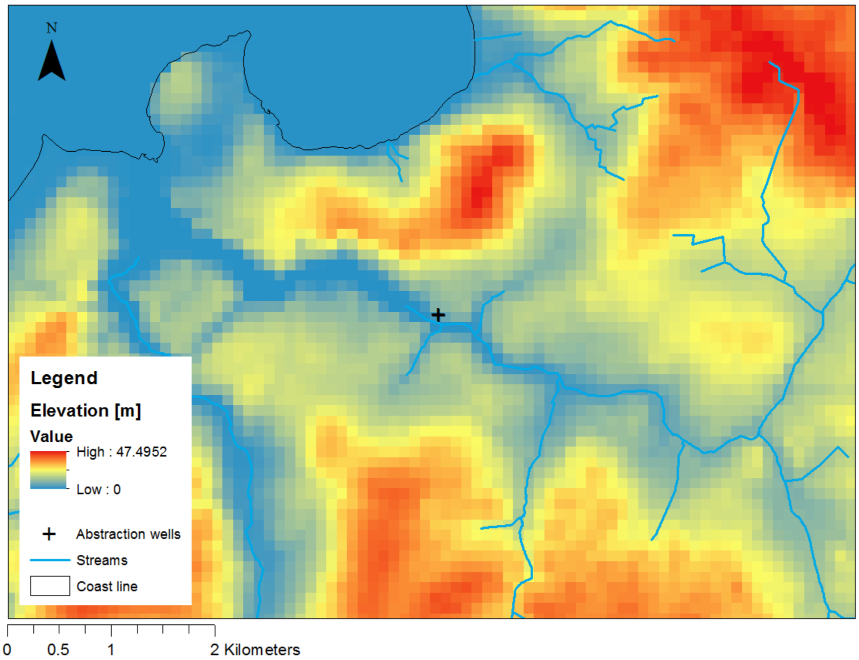

Figure 6.6 Topographical map of area surrounding Vester Hjerk.

6.5.2 Hydrogeology

The conceptual geological model for the Salling Peninsula is developed based on well logs from the national JUPITER database, maintained by the geological survey GEUS, and TEM (Transient Electro-Magnetic) soundings. The JUPITER database contains information about the geological profiles and groundwater chemistry amongst other things, yet the data quality and the level of detail varies considerably. As can be seen from Figure 6.7, the well log data is rather dense on Salling as is the case for the entire country. However, in the vicinity of the abstractions wells of Vester Hjerk there are only few well logs available to interpret the local geology. The TEM dataset is rather unique for

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Denmark and it is of major importance for mapping the subsurface and groundwater aquifers in an area like Salling, which is dominated by heterogeneous systems of buried valleys that cannot be mapped based merely on point measurements.

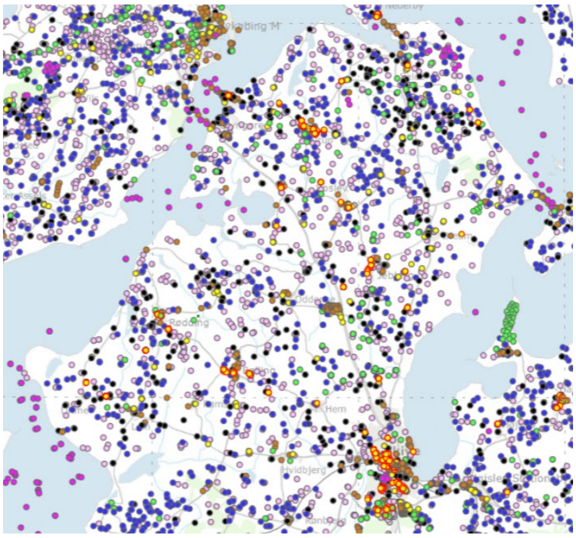

Figure 6.7 Wells on the Salling Peninsula from the JUPITER database (GEUS, u.d.).

The tertiary deposits on Salling are composed of calcite overlaid by mica, silt, sand, and clay with low permeability. The tertiary deposits are generally found close to the surface on Salling, but with large spatial variation. Aquifers used for drinking water are primarily found in the Quaternary deposits on top of the tertiary units.

The shallow subsurface of the Salling Peninsula is highly dominated by the occurrence of buried valleys formed below the ice by erosion of the tertiary deposits by meltwater flow (Rambøll , 2004). The buried valleys have subsequently been filled by quaternary deposits primarily composed of sand, coarse silt and sand. The buried valleys form complex networks, where some act as groundwater reservoirs while others constitute barriers for groundwater flow depending on the in-filled sediments. The heterogeneity of the subsurface caused by buried valleys is crucial for assessing aquifer extent and vulnerability as the deeper aquifers of drinking water interest are often found in these formations (Grontmij , 2010). Above the buried valleys aquitards are found between the aquifers, but in many cases, especially in connection with the buried valleys, there is direct hydraulic contact between the aquifers (Grontmij , 2010).

The upper part of the moraine till/clay are often associated with fractures due to tectonic activities, pressure during the glaciation or shrink/swelling. This may create preferential flow paths from the surface to the groundwater.

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Vester Hjerk waterworks abstracts water from a sandy aquifer which is partly located in a buried valley, and found only 10-15 m below terrain. In the buried valley the thickness of the aquifer is relatively thick (20-30 m) but with limited horizontal extent.

6.5.3 Climate

The climate on the Salling Peninsula is typical for the North-Western part of Denmark. The mean precipitation at Vester Hjerk in the period 1990 to 2016 was 962 mm, which is around 20% higher than the national average of 792 mm. It varies between 631 and 1175 mm with the highest amount recorded in 2015 (Figure 6.8).

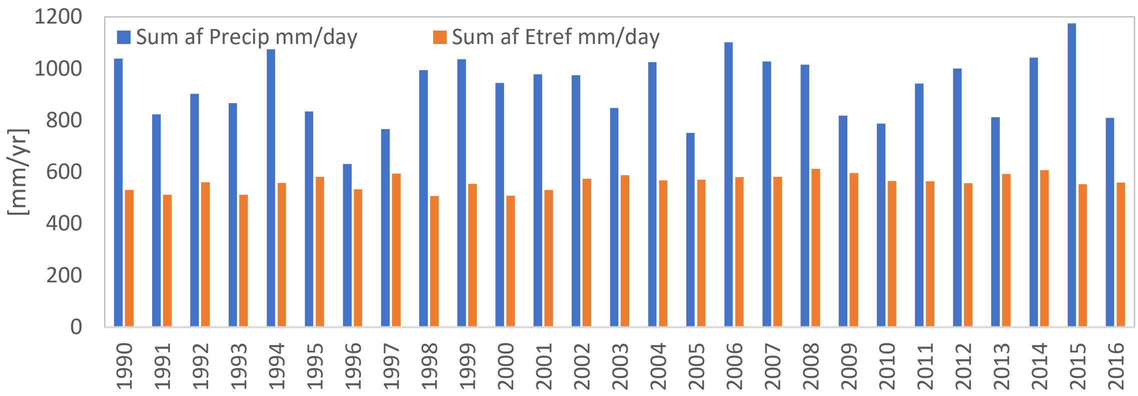

Figure 6.8 Total annual precipitation and reference evapotranspiration for Vester Hjerk 1990-2016. The numbers are derived from DMI's 10km precipitation grid.

The driest months are March to May and the wettest months are August-January (Figure 6.9). The seasonality in precipitation is not outstanding as there is a substantial amount of rainfall throughout the entire year with an average minimum of 53 mm in April and an average maximum of 109 mm in October. However, there is a strong seasonality in evapotranspiration and thereby in net precipitation. From August to March there is a positive net precipitation meaning that on average groundwater recharge occurs during these months. The actual amount of groundwater recharge depends on how much of the net precipitation discharges to surface waters either through surface runoff or via drains. During April to July, evapotranspiration exceeds precipitation (on average) i.e. negative net precipitation which results in low flow in streams and no net groundwater recharge.

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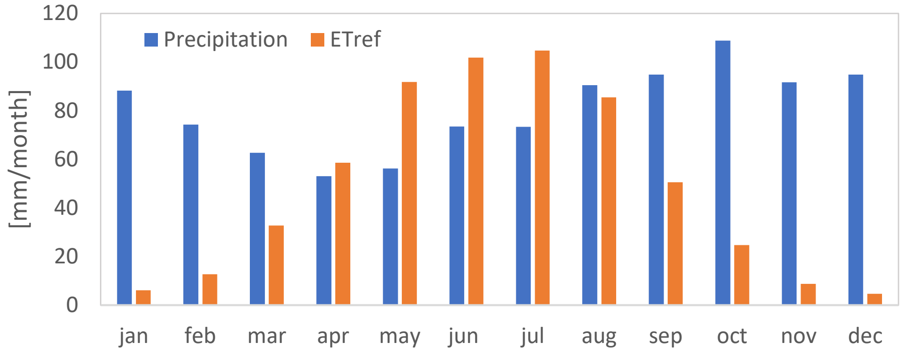

Figure 6.9 Mean monthly precipitation from 1990 to 2016. The numbers are derived from DMI's 10km precipitation grid.

6.5.4 Soil types, Land use and drainage

As illustrated in Figure 6.10 the dominating soil type on the Salling Peninsula is moraine clay followed by meltwater sand and gravel. Freshwater formations are found around the streams, like Vium mølle å. The high clay content in the soil makes the area well suited for agriculture.

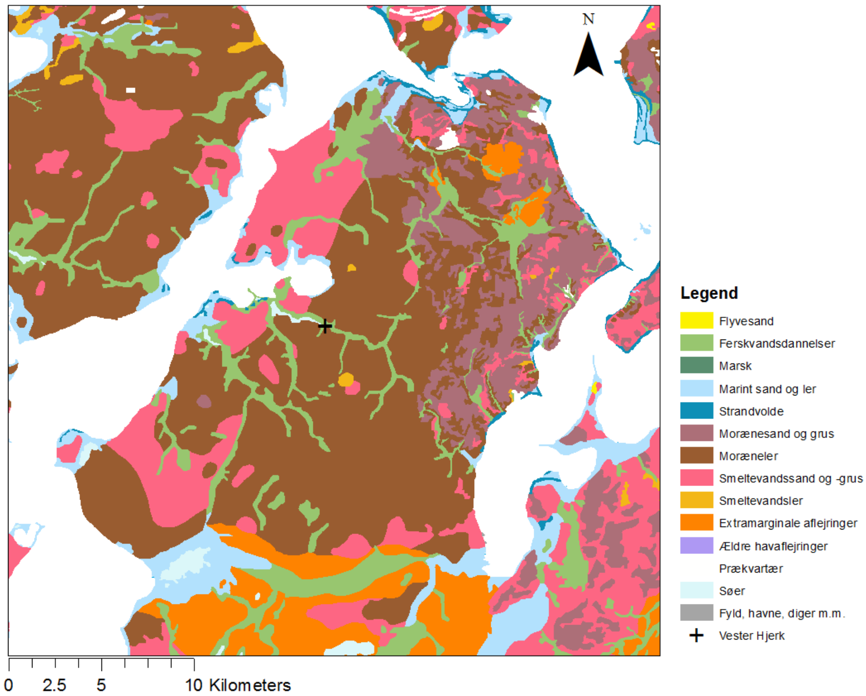

Figure 6.10 Soil types on the Salling Peninsula.

With a total of 800ha, intensively managed agriculture is the dominating land use covering approx. 85% of Vester Hjerk supply area. Within the expected capture zone (zone 1 in Figure 6.4), the land is managed by 27 different farms, who manages a total of 5954ha on the peninsula with an average

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farm size of 220 ha. Twelve of the farms are located within the water supply area. Three of these are full-time farms (one dairy, one beef calves and one plant production farm), whereas 9 farms are hobby farms. The main agricultural activity in the areas is cereal production, Figure 6.11, by conventional farming and livestock. Manure from the livestock comprise a substantial part of the N-application, but is supplemented by fertilizers. A large share of the crops produced in the area is used for fodder. Smaller areas are used for special productions like potatoes, seeds and Christmas trees.

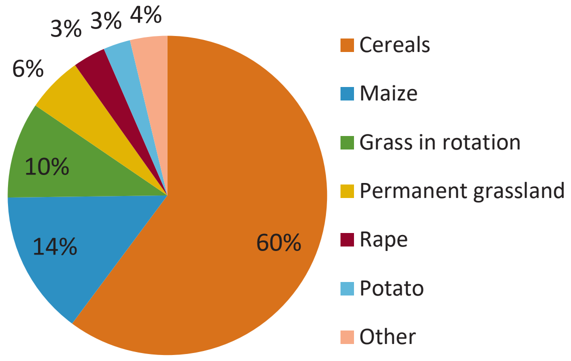

Figure 6.11. Crop production in the area of Vester Hjerk waterworks.

Clayey till is a common soil type in Denmark, which is often combined with a groundwater table located close to the surface. Artificial drainage is used to optimise plant production, and approximately 50% of the agricultural land is drained either by systematic drainage of the entire field or sporadic drainage in low-lying areas. With moraine clay/till being the dominating soil type at the action lab, it is expected that drainage is common. Drainage outlets have been identified at the site, but no complete information of the location and intensity of drainage networks exists at national scale. The local drainage thus has to be identified in collaboration with the local farmers.

6.5.5 Redox conditions

Nitrate is subject to denitrification under anoxic conditions, and the redox potential in the subsurface is thus crucial in determining whether nitrate is transported from the root zone to the groundwater aquifers, or the surface water system, or is removed during transport. At national scale approximately 70% of the nitrate leaving the root zone is degraded naturally in the environment, but with large spatial variations depending on the local redox conditions and transport pathways. Data on the redox conditions in the area are rather limited. Based on colour change of the sediments reported in the borehole logs from the abstractions wells, the redox interface, where conditions changes from oxic to anoxic condition, is located between 7 and 18 m.u.t. Figure 6.12 shows the best estimate of depth to the redox interface, based on a newly developed method using observational data and multiple covariates in machine learning (Random Forest). According to this dataset, the redox interface is found close to the surface in the vicinity of the streams, while it is found primarily between 4 and 6m in the other areas, but with depth down to more than seven meter. The location

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of the interface is, however, a very uncertain parameter, and the developed method also provides an estimate of the uncertainty of depth to the redox interface.

Elevated sulphate concentrations have been observed in water samples from the waterworks, which may indicate that the redox capacity is being used up. If this happens, no degradation of nitrate will take place in the groundwater, and nitrate leaving the root zone will be transported to the waterworks intake. However, this interpretation is carried out on sparse and ambiguous data.

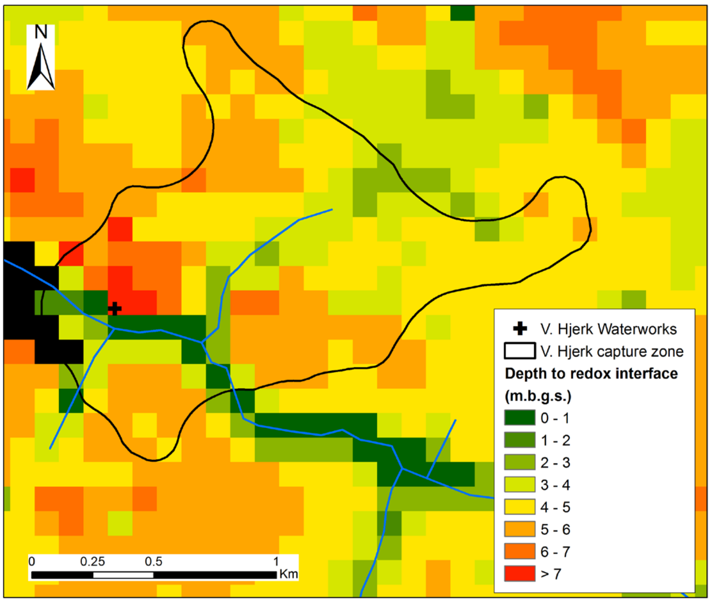

Figure 6.12 Depth to redox interface in the vicinity of Vester hjerk waterworks (Koch, et al., 2018).

6.6 Conceptual model

6.6.1 Landscape Analysis

The case area of Vester Hjerk is a typical example of the landscapes of the Salling peninsula where it is located, dominated by a pattern of undulating morainic flats and low hills with loamy soils intersected by erosion valleys with organic soils (see Table 6.2 and the land use map in Figure 6.13). Considered in a regional context the Salling area has relatively good growing conditions with easily tilled, fertile loamy soils. To the south of Salling the landscape shifts to being dominated by a combination of extramarginal deposits and hummocky morainic landforms intersected by meltwater valleys exhibiting relatively poor and highly varying conditions for agriculture. To the North and North West across the fjord, soils become increasingly sandy approaching the North Sea.

The land use system in Salling has been adapted historically to the relatively good conditions for agriculture and as such Salling is characterized by landscapes which were traditionally structured at

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a smaller scale and with a higher intensity of agricultural land use than neighboring areas located further to the south and north. The density of farms and villages is relatively high, fields are slightly smaller than average and most are used in various patterns of rotational land use, leaving relatively few areas with permanent crops and a smaller percentage of areas outside of agricultural use than average both for the region and for Denmark as a whole. The regional land use context of the case area on the peninsula of Salling is shown in Figure 6.13. Figure 6.14 contains a detailed land use map of the case area. In Figure 6.14 the primary geo-ecological gradients of the local agricultural land use system are visible, indicated by the relative distribution of fields in rotation placed on higher, well drained loamy soils and areas of permanent crops (grasslands mostly) located mostly on lower lying flats along the coastal margin and in the valleys.

In an international context the landscapes of Salling can be described as former open field landscapes, characterized by a landscape structure formed through the enclosure of a combination of single farms and village holdings in the period between 1790 and 1840. Please see Meeus (1995) for a discussion of the European context.

Current agricultural land use is dominated by rain fed rotational production of annual crops on fields drained with closed pipe drains. The most important crops are grains, rapeseed and various fodder crops including maize, but in general the variation of crops used is relatively high considered in a Danish context. A large part of the crops grown are used for fodder, a substantial part of which goes into the pig breeding industry. Fertilizer inputs for most crops are in most cases high, approaching production optimum.

Table 6.2 Soil types in Vester Hjerk and the surrounding landscape of Salling

Topsoil type *	Salling Peninsula	Extraction area	Supply area
1 - Coarse sand	6,6	0,0	10,0
2 - Fine sand	1,9	0,0	0,0
3 - Coarse loamy sand	3,6	0,4	5,8
4 - Fine loamy sand	56,3	34,9	47,7
5 - Coarse sandy clay	0,3	0,2	0,2
6 - Fine sandy clay	21,3	58,5	32,5
7 - Clay	1,0	0,0	0,0
11- Organic soil	7,3	6,0	3,1
0 - No soil data	1,6	0,0	0,8
Total area (ha.)	48442	174	992

** See Greve et al. (2007) and Greve (2015) for details regarding the dataset and classification key used*

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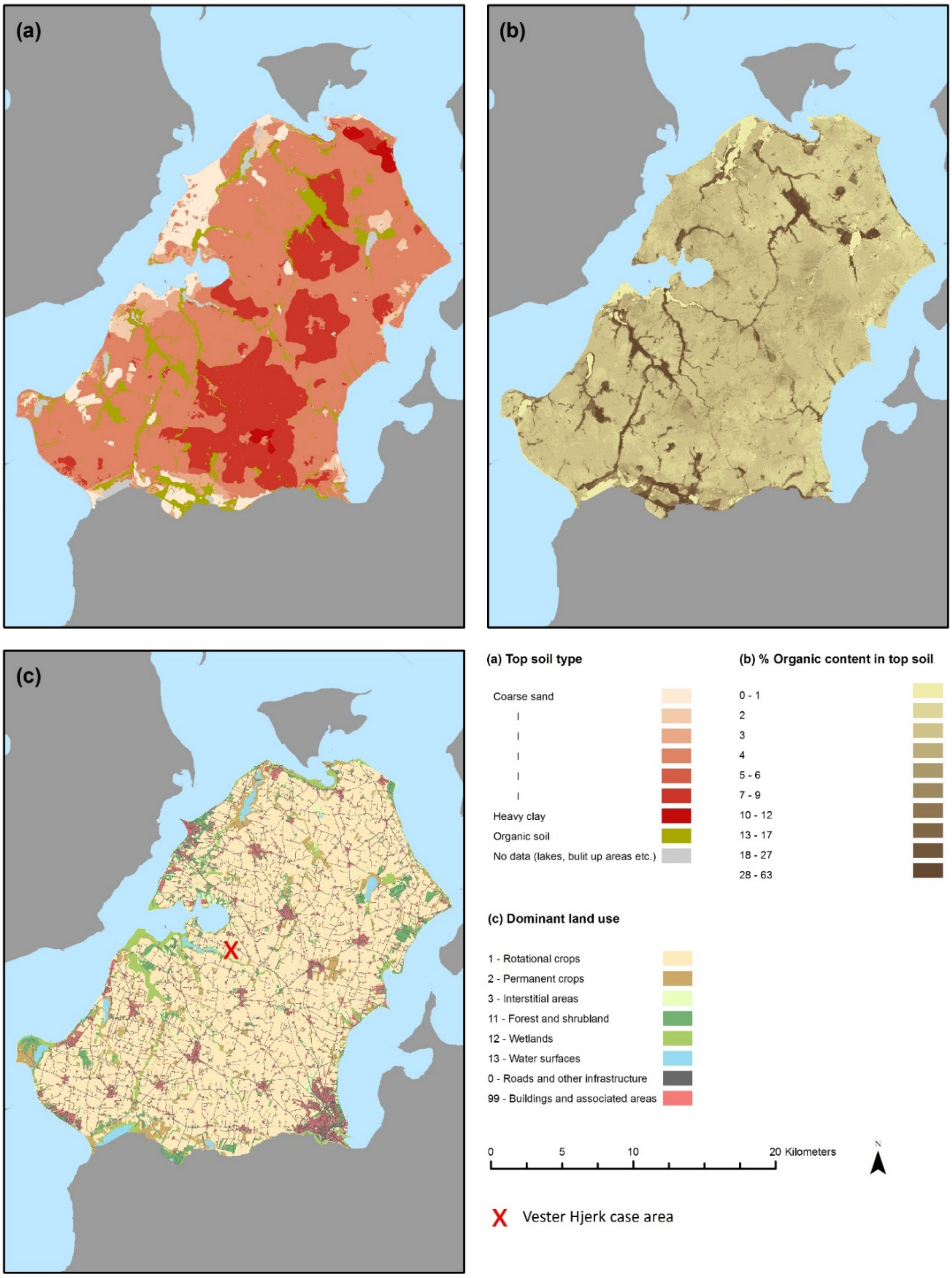

Figure 6.13 The regional context of the case area, located on the peninsula of Salling protruding North into the Limfjorden fjord in Northern Jutland.

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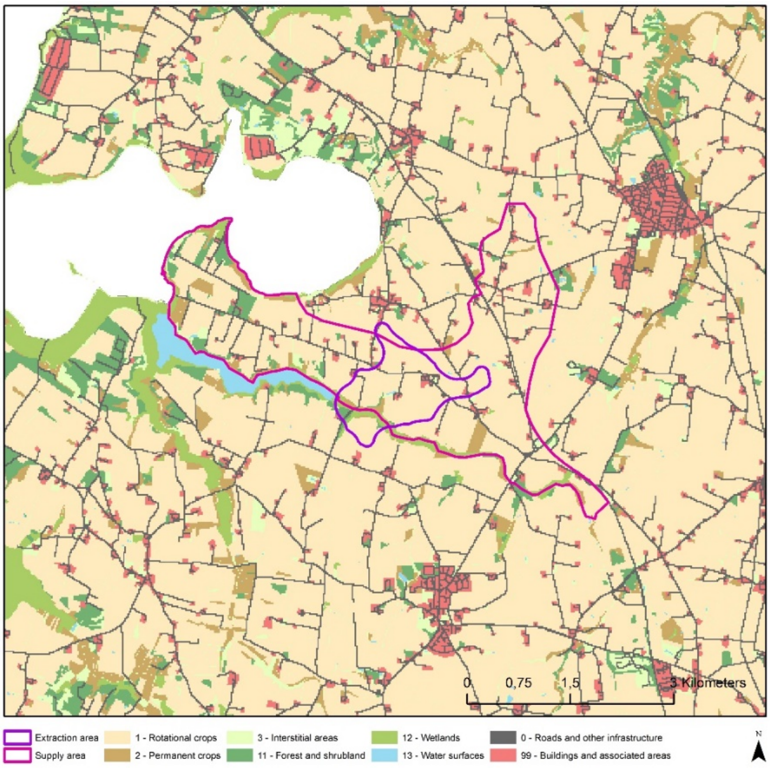

Figure 6.14 Land use in and around the case area in 2017. Land use data has been sourced from Christensen et al. (2017) and is represented in a 20x20 meter grid.

Figure 6.15 The landscape within the extraction area of Vester Hjerk.

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6.6.2 Nitrate transport pathways

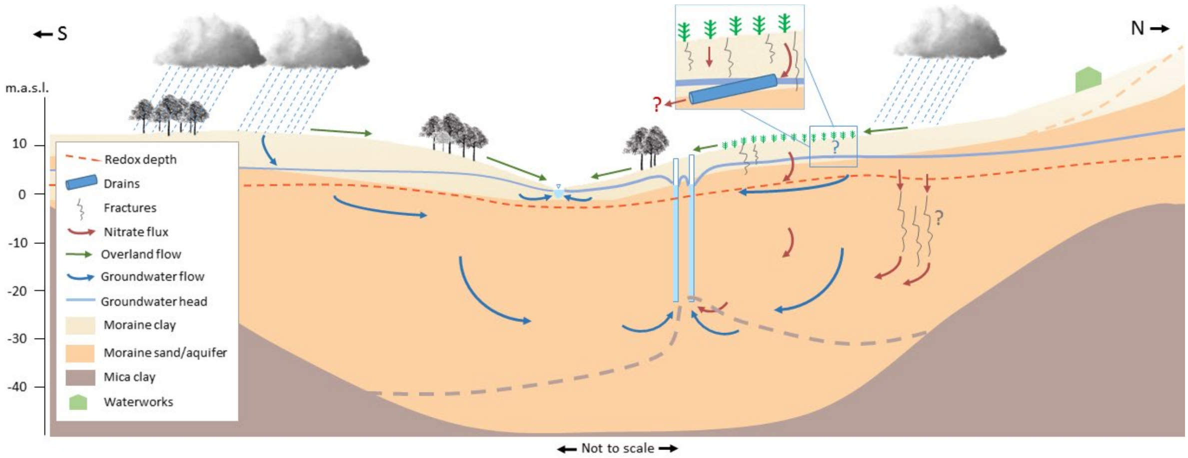

Figure 6.16. Schematic cross-section of the action lab indicating the most important transport pathways at the site. Dotted lines and questions marks indicate important areas of uncertainty.

In Figure 6.16 a schematic cross-section of the action lab at the location of the abstraction wells is shown. The location of the cross section is shown in Figure 6.17. Figure 6.16 illustrates the present understanding of the hydrogeological system and the pathways assumed to be the most important in relation to nitrate transport. The questions marks and dotted lines indicate important areas of uncertainty.

In the action lab, the terrain is sloping gently from north to south towards the wells and overland flow may be generated and possibly bring nitrate from the field to the wells. Generation of overland flow is generally limited and restricted to extreme precipitation events, and overland flow is expected to play a minor role in the hydrological system when considering the total volume of water. However, high nitrate concentrations have been found historically in one of the wells, which was ascribed to overland flow from the field entering the well through a leaky casing. The well has been renovated, followed by a decrease in nitrate concentration.

The fractures in the moraine till/clay (described in Section 6.4.2) may generate preferential flow paths and thereby alter the natural transport pathways in the matrix of the soil. The presence of drains may enhance the occurrence of fractures, due to the drying of the soil when water is removed by the drainage system. In later heavy precipitation events water may flow horizontal to the fractures and then vertically to the drains. In areas with no drains fractures may similarly affect the shallow transport pathways by fast vertical movement, if the fractures penetrates the entire thickness of the clay layer. Fractures are most often characterised by oxic conditions, and no or only limited denitrification of nitrate will take place.

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Drainage plays a major role in controlling the shallow transport. Under long periods with wet conditions, the groundwater table may build up to the surface in poorly drained soils and thereby generate overland flow. The efficiency of artificial drainage further controls the fractionation between water being transported by the drains directly to the surface water and water recharging the groundwater aquifers. Denitrification between the root zone and the drains is expected to be very limited in the area due to low organic matter content and the tile drains thus act as a "highway" for nitrate to the surface waters without any denitrification. Due to the high clay content in the soil on the Salling Peninsula, it is expected that a substantial part of the agricultural land around Vester Hjerk is drained and that drainage will have a very high impact on nitrate transport. Thus further investigation of the local drainage systems is important in order to come up with realistic estimates of the nitrate loads to surface water and groundwater. The Viummølle river valley is not cultivated and thus not drained.

The dominant flow pathways to the abstraction wells are expected to be water infiltrated from the root zone and not entering the drains. As part of the national groundwater mapping programme a groundwater model was developed to estimate the capture zone and the travel time from the land surface to the abstraction wells. It was estimated that the travel time from the land within the capture zone to the abstraction well is between 20-50 years, which is relatively short travel times.

The subsurface architecture and physical properties, i.e. hydrogeology, will determine the transport pathways in the subsurface, and thus the origin of the water ending up in the wells of the waterworks. This is naturally very important, as those areas are subject to protection and possible restrictions on the land use practise. The geological understanding of the subsurface is illustrated in Figure 6.16. Groundwater is abstracted from the lower part of the aquifer in a sandy Quaternary deposit which is found in a valley cut into Tertiary Mica clay. The width of the valley and composition of the valley in-fill, i.e. sand or clay, has been interpreted primarily from geophysical data. The geophysical data in the area is, however, sparse and the interpretation of the hydrogeological properties of the in-fill in the valley just east of the abstraction wells is highly uncertain, as illustrated in Figure 6.17.

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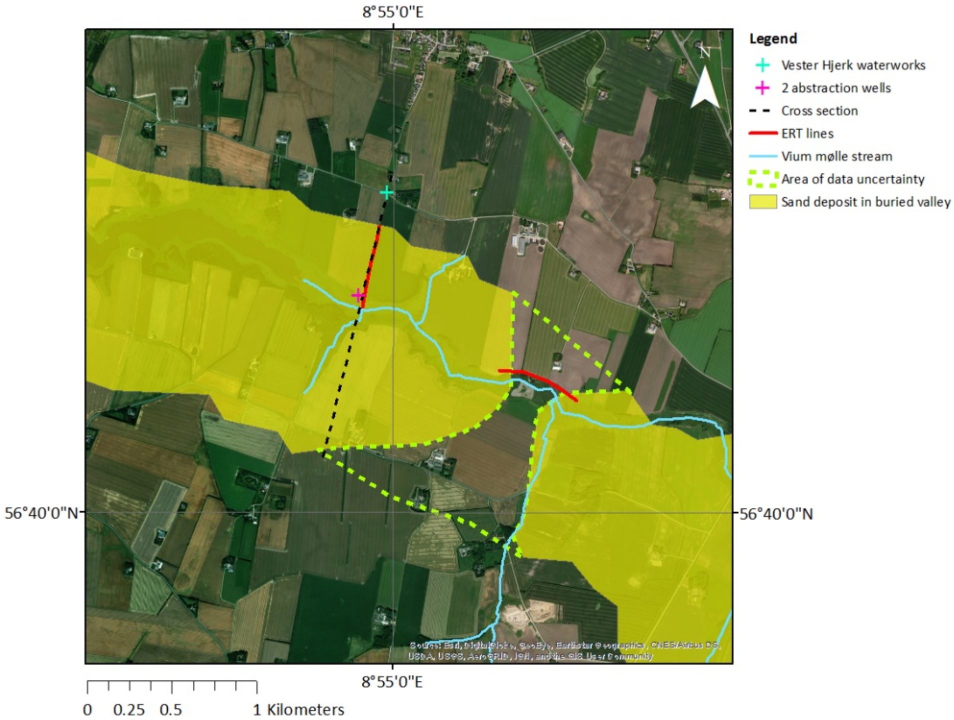

Figure 6.17 Map of the sand deposits in the buried valley underlying Vester Hjerk abstraction wells and the area of missing data and additional field investigations (ERT).

The pathways expected to be most important for nitrate transport in the action lab are summarised in Table 6.3.

Table 6.3. Transport pathways of nitrate in the action lab and their importance.

Transport pathway	Relative magnitude	Fate of nitrate	Importance
Overland flow	Generally small, but can be large under extreme precipitation events.	No transformation/ removal takes place.	Generally little. Only important under extreme precipitation events and if transported to a well that is leaky.
Preferential flow	The magnitude depends on the climate dynamics and soil type. Is not expected to be large in long-term assessments	No transformation/ removal takes place.	Not believed to be an important factor when evaluating long-term conditions.
Drainage	Depending on the drainage intensity, it is expected that between	Locally some nitrate may be degraded, but generally no	Very important.

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	10 to 70% of the infiltrating water may be transported by the drains directly to the surface water system.	degradation will take place.	Reliable information on the drainage in the area is a prerequisite for evaluation of nitrate loads to surface water and groundwater, and need to be collected from the local farmers.
Groundwater flow	Recharge not entering the drain will generate groundwater flow to the aquifers.	Depending on the redox conditions.	Very important. Transport in the subsurface determines from where water abstracted in the wells originate from, and thus the areas where protection is required.

6.6.3 Collection of field data and improving the conceptual model

The difference in capture zone delineation (Figure 6.4) calculated using two different conceptual models and modelling software clearly illustrates the importance of defining the conceptual model and the associated uncertainty. This uncertainty can to a large extent be attributed to the limited knowledge of the local geology structure and hydrogeological properties near the abstraction wells of Vester Hjerk waterworks. Within WaterProtect new field investigations were conducted in May 2018 in order to improve the conceptual understanding of the local hydrogeology.

The data review revealed that the geological profiles of the two abstraction wells at Vester Hjerk waterworks were deviating substantially from each other despite located only 9 m apart. The depth and thickness of the capping clay layer varied by up to 10 m. Therefore a gamma log survey was carried out in order to identify changes in lithology. It showed that the conductivity of the two profiles is nearly identical and furthermore there is little vertical variation. This means that i) the geological interpretation of the two wells is roughly identical and thereby more coherent than the initial descriptions indicated and ii) there is no clear distinction between sand and clay layers and thus the aquifer is not protected by an impermeable clay layer.

As explained above, the geophysical data about the buried valley underlying Vester Hjerk waterworks was insufficient (Figure 6.17). Thus, two additional ERT surveys were carried out, the location of the profiles are shown in Figure 6.17 and the inversion results are shown in Figure 6.18 and Figure 6.19.

Firstly, Figure 6.18 shows that the sandy aquifer, from which the drinking water at Vester Hjerk is abstracted, is only protected by approximately 7m of moraine clay at the top. The thickness of the layer varies along the profile and thus the aquifer can be considered vulnerable.

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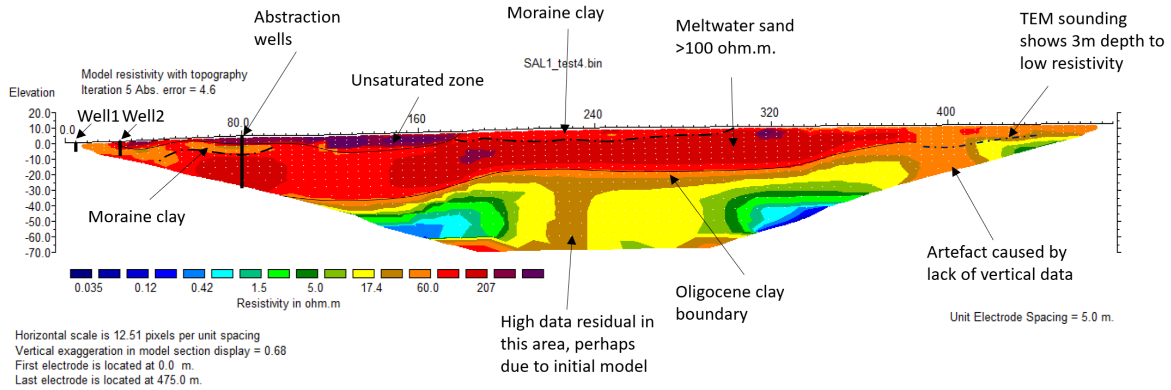

Figure 6.18 ERT profile running parallel to the abstraction wells at Vester Hjerk. Interpretation of the resistivity values is indicated on the figure.

The second profile (Figure 6.19) revealed that the two sand units shown in Figure 6.17 are actually connected, as the sandy layer continues throughout the entire length of the profile. The implications of this finding with relation to the groundwater flow will be investigated further using the numerical hydrological model (explained in Section 6.6).

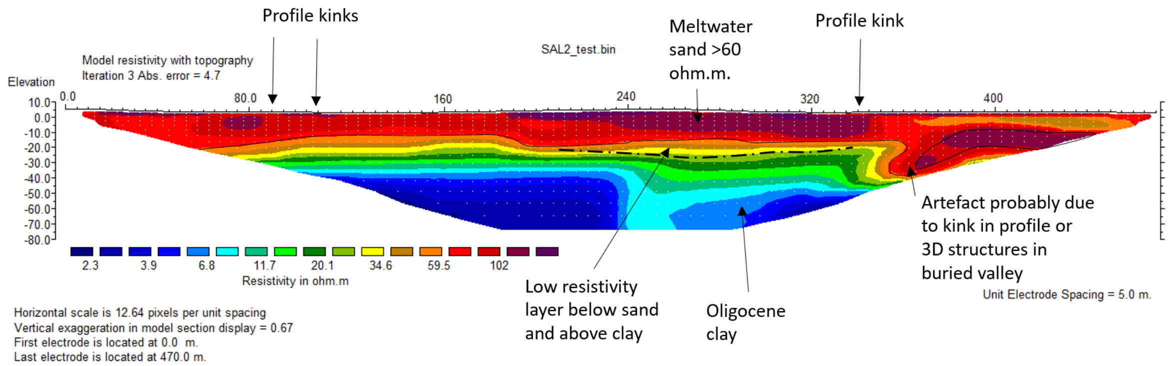

Figure 6.19 ERT profile located Southwest of Vester Hjerk in order to reveal if there is actually a break in the sand deposits. Interpretation of the resistivity values is indicated on the figure.

The field investigations furthermore included installation of and sampling of water from two piezometers at different depths located between Viummølle å and the boreholes. Hydrochemical data was collected (pH, EC, oxygen and temperature) and the groundwater was sampled for concentrations of N, P, sulphides, alkalinity, and anions and cations at different depths in the two piezometers.

The data explained in this section was used to update the conceptual model of the area.

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6.7 Numerical model

The numerical model is set up in the commercial Mike She/Mike Hydro code developed by DHI (Danish Hydraulic Institute). It comprises a deterministic, fully distributed and physically-based model complex for the simulation of the freshwater cycle. It is a suitable modelling tool for the water cycle of Denmark as it integrates groundwater and surface water with a direct coupling between the two systems, and its application in Denmark is well-established (Højberg, et al., 2015). Figure 6.20 illustrates how the natural system is transformed into the numerical model and the exchange between groundwater and surface water flow. The model domain is divided into grid cells in which the net precipitation (precipitation minus evapotranspiration) is calculated.

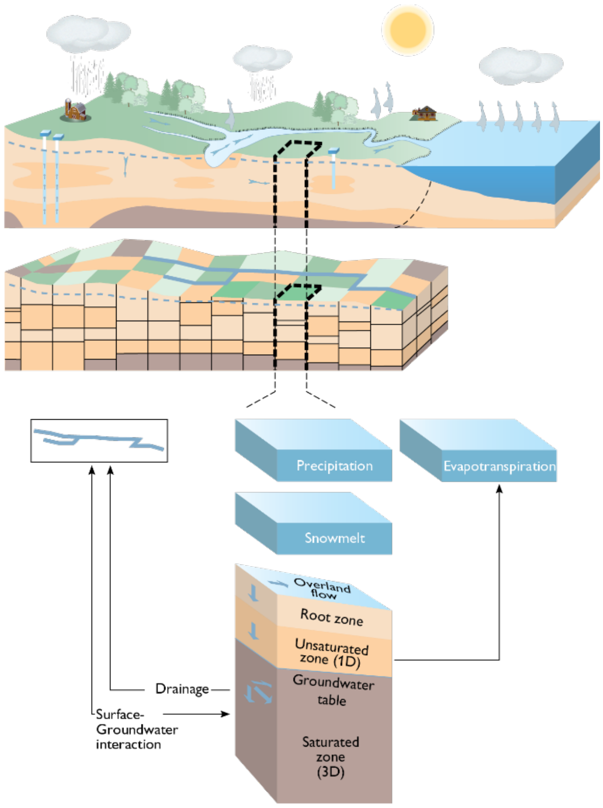

Figure 6.20 Conceptual illustration of the numerical hydrological model.

The model accounts for overland flow, however it may be impacted by the discretisation in the model (100m grid cells), which results in a relatively coarse resolution of the topography. Observations in the field are necessary to improve the understanding on this process and how often it occurs. The groundwater recharge is solved as a 1D problem in the unsaturated zone, while in the saturated zone the groundwater flow is calculated with the 3D finite difference method (Darcy flow). Drains are implemented in the model with a constant depth of 1m below terrain, and is activated when the groundwater table rises above the drain level. Drainage efficiency is implemented in the model via a drain time constant, describing how fast the area is drainage, which can be fully distributed in space.

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The model does not include discrete fractures to describe preferential flow. Instead the equivalent porous media assumption is made, where the fracture network is assumed to act as a porous media with higher hydraulic conductivity. Hence, preferential flow is accounted for by calibrating the hydraulic conductivity. This is assumed adequate for describing the mass flux of nitrate, but will not be able to catch early breakthrough to the saturated zone.

The redox conditions is crucial for describing the transformation of nitrate in the saturated zone. The redox interface is implemented in the model as a surface. Above the surface nitrate is assumed to be transported conservatively, i.e. no transformation, while the removal due to denitrification below the interface is assumed to be instantaneous and complete. The best estimate of the redox interface (Figure 6.21) will be used in the model initially, but it is planned to assess the impact of the uncertainty in the location of the redox interface by a sensitivity analysis using selected realisations of plausible location, as illustrated in Figure 6.21.

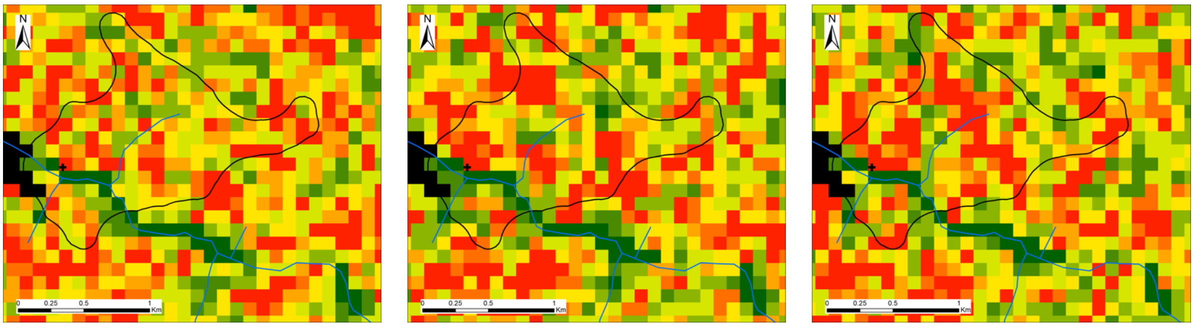

Figure 6.21. Examples of different realisation of depth to the redox interface in the vicinity of Vester Hjerk waterworks.

While we are interested in a smaller area around Vester Hjerk waterworks, this area cannot simply be isolated from the larger-scale regional variation in groundwater flow. Therefore a regional model is built which covers the entire Salling Peninsula (478 km^2) with well-defined boundary conditions along the coast (constant head) and river to the South (no flow), see Figure 6.22. Thereby, we account for distant outer boundaries and avoid adverse effects on the water balance due to abstraction from large well fields.

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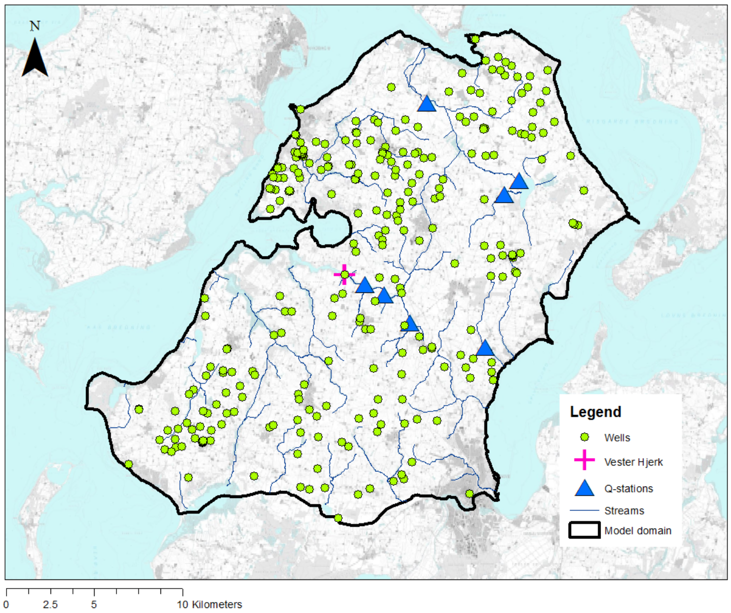

Figure 6.22 Location of wells and Q-stations used in the model calibration and the delineation of the model domain.

The conceptual hydrogeological model is based on an existing groundwater MODFLOW model developed for the Salling Peninsula for decision making by the local water authorities. This model has been transferred to the Mike-SHE/Mike Hydro software for the WaterProtect project and further developed with additional data. Based on the geological characterization, the model has been divided into 10 layers; 2 top layers of 0.5m (for the integration of drains at a sufficiently high resolution) and 8 geological layers of varying depth corresponding to the clay and sand layers. The spatial discretization is 100 m and the simulations are carried out at daily intervals.

The model parameters were determined through sensitivity analysis and non-linear parameter estimation using PEST (model-independent parameter estimation). The model is calibrated against discharge and head data for the period 2000-2006 and validated for the period 2007-2016. 1990-2000 is used for warm-up. Seven Q-stations with discharge time series (Table 6.4 and Figure 6.22). The head observations were extracted from the national JUPITER database which contains time series of all monitored wells in the country.

station	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16
160030																											
160031																											
160034																											
160054																											
160070																											
160105																											
160270																											

Table 6.4 Overview of discharge time series for the seven Q-stations used for calibration (yellow) and validation (green).

The model will be used to calculate the capture zone of the abstraction wells for Vester Hjerk waterworks using particle tracking. Previous modeling efforts in the area have shown very different results on this issue (Figure 6.4), and therefore further efforts will be put into testing assumptions which has an impact on this matter and using additional field data to test hypotheses.

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Furthermore, the numerical model is going to be used in combination with a GIS-based land use tool to calculate the flux of nitrate to groundwater and surface water respectively.

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Action lab: Llobregat case (Spain)

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7 Llobregat (Spain)

7.1 Executive summary

The Baixa valley and the Llobregat delta constitute an aquifer of 120 km2 with a current operating capacity of 50 hm3/year, which is used for the supply of drinking water as well as industrial and agricultural uses. The Baixa Valley is formed by alluvial that make up a free aquifer. The delta is formed by two aquifers, a confined and deep gravel aquifer with high transmissivities, and a sandy shallower aquifer of medium transmissivities. Between the two aquifers is an aquitard (clays and limes) that separates them, but that towards the edges of the delta vanishes.

During the 1960s, groundwater extraction was reduced firstly due to the surface water purification station of the Llobregat River in Sant Joan Despí and later by the supplementation of the River Ter water. Specifically since 1966 the extraction for industrial use exceeded the drinking water supply, which did not change until the 90s (see figure 7.2). During the 70s and 80s, the effort to improve industrial processes thanks to new technologies and sensitizing action of CUADLL brought about the most important reduction of extractions. Added to this phenomenon, since the 1980s, it has been assisting in a progressive reduction in industrial use extractions attributable to the closure of some of the most water-extracting industries. This reduction has had a steady trend and is the result of the modernization of our society. The causes of the de-industrialization process that is occurring in our area today can be attributed to the high price of land, to relocation, to the implementation of the Delta Plan and to the cases of export industries outside of Europe to the progressive increase of the value of the euro against the dollar. Among the industries that have recently closed, it is worth mentioning those that were large users of the deep aquifer of the delta; In 2000 the municipality of El Prat de Llobregat closed the Silk of Barcelona, and in 2003 the Laboratorios Eugène, Adams Spain was closed. The closure of these industries reduced the extraction approx. three hm3/year. At present, the situation of the industries is diverse according to the sector to which they are dedicated; while some have a secured future, others could join the long list of closed companies such as Fisipe or Reno de Medici.

As of 1997, extractions for drinking water supply exceed industrial use after the previous decade in relative balance. This balance will continue throughout the following years.

The agricultural production of the Baix Llobregat Agricultural Park depends mainly on surface water, but in areas with insufficient surface water, groundwater has an exclusive role. In general, however, it is common for surface water to be complemented with underground utilization since the surface water resource is temporally varying. There is also an area where regenerated water has a preponderant role. Over the last decades, the urban growth, together with the new large infrastructure works and the aging of the people dedicated to the agricultural sector, has caused the reduction of fields of cultivation and consequently the progressive reduction of the extraction of groundwater for these uses.

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7.2 Executive summary in Catalan

La vall Baixa i delta del Llobregat constitueixen un aqüífer de 120 km^2 amb una capacitat d'explotació actual de 50 hm^3/any i que s'utilitza per a l'abastament d'aigua, usos industrials i usos agrícoles. Aquest aqüífer se'l denomina estratègic al ser clau de cara a l'abastament de l'Àrea Metropolitana de Barcelona en situacions d'escassetat de recursos hídrics.

Geològicament la Vall Baixa està formada per unes graves al·luvials que conformen un aqüífer lliure. El delta està format per dos aqüífers, un format per graves que és confinat i profund amb alta capacitat transmissiva i un de superficial més arenós de mitjana capacitat transmissiva. El profund és el que s'usa per a abastament i indústria. Entre aquests dos aqüífers hi ha un aqüitard (argiles i llims) que els separa però que cap a les vores del delta per potència i s'atascona.

Durant els anys 60 la reducció d'extracció d'aigua subterrània està motivada primer per l'estació potabilitzadora d'aigua superficial del riu Llobregat a Sant Joan Despí i posteriorment per l'arribada d'aigua del riu Ter. En concret, des de 1966 l'extracció per a ús industrial supera a l'abastament, tendència que no canviarà ja fins als anys 90 (veure figura 7.2). Durant els anys 70 i 80 però, l'esforç per a la millora dels processos industrials gràcies a les noves tecnologies i a l'acció sensibilitzadora de la CUADLL provocà la reducció més important de les extraccions. Sumat a aquest fenomen, des dels anys 80 que s'està assistint a una progressiva reducció de les extraccions d'ús industrial atribuïble al tancament d'algunes de les indústries amb més extraccions d'aigua. Aquesta reducció ha tingut una tendència esglaonada i és fruit de la modernització de la nostra societat. Les causes del procés de desindustrialització que s'està donant en el nostre àmbit actualment es poden atribuir a l'elevat preu del sòl, a la deslocalització, a l'aplicació del Pla Delta i en els casos de les indústries exportadores fora d'Europa a l'augment progressiu del valor de l'euro enfront el dòlar. Entre les indústries que darrerament han tancat cal destacar aquelles que eren grans usuàries de l'aqüífer profund del delta; l'any 2000 al municipi del Prat de Llobregat tancà la Seda de Barcelona, i durant el 2003 s'ha anunciat el tancament de Laboratorios Eugène, Adams Spain totes elles dedicades a activitats productives. El tancament de totes aquestes indústries suposa una reducció d'extracció de 3 hm3/any. En l'actualitat la situació de les indústries és diversa segons el sector a què es dediquen; mentre algunes tenen el futur assegurat d'altres podrien sumar-se a la llarga llista d'empreses tancades com per exemple Fisipe o Reno de Medici.

A partir de 1997 les extraccions per abastament superen l'ús industrial després d'estar la dècada anterior en relatiu equilibri. Aquesta és una tendència que es mantindrà ja al llarg dels següents anys.

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La producció agrícola del Parc Agrari del Baix Llobregat depèn principalment de les aigües superficials. És en les zones on aquestes aigües no hi arriben que les aigües subterrànies tenen un paper exclusiu. En general, però, és habitual que les aigües superficials estiguin complementades amb aprofitaments subterranis ja que aquests darrers tenen garantia temporal. També hi ha zona on l'aigua regenerada hi té un paper preponderant. Al llarg de les darreres dècades el creixement urbanístic dels diferents municipis conjuntament amb les noves grans obres d'infraestructura i l'envelliment de la població dedicada al sector agrícola ha provocat la reducció de camps de conreu i conseqüentment la progressiva reducció de l'extracció d'aigua subterrània per a aquests usos.

7.3 Introduction

The Llobregat Delta is a medium-size Quaternary formation located at the SW edge of the densely populated area of Barcelona City, in the NE of Spain (Figure 7.1). This area of 120 km^2, formerly devoted to agriculture practice, now supports important industrial settlements and city suburbs. The high-water demand has led to an intense and continuous exploitation of surface and groundwater resources. Intense groundwater exploitation up to the late 1970's caused an important advance of the saline intrusion interface. Nowadays, saline intrusion still affects large areas of the delta. Moreover, the anthropogenic (agriculture, industrial and urban) activity caused several contaminations of surface water and groundwater.

At present, the Water Users Community and Catalonian Water Agency (Agència Catalana de l'Aigua), are trying to correct the actual situation and is developing a groundwater management program to recover groundwater quality and quantity while trying to guarantee sustainable pumping rates. Also, Agrarian Park Consortium is implanting new technologies and new practices to prevent the effects of agriculture in the environment.

To achieve the goal of improve groundwater state, it has been necessary to do, first, a groundwater review of previous studies along with data recollection and integration, and an exhaustive review of geological information. These two points are necessary to define a groundwater conceptual model. Secondly, groundwater modelling is needed to integrate and validate the conceptual model and to obtain a management tool, and thirdly, the simulation of some different scenarios is carried out to allow managers to quantify the effects of different future policies for these aquifers.

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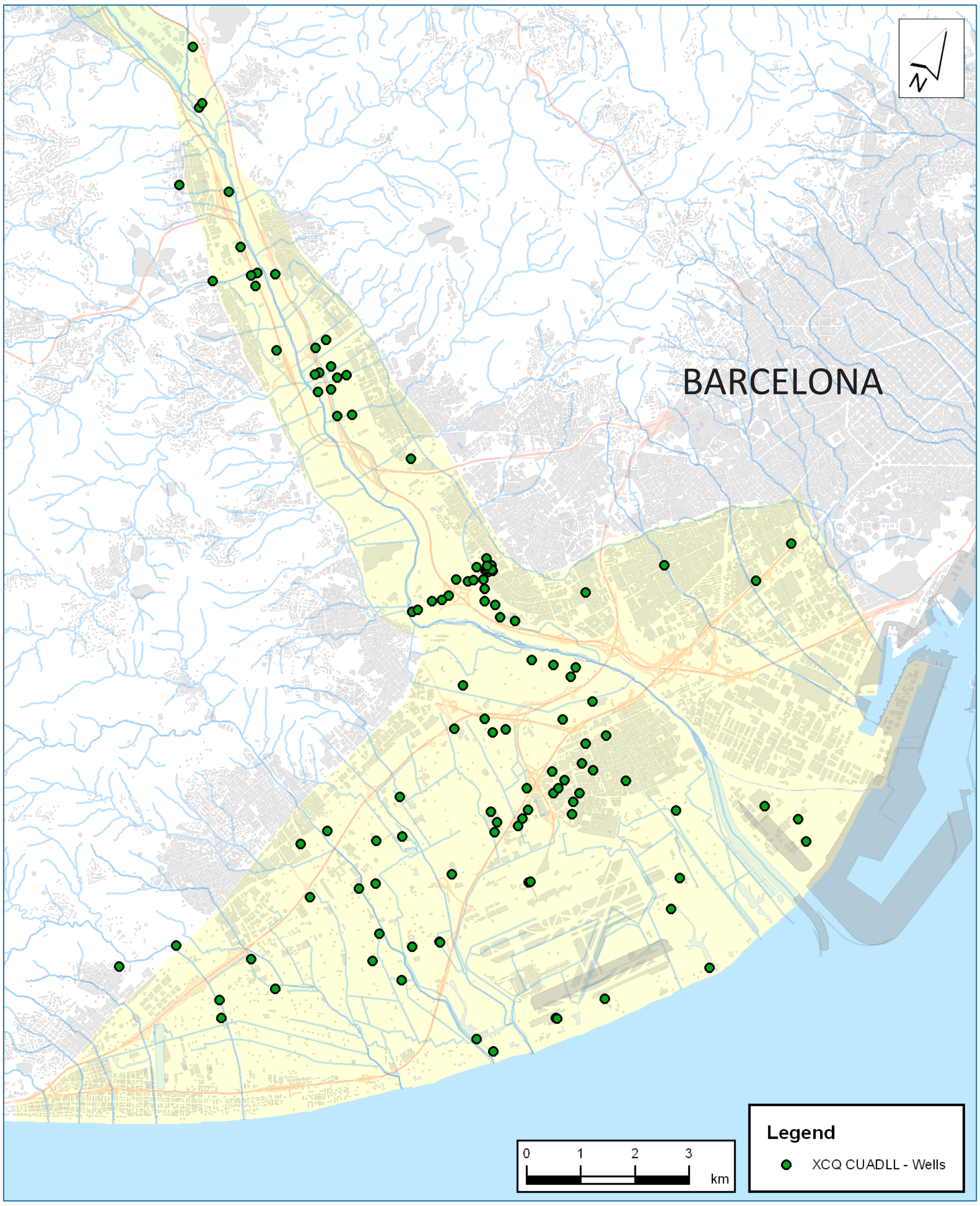

Figure 7.1 Spain Action Lab in Barcelona. Llobregat case. Monitoring quality wells .

The Llobregat delta is a well-known case in classical hydrology and seawater intrusion studies. Since the 1960's a multitude of groundwater studies have been carried out in this area. Among others, the hydrogeological synthesis made by MOP (1966), PHPO (1985) and more recently by Iribar and Custodio (1992) must be remarked. At the end of the 1970's, when salinization problems became increasingly worrying, hydrochemistry works improved the knowledge of the aquifer systems and the mechanisms that cause seawater intrusion in the main aquifer of the Llobregat delta (Custodio et al. , 1976; Custodio, 1981; Manzano et

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al. , 1992; Bayó et al. , 1977; Domènech et al. , 1983, etc.). Some groundwater flow models have been also developed for the Main Aquifer, named Deep Aquifer in previous works, (Custodio et al. , 1971; Cuena and Custodio, 1971; Iribar et al. , 1997) and, more recently, also for the upper aquifer (UPC, 1998).

7.4 System description

To achieve a detailed characterization, it is necessary to recover all the information used to define the conceptual model. One of the most difficult variables to obtain is recharge, which depends on soil use and varies with time, and groundwater extraction. The largest groundwater exploitation was in the 1970s, and reached values of more than 130 Mm^3/y. This period corresponds to the minimum groundwater heads ever reached, with values that went down below 22 m.b.s.l. in the central part of the delta (Figure 7.2, 7.3 and 7.4). Due to this groundwater level decrease and some anthropic modifications of the medium (inland harbour dock's enlargement), marine intrusion quickly progressed around the 1980s towards the central part of the delta, where some of the main pumping areas were located. The chloride concentration evolution in time in some selected measurement points is shown in Figure 7.5, in order to illustrate how seawater intrusion evolved in the main aquifer of the Llobregat delta.

The history of the delta deep aquifer or main aquifer can be explained with the evolution of the piezometric levels as well as with the evolution of extractions (Figure 7.2, 7.3 and 7.4). In 1976 the important water consumption along with a drought period resulted in a drop in the piezometric level. Meetings were arranged between the Prat Council and all the industries in order to solve that situation and to improve the management of the aquifer. The Water Users Association of Llobregat Delta was created in 1976. In the late seventies and early eighties the industry made a lot of investments to reduce the consumption and in eight years the consumption dropped by half. In the nineties, the average extraction was about 60hm^3/y and the management continued to improve. However, different wells were affected by seawater intrusion (the piezometric levels continued below the sea level). Due to the existence of a major regulation along with the increase of the benefits (chemicals and quantities) to use groundwater in certain periods, the extraction for water supply use increased progressively. In the period 2000-2006 big industries closed (Queralt, 2007). After a drought in 2008 the exploitation is about 50hm^3/y and the piezometric level is around zero. The intrusion stopped in many observation wells.

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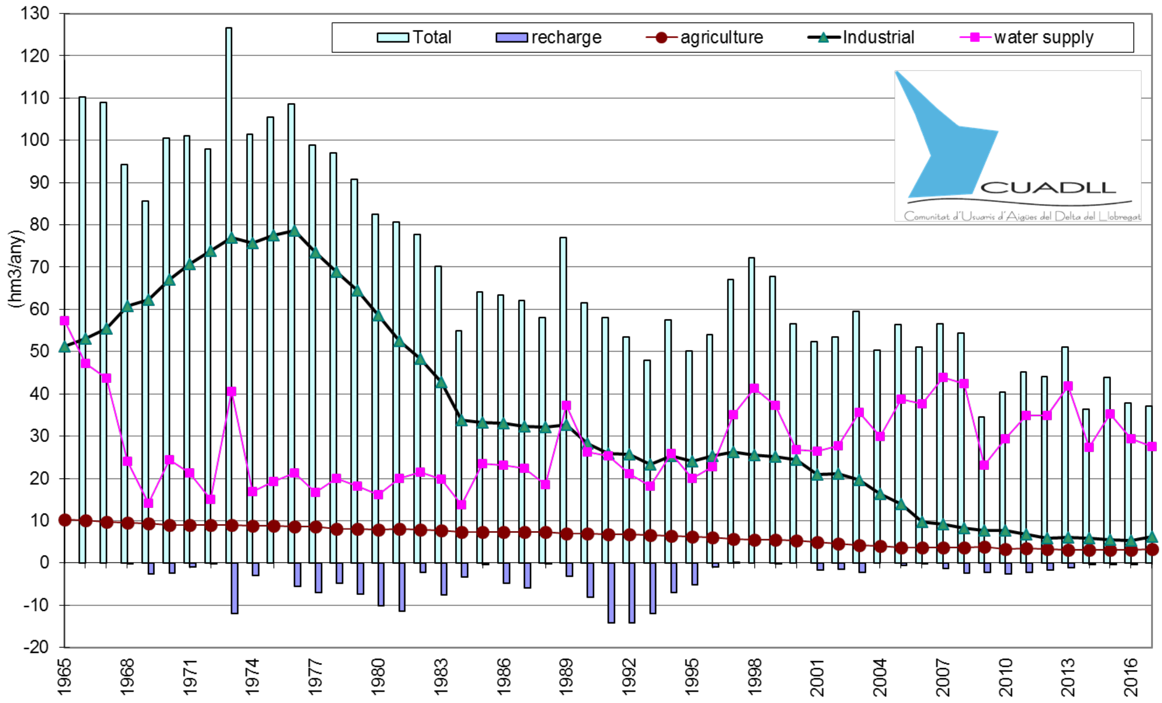

Figure 7.2 Historical evolution of extractions in CUADLL aquifer.

In this history the managed aquifer recharge plays a small but important role (the best year of recharge was about 14 hm^3/y) as it helps to improve the mass balance.

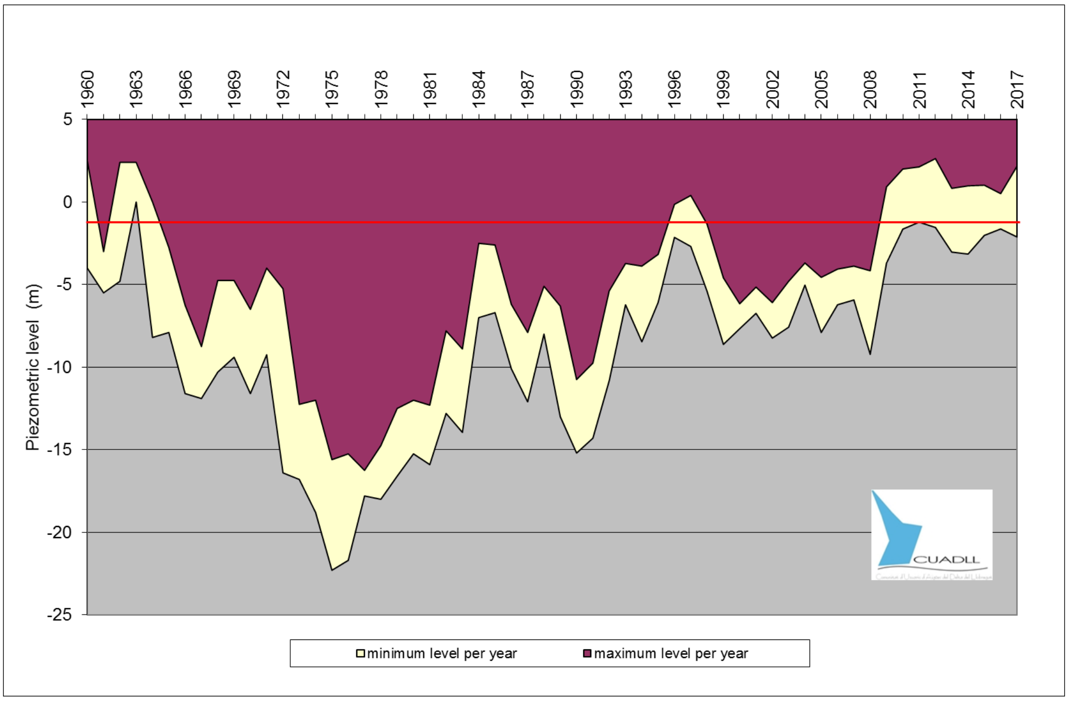

Figure 7.3 Historical evolution of piezometric level (maximum and minimum level per year) in the center of delta in main aquifer .

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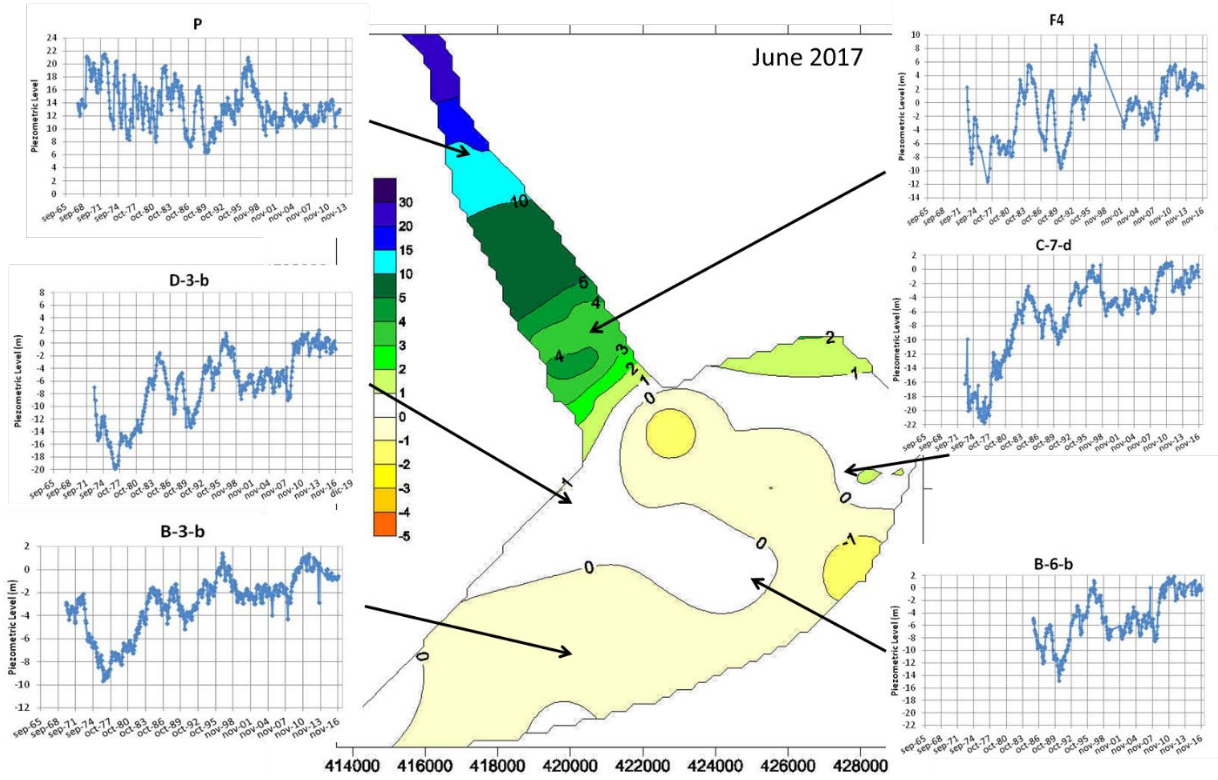

Figure 7.4 Piezometric surface corresponding to the Main Aquifer in 2017. Hydrographs in several points of the aquifer show the complex evolution of the hydraulic heads.

The actual delta is a relatively young formation. Some archaeological findings have shown that in Roman times, the shoreline was almost 2 km inland and that in the Middle Ages, Barcelona's harbour was placed at the shelter of the Western side of Montjüic Mountain, some 1.5 km landwards from the present coast line.

The general guidelines of the Llobregat Delta geology were established by Almera (1891), Llopis (1942, 1946) and Solé-Sabaris (1963). For hydrogeological purposes, the cross-sections proposed in the late 1960s and early 1970s in the framework of the project "Estudio de los recursos hidráulicos de la Cuenca del Llobregat" and some other reports published at that time, are still used today (MOP, 1966; Llamas and Molist, 1967; and Bayó, unpublished). Since then, additional geological information has become available thanks to the continuous constructions (related to civil works) that are carried out in the delta area. This additional information helped in defining a more accurate geological model. The motivation of the review of the model comes from the need to account for medium-scale heterogeneities that would control the contamination transport processes taking place in the Llobregat delta aquifers. This is especially true when there is a need to account for mass transport studies, moreover when remediation measures are to be designed or planned. A thorough sedimentological study was carried out to define in detail the three-dimensional geological structure. As an example, well-logs have been reviewed under a sedimentological point of

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view and it has been possible to redefine aquifer units, their geometries, and lateral connections, both between units and with the sea. The final geological model is presented in Figure 7.8.

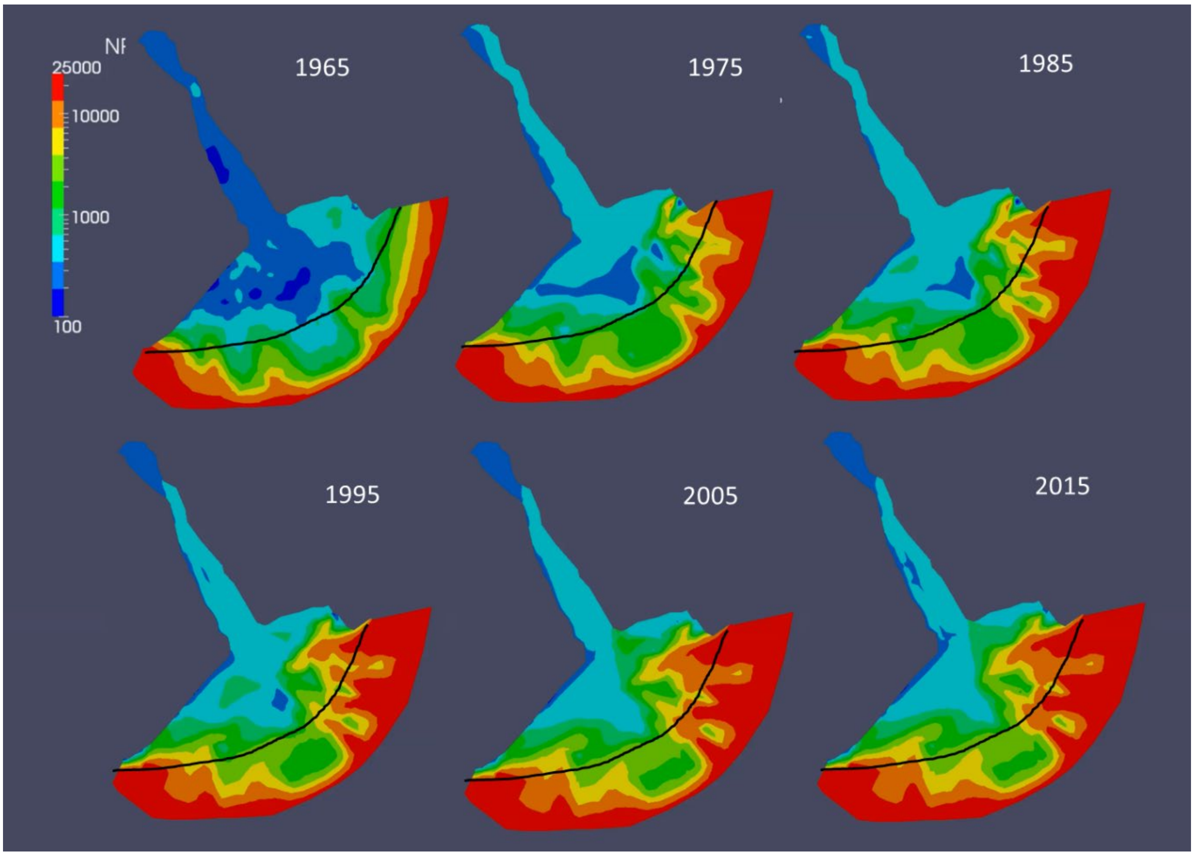

Figure 7.5 Chloride concentration data evolution in the main aquifer of the Llobregat delta. Two fingers of high salinity can be observed advancing towards the main pumping fields in the centre of the Llobregat delta.

The problematic of nitrates is focused in the right border of the delta and a few in the left border (Figure 7.6). This is because in the border the aquifer is more oxic than in the central zone. Human activity is the principal factor for this pollutant. The problematic of ammonia is more present in the agriculture zone and coastal zone where the aquifer is more anoxic (Figure 7.7).

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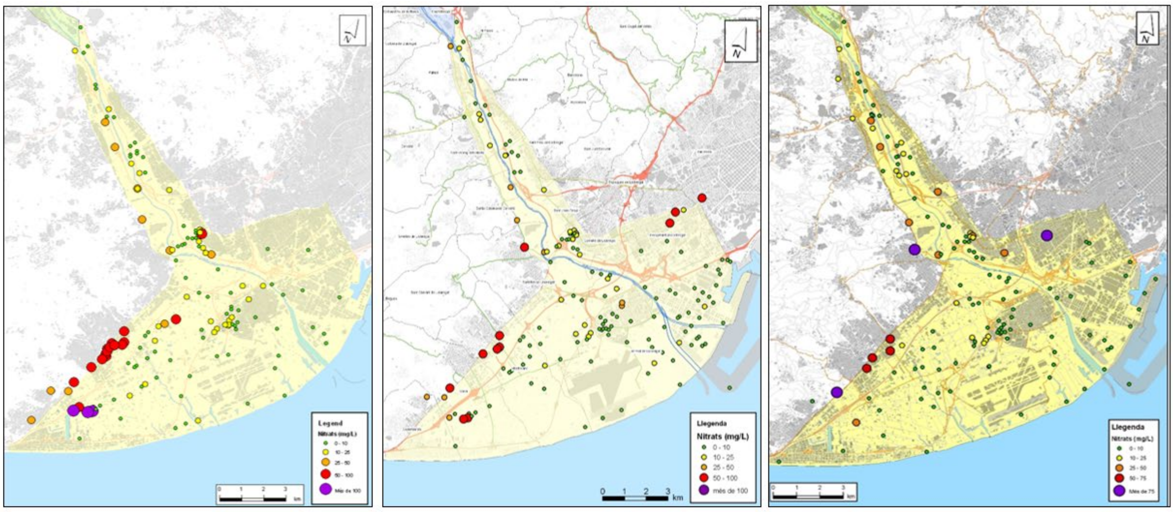
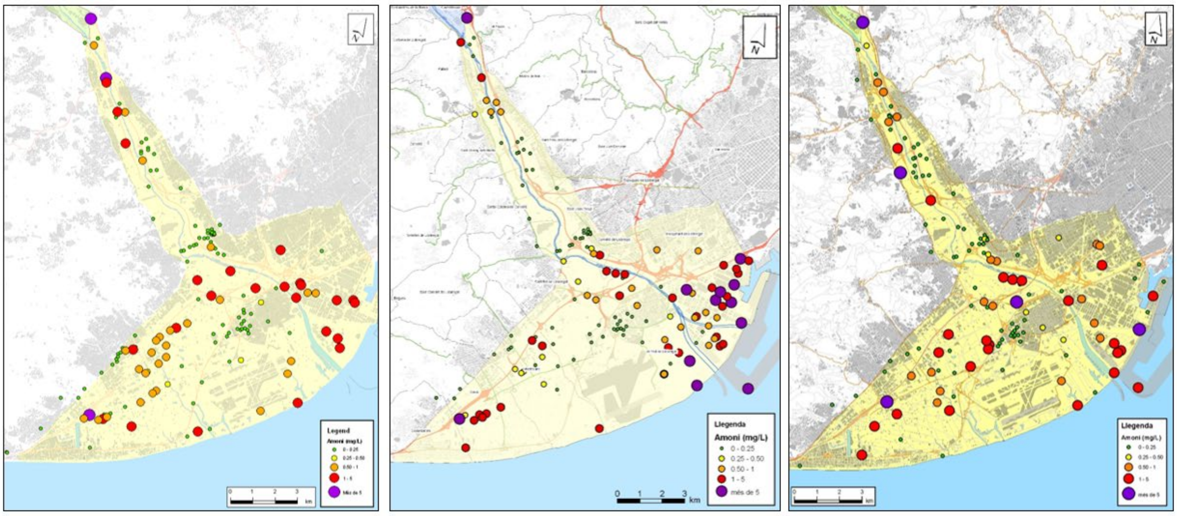


2005 2010 2015

Figure 7.6 Nitrate concentration data evolution in the main aquifer of the Llobregat delta.



2005 2010 2015

Figure 7.7 Ammonia concentration data evolution in the main aquifer of the Llobregat delta.

The most ubiquitous Plaguicide compounds are simazine, tebuconazole, terbutryn and diuron. All these are detected in Low Valley aquifer. In delta aquifer some of these parameters are not analysed, so it will be interest to include in monitoring plan.

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7.5 Conceptual and Numerical model

The Visual Transin code has been used for calibration of the numerical model (UPC, 2003). This code is not commercial and it has been made by UPC. The code does not take into account the effect of variable density, however, the seawater density is implemented in the boundary conditions, where equivalent freshwater head is prescribed. As a result of the geological characterization, the model was divided into two layers, corresponding to the Upper aquifer and the Main aquifer.

In the Low Valley there is a unique alluvial aquifer that separates into two aquifers when it arrives at the delta plain: a) a superficial aquifer that is the current Deltaic plain and b) a deep aquifer that is located below an impermeable silty wedge associated to the last marine transgression. Upstream the silty wedge disappears and both aquifers are connected. Low Valley and deep aquifer are the main aquifer.

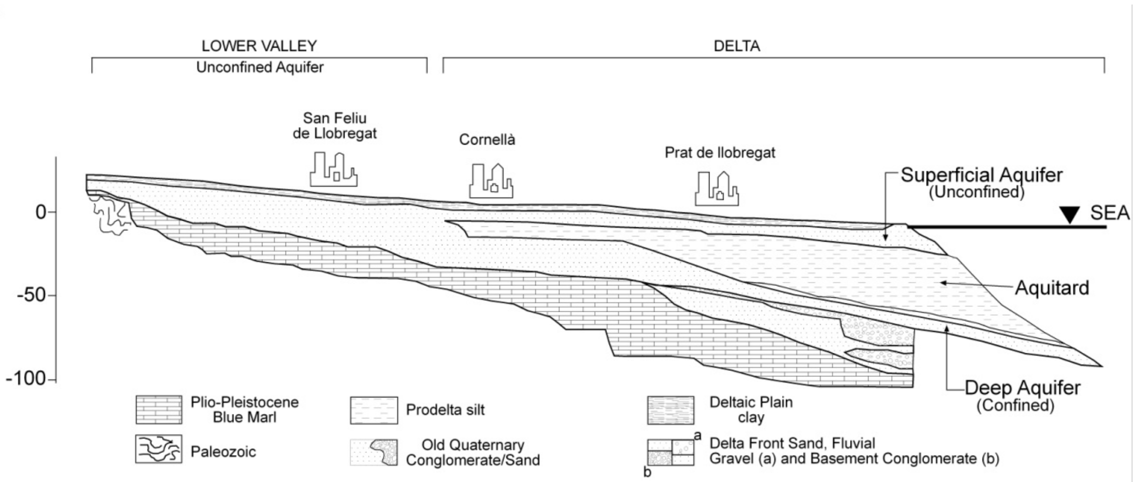

Figure 7.8. Cross section of Low Valley and Deltaic plain of Llobregat (Modified of Bayó, 1984)

The main parameters used in the model were estimated after data integration and completing the geological review. As an example, it was possible to define 101 transmissivity zones, defined according to aquifer thickness, lithofacies description and values obtained in hydraulic tests. The transmissivity zone map is shown in Figure 7.9, which also shows the aquifer thickness isolines above it.

As a result of the geological characterization, the model was divided into two layers, corresponding to the Upper aquifer and the Main aquifer. Spatial discretization (Figure 7.10) is very fine, especially near the main pumping areas, and the mesh is adapted to the main geographical features. The average size of each element is about 200 m. Simulation time steps were set to monthly frequency, from 1965 to 2001 (Vazquez et al, 2004).

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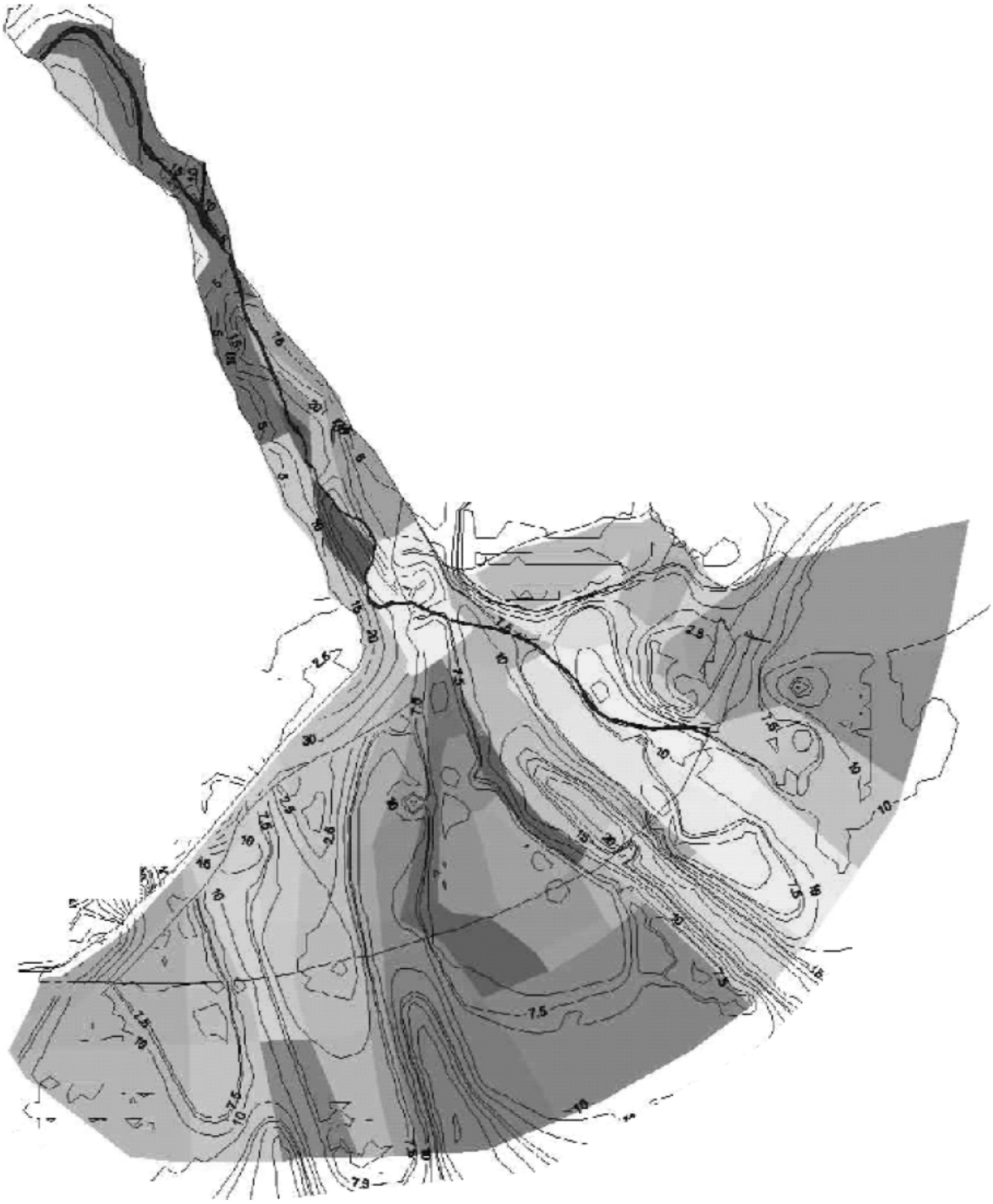

Figure 7.9 Map of transmissivity zones. 101 constant transmissivity zones are defined, based on several criteria: aquifer thickness, lithofacies, hydraulic tests and sediments grain size distribution of the sediments. Aquifer thickness isolines (in meters) are plotted over the map.

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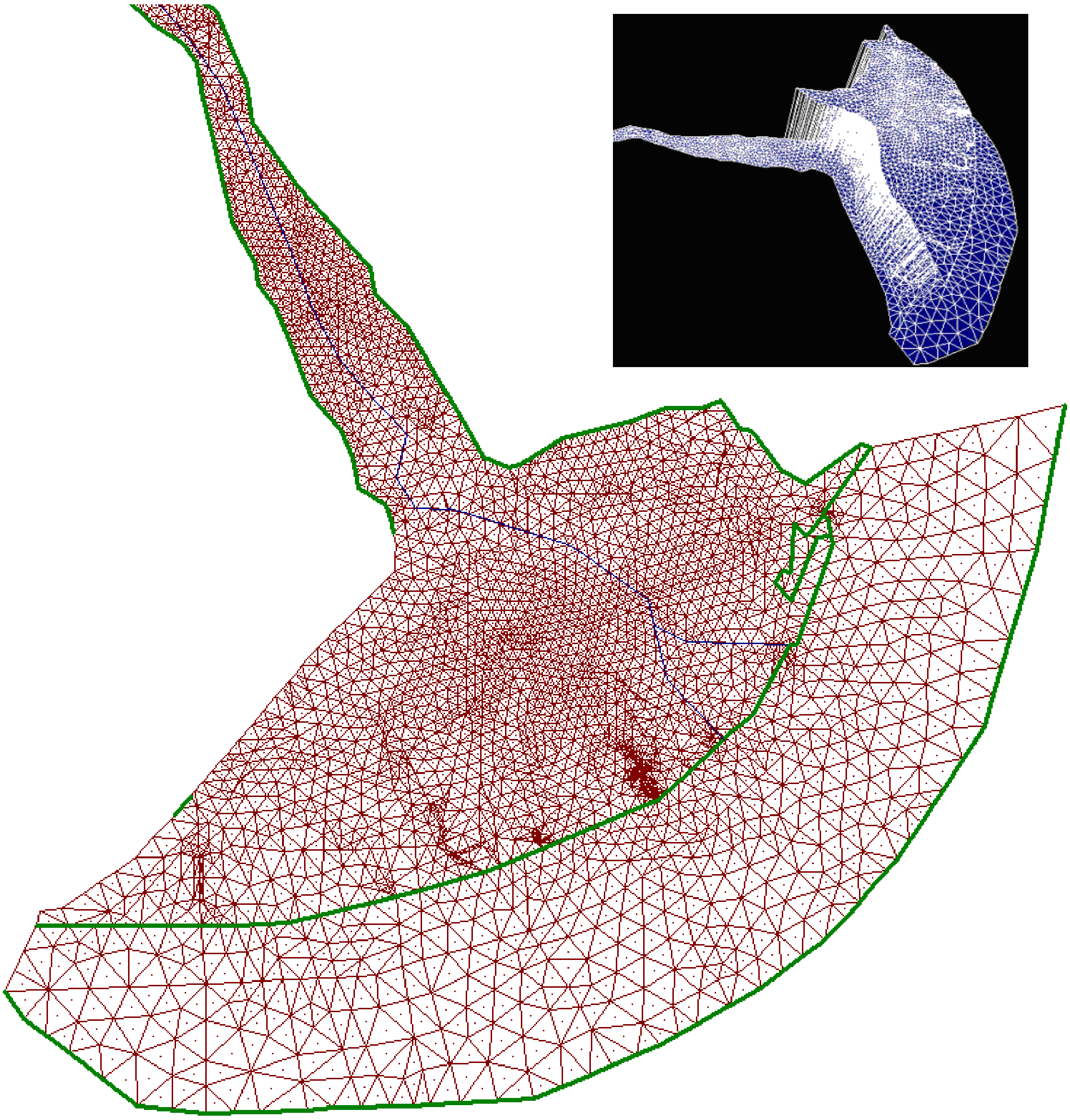

Figure 7.10. Finite element mesh divided into two layers connected by 1D elements. The complete mesh is composed of 4411 nodes and 9848 elements*.*

Three main points have to be taken into account while calibrating the model. Firstly, a good consistency between a priori information and calibrated parameters must be pursued; secondly, we must ensure a good fitting between measured and computed data, both in terms of piezometric heads and concentrations, and thirdly, the water and chloride mass balances should be coherent with the conceptual model and previous calculations. A synthesis of the water mass balance is shown in Figure 7.11.

From Figure 7.11 several relevant aspects arise, e.g. the recharge from the river during floods is the most important contribution to aquifer recharge together with infiltration from soil, while groundwater abstraction is the main term in aquifer discharge. The most significant

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contribution of the model is its ability to simulate the evolution of seawater intrusion and to define a path for it.

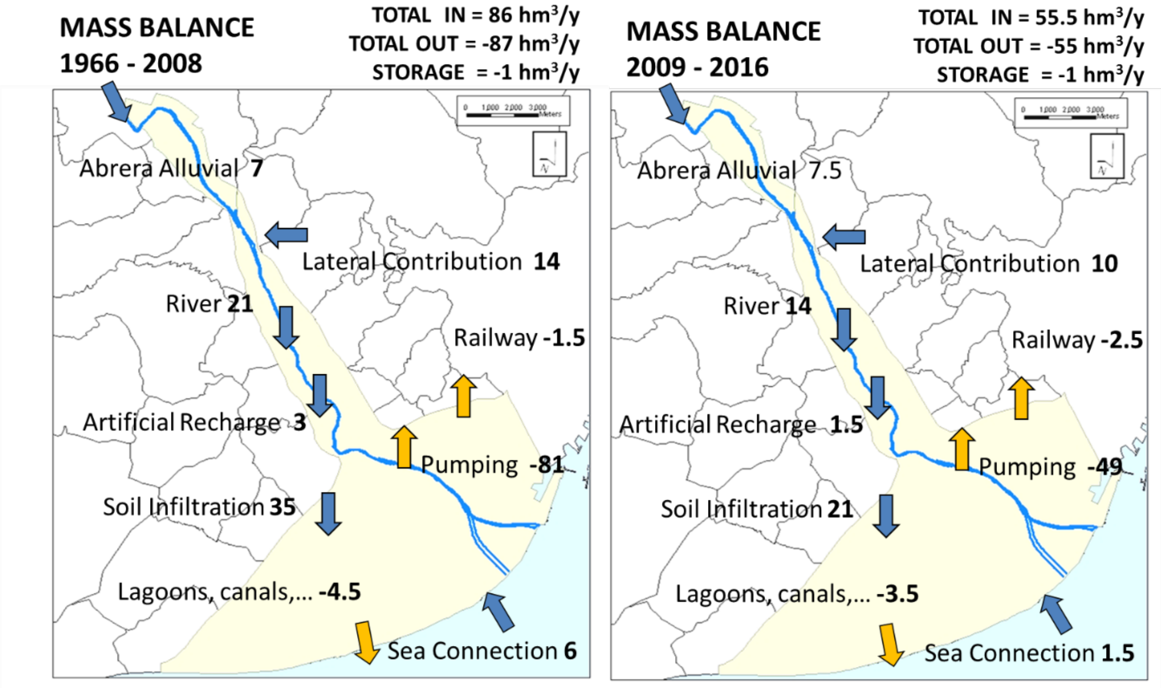

Figure 7.11. Water mass balance scheme for the Llobregat delta aquifers expressed in hm^3 /y. The mass balance for the main aquifer is shown on the left side and for the upper aquifer on the right. The black arrows show the flux from the upper to the main aquifer.

7.6 Why a new model?

As is mentioned before the code Transin is not commercial code. That lead to several problems. First the code is not enough known for the most aquifers modellers. In addition there is no official service to help if it is necessary. But the most important thing is explain next.

Numerical models has to be a dynamical tool. In this case the model was used for many projects: for planning and management; to test the artificial recharge; to test draught episodes; to assess the infrastructures impact. At same time the model was updated until 2016 in three episodes. These tasks has been possible with the actual model. Nevertheless there are some tasks that are impossible to do with this code. In particular the mesh are very rigid and it is too difficult change it. Therefore to zoom a local model is not possible add details in it. To solve this kind of problems locals models could be the solution, and the regional model can be used to frame it. But in this aquifer is difficult to cut it for study locals problems due to the great connectivity along the aquifer. Other problem around the impossibility to change mesh is the changes about soil uses or new information (as for example new zones of transmissivity) that could be interesting add to model. The migration of the regional model to a commercial code will allow to solve these questions.

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Action lab: Gowienica Miedwiańska (Poland)

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8 Gowienica Miedwiańska (Poland)

8.1 Executive summary

The conceptual model of the Gowienica Miedwiańska catchment includes understanding the natural conditions of the catchment that affect the quantitative balance of waters, such as: geological structure, occurrence of soils, the shape of the catchment and climatic conditions (precipitation, temperatures, insolation, rainfall distribution during the year) and factors determining the quality of surface water and groundwater, including point and area of biogenic elements (nitrogen and phosphorus) within the catchment. The range of factors affecting the quality of groundwater and surface water is wide. Among them, point pollution of surface water associated with the discharge of sewage, point pollution associated with uncontrolled infiltration into the ground of leachates connected with animal husbandry and area pollution resulted from fertilization of crops were identified.

Most of the Grzynica Miedwiańska catchment was formed in the area of Pyrzyce ice-damed lake. At the end of the last glaciation period, from 14000 to 15 000 BC, it was an area of a vast lake, whose remnant in the deepest place is today's Lake Miedwie. The effect of sedimentation in the periglacial climate was settling silty sands, silts and clays on the bottom of the water reservoir. The fragments of the melting ice sheet and glacial clays flowed from the surrounding plateaux, the traces of after melting and redeposition are layers of silty and sandy clays with pebbles and boulders and clayey sands, which occur in the basin's watershed. In the area of the discussed catchment almost all of its surface is covered with marly sands and sands, silty sands, sand sludges, silts and clays - all of them classified as glacilacustrine deposits. The thickness of these sediments is up to 4 m. These sediments gave rise to the creation of very fertile soils classified as chernozems and brown soils (Quaternary – Pleistocene). These sediments, sometimes underlain with glacial clays, are located on the fluvioglacial sands forming the first aquifer. The thickness of sandy sediments ranges from 7 to 12 m in the west and grows to the east, reaching locally up to 25 m. Along the shores of lake Miedwie at the level of the Gowienica catchment, there is elevation of Neogene sediments up to a maximum of 12 m above sea level and width from a few hundred to over 4000 m. This elevation blocks direct outflow of water towards the Miedwie lake.

After the ice sheet retreated and the start of surface water outflow to the Baltic Sea, the level of the ice-damned lake waters gradually decreased from about 36 to 15 m above sea level. Uncovering the part of the bottom of the former stand gave rise to the soil-forming process.

The Gowienica river basin, due to the presence of the highly draining Płonia valley with the Miedwie lake in the east and the Mała Ina river at NE from Gowienica, is poorly developed.

Land use of the Gowienica catchment consists of: arable land 85,72% of the basin area, 5,43% meadows, 2,3% arable lands, 2,2% forests, the area of the former air base - 3.5%, allotment gardens - 1.16%, others - 0.69% of the area.

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To understand character of groundwater connection with the surface waters of the Gowienica Miedwiańska river and the Miedwie lake itself, and thus the assessment of pollution migration, the knowledge of the hydrostructure of the Quaternary aquifer is of fundamental importance. Within this multiaquifer formation, two water-bearing horizons can be separated: upper intermoraine aquifer and lower intermoraine aquifer.

Only upper intermoraine aquifer is used for the purpose of drinking water production, due to its distribution and abundance. This level is characterized by a unconfined or poorly confined water table. Based on the archive sediment granulometric analysis from the boreholes, it can be concluded that the level filtration coefficients are in the range of 2 to 20 m/d. They correspond to fine-grained sands, sometimes on the border with silty sands. Variable thickness of the aquifer results in high variability of conductivity, reaches from about 16 to over 100 m2/d. Observations in the water gauge section closing the Gowienica catchment, allow to determine the supply of the river with groundwater in the amount of 0.1 - 0.2 m3/s. The maximum flows associated with floods after heavy rainfall reach 1.2 m3/s.

The water circulation in the catchment was recognized thanks to the hydrological model SWAT. This model also allowed to identify and assess the size of nitrogen and phosphorus balance in the catchment. As a result of modeling, based on real time-variable data, compiled for 2017 (climate, fertilization, crop types), a nitrogen and phosphorus balance was obtained in the Gowienica Miedwiańska catchment per hectare area. The analysis of the balance shows that the percentage of point pollution is only 1.91% of the total river nitrogen load, and for phosphorus - 0.28%. %. The remaining load of nitrogen and phosphorus comes from the area pollution associated with agriculture. Nitrogen discharge from the basin in 2017 was estimated in the model at 92.3 t, which in terms of the average concentration in the outlet profile gives 7.3 mgN/dm3.

8.2 Executive summary in Polish

Model konceptualny zlewni Gowienicy Miedwiańskiej obejmuje zrozumienie warunków naturalnych zlewni które mają wpływ na bilans ilościowy wód, takich jak: budowa geologiczna, występowanie gleb, ukształtowanie zlewni oraz warunki klimatyczne (opady, temperatury, nasłonecznienie, rozkład opadów w ciągu roku) jak i czynników determinujących jakość wód powierzchniowych i podziemnych, w tym obciążenia zlewni w zakresie pierwiastków biogenicznych (azot i fosfor) – punktowe oraz obszarowe. Zakres czynników wpływających na jakość wód podziemnych i powierzchniowych jest szeroki. Wśród nich należy wymienić zanieczyszczenia punktowe wód powierzchniowych związane ze zrzutem ścieków, zanieczyszczenia punktowe związane z niekontrolowaną infiltracja do gruntu odcieków związanych z hodowlą zwierząt oraz zanieczyszczenia obszarowe związane nawożeniem upraw.

Zlewnia Gowienicy Miedwiańskiej w większości ukształtowała się na obszarze Zastoiska Pyrzyckiego. Pod koniec ostatniego zlodowacenia, od 14 do 15 tys. lat BC, był to obszar rozległego jeziorzyska, którego pozostałością w najgłębszym miejscu jest dzisiejsze Jezioro Miedwie. Efektem sedymentacji w klimacie peryglacjalnym było osadzenie się na powierzchni dna piasków ilastych, pylastych, mułków i iłów. Z otaczających wysoczyzn spływały fragmenty wytapiającego się lądolodu oraz gliny

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lodowcowe, których śladem po wytopieniu i redepozycji są warstwy glin pylastych oraz piaszczystych z otoczakami i głazami oraz piasków gliniastych, które występują w rejonach wododziałów zlewni. Na obszarze omawianej zlewni prawie całą jej powierzchnię pokrywają piaski i piaski margliste, piaski pylaste, mułki piaszczyste, mułki i iły - wszystkie razem zaliczone do osadów zastoiskowych (czwartorzęd – plejstocen). Miąższość tych osadów wynosi do 4 m. Dały one podstawę do wytworzenia się bardzo żyznych gleb zaliczanych do czarnoziemów i gleb brunatnych. Osady te, czasem podścielone glinami lodowcowymi, położone są na piskach fluwioglacjalnych tworzących pierwszy poziom wodonośny. Miąższość osadów piaszczystych wynosi od 7 do 12 m na zachodzie i rośnie w kierunku wschodnim, osiągając lokalnie do 25 m. Wzdłuż brzegu jeziora Miedwie na wysokości zlewni Gowienicy, występuje wyniesienie osadów trzeciorzędowych do rzędnej maksymalnie 12 m n.p.m. i szerokości od kilkuset do ponad 4000 m. Wyniesienie to blokuje bezpośredni odpływ wód w kierunku jeziora Miedwie.

Po ustąpieniu lądolodu i uruchomieniu odpływu wód powierzchniowych do Morza Bałtyckiego, poziom wód zastoiska stopniowo obniżał się z około 36 do 15 m n.p.m. Odsłonięcie części dna dawnego zastoiska dało początek procesowi glebotwórczemu.

Zlewnia rzeki Gowienicy, z uwagi na obecność silnie drenującej doliny Płoni z jeziorem Miedwie na wschodzie i rzeki Mała Ina na NE od Gowienicy, jest słabo rozwinięta.

Zagospodarowanie zlewni Gowienicy określonego w bazie danych Corine Land Cover 2012. Grunty orne zajmują w zlewni 85,72% powierzchni, łąki – 5,43%, tereny zabudowy wiejskiej – 2,3%, lasy - 1,2 %, teren dawnej bazy lotniczej – 3,5%, ogrody działkowe – 1,16%, inne – 0,69% powierzchni.

Dla analizy związków wód podziemnych zanieczyszczonych substancjami pochodzącymi z nawożenia lub z hodowli, z wodami powierzchniowymi rzeki Gowienicy Miedwiańskiej i samego jeziora Miedwie, podstawowe znaczenie ma znajomość budowy hydrostrukturalnej czwartorzędowego piętra wodonośnego. W obrębie tego piętra wydzielić można dwa poziomy wodonośne: międzyglinowy górny poziom wodonośny oraz międzyglinowy dolny poziom wodonośny. Znaczenie gospodarcze, z uwagi na rozprzestrzenienie i zasobność, posiada poziom międzyglinowy górny. Poziom ten charakteryzuje się swobodnym, lub słabo napiętym lustrem wody. Na podstawie wykonanych analiz uziarnienia prób pobranych z wykonanych otworów można stwierdzić, że współczynniki filtracji poziomu mieszczą się w przedziale od 2 do 20 m/d. Odpowiadają one piaskom drobnoziarnistym, niekiedy na pograniczu z piaskami pylastymi. Zmienna miąższość poziomu powoduje, że przewodność zmienia się od około 16 do ponad 100 m^2/d.

Obserwacje w przekroju wodowskazowym zamykającym zlewnię Gowienicy, pozwalają określić zasilanie rzeki wodami podziemnymi w ilości 0,1 – 0,2 m^3/s. Przepływy maksymalne, związane z wezbraniami po intensywnych opadach dochodzą do 1,2 m^3/s.

Krążenie wód w zlewni zostało rozpoznane dzięki modelowi hydrologicznemu SWAT. Model ten pozwolił również na zidentyfikowanie i ocenę wielkości składników bilansu azotu i fosforu w zlewni. W wyniku modelowania, dla modelu podstawowego opartego na rzeczywistych danych zmiennych w czasie, zestawionych dla roku 2017 (klimat, nawożenie, rodzaje upraw), uzyskano bilans azotu i

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fosforu w zlewni Gowienicy Miedwiańskiej w przeliczeniu na hektar powierzchni. Analiza bilansu pokazuje, że udział procentowy zanieczyszczeń punktowych wynosi dla azotu to zaledwie 1,91% całkowitego obciążenia rzeki azotem, a dla fosforu – 0,28%. %. Pozostały ładunek azotu i fosforu pochodzi z zanieczyszczenia obszarowego związanego z rolnictwem. Odpływ azotu ze zlewni w 2017 roku oceniony został w modelu na 92,3 t, co w przeliczeniu na średnie stężenie w profilu ujściowym daje 7,3 mgN/l.

8.3 General description

Gowienica river is a relatively small river of some 15 km length, located in the north-western part of Poland. It constitutes one of the inflows to Lake Miedwie, which is a water source for the city of Szczecin – the capital of the Westpomeranian region. The Miedwie surface water intake supplies water to 330 000 people. Area of the Gowienica catchment is characterised by very good agricultural soils, hence it is dominated by intensive arable farming. There are 8 villages scattered within the Gowienica catchment with some 2600 inhabitants. There are 3 municipal groundwater intakes within catchment area, three wastewater treatment facilities with variable technologies and capabilities discharging directly into the Gowienica river.

The Gowienica catchment lies within a Nitrates Vulnerable Zone (NVZ) and Miedwie water intake protection zone. Monitoring within the area has been ongoing since 1982 including data on water quality (both surface and groundwater) and nitrate loadings. Despite large number of orders and bans introduced in land use management within the area, the problem of high nitrate concentrations in surface and groundwater feeding the lake still exists and despite the relatively low flows, the Gowienica river brings high loads of nutrients into the lake Miedwie (estimated at 15,5T/year of NO3). Inappropriate communal sewage systems might be an important source leading to nitrate problems in the area (although currently mainly attributed to agriculture). The relative contribution of different sources is still unknown.

8.4 Previous investigations

Quality of water in the lake Miedwie catchment has been observed for many years to assess impact of agriculture on water quality in the lake. Many monitoring programmes for surface and groundwater have been created, some of which still exist (Figure 8.1).

In order to determine share of pollutants brought to the lake from its direct catchment, the Institute of Technology and Life Sciences in Szczecin (former Institute of Land Reclamation and Grassland) in 1993 started a research in the catchment area of the Gowienica River, creating a monitoring programme that included monitoring of groundwater, surface water, rainwater, drainage water and sewage discharge. First studies were conducted between 1993 and 2014 and were later continued by a team of scientists from the West Pomeranian University of Technology in Szczecin (2015 – 2017). These studies have left a monitoring network, including shallow piezometers (observation boreholes) capturing the first water bearing horizon and a vast number of archival data. Some of observation points have been destroyed over the years due to intensive agricultural activities carried

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out on fields where monitoring boreholes were located. Archival data include physicochemical properties of examined waters, in particular nitrate concentrations.

Monitoring of surface and groundwater in the Gowienica catchment is carried out also by the Voivodship Inspectorate for Environmental Protection in Szczecin. Intensification of that water monitoring was introduced in 2006 due to establishment of a nitrate vulnerable zone (NVZ) in the catchment. Sampling points are identical with those from ZUT and ITP monitoring programmes.

During the communism in Poland, a military airport was located east of Miedwie, which resulted in soil pollution with oil-derived compounds. The airport was located within a recharge zone for the lake, from which water is abstracted by the Szczecin Water Services (ZWiK) - a water producing company. A monitoring network to control groundwater quality discharging into the lake from the airport's side was established by ZWiK. The network originally consisted of 19 piezometers, 13 of which were located within the Gowienica catchment. The research was focused on early detection of petroleum-derived pollutants to the lake through an underground inflow. However, in parallel observations of nutrient (NO3) as indicators of agricultural pollution were also carried out.

Physical and chemical analyses of surface waters discharging into the lake, including the Gowienica river, is also examined by the Szczecin Water Services.

PGI-NRI conducts observations of the quality and quantity of groundwater at two points located in the Gowienica Miedwiańska catchment in Kłęby and Koszewko. The borehole located in Koszewko was originally drilled as part of monitoring for the Miedwie intake, mentioned above, and was later taken over by the PGI-NRI for inclusion in the national groundwater monitoring network as part of WFD monitoring. Both, groundwater quality and quantity are observed in boreholes. Water level observations are carried out on a weekly basis. Water quality is carried out according to the national monitoring programme. Both boreholes are included in the operational and surveillance monitoring programmes. In addition to that, Koszewko borehole is equipped with an automatic datalogger to monitor water level changes on a daily basis.

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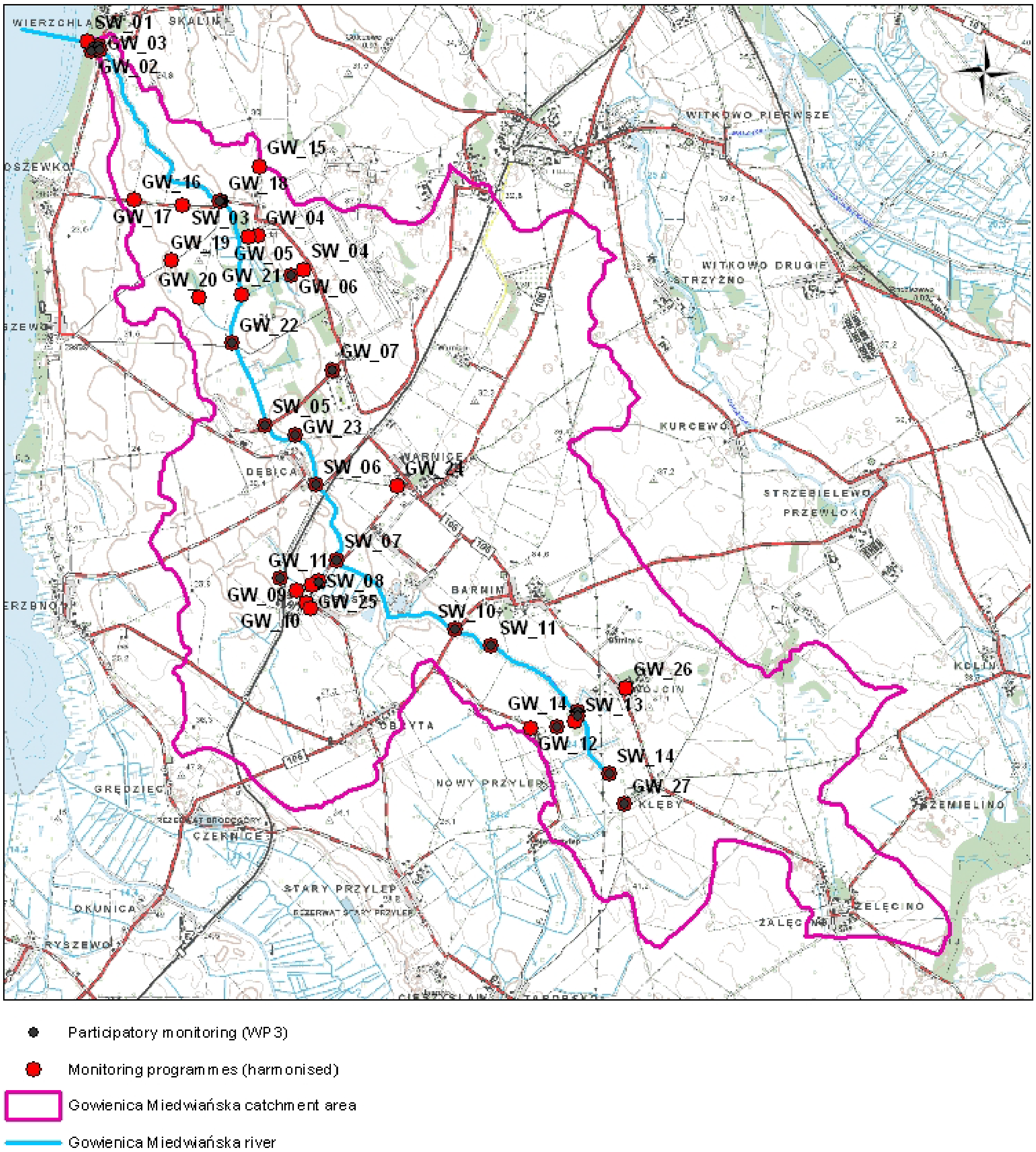

Figure 8.1 Monitoring programmes and Participatory monitoring under WaterProtect framework in Gowienica catchment area

Water quality monitoring is also carried out by the West Pomeranian Water Services (WZ), which abstracts groundwater for human consumption, i.e. supply of drinking water to the population of communes. Currently, water is abstracted from two groundwater intakes located in Wójcin and Warnice and is distributed to residents. In addition, water is also supplied from intakes located

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outside the pilot catchment - in Cieszysław and Wierzbno. Frequency and scope of parameters monitored is defined in respective water permits. Periodic water quality control is also carried out by the Voivodship Sanitary and Epidemiological Station, the purpose of which is to assess compliance of water quality with drinking water quality standards (DW Directive). Another water intake is located in Reńsko village and supplies an agricultural plant and inhabitants of the village. In addition to that, there are four factory intakes and private wells in the Gowienica catchment, where quality of water is only sporadically tested.

8.5 System description

8.5.1 Hydrology and Climate

Gowienica river catchment is located in the North-West Poland and has the surface of 69,23 km^2. The Gowienica river, which is 15,6 km long and of the average flow 0,15 m^3/s being one of the lake Miedwie inlets, is mostly regulated. The Gowienica River is a small, shallow lowland river with small flows. It has very few tributaries, all of which are drainage ditches that collect water mainly from agricultural areas. The width of the riverbed is variable and ranges from 1.4-1.8 m on the upper river section, 1.8-2.2 m on the middle section and 2.0 m on the estuary. The average catchment height is 34 m, altitude - 40 m., and the average slope is 5.01 m/km. The average annual rainfall in the catchment area is about 500 mm, the average annual temperature is 7.5-8.0 0C, and the vegetation period lasts 210-230 days.

8.5.2 Soil types, Land use and drainage

Within the catchment area there are fertile soils formed of clay and water-based silt. The dominant types of soils are the chernozem soils (*Gleyic Phaeozems*) occurring mainly in the western part of the catchment and brown soils (*Eutric Cambisols*) occurring in the raised basin areas, mainly in the western part of the basin.

Occurrence of fertile soils and favourable climatic conditions make the catchment area intensively utilized in agriculture, nearly 86% of the area is agricultural land. Forests occupy an area of less than 2.3% of the catchment. In the catchment area plant production dominates - 86% of agricultural land is arable land, meadows and pastures - 10%, a large part of land is reclaimed, and drainage water flow to melioration ditches or directly to the river. In addition to the production of crops including mainly cereals (wheat and barley) and industrial plants (sugar beet and rape), animal husbandry is also carried out in the catchment area. There is a large farm for cattle breeding, with 913 heads of cattle in 2016. In addition to that individual farmers own 115 heads of cattle and a total of 290 pigs (2016). Manure and slurry handling and storage is still not well solved on some farms. Since recent years large area farmers use monocultures and grow industrial plants (e.g. corn) using very high doses of fertilizers and pesticides, causing high risk for environment, especially water quality. A new problem is the import of various types of wastes (eg biogas plant waste) used as natural fertilizers.

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8.5.3 Geology

Over 90% of the catchment area of the Gowienica Miedwiańska river is located in the Pyrzyckie ice-dammed lake. At the end of the Pleistocene, the catchment area of Gowienica was part of a vast lake, released from the ice preserving the gutter of lakes: Miedwie, Będgoszcz, Żelewo and Płoń. From the surface to the depth from a few to about 100 meters, the area is built of glacial and fluvioglacial Pleistocene deposits. Holocene sediments occur on the surface, mainly river, silts and organic sediments (peats) in the Gowienica river valley and in small valleys of smaller watercourses and in thaw depressions (Figure 8.2). The direct basement of the Quaternary formations are Miocene sediments. The relief is very diverse. There is a number of humps with heights up to +10 m above the sea level and depressions up to -100 m beneath the sea level. There is no connection between the formation of the Quaternary sediment bed and the shape of the ice-dammed lake existed during the North Polish glaciations.

8.5.3.1 Quaternary - Pleistocene

Quaternary glacier deposits are usually the last two glaciations. They are mainly represented by complexes of boulder clays, separated by lacustrine or fluvioglacial deposits. In the previous studies of the area, no interglacial deposits were found. Almost in the entire research area, the Neogene sediments' roof is located high, therefore the thickness of the Quaternary sediment cover is from 6 m in Koszewo (west of the discussed basin) and 8 m in Słotnica, up to 40 m in Burzykowo and probably 70 - 80 m north from Dębica and Warnica region. In the southern and eastern part of the basin, the roof of Neogene sediments decreases to about -100 m beneath sea level, thanks to which the thickness of Quaternary sediments reaches 130 m.

In the area of the discussed catchment almost all of its surface is covered with marly sands and sands, silty sands, sand sludges, silts and clays - all of them classified as glacilacustrine deposits. The thickness of these sediments is up to 4 m. These sediments gave rise to the creation of very fertile soils classified as chernozems and brown soils (Figure 8.2).

The surface deposits are associated with the recession of the glaciers of the Pomeranian phase. Dammed lake deposits do not form a continuous cover and often interlock with dusty tills. In the current geological literature on this area, these sediments were treated as of the highest terraces of Pyrzycki's ice-dammed lake. These deposits usually lie on a thin layer of sandy glacial till of the Pomeranian phase or directly on the fluvioglacial sands of the same age. The thickness of Pomeranian tills is variable and they characterize with change in colour – brown in roof parts, grey deeper.

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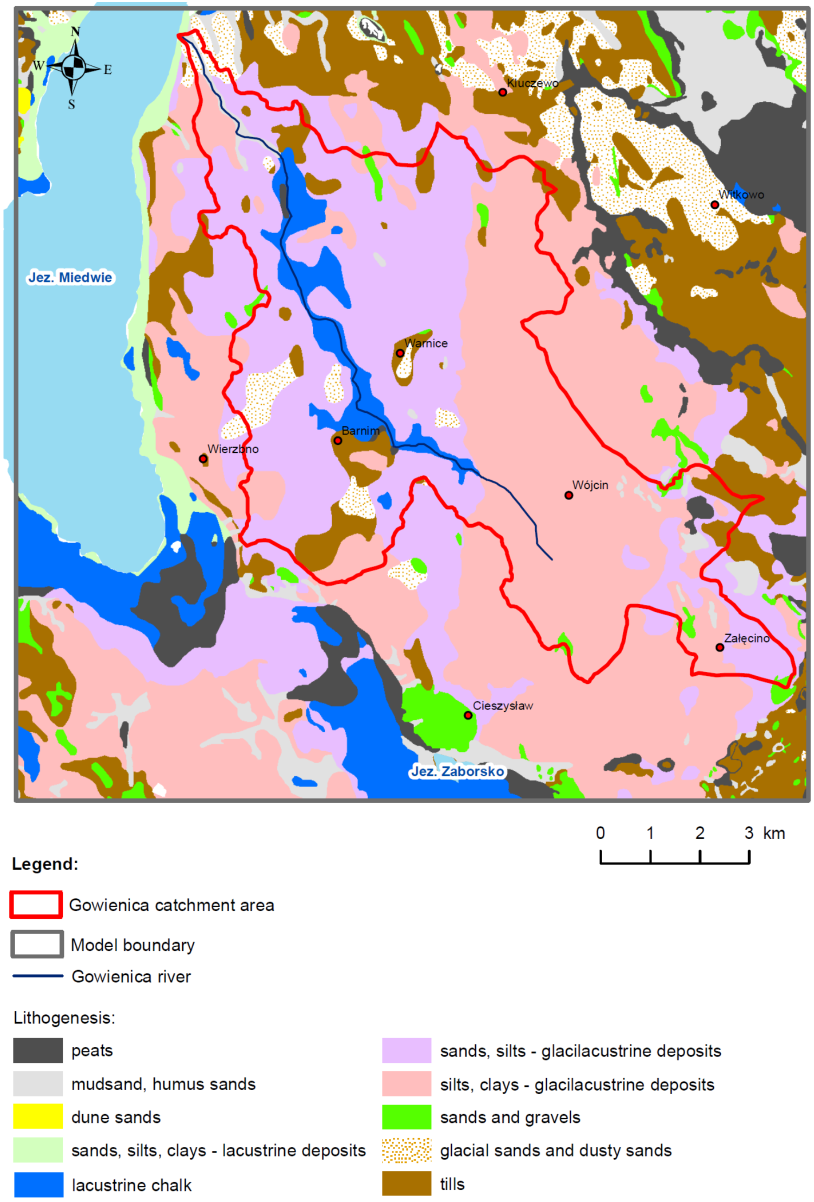

Figure 8.28 Geological map of surface deposits in the area of Gowienica Miedwiańska catchment.

In the northern part of the area, these tills form a thin layer of 2 to 5 m and may not be locally present, and then the sediment deposits lie directly on the fluvioglacial sands of the Pomeranian glacier transgression. A similar thickness is achieved by these tills in the area between Koszewko and Słotnica, except that here there are large areas where glacial tills and glacilacustrine deposits are reduced to a thickness of about 0,5 m and form a soil layer under which there are fluvioglacial sands. The tills do not occur on the slope between the plateau and the shore of Lake Miedwie. However, directly on the surface reveal the fluvioglacial sediments of the Pomeranian phase or older glacial tills. In the southern part of the area, where shores of the lake is higher elevated, the thickness of tills increases to about 8 m.

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Beneath sediments of the Pomeranian phase, the most common are the fluvioglacial sands originating from the Pomeranian glacier transgression. These sands fill depressions in older glacial tills (Leszno phase) or form extensive sandr. In the northern part of the area, the occurrence of the described above sediments is not continuous. They fill flat-bottomed shallow depressions. There is also a lack of these deposits on a considerable surface, then Pomeranian glacial tills lie directly on the tills of the Leszno-Poznań phase. The thickness of sandy sediments ranges from 7 to 12 m in the west and grows to the east, reaching locally up to 15 m. In the southern part of the catchment area, where the location of the Miocene sediment roof is lowered, the described fluvioglacial deposits are a continuous sandy cover which spreads from Lake Miedwie to the eastern boundaries of the catchment (Figure 8.2). The thickness of sands, which are fine-grained and mixed with small pebbles, ranges from 15 to 25 m. These sediments form the first aquifer.

The described sandy deposits on the Neogene elevation near the Miedwie lake are located directly on Miocene silts and muds, or on glacial tills of the Leszno-Poznań phase. In the whole area of research, these tills constitute, apart from the mentioned Neogene elevation zone at Lake Miedwie, almost continuous cover of sediments with a thickness from a few to over 30 m. The height of the roof of these tills is variable. In the north they appear on the ordinate from 20 to 30 m above sea level, while in the southern part from 0 to 10 m above sea level. They constitute the substrate of the first aquifer. Under the mentioned tills, usually as fillings of fossil valleys, there are fluvioglacial sands and gravels originating from the older stages of the North Polish glaciation. The thickness of these sediments reaches locally up to 30 m, but their spread is limited. These sediments form the second aquifer, which has little utility meaning.

8.5.3.2 Neogene

On the basis of the descriptions of archival drilling, it can be stated that the Neogene settlements near the shores of Lake Miedwie are strongly disturbed by glacitectonics. The upper Miocene sediments are represented by dark brown silts, with characteristic leafy separateness, with numerous tectonic mirrors, indicating strong glacitectonic deformations. Other sediments are dusty sands and dusts with a high content of muscovite, almost devoid of calcium carbonate, locally passing into fine-grained sands, light-gray and brown. These sands, very similar to quaternary sediments, were found in the P29 drilling carried out at Gowienica near Słotnica. In those sands at a depth of 24 m, a brown coal deposit was found, also exhibiting the characteristics of strong tectonic engagement. Sludges similar to those in borehole No. 29 were found in well drilling in Koszewko and in Wierzchląd. In drilling at the site of a former slaughterhouse in Koszewo under the Quaternary sands, the presence of strongly illustrated black silty loams and claystones classified as Miocene was observed.

Summing up, it can be concluded that along the bank of Lake Miedwie at the level of the Gowienica catchment, Neogene sediments are elevated to the ordinate to a maximum of 12 m above sea level and width from a few hundred to over 4000 m. The genesis of this elevation is complex. It is probably a fragment of the original Neogene surface remodeled and additionally piled up near the gutter of the Miedwie lake due to the glacitectonic processes.

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8.5.4 Hydrogeology

In the Gowienica catchment area there are two water-bearing horizons: Neogene and Quaternary. To understand character of groundwater connection with the surface waters of the Gowienica Miedwiańska river and the Miedwie lake itself, and thus the assessment of pollution migration, the knowledge of the hydrostructure of the Quaternary aquifer is of fundamental importance. Within this multiaquifer formation, two water-bearing horizons can be separated: upper intermoraine aquifer and lower intermoraine aquifer.

The upper intermoraine aquifer (I water-bearing horizon) is associated with the fluvioglacial sediments from the period of glacier transgression of the Pomeranian phase. This layer occurs almost continuously, with the exception of the slope of the high plain close to Miedwie lake, where the high elevation of Neogene sediments has resulted in the reduction of sandy sediments (Figure 8.3). On the basis of archival geological drilling and geoelectrical research, it can be stated that on the north from Koszewo there is no contact of this layer with the Miedwie lake basin. This contact is possible further south of Koszewo towards the region of Dębica. Moreover, further south of this area, there is no connection of the described aquifer with the Miedwie lake basin again.

The upper intermoraine aquifer is characterized by a unconfined or poorly confined groundwater table, however, where the complex of Pomeranian till is thicker, the water mirror is confined. Based on the granulometry analysis of the waterbearing sediments, it can be concluded that the filtration coefficient ranges from 2 to 20 m/d, however although the values are usually in the range of 5 a 10. They correspond to fine-grained sands, sometimes on the border with dusty sands. The average filtration coefficient for the aquifer was calculated to 8.85 m/d. Variable thickness of water-bearing horizon leads to variety of conductibility from about 16 to over 100 m^2/d. In the north-western part of the area, conductibility values are identified in the range of 0-25 m^2/d. In the middle part of action lab, in the vicinity of Słotnica and Koszewo, where the aquifer is in hydraulic connection, this parameter varies from 50 to 100 m^2/d. The highest values of conductibility occur in the region of Warnice, Dębica and to the south - over 100 m^2/d. Lastly, in the area of the former airport, between Słotnica and Burzykowo, aquifer is characterized by the value of 25 to 50 m^2/h.

Based on groundwater table observations in “Miedwie” intake monitoring boreholes, in which upper intermoraine aquifer was found, maps of hydroisohyps were produced to assess groundwater dynamics. Therefore, Gowienica Miedwiańska is recognized as a poorly draining river. This confirms the results of mathematical modeling described in section 8.6 In the northern part of the catchment, where a large area without upper intermoraine aquifer occurs, Gowienica flow almost without draining nor groundwater recharging. To the south of Słotnica, the Gowienica River drains groundwater from pollution zones within the former Soviet Army airport (currently, the area is developed as an agricultural area, some parts remained as wasteland). The drainage scale on the west bank of the river is small. In the northern vicinity of Dębica village, the border of groundwater watershed of Gowienica catchment runs about 300 m to the west from the river. Gowienica supplies the aquifer on the west bank. Further to the north up to Słotnica, the drainage from the west bank of Gowienica does not extend further than 300 - 400 m. To the south of Dębica, the river has a clearly

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draining nature, the range of groundwater runoff to the river is extended especially in the right-bank part of the catchment.

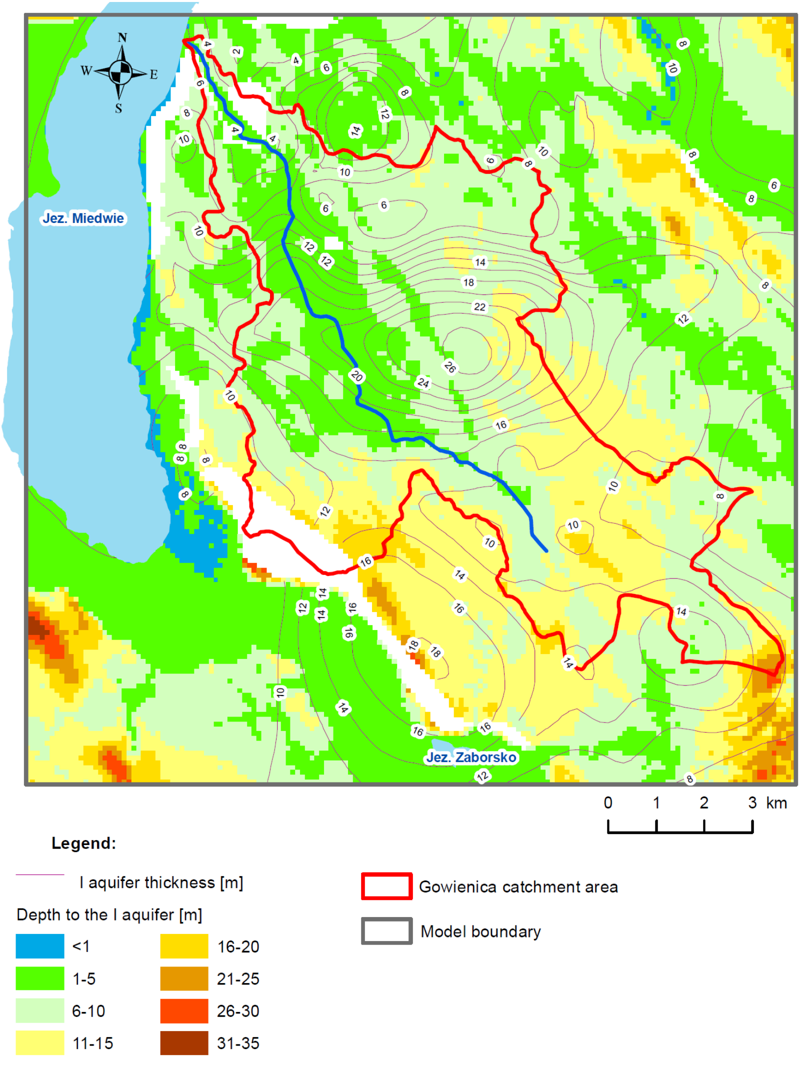

Figure 8.4 First aquifer thickness and depth of occurrence map in the Gowienica catchment area.

The Miedwie lake drains upper intermoraine aquifer within the area which is situated on the west Gowienica river bank, where link between those two horizons occurs. In regions without existing connection, hydraulic gradient is very small. Close to Koszewko village, the hydraulic gradient is I = 0.002. Bearing in mind the path between the area where losing streams are formed and drainage zone (south of Koszewo), which is about 2500 to 2000 m, the time of water exchange in the aquifer in this region takes 300 - 350 years. Long water exchange time, in a layer practically without any isolation from above, significantly affects the groundwater quality.

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The lower intermoraine aquifer (II water-bearing horizon) appears as a filling of fossil valleys and as a sandr in the south-eastern part of Gowienica catchment (Figure 8.4). Connection between this aquifer and Miedwie lake has not been confirmed by geological drillings. What is more, hydrogeological boreholes in the northern part of the basin where made, which did not proved the existance of this aquifer here. Directly under the first aquifer bottom tills, there are Miocene deposits. In the drilling situated in the vivinity of Słotnica, dusty sands classified as Miocene were bored at a depth of 8 m. This leads to a conclusion, that if the lower intermoraine aquifer exist on a significant depths, its vulnerability to pollution is highly limited and can be regarded as non-vulnerable. In the south-eastern part of the catchment, in the borehole in Wójcin village, the roof of the second water-bearing horizon was found on the ordinate of about -70 a.s.l. This aquifer is not exploited within Gowienica catchment area.

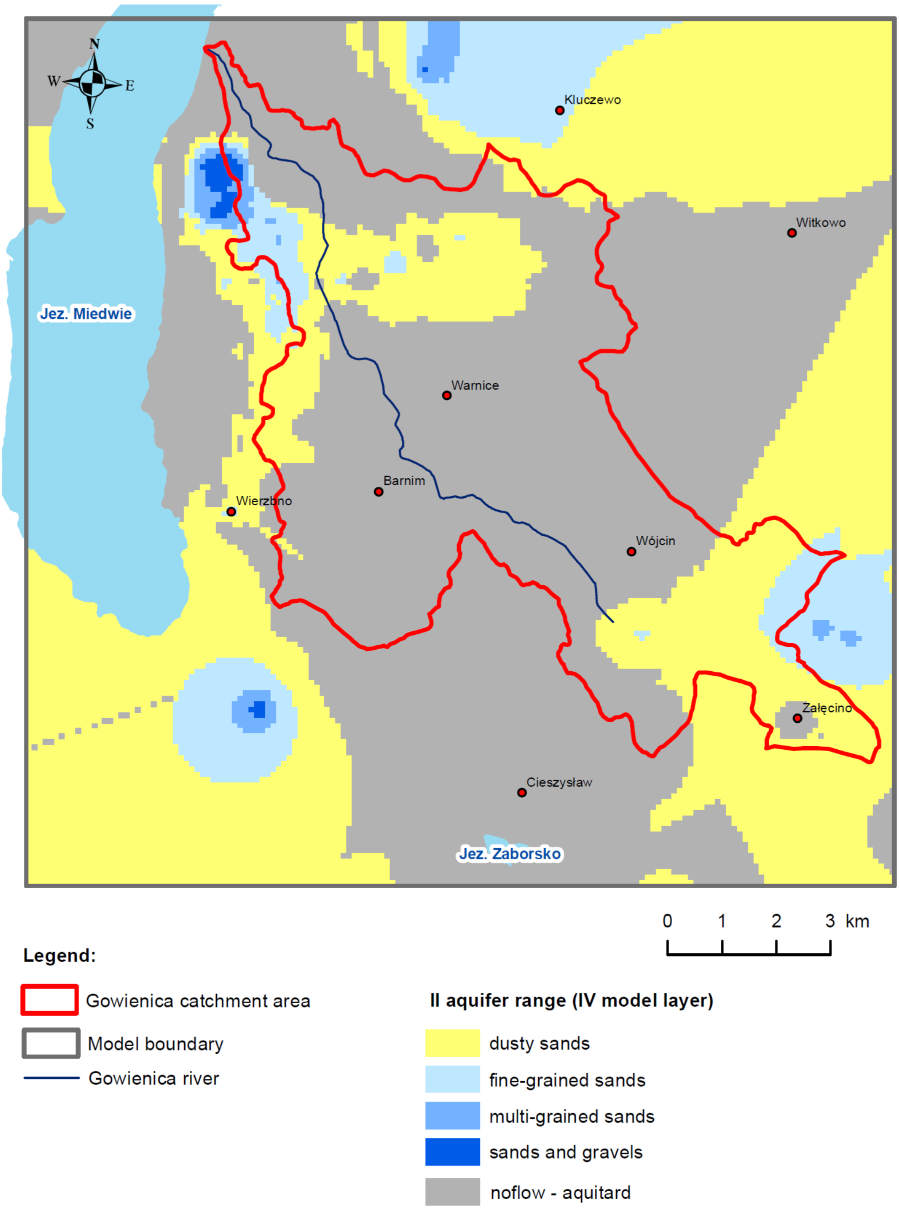

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Figure 8.5 The range of occurrence of the lower intermoraine aquifer and Neogene aquifer.

Neogene waterbearing sediments were found in a narrow belt, several hundred meters to a thousand meters wide on the east side of Miedwie lake. Dusty sands and fine-grained sands lay on ordinate from -15 to -30 m a.s.l in Wierzchląd, Koszewko and Koszewo. Above the aquifer there are mudstones with brown coal deposits or sand sludge. The thickness of the Miocene aquifer is about 7 m in Koszewo, 14 m in Wierzchląd and about 22 m in Koszewko (the layer is not drilled, the thickness is based on geoelectric research). The water-bearing filtration coefficient is low and average from 0.49 m/d in Wierzchląd, through 16.9 m/d in Koszewo to 19.5 m/d. The Neogene aquifer, insulated in the roof part with poorly permeable deposits, probably does not remain in direct contact with the upper intermoraine aquifer. However, hydraulic contact with lower intermoraine aquifer is possible. When constructing the numerical model of groundwater flow, these levels were combined into one model (IV layer). Neogene groundwater, due to thick isolation is regarded as non-vulnerable to pollution from surface area.

8.5.4.1 Groundwater flow to the Gowienica river

On the basis of the numerical model, the time of groundwater flow to the Gowienica River was calculated (Figure 8.5). The results were performed on the MODPATH calculation module. As a maximum retrograde time step for the flow of groundwater from the river was assumed as 600 years. In each case, the inflow time calculated for a given trace (line) of groundwater runoff (in both aquifers) to the river was less than 600 years. The envelope of the designated water runoff lines to the river is the area of groundwater runoff to the river. This line shows the area from which conservative pollution can reach the river. This area does not include the southern part of the river basin, from which groundwaters flow to the Płonia River or to Mała Ina and SW part of the catchment (to S and W from Reńsko), from which groundwaters flow directly towards Miedwie lake.

Based on the indirect times of the inflow of water to the Gowienica River, 10 and 25 years isochrones were designated. Isochrones and the area of water runoff are marked in Figure 8.5 In the same model program, the range of water runoff to active groundwater intakes in the river catchment area was also determined.

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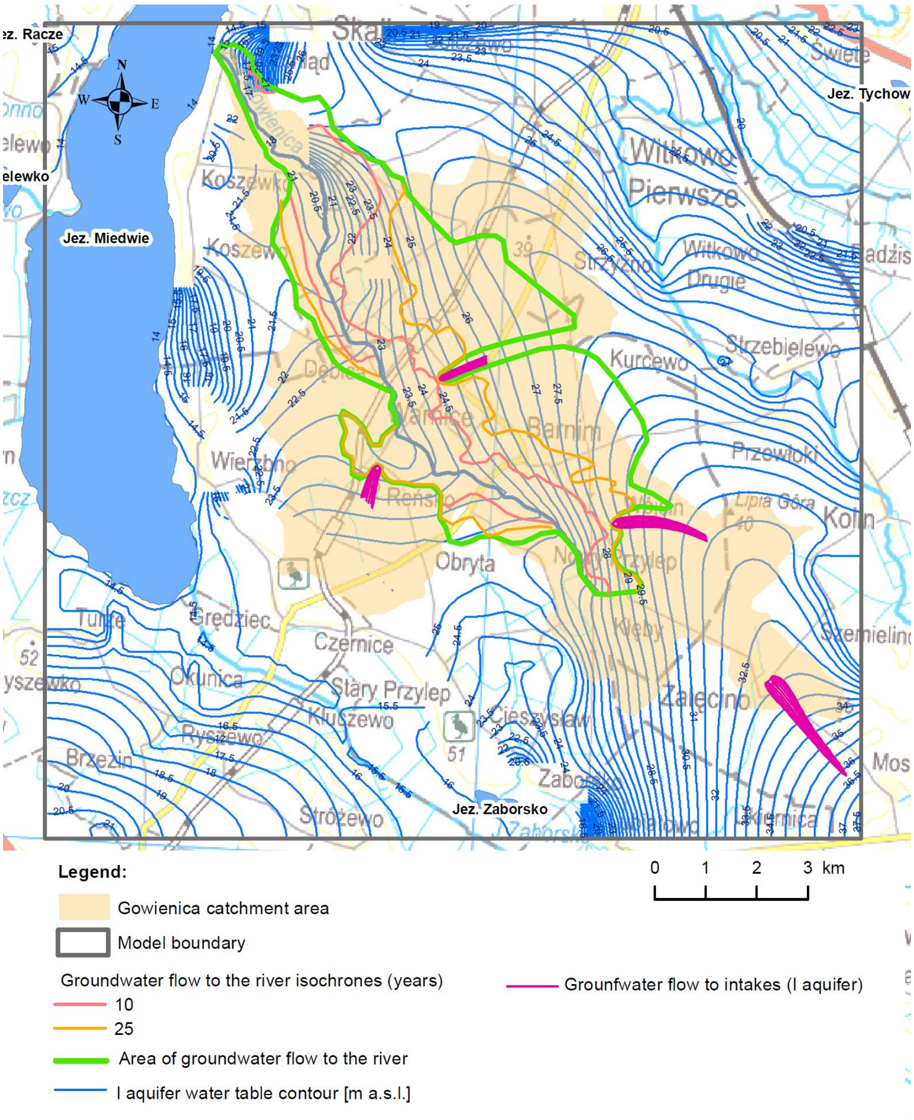

Figure 8.6 Areas of groundwater flow to Gowienica and groundwater intakes.

8.6 Conceptual model

8.6.1 Introduction

The conceptual model of the Gowienica Miedwiańska catchment includes understanding the natural conditions of the catchment that affect the quantitative balance of waters, such as: geological structure, occurrence of soils, the catchment geomorphology, climatic conditions (precipitation, temperatures, insolation, rainfall distribution during the year) and factors determining the quality of surface water and groundwater, including point and area of biogenic elements (nitrogen and phosphorus) within the catchment. The range of factors affecting the quality of groundwater and surface waters is wide. Among them, point pollution of surface water associated with the discharge of sewage, point pollution

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associated with uncontrolled infiltration into the ground of leachates connected with animal husbandry and area pollution resulted from fertilization of crops were identified.

To understand the conditions of groundwater circulation, the hydrogeological model was made, described extensively in Chapter 1.6. Water circulation associated with other components of the quantitative balance: surface run-off, intra-ground flow, evapotranspiration, infiltration into groundwater was identified thanks to the hydrological SWAT (Soil And Water Assessment Tool) model. This model also allowed to identify and assess the nitrogen and phosphorus balance in the catchment.

Thanks to these two models, a complementary model of the Gowienica catchment was obtained. Input data to the models are data from surface water and groundwater monitoring conducted by project stakeholders, both quantitative and qualitative and monitoring carried out as part of the Work Package 3 – *participatory monitoring*. This model allowed to understand what factors have the greatest impact on the quantitative and qualitative status of groundwater and surface waters in the catchment.

Natural conditions that have vast impact on the quantitative balance of waters in the catchment are its shape and geological structure as well as the resulting soil conditions as well as climatic conditions. The geological cross-section below is representative for the geological structure of the site (Figure 8.7).

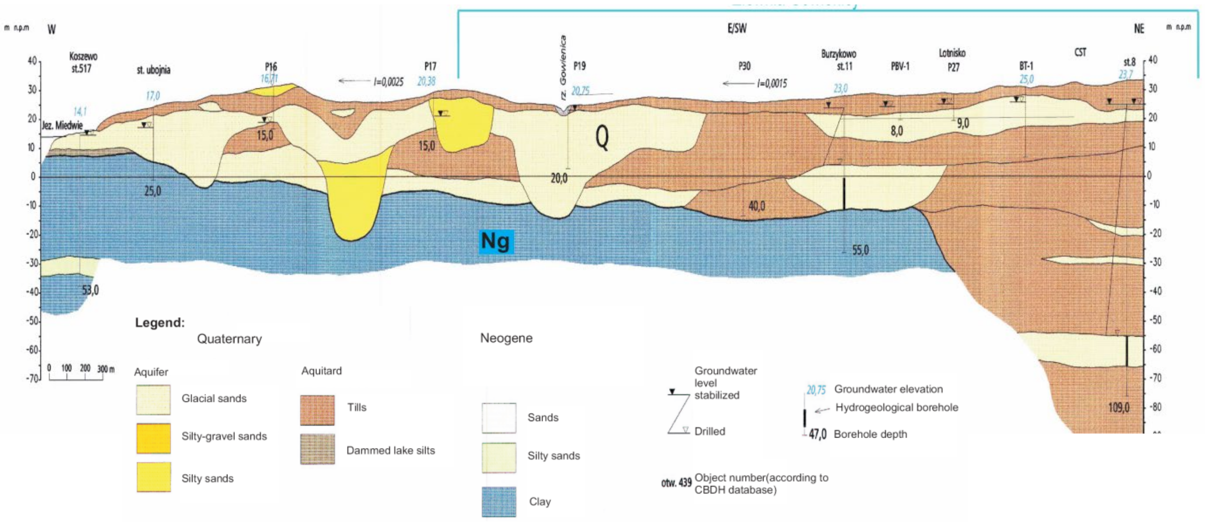

Figure 8.7 Hydrogeological cross-section through the middle part of Gowienica Miedwiańska catchment.

The quantitative water balance is presented in the drawing from the SWAT model (see below Figure 8.8). This model was made on the basis of data for 2017. In this year the highest

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amount of precipitation was recorded, which was 868 mm. The results of nitrogen and phosphorus balances in the catchment are presented in section 8.5.3

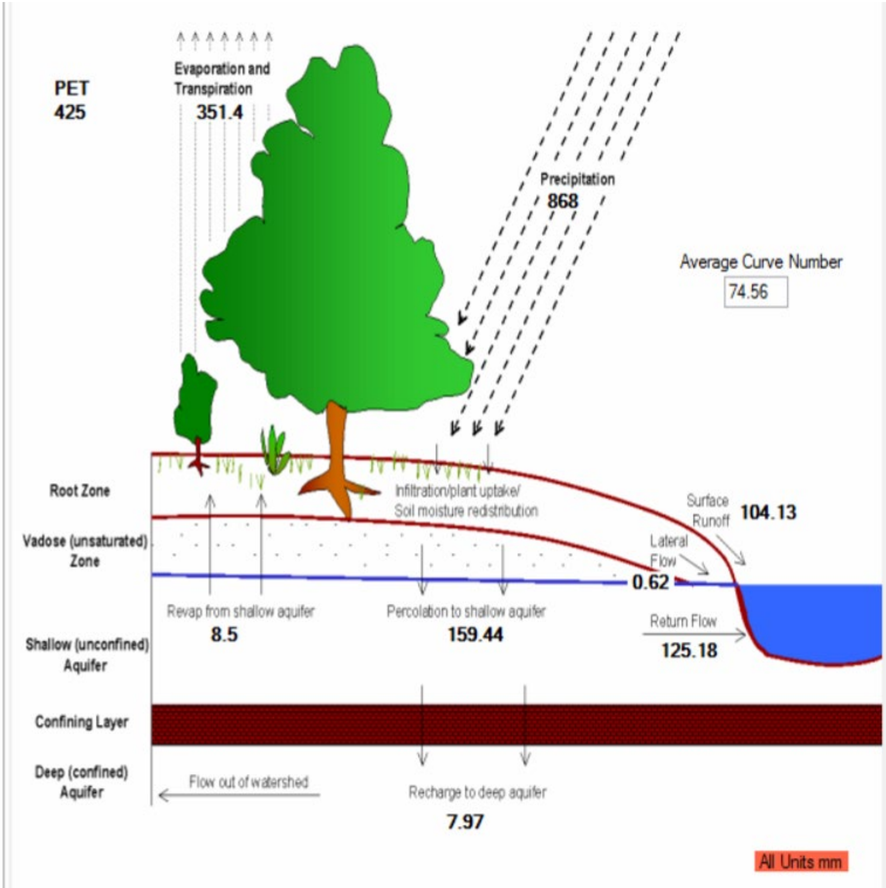

Figure 8.8 Water balance in Gowienica Miedwiańska catchment [mm] (analysis period 01/01/2017 - 31/12/2017)

8.6.2 Landscape Analysis

Landscape analysis includes the basin's morphology and its management. The mentioned landscape description areas are indirectly related to the geological structure and climate. Most of the Gowienica Miedwiańska basin was formed in the area of Pyrzyce ice dammed lake. At the end of the last glaciation, from 14 000 to 15 000 aBC, it was an area of a vast lake, which remnant in the deepest spot is today's Lake Miedwie. Due to the periglacial climate, clay sands, silty sands and clays were formed on the bottom. The fragments of the melting ice sheet and glacial tills flowed from the surrounding plateaux, which traces after melting and redeposition are layers of silty tills and sandy tills with pebbles and boulders and clayey sands, which occur in the basin's watershed. After the ice sheet resigned and the

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launch of surface water outflow to the Baltic Sea, the water level in the lake gradually decreased from approximately 36 to 15 m above sea level. Uncovering the part of the bottom of the former ice dammed lake initiated soil-forming process.

Vegetation entered the area covered by sediments with a large share of clays and sands. Thanks to the good permeability and high content of clay minerals and calcium carbonate in the surface layers of the stand, fertile soils developed on its surface. A significant role in the soil-forming process was played by the mild climate and shallow occurrence of groundwater (in the most part of the catchment area from 2 to 3 m depth), associated with a slight decline in the Gowienica basin and small denivelations in the catchment. Along the Gowienica, its valley and in the area of depressions, organic-mineral sediments were formed, as well as lake chalk and peat. These sediments provided the basis for the development of chernozems. At the higher levels of the basin, the conditions for the formation of brown soils arose, and in the highest levels - for the creation of chernozems (thanks to settling by step-like vegetation). The mineral substrate for these soils were often glacial sandy tills and clayey sands. Chernozems, developed on dusty deposits, are regarded as the most fertile, while those formed on marshy sediments are characterized as least fertile. The described soils occur on flat or slightly folded terrain, where surface waters have been regulated since the 12th century through the construction of ditches, and from the end of the 19th century, also drainage system.

The Pyrzyce chernozem in the Gowienica catchment area, and more broadly in the Pyrzycki area, is one of the most fertile soils in Poland, among others as a result of specific mild microclimate, with high temperatures in winter and a mild terrain.

The upper section of Gowienica was drained, and the water in the watercourse considered the beginning of the river appears as an outflow from the drain on an ordinate of about 25.0 m above sea level. Within the boundary of Gowienica catchment, there are also areas located southeast from initial section of the river, towards the Żalęcin village. The elevated terrain reaches 53 m above sea level (Figure 8.9). The river basin, due to the presence of the strongly draining Płonia valley with the Miedwie lake in the east and the Mała Ina river at northeast from Gowienica, is poorly developed. The inflows are mostly periodic drainage ditches in the areas of depressions through which Gowienica flows. There are no natural side tributaries to Gowienica river. The watershed between the Gowienica catchment and the Mała Ina catchment is lays higher than the watershed with Jez. Miedwie. Elevations in the watershed zone with Mała Ina range from 25 to 38 m above sea level. The watershed with Miedwie is mostly located on ordinates from 25 to 30 m above sea level, and only in its southern part reaches 45 m above sea level (Grędziec - Czernice area). The elevation of the catchment area decreases gently from the watershed to the river valley,

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which runs its waters on ordinates from 25 to 14 m above sea level at the mouth to Lake Miedwie.

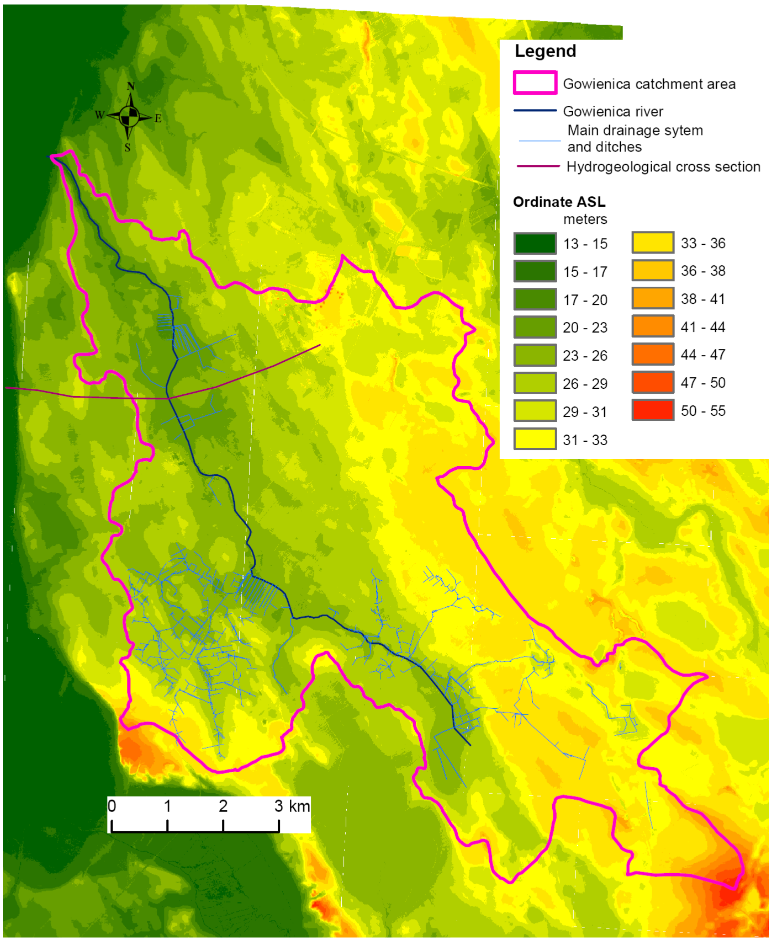

Figure 8.9 Digital terrain model made based on LIDAR radar photo.

Except for the areas occupied by the village buildings and individual households as well as areas of bushes and tree stands situated locally in the valley extensions and around the melt-shaped hollows, the entire catchment area is occupied by arable fields and meadows. The Gowienica riverbed is partly a ditch within the natural erosive and accumulation valley. In the upper part of Gowienica valley, the flat bottom reaches of the river slightly separates from the flat plain. The channel of Gowienica itself, with a bottom width of 1 to 2 m, cuts a flat plain on this section to a depth of 1 to 2 m, and arable fields and meadows reach the cutting edge. The riverbed in the upper and partly middle section to the Dębica village is strongly transformed by drainage works carried out since the end of the 18th century. North from Dębica, the riverbed is still regulated, but the valley has a wider

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bottom and locally runs through melting depressions. In this region, up to the former Słotnica village, the river banks are bushy, and the wider bottoms of the valley are covered by trees with alder forests and wild meadows, re-transforming into peat bogs. On the bottom of the Gowienica valley, there are sands, mineral-organic silts, limy sediments, lake chalk and peat (Holocene age). These sediments, at a short distance from the river bed (from 10 to 30 m), laterally contact lacustrine sediments or older, late-glacial hydrogenic sediments (lake chalk, gyttia). The lower section of the Gowienica valley, from Słotnica to Miedwie Lake, has a clear erosive character. The bottom of the valley has a width of 20 to 40 m. The width of the whole valley is from 100 to 150 m, but its edges are not readable in morphology. With the reference to the surrounding plain its bottom is cut to a depth of 2 to 4 m (Figure 8.9).

The spatial development of the Gowienica catchment is presented on the basis of land cover specified in the Corine Land Cover 2012 database (Figure 8.10). Arable land occupies 85.72% of the area in the catchment, 5.43% - meadows, rural areas - 2.3%, forests - 1.2%, the area of the former air base - 3.5%, garden plots - 1.16 %, others - 0.69% of the area (Figure 8.10).

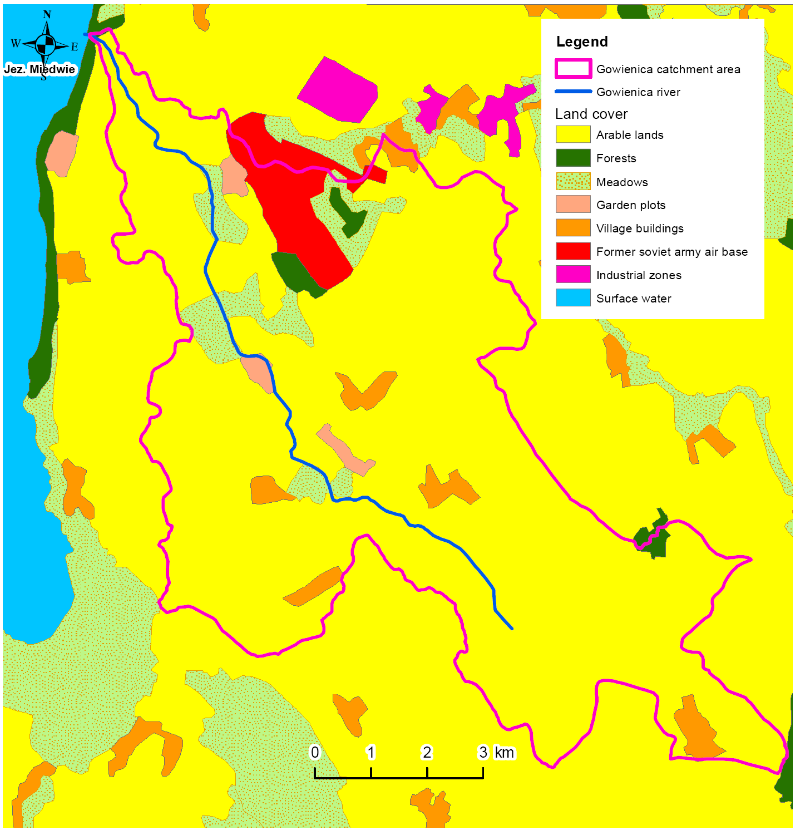

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Figure 8.10 Land cover of the Gowienica catchment according to Corine Land Cover 2012 (upper figure) and ortofotomap (lower figure).

8.6.3 Nitrate transport pathways

The circulation of nitrogen and phosphorus in the Gowienica Miedwiańska catchment was investigated using a model SWAT (Soil And Water Assessment Tool). The SWAT model is an advanced tool for modeling pollutant loads taking into account various forms of nitrogen and phosphorus, both mineral and organic. The model enables continuous simulation with a maximum calculation step equal to one day. The catchment area is divided by the model into smaller units called HRU, based on data provided such as land management, soil and agricultural characteristics as well as NMT. On the designated areas a simulation of N and P balance if performed by model SWAT. Finally, the data is transferred to the catchment level. The SWAT model takes into account a number of data: land use, crops, soils and climatic data (rainfall, temperatures, insolation, relative humidity, wind power). It is a non-commercial tool, the source code has been made available through the website along with full documentation and overlays for GIS (commercial and non-commercial) programs. The model can be modified and expanded to guarantee better quality results. During the construction of the SWAT model, a numerical model of the DEM ISOK terrain with a

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resolution of 1 m was used, which for the needs of analyzes was generalized to a resolution of 10 m. Based on the NMT in the SWAT model, 5 sub-basins were designated covering the Gowienica catchment, in which calculations were made regarding the quantitative water balance and the nitrogen and phosphorus balance.

The SWAT model is based on many soil parameters using the USDAT Soil Taxonomy classification, mainly used in the United States. Therefore, some difficulties were encountered while matching Polish soil types with those meeting the requirements of the model. The model uses the physical and chemical properties of soils. Physical properties determine a water and air flow in the soil profile, also a water cycle in the catchment together with a size of sedimentation. However, the chemical properties of soils affect mainly the circulation of organic matter. The most important physical properties required within the input data are the granulometric composition and associated other properties such as permeability, shrinkage or soil porosity. Required input data concerning soil granulometric composition were taken from soil and agricultural maps. Information on the amount of fertilization, i.e. introduced into the soil nitrogen and phosphorus loads, were obtained as a result of the questionnaire of farmers in the catchment. Then, data on fertilization were processed into surface data (GIS). Found values are probably underestimated: nitrogen max 203 - min 98 kg/ha, phosphorus max 70 - min 40 kg/ha. Data on the thickness of aeration zone were derived from the numerical model of groundwater flow, which is described in Chapter 1.6. As a result, the model based on real time variable data, compiled for 2017 (climate, fertilization, types of crops), a nitrogen and phosphorus balance was obtained in the Gowienica Miedwiańska catchment per hectare area.

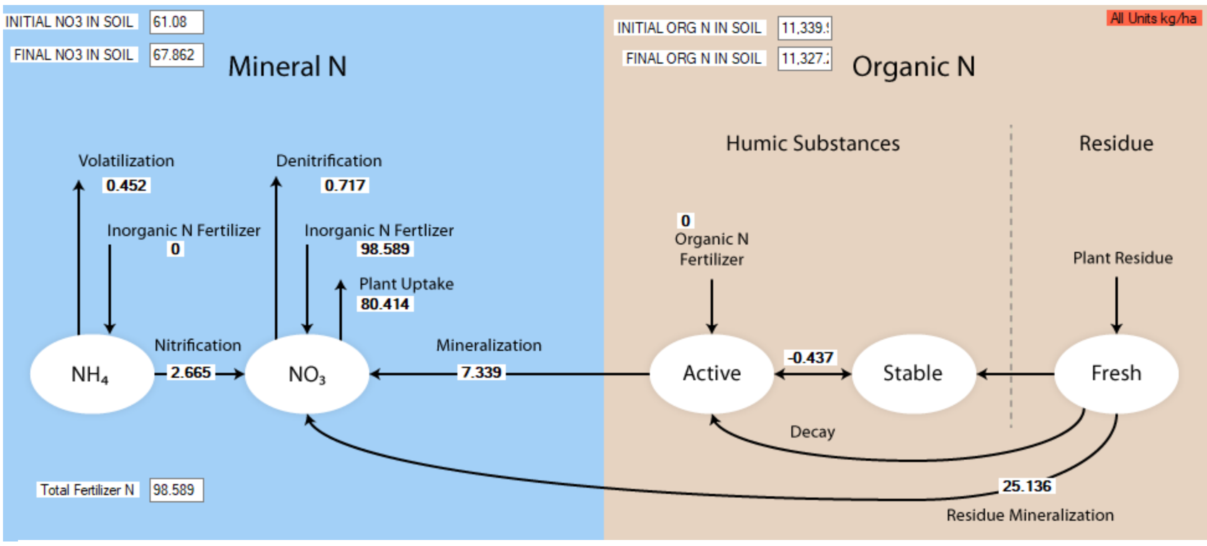

Figure 8.11 Nitrogene balance in Gowienica catchment.

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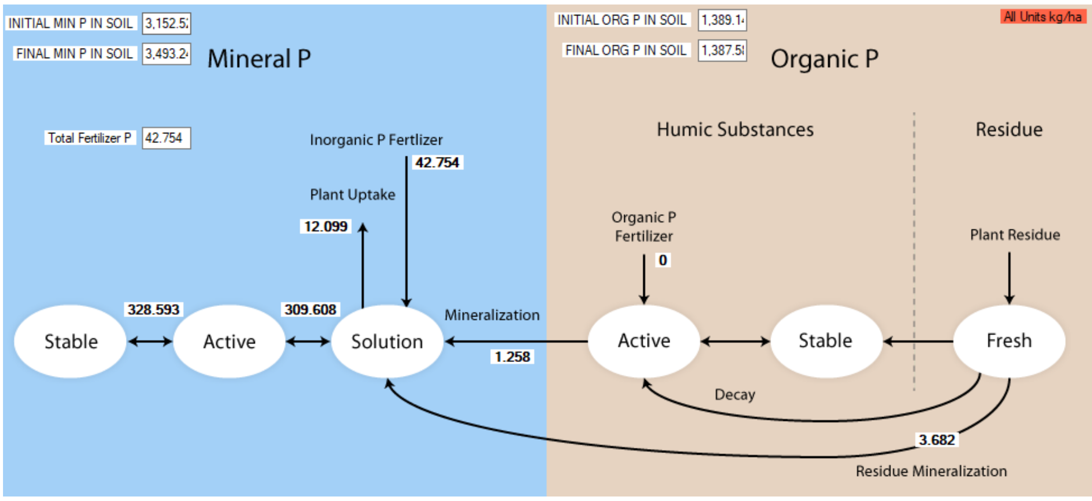

Figure 8.12 Phosphorus balance in Gowienica catchment.

On the basis of river water chemical analyses of the Gowienica, performed once a month, the average concentration of nitrogen at the level of about 4 mg/L (data for the period of 10.2017 - 07.2018) and phosphorus - 0.06 mg/L, were determined. Together with the river flow calculated in the model - 0.4 m3/s, an estimated average nitrogen outflow from the catchment in 2017 calculated on the basis on the average monitoring concentrations, was 50.45 tN. However an estimated average outflow of phosphorus from the catchment in 2017 is 0.76 tP. The above figures of nitrogen are about 50% lower than those calculated in the SWAT model. Loads of phosphorus calculated in SWAT are much higher than estimated loads.

The balance analysis shows that the percentage of point pollution is just 1.91% of the total river load of nitrogen, and 0.28% of phosphorus. The remaining load of nitrogen and phosphorus comes from the area pollution associated with agriculture. Nitrogen outflow from the catchment in 2017 was estimated in the SWAT model at the level of 92.3 t, which corresponds to average concentration in the estuary profile at the level of 7.3 mgN/L.

At the current stage of the model's development, there are some differences between nitrogene and phosphorus estimated concentration on the basis of monitoring data and those calculated in SWAT model. This may be the result of too short period of qualitative and quantitative observations at the point of catchment cross-section (Wierzchląd) and due to rarely collected water samples for chemical analyses. As a result , the data do not reflect the variability of nitrogen and phosphorus concentration in river waters during heavy rainfall, when an important factor increasing the inflow of these nutrients to the river is surface runoff.

The maps below present the amount of nitrogen fertilization and phosphorus as well as components of the nitrogen balance in individual sub-accounts (Figure 8.13 - 8.17).

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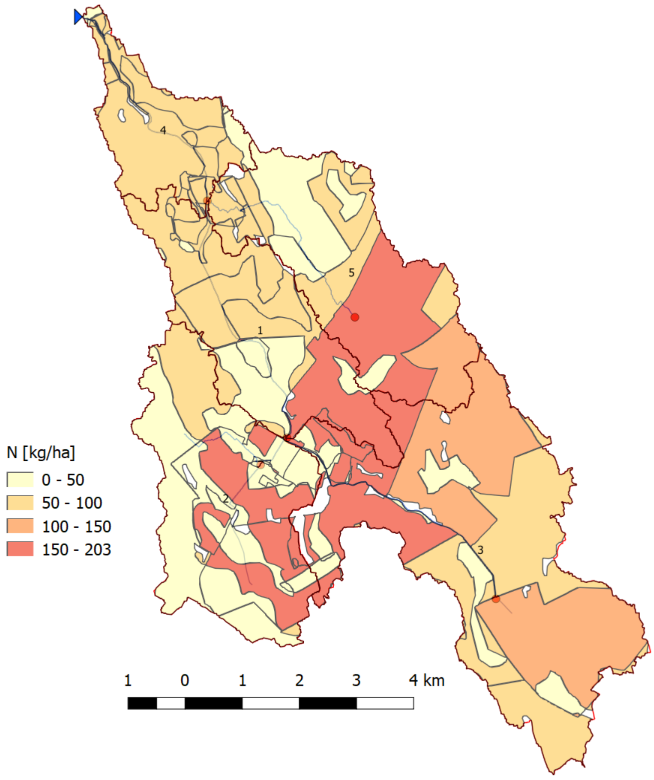

Figure 8.13 The amount of nitrogen fertilization [kg/ha]

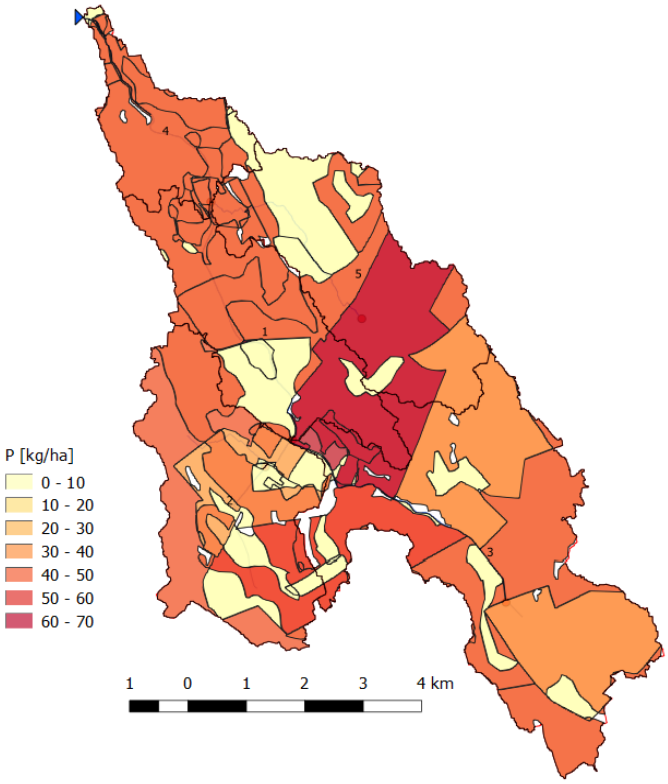

Figure 8.14 The size of phosphorus fertilization [kg/ha]

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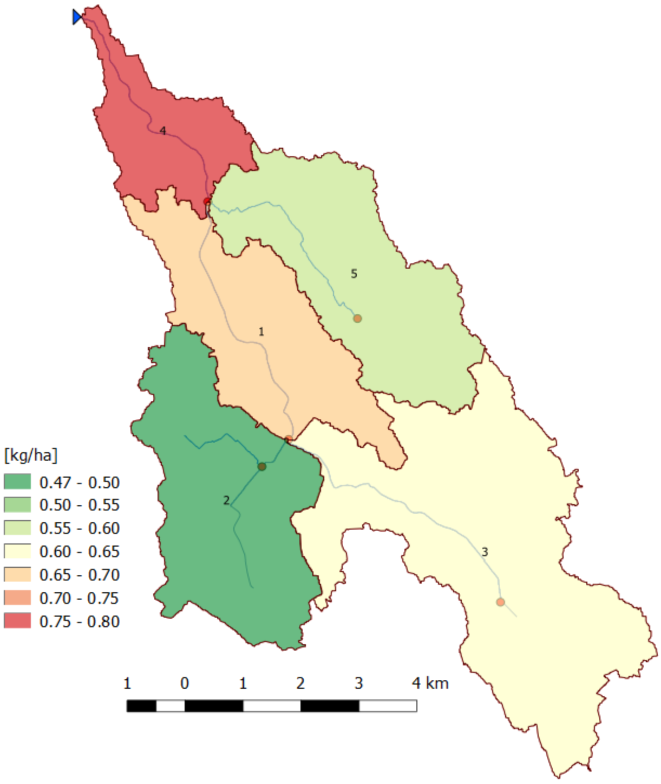

Figure 8.15 Nitrate contribution to groundwater [kg/ha]

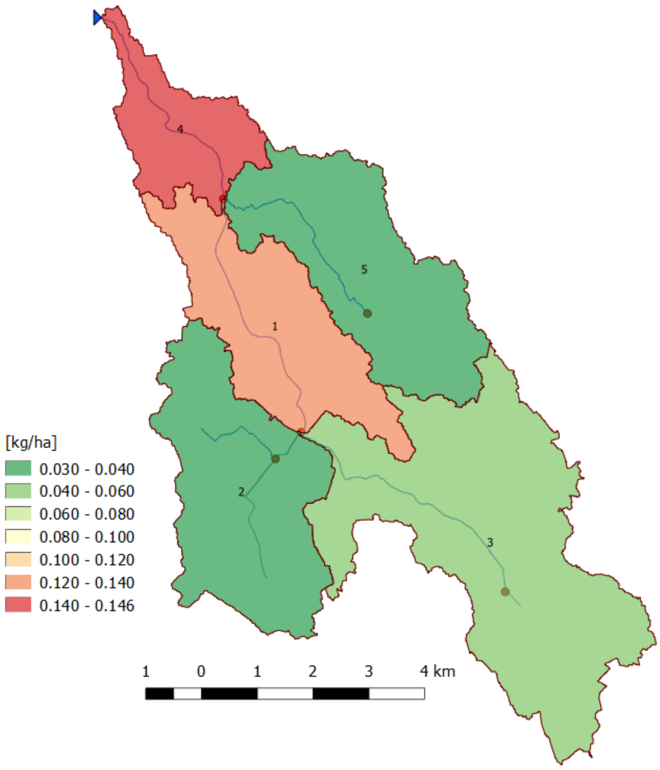

Figure 8.16 Nitrate contribution to lateral water [kg/ha]

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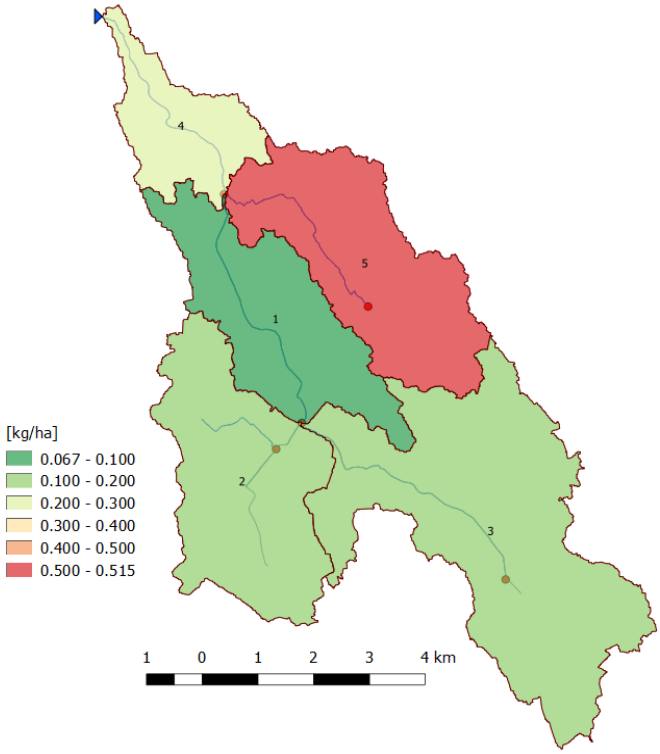

Figure 8.17 Nitrate contribution from surface flow [kg/ha]

8.6.4 Additional field data and improving the conceptual model

Despite years of research within Gowienica Miedwiańska catchment area (see Chapter 8.4) and wide range of data provided, the need for additional new field investigations occurred, as the relative contribution of different sources of pollution is still unknown.

Taking into account inappropriate communal sewage systems, which might be an important source leading to nitrate problems in the catchment and uncontrolled wastewaters discharges from households, a infra-red camera research was designed and implemented in late March in 2018. The main aim was to determine the presence of sewage pipes discharging sewage directly into the Gowienica Miedwiańska river using unmanned aerial vehicles equipted with readiometric cameras. The results are influenced by the temperature of discharged sewage as well as their colour and turbidity. Conducted research proved that identifying anthropogenic sewage discharges is possible. Therefore, ten potential points were recognised and described in details. This lead to improve understanding the water contamination issue in Gowienica catchment.

Additionally, groundwater profile – sampling at different depths, was designated and implemented in May 2018. Research main aim was to determine NO_3 concentration in vertical profile. Moreover, groundwater and surface water sampling was performed for N and O isotope analysis. Results of

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described above investigations will be discussed in work package WP3 – participatory monitoring according to deliverables timetable (D3.2).

8.7 Numerical model

8.7.1 Introduction

Mathematical models of the Gowienica Miedwiańska catchment were built using the Groundwater Vistas program from 2010 - version 6.7 (Build 4, 32-bit) from the Modflow program series, used to solve groundwater flows in mutual bond with surface waters for the conditions of fixed filtration. The description of the program including a description of the calculation algorithm - based on a numerical approximate solution of the system of filtration equations in three-dimensional space and the method of model research implementation are presented in instructions published by Environmental Simulations, Inc. The general filtration equation with external recharge in a non-homogeneous and anisotropic pore medium is as follows:

$$\frac{\partial}{\partial x}\left(A_x \frac{\partial H}{\partial x}\right)+\frac{\partial}{\partial y}\left(A_y \frac{\partial H}{\partial y}\right)+\frac{\partial}{\partial z}\left(A_z \frac{\partial H}{\partial z}\right)+Q=C\frac{\partial H}{\partial t}$$

where:

H (x, y, z, t) - height of the water table,

Ax, Ay, Az - functions determining the water's ability to move through the area along the x, y, z directions,

Q (x, y, z, t) - recharge function from external sources,

C - function of the internal resources of the area.

This equation may take different forms depending on the nature of the described filtration process and the modeled unit, and thus:

if $\frac{\partial H}{\partial t}=0$ it means a steady flow,

if $\frac{\partial H}{\partial t}\neq 0$ it means a transient flow,

if $\frac{\partial H}{\partial z}=0$ it means a two-dimensional stream identified as a single aquifer.

A version of the Modflow 2000 package was used to simulate / count the model. This software enables the desired detail of the mapping in terms of:

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- stratification of the hydrogeological model as a system of aquifers, poorly permeable and impermeable,

- the degree of complexity of circulatory systems of waters depending on the type of drainage zones (natural, artificial, point, linear, area) and recharge areas.

Using this software, the steady filtration equation in the system of two aquifers and two poorly permeable layers was solved. The PCG2 iterative method was used for calculations. Model parameters were reduced to the k type diagram (filtration coefficient), m (thickness), i.e. mapping of aquifers by means of filtration coefficient and thickness. In individual layers a flat flow is assumed, taking into account the possibility of permeation through the separation layers. Poorly permeable layers are mapped by the permeation parameter k '/ m'.

8.7.2 Model limits

After detailed analysis of hydrogeological and hydrological data, a numerical model was proposed covering an area of 256.0 km^2. The area of research is limited by geographical coordinates: 53 ° 09'59 "- 53 ° 19'05,5" latitude N 14 ° 52'30 "- 15 ° 06'02,7" longitude E. The water balance area of the Gowienica Miedwiańska catchment has an area of 69,23 km2. The boundaries of the water balance area are relatively irregular with a shape in the square area of 16 km. The external boundaries of the model were delimited from the catchment boundary to maximally limit the possibility of impact of boundary conditions on the results of balance analyzes and on the location of hydroisohypse. The whole groundwater circulation system was separated in Quaternary and Neogene formations, creating a complex multi-layer hydrostructural system. The surface determining the aquifer system in a vertical arrangement is the roof of poorly permeable aquifer or it is limited by the range of occurrence of aquifers.

8.7.3 Schematization of hydrostructural and hydrodynamic systems and their parameters

The hydrogeological schematization of the water-bearing system of the Gowienica Miedwiańska basin, presented in Figure 8.18, for the needs of preparing a mathematical model was brought to the system of 2 aquifers separated by 1 weakly permeable layer and one weakly permeable layer lying in the roof of the first aquifer. In addition to the permeable layers, part of the water-bearing system are the surface waters of the Gowienica River and Lake Miedwie.

Featured aquifers in the catchment area of Gowienica Miedwiańska are the second and fourth model layer:

II – upper intermoraine aquifer with a regional extent, sometimes local, connected in a hydrostructural and hydrodynamic system with a lower intermoraine confined aquifer or Neogene aquifer (in vicinity of glacitectonic deformations) - the area of 246.7 km2,

IV – lower intermoraine aquifer and Neogene aquifer with regional extent - area of 227,8 km2, The model is based on a large layer of glacial clays from South Polish and Mid-Polish glaciations as well as clay, mule and brown coal of the Miocene.

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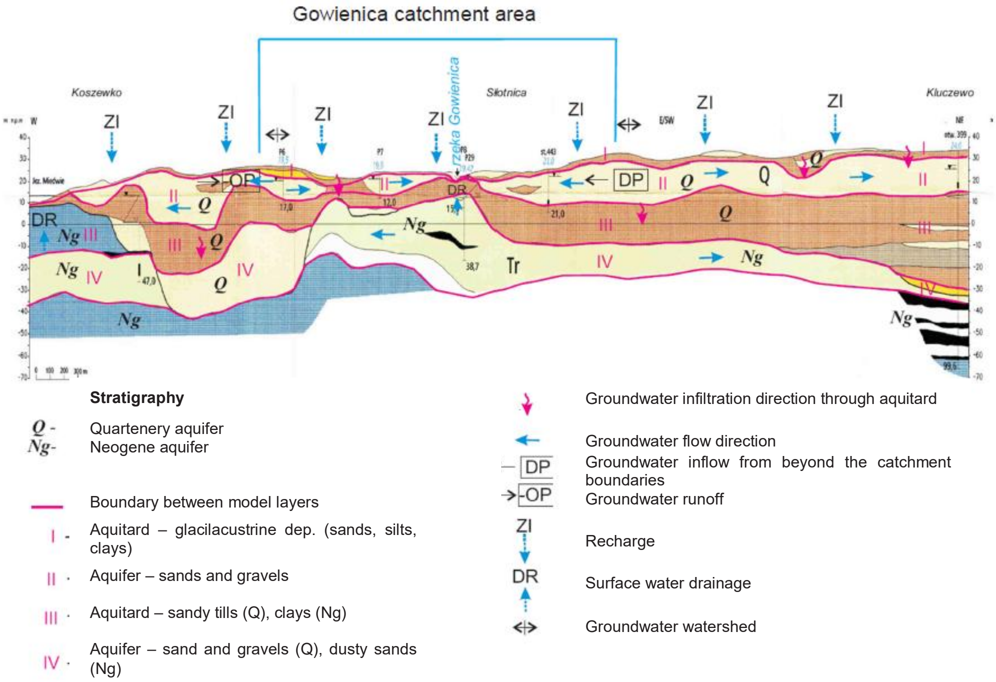

Figure 8.18 Conceptual diagram established for the mathematical model of the Gowienica Miedwiańska catchment

Deeper water-bearing levels of the Neogene were not modeled, because of the water quality (high color and salinity), they are not included in exploitation. The mentioned above aquifers are in the regional, common circulatory system of waters. The water-bearing horizons are separated by three weakly permeable layers, which are:

I - layers of loamy sands, locally dammed lake silts and sandy tills, clays and dusty sands within high plain,

I / II - layers of moraine tills, locally silts, Neogene clays.

All aquifers were treated as confined. The hydrogeological parameters of aquifers are the filtration coefficient "k" and the thickness "m". Contour maps of aquifer thickness imported to the model were made on the basis of data from existing drilling database in the ArcGis program as SHP files. The data on the filtration coefficient, also as SHP files, were imported as point data obtained from the Central Hydrogeological Data Base (Hydro Bank). The thickness of the individual layers and filtration coefficient was interpreted based on data from hydrogeological boreholes, stored in the Hydro Bank. The tared model shows groundwater circulation system as of January 2018 (Figure 8.19).

The filtration coefficient for individual layers of the model is variable in the following ranges:

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I layer: from 0.00036 to 0.0973 m / h, with an average value of 0.02163 m / h (weakly permeable layer, kx = ky = kz)

II layer: from 0.0595 to 2.024 m / h, with an average value of 0.665 m / h (aquifer, kx = ky, kz = kx / 10)

III layer: from 0.000073 to 0.0034 m / h, with an average value of 0.000613 m / h (weakly permeable layer, kx = ky = kz)

IV layer: from 0.00029 to 0.965 m / h, with an average value of 0.214 m / h (aquifer, kx = ky, kz = kx / 10).

Hydraulic contacts between watercourses and Lake Miedwie and aquifers were tarred by changes in filtration coefficient and thickness of bottom sediments (the rivers were mapped in the first and second layer of the model). The discretization of the filtration area was made with the help of a square grid $\Delta x = \Delta y = 100$ m. In the water intake areas the discretization grid was compacted to the size $\Delta x = \Delta y = 50$ m The infiltration flow rate for the 1st model layer was tared for the hydrodynamic model as of 1st July 2017. For boundary conditions of the III type - River, ordinates of the surface water table of watercourses, lakes and artificial water reservoirs, were adopted according to topographic maps in 1:50 000 and 1:25 000 scale (systems 92 and 42) and were supplemented with data from the Geoportal. The average annual value of effective infiltration was determined for the separated hydrotopes using the Bagrov-Glugla method. The average precipitation infiltration in a modular form obtained on the model for the state from 01.2018 is: 87 mm / r · m^2 (i.e. 9.93 m^3/h · km^2).

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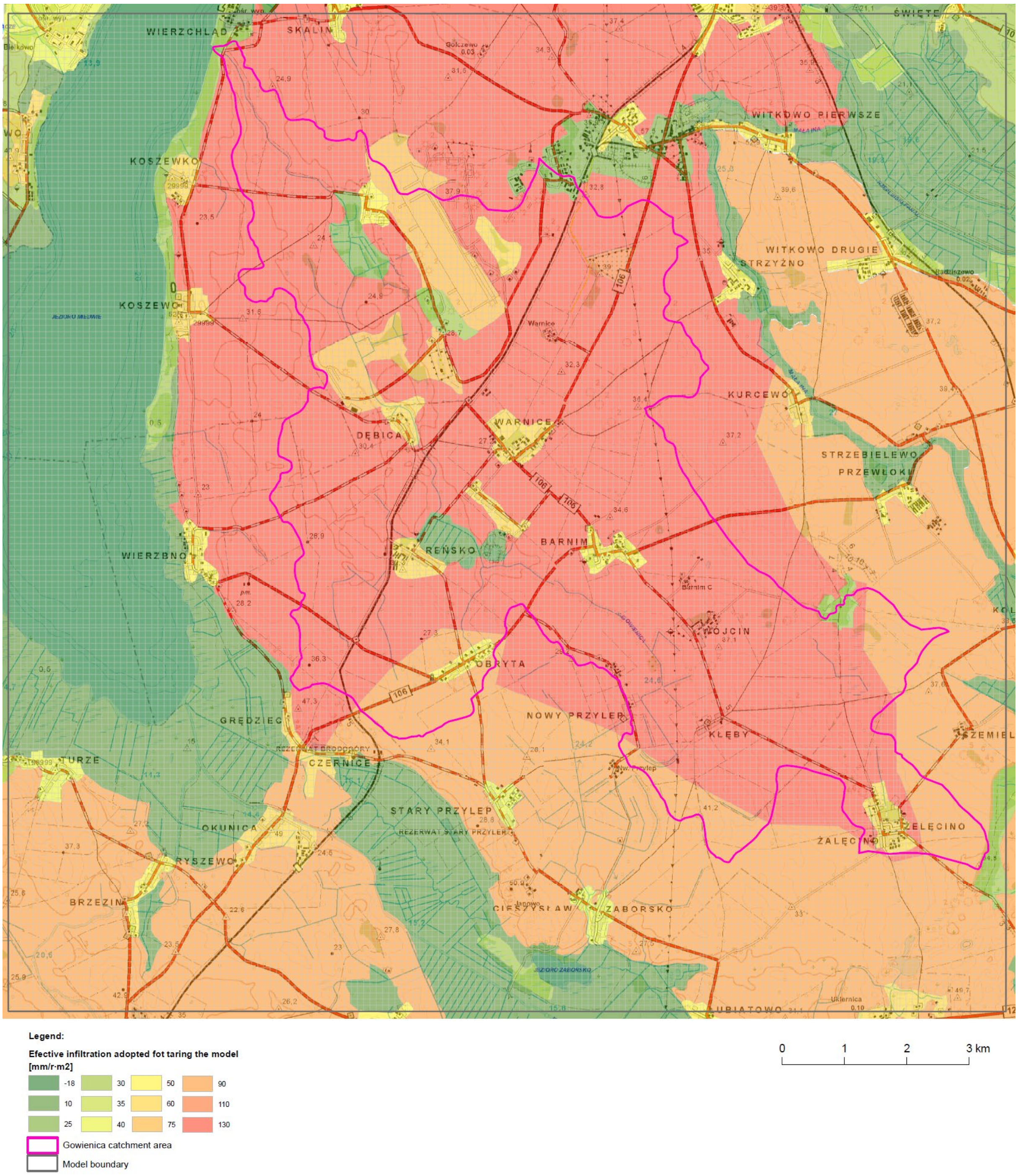

Figure 8.19 Groundwater recharge in the area of the Gowienica Miedwiańska catchment area

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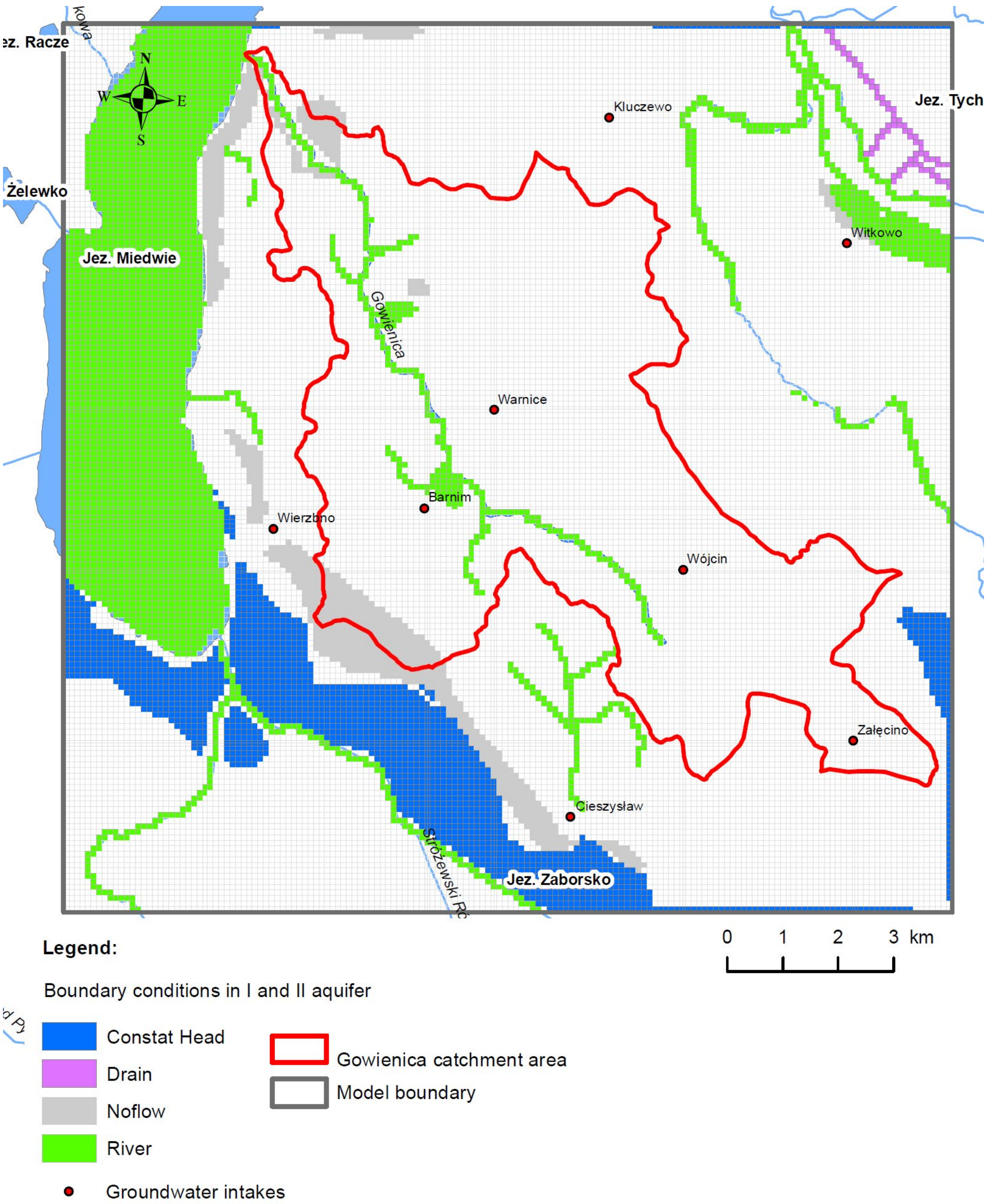

Figure 8.20 The boundary conditions of the I and II model layer in the Gowienica Miedwiańska catchment model.

8.7.4 Discretization of the research area and boundary conditions

For the needs of the mathematical model, the adopted research area was discretised with a 100 m square grid in a system of 160 rows and 160 columns. Computational blocks have a surface area of 0.01 km2. The grid engagement point in layout 92 has the following rectangular coordinates: x = 224384, y = 596986. The boundary conditions of the model were determined as follows in accordance with the adopted and applied principles of mathematical modeling (Figure 8.20).

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All numerical solutions were carried out using fixed filtration. Initial conditions of the solution were digital maps of aquifers in shp format: thickness, filtration coefficient and water intakes for which a mathematical model was created.

8.7.5 Criteria for identification and verification of the model

According to the Mathematical modeling methodology [1] in the first stage of taring the model, the stratification structure and filtration parameters of aquifers and poorly permeable layers were adopted and the drainage of water circulatory systems was identified. In stage II of taring, which mainly consisted testing the parameters of recharge (infiltration, inter-layer flows), in order to obtain the adopted objective functions, the model was developed for mapping water levels at representative points in the area in order to achieve reliable drainage amounts. For this stage of taring, the main criteria for the identification and verification of the model were: 1) compliance of the water levels calculated on the model with the size of the measurements in the openings and the water table contour maps, 2) obtaining comparable drainage of watercourses on a model with specific groundwater outflows in hydrological surveys, 3) compliance of the supply of the aquifer system of the catchment areas with the previously determined results in regional hydrogeological surveys in the catchment area and its surroundings. Due to the lack of geodetic locations with the reference to the state system of some hydrogeological boreholes, the determination of land elevations was made from topographical maps with an accuracy of ± 0.5 m. Due to the occurrence of natural fluctuations of the water table resulting from variable recharge (in amplitudes varied for the levels from 0.1 to 1.0 m), as well as the prevalent changes in the water table resulting from the exploitation of the intakes, it was assumed that the specific water table depths and the created maps for the hydrodynamic state from January 2018 have accuracy varying in ± 1,5 m. All benchmarks capture the first water-bearing level from the surface, i.e. the II model layer.

Table 8.1 Groundwater table depths of modeled aquifers at selected calibration points (piezometers)

WaterProtect Name	Latitude	Longitute	Elevation m (a.s.l.)	Measured groundwater elevation 01.2018 m (a.s.l.)	Modelled groundwater elevation m (a.s.l.)	Error [m]
GW_01	53.3062	14.9121	15.90	15.44	14,39	1.05
GW_18	53.2873	14.9416	21.80	21.30	20,11	1.19
GW_06	53.2780	14.9576	24.40	22.60	22,68	-0.08
GW_07	53.2661	14.9677	25.08	22.96	23,63	-0.67
GW_23	53.2575	14.9605	24.57	22.61	22.45	0.16

[1] Dąbrowski S. and others, 2011. Mathematical modeling methodology in hydrogeological research and calculations. Methodological guide. Hydroconsult Ltd., Polgeol JSC, Poznań, Poland

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GW_11	53.2388	14.9591	24.48	23.40	23,17	0.23
GW_27	53.2122	15.0361	29.00	27.63	27.84	-0.21
GW_22	53.2689	14.9459	22.21	21.73	21,20	0.53

Statistics:
Amount of measure points – 8
Residual Mean – 0,28
Residual Standard Dev. – 0,59
Absolute Residual Mean – 0,52
Residual Sum Squares – 3,38
RMS Error – 0,65
Scaled Res. Std.Dev. – 0,048
Scaled Abs. Mean – 0,042
Scaled RMS – 0,053

The compatibility of the mathematical model with the hydrogeological model is also reflected in the pressure measurements in the hydrogeological wells and calculated on the model in the appropriate discretization blocks presented in the Figure 8.21 (below).

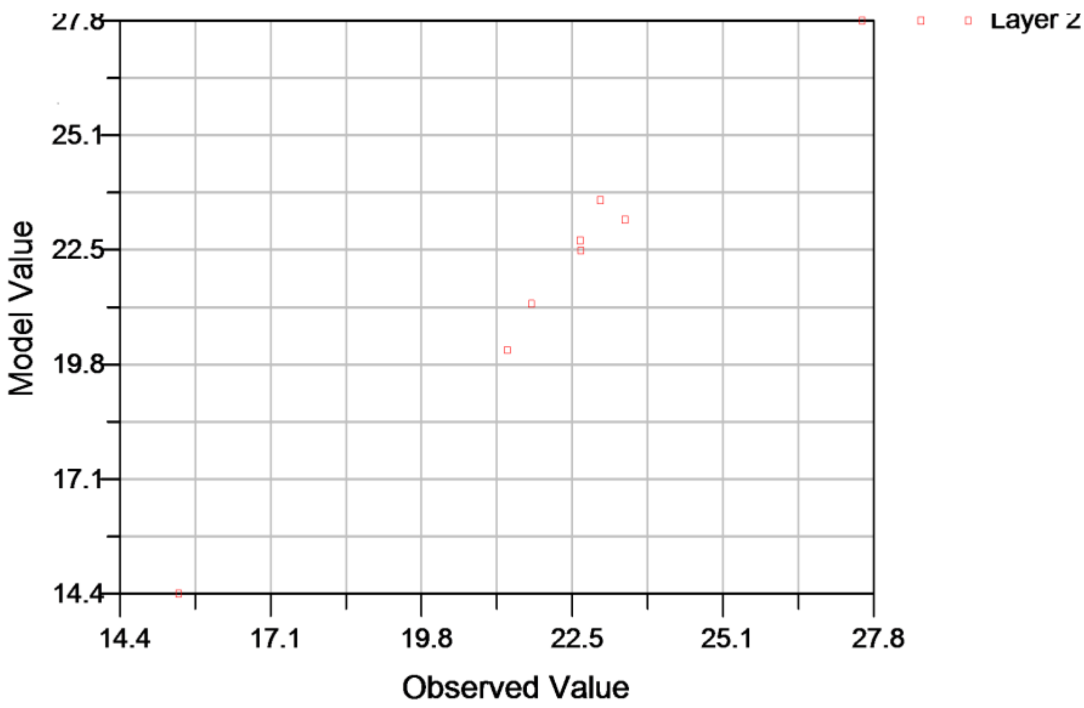

Figure 8.21 Observed (Observed Val.) and calculated (Model Val.) values on the water table elevation model [m. I.p.] for model benchmarks

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It should be noted that the real measurements in the benchmarks are one-off measurements, reflecting the momentary water levels caused by hydrometeorological factors, as well as the exploitation of groundwater, which are difficult to consider as average states. The existing differences between the measurements and the calculations on the model are the result of the above factors as well as the different position of the observation point in model blocks with a constant grid step of 100 m, in relation to the center of the block. The results obtained show the average hydrogeological conditions. They represent values accepted as reliable, with an assumed accuracy of ± 1.5 m.

8.7.6 Results of modelling the circulatory system of groundwater as for January 2018.

This model reflects the average quasi- steady state of groundwater obtained in the process of taring boundary conditions, filtration and infiltration parameters of the aquifer system of isolated layers when obtaining the assumed compatibility of the circulatory system of waters in layers with a hydrogeological model.

In order to obtain the desired hydrodynamic condition of the system, approximately 30 model simulations were performed with a constant analysis of the correctness of the determined pressures in the hydrogeological model layers. This state is reflected in the water table contour map for the first aquifer, which is also the main utility aquifer, shown in the figure below (Figure 8.22).

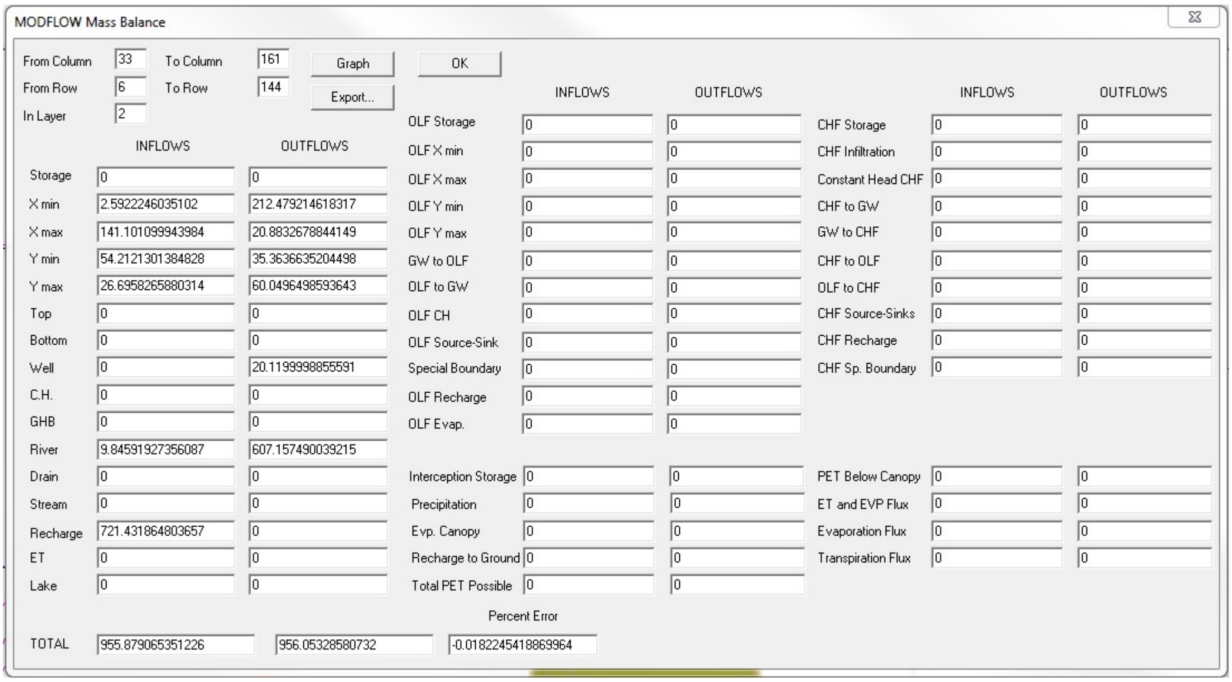

Figure 8.22 The groundwater balance in Gowienica catchment (m3/h)

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According to the taring and calibration process of the model reflecting actual hydrodynamic conditions, data on the water balance were obtained. For the hydrodynamic state of 2018, circulations of aquifers in the system of 2 aquifers were drawn up. The summary balance for all model layers is presented below. From the presented balance sheet – Figure 8.22, it follows that Gowienica drains about 607.16 m^3 of water per hour, which gives 0,167 m^3 / s. This value is used to verify the model by comparing it to the flows observed on the measurement cross-section in Wierzchląd. Thanks to the knowledge of consumption curve for the section in Wierzchląd, for continuous measurements performed on this cross-section in the period from September 2017 to January 2018, the average flow in the river was calculated, which amounted to Q = 0.227 m^3/s.

Bearing in mind that the balance represents the average values for the year, it may be assumed that the inclusion of the average flow data in the remaining part of the year will reduce the calculated average flow, thus the average flow calculated for the year will get closer to the model balance. At this point, based on the preliminary data, it can be stated that the model is well reflected by the actual drainage of the Gowienica River. The comparison of flow in the river: calculated and real, showing the basic consistency of flow values obtained by two methods, positively verifies the model tared based on hydrogeological parameters and infiltration recharge.

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9 Conclusion

In order to identify and implement optimal mitigation measures, a thorough understanding of the physiochemical system is crucial. Such understanding is need not only to evaluate the type of possible measures and their likely effects, but also in the communication to the stakeholders. The willingness of the stakeholders to change behaviour and implement new mitigation measures is strongly linked to the stakeholder's ability to realise that the changes suggested will have a real impact.

Based on existing data as well as additional data collected in WaterProtect, a conceptual model is developed in the seven WaterProtect action labs and described in the present report. Although water quality data existed the majority of the action labs or in the proximity of the action labs, they have not previously been used in an analysis of the local conditions. Through the analysis in WaterProtect, it was found that additional data collection was required in most action labs in order to understand the system adequately, and also for the sake of establishing local data that can be related directly to the local conditions, including farming practise.

In several action labs preliminary discussions with stakeholders revealed that they were unaware of existing water quality data, and thus also unaware of the water quality. Bringing together all data in a comprehensive analysis of the physiochemical conditions of the action labs, will thus advance not only the scientific understanding of the system but also the insight to problems and solutions by the local actors and stakeholders.

Different approaches has been utilised in the different action labs. Where data are sparse, simpler tools/approaches has been followed. In action labs where surface water is used as a drinking water resource focus is on surface runoff, which can be assessed from topographical data and tools accounting for slopes and connectivity to water courses. While high resolution maps often are available for topographical and surface related data obtainable from aerial photometry, subsurface data are often sparse and limited to point observations from wells. To understand the subsurface and the associated transport of substances, a hydrogeological interpretation are required, which needs to be incorporated into a numerical model to allow an assessment of the system and evaluation of the effect of various measures. In the action lab where the groundwater is an important drinking water resource, it has been found necessarily in most action labs to develop a numerical model.

The analyses in D5.3 have advance the system understanding in the action labs. The analysis provides the basis for the further developments in the project, both in relation to the identification of optimal solutions, but also in the process of communicate with the local stakeholders.

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