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# 1. Introduction

Within the DEEPWATER-CE project’s work package T3, an activity A.T3.7 “Preliminary environmental impact assessment of the MAR on decreasing water resources and ecosystems” is envisaged. The main subject of this activity is to assess the effects of the potential implementation of Managed Aquifer Recharge technology (MAR) within the designated pilot areas across CE (Hungary, Poland, Slovakia, and Croatia), which were identified within D.T2.4.3 Transnational Decision Support Toolbox for designating potential MAR locations in Central Europe.

MAR is a term conceived by the British hydrogeologist Ian Gale and refers to a process by which excess surface water is directed into the ground – either by spreading on the surface, by using recharge wells, or by altering natural conditions to increase infiltration to replenish the aquifer. Generally, MAR is important as one of the solutions aiming to facilitate the protection of water resources endangered by climate changes and user conflict, which are burning issues of our time.

MAR encompasses a range of methods, which are increasingly used to maintain, enhance and secure groundwater systems under stress. MAR has application in sustaining and augmenting:

- groundwater quality (improvement of water quality in degraded aquifers, reducing the concentration of geogenic pollutants like arsenic or fluoride);
- groundwater quantity (to store water in aquifers for future use, to increase groundwater levels in over-exploited aquifers);
- in environmental management (to mitigate floods and flood damage, to control seawater intrusions, to prevent storm runoff and soil erosion, to prevent environmental flows in rivers and streams, etc.).

Potential reasons for MAR implementation differs from location to location, but certain similarities can be singled, such as (Grutzmacher and Kumar, 2012):

- declining groundwater levels;
- inadequate groundwater availability, especially in dry months;
- a substantial amount of aquifer has already been desaturated;
- aquifers show signs of seawater/saline intrusions;
- the site is adjacent to a leaky fault or semiconfined layer containing contaminated water or water of poor quality and;
- the aquifer contains water of poor quality and is highly heterogeneous or has a high lateral flow rate.

Each CE country has its legal basis referring directly or indirectly to environmental impact assessment (EIA) for MAR. Therefore, in this report, country-specific EIA reports are provided respectively, following a common structure that is easy to follow and allows a comparison between different environments and different technical solutions of MAR in Croatia, Hungary, Poland, and Slovakia.

# CROATIA

# 2. Project description - Managed aquifer recharge

## 2.1. MAR technology

MAR technology scheme planned for the island of Vis (Korita well field) is predominantly focused on the prospective method of infiltration pond (Fig. 2.1). Infiltration ponds are constructed in areas with sufficient permeability and storage capacity of the targeted aquifer (https://demeau-fp7.eu/toolbox/introduction/basic-concepts/classification-mar/infiltration-ponds.html). The pond can be either excavated or the source water is directly flooded on land surrounded by a confining ditch.

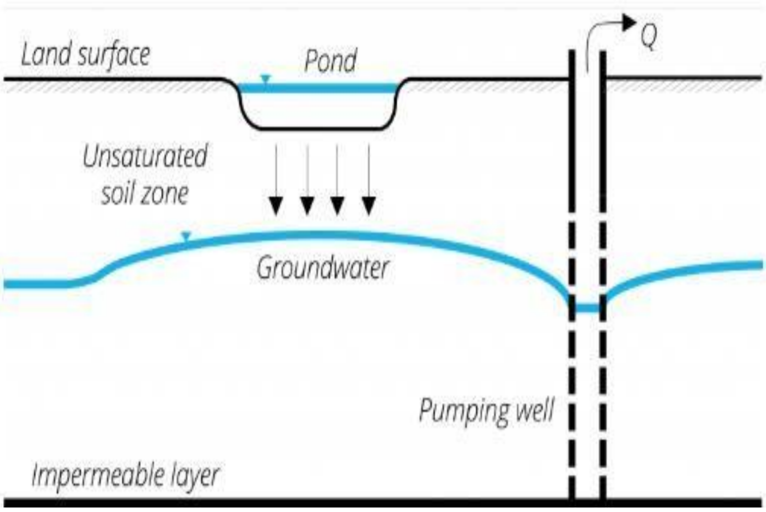


**Figure 2.1** Infiltration pond scheme (modified after Dillon, 2015)

Advantages of this kind of MAR method are following:

- infiltration of large quantities of water at relatively low cost;
- maintenance and anti-clogging procedures are relatively simple;
- organic contaminants in source water are filtered out in the soil.

On the other hand, constraints of this method are:

- that it requires a large permeable surface area;
- the potential for development of water-related disease vectors;
- the potential for water pollution;
- the potential for high evaporation.

## 2.2. Variant MAR solutions

A variant MAR solution considered for the island of Vis is the aquifer storage and recovery method (ASR). This technique is referring primarily to infiltrating water via injection borehole, which taps directly into aquifer, usually below the water table (Fig. 2.2). However, the most likely variant solution also requires an accumulation lake to enable the accumulation of source water.

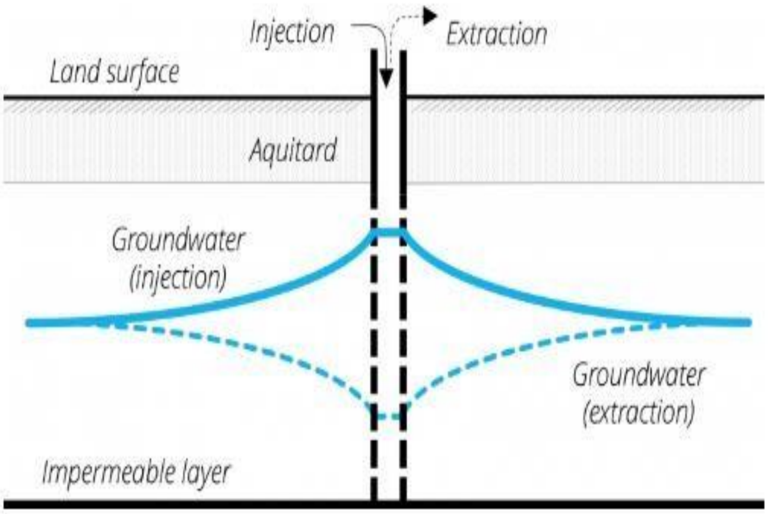


**Figure 2.2** Aquifer storage and recovery scheme (modified after Dillon, 2015)

Advantages of this kind of MAR method are:

- clogging is partially removed during the recovery cycle;
- infiltration of large quantities of water at a relatively low cost.

Constraints of this method are:

- complex design and construction;
- complex decision on injecting well location and depth (especially in karstic terrains)
- complex operation and maintenance;
- intensive monitoring is required;
- high-quality requirements of source water.

A suitable environment for this specific MAR method is confined or unconfined aquifers composed of unconsolidated rocks, however, the method can also be applied in fractures aquifers, given that the uncertainties are greatly reduced by an extensive research effort (e.g. geophysical research, well tests, aquifer tests, tracer test).

# 3. Environmental setting of the proposed project location

Having a good baseline knowledge of the potentially affected environmental resources and communities located at or near the proposed project site is crucial for conducting every environmental impact assessment study. Thematic maps (e.g. land use and land cover, geological and hydrogeological map, map of nature-protected areas, etc.)

This chapter provides sufficient information so that decision-makers and reviewers unfamiliar with the general location can develop an understanding of the environmental characteristics of the study area.

## 3.1. Site description

Korita well field in which MAR technology will potentially be implemented is located in the central part of the island Vis. Vis is a small remote island (total area of 89.7 $km^2$) located in the Adriatic Sea (Fig. 3.1) and belongs to the group of central Dalmatian islands. The designated pilot site belongs to the regional self-government of Split–Dalmatia County, the local self-government unit of the City of Vis, and the cadastre municipality of Vis.

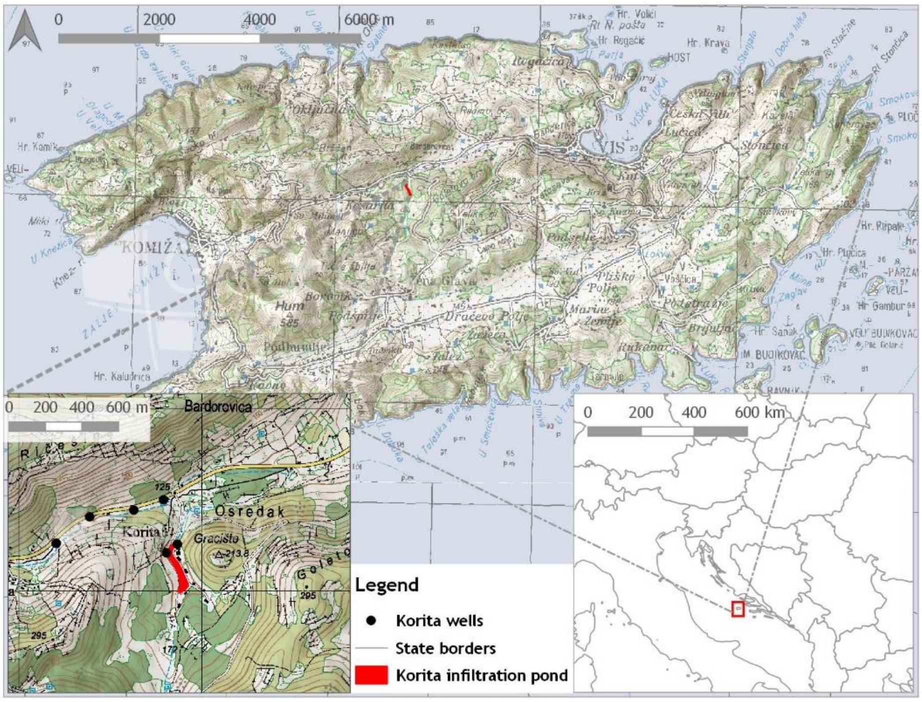


**Figure 3.1** The location of the Croatian pilot site - Korita well on Island Vis (background: ArcGIS Elevation World Hillshade, Topographic Map of Republic of Croatia in scale 1:100 000 and 1:25 000)

The Korita well field, constructed in the late 1960s, consists of five active wells and represents one of three island's water supply systems. The island itself is not connected to the mainland or any other island by water supply pipelines. Water is abstracted from the karst aquifer from a depth of approximately 120 m, with a maximum pumping rate of 42.5 l/s (from all five wells).

The Korita pumping site is positioned favorably in terms of implementing MAR technology because it has enough available land for the potential construction of an accumulation structure, which would be used as the source of water for MAR. Other advantages of this location are available essential infrastructures such as road, telecommunication, electrical power, water distribution, and the high degree of security in terms of potential pollution sources. This makes described site potentially very suitable for the application of the proposed MAR schemes.

### 3.1.1. Proposed MAR site in relation to other spatial interventions

According to valid spatial planning documents Spatial plan of the City of Komiža (Official Gazette no. 10/06, 06/08, 01/10, and 02/15) and Spatial plan of the City of Vis Official Gazette no. (Official Gazette of City of Vis no. 1/10, 2/17, and 6/17), planned MAR location is surrounded (to the west and north) with the land of use category “other agricultural soil, forests, and forest land” (Fig. 3.2). To the south and east of the planned site, valuable arable and forest land are located. In the wider area surrounding the planned MAR location, no industrial sites or urban development areas are planned.

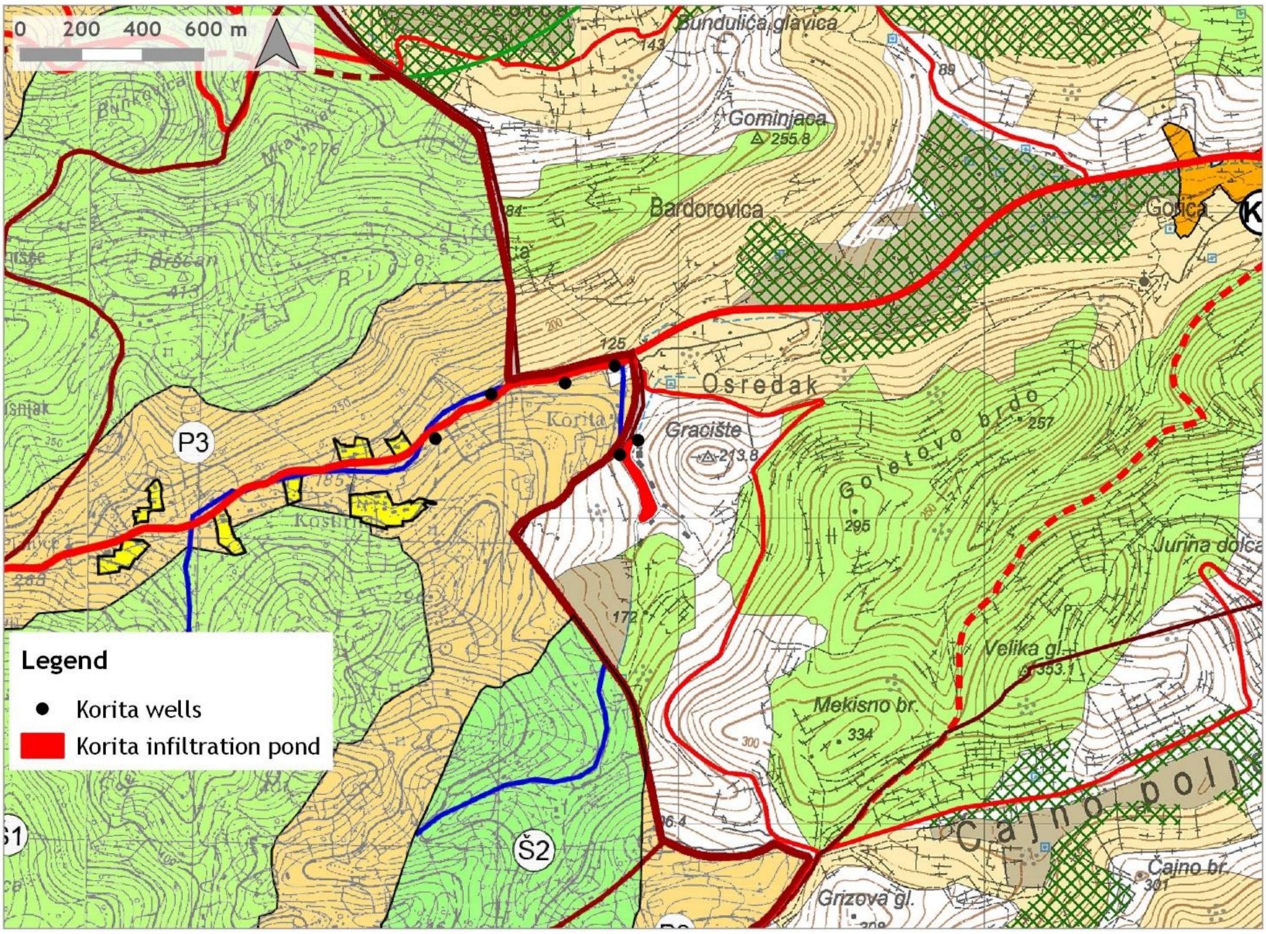


**Figure 3.2** Planned MAR location in relation to other spatial interventions (background: Spatial plans of the City of Vis and City of Komiža).

### 3.1.2. Compliance with valid spatial planning documentation

Regarding the Croatian pilot site, the following spatial planning documents are relevant for the potential implementation of the MAR project:

- Spatial plan of Split-Dalmatia County (Official Gazette no. 1/03, 8/04, 5/05, 13/07, 9/13, and 147/15) and
- Spatial plan of the City of Vis (Official Gazette no. 1/10, 2/17, and 6/17)
- Spatial plan of the City of Komiža (Official Gazette no. 10/06, 06/08, 01/10, and 02/15).

Under section 4.1.2.6. and articles 26, 27, 28, and 29, the Spatial plan of Split-Dalmatia County (Official Gazette no. 1/03, 8/04, 5/05, 13/07, 9/13, 147/15) provides the framework for the protection of drinking water sources (including karst springs, lakes, and reservoirs), by identifying water resources of strategic importance for current and future drinking water supply as well as potential sources of drinking water, and by prescribing the delineation of protection zones.

According to the Land use map of the Spatial Plan of Split-Dalmatia County (Official Gazette no. 1/03, 8/04, 5/05, 13/07, 9/13, 147/15), the area where implementation of MAR technology is planned (Korita) belongs to the category "other agricultural soil, forests, and forest land". According to the Water management system map of the Spatial Plan of Split-Dalmatia County (Official Gazette no. 1/03, 8/04, 5/05, 13/07, 9/13, 147/15), the area where implementation of MAR technology is planned has an existing use as a water abstraction point and a pumping station.

## 3.2. Climate characteristics

Climate characteristics represent a key factor in selecting the most appropriate MAR technology, as they determine the need, dimensions, and type of required structure.

According to Köppen's climate classification, Vis Island and surrounding archipelago belong to the Csa climate type, characterized by dry and hot summers and mild and short winters. Due to its position in the open sea, a strong maritime influence mitigates climate extremes and air temperature variations. According to data from meteorological station Komiža, the average annual temperature is 16.9˚C. Throughout the year, only two months have the average air temperature below 10˚C and those are January and February. The minimum average monthly temperature is 9.5˚C. Four months of the year have an average temperature above 20˚C (June, July, August, and September). The average temperature in the warmest month (July) is 25.7˚C (Table 3.1).

**Table 3.1** Absolute minimum, maximum and average monthly air temperature (˚C) measured at the meteorological station Komiža in the period 1981-2009

| *Month* | *I.* | *II.* | *III.* | *IV.* | *V.* | *VI.* | *VII.* | *VIII.* | *IX.* | *X.* | *XI.* | *XII.* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Minimum temperature (˚C)* | -3.30 | -3.00 | -3.10 | 0.70 | 8.20 | 11.70 | 14.80 | 12.60 | 10.10 | 5.40 | 2.40 | -3.20 |
| *Average temperature (˚C)* | 9.70 | 9.50 | 11.60 | 14.50 | 19.10 | 22.70 | 25.70 | 25.50 | 21.60 | 18.30 | 13.90 | 11.00 |
| *Maximum temperature (˚C)* | 19.60 | 22.80 | 24.20 | 25.00 | 31.80 | 37.20 | 38.80 | 38.70 | 34.80 | 30.40 | 25.60 | 21.40 |

The precipitation regime on the island of Vis is predominantly maritime with the largest values in the cold part of the year and with pronounced summer dryness. Maximum precipitation occurs in late autumn and early winter with a minimum in July (Table 3.2). The average annual precipitation is between 600 and 700 mm in the coastal areas and slightly higher in the central part of the island.

**Table 3.2** The minimum, maximum, and average monthly values of precipitation (mm) measured at the meteorological station Komiža in the period 1981-2009

| *Month* | *I.* | *II.* | *III.* | *IV.* | *V.* | *VI.* | *VII.* | *VIII.* | *IX.* | *X.* | *XI.* | *XII.* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Minimum precipitation (mm)* | *0.00* | *3.10* | *5.50* | *4.00* | *2.10* | *2.40* | *0.00* | *0.00* | *4.40* | *5.50* | *19.60* | *4.80* |
| *Average precipitation (mm)* | *75.40* | *62.60* | *0.50* | *58.40* | *28.20* | *42.10* | *20.20* | *39.00* | *52.30* | *53.00* | *95.80* | *107.90* |
| *Maximum precipitation (mm)* | *183.70* | *220.00* | *192.20* | *121.30* | *79.40* | *126.90* | *90.70* | *304.10* | *133.50* | *120.20* | *201.50* | *268.00* |

## 3.3. Geological and hydrogeological settings

Geological and hydrogeological settings are crucial for choosing the optimal location for MAR and defining the required amount of water to be recharged.

The island of Vis is part of the Dinaric karst region and mezogeomorphological unit of the Central Dalmatia archipelago (Bognar, 1999). The main structural elements are oriented W-E, i.e. they differ from the typical Dinaric strike (NW-SE). The following rocks predominantly occur at the island surface: karstified Cretaceous carbonates (limestone, dolomite), Quaternary sediments (terra rossa in karst poljes; breccia; aeolian sands; colluvial deposits), and a mixture of volcanic-sedimentary-evaporitic rocks (andesite, gypsum, dolomite, siltite, tuffite; hereafter referred to as VSE) forming the Komiža diapir.

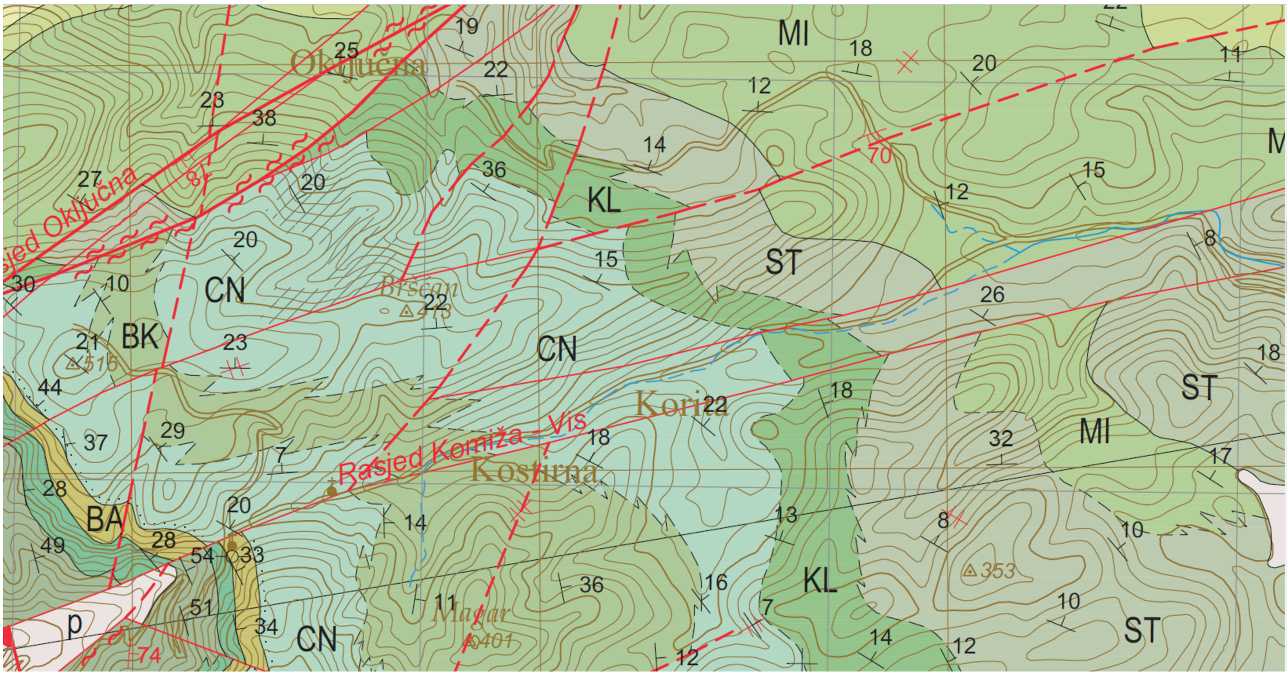


**Figure 3.3** Geological map of the Korita well field (detail from Korbar et al., 2012)

The island Vis has favorable geological and hydrogeological conditions that enabled the formation of a high-quality karst aquifer from which the groundwater is abstracted. The aquifer in the central part of the island is protected from seawater intrusions from the west by impermeable rock formations of the Komiža diapir and from the south by the fine grain infilling of the fractures and karst conduits that drain the Quaternary polje deposits, decreasing the permeability field of the underlying rock masses. Moderate permeability carbonate rocks (Fig. 3.4) are the most important hydrogeological unit as they are permeable enough to allow groundwater infiltration, accumulation, and flow, but are not too permeable to allow excessive penetration of seawater into the island's aquifer. Due to the presence of dolomitic and dolomitized rock mass and its characteristic weathering into sand-like sediment, this material fills in most of the karst and fracture voids within this rock mass, thereby reducing its permeability. This hydrogeological member consists of several formations and members. Lithologically, these are laminated and bedded limestones with dolomitic beds/interbeds, bedded dolomites, even some dolomitic breccias in some places. Stratigraphically, they are of the Cretaceous age (K1, K2; from Barremian to Cenomanian).

Besides the Korita well field, the water supply system on the island consists of Pizdica spring and K1 well (Fig. 3.4). Pizdica, a small coastal spring formed at a fault contact of permeable carbonates and impermeable VSE complex of Komiža bay, has an average yield of 3.3 l/s, and due to its position, it exhibits increased chlorides. Due to increased chlorides, water from Pizdica is mixed with water from Korita in a 1 to 5 ratio before the distribution. K1 well has a maximum pumping yield of 1.5 l/s and it is protected from seawater intrusions by the VSE complex. The pumping test in 2012 proved that catchment areas of Pizdica and Korita are not connected.

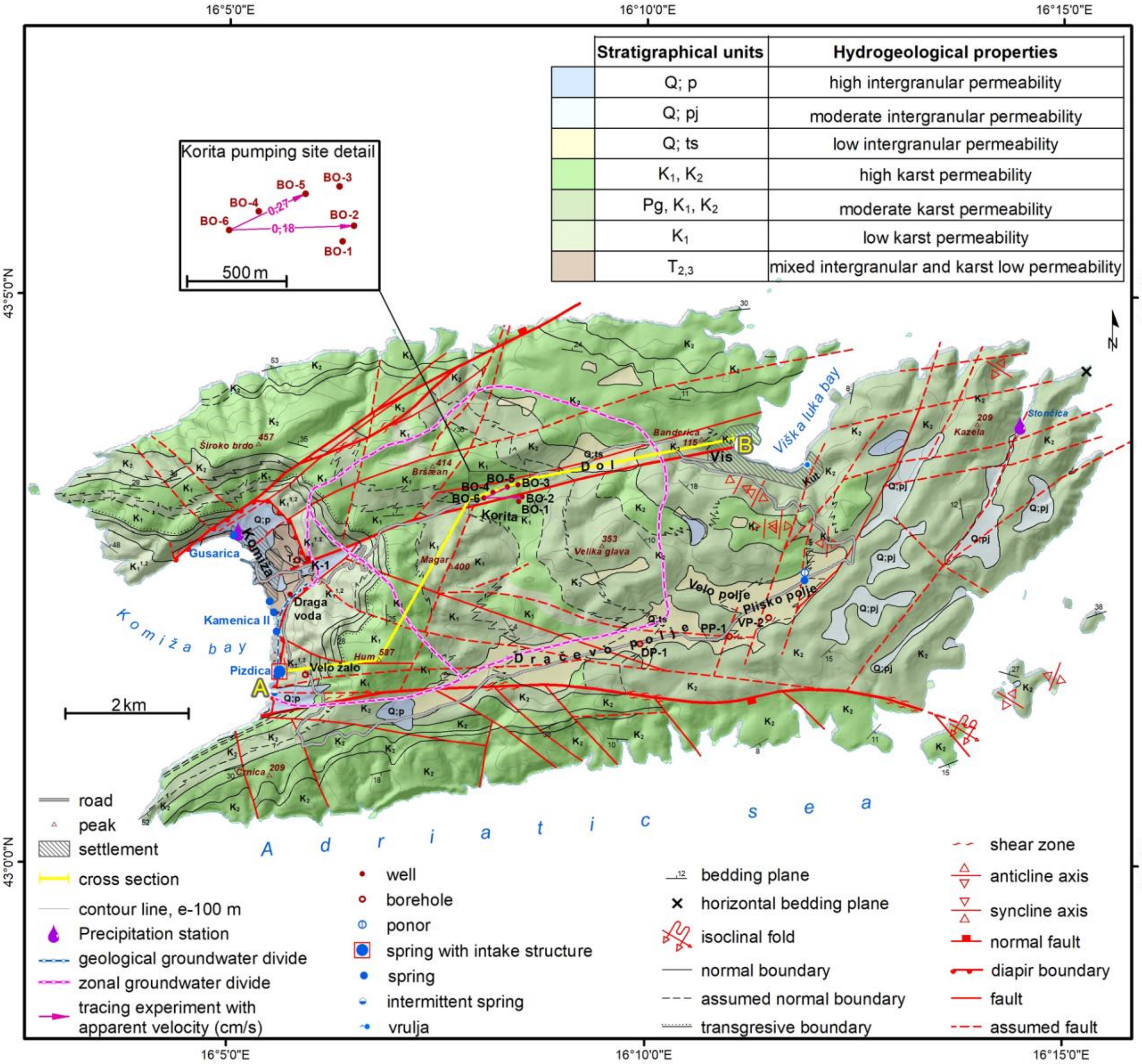


**Figure 3.4** Hydrogeological map of the Vis island (Terzić et al., 2022)

In Korita, the average seasonal variation of the groundwater level (GWL) (minimum in August and September, maximum in January) in operational wells is a little over 4 m. Aquifer recharge usually starts in October and continues mostly until March. Infiltration in the close vicinity of operational wells is very fast, especially through highly permeable limestones. This aquifer is very heterogeneous and consists of voids of different scales that are interconnected by fractures, cracks, and even karst conduits.

Hydraulic properties were determined from older pumping tests when the wells were being constructed (1960-1970). Terzić (2004) utilized Thiem's equation to obtain values of hydraulic conductivity and transmissivity for well BO5: T= $9\times10^{-4}$ – $2.3\times10^{-3}$ $m^2/s$, and K=(2.3 – 4.9) × $10^{-5}$ m/s.

Newer research focused on detailed chemical analyses of groundwater samples from the most important springs and wells on the island of Vis. The dominant hydrochemical facies at Korita is Ca-$HCO_3$ type as this is the typical chemical footprint of groundwater from carbonate (limestone and dolomite) aquifer. During the dry season, only a slight increase in chlorine concentration was observed. Water quality is excellent and the water is not treated in any way (UV, ultrafiltration, reverse osmosis) except chlorination.

### 3.3.1. Tectonic relations

The tectonic unit of the island Vis is characterized by an anticline, whose center is made out of clastites with gypsum and eruptive rocks of Upper Jurassic age, while its limbs are composed out of Cenomanian-Turonian to Senonian deposits. This structure is a result of tangential forces and strengthens with diapiric processes.

Three main faults occur on the island Vis (from N to S: Oključna, Komiža-Vis, and Podšpilje-Rukavac faults), and the main water abstraction site Korita is located within/along the damage zone of the Komiža-Vis fault (Fig. 3.4).

### 3.3.2. Seismic features

The area of the island of Vis belongs to a relatively stable area in relation to seismic activities. Although it is located near a large tectonic fault, the so-called Middle Adriatic Pit (i.e. Jabuka Pit), it belongs to the VI earthquake zone of the Mercalli scale. No devastating earthquakes have been recorded previously.

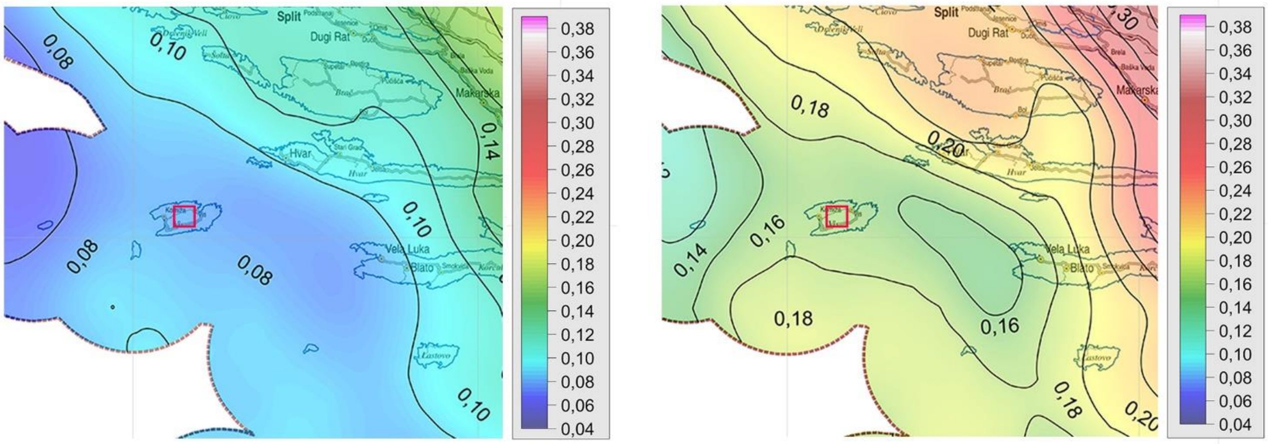


**Figure 3.5** Korita well field location on the Earthquake map zones of the Republic of Croatia, printed on an approximate scale of 1:800.000 (Herak, 2011)

The maps in Fig. 3.5 show earthquake-induced horizontal peak accelerations of soil type A (agR), for return periods $T_p$ = 95 years and $T_p$ = 475 years, expressed in units of gravitational acceleration g (1g = 9.81 m / $s^2$) (Herak, 2011). For the Korita well field the horizontal peak accelerations is $a_{gR}$ = 0.08 g (for Tp= 95 years) and $a_{gR}$ = 0.16 g (for Tp= 475 years).

These maps are part of the National Supplement to the HRN EN 1998-1: 2011 / NA: 2011, Eurocode 8: Design of seismic resistance of structures - Part 1: General rules, seismic actions, and rules for buildings.

## 3.4. Soil

The dominant soil types in the wider area of the Korita well field are the anthropogenic soil on karst and Terra rossa, while other present soil units are calcocambisol on limestone and dolomite, calcomelanosol, and colluvial soil (Fig. 3.6). Anthropogenic soil on karst is characterized by a depth of 30 to 100 cm, a proportion of stone particles of 2 to 10% and is present generally in lower field areas. The hills surrounding the field are covered mainly with Terra rossa with the depth of 30 to 50 cm and a larger amount of stone particles of 10 to 20%.

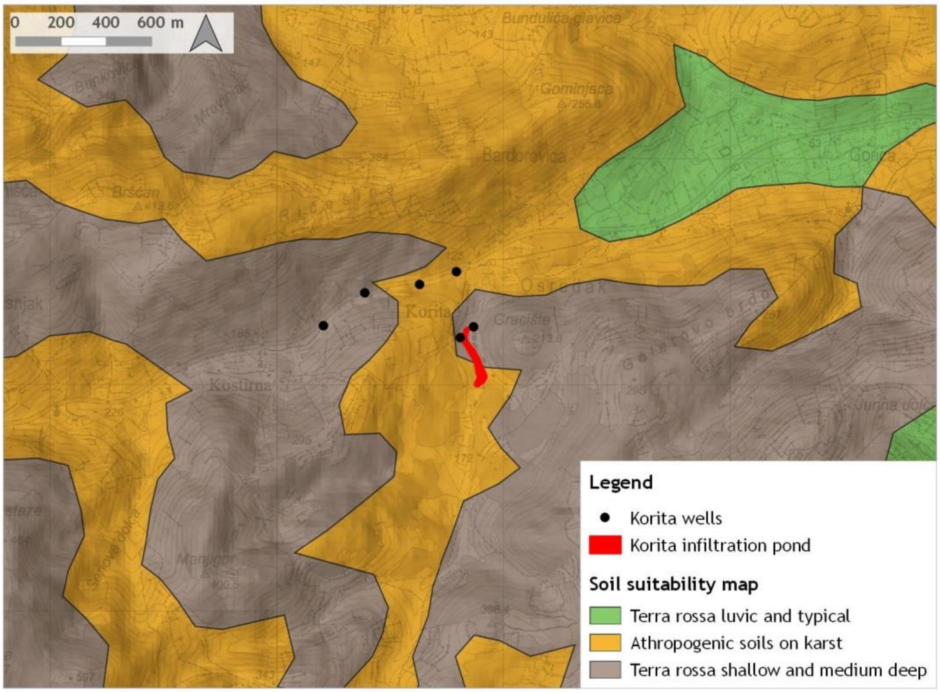


**Figure 3.6** Korita well field (wells and potential future infiltration pond) in relation to main pedological soil units (modified from Bogunović et al., 1997)

## 3.5. Water

### 3.5.1. Surface water

The interior of the island, the so-called Vis plateau is characterized by a complete lack of a hydrographic network and hydrographic phenomena. There are no springs, neither occasional nor fluvial flows. This is because of geotectonic structures and highly permeable limestones that cover the majority of the island and cause rapid infiltration. Atmospheric water sinks into the depths and drains underground to outflow only in coastal zones at the contact of permeable and impermeable rocks in the form of smaller springs.

According to the information given from Croatian Waters, the only water body that crosses the Korita well field is the water body JORN0012_001 categorized as a river of ecotype: lowland small occasional streams (16B). The length of this unaltered watercourse is 2.19 km + 6.66 km. It belongs to the Jadran water area and sub-basin "islands" and is part of the Dinarides ecoregion (Fig. 3.7). Additionally, by the information from Croatian Waters (Classification code: 008-02/21-02/511, Registry Number: 383-21-1, 28th August 2021.), which is referring to a state of waterbody JORN0012_001, load and impact analysis, its overall status is moderate. Ecological status is evaluated as moderate and chemical status as good.

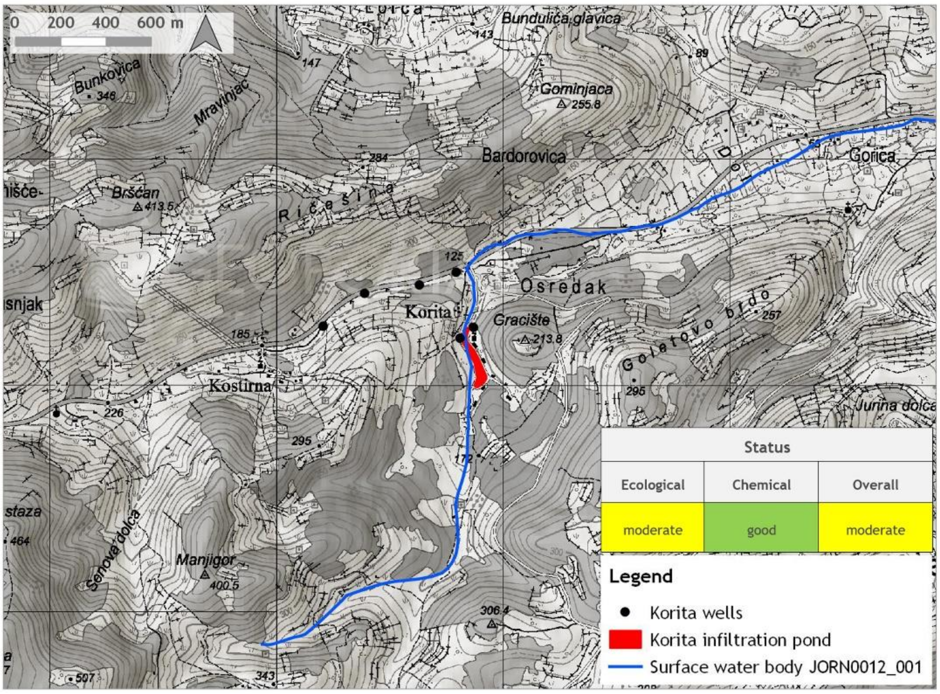


**Figure 3.7** The overall status of surface water body JORN0012_001, located in the wider area of Korita well field (Register of water bodies in accordance with the River Basin Management Plan 2016-2021. Classification code: 008-02/21-02/511, Registry Number: 383-21-1, 28th August 2021.)

### 3.5.2. Groundwater

Korita well field (according to River basin management plan 2016.-2021. of the Republic of Croatia) belongs to the groundwater body called JGN_13 Adriatic islands – Vis that stretches over an area of 90 km$^2$. The aquifer has a fracture-cavernous porosity and assessed medium intrinsic vulnerability. Moreover, it has an estimated groundwater recharge rate of 122x106 m$^3$/year, while utilization is around 3.22x106 m$^3$/year (0.26% of recharge). The overall chemical status is estimated as good, but with low reliability while good quantitative status is estimated with high reliability (Table 3.3). However, it is important to emphasize the shortcomings of these kinds of assessments where all islands are grouped into one single groundwater body, while the realistic conditions vary significantly between each island.

**Table 3.3** Status of the groundwater body JOGN_13 Adriatic islands – Vis (River basin management plan 2016.-2021. of the Republic of Croatia)

| STATUS | EVALUATION OF GROUNDWATER BODY STATUS |
|---|---|
| Chemical status | good |
| Quantity | good |
| Overall status | good |

There are no springs in the interior of Vis island. The main hydrogeological objects on the island are Korita well field (pumping rate of 42.5 l/s) located in the central part of the island, K-1 well (pumping rate of 1.5 l/s) located in the hinterland of Komiža, and Pizdica spring (pumping rate of 3.3 l/s) located in Komiža bay. The groundwater abstracted at the Korita and K-1 sites is of high quality, while the groundwater on Pizdica coastal spring exhibits elevated chloride concentration as it mixes with the seawater. The aquifer of Korita in the central part of the island is protected from seawater intrusions from the west by the impermeable rock formations of the Komiža diapir and from the south by the fine grain infilling of the fractures and karst conduits that leaches from the Quaternary polje deposits decreasing the permeability field of the underlying rock masses. Pizdica spring is formed at the contact of permeable Cretaceous carbonates and impermeable formations of the VSE diaper. K-1 well is constructed in a dolomite aquifer of relatively low permeability behind the VSE barrier.

Previous hydrogeological investigations (Terzić, 2004) on the island of Vis included a water balance calculation, determination of hydraulic parameters of the aquifer from pumping test data, a tracer test, and hydrochemical sampling campaigns.

### 3.5.3. Floods

The Korita well field is located in an area with potentially significant flood risk, as shown in Fig. 3.8 (data provided by Croatian Waters). The flooding and torrential flows occur periodically during heavy rain events.

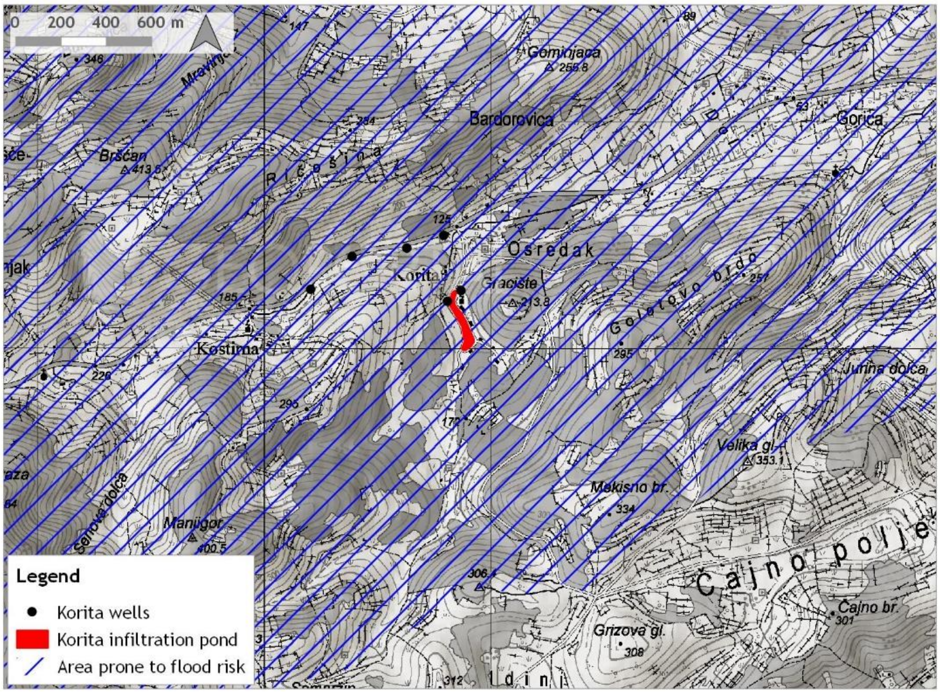


**Figure 3.8** Flood risk area map according to the likelihood of occurrence (Water management plan 2022-2027, shapefile provided by Croatia Waters)

## 3.6. Landscape features

The planned MAR site is surrounded by dynamic hilly relief (up to 400 m a.s.l.). The area is generally covered with dense natural Mediterranean vegetation, while anthropogenic landscape elements are state road 117, the access road to well field, and well field infrastructure. There are no bigger settlements or villages in the vicinity.

Korita well field does not belong to the area of valuable landscape features (protected by the Spatial plans of Vis and Komiža cities) and there are no significant panoramic vistas or landmarks (Fig. 3.9). In addition, there are no landscape areas protected by the Nature Protection Act. The nearest area of significant landscape features (protected with the Spatial plan of Vis) is located around half a kilometer to the northeast (Glavica area, according to the Spatial plan of Vis).

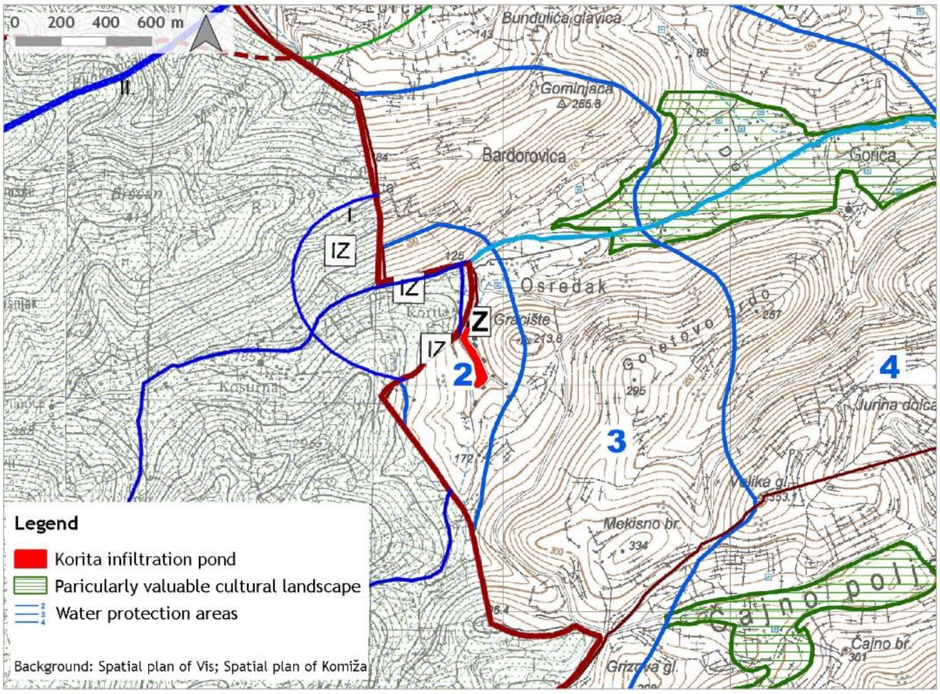


**Figure 3.9** Korita well field in relation to areas of significant landscape features (background: Spatial plan of Vis and Spatial plan of Komiža in WMS provided by ISPU MGIPU, https://gis1.mgipu.hr/srv1/PPRasterZ17_Public/wms)

## 3.7. Cultural heritage

According to the Spatial plan of Vis and Spatial plan of Komiža, there are no archaeological, historical, ethnological, or memorial heritage monuments or areas at the planned MAR site (Fig. 3.10). The nearest archaeological site is located at around 800 m to the northeast and the south.

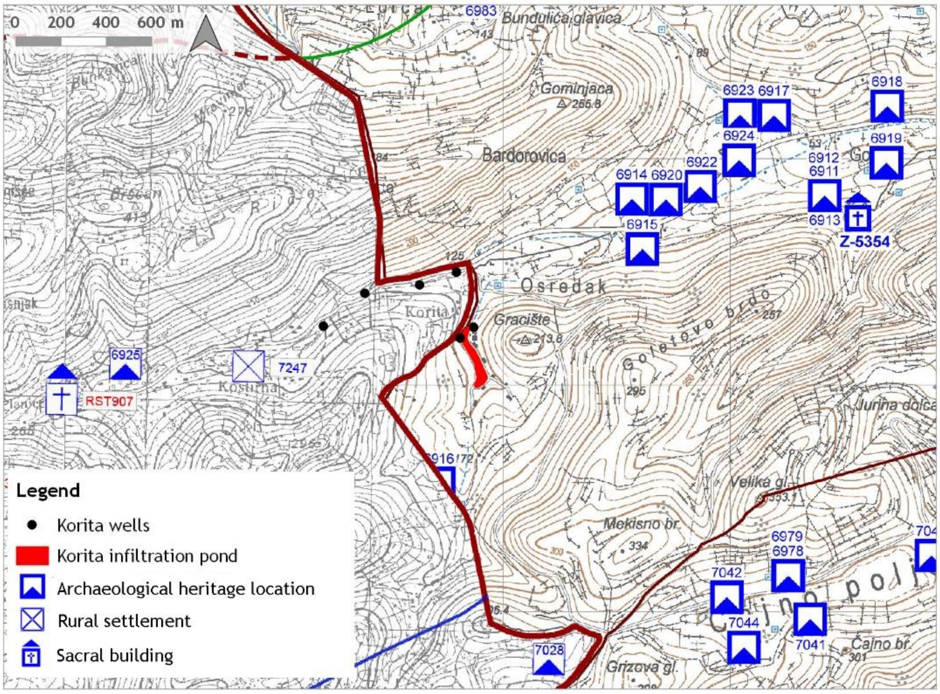


**Figure 3.10** Korita well field in relation to cultural heritage locations (background: Spatial plan of Vis and Spatial plan of Komiža in WMS provided by ISPU MGIPU, https://gis1.mgipu.hr/srv1/PPRasterZ17_Public/wms)

## 3.8. Biodiversity

The project area is zoologically in the Mediterranean sub-area and geobotanically in eumediterranean zone. From the information in the habitat map, Illyrian garrigues are a predominant habitat that alternates with evergreen forests and holm oak maquis scrubland in the surrounding area (Fig. 3.11). Garrigues usually consist of plant families Cistaceae (*Cistus, Fumana*), Ericaceae (*Erica*), Fabaceae (*Ononis minutissima, Coronilla valentina*) and Laminaceae (*Rosmarinus officinalis*).

Characteristic fauna for these habitats is smaller mammals such as eastern hedgehog (*Erinaceus concolor*), lesser white-toothed shrew (*Crocidura suaveolens*), European hare (*Lepus europaeus*), wood mouse (*Apodemus sylvatius*) and, brown rat (Rattus norvegicus). Bats that can use the habitats present in the project area (i.e. for foraging) include the common bent-wing bat (*Miniopterus schreibersii*), Geoffroy's bat (*Myotis emarginatus*), greater horseshoe bat (*Rhinolophus ferrumequinum*), and Lesser horseshoe bat (*Rhinolophus hipposideros*). Mines Vora is the largest *Rhinolophus ferrumequinum* hibernaculum in the Mediterranean biogeographical region in Croatia (SDF data from HR2000942 Otok Vis, Pavlinić and Đaković 2010).

Bird species that were recorded near the project area include pheasant (*Phasianus colchicus*), warblers (*Hippolais palida, Slyvia cantillans, Slyvia melanocephala, Slyvia atricapila*), swift (*Apus apus*), hooded crow (*Corvis cornix*), chaffinch (*Fringilla coelebs*), red-backed shrike (*Lanius collurio*), Eurasian golden oriole (*Oriolus oriolus*).

The habitats are also suitable for different herpetofauna, such as snakes (*Elaphe quatorlineata, Zamenis situla, no vipers*), lizards (*Podarcis situla, Podarcis melisellensis*), and the tortoise (*Testudo hermanni*). Only one species of amphibian, the green toad (*Bufo viridis*), was found on the island of Vis, in only two localities.

Mine Knegla and cave Spila od vore (locality Bardorovica) are located less than 500 m north of the project area. In mine Knegla species from taxa *Pseudoscorpiones* were recorded (Kučinić 2019) and Spila od vore is the type locality for *Otiorhynchus radjai* (SDF data from HR2000942 Otok Vis).

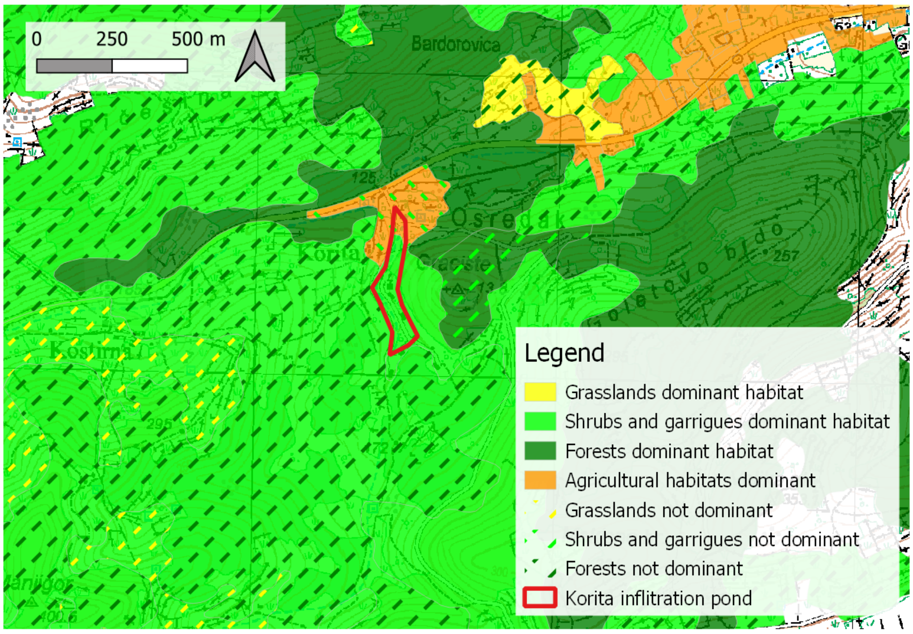


**Figure 3.11** Korita well field in relation to habitat map (background: Habitat map Bardi et. Al 2016; Topographical map 1:25 000)

## 3.9. Protected areas

According to the map areas protected with Nature Protection Act (OG 80/13, 15/18, 14/19, 127/19), the project area is not within the protected nature area (Fig. 3.12). The closest protected areas are significant landscape Cove Stiniva (surface area: 4.12 ha) and Island Ravnik (surface area: 27.30 ha), which are positioned around 3.9 and 7.4 km southeast from Korita well field, as well as nature monument Green cave on Island Ravnik located 7.7 km away from the pilot area to the southeast.

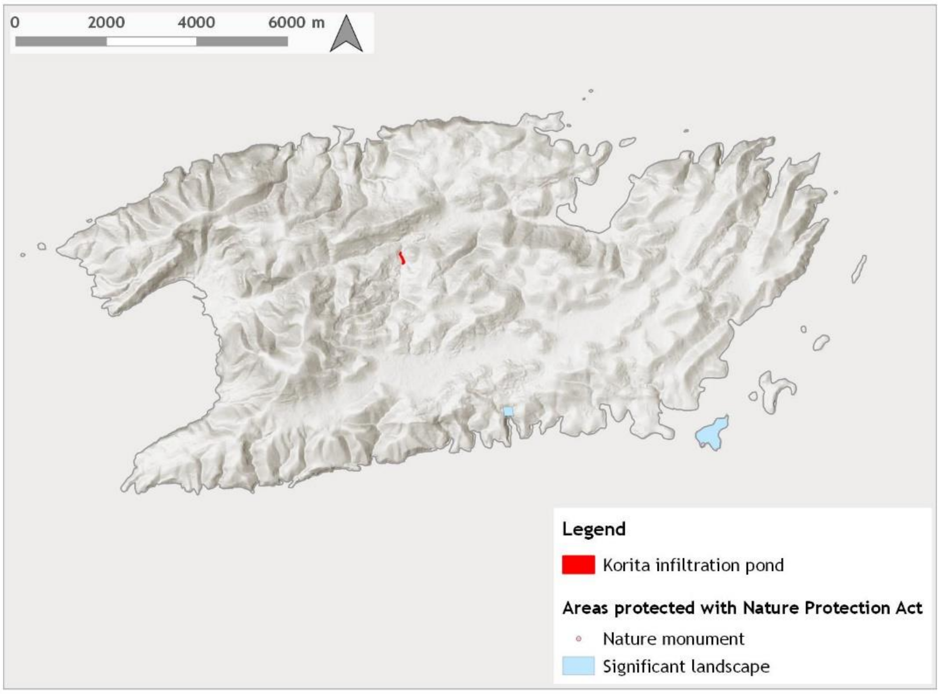


**Figure 3.12** Korita well field in relation to areas protected under Nature Protection Act

## 3.10. Ecological network

By inspecting the excerpt from the Map of the ecological network of the project area (Fig. 3.13), it is determined that the project area is located within the area of ecological network important for birds, species, and habitat types Site of Community Importance (SAC) HR2000942 Otok Vis, and within the area of ecological network important for bird conservation Special Protection Area (SPA) HR100039 Pučinski otoci. The list of species and habitats in these areas is listed below in the tables.

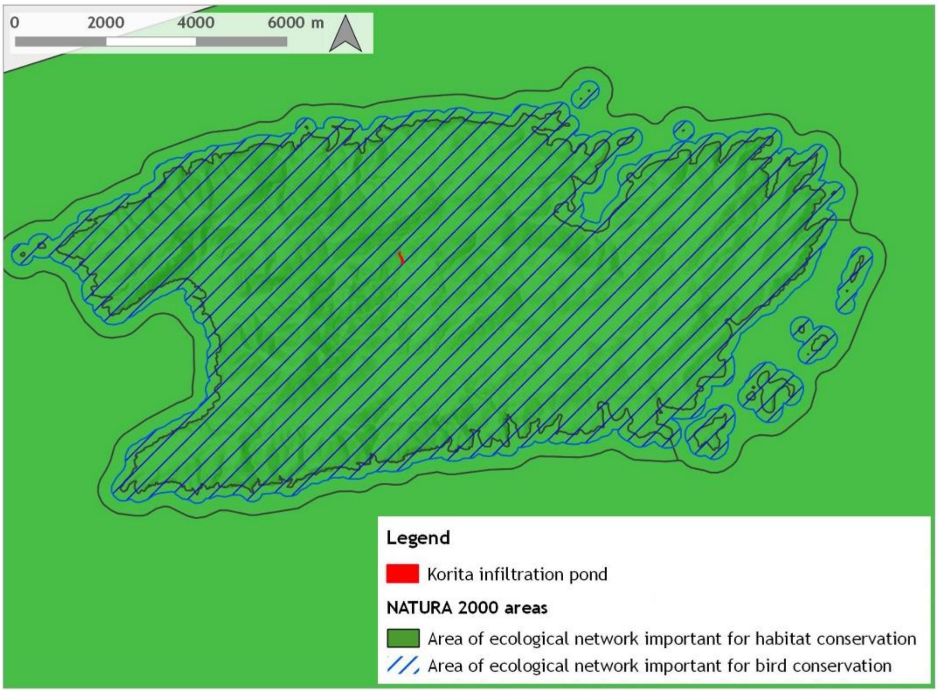


**Figure 3.13** Korita well field in relation to areas protected under ecological network NATURA 2000

**Table 3.4** Target species and habitat types for HR2000942 Otok Vis

| Site of Community Importance HR2000942 Otok Vis | |
|---|---|
| **Species** | **Habitat types** |
| *Miniopterus shreibersii*<br>*Myotis emarginatus*<br>*Rhinolophus ferrumequinum*<br>*Rhinolophus hipposideros*<br>*Elaphe quaturolineata*<br>*Elaphe situla* | 1210 Annual vegetation of drift lines<br>1240 Vegetated sea cliffs of the Mediterranean coasts with endemic *Limonium spp.*<br>2110 Embryonic shifting dunes<br>3170 Mediterranean temporary ponds<br>5210 Arborescent matorarral with Juniperus spp.<br>6220 Pseudo-steppe with grasses and annuals of the Thero-Brachypodietea<br>8210 Calcareous rocky slopes with chasmophytic vegetation<br>8310 Caves not open to the public<br>8330 Submerged or partially submerged sea caves<br>9320 Olea and Ceratonia forests |

**Table 3.5** Target species for HR100039 Pučinski otoci

| Special Protection area HR100039 Pučinski otoci |
| --- |
| Species |
| *Calconectris diomedea, Caprimulgus europaeus, Circaetus gallicus, Circus cyaneus, Falco eleonorae, Falco peregrinus, Grus grus, Lanius collurio, Pernis apivorus, Phalacrocorax aristotelis desmarestii, Puffinus yelkouan* |

## 3.11. Socio-economic conditions and main end-users

The water supply for around 3700 inhabitants of island Vis is provided by the abstraction of wells Korita and Pizdica spring, and the K1 well near Komiža. The majority of the population lives in cities of Vis and Komiža (Fig. 3.14), followed by settlements Rukavac, Oključna, Podhumlje, Podšpilje, Žena Glava, and Kostirna.

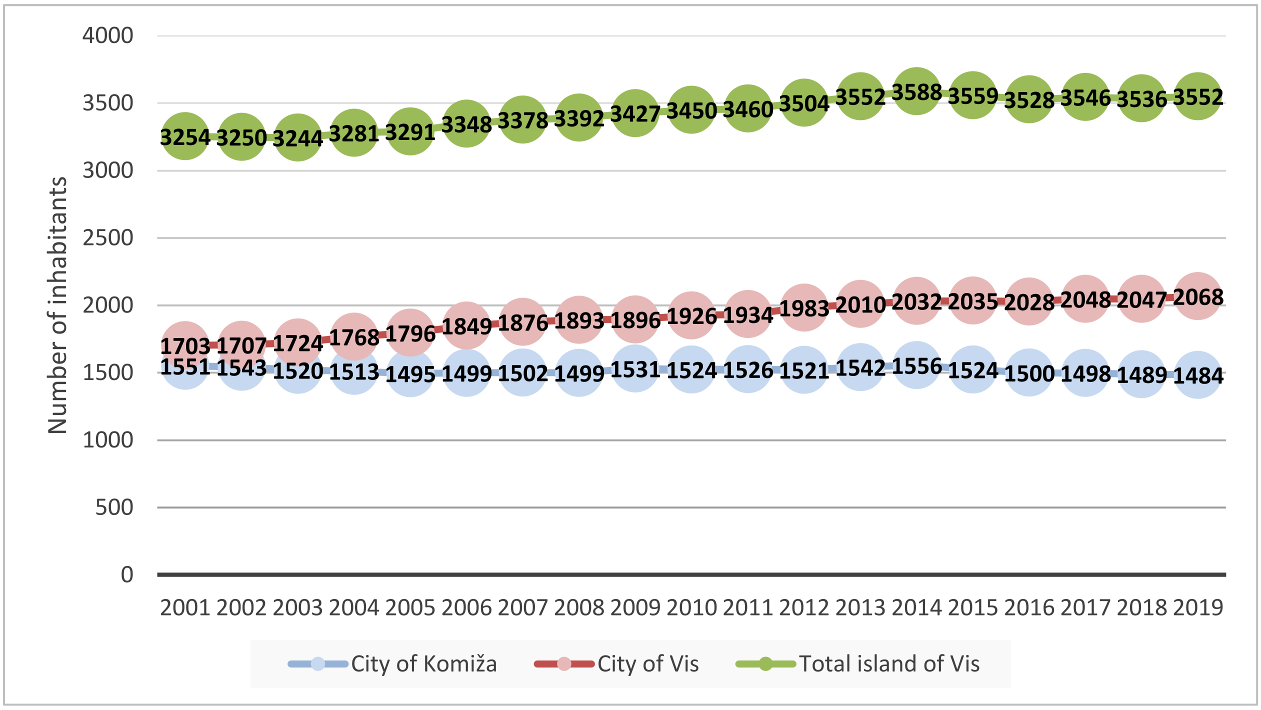


**Figure 3.14** Number of inhabitants of the island of Vis, 2001-2019 (source: Croatian Bureau of Statistics / DZS)

Economic potentials of the island of Vis are focused on traditional agricultural activities such as the revitalization of olive groves, producing wine and other fruits as well as fisheries through catching, processing, and fish farming. The most important economic branch on the island is tourism, especially nautical tourism, and today active tourism is developing more and more such as eco and agro-tourism. These activities require higher amounts of water, especially during summer periods so the project would provide a more reliable source of water.

# 4. Potential impacts of MAR on the environment

### 4.1.1. Impact on the microclimate

Water bodies can mitigate the microclimate of their surroundings by cooling and heating the local atmosphere during the day and night in summer and winter, respectively. The capability of water bodies to reduce daily and seasonal temperature fluctuation depends on the size of the lake itself and its surface/volume ratio (Pisello et al. 2015). Korita infiltration pond area will be around 0.9 ha, so it is not likely that significant changes to microclimate would occur.

### 4.1.2. Impact on the geology

The impact of MAR on the geological conditions will be significant during the construction phase of the infiltration pond/accumulation structure. Most significant risks related to the disturbance of the surficial rock mass are connected with situations in which there would be leeks of motor oils and fuel from heavy machinery, which could potentially penetrate deeper layers and/or aquifer. During the operational phase, a considerable modification in the flow patterns can be expected in this carbonate aquifer within a short period. Changes are expected in the rock dissolution process along with fractures and conduits. Clogging with soil particles could lead to lower infiltration rates.

### 4.1.3. Impact on the soil

The main expected impact on soil is related to the construction works and the change in land use, soil stability, as well as wetting and moisture content during the operation phase. According to the Spatial plan of Vis and Spatial plan of Komiža cities, the area is marked as “other agricultural land” and “other agricultural and forest land”. However, the Korita well field is already under the anthropogenic impact and is not used for agricultural purposes therefore, no agricultural land will be lost, but the category of “forest land” will change its function.

The construction works with large machinery could potentially damage the soil structure and stability, as well as cause erosion on slopes, if not planned and handled properly. Within the construction zone, there is a chance for accidental spills and leaks (fuels, oil, paints, cooling fluids, etc.) which could infiltrate the soil and pollute it.

The introduction of large volumes of "standing" water may cause soil erosion (e.g. aggregate destruction, compaction, and formation of crusts), and thus limit the water infiltration rate.

During MAR “operation phase” soil will have a significant role in the purification of the recharged waters by enabling the elimination of pathogenic agents or potentially harmful substances. The microorganisms can grow on the recharging surface, form biofilms, and consequently, clog the soil.

The overall impact on soil is categorized as long-term, direct and negative.

### 4.1.4. Impact on the water

#### 4.1.4.1 Impact on surface water

The implementation of MAR technology will not affect the surface water bodies, as there is only one surface water body in the area (river JORN0012_001), however, it is dried out and can occur only in case of intensive and long rain periods.

The positive impact could be seen in the collection of water runoff from surrounding terrain in the accumulation pond that will be built as part of the MAR infrastructure.

#### 4.1.4.2 Impact on groundwater

The planned MAR technology envisaged the treatment of collected water before its discharge into the aquifer. Therefore, no negative impact is expected on water quality, given that the strict regime regarding the quality of the source water is respected. This may include various methods of pre-treatment to remove any unwanted pollutants and/or suspended particles that would eventually cause clogging. However, in case of non-compliance with appropriate procedures during construction works spills and leakages are possible (solvents, fuel, lubricants, etc., which may infiltrate into the soil, and ultimately reach groundwater). These potential negative impacts can be avoided by compliance with applicable legal regulations and adequate organization and proper managing of construction works.

Due to anisotropic and heterogeneous properties, carbonate aquifers can show high dissipation of recharged water. Together with soil protective layers epikarst represents the area where geochemical and microbiological processes might enable the purification of the recharged water. However, large fractures and conduits represent relatively fast pathways for infiltrated pollutants (e.g. pharmaceuticals, pesticides, metals, PBCs, etc.). Therefore, a clear understanding of flow direction (especially preferential flow directions) is a prerequisite for the identification of potential pollution sources.

The positive impact of the planned project will be the replenishment of the island’s aquifer i.e. improved water balance of currently endangered by climate change and growing water needs, especially during the dry period of the year.

### 4.1.5. Impact on the landscape

To assess the potential impact of the planned MAR site on the landscape the analysis is conducted based on existing spatial documentation and cartographic materials (satellite images, topographic map of Republic of Croatia in scale 1:25 000, Corine land cover).

The location chosen for the implementation of MAR technology does not belong to a protected significant landscape area. Change in vistas, morphology, land cover, and overall perception of the area is expected with the construction of an artificial pond, which is a landscape form that did not exist before in the wider area. However, the area is not populated or frequently visited by locals, and will not be visually exposed from the local road. Also, if the slopes and area surrounding the artificial accumulation will be planted with local autochthone plants, after the construction, this new landscape element could visually be harmonized with its surroundings. Therefore, the overall impact is assessed as long-term and neutral.

### 4.1.6. Impact on the cultural heritage

No impact (during construction or operation) is expected on cultural heritage as there are no archaeological or memorial sites within the planned MAR location.

### 4.1.7. Impact on the biodiversity

The main direct impact of the project will be loss of garrigue habitats and change to permanent surface standing waters. Since garrigues are widely distributed on the island and are a result of a succession of pastures and degradation of forests, the impact of habitat loss is expected to be acceptable. Before removing the top layer, the area should be checked for nests of endangered species to minimize the disturbance effect. Removing of the top layer should be carried out in winter periods since the activity of most animals is lower at this time.

In the operation phase, a new water body will be present. In addition, there are not any water bodies present on the island because of the soil permeability), so this will be an attractive site for many species like bats, birds, insects, herpetofauna, etc. In the vicinity (less than 1 km) there are known bats hibernaculums and other bat species are present on the island so there is a medium risk of causing disturbance from noise and vibrations during the construction phase. It is expected that the bats will use the area as a water source.

### 4.1.8. Impact on the protected areas

The planned MAR location of the Korita well field does not belong to an area protected by Law on Nature Protection (OG 80/13, 15/18, 14/19, 127/19), therefore no impact is expected on protected areas.

### 4.1.9. Impact on the ecological network

Most target species from the SPA area HR100039 Pučinski otoci are species that reside close to the sea and coastal areas. Species *Caprimulgus europaeus* and *Lanius collurio* could be found on habitats present in the project area. According to The Decree on conservation objectives and conservation measures for target bird species in the areas of the ecological network (OG 25/20, 38/20), for *Caprimulgus europaeus* the conservation objective is to preserve enough garrigues and suitable habitats (extensive agricultural areas) to sustain 50-100 pairs. For species *Lanius collurio* the conservation objective is to preserve mosaic habitats to sustain 500-1000 pairs. For species *Lanius collurio* there is a small risk of negative impacts since the project area is small and it is not mosaic. For *Caprimulgus europaeus*, if the construction work is carried out in winter or early spring time, the risk of negative impacts is minimal since the species is not present at the site then.

Habitat types from SAC area HR2000942 Otok Vis are not expected to be at the project area, so the risk of negative impact is low. On the other hand, target species *Zamenis situla* and *Elaphe quatuorlineata* must have 9040 ha of habitats as conservation objectives according to the beforementioned Decree. The project area is a suitable area for these species, so more detailed research should be carried out before the construction phase to analyze if these species are present in the project area so the risk of negative impacts is medium. Other target species for this area are bat species and the conservation objective for *Rhinolophus ferrumequinum* is to preserve underground shelters, especially hibernation colonies in Vora mines which are less than 1 km from the project area. There is a medium risk of disturbing the colonies if the construction will cause vibrations or noise strong enough to reach the mines. There is also a possible positive impact of an infiltration pond formation in terms of becoming a source of water for bat species.

### 4.1.10. Socio-economic impacts

Properly planned investment in groundwater management can be seen as an investment in public health. The main expected benefit from the implementation of the MAR project at island Vis is the enhancement of the drinking water supply, which will indirectly positively affect the quality of life. Another positive indirect impact could be new job opportunities at the MAR site. Moreover, the planned intervention could potentially contribute to the future spatial development of this part of the Vis.

However, the development, implementation, and maintenance of MAR can be a substantial and continuous investment and as such represents a significant challenge for local policy-makers. A key to addressing these financial challenges is finding funding and investment opportunities.

## 4.2. Cumulative impacts

The selected MAR location is not part of future spatial interventions as it is a state-owned drinking water protection zone. In the near future, the only new infrastructure will be related to water abstraction, purification, and distribution to the water supply network. Therefore, no cumulative impacts are expected.

## 4.3. Overview of recognized impacts

The following table shows the grade for each particular impact.

**Table 4.1** Overview of recognized impacts - Croatia

| Grade | Description |
|---|---|
| -1 | Negative impact |
| 0 | There is no impact |
| 1 | Positive impact |

| *ENVIRONMENTAL COMPONENT* | | *IMPACT CHARACTERISATION* | | | |
|---|---|---|---|---|---|
| | | *DIRECT/ INDIRECT/ CUMULATIVE* | *SHORT-TERM/ LONG-TERM* | *POSITIVE/ NEUTRAL/ NEGATIVE* | *GRADE* |
| *Climate* | | *indirect* | *long-term* | *neutral* | *0* |
| *Geology* | | *direct* | *long-term* | *neutral* | *0* |
| *Soil* | | *direct* | *long-term* | *negative* | *-1* |
| *Surface waters* | | *indirect* | *short-term* | *positive* | *1* |
| *Groundwater* | | *direct* | *long-term* | *positive* | *1* |
| *Landscape* | | *direct* | *long-term* | *neutral* | *0* |
| *Cultural heritage* | | - | - | - | *0* |
| *Biodiversity* | *Terrestrial habitats* | *direct* | *long-term* | *negative* | *-1* |
| | *Underground habitats* | | | | |
| *Protected areas* | | - | - | - | *0* |
| *Ecological network* | | *direct* | *long-term* | *neutral* | *0* |
| *Population* | | *indirect* | *long-term* | *positive* | *1* |

# 5. Conclusion and summary / Croatia

The presented Environmental Impact Assessment aimed to evaluate the impact of two MAR methods (i.e. infiltration pond and aquifer storage and recovery) on various components of the environment and society in the Croatian pilot site on the island of Vis. In particular, EIA was conducted specifically for the Korita site, where the infrastructure related to water abstraction, purification, and distribution already exists. As the island faces a potential water shortage during the dry period, which coincides with the highest freshwater demand due to increased summer tourism, the main objective of the two proposed MAR methods is to increase groundwater levels by artificially recharging the aquifer during the wet season (October-March). The source water is represented by precipitation, storm, and floodwaters, captured in the accumulation or infiltration pond.

The addition of the MAR facility (pre-treatment facility, accumulation structure, and infiltration pond/injection well) to the Korita site and its operation would exert a neutral impact on climate, geology, landscape, cultural areas, protected areas, and ecological network. A negative impact is expected on the soil, as the construction of the MAR infrastructure would require its disturbance or removal. However, this effect is localized. Furthermore, a negative impact is expected for the terrestrial habitat of garrigue, but since garrigue is widespread and almost dominant all over the island, this negative impact is not considered as significant. A positive impact is expected for surface water, groundwater, and population. Risks related to the implementation of MAR in the karstic aquifer (e.g. aquifer dissolution, degradation of water quality, increased marine discharge of groundwater) must be minimized by conducting detailed and high-resolution investigations (e.g. 3D flow and transport models, geochemical modeling, tracer test, hydrogeochemical investigation, etc.). In particular, the positive effect is represented by the formation of a surface water reservoir (i.e. source water) and revitalization of old river beds in Korita, and by increasing groundwater levels, which would improve the safety and resilience of the water supply during dry summer months. The beneficiaries of conducting safe and sustainable MAR are the island's community that could continue to improve urban and social infrastructure, as well as tourists, whose freshwater demand could be met during the surging summer season.

# HUNGARY

The objective of this Preliminary Environmental Impact Assessment (EIA) is to examine and evaluate the possible environmental impacts of a theoretical underground dam in the Hungarian pilot site. The wider Hungarian pilot area is the Maros alluvial fan, which is the most important agricultural region in Hungary. It is in the southeast part of Hungary (in Békés County) between two major rivers Körös and Maros. Irrigation has special importance due to the climatic conditions that can be supported mainly from groundwater. From a geological point of view, the pilot area is situated in the territory of Békés Basin, which is one of the deepest sub-basins of the Pannonian Basin, filled with several thousand-meter-thick Neogene porous sediments. The Pleistocene sediments are represented by the alluvial fan formations deposited by the ancient Maros River. The surface of the extensive Maros alluvial fan is densely covered by paleo-channels. This region is characterized by rural land use therefore a big amount of irrigation water demand occurs.

Within the 3rd Work package of the DEEPWATER-CE project, we carried out a MAR suitability mapping to find the best places for the construction of an underground dam (UD) in Hungary. The selection of a specific pilot site, where we can perform a preliminary MAR feasibility study was a crucial step of the DEEPWATER-CE project. To find the appropriate place, we have carried out a preliminary suitability mapping based on the 8 selection criteria specified within the 2nd Work package of the project (DEEPWATER-CE, 2020a). This mapping process highlighted several sites within the Maros alluvial fan, characterized by high suitability. To choose the final location, additional data was required, which can be collected by field observations and measurements.

Based on our preliminary examinations we chose the area between Csanádapáca and Medgyesbodzsás as our final pilot site for further investigations.

The chosen MAR technology is the underground dam (UD). The most common geological environment of the underground MAR scheme is related to alluvial sediments. These aquifers are situated along the recent and ancient flow direction of main river courses, sometimes forming large, extended alluvial fans. During the construction, structures (slurry walls) are installed in streambeds, and therefore it does not interfere with land use. With the help of the slurry walls, the intensity of the groundwater flow will decrease horizontally so the level of the groundwater will increase, and the water can be stored in the aquifer for later use.

There is no specific regulation for MAR systems in Hungary but based on the EU Directives there are some general national regulations about groundwater protection, groundwater management, and monitoring activity: Government Regulation 123/1997. (VII.18.) on the protection of vulnerable water supplies concerns their protection measures and the criteria of water protection zones. The Act LVII of 1995 on water management regulates the recharge of aquifers by artificial recharge and reinjection. The Government Regulation 219/2004. (VII.21.) on the protection of groundwater regulates the artificial recharge and reinjection in order to preserve the quality and quantity of the underground water resources. The 30/2004. (XII. 30.) KvVM Decree on rules of monitoring of groundwater regulates the monitoring of quality and quantity status of groundwater bodies. The 201/2001. (X.25.) Government Regulation has a focus on quality requirements of drinking water and regulates respective monitoring.

# 2. Project description - Managed aquifer recharge

## 2.1. MAR technology

The chosen MAR technology to be used on the Maros alluvial fan is the underground dam. An underground (or subsurface dam) dam is a facility that stores groundwater in the pores of strata and sustainably uses groundwater. This edifice is very similar to a regular dam operating on the surface in a way that it also holds back water on the side of the water flow direction, but in contrast to surface constructions, this dam holds back groundwater and for this reason, its viability requires a special geological setting. In such an environment a layer of high-permeability sediments (aquifer) must be present, underlain by a coherent, very-low-permeability aquitard layer, which must also surround the aquifer from the sides. An underground dam is built in the aquifer, in a way that its walls would also reach deep enough into the horizontally and vertically present aquifer, and – in the most optimal case – to be perpendicular to the groundwater flow direction. This way groundwater levels will rise behind the dam to be optimal for production (Fig. 2.1).

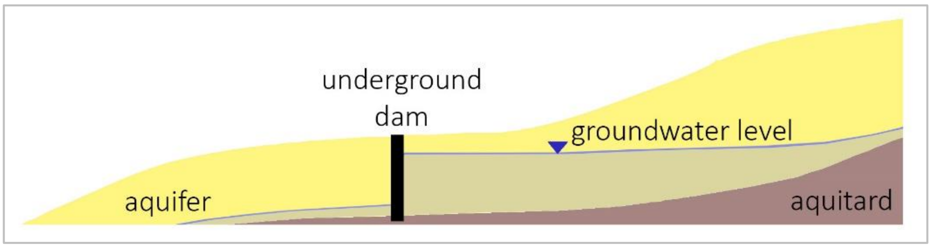


**Figure 2.5** Schematic illustration of an underground dam

The planned underground dam facility in the pilot site, based on discussions with a company (Békés Drén Ltd.) being expert in the implementation of such edifices, would be comprised of numerous different elements (Fig. 2.2):

1) The **underground dam** itself would serve as a vertical impermeable wall.
2) **The drainpipe** (s) run at the bottom of the aquifer, going through the foot of the dam and being parallel to the groundwater flow direction. This pipe facilitates subsurface water migration and drives a certain amount of groundwater to the other side of the dam, to maintain groundwater supply. Its material is usually PVC or PE plastic, wrapped in geotextile.
3) **The gate of the underground dam**. This element is a sluice installed in a shaft, reaching the drainpipe, and is used for water governance. It provides the possibility to regulate the amount of water going through the dam via the drainpipes and to make the groundwater reachable for production via the shaft. It is made up of concrete and metal elements.
4) **Surface ditches** take and transport the water extracted at the gates along the area of interest behind the dam. These 2-3 m wide concrete ditches are easily accessible for farmers and let them use their water for irrigation.
5) **Intermediate water-governing structures** are similar to the gate in both function and material. They provide water-access points and control to the groundwater at certain, approx. 2 km long intervals of the system.
6) **Monitoring wells** are used to oversee the changes in the groundwater level. The number and location of wells depend on the aims and budget, which defines how dense the monitoring network will be used.

The applied theoretical underground dam facility for the pilot site is supposed with a minimum of 10 m deep and 200 m long, a maximum of 20 m deep, and a 2 km long dam wall. Though the spatial extents of the underground dam might seem to be large, most of this construction is situated below the ground surface, thus they do not interfere with surface land use and are out of sight. This hidden nature of the facility provides the number one advantage of such an installation: the decreased possibility of environmental impacts due to the protection of geotechnical solutions or the minimized evaporation.

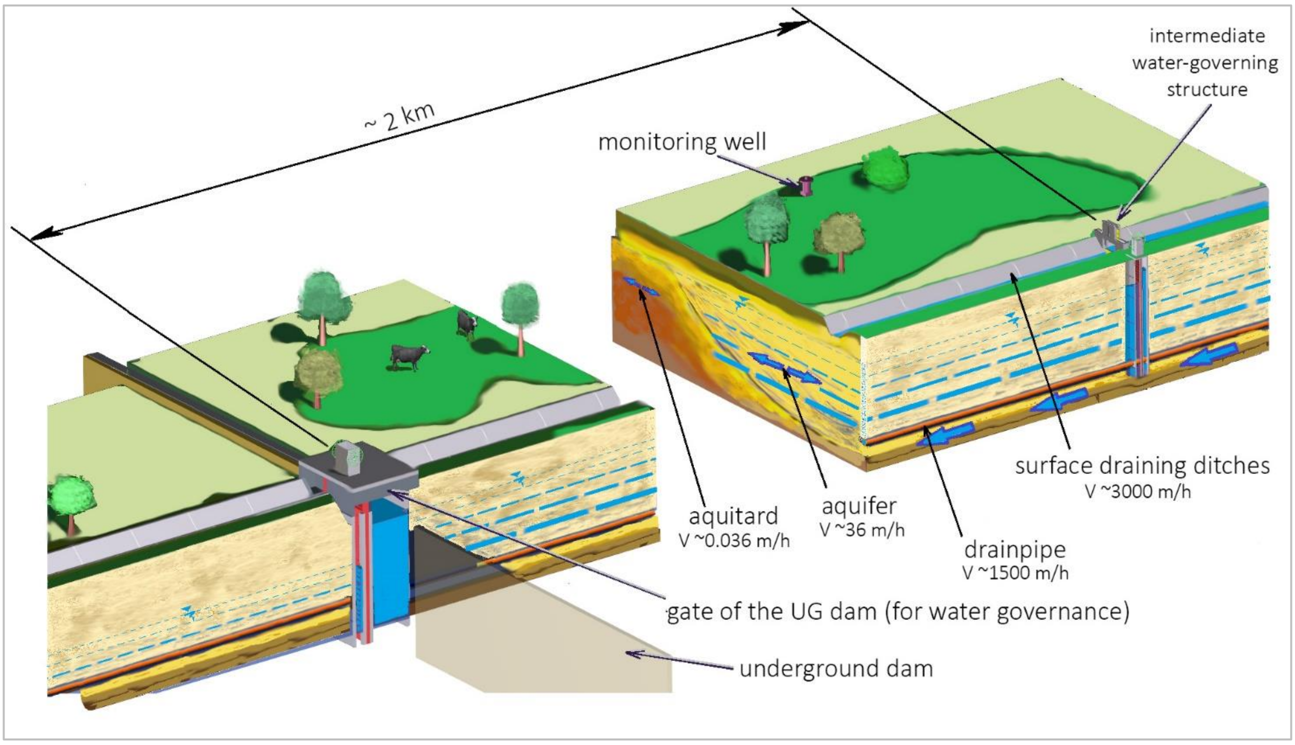


**Figure 2.6** Illustration of an underground dam system
(Source: modified illustration of DELTA organization (Dél Alföldi Tálentum Akadémia, 2021))

## 2.2. Variant MAR solutions

MAR solutions, which use surface water (e.g. infiltration ponds, induced river or lake bank infiltrations, recharge dams, etc.) are not considered optimal solutions in the area due to the lack of surface water. For this reason, the usage of underground dams – which are designed specifically for trapping groundwater – are highly viable.

The underground dam, which is planned for the geological setting of the pilot site, depending on the different technical solutions and locations within the alluvial fan, can vary greatly in extent, therefore in the magnitude of stored water as well. The option, which is studied in the Cost-Benefit Analysis (CBA) as well, aims to construct a dam until the bottom of the first aquifer, thus trapping the uppermost groundwater table. However, this one is not optimal for human consumption but is ideal for agricultural usage, which is the aim of the application. This construction can be realized by a 10 m deep, 200 m long dam and would store groundwater in an area of 2 km length behind the dam itself. Nevertheless, if the aim is to provide drinking water, then deeper aquifers are needed to be aimed with the dam, but for that a new study is needed, focussing on deeper geology.

Not only the simple dimensions of the dam are extendable in the light of needs, but several separate underground dam facilities can be connected in a 'cascade-like' manner. As mentioned in the previous chapter, the MAR facility can be supported with a so-called ‘intermediate water-governing structure’. These edifices can serve as joining points of two underground dam systems, put perpendicular to the direction of the groundwater flow path to retain it. With a thorough water governance idea, the groundwater can be controlled in extensive areas and provided for a wide number of water users. This MAR solution of an underground dam requires huge costs, and it is considered viable only in those regions where the use of water is inevitable, and due to water scarcity, its price would be extremely high.

# 3. Environmental setting of the proposed project location

Having a good baseline knowledge of the potentially affected environmental resources and communities located at or near the proposed MAR site is crucial for conducting every environmental impact assessment study. Thematic maps (e.g. land use and land cover, geological and hydrogeological map, map of nature-protected areas, etc.) served as basic data for the definition and characterization of the effects.

This chapter provides sufficient information for decision-makers and reviewers about the geographical, geological, and hydrogeological settings of the location of the selected pilot site of an underground dam MAR system.

## 3.1. Site description

The pilot area is situated in the southeastern part of the Great Hungarian Plain (in Békés County) between the two largest tributaries of River Tisza (Körös and the Maros) along the national border. The pilot area covers the territory of two micro-regions: Csanád Ridge and Békés Ridge (Dövényi, 2010), and is situated in one of the largest fluvial alluviums in Hungary (Figure 7.1). The special geographical settings (climate exposure, low relief, etc.) determine the land use, water demand, and possibilities in the water supply.

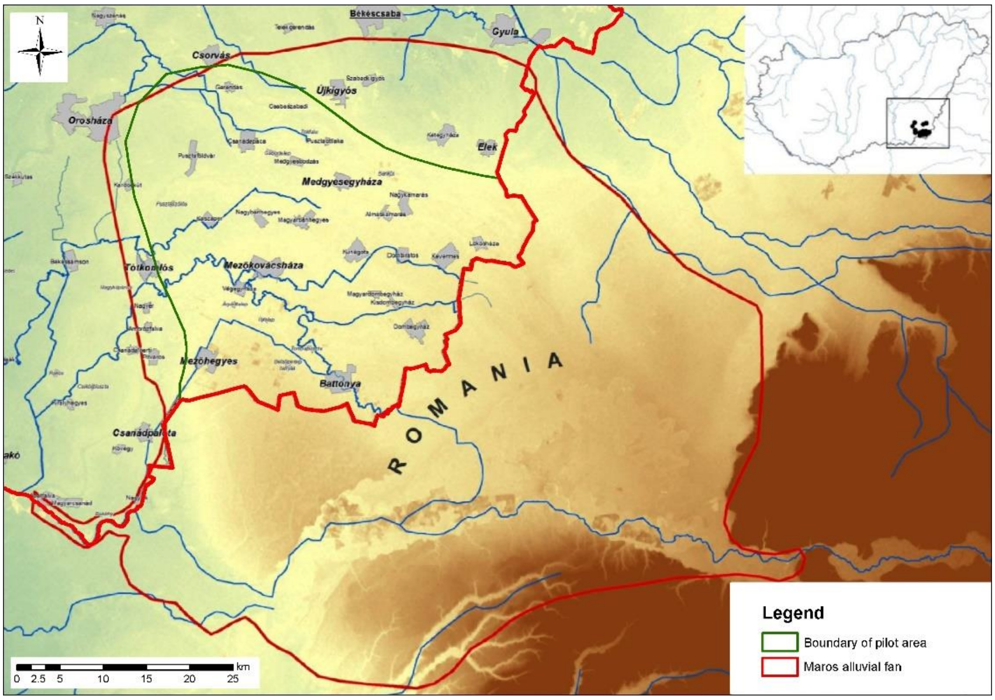


**Figure 7.1** Location of the Maros alluvial fan (Fiala and Juhász, 2015)

In the frame of the 3rd Work package of the DEEPWATER-CE project, we carried out a MAR suitability mapping to find the best suitable places for the construction of an underground dam in Hungary. Based on mapping different limiting parameters as constraints, like some geological-hydrogeological criteria (slope, depth of the groundwater table, lithology of the shallowest aquifers), climate exposure, and need for a sustainable source of water, the Maros alluvial fan was selected as a pilot area (DEEPWATER-CE, 2020a). The selection of a specific pilot site was a crucial step of the DEEPWATER-CE project, where a preliminary MAR feasibility study was performed. To find the appropriate place, we have carried out a preliminary suitability mapping based on the 8 selection criteria specified within the 2nd Work package of the project (DEEPWATER-CE, 2020a). This mapping process highlighted several sites in the region of the Maros alluvial fan, characterized by high suitability. To choose the final location, additional data was required, which can be collected by field observations and measurements.

Based on our preliminary examinations the area between Csanádapáca and Medgyesbodzás was chosen as a final pilot site for further investigations (Figure 3.2).


**Figure 3.2** The location of the Hungarian pilot site

### 3.1.1. Proposed MAR site in relation to other spatial interventions

The actual and valid urban development plans for Medgyesegyháza and Csanádapáca are available on the websites of the settlements (http://www.csanadapaca.hu; https://www.medgyesbodzas.hu/). These plans provide a very good overview of the current land use of the urban and periphery area of the towns. Fig. 3.3 shows the land use structural plans and the border of the pilot site.

The pilot site is situated mainly in the administrative area of Medgyesbodzás and barely touches the administrative area of Csanádapáca in the West. This small area of Csanádapáca is mainly a common agricultural area but there is an industrial area as well. Also, a mid-to high-pressure gas pipe runs from NW to SE.

About 90-95 % of the pilot site is situated in the administrative area of Medgyesbodzás. In this territory, the main land use is agricultural with a small percentage of forest and pasture. In addition, there are lines of forests as buffer lines. The local water reserve is situated at the SE of the marked pilot site.

Based on the Urban Development Plan from 2010 in Medgyesbodzás the only planned spatial intervention was the unburdening of the main road with a bypass road. As written in the Urban Development Plan (2019) for Csanádapáca, a wastewater treatment plant was planned in the western corner of our pilot site, and eventually, the plant was built.

At this point based on the information from the municipalities, there are no other spatial intervention plans for this area.

Because the MAR scheme in this pilot site is very theoretical, in the case of planning the installation of the MAR system in the future the other respective spatial plans must be considered.

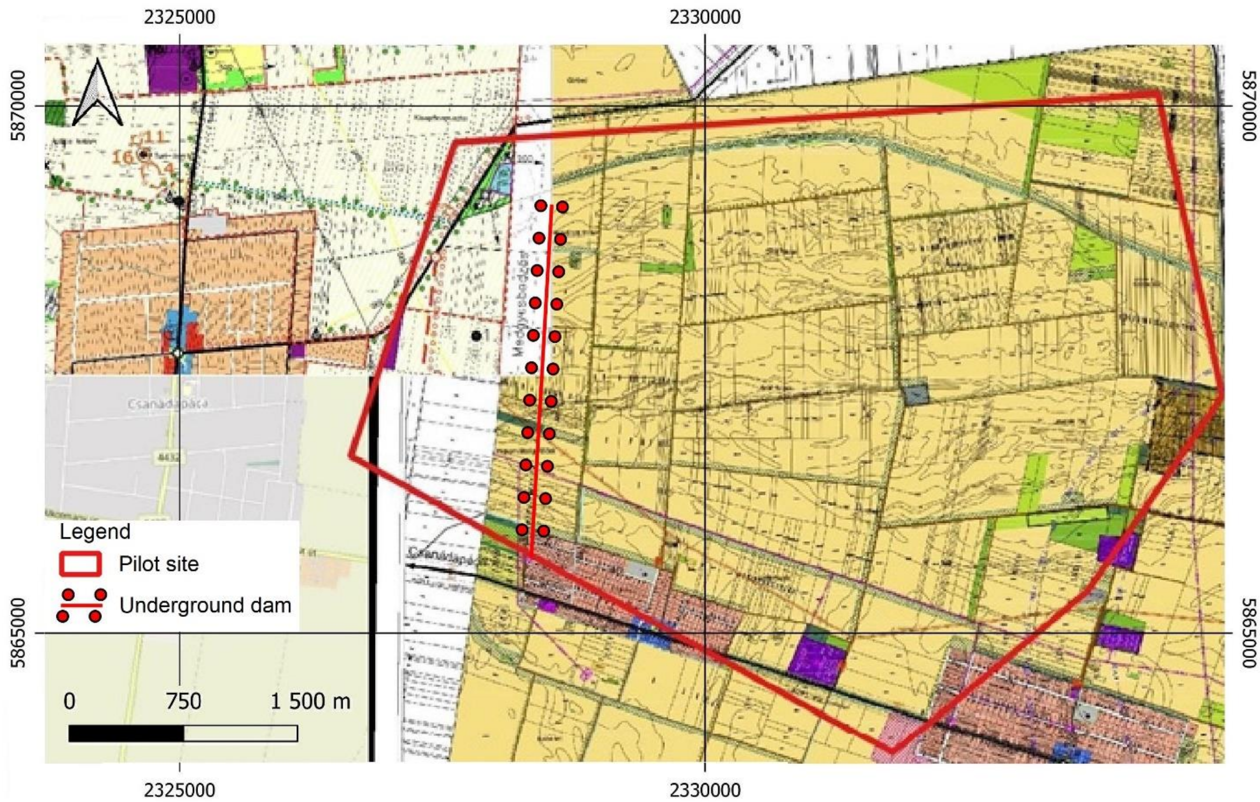


**Figure 3.3** The pilot site with the valid georeferenced land use structural plans

*purple – industrial area; light brown – agricultural area; green – forest; green with stripes –forest buffer zone; grey –special area (graveyard); red – small-town residential area; orange –town residential area; blue – mixed town center area*

(The maps are georeferenced and the base map's source is the Open Street Map)

## 3.2. Climate characteristics

The climate of the pilot site is warm-dry and moderately warm. The number of hours of sunshine per year is extremely high, and varies between 2000-2020 hours, about 810 hours in summer, and is about 190 hours in winter (RBMP, 2015).

The average annual temperature is 10.3-10.5 °C and the average temperature during the growing season is between 17.3-17.5°C, according to most of the projections of different climate models, temperatures are expected to increase further due to climate change. The frost-free period begins in April and ends in October and lasts about 196-198 days (Dövényi, 2010). In winter, the land is covered with snow for 28-35 days, with an average maximum snow thickness of 18-20 cm (RBMP, 2015).

The annual rainfall varies between 550-620 mm, the average during the vegetation period is approx. 340 mm. According to historical meteorological data, the region can be classified into heavy drought and extremely heavy drought categories (Pálfai, 2002).

The most common wind directions are NE and SE; the average wind speed is slightly below 3 m/s (Dövényi, 2010).

## 3.3. Geological and hydrogeological settings

The pilot site is located in the Quaternary fluvial fan of the Maros River, which is one of the most representative distributive fluvial systems in the Hungarian Quaternary succession. These fluvial deposits reach 450–500 m of thickness. Stratigraphically correlated sand bodies have been identified and are in line with the results of modern research on the geology of alluvial fans (Weissmann et al., 2013). Well-documented braided and meandering channels can be observed and were reported (Sümeghy et al., 2013) on the top of the distal fan. The pilot site is situated on one of the distal lobes of the fan abandoned due to the changes in the flow direction of the Maros River during the Holocene.

The fluvial sediments deposited in channels, point bars, islands, and incised valleys of the fan act as aquifers, while fine-grain silts and clays, derived from floodplain environments, represent the aquitard layers. Although the entire alluvial complex forms a hydraulically connected aquifer system, in the conceptual hydrogeological model of the focus area (within the upper 60 m) of the pilot site four hydro-stratigraphical units were distinguished according to the analysis of the fluvial cycles.

The thickness of the uppermost aquifer – with regionally correlated sand bodies - varies but it is mostly in the range of 5-15 m in the pilot site, representing the uppermost part of the Upper Pleistocene fluvial cycle. The shape of this sand body roughly follows the surface manifestation of the fluvial belt towards the depth, elongated in an E-W direction and laterally thinning. The groundwater table is at a depth of 1.5-4.5 m below the surface. The direction of the regional groundwater flow is SSE—NNW.

The underlying layer, the lower part of the Upper Pleistocene fluvial cycle, with fine-grained sediments is considered the first aquitard layer in the conceptual hydrogeological model of the pilot site. It consists of clay, silty clay, and silt in different proportions, usually with a significant thickness of 15-25 m. Where the first aquifer is missing or wedges out, the aquitard layer outcrops on the surface. Locally isolated sand bodies can also be detected within this layer. Where the thickness of this first aquitard is higher (more than 20 m), it can hydraulically separate the neighboring aquifers, but due to heterogeneity, semi-permeable behavior can be dominant, and locally hydraulic connections cannot be excluded between the uppermost and the lower aquifers.

The second aquifer below the surface – with regionally correlated sand bodies - from the upper part of the Middle Pleistocene represents climatic cycle I. This aquifer has a greater thickness than the first aquifer, with values between 10-20 m. This confined layer with varying proportions of silt content can be identified all over the pilot site.

The lower, the second aquitard separates the near-surface aquifer from the deeper situated drinking water aquifer layers. It also has significant heterogeneity as a result of the combined effect of the location, variable width, and heterogeneity of the fine-grained layers. A direct hydraulic connection cannot be identified between the shallow aquifer layers and the drinking water resources of the pilot sites, however indirect hydraulic connection cannot be excluded.

The hydrochemical facies of the groundwater in the shallow uppermost sand horizon varies over a wide range, both regarding its cation and anion composition. The dominant cations are $Ca^{2+}$ and $Mg^{2+}$, but higher $Na^{+}$ and $K^{+}$ concentrations can be observed in the Csanádapáca region. Besides the $HCO_3^{-}$-$CO_3^{2-}$ dominance, high $SO_4^{2-}$ can also be detected. Different infiltration conditions can exist locally, which are reflected by a wide spectrum in the water types in the upper two sand horizons. The nitrate concentration covers a wide range, from below detection limit up to more than 100 mg/l, reflecting the effects of the agricultural activity. High concentrations can be detected in the topmost sand layer.

### 3.3.1. Tectonic relations

Tectonic structures are identified in the basement formations that are situated more than 2000 m depth in the territory of the pilot site. Some of these tectonic structures are supposed to continue in the overlaying Neogene sediment series, but active neo-tectonic elements are very uncertain in the Quaternary layers. However, their hydrogeological importance is negligible in the porous groundwater body.

### 3.3.2. Seismic features

Hungary is situated between the seismically active Mediterranean region and the nearly aseismic East European platform. The ongoing deformation process was verified by GPS geodetic data by Grenerczy et al. (2002). However, seismic activity of the Pannonian region can be characterized as moderate, while the seismicity rate is lower in the territory of Hungary.

Seismic hazard assessment was carried out using a probabilistic approach where the uncertainties were taken into account by logic tree methodology (Tóth et al., 2006). The seismic hazard map compiled in the frame of this assessment describes expected shaking with a 475-year return period in terms of peak ground acceleration (Fig. 3.4).

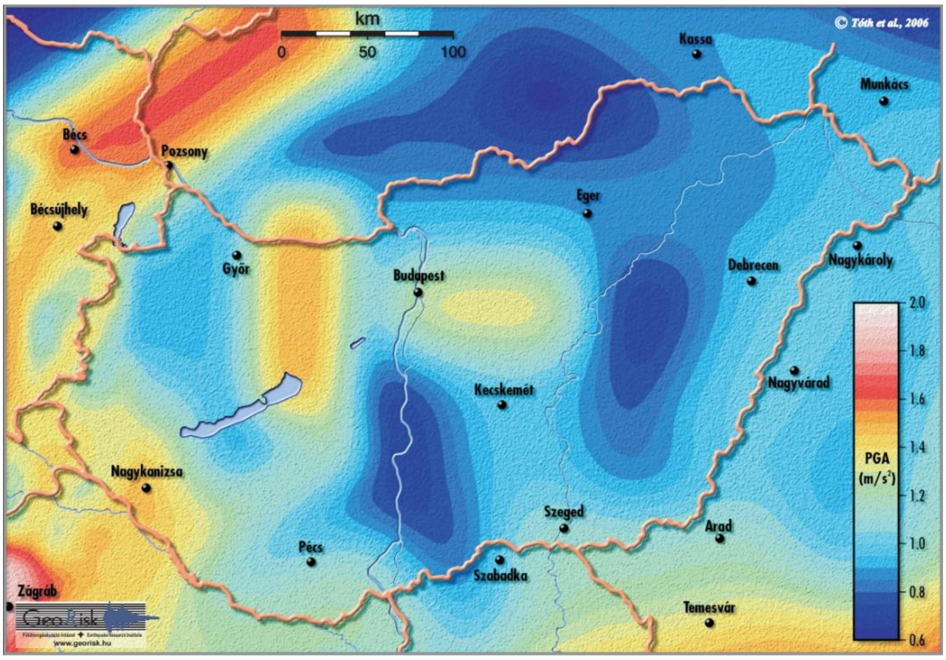


**Figure 3.4** Seismic hazard in the Pannonian region. Expected peak ground acceleration in m/s$^2$ (Tóth et al., 2006)

(10% probability of exceedance in 50 years, 475 year return period)

## 3.4. Soil

The most common soils in the Hungarian pilot site are the dark Chernozems (Fig. 3.5) that were developed predominantly in lowland areas in loess and loess-like sediments under ancient grasslands. Highly productive soils that are used for agriculture, Chernozems have a deep, dark, surface horizon that is rich in organic matter. They carry favorable physicochemical properties, such as a good granular structure, high porosity, good infiltration, and water storage and nutrient holding capacity. These characteristics ensure good yields for almost any crop type that is grown in them. The only limitation to agricultural production is the availability of water. A typical Chernozem soil profile will exhibit a 40-60 cm deep topsoil that is soft and rich organic matter, overlaying a subsoil containing calcium carbonate-rich parent material. There is usually a transitional horizon between the two. Chernozems are sensitive to mismanagement and can lose several of the highly sought-after properties mentioned above if care is not taken. Compaction, structural degradation, and erosion are the most common issues. Compacted soils have reduced porosity and infiltration causing increased runoff, erosion, and less storage of soil moisture. With appropriate soil management practices, the organic carbon content and the biodiversity of the soils can be maintained or even enhanced. Chernozem soils contain between 5 and 15 percent of 'mild' humus with a high proportion of humic acids and a C/N-ratio that is typically around 10. The surface horizon is neutral in reaction (pH 6.5-7.5) but the pH may reach a value of 7.5-8.5 in the subsoil, particularly where there is an accumulation of lime. Chernozems have good natural fertility; the surface soil contains 0.2-0.5 percent nitrogen and 0.1 to >0.2 percent phosphorus. In Chernozems, the humus contents are lower (4-5 percent) and consequently also the cation exchange capacity: 20-35 cmol(+)/kg dry soil (Stefanovits, 1981).

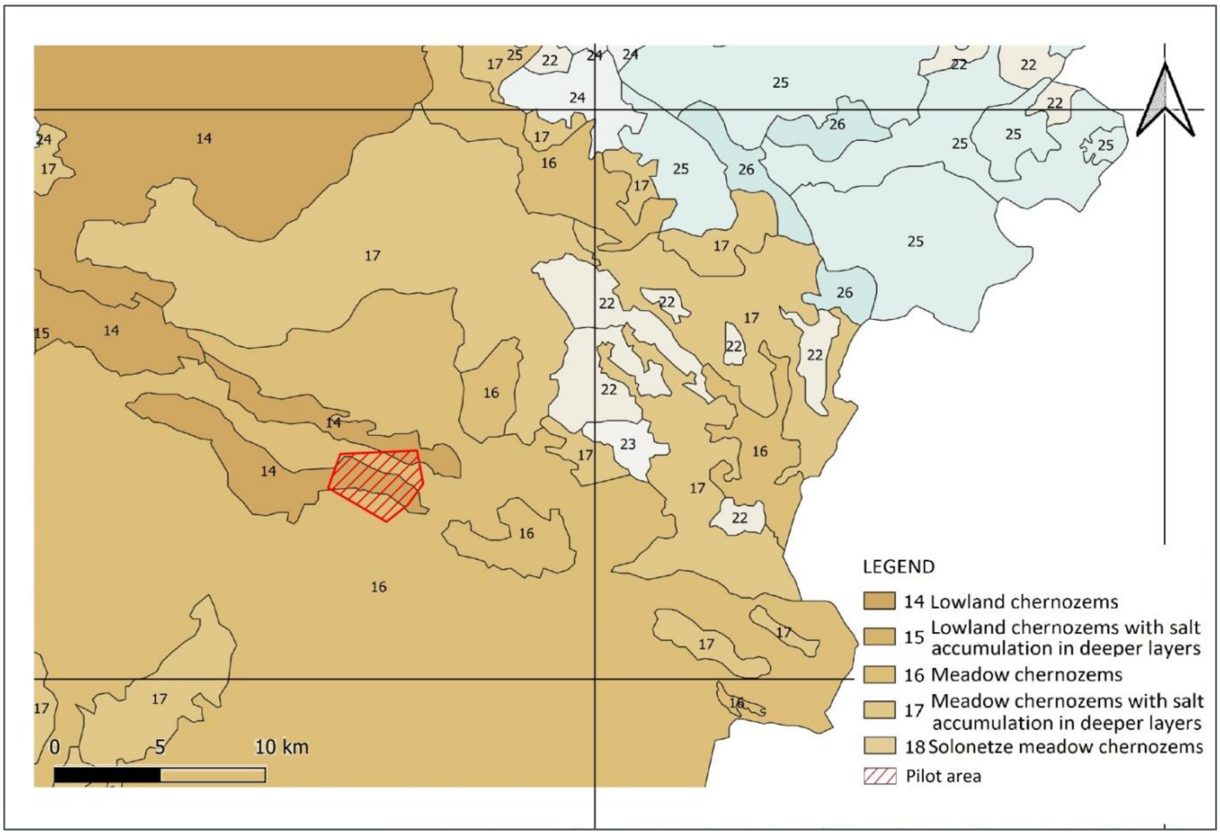


**Figure 3.5** The main type of soils in the Hungarian pilot site

(Source: AGROTOPO (1991))

## 3.5. Water

### 3.5.1. Surface water

Despite its large catchment area, the surface water network of the Maros alluvial fan is sparse, and except for artificially maintained channels, the surface waters are temporary in the pilot area. It has to be mentioned that not all surface waters are classified as water bodies. In total, 3 out of the 7 surface water bodies are artificial, while 4 are heavily modified water bodies (Fig. 3.6). The result of the status assessment of all 7 surface water bodies is moderate according to the 3rd River Basin Management Plan launched for public debate in the summer of 2021 (not yet finalized). There is one water body, the Hajdúér–Ottlaka channel or ditch, which goes through the pilot site, in its Northern part. Its moderate status is the result of moderate biological and ecological, poor physico-chemical, good hydromorphological, and specific pollutant (metals, pesticides) status.

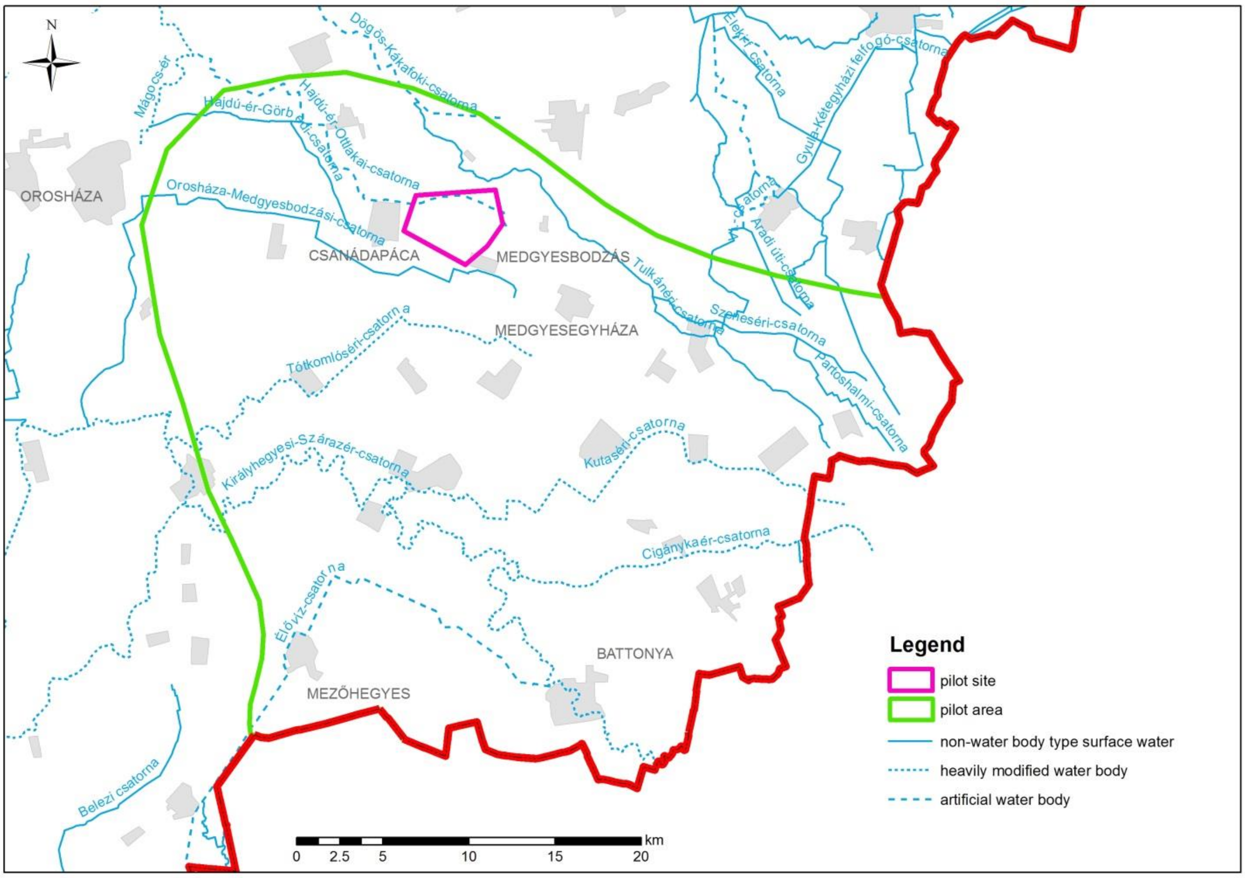


**Figure 3.6** Surface waters in the Hungarian MAR pilot area

### 3.5.2. Groundwater

Both the study site and the whole study area can be found in the shallow porous Maros alluvial fan, the so-called sp.2.13.1 groundwater body (GWB) (Figure 3.7). Its quantitative status was good within the framework of the 2nd River Basin Management Plan (RBMP), while its quality status was good, with a risk to reach poor status. The 3rd River Basin Management Plan launched for public debate in the summer of 2021 (not yet finalized) shows that the quantitative status of this groundwater body is good, with a risk of degrading to poor status due to the result of the water budget assessment and the status of groundwater-dependent terrestrial ecosystems. The quality status was evaluated as poor, due to $NH_4^+$, $NO_3^-$, $Cl^-$, $SO_4^{2-}$ pollution in the drinking water protection zone. Additionally, the $NO_3^-$ and $SO_4^{2-}$ concentrations also show a negative, worsening trend. The deeper, confined porous aquifer (p.2.13.1) is in good qualitative status at present, but with a risk to reach poor status due to concentrations above reversal points for $Cl^-$ and $SO_4^{2-}$ within the drinking water protection zone. This is a negative change since the assessment of the 2nd River Basin Management Plan when this GWB had good chemical status. The quantitative status of this deeper GWB was evaluated as good within both the 2nd and the 3rd RBMP.

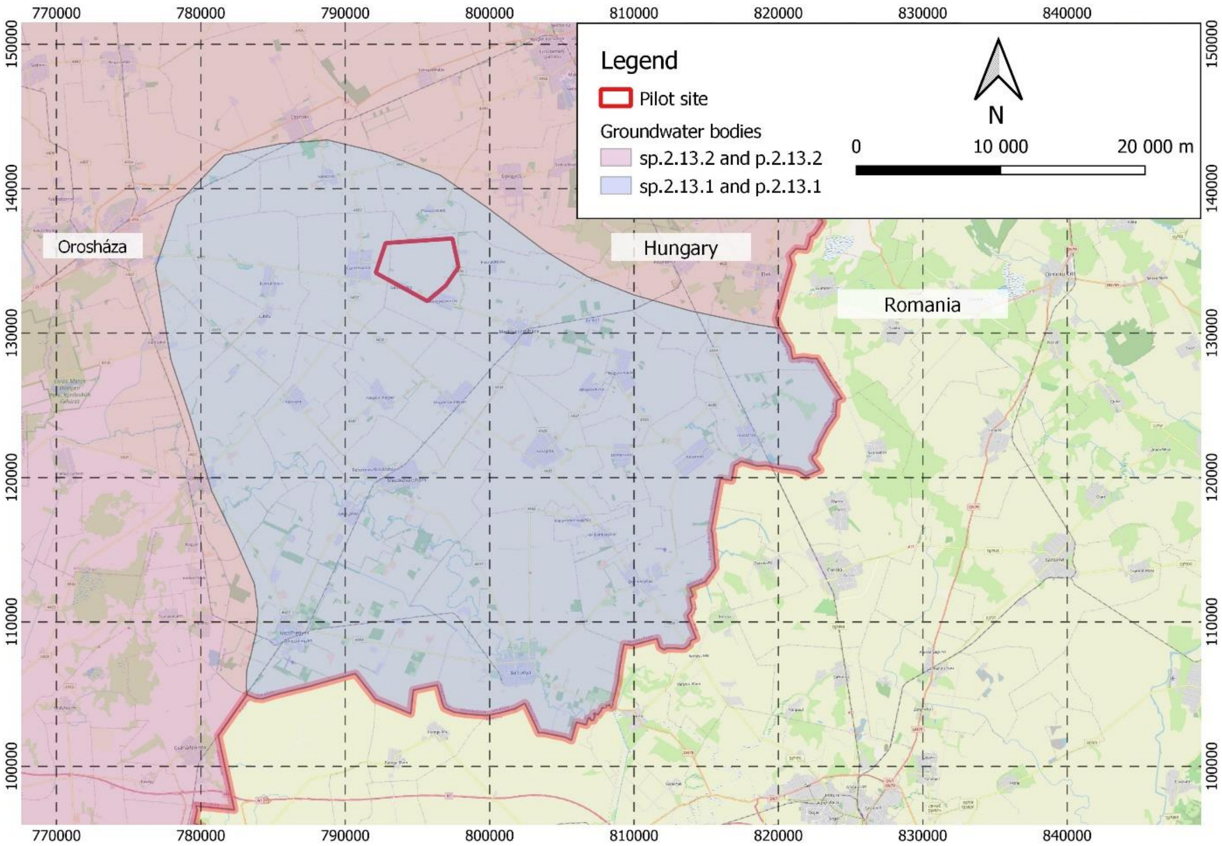


**Figure 3.7** Groundwater bodies on the pilot area

### 3.5.3. Floods

As there are no natural surface waters, the highly modified surface waters or manmade ditches are underwater management, therefore the pilot site is not prone to floods.

## 3.6. Landscape features

According to the Corine database, using the CLC50k dataset, on the pilot site the following land cover types are occurring: Arable land with small fields (60.3%); Arable land with large fields (37.2%); Complex cultivation patterns without scattered houses (0.8%); Industrial and commercial units (0.8%); Intensive pastures, degraded grassland without trees and shrubs (0.6%) and Plantation of broad-leaved forests (0.4%) (Fig. 3.8). Regarding paved (asphalt) roads, only 5.1 km crosses the pilot site: 2.9 km secondary main roads and 2.2 km local roads. All other roads are dirt roads with low, agricultural vehicle usage.

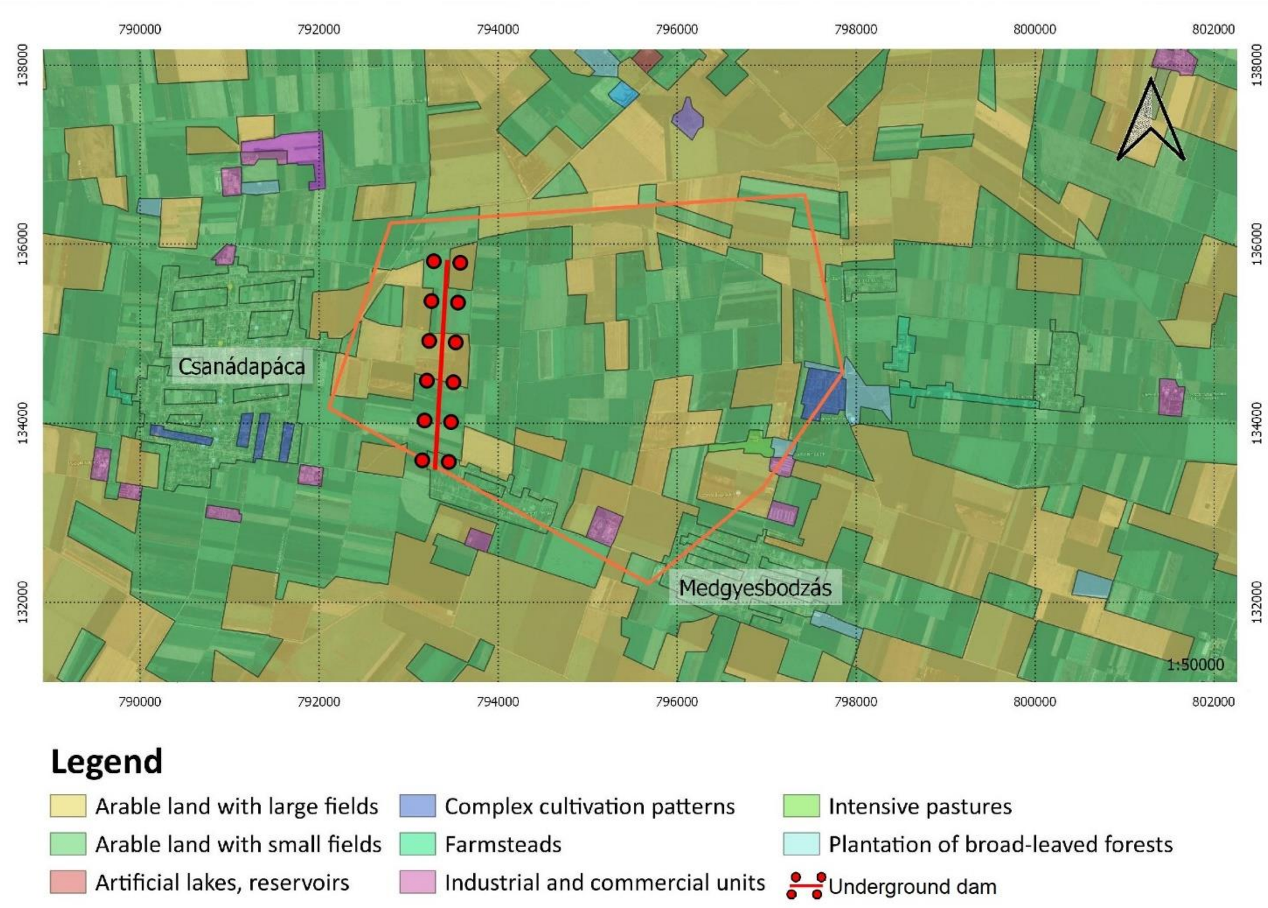


**Figure 3.8** Land cover map of the surroundings of the pilot site (1:50.000) based on the Corine database (2018).

## 3.7. Cultural heritage

### 3.7.1 „Ex lege" protected „Cuman Mounds"

Near the Hungarian pilot site, there is some „Ex lege" protected „Cuman Mounds" (Fig. 3.9). The name"kunhalom" (Cuman Mound) in the literature was first used by István Horvát historian at the beginning of the 19th century because he attributed these formations to the work of the settlers of the Cuman people.

Kunhalom is the name of the artificially created characteristic earth mounds in the Great Plain areas of the Carpathian Basin, dating from the times before the conquest of the Carpathian Basin. The "kunhalom" is "a cone or hemispherical formation 5-10 m high, 20-50 m in diameter that was a burial site, tomb, guard or boundary mound."

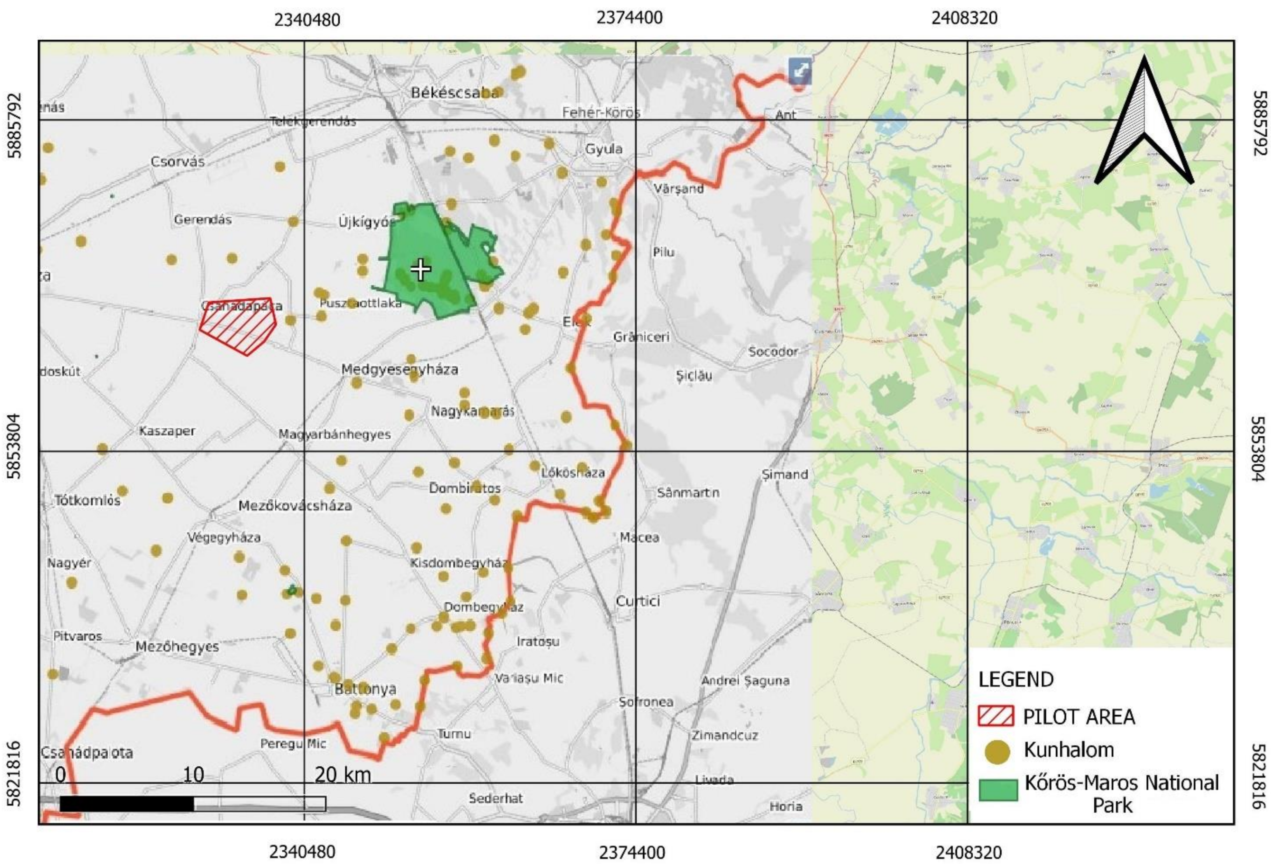


**Figure 3.9** „Ex lege" protected „Cuman Mounds" (1996 LIII. law on the protection of nature), and the nearby Körös-Maros National Park.

### 3.7.2 Protected archaeological sites

Based on the structural plan of the settlements of Csanádapáca and Medgyesbodzás, there are protected archaeological sites in the pilot site and its surroundings, which are marked in Fig. 3.10 as follows:

In the administrative area of Medgyesbodzás there are:

1. Agricultural airfield
2. Hajdúér-Görbedi channel

3. The land of Imre Szántai Sr.

4. Church Hill

According to the local ordinance, the licensing authority for all earthmoving activities affected properties and their 250 m surroundings is the Office for Cultural Heritage Protection.

In the administrative area of Csanádapáca there are:

5. Farmstead Szekercés

Site 5 is located in the NW part of the pilot site, 200 meters south of the Csanádapáca road. On the northern bank of the contemporary riverbed, Sarmatian pottery fragments were found in a relatively small area of 100 x 70 meters.

The area deserves special attention during earthworks.

Sites 1 and 5 are located directly on the pilot site, site 2 is located on the western border of the pilot site, sites 3 and 4 are located approx. 1770 m west of the pilot site.

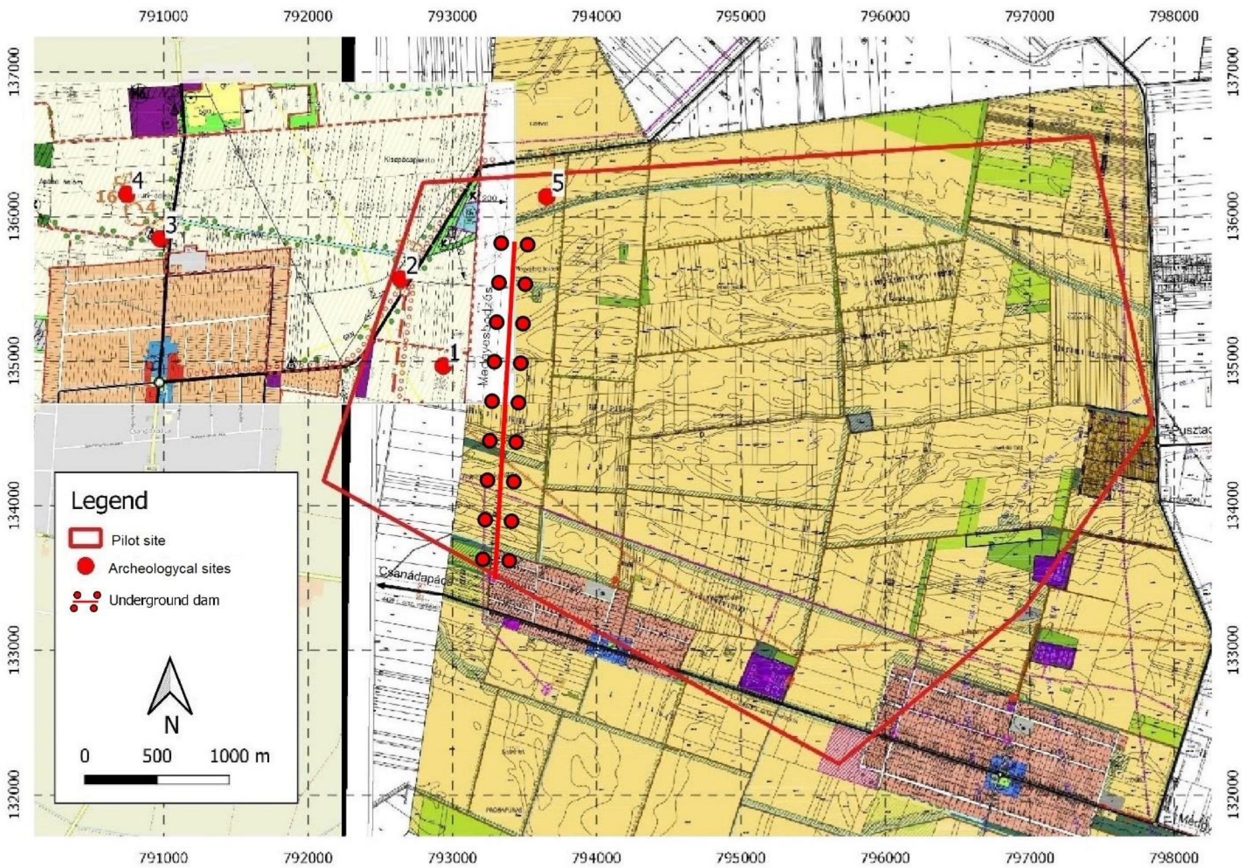


**Figure 3.10** Archaeological heritage sites on and in the vicinity of the pilot site (based on Structural plans of the settlements of Csanádapáca and Medgyesbodzás)

## 3.8. Biodiversity

In the Hungarian pilot site, there are two main habitats, extensive agricultural landscapes and semi-natural habitats (Fig. 3.11). The impoverishment of the natural flora of agricultural landscapes became increasingly drastic throughout Europe during the 20th century, with both local intensification and homogenization playing a significant role (Sutcliffe and Kay, 2000; Gabriel et al., 2005, 2006). Vegetation impoverishment is largely responsible for the significant decline in trophic levels based on it, including arthropod and bird populations (Biesmeijer et al., 2006; Taylor et al., 2006; Clough et al., 2007; Ebeling et al., 2008). With the disappearance of flowering plants, pollinator insects such as bees and butterflies, and with the displacement of weeds in general, the food source of herbivorous insects such as orthopedos has decreased significantly, leading to large population declines and extinction of many species (Kemp et al., 1990; Ouin et al., 2004; Goulson et al., 2008). The structural degradation of vegetation, which in the case of herbicides and grasslands can result from intensive mowing and/or grazing, also has an adverse effect on arthropods seeking habitat there, such as spiders (Baines et al., 1998). The changed vegetation structure affects the soil surface microclimate, and thus also the beetles living there (Woodcock et al., 2005).

In addition to local intensification, landscape homogenization, the disappearance, and shrinkage of semi-natural habitats (grasslands, rows of trees, borders, hedges) are also largely responsible for the decline of plant and animal populations (Burel et al. 1998; Benton et al.).

### 3.8.1. Flora

Only a few weed species can be found on arable lands, the high densely closed cover of the grain formed a uniformly closed vegetation. Semi-natural grasslands, on the other hand, were home to a relatively large plant species richness, which was dominated by grasses. The grasslands are covered with smooth meadow-grass (*Poa pratensis L.*), *Festuca pseudovina Hack. Ex Wiesb.*, and field meadow foxtail (*Alopecurus pratensis L.*). Other characteristic plant species are the Hungarian yarrow (*Achillea pannonica Scheele*) and the Hungarian salt flower (*Limonium gmelinii Willd.*).

### 3.8.2. Fauna

*Butterflies*

Agricultural areas are usually characterized by small species, small heath (*Coenonympha pamphilus L.*), silver-studded blue (*Plebejus argus L.*), common blue butterfly (*Polyommatus icarus Rott.*).

*Arthropods*

Larger populations of the grasshoppers (*Calliptamus italicus L.*) and (*Chorthippus dorsatus Zetterstedt*) are characteristic, which typically feed on grasses, so fallows and grasslands may provide more favorable conditions for them. Large-bodied grasshoppers, such as the wart-eating grasshopper (*Decticus verrucivorus L.*) and the protected dagger grasshopper (*Gampsocleis glabra Herbst*), are also common in Hungary.

*Birds*

Typical birds in the arable land are quail (*Coturnix coturnix*), Eurasian skylark (*Alauda arvensis*), western yellow wagtail (*Motacilla flava*), common stonechat (*Saxicola torquatus*), and corn bunting (*Emberiza calandra*).

*Mammals*

Common mammals in the fields are common vole (*Microtus arvalis*), mice (*Mus agrarius Pall*), brown hare (*Lepus europaeus*), European ground squirrel (*Spermophilus citellus*), and Common mole (*Talpa europaea*).


**Figure 3.11** Different habitats in the Hungarian pilot site

## 3.9. Protected areas

### 3.9.1. Drinking water protected areas

The surface projection of the designated hydrogeological protective block (B) of the Medgyesbodzás drinking water base is situated on the eastern border of the Hungarian pilot site (Figure 3.12). The role of the hydrogeological protective blocks (zone) is to protect against non-degradable pollutants.

Within the hydrogeological protective blocks and protective areas, it is prohibited to locate a facility whose presence or its operation causes damage to groundwater quality. Furthermore, activities that reduce the natural protection of water resources or increase the vulnerability of the environment are prohibited in the area of the protection zones. It is forbidden to carry out any activity that lets degradable materials get into the water supply that causes damage to groundwater quality.

The NW corner of the surface projection of the protective block hangs about 250 m into the eastern part of the pilot site.

The surface projection of the protective block (identified by hydrogeological models) of the Csanádapáca drinking water source is located outside, at a distance approx. 250 m from the SE-E boundary of the pilot site.

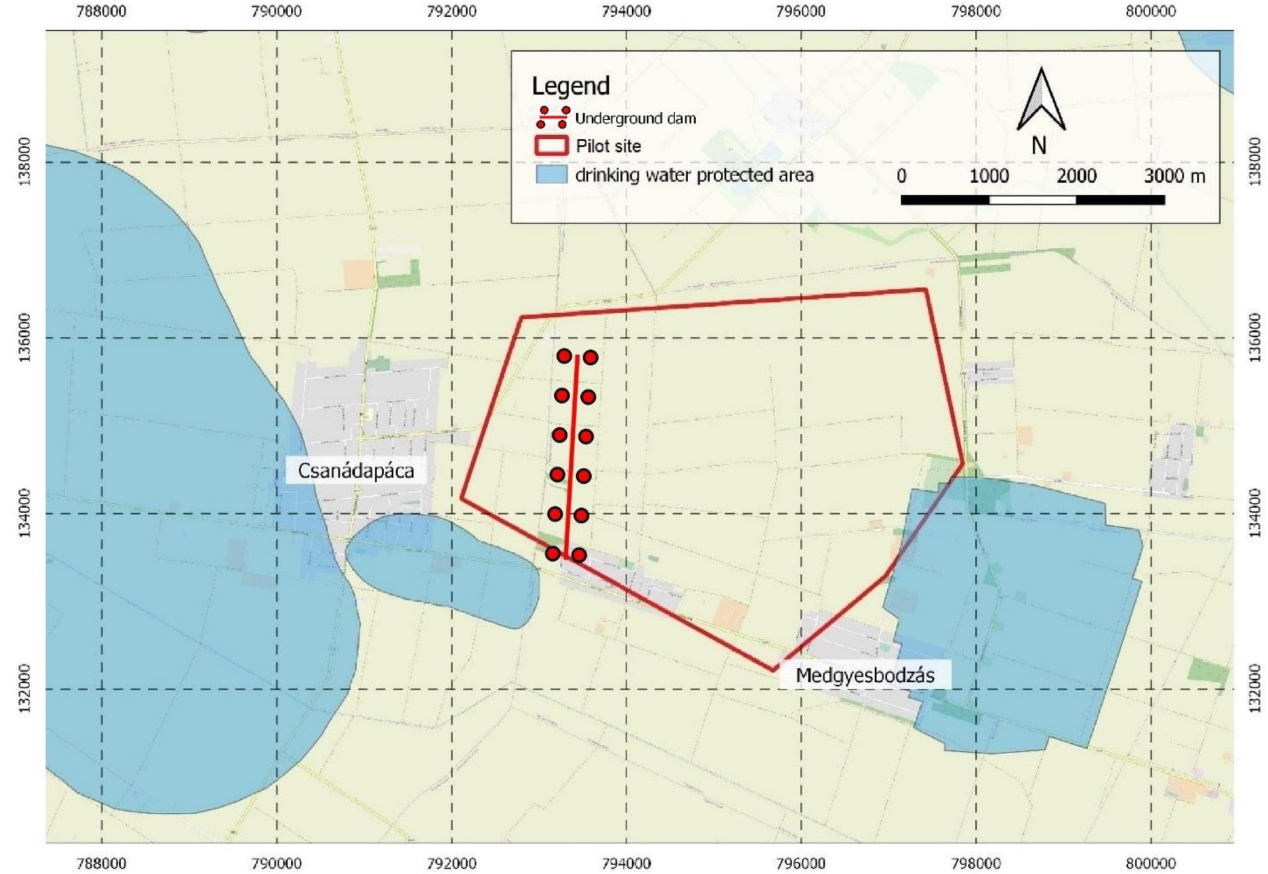


**Figure 3.12** Drinking water protected areas (http://geoportal.vizugy.hu/vizgyujtogazd02/)

## 3.10. Ecological network

Natura 2000 sites in the vicinity of our pilot sites are presented based on the European Environment Agency's Natura 2000 (2020) database (https://sdi.eea.europa.eu/data/b1777027-6c85-4d19-bdf2-5840184d6e13?path%253D%25252FNatura2000_end2020_shp).

According to this database, the closest Natura 2000 site is the NATURA 2000 Birds Directive Sites at Kígyósi-puszta Special Protection Area (SPA), lying 7.5 km to the East from the pilot site (13).

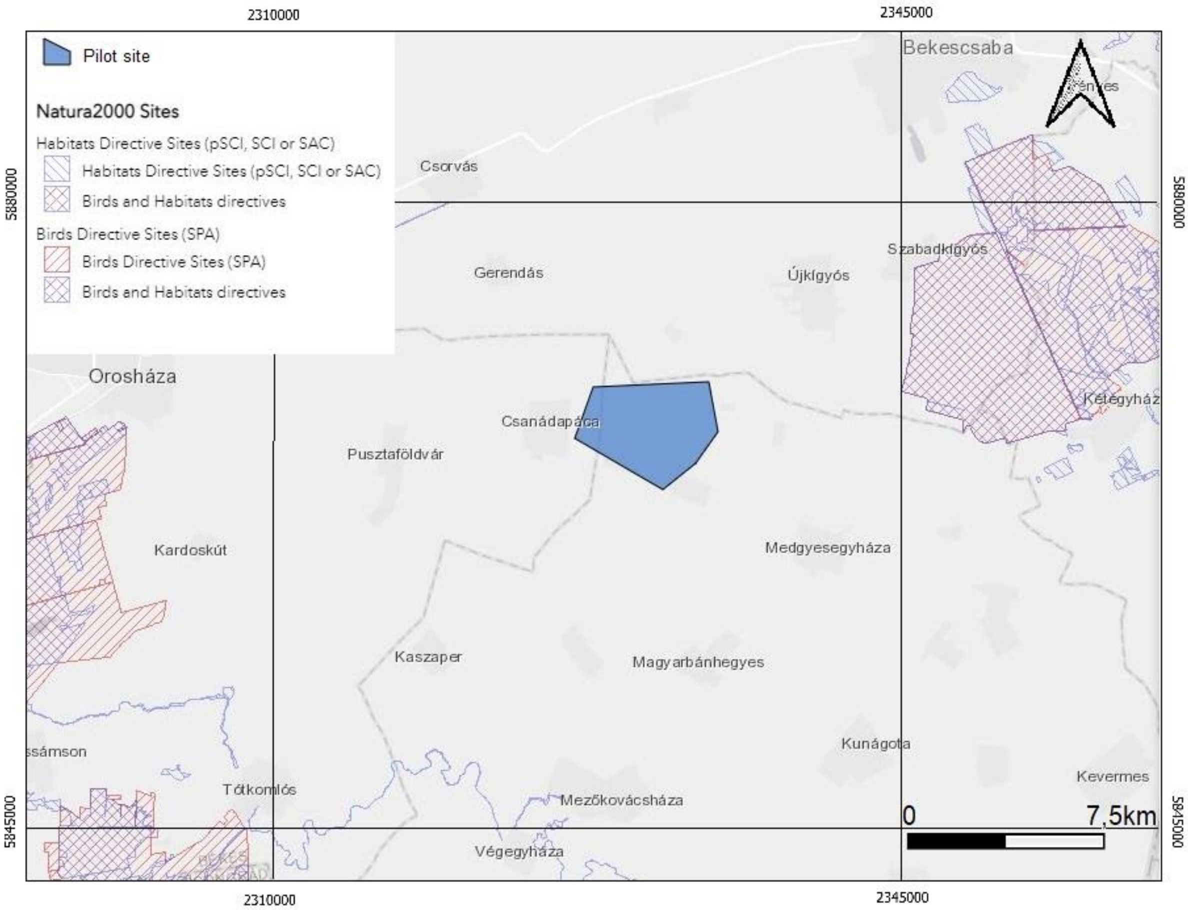


**Figure 3.13** Location of Natura 2000 sites in relation to the pilot site
(Source: European Environment Agency's Natura 2000 (2020))

## 3.11. Socio-economic conditions and main end-users

The pilot area is relatively moderately populated (2 to 3 settlements per 100 km$^2$, and 67 people per km$^2$, KSH 2020), but compared to the average values of Hungary (6 to 7 settlements per 100 km$^2$, and 105 people per km$^2$, KSH 2020) the number of municipalities and inhabitants is relatively low. Out of 25 settlements, 3 are towns. These towns are the centers of the micro-regions. The proportion of the urban population is significantly less than the national average. In addition to their "so-called 'giant villages' with more than 5000 inhabitants, there are several large villages (3000-5000 inhabitants) and medium-sized villages (1000-3000 inhabitants) with smaller populations (Fig. 3.14). Most of the villages exhibit a chessboard pattern. The proportion of the relatively poor and sparse population is higher than the average.

Favorable soil conditions provide exceptionally potential for agricultural production (93% of the total is rural area), so the main economic activity in the area is agriculture. Due to climatic exposure crop production relies heavily on the availability and quality of irrigation water, especially under increasing temperature levels, and satisfying irrigation water demand is one of the core pressures for the area. After the wet periods, water shortages appear in the summer, which affects most of the region, causing serious damages to agricultural activity. As it is an agricultural region without permanent surface watercourses, the water demand is expected to increase in the future. Therefore, managed aquifer systems (MAR) can play an important role in water management.

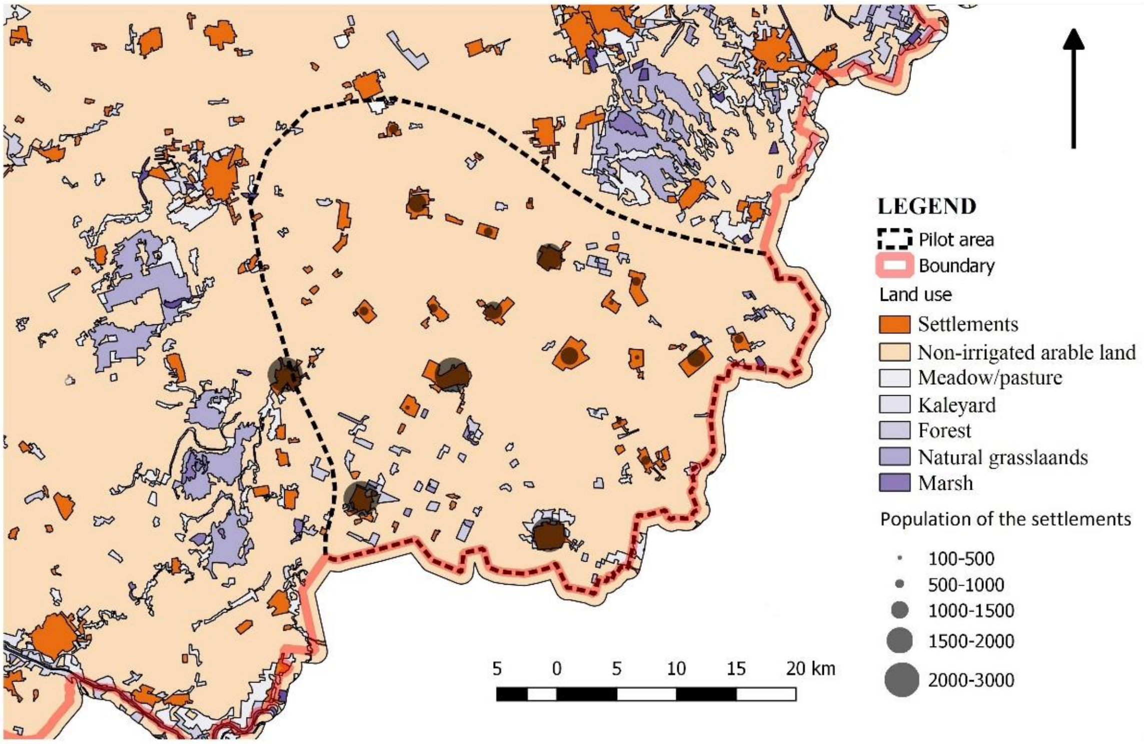


**Figure 3.14** Land use map of the pilot area

(Compiled based on the CORINE database, 2018)

# 4. Potential impacts of MAR on the environment

### 4.1.1. Impact on the microclimate

Since most of the establishment of the underground dam technical solution is situated below the surface, significant impact on microclimate is not expected. However, the increasing groundwater table triggered by the underground dam together with the more intensive agricultural production may result in an increase in the intensity of evapotranspiration. Prediction the magnitude of the potential change depends on several climate factors, details of the applied plantation method, and crop types, but it has to consider as additional effect to the expected increasing of the potential evaporation expected by the different projections of the regional climate models.

### 4.1.2. Impact on the geology

Installing an underground dam, the most important factor is that the bottom of the dam ends in an aquitard formation. If this does not happen, a flow will develop under the dam, which could lead to extensive rock dissolution and erosion. During the installation of an underground dam, the construction works will locally change the near-surface layers.

### 4.1.3. Impact on the soil

The construction of an underground dam involves disturbing the soil structure. To reduce the environmental impact, it is appropriate to remediate the original soil cover. Since most of the pilot site is arable land, the nutrient content of the crop layer may vary because of the installation process of an underground dam. The soil structure loosens in the area of the subsurface dam and then returns to its original state over time with the typical compaction of chernozem soils. The water balance of the soils changes somewhat during and after installation.

### 4.1.4. Impact on the water

#### 4.1.4.1 Impact on surface water

Only one surface water body can be found in the pilot site, therefore the impact might occur only along it, the Hajdúér–Ottlaka channel or ditch. An underground dam will raise the groundwater level behind the dam (DEEPWATER-CE, 2021d), which can result in potentially higher surface water in this temporary channel. This can be a local effect, which should be monitored and modelled during and after the construction of the MAR system. Basically, there is no effect on water quality. However, in case of local surface agricultural pollution, the dilution caused by the additional discharged water can improve the water quality in the channel.

#### 4.1.4.2 Impact on groundwater

Since the dam is built in the near-surface layer, the quality of the fresh water in this layer is only affected by the pollutant sources in the immediate vicinity of the dam.

As demonstrated by hydrodynamic modelling (DEEPWATER-CE, 2021d), in the operation phase of the MAR system, the water levels in the upstream side will increase, while behind the dam the water levels will decrease. As a result of the modelling, in the areas affected by the water level change there currently are no sources of pollution and no further pollutions are expected. Thus, the current groundwater quality is not expected to change as a result of the artificially elevated groundwater.

### 4.1.5. Impact on the landscape

Since most of the volume of the underground dam is placed beneath the surface and therefore it is out of sight, directly it has a small impact on the landscape. The visually most perceivable objects are the water-governing structures (point like objects) and surface draining ditches (linear objects). The water-governing structures are 2-3 m wide concrete constructions with maximum 1.5 m height, so these are really neglectable from the point of view of visual disturbance of the landscape. Surface draining ditches are 2-3 m wide concrete-bedded linear structures which are used to transport the extracted water. Their presence changes the landscape somewhat, but since they do not stand out of the surface, they are not easy to detect from afar. Nevertheless, water transported in them might contribute to the landscape evolution. With the improving irrigation, so far not grown crops, which need more water could be planted, which can have an impact changing landscape (e.g. changing from corn to paprika plantation).

### 4.1.6. Impact on the cultural heritage

#### 4.1.6.1 Impact on the „Ex lege" protected „Cuman Mounds"

Near the Hungarian pilot site there are some **„Ex lege" protected „Cuman Mounds"**, but none in the pilot site. The construction and operation of the planned underground dam will take place exclusively in the pilot area, the disturbance of the surface will take place only in this area, so it will not endanger these protected „Cuman Mounds".

### 4.1.6.2. Impact on the protected archaeological sites

There are two archaeological sites in the pilot site. According to the local ordinance, the licensing authority for all earthmoving activities affected properties and their 250 m surroundings is the Office for Cultural Heritage Protection. During the construction of the planned underground dam and the service facilities, it is planned to carry out earthworks. The supposed construction of the planned MAR system will not take place near of the archaeological sites, therefore it is not endangering the protected archaeological sites.

The operation of the proposed MAR system will not have any impact on protected archaeological sites.

### 4.1.7. Impact on the biodiversity

Installation of the underground dam can affect semi-natural habitats, the habitat of birds nesting there may be temporarily disturbed by the process. Other organisms in this area of poor biodiversity are not affected by the installation process. After installation, the operation of the underground dam has no impact on biodiversity.

### 4.1.8. Impact on the protected areas

**Drinking water protected areas**

The surface projection of the designated hydrogeological protective block (B) of the Medgyesbodzás drinking water base is situated on the eastern border of the Hungarian pilot site. The NW corner of the surface projection of the protective block hangs about 250 m into the eastern part of the pilot site. However, the effect on drinking water resources was beyond the target of the hydrogeological modelling, the registered groundwater time series provide some information about the hydraulic conditions. As it is illustrated in Figure 4.8, significant differences can be observed between the hydraulic potential of the monitored depth intervals, which imply that locally there is no direct hydraulic connection between the near surface and the deeper drinking water aquifers.

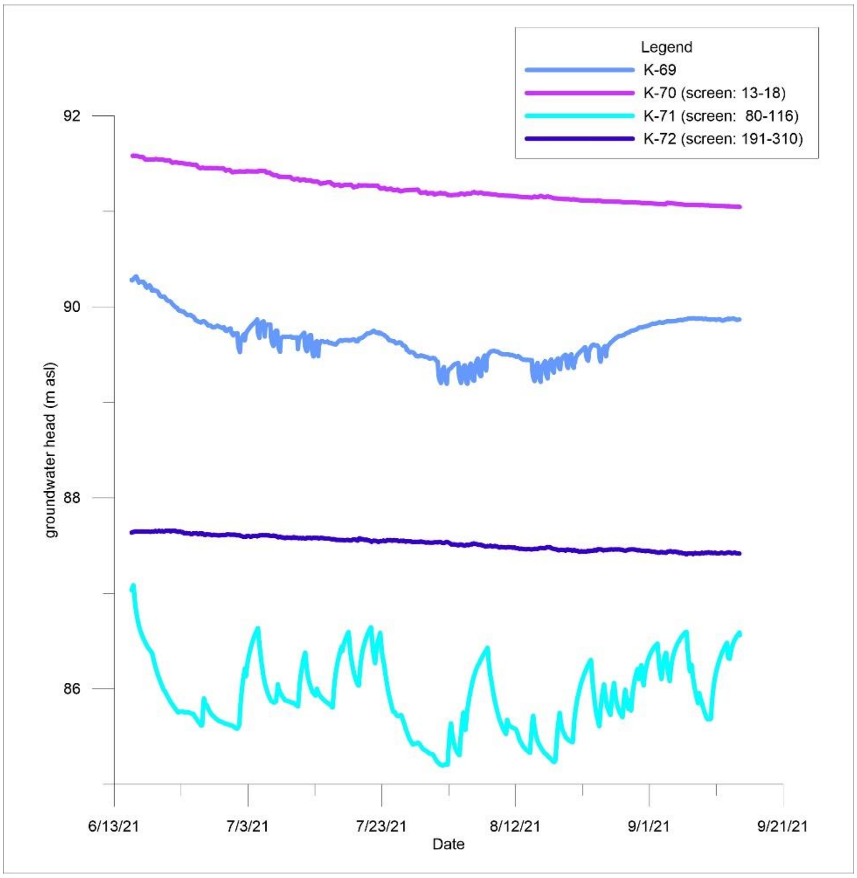


**Figure 4.8** Registered groundwater level changes in the monitoring wells

### 4.1.9. Impact on the ecological network

The closest Natura 2000 site, the Birds Directive Sites at Kígyósi-puszta is located 7.5 km to the east from the pilot site. The construction and operation of the underground dam would not have an impact on any ecological network.

### 4.1.10. Socio-economic impacts

The objective of the construction of an underground dam MAR scheme was to increase the availability of the shallow groundwater at the pilot site and its surroundings for irrigation purposes. However, most of the climate projections based on regional climate models expect the climate exposure of the pilot area to amplify which can be followed by the increased irrigation water demand.

Among promising water management solutions, the MAR systems have received noticeable attention as they can be used to maintain, enhance, and secure the balance of groundwater systems under stress. Among many benefits that MAR schemes can potentially provide, the major ones include increased water supply, in the case of the Hungarian pilot site irrigation water.

The main beneficiaries can be the agricultural producers (local farmers and agricultural companies). The direct benefit of the construction of the MAR systems can be measured with the supposed increasing revenue of the crops.

An estimate of direct benefits for agricultural producers in the project lifespan period was obtained by multiplying the value of agricultural production in HUF per $m^3$ by the annual demand for irrigation water from the MAR scheme. Based on survey data the average value of crop revenue was calculated per volume of applied irrigation water for major crops grown in the pilot study area (DEEPWATER-CE, 2021c). The results are illustrated in **Table 4.2**.

**Table 4.2** Calculation of direct benefits

| Indicator | Unit of measurement | Value |
|---|---|---|
| Annual irrigation water demand | $m^3$ | 300,000 |
| The weighted mean of crop revenue, Euro/$m^3$ of irrigation water | HUF per $m^3$ | 1,122.36 |
| The annual direct benefit | mil HUF | 336.7 |

*Source: Expert estimations based on data for Békés County (as reference area) from Hungarian Central Statistical Office, own calculations*

The proposed MAR scheme is expected to provide a source of water that can be legally used to fulfil the need for irrigation water. Moreover, the introduction of the MAR system is envisaged to mitigate the negative effects of unregistered wells that may lead to the contamination of groundwater in the pilot study area. Applying underground dam MAR scheme for supplying irrigation water may contribute to the reduction of the rate of non-registered wells and hereby help to protect the quality and quantity of groundwater including the vulnerable drinking water resources.

## 4.2. Cumulative impacts

The pilot site is dominated by agricultural production. Most of the climate projections based on regional climate models expect the climate exposure of the pilot area to amplify which can be followed by the increased irrigation water demand. The objective of construction an underground dam MAR scheme was to increase the availability of the shallow groundwater at the pilot site and its surroundings for irrigation purposes. The main beneficiaries can be the agricultural producers (local farmers and agricultural companies). With increased irrigation water capacity, local farmers will have the opportunity to achieve higher yields and grow more diverse crops than in the present. This will create new jobs and increase the local's income. However, applying underground dam MAR scheme for supplying irrigation water may contribute to the reduction of the rate of non-registered wells and hereby helps protecting the quality and quantity of groundwater including the vulnerable drinking water resources.

The underground dam would affect mainly the local geological, hydrogeological settings (groundwater levels), the landscape and the socio-economic aspects as written above. However, these effects are not significant neither individually nor jointly.

There is no other intervention in the pilot area that would interact with the MAR scheme. Due to this, the cumulative impact of an underground dam is negligible.

## 4.3. Overview of recognized impacts

The following table shows the grade for each particular impact.

**Table 4.2** Overview of recognized impacts - Hungary

| Grade | Description |
|---|---|
| -1 | Negative impact |
| 0 | There is no impact |
| 1 | Positive impact |

<table>
<tr><th colspan="2" rowspan="2">ENVIRONMENTAL COMPONENT</th><th colspan="4">IMPACT CHARACTERISATION</th></tr>
<tr><th>DIRECT/ INDIRECT/ CUMULATIVE</th><th>SHORT-TERM/ LONG-TERM</th><th>POSITIVE/ NEUTRAL/ NEGATIVE</th><th>GRADE</th></tr>
<tr><td colspan="2">Climate</td><td>indirect</td><td>long-term</td><td>neutral</td><td>0</td></tr>
<tr><td colspan="2">Geology</td><td>indirect</td><td>long-term</td><td>neutral</td><td>0</td></tr>
<tr><td colspan="2">Soil</td><td>indirect</td><td>long-term</td><td>neutral</td><td>0</td></tr>
<tr><td colspan="2">Surface waters</td><td>indirect</td><td>long-term</td><td>neutral</td><td>0</td></tr>
<tr><td colspan="2">Groundwater</td><td>direct</td><td>long-term</td><td>positive</td><td>1</td></tr>
<tr><td colspan="2">Landscape</td><td>direct</td><td>long-term</td><td>neutral</td><td>0</td></tr>
<tr><td colspan="2">Cultural heritage</td><td colspan="4">the MAR system does not affect a site of cultural heritage</td></tr>
<tr><td rowspan="2">Biodiversity</td><td>Terrestrial habitats</td><td rowspan="2">indirect</td><td rowspan="2">short-term</td><td rowspan="2">neutral</td><td rowspan="2">0</td></tr>
<tr><td>Underground habitats</td></tr>
<tr><td colspan="2">Protected areas</td><td colspan="4">the MAR system does not affect a protected area</td></tr>
<tr><td colspan="2">Ecological network</td><td>direct</td><td>short-term</td><td>neutral</td><td>0</td></tr>
<tr><td colspan="2">Population</td><td>cumulative</td><td>long-term</td><td>positive</td><td>1</td></tr>
</table>

# 5. Conclusion and summary / Hungary

The objective of this Preliminary Environmental Impact Assessment is to examine and evaluate the possible environmental impacts of a theoretical underground dam in the Hungarian pilot site. The pilot area is in the south-eastern part of the Great Hungarian Plain (in Békés County) between the two largest tributaries of River Tisza (Körös and the Maros), in the Maros alluvial fan. The surface of the extensive Maros alluvial fan is densely covered by palaeochannels. This region is characterized by rural land use therefore a big amount of irrigation water demand occurs. The chosen MAR technology is the underground dam (UD). The most common geological environment of the underground MAR scheme is related to alluvial sediments. During the construction, structures (slurry walls) are installed in streambeds, and therefore it does not interfere with land use. With the help of the slurry walls, the intensity of the groundwater flow will decrease horizontally so the level of the groundwater will increase, and the water can be stored for later use. The stored water will be used for irrigation purposes. Neither in Hungary nor in Central Europe has such groundwater storage technology been used, so there is a practical experience only from outside Europe.

Based on the Preliminary Environmental Impact Assessment, the impact of the proposed MAR system on climate, geology, soil, and surface waters is minimal or there is no effect at all. The impact of the MAR system (underground dam) on the biodiversity and ecological network is minimal and can be predicted mainly for the construction period, (short-term), there is no impact on the same elements during operation. As a positive effect of the groundwater dam, the groundwater level would rise, so the amount of water that can be used for irrigation would increase. This amount of stored water can be extracted later, during periods of water scarcity. Among other things, the underground storage of water has the advantage over surface water storage by minimizing water losses to evaporation, while the disturbance of surface environmental elements is also low. The main beneficiaries can be the agricultural producers (local farmers and agricultural companies) and the local people.

# POLAND

The subject of this preliminary Environmental Impact Assessment (EIA) is to evaluate the environmental consequences of a potential expansion of an existing MAR facility in the Polish pilot site. The pilot site is located in Tarnów, southern Poland. The existing MAR system, Świerczków well field, consists of infiltration ditches and wells. Two wells pump mainly water that infiltrates through the Dunajec river bank (IBF) and the remaining wells are supplied mostly with the water infiltrating through the infiltration ditches beds (Fig. 2.2). Based on modelling studies, it was determined that more than 70% of water abstracted at the Świerczków well field comes from the Managed Aquifer Recharge (MAR), and the remaining minor part is the native groundwater.

In order to provide potable water for the inhabitants of the Tarnów agglomeration at present and for future generations, the DEEPWATER-CE project has undertaken studies to determine the possibility of expansion of the Świerczków MAR site to an area directly adjacent to the well field from the north. The potential application of MAR facility in this area would contribute to increasing groundwater resources, but most of all, it would improve groundwater quality. The groundwater inflow from the southeast is characterized by poor quality due to the extensive industrial area. Based on the detailed field and modelling studies conducted, it was possible to determine a high degree of effectiveness in improving the quality of groundwater abstracted by wells through the use of ditches and bank filtration.

The construction of the MAR facility, its operation, and eventual closure must have an impact on the environment. This report aims to assess these impacts on the various components of the environment, with particular emphasis on the operation phase. At this stage, without knowing the technical details related to the potential use of the IBF and ditches and the possible range of impacts, the area of consideration of the potential influences of the MAR on all major environmental components was analyzed within the boundaries of the planned groundwater flow model. The model border extends between the two rivers, Dunajec river to the west and its tributary the Biała river to the east. The analyzed area covers 27 $km^2$. The choice of this area is also in agreement with the other reports, where the model area, with particular emphasis on the Świerczków well field, was taken as the boundary of the pilot area.

In Poland, EIA is performed based on the legal regulations contained in three legal acts:

- the Environmental Impact Assessment (EIA) Directive 2014/52/EU of the European Parliament and of the Council of 16 April 2014 amending Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment Text with EEA relevance (Directive 2014/52/EU).
- The Act on access to information relating to the environment and its protection, on public participation in defense of the environment, and on environmental impact assessments, consolidated text, 20 January 2021(Journal of Laws of 2021, item 247).
- Regulation of the Council of Ministers of 10 September 2019 on projects that may significantly affect the environment (Journal of Laws 2019, Item 1839).

The work on the preliminary EIA report for the Polish pilot site was carried out by a team from the University of Silesia in Katowice. At the report writing stage, preliminary results were presented and discussed during the project stakeholders' meeting on October 19, 2021. In addition, our associated partner, Tarnów Waterworks, was directly involved in the preparation of the preliminary Environmental Impact Assessment for the selected subsections. The topic of the EIA of the MAR was also discussed during a meeting with project stakeholders in the pilot area in Tarnów on September 24, 2021.

# 2. Project description - Managed aquifer recharge

## 2.1. MAR technology

In the Polish pilot site, the study is focused on two types of MAR out of the six methods investigated in the DEEPWATER-CE project. These were induced bank filtration (IBF) and infiltration ditches, respectively.

The IBF method involves inducing water inflow from the river/lake into the well(s) due to lowering the groundwater table caused by pumping groundwater from the aquifer. River water infiltrating into an aquifer can be self-purified (quality improvement) by physical processes such as soil filtration reducing suspended solids, biological processes such as removing organic matter by microorganisms, or chemical processes such as ion exchange.

The second MAR method - infiltration ditches - can be implemented in the pilot area due to the very favorable permeability of the aquifer and its shallow subsurface location. The aquifer, composed of sands, gravels, and pebbles, facilitates rapid infiltration through the bottom of the ditches, representing a substantial part of groundwater recharge. At the Świerczków well field, where the effectiveness of the MAR methods was tested, the inflow of water into the aquifer by means of the ditches alone accounts for 60% of the total pumped water at the well field. As in the case of the IBF, the water infiltrating from the ditches into the aquifer may undergo the same physical, biological, and/or chemical processes.

A scheme of the operation of both MAR methods at the Świerczków well field is shown in Fig. 2.1. In the western part, the inflow to the wells is mainly generated by the IBF. In the central and eastern parts, the ditches are the primary source of water inflow to the well. The water in the ditches comes from the river Dunajec. Before entering the ditches, it flows through settling ponds in order to reduce the amount of suspended material. In both cases, the groundwater inflow to the wells represents a minor contribution.

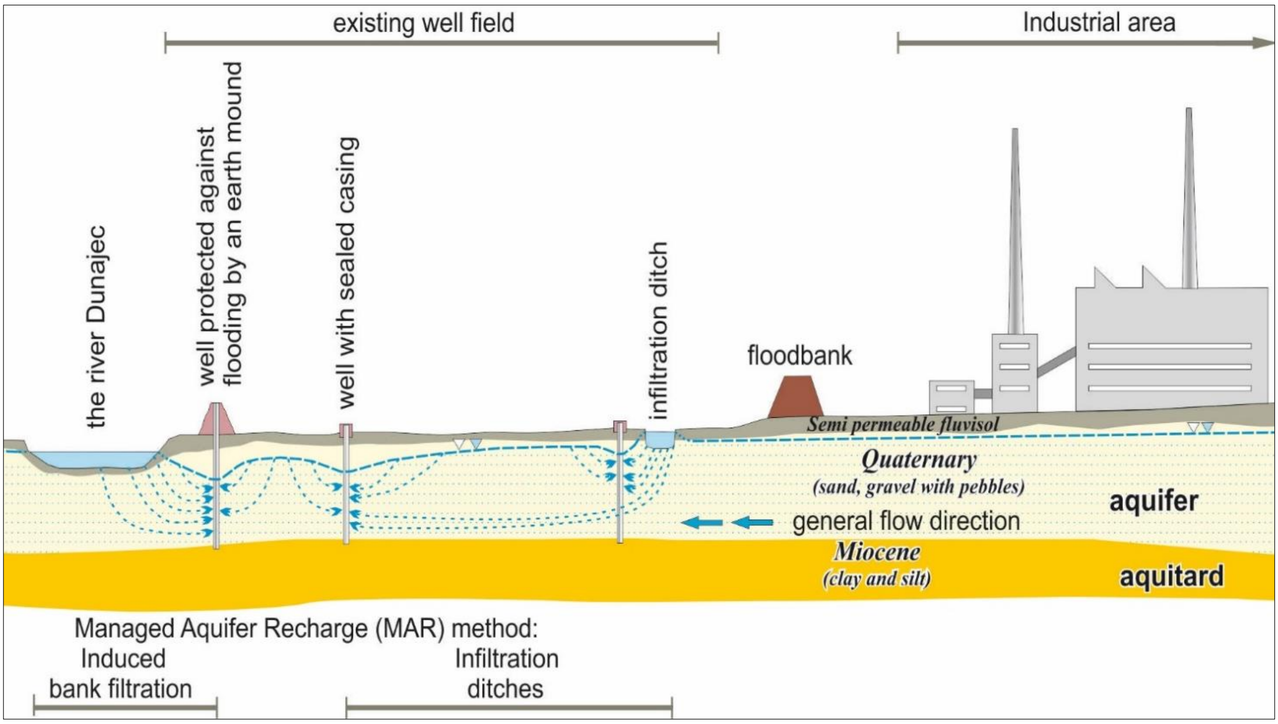


**Figure 2.1** A situation diagram of the MAR methods used in the pilot area.

Groundwater inflow from the industrial zone does not meet standards for drinking water in terms of chemical parameters with respect to exceeded concentrations of manganese, inorganic N ions (exceeded concentrations for ammonium ion, increased concentrations of nitrates in the area of the existing well field), sodium and chlorides (in the northern part of the pilot area for which the feasibility study was conducted). Research carried out in the pilot area has shown that by using MAR methods and mixing surface water with groundwater, the water in the collection well (water collection tank for all wells from the well field) has much better quality and meets the criteria for drinking water. The only treatment before pumping the water into the water supply network is disinfection with chlorine dioxide. The demonstration of the effectiveness of MAR methods for improving the quality of groundwater contaminated by industrial activities was one of the main objectives of the studies carried out in the Polish pilot area.

The studies were carried out at the existing MAR site and in the northern parcel where MAR is not applied. This study aimed to demonstrate, besides the mentioned possibility, to assess the improvement of groundwater quality due to the application of the MAR methods and to determine the possibility of increasing the groundwater resources.

The map below (Fig. 2.2) shows the location of the existing MAR system, consisting of 17 wells (2 temporarily excluded) and an infiltration ditch system. In addition, an example of a potential expansion of the well field with new wells and a ditch is shown in the northern part. The location of the wells and ditch presented on the map is only one of many possible concepts. This concept assumes that in the area adjacent to the well field, 5 wells and one ditch about 300 m long will be constructed to increase the current water withdrawal capacity by about 100 $m^3/h$. For similar assumptions, risk analysis and cost-benefit analysis were also carried out within the DEEPWATER-CE project for the Polish pilot area (DEEPWATER-CE, 2021b).

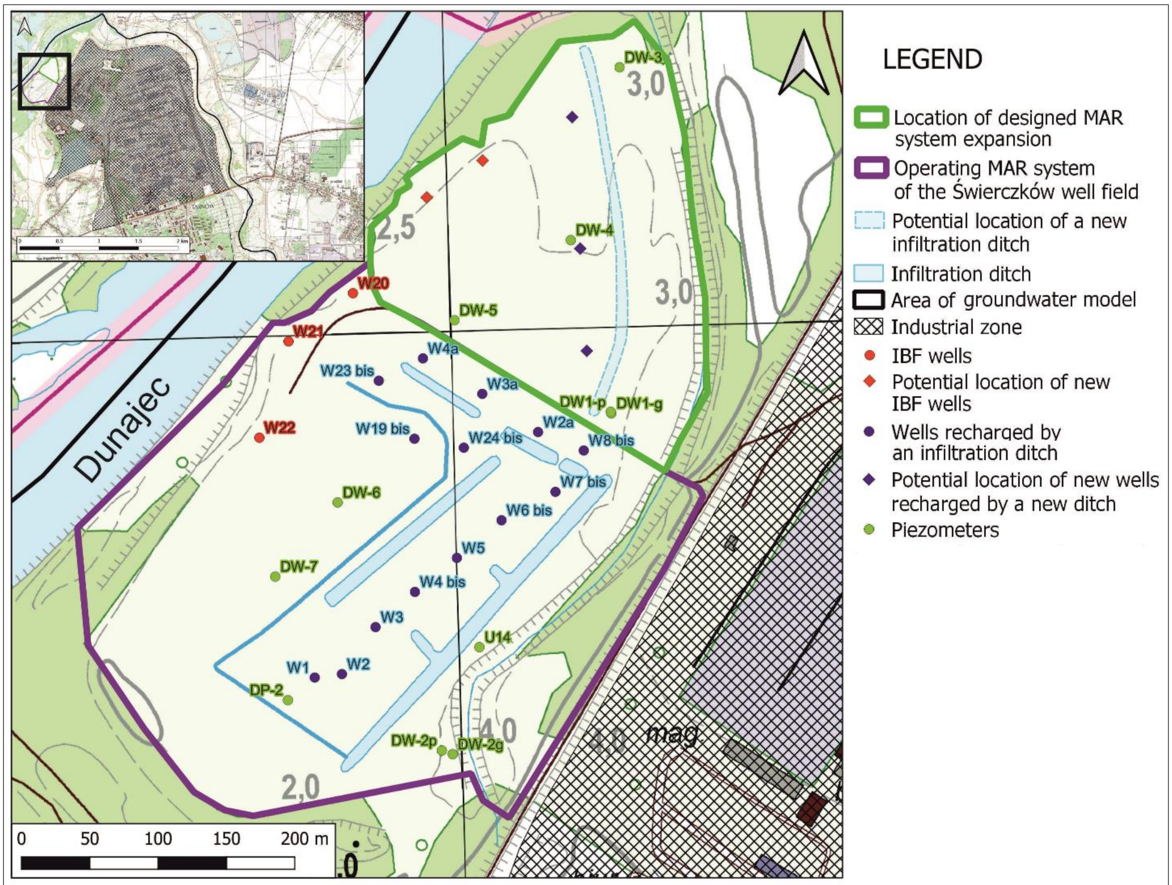


**Figure 2.2** MAR system on the Świerczków well field together with the location of its potential expansion.

# 3. Environmental setting of the proposed project location

## 3.1. Site description

The EIA study area is located in the southern Poland, in the eastern part of the Lesser Poland Voivodship, near the city of Tarnów - one of the largest cities of this region. Tarnów covers an area of 72.38 km² and is inhabited by over 100 thousand people. However, with a size of 27 km², the study area covers only the westernmost, industrial part of the city. The central and southern parts of the study area include smaller settlements such as Kępa Bogumiłowicka, Zbylitowska Góra, or Zgłobice (Fig. 3.1).

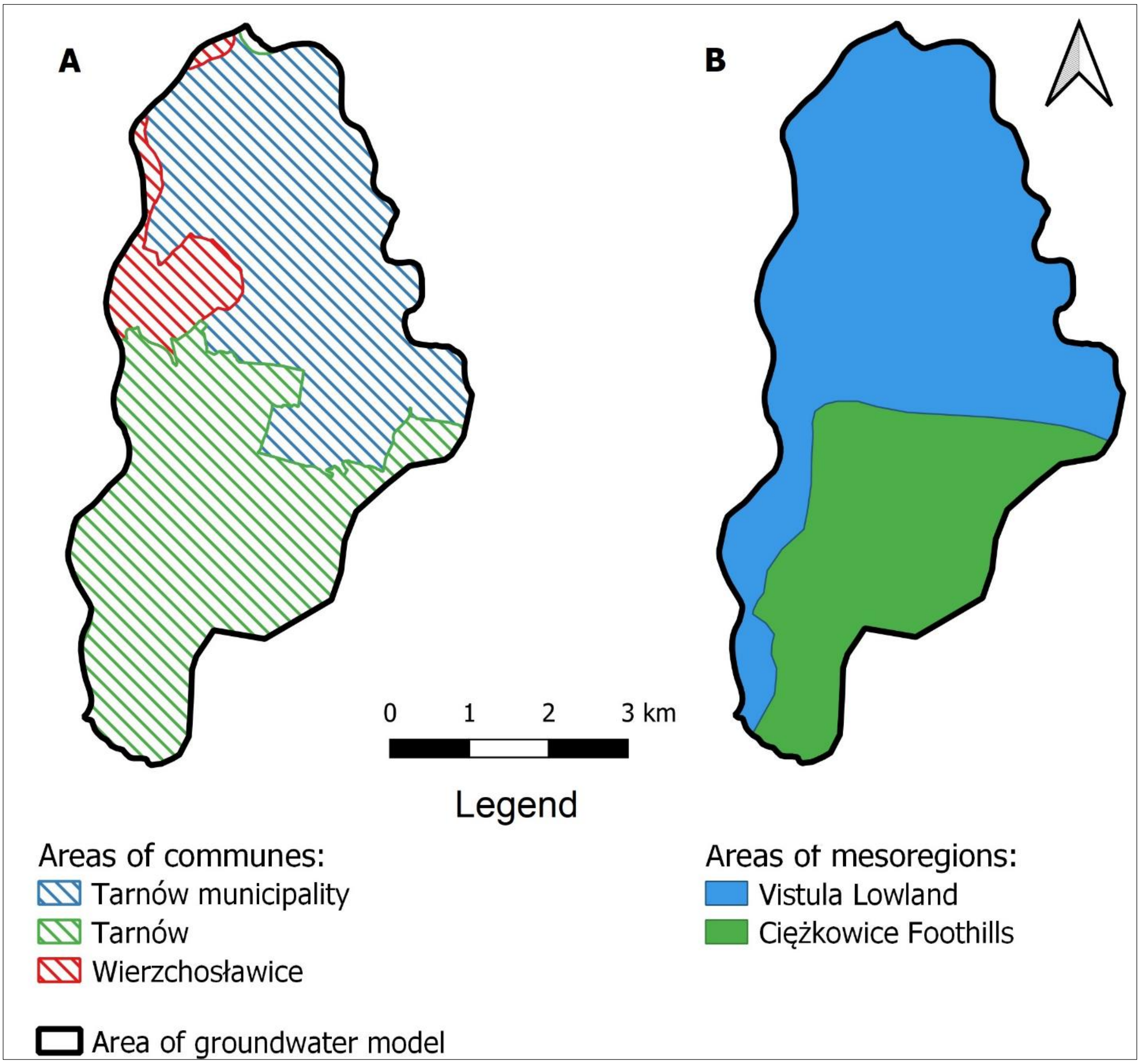


**Figure 3.1** The area of the study on the background of administrative division (commune) [A] and division into mesoregions according to Kondracki (1998) [B].

The study area is located mainly within the mesoregion of the Vistula Lowland, belonging to the Sandomierz Basin. Only in its southern part, there is a distinctive fragment of the Ciężkowice Foothills, belonging to the Central Beskids Foothills (Kondracki, 1998). In the study area, population and industry are supplied with water from both surface and groundwater resources (Fig. 3.2)

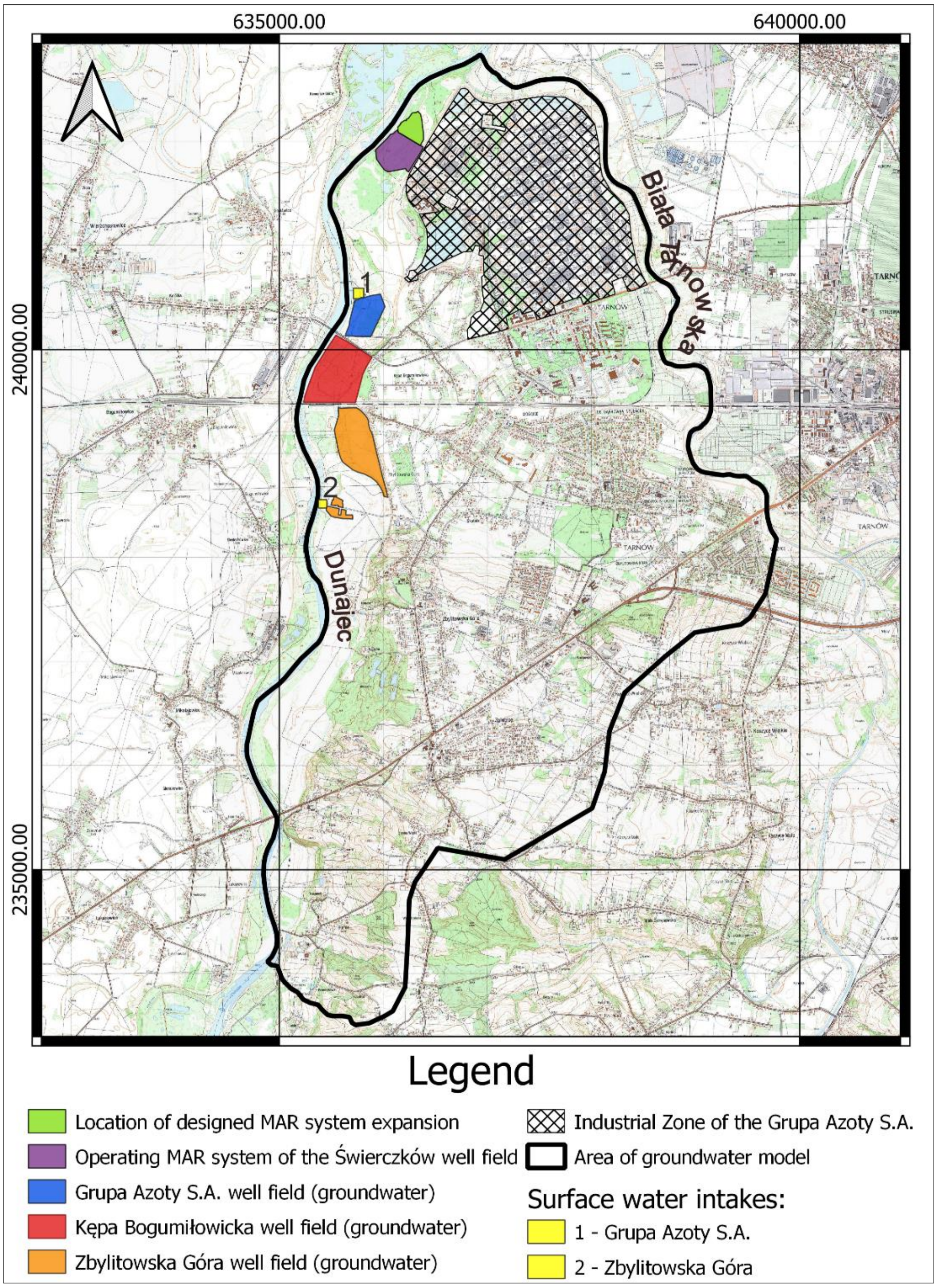


**Figure 3.2** Planned MAR location and existing surface and groundwater supply systems within the study area.

### 3.1.1. Proposed MAR site in relation to other spatial interventions

The proposed MAR area is relatively secure in terms of its relation to other spatial developments. The plot, where MAR extension is planned, is located entirely on the land owned by Tarnów Waterworks. From the west, the area is bordered by the Dunajec River (Fig. 2.2 & 3.1). This river is a source of water supplying the MAR. On the other side of the Dunajec, there is the floodplain area near the town of Komorów. The northeast and southwest study areas are bordered by green areas (forest), and from the east, a large industrial area belongs to Grupa Azoty S.A. (Fig. 3.2). It should be added that from the southwest, the plot does not directly border the forest because the closest neighbor of the study area is the second plot of the waterworks, where the currently operating Świerczków well field is located (Fig. 2.2).

### 3.1.2. Compliance with valid spatial planning documentation

The planned MAR project is in compliance with the local spatial development plan (LSDP) of the Tarnów city. The operating MAR system of the Świerczków well field and the designed MAR system expansion are located within the areas intended for water supply systems (Fig. 3.3).

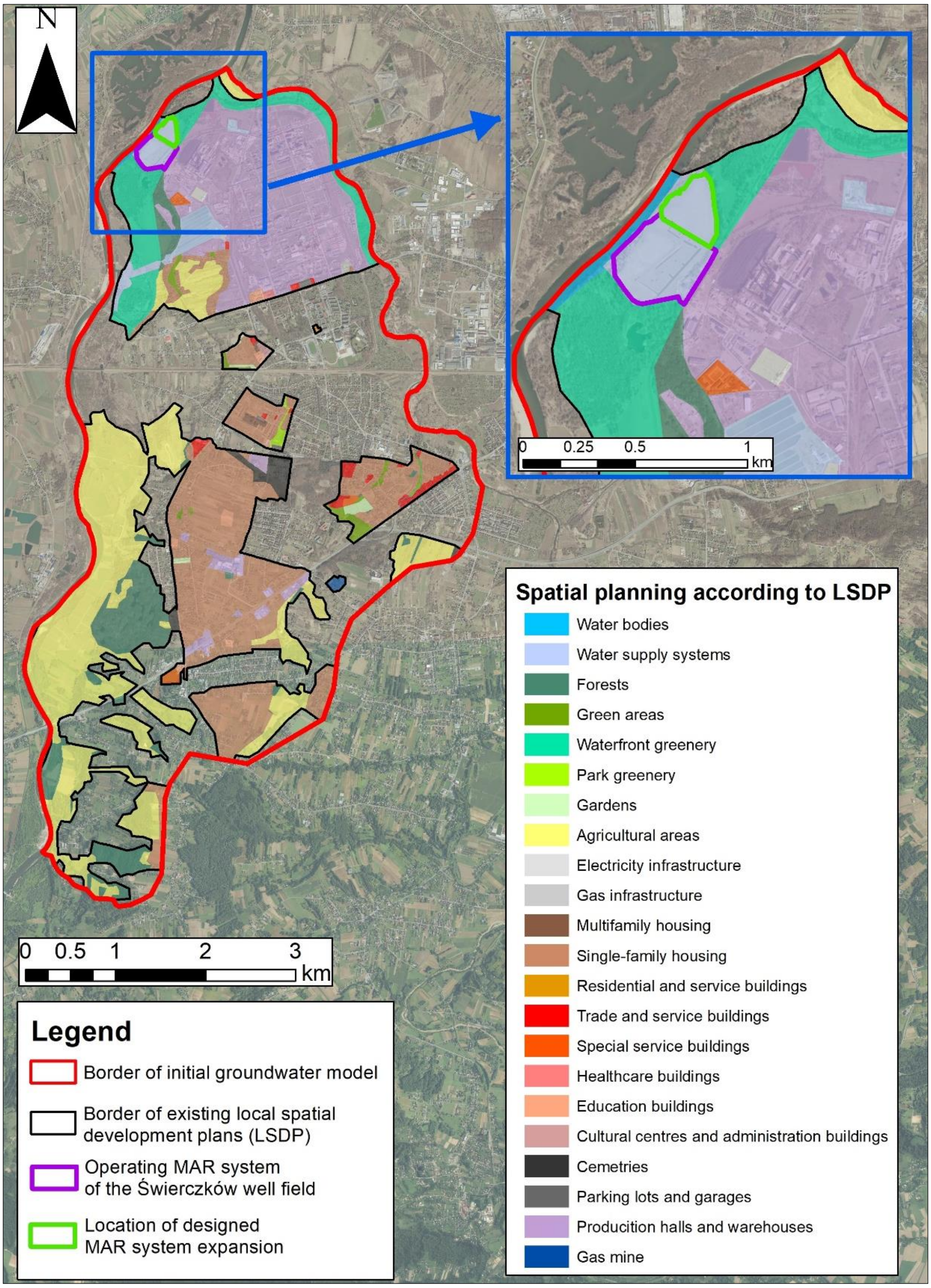


**Figure 3.3** Existing local spatial developments plans (LSDP) within the study area.

## 3.2. Climate characteristics

The area of the proposed MAR site, in terms of climate, is located in the Southern Lesser Poland climatic region according to A. Woś (2010) classification. This region is distinguished by the relatively frequent appearance of warm days with recorded precipitation (in total, about a month during the year). Moderately cool days with frosts are around 8. Quite often, there are also very cool days with frosts and at the same time sunny without precipitation.

The weather of the area is mostly shaped by polar maritime air masses which occur with an annual frequency of 66%. The frequency of other air masses is much lower, reaching 18% for arctic air masses) and 14% for polar continental air masses. The warm tropical air masses are noted during ca. 2-3% of days a year. Another factor having an important impact on the weather are the weather fronts that mark the transition zone between two air masses and lead to weather change and precipitation. The warm front crosses the region during ca. 66% of days a year with the maximum in January (8.3%). The annual frequency of cold fronts is higher – 126% a year – and the peak of their occurrence falls in November and December (c.a. 12% in both months).

The analysis of a long-term weather observations for Tarnów from 1966-2019 allows determining that the average annual air temperature in this area is 8.9°C and it has been significantly rising since 1966 with the rate of 0.4°C per decade (DEEPWATER-CE, 2021a). The general increase in mean air temperature is related to increased high air temperatures rather than changes in air temperatures below the freezing point. This region has the longest thermal summer in Poland - it lasts 114 days (the number of days with average daily temperature above 15 degrees Celsius).

Tarnów annually receives an average of 725 mm of precipitation (1966-2019). The annual course of precipitation in Tarnów is typically continental with a clear maximum in the summer months (July) and minimum in winter (February).

## 3.3. Geological settings

The investigated region lies on the Carpathian Foredeep Basin, a deep mountain basin between the massifs of the Carpathians and the Świętokrzyskie Mountains. The basin is filled with a thick series of Miocene sediments lying inconsistently on the Precambrian, Palaeozoic and Mesozoic deposits, covered with the Quaternary deposits (Fig. 3.4). In terms of the Dunajec catchment, Miocene sedimentation developed in several stages, in two sedimentary basins: internal (in the south, between Nowy Sącz and Tarnów) and external (in the north, the area of the present Carpathian Foredeep Basin). In the first stage, sedimentation of silt and clay deposits with interbeds of sandstone and conglomerates developed only in the inner basin. In the next step, the sea extended, initiating sedimentation in the outer basin. In the north, shallow-water deposits formed, and in the south - deeper facies. In the next stage, sedimentation took place only in the external basin, associated with an increased inflow of terrigenous material—the clay-sandy sediments formed at that time. From the point of view of the planned works and modelling activities, the Quaternary formations present in the study area are of key importance. The occurrence, form, and thickness of the Quaternary formations are mainly related to the glacial, fluvial, and aeolian activities. Their thickness depends mainly on the morphology of the terrain and the relief of the Miocene's top. The oldest formations are formed by glacial deposits of the South Polish Glaciations - tills on the plains and fluvioglacial sands and gravels in the valleys. In the great interglacial period, the backfill area formed during the Middle Polish Glaciations was cut with valleys to a depth of 10-20 m below the present river beds. Numerous gravel pits date from this glaciation period (Wojtal et al., 2009; Kruk et al., 2017).

In general, the top 10-20 m (for the northern and southern part, respectively) below ground level are the Quaternary deposits. They consist of loams (muds), silts, and organic silts or clays in the upper part of the profile (particularly in the northern part), and alluvial deposits in form of sands and gravels with a substantial fraction of pebbles in the lower part of the profile. Quaternary deposits lie on a clay Miocene bed. It is also worth noting that in the southern part of the investigated region Middle Miocene sediments outcrop, mostly as mudstones, sandstones, claystones, marls, and conglomerates. The youngest sediments are represented by the so-called “Anthropocene”: embankments, landfills, and anthropogenically transformed land.

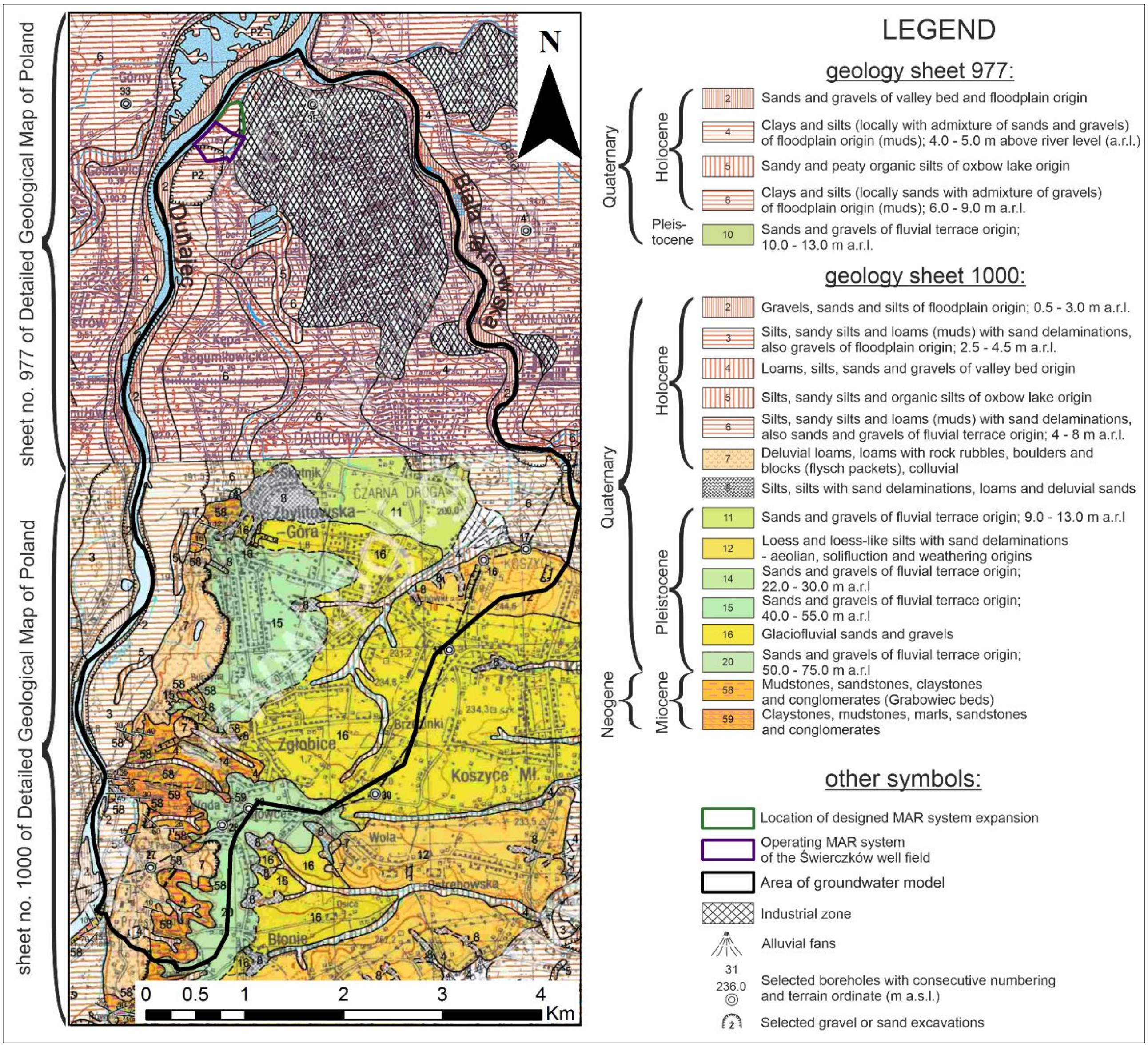


**Figure 3.4** Geological map of the study area (according to Purchla, 1991, Marciniec et al., 2006)

### 3.3.1. Tectonic relations

The study area is located within two major tectonic units: the Carpathian Flysch Mantle in the south and the Carpathian Foredeep filled with Miocene formations in the north. In the southern part, in the zone of overthrust of the Flachian Carpathians, on autochthonous Miocene formations of the depression, there is overthrust of the Zglobytic Mantle built of folded Miocene formations, which are partially exposed on the surface. Underlying these units are Precambrian rocks with a Paleozoic-Mesozoic cover. The formations are covered by Quaternary sediments, mainly Pleistocene water-glacial and Holocene fluvial deposits (Purchla, 1991, Marciniec et al., 2006).

### 3.3.2. Seismic features

The study area is located in the foreland zone of the Polish Carpathians. In the Polish Outer Carpathians, the observed velocities of the contemporary vertical movements of the Earth crust range from about 0 mm/year in the western and central part to +1 mm/year in the eastern part, whereas the rate of the contemporary horizontal movements in the region of the Pieniny Rock belt does not exceed 0.5 mm/year (Zuchewicz, 2001). In view of the above, no manifestations of seismic activity are expected in the described area.

## 3.4. Soil

The occurrence of soils was described based on soil maps available at the Geoportal of the Malopolska Region (MIIP, 2021). The soil conditions in the analyzed area are varied (Table 3.1). In terms of the study area, brown leached and acid brown soils, then podzolic soils and pseudo-podsols, as well as alluvial soils, dominate. In the area of the Świerczków well field, in the area of planned works, there are very good and good grasslands, developed as medium-dusty loams (Fig. 3.5). The soils found in the study area are summarised in Table 3.1.

Table 3.1 Soil characteristics of the study area.

| No. according to map (Fig. 3.5) | Characteristics | | |
|---|---|---|---|
| | agricultural complex | mineral origin | type |
| 1 | very good agri-rye | brown leached and acid brown soils | silty loam |
| 2 | good agri-rye complex | podzolic soils and pseudo-podsols | silty loam |
| 3 | good wheat | fluvisol | medium-silty loam |
| 4 | very good wheat | fluvisol | heavy-silty loam |
| 5 | strong grain-forage | brown leached and acid brown soils | loam |
| 6 | weak agri-rye | brown leached and acid brown soils | loamy sand |
| 7 | defective wheat complex | proper brown soil | heavy loam |
| 8 | medium grassland | fluvisol | silty loam |
| 9 | grassland weak and very weak | brown leached and acid brown soils | loam |
| 10 | weak strong grain-forage | podzolic soils and pseudo-podsols | loam |
| 11 | strong grain-forage complex | fluvisol | heavy-silty loam |
| 12 | grassland good and very good | fluvisol | medium-silty loams |
| a | built-up and invested areas | | |
| b | forests | | |
| c | agricultural wastelands | | |
| d | State Forest Holding | | |

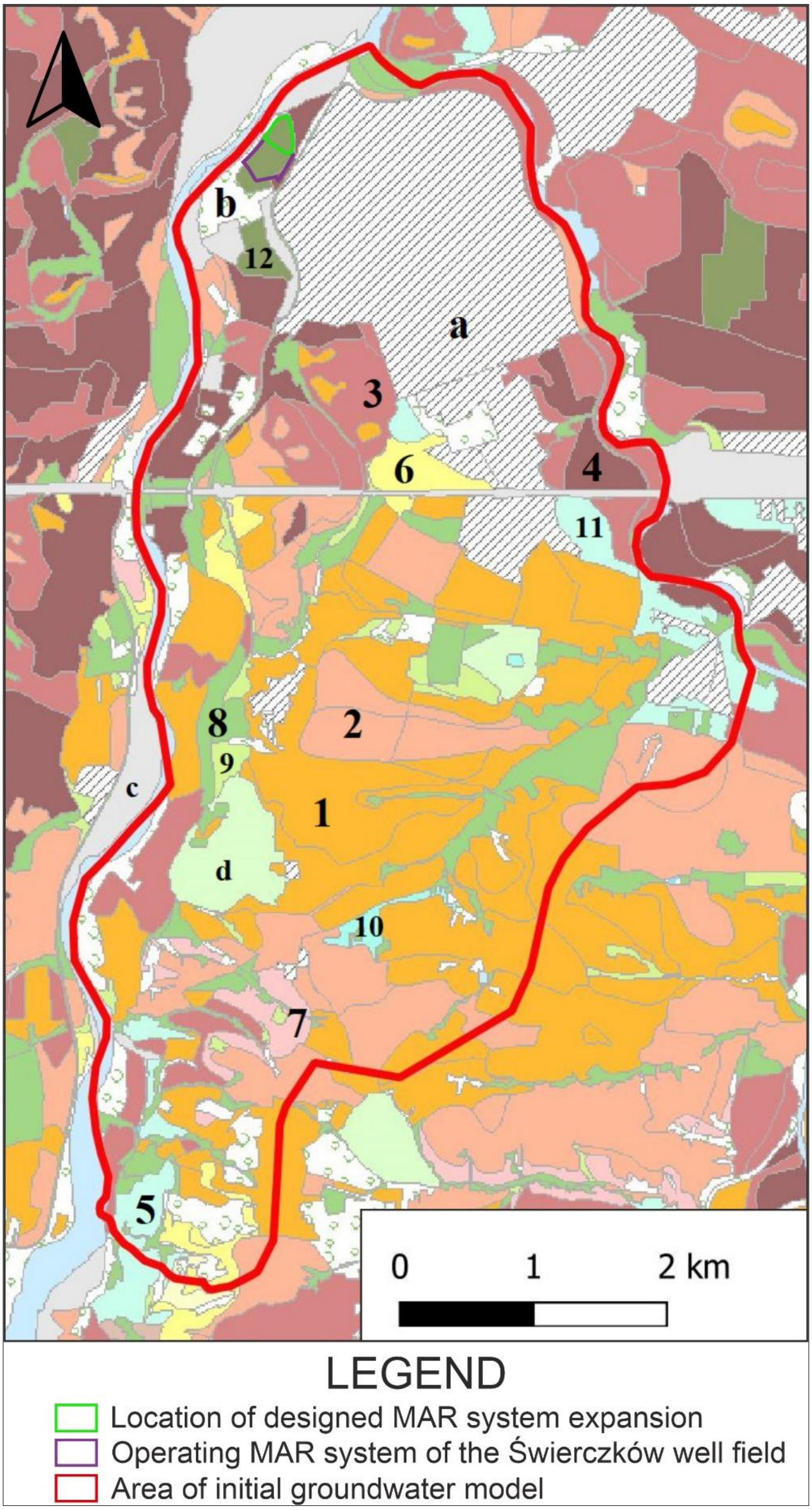


**Figure 3.5** Soil map of the study area. Soil numbers are in accordance with Table 3.1.

## 3.5. Water

### 3.5.1. Surface water

The examined area is located in the Baltic Sea drainage basin, the Vistula river basin, in the Upper Vistula water region, within the Regional Water Management Board in Cracow. It is situated at the fork of the Dunajec and Biała Tarnowska rivers and is located within 2 surface water bodies (SWB): the Dunajec river from the Czchów reservoir to the estuary (code PLRW20001921499) and the Biała river from Rostówka to the estuary (code PLRW200014214899) (Fig. 3.6). In the northern part of the study area, there is a local network of drainage ditches carrying away rainwater from parts of the industrial area of Grupa Azoty S.A (GA S.A.). Apart from the aforementioned watercourses, there are numerous small surface water reservoirs. They are mainly artificial reservoirs (small water reservoirs after former gravel pits, infiltration ditches in the Świerczków well field area, settling ponds for surface water withdrawal GA S.A., reservoirs for hazardous substances or settling ponds of sewage treatment plant GA S.A.)

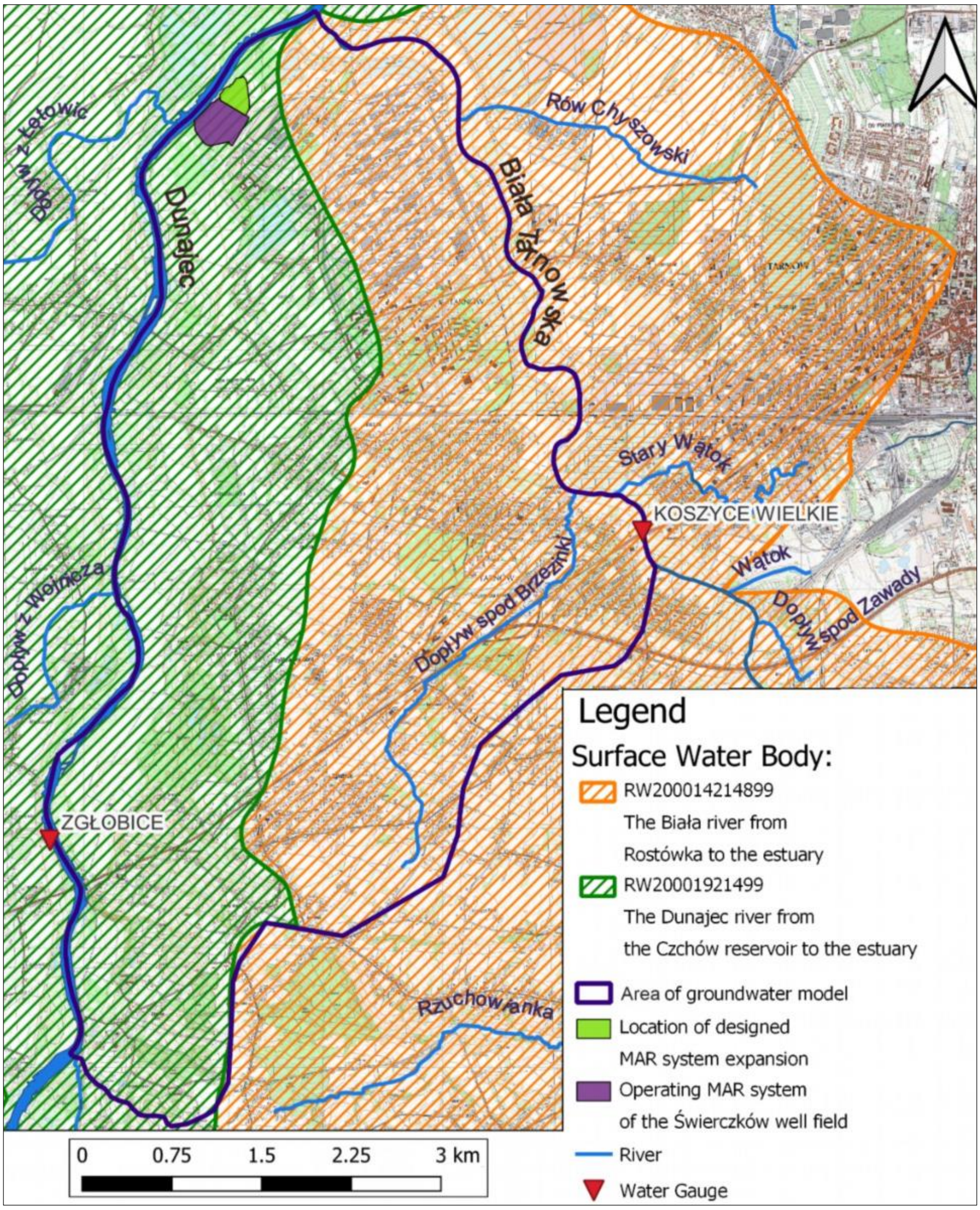


**Figure 3.6** Hydrographic network within the study area.

**THE DUNAJEC RIVER**

The western part of the research area, which belongs to the SWB RW20001921499, is described as type no. 19 - a sandy-clay lowland river. Its length is 69.8 km, and the catchment area is 251.2 $km^2$ (Fig. 3.7).

The flow rate of the Dunajec River at the water gauge station Zgłobice, located at km 38+560 of the river course, in the years 1981-2017 was: the lowest 8.80 $m^3$/s, average low 18.7 $m^3$/s, average annual mean 77.4 $m^3$/s, average high 882 $m^3$/s, highest 2510 $m^3$/s and in the years 2016-2020: the lowest 20.8 $m^3$/s, average 80.07 $m^3$/s, highest 1030 $m^3$/s. The calculated base flow for the 2016-2020 period ranged from 20.8 to 124 $m^3$/s with a mean value of 40.44 $m^3$/s.

According to the SWB assessment for the years 2010-2012 and currently, the ecological state/potential was good and above good, with a good chemical state and good general state. Anthropogenic pressure on water is related to the agricultural use of water bodies and hydromorphology. SWB (the Dunajec River from the Czchów reservoir to the estuary) is at risk of failing to achieve the environmental goal.

**THE BIAŁA RIVER** (also called BIAŁA TARNOWSKA)

The SWB code RW20001424899, named "Biała od Rostówka do ujścia" (eastern part of research area), belongs to type 14 - small flysch river. The Biała River is the right-bank tributary of the Dunajec River. The length of the water body is 34.4 km, the catchment area is 125.8 $km^2$ (Fig. 3.7).

The flow rate of the Biała River at the water gauge station IMiGW Koszyce, located in km 2+000 of the river's course, in the years 1971-2013 were: the lowest 0.60 $m^3$/s, average low 1.38 $m^3$/s, annual average 9.36 $m^3$/s, average high 282 $m^3$/s, highest 836 $m^3$/s and in the years 2016-2020: the lowest 0.92 $m^3$/s, average 7.68 $m^3$/s, highest 270 $m^3$/s. The calculated base flow for the 2016-2020 period ranged from 0.92 to 13.8 $m^3$/s with an average value of 3.68 $m^3$/s.

According to the assessment of the state of the SWB for 2010-2012 and currently, the ecological state/potential was poor, with a good chemical state and poor overall state. The components determining the status were Ichthyofauna, Phytobenthos. Anthropogenic pressure on the water state is related to agricultural use of the water body. The other impacts are unrecognized. The water body is at risk of not achieving the environmental objective.

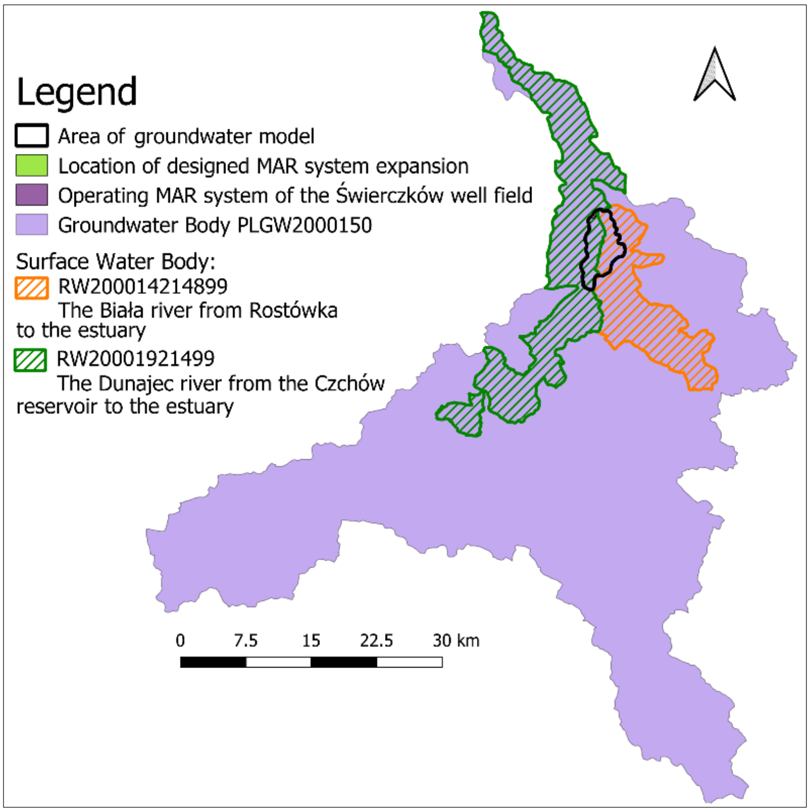


**Figure 3.7** Location of the study area in relation to water bodies

### 3.5.2. Groundwater

According to the division of Poland into 172 groundwater bodies, the study area is covered by one groundwater body no. PLGW2000150 (Fig. 3.7). The groundwater body (GWB) no. PLGW2000150 has an area of 2042.3 km$^2$ (JCWPd, 2017) and is located in the XIII-pre-Carpathian and XIV-Carpathian hydrogeological region (Paczyński, 1995), within the first-order catchment of the Vistula river basin and the second-order catchment of the Dunajec river basin. Administratively, it lies in the Małopolskie Province, within the range of the Regional Water Management Board in Cracow .

Within the described GWB, there are two aquifers: Quaternary and Paleogene-Cretaceous. The Quaternary aquifer occurs in sands, gravels, and pebbles, and its thickness varies from 0.1 to 18 meters. It is an unconfined aquifer with a groundwater depth of 0.3-17.6 m below surface level. The hydrogeological parameters of the Quaternary aquifer are highly variable - hydraulic conductivity varies from 0.36 to 0.00036 m/h. From the hydrochemical point of view, the aquifer is characterized by natural water of the $HCO_3$-Ca, $HCO_3$-Ca-Mg, and $HCO_3$-$SO_4$-Ca-Mg types, and waters deviating from the natural types, i.e. $HCO_3$-Cl-Ca.

The Paleogene-Cretaceous flysch-type aquifer of dual-porosity: granular and fractured, occurs in sandstones and shales and is of variable thickness, ranging from 0.5 to 55 m. It is an unconfined aquifer with a groundwater level occurring at a depth of 0-130 m below surface level. Hydraulic conductivity varies from 0.036 to 0.0036 m/h. From the hydrochemical point of view, the aquifer is characterized by natural water of the $HCO_3$-Ca, $HCO_3$-Ca-Mg, and $HCO_3$-$SO_4$-Ca-Mg types, and several water types deviating from natural ones are found, i.e. $SO_4$-$NO_3$-Ca-Mg, $HCO_3$-Ca-Na, $HCO_3$-Na-Ca, $HCO_3$-Ca-Na-Mg, $HCO_3$-$SO_4$-Cl-Ca-Mg.

According to the assessment of groundwater resources for PLGW2000150, 235 550 m$^3$/d are generally available for use and 10.9% of the existing resources are currently used.

In the research area, the Quaternary aquifer is of major importance. The Quaternary aquifer lies on an impermeable clayey Miocene bed and is mostly covered with silts and loams. Locally, in the upper part of the aquifer, there is a significant thickness of clay deposits. The depth to the aquifer generally varies from 2 to 5 m (on the southern upland, the depth increases to over 35 m) and its thickness is generally 5 - 9 m. The aquifer is mostly unconfined (Treichel et al., 2015). Depth to the groundwater table depends on the water level in the Dunajec and Biała Tarnowska rivers, the amount of groundwater abstraction, and the intensity of the aquifer recharge from precipitation and infiltration ditches (in the Świerczków well field). The aquifer's recharge takes place in its entire catchment area by direct infiltration of rainwater and in the periods of high surface water levels also by infiltration from the rivers. The aquifer's hydraulic conductivity varies from a few dozen to more than 100 m/d. The highest permeability of the aquifer occurs in the valley of the Dunajec, reaching up to several hundred m/d (Wojtal et al., 2009; Wojtal, 2013). According to the division from the 1:50 000 Hydrogeological Map of Poland: First Aquifer – Extent and Hydrodynamics, the research area is located within three hydrogeological units (numbers 1, 3, and 5) the most important of which is unit no. 1 (Fig. 3.8). The unit is associated with the formations filling the valleys of the Dunajec and Biała Tarnowska rivers, covering around 60% of the modelling area: [1 p,ż, ma-p/dz/zsG/Q]. This abbreviation means: the dominant material in unit no. 1 is sand and gravel, the subordinate sediments are muds with underlying sand / hydrodynamic-geomorphological type of the aquifer is a floodplain / the aquifer is unconfined and is also the main useful aquifer in this area/ geological formations are of the Quaternary age. These described deposits relatively often contain pebbles.

The groundwater level varies from 185 (Dunajec riverbed) to 260 (southern side of the region) m a.s.l. (Fig. 3.8) The hydrodynamic system is typical for an interfluve area. In this case, the groundwater flow is in the W and NW direction towards the Dunajec river, and E and NE direction towards the Biała Tarnowska river. The aquifer under natural conditions (before the abstraction of groundwater by wells) was drained by these two rivers. During the flood periods the hydraulic gradient in the aquifer next to the rivers is reversed and rivers temporarily lose water and feed the aquifer. It should be emphasized that nowadays, the flow rate in the Dunajec river is regulated by water discharge on the dam in Czchów (the well field is located about 5 hours from the dam). The Biała Tarnowska river is not regulated, therefore the periodic floods in this river are more violent (Wojtal, 2013).

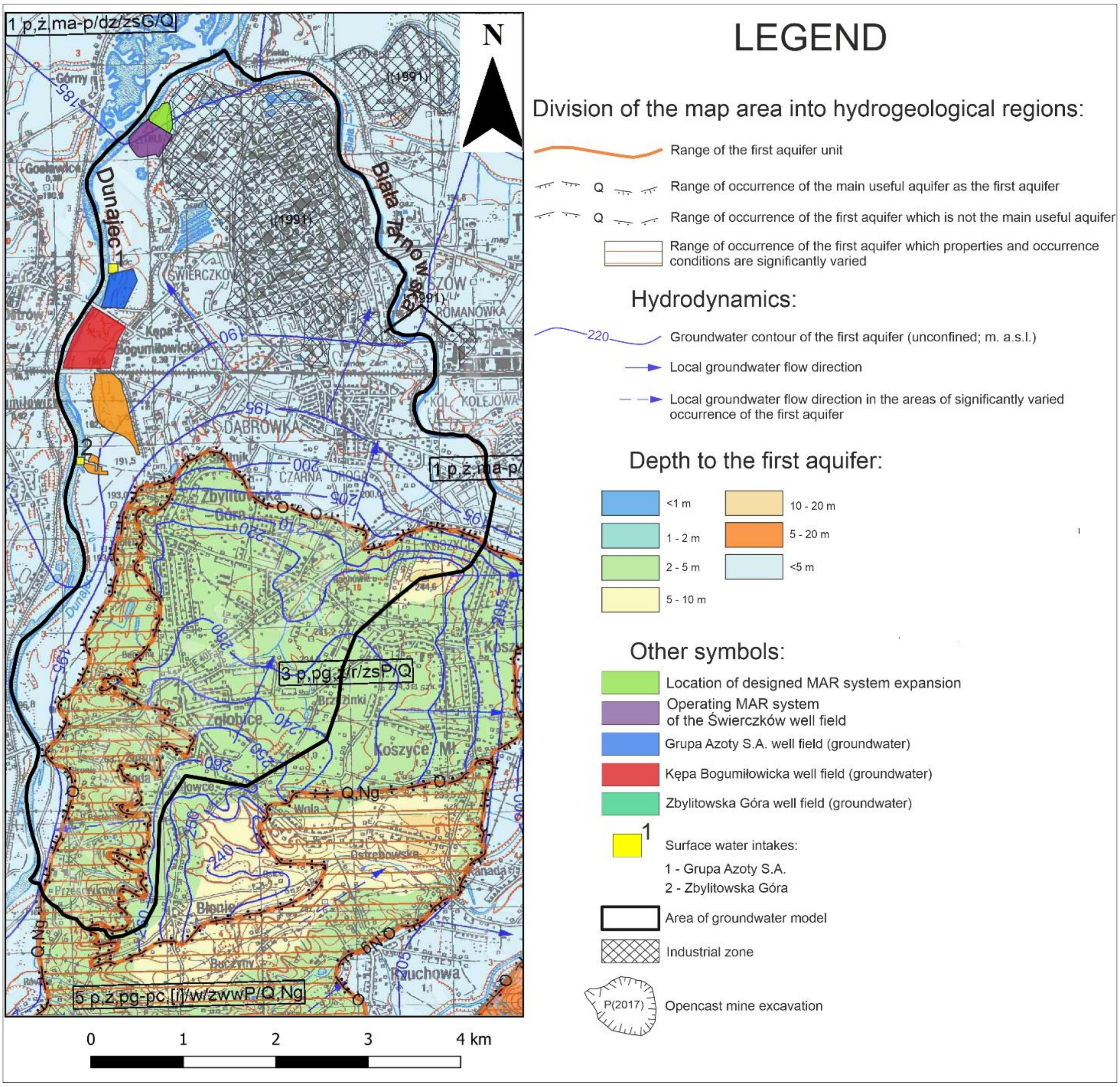


**Figure 3.8** Hydrogeological map of the study area (based on Gorczyca, Gągólski, 2018; Gorczyca, Koziara, 2018).

Groundwater dynamics in the studied area is dependent on such factors as topography, geological structure, the intensity of recharge, and drainage of the Quaternary aquifer. The location of the area in the inter-river basin of the Dunajec and Biała Tarnowska rivers is also associated with periodic fluctuations in the groundwater table caused by changing water levels in the rivers. The groundwater divide runs approximately from the south to the north, dividing the study area into two areas: the western one, from which groundwater flows towards the Dunajec River, and the eastern one, from which groundwater flows towards the Biała Tarnowska River. Groundwater flowing westwards supply the wells of the Świerczków well field.

### 3.5.3. Floods

The flood hazard maps include areas with a defined probability of flooding from low (equivalent to 0.2%, once in 500 years or an extreme event scenario) to high (equivalent to 10%, once in 10 years) and also refer to dike failure situations with a probability of 1% or dam failure. In addition, the flood hazard maps include water depths, water velocity, and water flow direction in classes that determine the level of danger to people and how buildings will be affected, according to the relevant decree.

Flood risk maps are produced for areas covered by flood hazard maps. They show the potential adverse consequences of flooding on human health and life, the environment, cultural heritage, and economic activity. Flood risk maps present objects of relevance for flood protection and the information necessary to assess flood risks and potential consequences of flooding in line with the objectives of the Floods Directive.

For the first report D.T3.4.1 made for the pilot area entitled "Report on the desk analysis of the pilot feasibility study for MAR deployment in porous aquifers located near industrial sites on contamination of aquifers" (DEEPWATER-CE, 2021a), the authors prepared four selected maps showing the region of the designed groundwater flow model:

- flood hazard maps with water depths: areas with a medium probability of flooding corresponding to 1% (once in 100 years)
- flood hazard maps with water depths: areas with a high probability of flooding corresponding to 10% (once in 10 years) (Fig. 3.9);
- flood risk maps: potential negative impacts on human health and life and values of potential flood losses - areas with a medium probability of flooding, which corresponds to 1% (once in 100 years)
- flood risk maps: potential negative impacts on human health and life and values of potential flood losses - areas with a high probability of flooding, which corresponds to 10% (once in 10 years) (Fig. 3.10).

On the map of flood hazard with water depths where the probability of flooding is medium, the Świerczków well field is located in the area of 2 m < h < 4 m (high hazard to people and very high damage). The water depth in the area of the groundwater flow model is diversified (0.5 m < h < 4 m). On the map of flood hazard with water depths where the probability of flooding is high, the Świerczków well field is located partly in the area of water depth h < 0.5 m (low hazard to people and buildings) and partly in the area of water depth 0.5 m < h < 2 m (medium hazard to people, but high damage). The water depth in the area of the groundwater model does not exceed 2 m.

On the flood risk maps with potentially negative consequences for human health and life, as well as with values of potential flood losses where the probability of flooding is medium and high, the Świerczków well field is located in an area where the value of potential flood losses falls within the range <1 to 50 PLN/$m^2$. In the area of the groundwater flow model, the value of potential flood losses is also included in both flood risk maps in the range <1 to 50 PLN/$m^2$.

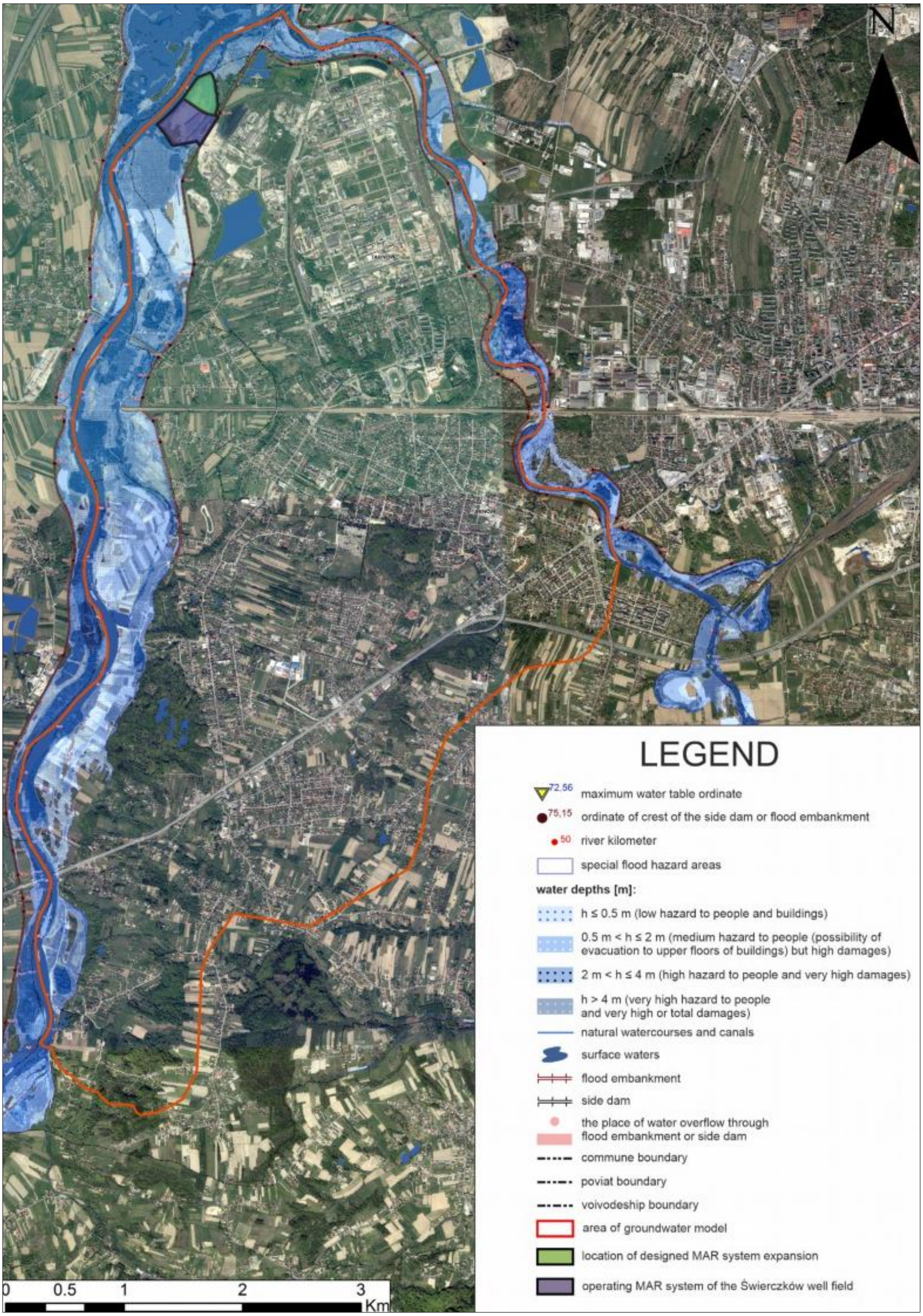


**Figure 3.9** Flood hazard map with water depths: areas where the probability of flooding is high, which corresponds to 10% (once per 10 years).

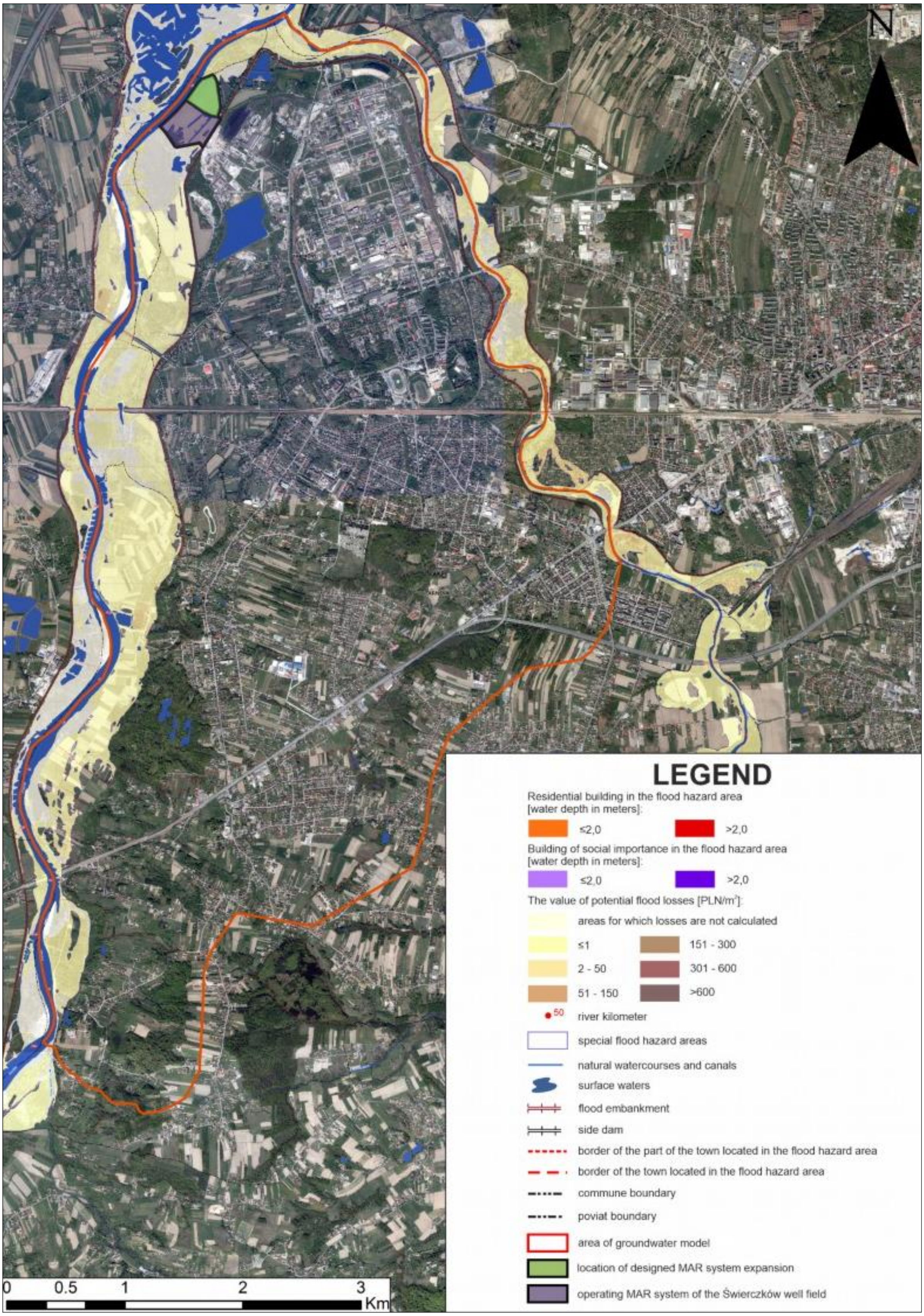


**Figure 3.10** Flood risk map: the potential adverse consequences for human health and life and values of potential flood losses - areas where the probability of flooding is high, once per 10 years.

## 3.6. Landscape features

The study area is located within the river valleys of the Dunajec and Biała Tarnowska, which cover the flood and alluvial terraces of both rivers. The average width of the Dunajec valley in this region is about 1000 m. The Biała Tarnowska valley has an average width of about 300 m. In the area of the Świerczków well field, the ordinates of the river terraces are 190-200 m.a.s.l. The land surface is practically flat there, rising slightly in the southern part of the well field. Larger height differences are of anthropogenic origin and include flood banks, gravel pits, drainage ditches, and landfills. In the southern part of the described area in the region of Zbylitowska Góra, there is an upland where ordinates rise to the level of 230-260 m.a.s.l. (Fig. 3.11).

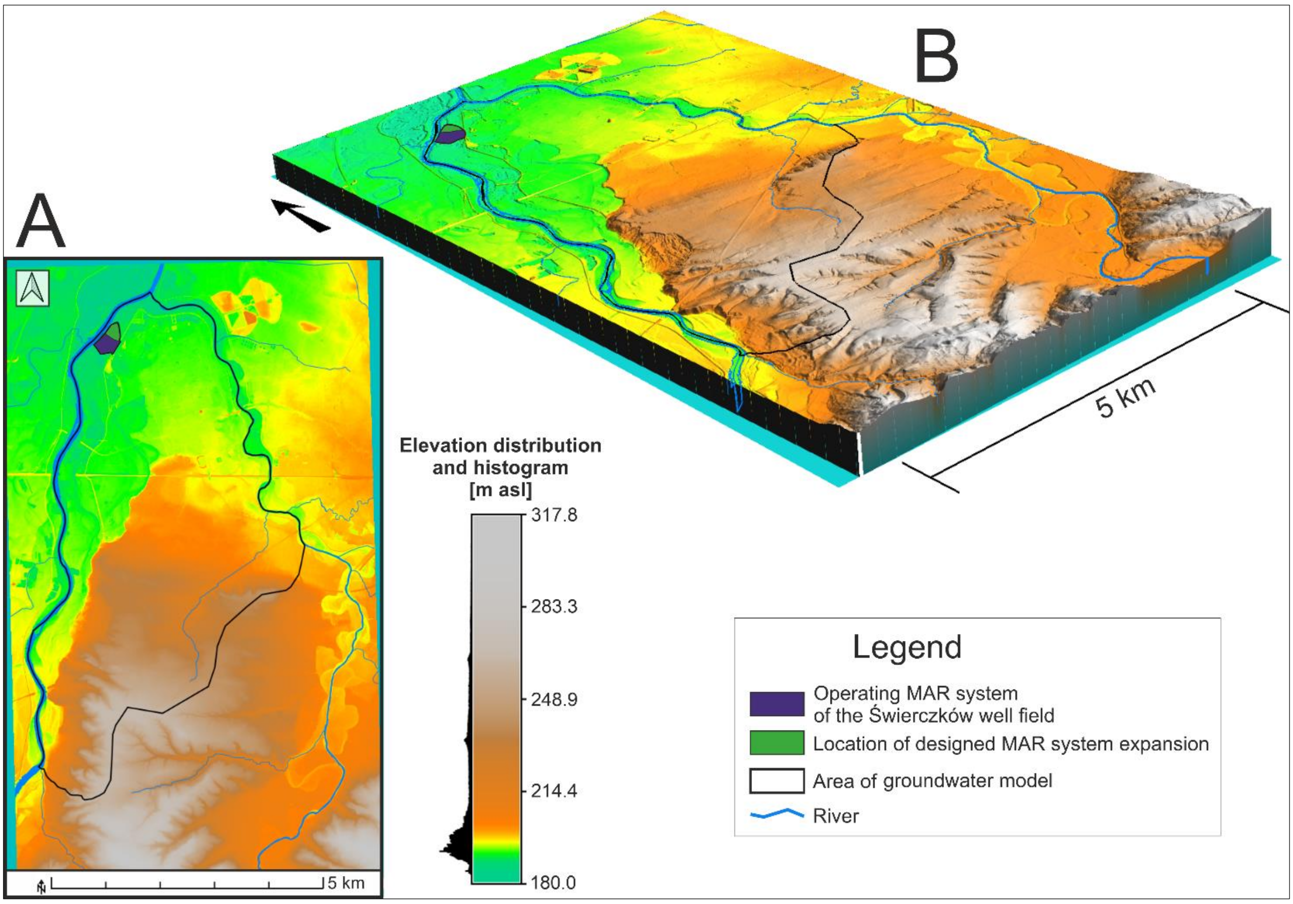


**Figure 3.11** Site morphology of the study area A: 2D map, B: view of the 3D surface.

The main land use type of the study area (47%) are the anthropogenic areas - terrains related to "urban fabric" and the industry of the city of Tarnów. Most important is the huge chemical plant (Grupa Azoty S.A.) situated close to the well field. Świerczków site is also surrounded by two reclaimed ash landfills and the toxic waste reservoir (Wojtal et al., 2009; Treichel et al., 2015). Few roads (for instance, the busiest no. 94) and also railway lines (no.115 and 91) pass through the southern and central part of the area. Agriculture is the second largest type (39%), including non-irrigated arable land (15,7%), pastures (8,7%), land principally occupied by agriculture, with significant areas of natural vegetation (8,6%), and complex cultivation patterns (6%). The remaining 14% are natural vegetation (e.g. forests) and water areas (Fig. 3.12). The land-use types were derived from the CORINE Land Cover (CLC, 2018) database.

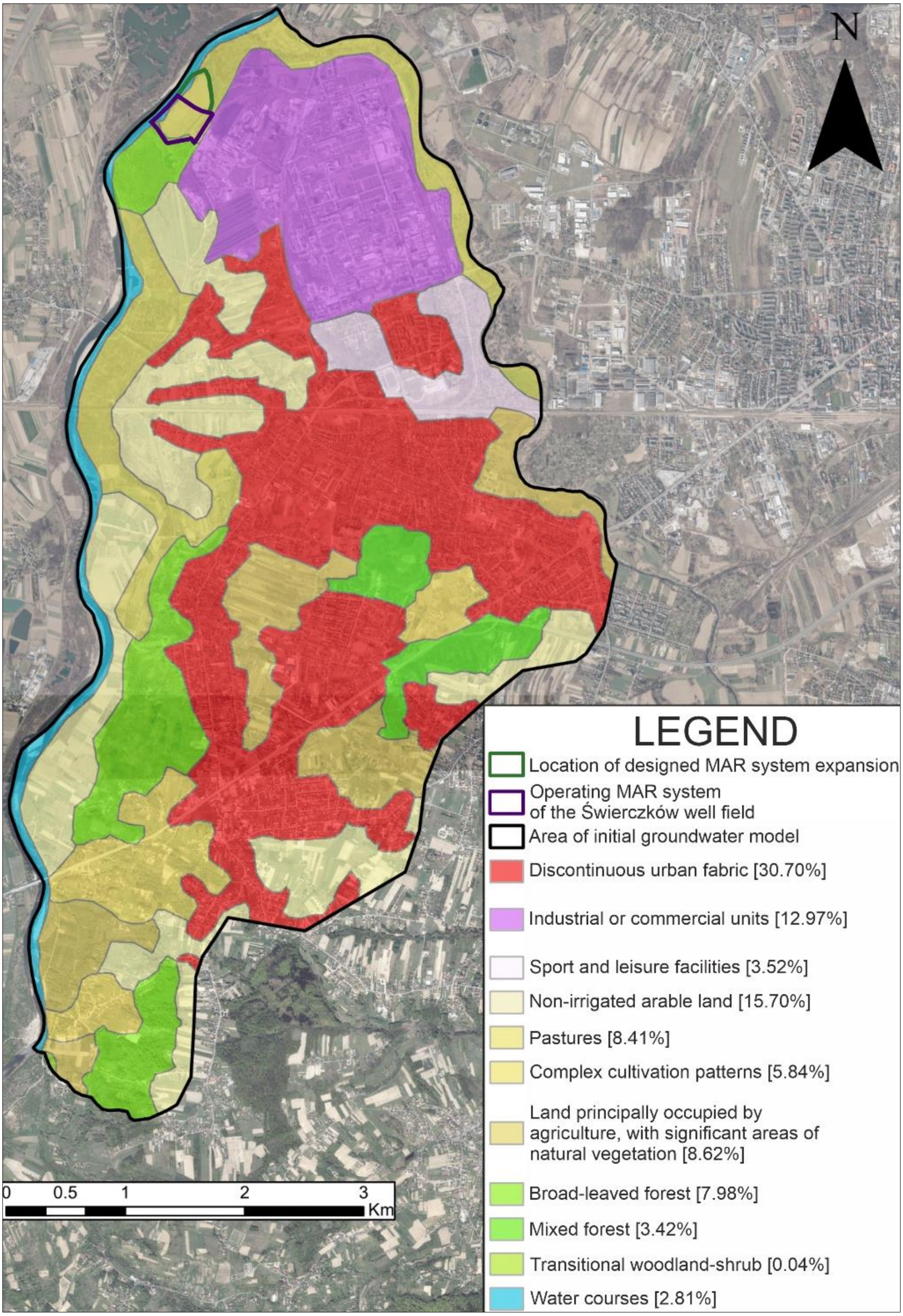


**Figure 3.12** Land use map of the study area based on CORINE Land Cover 2018 database.

## 3.7. Cultural heritage

There are no cultural heritage sites in the study area.

## 3.8. Biodiversity

The natural inventory of the area in the study was not the aim of the DEEPWATER-CE project. The analysis of the impacts of the planned project shows that the following areas will be of key importance in terms of their impact on biodiversity:

- the catchment area in its reserve field together with the surroundings,
- the Dunajec valley in the vicinity of the surface water withdrawal,
- In the case of well field, where MAR extension is planned, it would be necessary to perform:
    - phytosociological photos,
    - research on invertebrate fauna,
    - chiropterological, ornithological, and herpetological research, to obtain detailed data.

In the case of the surface water withdrawal area - a source of water for MAR-ditches (Fig. 3.8), it is necessary to perform research mainly on the river fauna. The available data show (SDF, 2021) that in the lower part of the Dunajec there are species from Annex II of the Habitats Directive (Council Directive 92/43/EEC): *Aspius aspius, Barbus carpathicus, Cottus gobio, Lampetra planeri*. Other species important for the EU include *Castor fiber, Lutra lutra, Bombina bombina, and Triturus cristatus*. Moreover, in the waters of the Dunajec river, the following species were found: *Unio crassus, Barbus barbus, Alburnoides bipunctatus, Chondrostoma nasus, Lota lota, Thymallus thymallus and Vimba vimba.*

## 3.9. Protected areas

In the area of the planned project, apart from Natura 2000 sites, there are situated (Fig. 3.13):

- the Debrza nature reserve (8 km from the Świerczków well field towards the northeast), a forest nature reserve with an area of 9.50 ha, the oak and linden old trees are protected here;
- the Radłowskie Forest floristic nature reserve (8.5 km from the Świerczków well field in the west direction) - aims to preserve the site of Spiš saffron (*Crocus scepusiensis*) along with accompanying species, the area of the reserve is 30.99 ha;
- Radłowsko-Wierzchosławicki Protected Landscape Area (3.7 km on the west from the Świerczków well field);
- Protected Landscape Area of the Ciężkowickie Foothills (6 km on south from the Świerczków well field).

Due to the significant distances of the planned projects, it will not affect the above-mentioned areas.

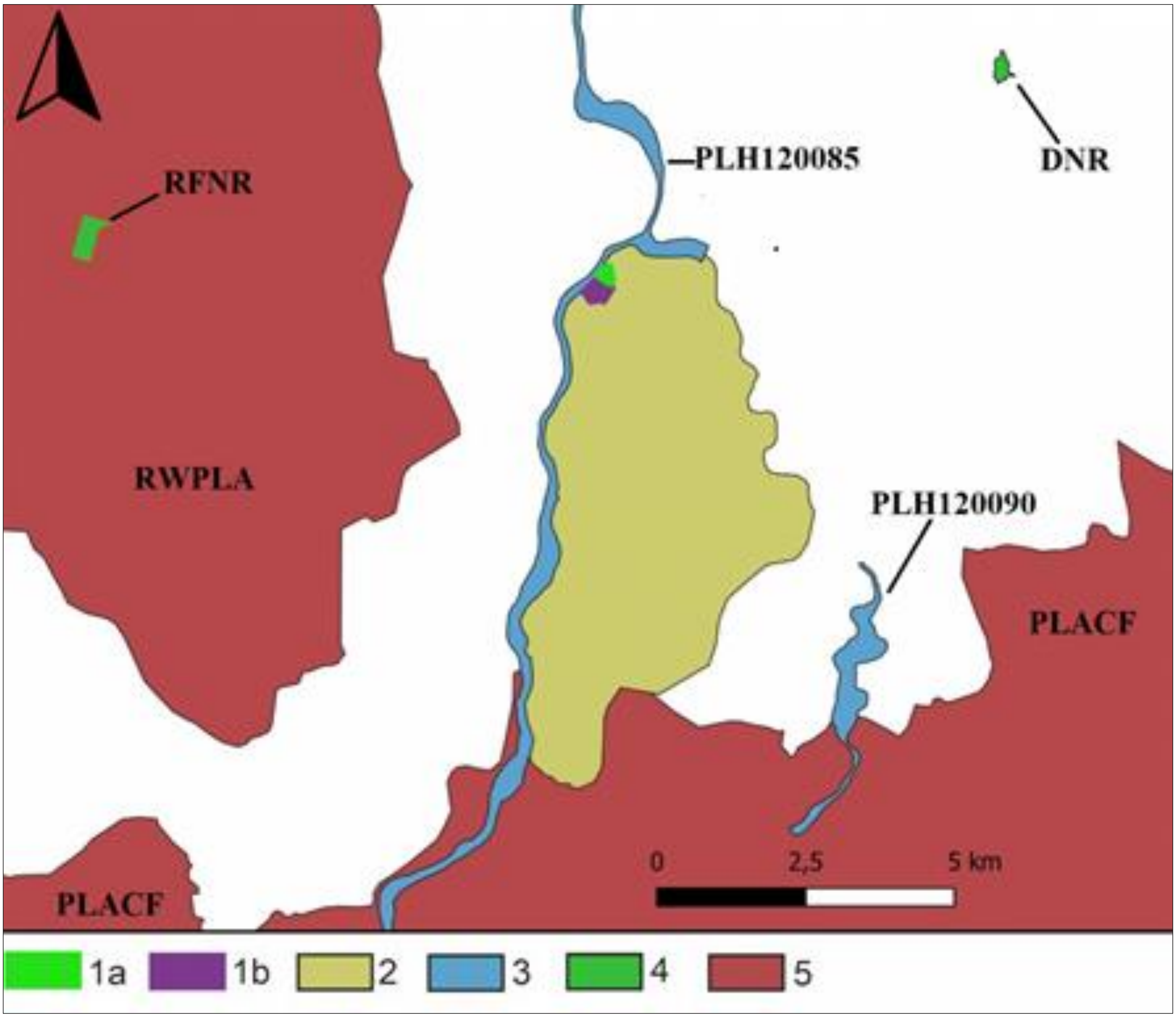


**Figure 3.13** Protected areas in the study area and its surroundings.

1a - location of the designed MAR system expansion, 1b - operating MAR system of the Świerczków well field, 2 - area of initial groundwater model, 3 - Natura 2000 areas: PLH120085 Dolny Dunajec, PLH120090 Biała Tarnowska; 4 - nature reserves: DNR – the Debrza nature reserve, RFNR- the Radłowskie Forest floristic nature reserve; 5 - protected landscape areas: PLACF- Protected Landscape Area of the Ciężkowickie Foothill, RWPLA - Radłowsko-Wierzchosławicki Protected Landscape Area.

## 3.10. Ecological network

In the immediate vicinity of the planned investment, there is the Natura 2000 area PLH120085 Dolny Dunajec (Fig. 3.13). The subject of protection there is:

- habitat 3220 - stones and gravel beds of mountain streams;

- fish populations: *Aspius aspius*, *Barbus carpathicus*, *Cottus gobio*, and *Lampetra planeri*.

Another area of N2000 - PLH120090 Biała Tarnowska is located almost 1 kilometer from the research area and therefore it is not taken into account (Fig. 3.13).

## 3.11. Socio-economic conditions and main end-users

The efficient MAR system has allowed the Świerczków well field to operate continuously for over 60 years. In the earlier period (until the end of the 1950s), the well field used only bank and bottom filtration from the Dunajec River. All these years, the well field has produced millions of $m^3$ of good quality water, which is an extremely important factor for the development of the Tarnów agglomeration. The main end consumers of the MAR system applied at the Świerczków well field are the inhabitants of the Tarnów agglomeration and industrial plants, agriculture, service establishments, and small businesses. The price of water supplied from this well field is relatively low (one of the lowest in the region) due to the lack of need for complicated raw water treatment processes. The area supplied with water from the Świerczków well field is inhabited mainly by people with medium and low levels of affluence. Therefore, the affordable price of the water supplied positively impacts the household budgets of the community living in the Tarnów agglomeration. It is also beneficial for industrial and agricultural production plants, especially in industries where the costs of water supply constitute a significant portion of the total economic balance, which can have a clear positive impact on economic performance. The ongoing socio-economic development of the area supplied from the Świerczków well field and the prospects of connecting more areas to the water supply system indicate a need to increase the production capacity of this well field, which is possible only through the introduction of the planned MAR technology.

# 4. Potential impacts of MAR on the environment

### 4.1.1. Impact on the microclimate

The impact on the microclimate in the study area should be assessed in two aspects:

- pollutants emitted during the execution (construction) phase of the project;

- local climate changes in the surroundings of the MAR.

Air pollution during the implementation of the project will be associated with the emission of fumes from construction machinery and drilling equipment. Emissions of pollutants will be temporary and, due to the required small size of the machinery park, will not have a noticeable impact.

During the operational phase, infiltration ditches will be located within the well field. The surface of the ditches influences the local air circulation resulting from temperature differences over water and over land. However, in the case of the infiltration ditches for the planned project, evaporation areas will be too small to have a noticeable impact on the climate, even at the local scale. The absence of any expected visible changes in the (micro)climate is also supported by the presence of the Dunajec river. The river in the vicinity of the existing and planned well field is about 80 m in width. If we consider that the length of the Dunajec river bank adjacent to the well field is 550 m, then the water surface in the river is about 4.4 ha, i.e. many times larger than the surface of the planned ditches.

The analysed investment consisting of the construction and operation of the MAR system is an investment of local importance. Its scale, location, and size will not affect the climate and its changes. The only changes in climate elements are the increased evaporation from the water surface in the MAR system and increased air humidity. The impact of climate change on the durability of the project is insignificant, it results from the location of the investment, its size, and the forecasted climate changes. Adaptation of the investments to climate change is not required.

### 4.1.2. Impact on the geology

The impact of MAR on the geological conditions will be clearly visible during the project's execution phase only due to the construction of the infiltration ditches and wells. The works conducted will disturb the rock mass. However, the overall geological conditions will not be affected. Threats associated with rock mass disturbance may arise in emergency/catastrophe situations that would result in contaminants entering the geological strata, e.g. coming from motor vehicles or drilling equipment.

During the exploitation phase of MAR, the potential impact on geological conditions can be predicted mainly for the possibility of dissolution and precipitation of mineral phases in the unsaturated zone. Considering this issue, a detailed prognosis will be possible after applying geochemical modelling based on the results of studies of the unsaturated zone. However, preliminary results of the new, detailed studies, as well as the experience from observations of the currently operating MAR system, indicate that the impact of the proposed extension of MAR is not significant for geochemical changes in the unsaturated zone. Mineralogical investigations of the unsaturated zone in the area of the planned project, as well as of the sediments from the currently operating infiltration ditches, showed a dominance of the mineral phase of quartz, which indicates a negligible potential for dissolution and geochemical precipitation of mineral phases to occur.

### 4.1.3. Impact on the soil

Risks of soil quality disturbance could occur in emergency/catastrophic situations where contaminants would enter the soil, e.g. from motor vehicles and drilling equipment, during the construction phase of the MAR.

At the stage of the investment implementation, the impact on the soil will be noticeable, as soil removal (excavation) will be necessary for the place(s) of the planned ditch(es) and in the vicinity of the planned wells. The impact on soils concerns small areas in the implementation phase and although it will be permanent, it is negligible.

There will be no impact on the soil during the exploitation phase of the well field.

### 4.1.4. Impact on the water

#### 4.1.4.1 Impact on surface water

To analyze the potential impact on surface water quality and quantity, particular attention was paid to the characteristic flows in the Dunajec River, from which the water is pumped to the current Świerczków well field and will also be pumped to the planned extended area. The current water abstraction situation at the existing well field was also analyzed. The data contained in the report D.T3.4.1 “Report on the desk analysis of the pilot feasibility study for MAR deployment in porous aquifers located near industrial sites on contamination of aquifers” were used for the analysis of an impact on surface water (DEEPWATER-CE, 2021a).

The flow rate of the Dunajec River at the water gauge station Zgłobice, located at km 38+560 of the river’s course, in the years 1981-2017 was: the lowest 8.8 $m^3/s$, average low 18.7 $m^3/s$, average annual mean 77.4 $m^3/s$, average high 882 $m^3/s$, the highest 2510 $m^3/s$, while in the years 2016-2020: the lowest was 20.8 $m^3/s$, average 80.07 $m^3/s$, the highest 1030 $m^3/s$. The calculated base flow for the 2016-2020 period ranged from 20.8 to 124 $m^3/s$ with a mean value of 40.44 $m^3/s$.

The amount of water from the Dunajec River pumped to supply the infiltration ditches at the Świerczków well field currently varies from about 3200 $m^3/d$ (133 $m^3/h$) to about 4900 $m^3/d$ (about 204 $m^3/h$), which is about 40% to over 60% of the total water abstraction from the Świerczków well field.

Concerning the lowest, the mean, and highest annual flow rate of the Dunajec River at the Zgłobice water gauge station for the period 1981-2017, the highest water withdrawal constitutes respectively: 0.64%, 0.07%, and 0.002% of the river flow rate. With respect to the lowest, the mean, and highest annual flow rate of the Dunajec River at the Zgłobice water gauge station in 2016-2020, the highest water abstraction from the Dunajec River constitutes respectively: 0.27%, 0.08%, and 0.006%.

The already operating Świerczków well field has a water permit based on the decision of the President of Tarnów dated 13 June 2013, valid until 13.06.2033.

According to the well field permit, water can be drawn at:

- maximum hourly volume rate: 380 $m^3/h$;
- daily average amount: 8,500 $m^3/d$;
- maximum annual volume: 3,100,000 $m^3/year$.

It should be noted that the aforementioned water permit refers to both groundwater and water originating from the MAR (infiltration ditches and river bank filtration). If we compare the water abstractions permitted under the water permit with the flow rate of the river Dunajec, we obtain the following proportions.

With respect to the lowest, annual average and highest flow rate of the Dunajec River at the water gauge station Zgłobice in the period 1981-2017, the maximum hourly amount (380 $m^3/h$) constitutes respectively: 1.20%, 0.13%, and 0.004% of the flow rate in the river. With respect to the lowest, mean annual, and highest flow rate of the Dunajec River at the Zgłobice water gauge station during 1981-2017, the mean daily amount (8,500 $m^3/d$) represents respectively: 1.10%, 0.13%, and 0.004% of the river flow rate. With respect to the lowest, mean annual, and highest flow rate of the Dunajec River at the Zgłobice water gauge station during 1981-2017, the maximum annual amount (3,100,000 $m^3$/year) represents respectively: 1.12%, 0.13%, and 0.004% of the flow rate in the river. Similar results would be obtained for the lowest, mean annual, and highest flow rate of the Dunajec River at the Zgłobice water gauge station in 2016-2020.

The analysis of the potential impact on the quantity and quality of surface water during the operation of the Świerczków MAR led to the conclusion that it is insignificant and that the water abstraction from the Świerczków well field does not exceed 1.5% of the Dunajec flow rate in the most unfavorable variant, which will not result in adverse changes in surface water quality.

In the 1970s, after locating the fly ash waste disposal site within the well field area and constructing a sheet pile wall in the southern part of the well field, the role of water supply for the infiltration ditches was taken over by Nitrogen Plant, currently, Grupa Azoty S.A. Surface water drawn from the Dunajec river is passed through settling ponds before use for MAR, which significantly reduces the amount of suspended solids, which in turn reduces the clogging of infiltration ditches. The infiltration ditches are cleaned approximately every 3-5 years.

#### 4.1.4.2 Impact on groundwater

At the stage of implementation of the designed MAR system, the negative impact is possible only in case of equipment failure or improperly conducted drilling works. Ensuring the appropriate technical level of ground and drilling works and applying occupational safety rules practically eliminates any threat to groundwater at the stage of project implementation.

During the exploitation phase, a change of hydrodynamic conditions in the area of the designed MAR system will certainly occur. Groundwater will receive additional recharge from surface water supplied to the infiltration ditches and partly from the IBF from the Dunajec River. Forecasting of the hydrodynamic conditions, groundwater flow directions, and the amount of water resources in the capture zone of the designed MAR system (including additional recharge) will be possible on the basis of the numerical hydrodynamic model under development, based on detailed studies performed as part of the DEEPWATER-CE project. Long-term observations for the currently operating MAR system of the Świerczków well field indicate that the application of MAR to the designed well field will definitely increase the groundwater resources. Moreover, it will improve the quality of the extracted water as well as limit the inflow of polluted groundwater from industrial zones.

The resources for the existing Świerczków well field are formed mainly by surface water infiltration (infiltration from ditches and IBF). According to the appendix to the well field documentation, it constitutes about 88% of the total abstracted water, i.e., about 7000 $m^3/d$ for the production rate of about 8000 $m^3/d$ (Wojtal, 2012). The results of previous solutions and observations indicate that for the designed well field it is possible to achieve an increase in resources that will satisfy the demand by developing an appropriate MAR system.

In terms of protecting the water from pollution, long-term observations indicate that proper management of water table levels in the infiltration ditches will create a protective hydrodynamic barrier to limit the inflow of contaminated groundwater from the industrial zone where elevated values of electrical conductivity, ammonium ion, nitrate, chloride, sodium or sulfate are observed. At the same time, the process of groundwater recharge from the Dunajec River using infiltration ditches clearly improves the quality of groundwater, which is documented by the results of investigation for the existing MAR system (DEEPWATER-CE, 2021c).

Assessment of the potential for groundwater contamination with emerging contaminants is possible on the basis of detailed studies performed as part of the DEEPWATER-CE project (DEEPWATER-CE, 2021c). The results of these studies showed that no or very low concentrations of pharmaceuticals were found in water abstracted by the existing Świerczków well field, while they were found in the surface water recharging the infiltration ditches. It can be expected that the use of the MAR system will reduce the migration of emerging contaminants to groundwater abstracted in the future by the proposed well field.

### 4.1.5. Impact on the landscape

Expansion of the well field will cause changes in the existing landscape. The northern area of the Świerczków well field (currently undeveloped) will become similar in landscape terms to its southern part, where infiltration ditches, wells, and concrete well casings are located. Transformation of the landscape at the stage of project implementation will be temporary and permanent at the stage of the well field operation. Due to the small size of the concrete well casings (5 wells planned) and their greenery surroundings, they are neither significant nor destructive for the landscape. The planned infiltration ditch (approx. 300 m long, approx. 10 m wide at the ground surface, and approx. 3 - 4 m deep) will change the hydrographic system of the area and alter its existing landscape functionality.

### 4.1.6. Impact on the cultural heritage

The project related to the construction of the well field will not affect the cultural heritage as it does not interfere with the area of this nature.

### 4.1.7. Impact on the biodiversity

The stage of the project implementation will be limited to carrying out works on small areas of the site which is currently used as a grassland. It is regularly mowed, which limits the processes of natural succession within it. It is a potential feeding ground for invertebrates, amphibians, birds, and bats.

If protected species are found, applying an appropriate schedule and environmental supervision that performs active protection tasks will virtually eliminate the negative impact of the planned project on biodiversity.

Due to the green land use and limited human access at the exploitation stage, the negative impact on biodiversity will be negligible. A positive impact can be expected due to the creation of infiltration ditches. The appearance of water in a green area with natural vegetation will create new ecological niches, particularly attractive to invertebrates, amphibians, birds, and bats.

The issue that cannot be ignored is the impact of the surface water withdrawal site from Dunajec which is supplying MAR. Such site is already in operation on the Dunajec River, south of the Świerczków well field (Fig. 3.2). The surface water withdrawal site poses a potential risk of aquatic organisms, particularly fish, getting into the pump installations if appropriate safeguards were not in place. This aspect has not been studied as part of the project, therefore, at the stage of planning the expansion of the MAR, there are a number of technical solutions to minimize the access of fish to the inlet, and thus protect aquatic organisms from injury and killing. In the case of larger surface water abstraction sites, behavioral barriers are preferred, such as louvre barriers, light, and acoustic barriers, electrical barriers, curtains made of air bubbles forced into the water, curtains made of a strong stream of water, and curtains made of suspended chains (Pawłowska, Zielina, 2015). The impact on aquatic organisms through the MAR supply station is an active impact at the stage of MAR functioning and is already taking place. At the moment, due to the lack of technical assumptions, it cannot be determined whether the existing surface water withdrawal site will be sufficient to supply the MAR, whether it will require expansion.

### 4.1.8. Impact on the protected areas

Due to the specific nature of the planned project, impacts on protected areas may be expected only in the areas bordering the planned project – i.e. the Natura 2000 PLH120085 Dolny Dunajec, which is a part of the ecological network Natura 2000. However, as shown in subchapter 4.1.4.1., the surface water abstraction for MAR is very small compared to the flow in the Dunajec River, and therefore, it can be assumed that there will be no negative impact of MAR on NATURA 2000 sites.

The remaining protected areas are within a few kilometers of the planned engineering works, therefore the authors do not predict the impacts on these areas. The impact on protected areas Natura 2000 PLH 120085 is described in section 4.1.9.

### 4.1.9. Impact on the ecological network

Due to the specific nature of the planned project, impacts on ecological networks and protected areas may be expected only in the areas bordering with the planned project.

The Natura 2000 PLH120085 Dolny Dunajec area is located in the immediate vicinity of the existing and planned well field. The subject of protection here is: habitat 3220 - stones and gravel beds of mountain streams and fish populations: *Aspius aspius*, *Barbus carpathicus*, *Cottus gobio and Lampetra planeri*. From a formal point of view, it is important to determine the impact of the planned project on the subject of protection and the integrity of the Natura 2000 network.

Due to the already existing surface water withdrawal site, at the moment there are no plans to interfere with the riverbank zone outside the area of the existing site, therefore there will be no impacts on the stones, gravels, and pebbles of mountain streams that are to be protected.

There is no information on the current impact of the existing surface water withdrawal site on the ichthyofauna, including the protected species mentioned above. There is no doubt that in case of undertaking investment activities will be an opportunity to implement/modernize the protection of the surface water supplying site against the access of ichthyofauna in accordance with the current state of knowledge.

During the field works, beaver (*Castor fiber*) was found in the planned investment area. The presence of the fire-bellied toad (*Bombina bombina*) and the great crested newt (*Triturus cristatus*) cannot be ruled out - however, these species are not under protection in PLH120085 site. In the case of amphibians, active herpetological protection at the implementation stage practically eliminates threats to these species, and the appearance of stagnant waters will practically improve the habitat conditions of amphibians.

Summing up, the analysis of the standard data form shows that in terms of the impact on the Natura 2000 network, it is important to eliminate potential threats to ichthyofauna from the surface water withdrawal site.

Due to the significant distances from other protected areas, no impact of the planned MAR is expected.

### 4.1.10. Socio-economic impacts

The influence of the MAR site on the socio-economic conditions will be positive at both stages of the project (implementation and exploitation). For the time of the well field expansion, the supply on the market of specialist design and execution works - earth (excavation, construction), geological, installation - will be increased. Based on the previous experience, we assume that the expansion of the well field will allow drawing water of similar quality as now. The water from the Świerczków well field, as opposed to surface water, does not require complicated purification processes, so it is a “cheap water”, which requires only protection against secondary contamination in the water supply network through chlorination.

Increasing the water capacity of the well field will result in some reduction in the amount of surface water abstracted from the Dunajec River. Currently, Tarnów Waterworks is planning investments in renewable energy. These include a photovoltaic power plant at the Świerczków site and plans to connect the well field with the Wastewater Treatment Plant via a power cable, where the company also plans to build a photovoltaic power plant. In addition, the company already produces electricity from biogas obtained from the fermentation of sewage sludge. The use of electricity from renewable sources for the purpose of water abstraction will reduce water exploitation costs, which, with the current increase in energy prices, is an important element influencing the social and economic conditions. Maintaining relatively low water prices directly affects the quality of life of Tarnów agglomeration residents. Increasing the capacity of the Świerczków well field also means diversification of this vital resource. It ensures greater security of water supply (in case of failure of other surface and groundwater sites) and the possibility of selling water to neighbouring water supply systems or connecting water supply systems to increase the stability of water supply.

At the operation stage of the expanded well field, the key impact is to expand access to water for the population within the transmission network and for new groups that will come within the reach of the network if it is expanded.

## 4.2. Cumulative impacts

The presented analysis indicates that the key issue of cumulative impacts is the impact on the surface and groundwater of their users. These are Tarnów Waterworks and Grupa Azoty S.A. An appropriate tool for analyzing cumulative impacts are groundwater flow models that allow the prediction of groundwater hydrodynamic parameters under different user scenarios. The model is currently under calibration so results from it can be used later.

Among the cumulative impacts that may significantly influence the Świerczków well field, two major factors should be mentioned: the impact of the industrial zone of Grupa Azoty S.A. and other companies in the industrial zone, and the impact of the Dunajec River. In terms of cumulative impacts associated with the enhancement of the MAR functioning, which are directly affected by the industrial zone , it is necessary to point out, among others, the reduction of the industrial pressure, e.g. liquidation of the coal stockpile in the future (switching the CHP plant to a more environment-friendly fuel), remediation of industrial areas, reduction of the pressure on the environment, etc. Conversely, weakening of MAR may occur in case of increasing industrial anthropopression.

The cumulative impacts associated with enhancing MAR performance that are directly affected by the Dunajec River are the river's water quality and the flow rate, which directly affect the water level in the riverbed. The improvement of water quality in the river will obviously influence the increase of MAR efficiency and vice versa. The experience from the well field operation allows us to look positively into the future. Changes in the water level of the Dunajec River that contribute to bottom erosion and a decrease in the proportion of bank and bottom filtration are the processes that can undermine the MAR functioning. In addition, aggregate mining in the Dunajec valley has some influence on the channel dredging process.

The cascade of hydroelectric power plants downstream of the Dunajec River and the damming up of the river at the level of the well field Świerczków and surface water withdrawal site can be a beneficial factor.

Obviously, the above-mentioned cumulative impacts from the industrial areas and the Dunajec River are interrelated and may reinforce, weaken or balance each other.

## 4.3. Overview of recognized impacts

The synthetic characteristics of the planned MAR in the exploitation stage are presented in Table 2. The table also distinguishes the impact on biodiversity on land and in flowing water. This is due to different effects on the individual components - mostly positive for terrestrial fauna and negative for aquatic fauna. Separations have also been introduced for individual elements included in the standard data form of the Natura 2000 area: for fish species subject to protection, for protected habitats, and for protected species in terrestrial areas.

The following table shows the grade for each particular impact.

**Table 4.1** Overview of recognized impacts - Poland

| Grade | Description |
|---|---|
| -1 | Negative impact |
| 0 | There is no impact |
| 1 | Positive impact |

| ENVIRONMENTAL COMPONENT | IMPACT CHARACTERISATION | | | |
|---|---|---|---|---|
| | DIRECT/ INDIRECT/ CUMULATIVE | SHORT-TERM/ LONG-TERM | POSITIVE/ NEUTRAL/ NEGATIVE | GRADE |
| *Climate* | *indirect* | *long-term* | *neutral* | *0* |
| *Geology* | *indirect* | *long-term* | *neutral* | *0* |
| *Soil* | *indirect* | *long-term* | *neutral* | *0* |
| *Surface water* | *direct* | *long-term* | *neutral* | *0* |
| *Groundwater* | *direct* | *long-term* | *positive* | *1* |
| *Landscape* | *direct* | *long-term* | *neutral* | *0* |
| *Cultural heritage* | *component not present in the study area* | | | |
| *Biodiversity on land* | *indirect* | *long-term* | *neutral* | *0* |
| *Water biodiversity, including ichthyofauna* | *direct* | *long-term* | *neutral* | *0* |
| *Protected areas* | *component not present in the study area* | | | |
| *Natura 2000 area - habitat 3220* | *indirect* | *long-term* | *neutral* | *0* |
| *Natura 2000 area - ichthyofauna* | *direct* | *long-term* | *negative*/neutral* | *(-1)*/0* |

| | | | | |
|---|---|---|---|---|
| *Socio-economic conditions* | *indirect* | *long-term* | *positive* | *1* |

Grade description: -1 negative impact; 0 no impact; 1 positive impact

***** - impact characterization when the proposed active protection will not be applied.

The liquidation phase in practice means demolition works, decommissioning of individual wells and leveling of the area. The impact of these works is comparable to the impacts at the stage of project implementation.

It is difficult to unequivocally assess the impact of the decommissioning stage on the socio-economic effects - apart from a temporary impulse on the service market, the decommissioning of the well field means excluding the aquifer from use for the inhabitants and the need to find an alternative source of water supply. However, on the other hand, it frees up the land for other needs.

In the event of liquidation of the infiltration ditches and the accompanying grasslands, potential natural habitats will be lost, which will have a negative effect on biodiversity.

## 5. Conclusion and summary / Poland

The aim of this preliminary Environmental Impact Assessment was to evaluate the environmental effects of a potential expansion of the existing MAR system in the Polish pilot site, located in the Tarnów area. The pilot site is located in the immediate vicinity of the Świerczków well field, which has been in operation for several decades as a MAR system. The study focused on two types of MAR: induced (river) bank filtration (IBF) and infiltration ditches, supplied with water from the Dunajec river. The potential application of the designed MAR facilities in this area would contribute to the increase of groundwater resources and to the improvement of its quality, as confirmed by the results of long-term observations of the currently existing MAR system of the Świerczków well field and the results of field studies carried out within the DEEPWATER-CE project.

The conducted preliminary assessment of the impact of planned MAR expansion on climate, geology, soil, landscape, and surface water showed that there is little or no negative impact on these elements of the environment. On the other hand, a positive significant impact on groundwater is anticipated, with an improvement in groundwater quality and an increase in usable resources. It is highly likely that the planned expansion of the MAR system will not have a negative impact on habitat biodiversity in the study area. Application of active protection measures will practically eliminate the negative impact on legally protected species, provided their presence is confirmed by detailed inventory in the future. In terms of impact on the Natura 2000 network protection objectives, threats to ichthyofauna were identified from the surface water withdrawal site on the Dunajec River, from which water would be drawn to supply the infiltration ditches. Detailed ichthyological reconnaissance and technical inventory will allow to propose the measures minimizing the threat to ichthyofauna due to the operation of the surface water withdrawal site, which supplies the MAR system. The application of currently used and improved barriers protecting ichthyofauna from inflow to the water inlet to the pumps will practically eliminate the possible threat in this aspect.

# SLOVAKIA

The aim of this report is to present the preliminary Environmental Impact Assessment (EIA) of the Slovak pilot site. The assessment is focused on the potential impact of the MAR scheme on the environment. Within the Slovak pilot site, which is situated in Žitny Ostrov, the impact of the recharge dam was evaluated.

In the pilot area, roughly delineated by the towns of Samorin, Dunajská Streda, and Gabčíkovo, there is a network of irrigation channels equipped with technical tools (sluices/gates) for regulation of water flow. The existence of the sluices on primary channel S VII (Gabčíkovo-Topoľníky channel) and secondary channels A VII (Vojka-Kračany,) and B VII (Šuľany-Jurová,) is a crucial point to create MAR type recharge dam, i.e. accumulation of water between closed sluices.

The pilot area is agricultural land. It is located in the Slovak part of the Danube Basin, in the north-western part of the Pannonian Basin System. The sedimentary in-fill of the depression is represented by Neogene and Quaternary sediments. The thickness of Neogene sediments in the Gabčíkovo-Győr depression reaches more than 8,500 m (Kilényi & Šefara, 1989; Hrušecký, 1999), and is overlain by up to 320 m thick Quaternary sedimentary cover (Šujan et al., 2018). Benková et al. (2005) estimated the average values of the hydraulic conductivity coefficient of Quaternary gravels and sandy gravels in the wider area of the pilot site on $2.91*10^{-3}$ m/s and the transmissivity coefficient on $2.96*10^{-2}$ $m^2/s$. The Quaternary sediments have mostly the phreatic groundwater table.

The evaluation is focused on the channel Vojka-Kračany (AVII), where already 5 sluices are in operation. Construction of three new slices on the channel was proposed based on modelling results. Construction of the new slices could get a recharge of more than 32,789 $m^3/d$ during the dry year. The impact of MAR on both, construction and operation phases was considered.

In Slovakia, EIA is performed based on the legal regulations contained in next legal acts:

- the Act No. 24/2006 Coll. on environmental impact assessment and on amendments and supplements to certain acts applies, which entered into force on 1st February 2006. It regulates the process of expert and public assessment of expected impacts of strategic documents on the environment prior to their approval and impact assessment of proposed activities before their permission under special regulations. Published in Journal of Laws 13/2006.
- Act 359/2007 Coll. on the prevention and remedying of environmental damage and amendments to some acts.

# 2. Project description - Managed aquifer recharge

## 2.1. MAR technology

As a part of the project, a pilot site at the "Žitný Ostrov" area was selected for a detailed study, where drainage canals with functional sluices are already present. By closing the sluices in the channel, several MAR recharge dams are created in the channel.

The assignment aimed to determine how much water from the channels can infiltrate into the surrounding environment during full operation of the sluices and thus improve the groundwater resources of the first aquifer intended for irrigation purposes. After verifying the current state of the pilot site, it was proposed to build three more sluices on the Vojka - Kračany channel, which would increase the level in the channel and at the same time increase the infiltrated amount of water into the aquifer, which was verified by modelling.

The proposed sluices would be placed as follows (Fig. 2.1 vertical red lines):

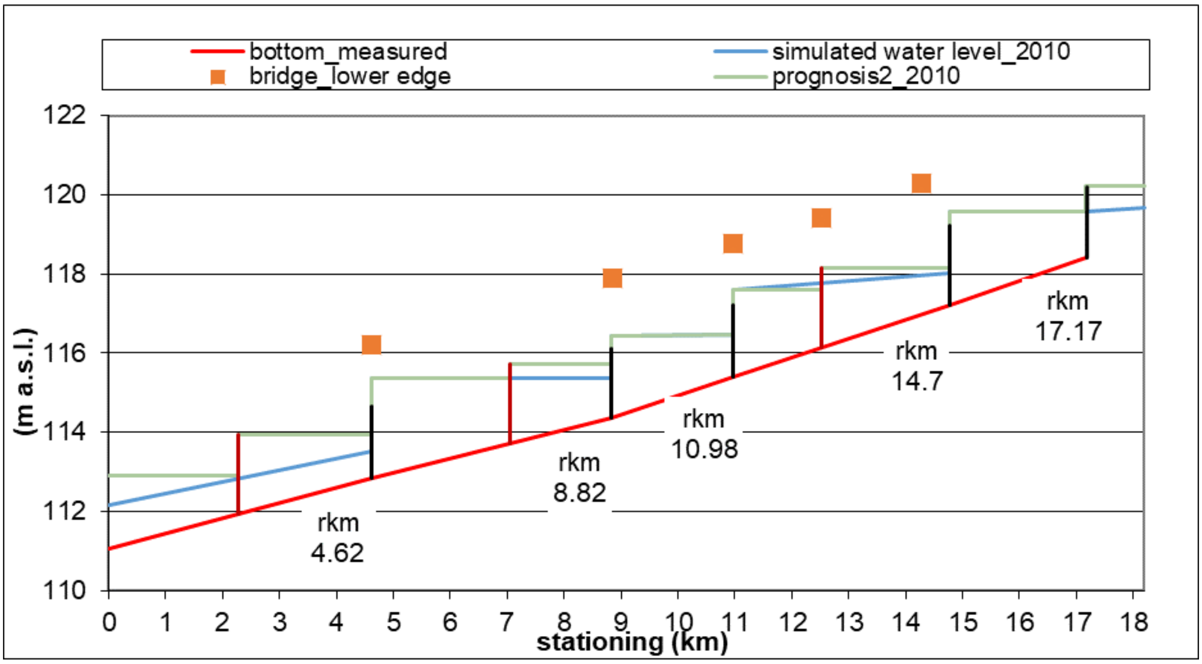


Fig. 2.1 Longitudinal profile of the A VII drainage channel – simulated water level and prognosis 2 (2010)

Based on the modelling results, building another 3 flood-gates will increase the water level in channels A VII, and thus the volume of 32,789 $m^3.d^{-1}$ will be replenished along the entire length of the channel during a dry year (based on the year 2018).

The EIA assessment was focused on the Vojka-Kračany (A VII) channel and on the possible impact of three new flood-gate constructions. These sluices could supplement five existing ones. The new gates are proposed at the rkm 2.270, rkm 7.060 and rkm 12.530 with a height of 1.6 m for each sluice. All three sluices are proposed to be built within the existing bridge constructions, as is usual for older sluices. This technical solution reduces the cost of building new access to main roads.

# 3. Environmental setting of the proposed project location

## 3.1. Site description

The Žitný Ostrov area is located in the south-western part of Slovakia, on the border with Hungary. In the south-west, its boundaries are formed by the banks of the Danube, in the north by the branches of the Little Danube, and on a short stretch in the east, it is bounded by the Váh River (Fig. 3.1). The territory belongs geographically to the Podunajska (Danube) Lowland.

The pilot area is roughly delineated by the towns of Šamorín, Dunajská Streda and Gabčíkovo. The borders of the pilot area were set for modeling, where the primary channel S VII (Gabčíkovo-Topoľníky channel) and secondary channels A VII (Vojka-Kračany,) and B VII (Šuľany-Jurová,) were considered as a source for groundwater recharge. The dense network of irrigation channels equipped with technical tools (sluices, barriers) for regulation of water flow is a crucial point to create recharge dam MAR type, i.e. accumulation of water between closed sluices.

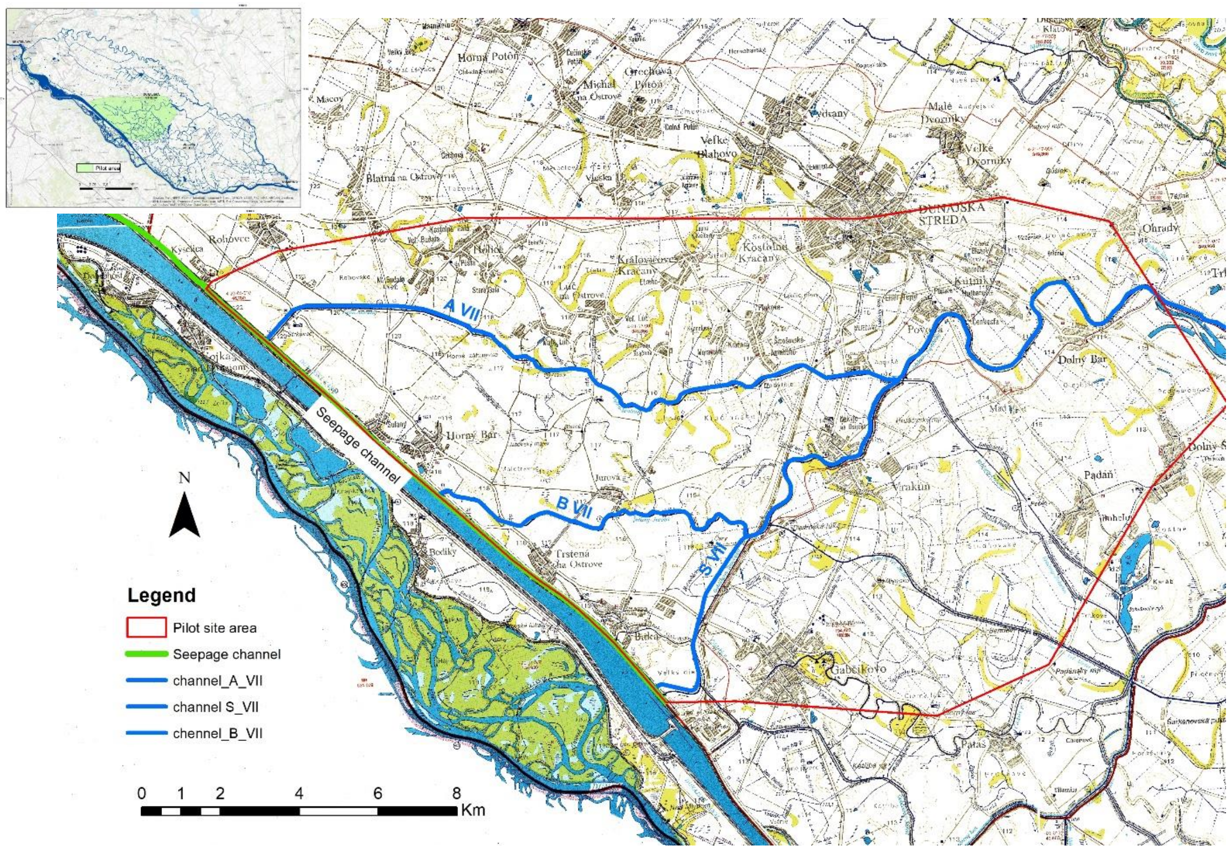


**Figure 3.1** Pilot site area in Žitný Ostrov, channel Vojka-Kračany (A VII) is relevant for EIA assessment (*Výskumný ústav vodného hospodárstva, 1999*).

### 3.1.1. Proposed MAR site in relation to other spatial interventions

As the planned MAR solution is located in the existing infrastructure of the irrigation channels, which is managed by the Slovak Water Management Enterprise (SWME), and thus the state, we do not anticipate any constructions directly in its territory that could interfere with the construction of additional sluices and recharge dams. The area is intensively used for agriculture and the Vojka-Kračany channel itself can already be used by local farmers for irrigation in the period from March to September, when the gates are closed.

Completing the other three sluices will thus dense up the existing network, and will increase the water level in the channel. Consequently, the groundwater level in this area will rise which is a positive aspect for the local farmers. The channel represents a linear construction and passes through several cadastral areas. However, it is always in the outskirts of the municipalities, so we do not expect any construction in the vicinity of populated areas. Moreover, the channel itself and the adjacent 2m area on one side belong to the state, so there is the existing access road.

### 3.1.2. Compliance with valid spatial planning documentation

The channel crosses next cadastral areas: Povoda, Dunajská Streda Vrakúň, Kostolné Kračany, Kraľovičove Kračany, Lúč na Ostrove, Holice, Blatná na Ostrove, Rohovce.

Within the locally governed territories of the municipalities, the canal is located in their extra-urban area, where no construction activity is proposed, and the wider area is intended for agricultural use and forestry. The spatial development plans of the municipalities are subordinated to the spatial development plan of the Trnava region.

The proposal is in accordance with the principles of the spatial development plan of the Trnava region. New sluices are designed for construction in the following cadastral areas: Kostolné Kračany (2.27 rkm bridge – flood-gate construction, field road, accessible), Kraľovičove Kračany (7,060 rkm - near a bridge – flood-gate design) / Lúč na Ostrove (7,060 rkm – near a bridge – flood-gate design) and Holice (third flood-gate - 12,530 rkm – near a bridge) – see Fig. 2.1.

## 3.2. Climate characteristics

The climatic conditions of the area are determined primarily by geographical factors, by its latitude, longitude, and altitude. According to Končekʼs climate classification scheme, (Fig. 3, left) the whole pilot site area is located in a warm region. The pilot site area is situated in a warm, very dry sub-region with mild winter. The average annual air temperature (for the period 1961-2010) is higher than 10°C. During spring and autumn, the average air temperature is also higher than 10°C (Fig. 3.2, right). The average air temperature in summer (April to October) ranges from 19 to 20°C. Average air temperature during the hottest month – July is between 21.0°C to 21.5°C and during the coolest month – January is between -1°C to -0.5°C (Climate Atlas of Slovakia, 2015).

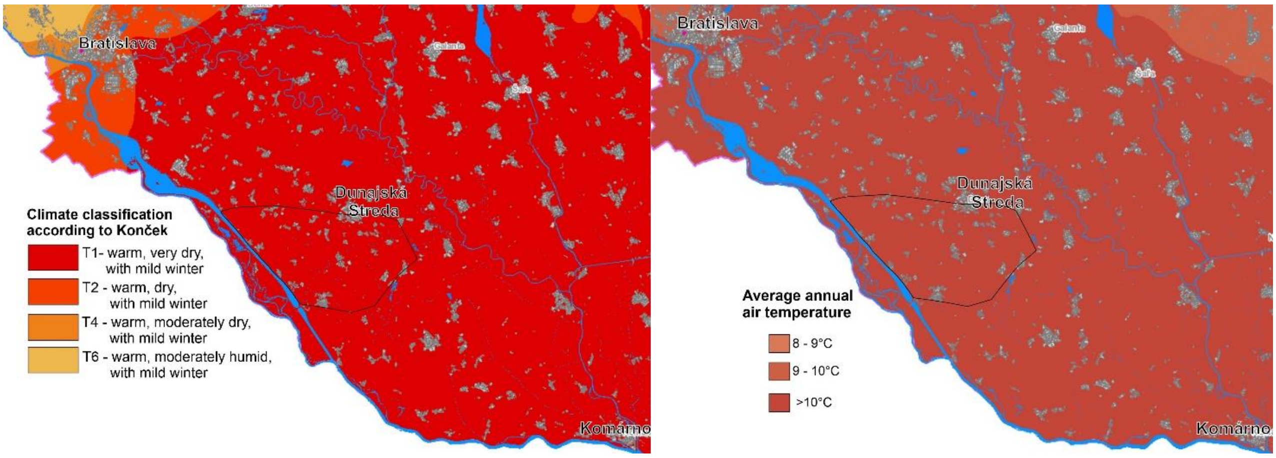


**Figure 3.2** Left: Climate classification according to Konček; Right: Average annual air temperature (Climate Atlas of Slovakia, 2015)

Total annual precipitation (for the period 1981-2010) varies between 551-600 mm in the whole area of the A VII channel (Fig. 3.3, left). Total precipitation in the summer period (April-October) varies in the range of

307-350 mm. The lowest values are typical for winter, ranging between 20 and 40 mm. The average number of snowy days in the winter season (November-April) varies between 21 and 30 and the snow cover stays from 31 to 45 days. The mean annual potential evapotranspiration (for the period 1961-2010) is higher than 700 mm (Fig. 3.3, right) (Climate Atlas of Slovakia, 2015).

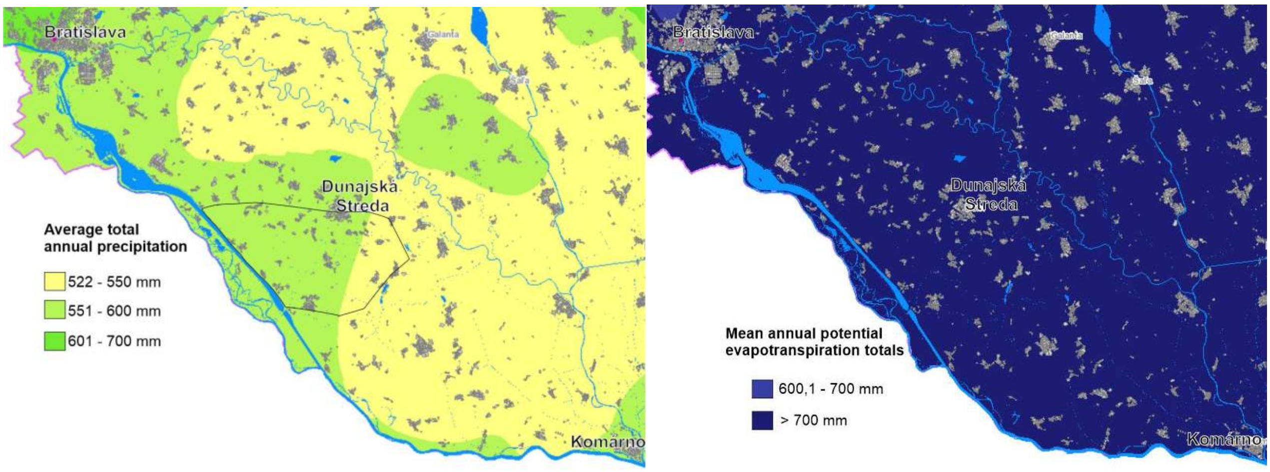


**Figure 3.3** Left: Average total annual precipitation; Right: Mean annual potential evapotranspiration totals (Climate Atlas of Slovakia, 2015)

## 3.3. Geological settings

The pilot site is located in the Slovak part of the Danube Basin, occurring in the north-western part of the Pannonian Basin System. The shape of the Slovak part of the Danube Basin is the result of a complex process associated with polyphase back-arc rifting, post-rift thermal subsidence, and basin inversion (Šujan et al., 2021). The sedimentary in-fill of the depression is represented by Neogene and Quaternary sediments. The thickness of Neogene sediments in the Gabčíkovo-Győr depression reaches more than 8 500 m (Kilényi & Šefara, 1989; Hrušecký, 1999), and is overlain by up to 320 m thick Quaternary sedimentary cover (Šujan et al., 2018).

Quaternary sediments are the most relevant for the MAR solution. The upper Miocene and Pliocene sediments are covered by a thick accumulation of fluvial Quaternary succession. The lower-Pleistocene sediments (Donau to Günz) are represented by cyclically alternating sandy - gravely layers intercalated by layers of silty clays. Mindel sediments create the basal part of the large fluvial fan of the Danube built by gravels, sandy gravels, and sands. The thickness of the sediments reaches up to 100 m in the area of the Gabčíkovo depression. Riss sediments are separated from the Mindel ones by the 3 – 8 m thick, mostly discontinuous layer of clayey-sandy silts representing the Holstein interglacial. The Riss sediments with a thickness up to 50 m are represented by coarse gravels, sandy gravels, and coarse-grained sands. The upper-most Pleistocene - Würm sediments have a thickness of over 50 m, being built mostly of sandy gravels. The upper-most (Holocene) layer consists of alluvial sediments – silts, silty sands, sandy gravels to gravels (Maglay et al., 2017). The flood silty sediments cover the whole Holocene sedimentary complex. Fluvio-organic, organic, and palustric sediments occur in the buried ox-bow fillings. The recent anthropogenic deposits occurring in the urban areas represent the specific type of sediments.

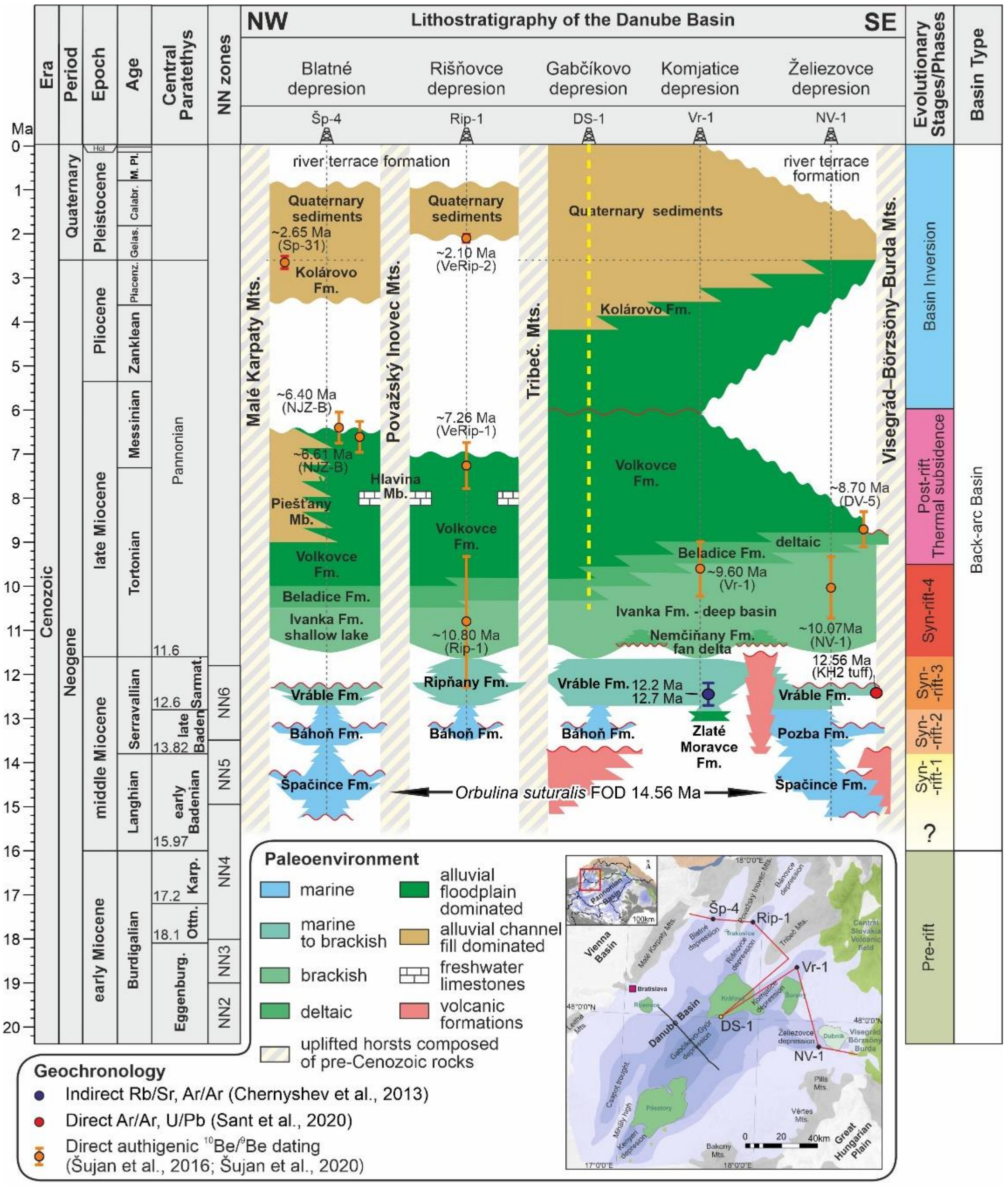


**Figure 3.4** Lithostratigraphic scheme of the Danube Basin according to Šujan et al. (2021)


**Figure 3.5** Geological map 1:50 000 (http://apl.geology.sk/gm50js)

### 3.3.1. Tectonic relations

The pilot site is divided into two tectonic blocks, which are separated by a pronounced normal fault with a NW-SE trend (Fig. 3.6). This fault dips towards the southwest and was active during the lower Pliocene (Maglay et al., 1999). The activity at this fault probably took place due to differential compaction connected to preexisting Miocene extensional tectonics (Šujan et al., 2021).

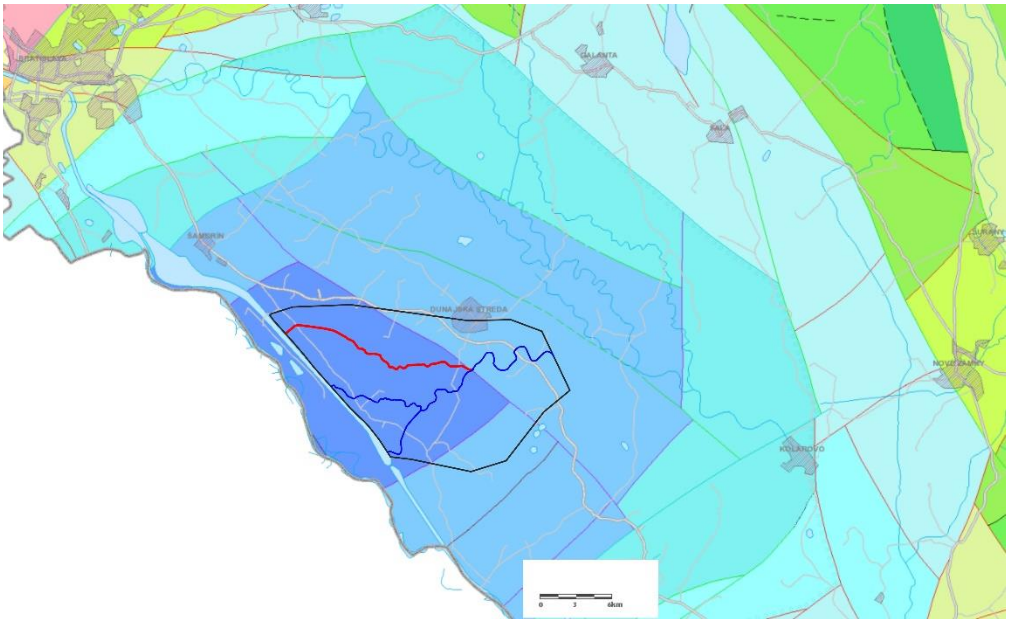

**Figure 3.6** Neotectonic map of Slovakia 1:500 000 (J. Maglay et al., 1999)

### 3.3.2. Seismic features

Although in Slovakia there are areas with moderate seismic hazard, the pilot site is situated in a space with low seismic hazard (Fig. 3.7)

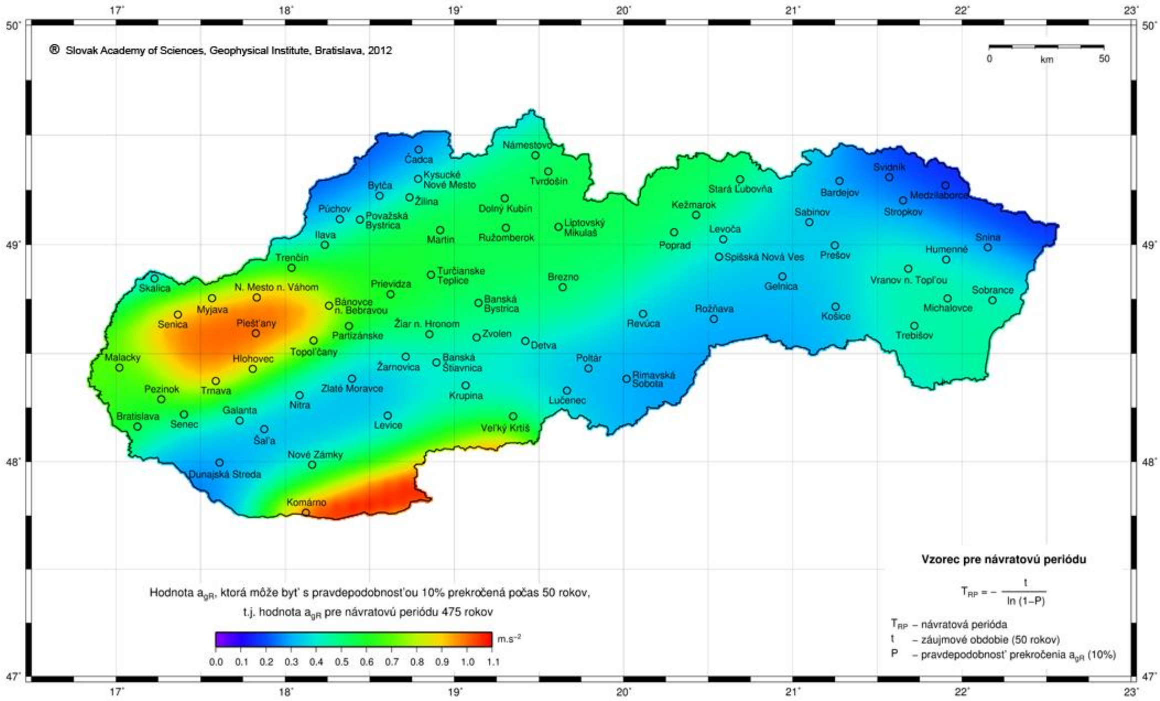


**Figure 3.7** Map of seismic hazard for the territory of Slovakia in terms of peak ground acceleration on rock site - 475-year return period (SAV, 2012) (10% probability of exceedance in 50 years, 475-year return period)

## 3.4. Soil

Žitný ostrov is one of the best areas for agricultural production due to favorable soil and climatic conditions. The occurrence of soil types in the pilot site is related to utilized agricultural land (registered in LPIS-Register of agricultural land). The map (Fig. 3.8) and Table 3.1 show that Happlic Chernozems and Mollic Fluvisols (together with Mollic Gleysols) dominate in the area of interest.

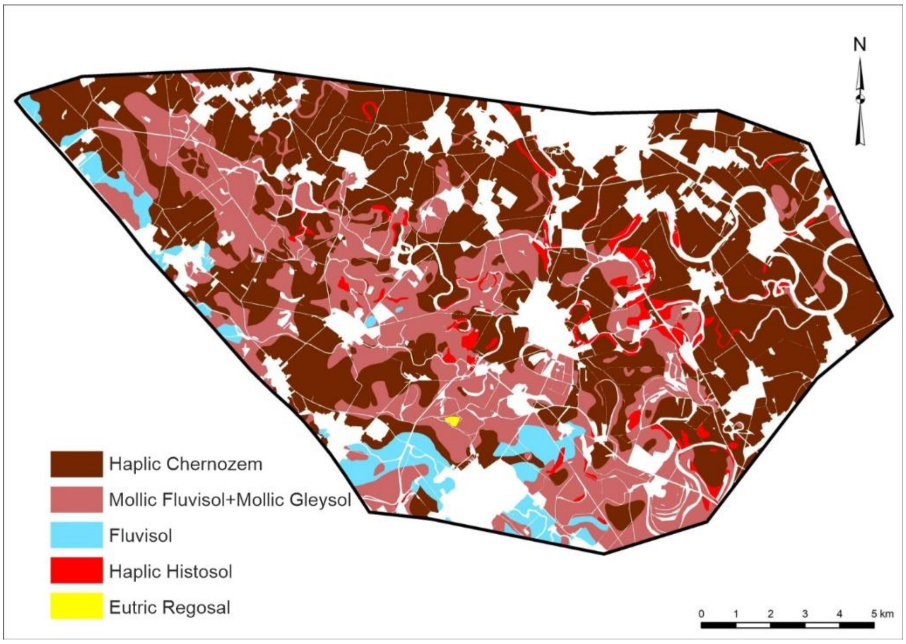


**Figure 3.8** Pilot site area in Žitný Ostrov (source: National Agricultural and Food Centre – Soil Science and Conservation Research Institute in Bratislava)

Table 3.1 Soil types present at the pilot area

| **Main soil types** | **Soil subtypes** | **Share (%)** |
|---|---|---|
| Haplic Chernozem | | 60.04 |
| Mollic Fluvisol + Mollic Gleysol | Mollic Fluvisol | 25.55 |
| | Mollic Gleysol | 5.74 |
| Fluvisol | Eutric Fluvisol | 5.01 |
| | Gleyic Fluvisol | 0.10 |
| Haplic Histosol | | 3.52 |
| Eutric Regosol | | 0.05 |

# 3.5. Water

## 3.5.1. Surface water

The Danube River created an extensive branch system on the territory of the Žitný Ostrov. The natural character of the river was altered by embankments and equalizing parts of the watercourse. This has also changed the natural hydrological conditions: the Danube’s branches and meanders were separated from the main stream by the embankments. The current hydrological conditions are strongly affected by the construction of the Gabčíkovo hydropower water structure (VD Gabčíkovo) (Fig. 3.9).

The Gabčíkovo-Topoľníky channel, which stretches in our pilot site area is interconnected with the Danube River by an inflow structure and leads to the Klátovský branch of the Little Danube (Malý Dunaj). According to hydrological distribution, the area belongs to the catchment of the Váh River (No.4-21) and sub-catchment of the Little Danube - Malý Dunaj (No.4-21-17, from Čierna voda to estuary). The south-western boundary of our pilot site area is situated on the border of two catchments: Danube and Váh Rivers, formed by seepage channel on the left side of the Hrušov Reservoir.

According to the SR Government Regulation No 211/2005 Coll. the Gabčíkovo – Topoľníky (S VII) channel and also its tributaries, channels Vojka – Kračany (A VII) and Šuľany – Jurová (B VII) are considered as significant water management watercourses.

Based on the second River Basin Management Plans (2016-2021), one artificial surface water body: *SKW0023 – P1M - Gabčíkovo-Topoľníky* was identified within the pilot site area. Based on evaluation results (monitoring period 2013 – 2018) the water body has moderate ecological potential and does not reach good chemical status.

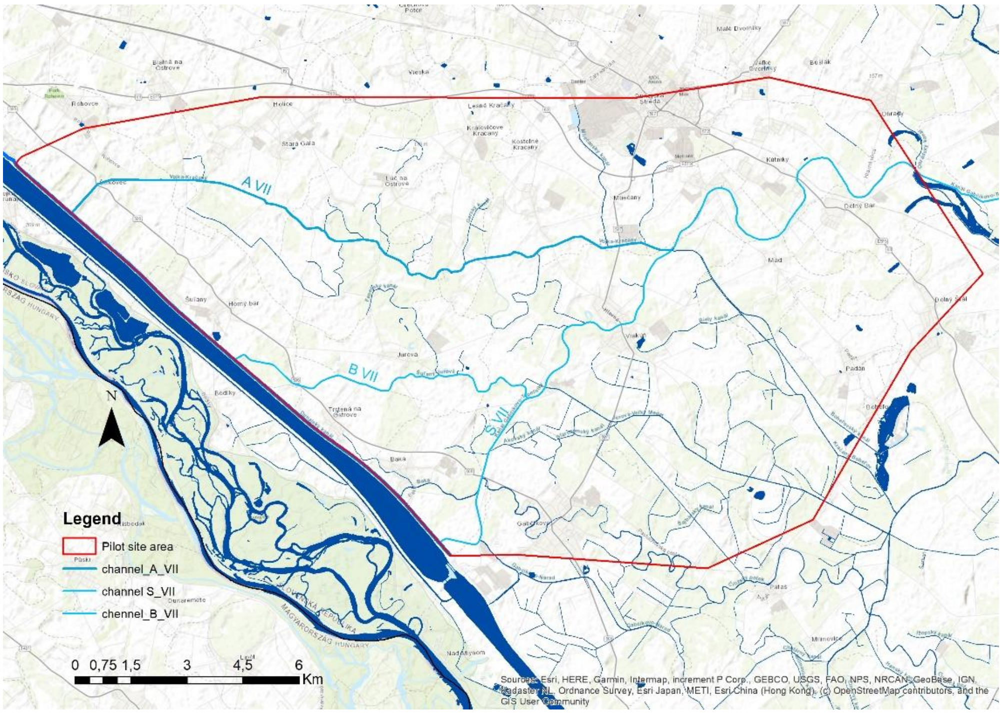


**Figure 3.9** Watercourses of pilot site area in Žitný Ostrov

### 3.5.2. Groundwater

The hydrogeological situation in the pilot site wider area is conditioned by geological and tectonic structure of the area, morphological, hydrological, and climatic conditions. The pilot site area, located in the Žitný ostrov, geomorphologically belongs to the Danubian Lowland and geologically to the Gabčíkovo-Győr depression – part of the Danube Basin.

The whole Žitný ostrov area is covered by Quaternary sediments with the thickness ranging from 12 m to approximately 320 m in the area of the Gabčíkovo depression (Šujan et al., 2018). Quaternary sediments are lithologically represented mostly by gravels and sandy gravels, locally intercalated by thin layers of clays. The sand content in sandy gravels reaches 50 – 70 %. A layer of flood loams with a variable thickness from 1 up to 3 m covers the underlying gravels. The river sedimentation is irregular and the content of respective facies can change within short distances. A larger thickness of loamy sediments with the presence of organic material can be found in buried old river branches - oxbows (Benková et. al., 2005).

Permeability of the Quaternary gravels and sandy gravels was evaluated by many authors (see Bujalka and Drobáň; Jakubec, 1967; Benková et al., 2005; Némethyová et al., 2017) and the average values of the hydraulic conductivity coefficient in the wider area of the pilot site was estimated on $2.91 \cdot 10^{-3}$ m/s and the transmissivity coefficient on $2.96 \cdot 10^{-2}$ m$^2$/s.

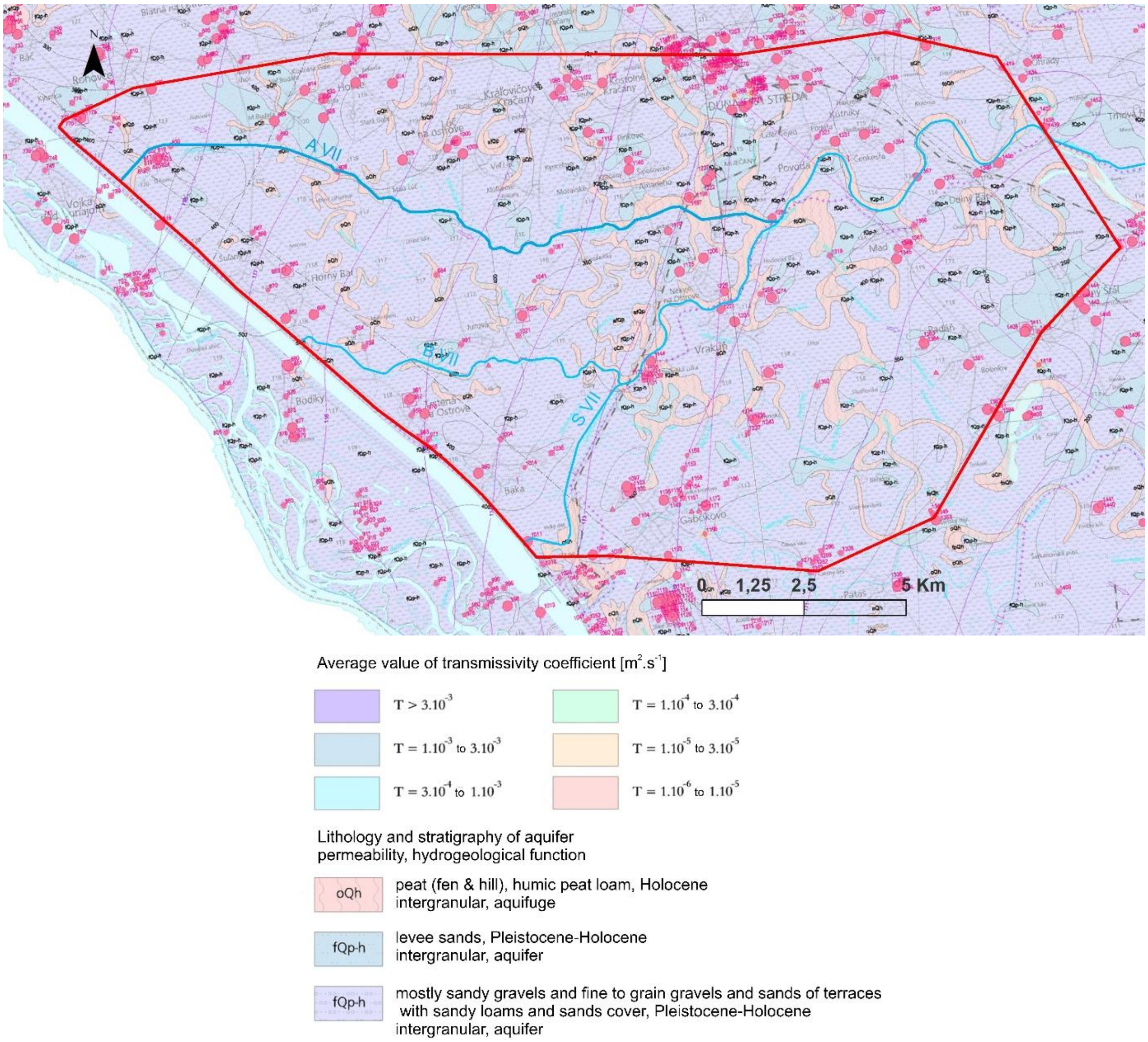


**Figure 3.10** Groundwater map of the pilot site 1:50 000 (Benková et al., 2005)

Groundwater in Quaternary sediments of the evaluated area can be generally characterized as fluviogenic water having an origin of its chemical composition in infiltrating water from the surface watercourses. The main cations are $Ca^{2+}$ and $Mg^{2+}$, values of $Fe^{2+,\,3+}$ and $Mn^{2+}$ contents are often increased. The main anions are $HCO_3^-$ and with lower concentration values also $SO_4^{2-}$. The presence of $NO_3^-$ and $NO_2^-$ indicates anthropogenic pollution. Groundwater is of middle to high mineralization. The basic distinct Ca-$HCO_3$ and basic non-distinct Ca-(Mg)-$HCO_3$ hydrochemical types prevail.

Results of groundwater quality monitoring in the four wells of the pilot site within the period 2017 and 2018 (Ľuptáková et al., 2019) showed good water quality, according to inorganic compounds, and over-limit values were measured for organic compounds PAH (polyaromatic hydrocarbons) and anthracene in a few cases.

The main source for groundwater recharge in the area is the surface water of the Danube River. General flow direction is from the northwest to the southeast, even from the west to the east.

Groundwater regime from the long-term point of view was influenced by the Gabčíkovo Waterworks, which was constructed on the Danube River between Čuňovo and Gabčíkovo villages. The Hrušov water reservoir fills the left-hand seepage channel, which is the water supply source for the channel network of the Žitný Ostrov.

At present, the groundwater depth in the wider surroundings of the pilot area varies between 4.5 – 7.0 m below the surface in the upper part of the Žitný ostrov, in the central part, it makes 1.0 – 3.0 m below the surface (Benková et al., 2005).

There are several groundwater sources used for drinking water supply exploiting water from the Quaternary sediments. Among them, the water source Jelka, located in the northern part of Žitný ostrov, Kalinkovo, Šamorín and Gabčíkovo in the southern part of the Žitný ostrov are worth mentioning.

The pilot site area is a part of Quaternary groundwater body SK1000300P Intergranular groundwater body of Quaternary sediments of the central part of the Danube Basin, which reaches good chemical and quantitative status. Neogene aquifers in the area belong to the Pre-Quaternary groundwater body SK2001000P, but it is not relevant for our MAR scheme.

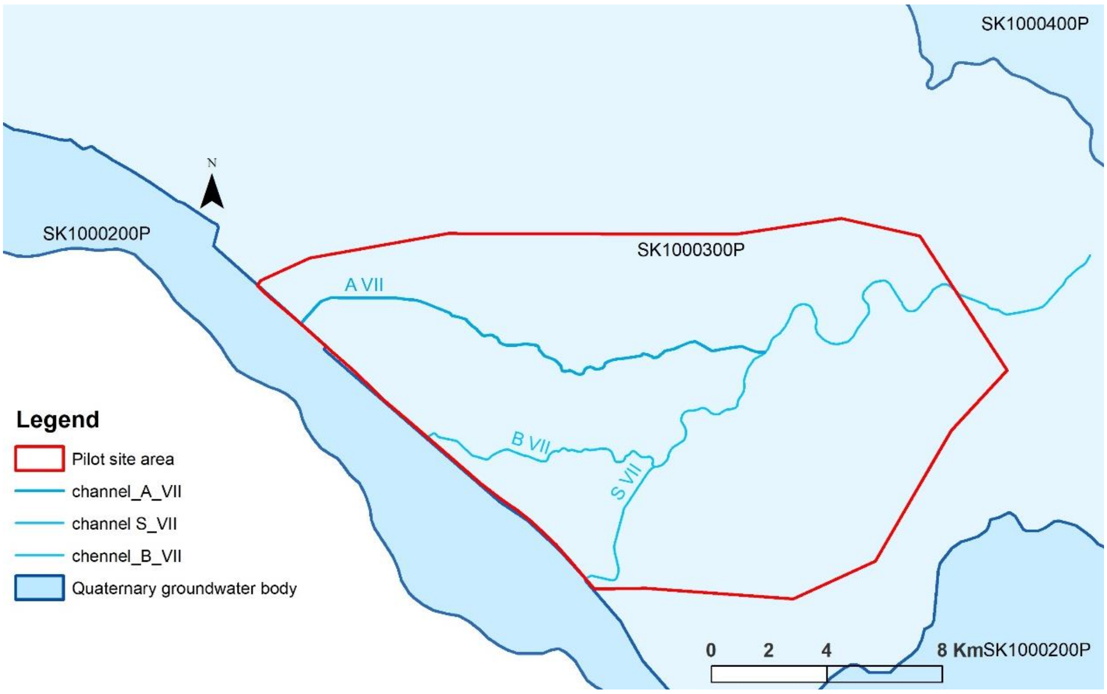


**Figure 3.11** Quaternary groundwater body in pilot site area (database of WRI)

### 3.5.3. Floods

Within the pilot site area, there exists an area in Baka and Gabčíkovo with significant flood risk in the Partial Danube River Basin District (Fig. 3.12). In Baka, the length of the river course at risk (4-21-17-554 – Baka-Gabčíkovo) is 2.4 km. In Gabčíkovo the length of the river course at risk (4-21-17-517 – Gabčíkovo-Topoľníky) is 4.4 km. The A VII Vojka-Kračany channel is not at flood risk.

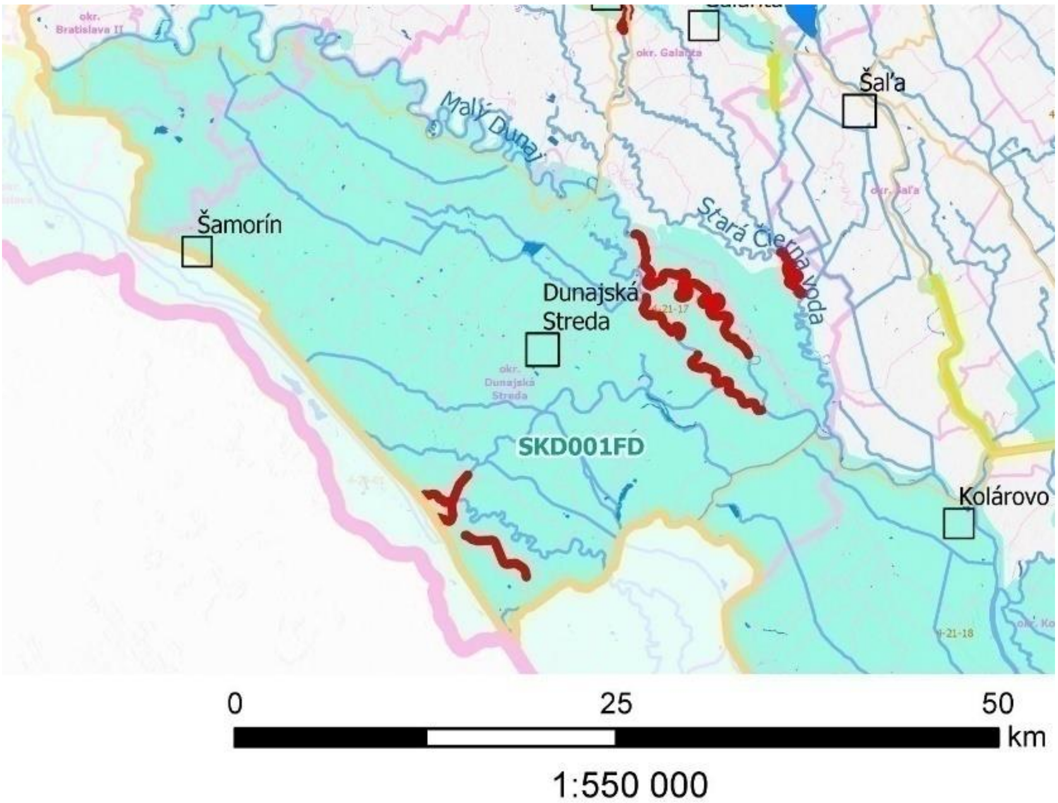


**Figure 3.12** Territory within the pilot site area with existing significant flood risk (Anon, 2018)

## 3.6. Landscape features

The topography of the pilot site area is similar to the whole Žitný ostrov, i.e. a lowland area with a low slope and small differences between elevations above sea level. The altitude of the terrain in the locality is 110 m a.s.l. up to 122 m a.s.l. The slope in the area is up to 1°.

The study area is mostly covered by non-irrigated arable land (more than 80% - see Table 4.2; Fig. 3.13). Urbanized and technical areas occupy 11.29% of the territory, of which 9.09% are discontinuous urban fabric, 2.09% are industrial or commercial units and the rest are mineral extraction sites (Fig. 3.13). These forms of land use, together with the agricultural areas, represent potential sources of diffuse pollution and cover up to 97.6% of the pilot area. The rest of the area (2.4%) represents land use that does not mean a potential diffuse source of pollution. Part of the area is occupied by broad-leaved forest (1.19%) (Table 4.2; Fig. 3.13).

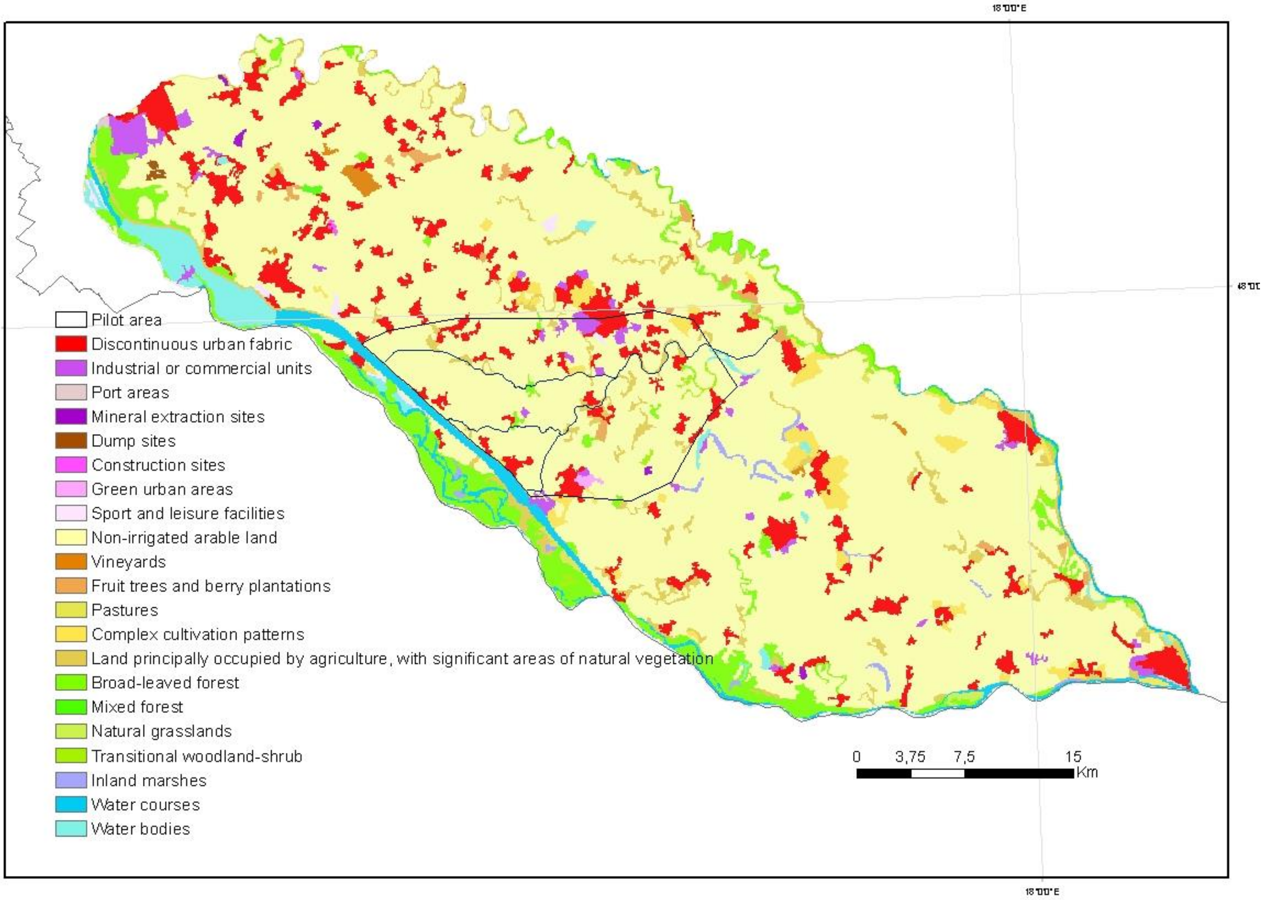


**Figure 3.13** Land use in Žitný Ostrov area according to Corine Land Cover (2018)

**Table 3.2** Land use in pilot site area according to CORINE 2018

| Land use | Area [km$^2$] | Percentage [% from the pilot site area] |
|---|---|---|
| Non-irrigated arable land | 180.992 | 80.29 |
| Discontinuous urban fabric | 20.495 | 9.09 |
| Land principally occupied by agriculture, with significant areas of natural vegetation | 9.907 | 4.39 |
| Industrial or commercial units | 4.720 | 2.09 |
| Broad-leaved forest | 2.678 | 1.19 |
| Complex cultivation patterns | 2.417 | 1.07 |
| Transitional woodland-shrub | 1.520 | 0.67 |
| Green urban areas | 1.013 | 0.45 |
| Fruit trees and berry plantations | 0.900 | 0.40 |
| Sport and leisure facilities | 0.328 | 0.15 |
| Mineral extraction sites | 0.252 | 0.11 |
| Water bodies | 0.189 | 0.08 |
| Water courses | 0.013 | 0.01 |

## 3.7. Cultural heritage

There are no cultural heritage locations within or near the channel Vojka – Kračany (A VII).

## 3.8. Biodiversity

In terms of phytogeographical division (Kolény, Barka, 2002, In Atlas of the Slovak Republic), the whole territory of Slovakia belongs to the Eurosiberian subregion of the phytogeographical kingdom of the Holarctic, formed by a single, Holarctic region. Two provinces of the Eurosiberian sub-region meet in our territory, namely the Pontic-Pannonian province and the Central European province. The Pontic-Pannonian province occupies most of the pilot site.

In terms of phytogeographical-vegetation division (Plesník, 2002 in Atlas of the country), the entire pilot area is classified into an oak zone, a lowland subzone, and a flat area. The majority of the pilot area belongs to the non-wetland district with a significant predominance of floodplain subdistricts. Marginal parts belong to the wetland district and are presented by the dubravina sub-area of the upper Žitný Ostrov area.

The pilot area is strongly marked by the influence of human activity. The occurrence of natural plant communities is very rare. Substantially larger areas of the pilot site are occupied by man-made plant communities, and by plant communities conditioned by human activity.

In the pilot area, the floodplain forest has an unnatural character due to the cultivation and planting of popular tree monocultures. In the inter-dam area, such forests occupy about 80% of the total forested area, which is reflected in a high suppression degree of the original vegetation. Other woody plants, mostly cultivated, include ash, poplar, willow, agate, maple, and others less common like pine, oak, alder, and linden. The aquatic and wetland vegetation types include vascular plants such as Magnopotamion or Hydrocharition and benthic Charophyta vegetation which are commonly present and protected.

The diversity of natural conditions and plant communities is also reflected in the numerous fauna species. The pilot site has suitable conditions for aquatic, wetland, deciduous forest, and forest-steppes species. The most abundant species is the insect fauna. Dragonflies and river clubtails belong to an important group and are tied to flowing waters. Beetles are represented by e.g. great capricorn beetle (*Cerambyx cerdo*), and by the European stag beetle (*Lucanus cervus*).

The fish fauna is also rich, this is the result of diverse and extensive water bodies, from rapidly flowing through slowly flowing, standing, variously overgrown to bodies with periodically drying water. From the point of view of protection, the European mudminnow (*Umbra krameri*), the weatherfish (*Misgurnus fossilis*) and the European bitterling (*Rhodeus sericeus amarus*) are important. Among amphibians, the Smooth newt (*Triturus vulgaris*), less rarely the The Danube crested newt (*Triturus dobrogicus*), European tree frog (*Hyla arborea*), agile frog (*Rana dalmatina*), and others like European fire-bellied toad (*Bombina bombina*), together with the common toad (*Bufo bufo*).

Reptiles are represented by the grass snakes (*Natrix natrix*) which are very common. The area is also important for birds. Most of them live in old forest stands and in domestic trees, which provide them with ideal conditions for nesting, e.g. The Eurasian blackcap (*Sylvia atricapilla*), the Eurasian tree sparrow (*Passer montanus*), the middle-spotted woodpecker (*Dendrocopos medius*), etc. The Eurasian wryneck (*Jynx torquilla*), the black woodpecker (*Dryocopus martius*), the willow tit (*Parus montanus*) and others are tied to the old forest stands. The floodplain forest provide home to the black kite (*Milvus migrans*), as well as to the white-tailed eagle (*Haliaeetus albicilla*).

The mammals are represented by species typical of deciduous forests, e.g. the southern white-breasted hedgehog (*Erinaceus concolor*), The European pine marten (*Martes martes*), the red fox (*Vulpes vulpes*), The European badger (*Meles meles*), Roe deer (*Capreolus capreolus*), Wild boar (*Sus scropha*) and others. The Eurasian otter (*Lutra lutra*) is one of the rarest European mammals. In recent years, the Eurasian beaver

(*Castor fiber*), extinct in the past in Slovakia, has spread around the area once again. Moreover, the remarkable Northern Pannonian Vole (*Microtus oeconomus mehelyi*), has been preserved in the wetlands and represents a glacial relic (Kočický et al, 2019).

The assessment of biodiversity is based on the available literature. In the case of MAR implementation, it will be necessary to conduct an exact characteristic and detailed observation in the field.

## 3.9. Protected areas

Act No 305/2018 Coll. on establishing the protected areas of natural accumulation of water, deals with activities that are prohibited in the protected areas and introduces measures to be implemented for the protection of surface water and groundwater naturally occurring in protected areas. According to the act, the whole pilot site belongs to Žitný Ostrov protected area of natural accumulation of water.

Act No. 364/2004 Coll., Resolution No. 29/2005 Coll. delineated protection zones of all surface and groundwater supply sources in Slovakia. In our pilot site area (Fig. 3.14), there are five small drinking water sources.

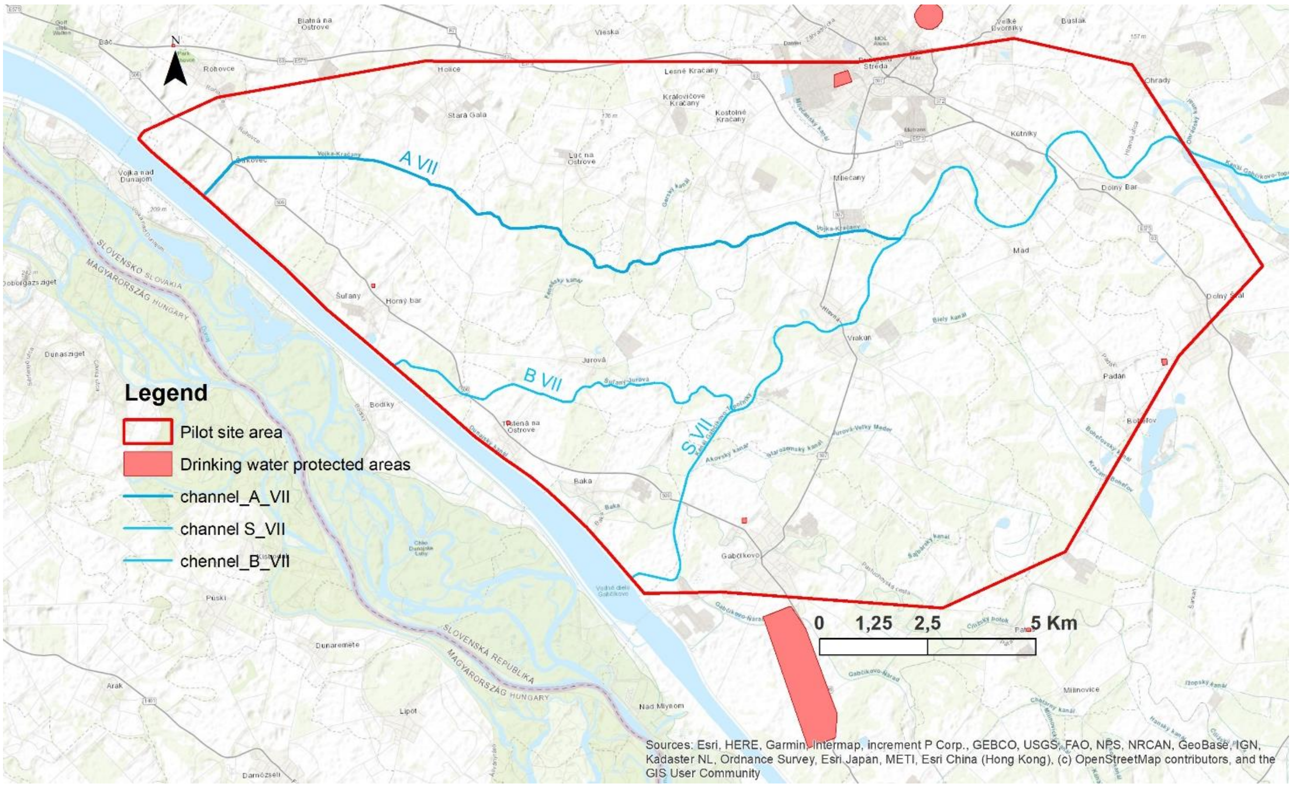


**Figure 3.14** Drinking water protection zones (database of WRI)

Moreover, in accordance with the Act No 543/2002 Coll (on nature and with other protected areas, being represented mainly by parks near some landscape protection) there is a nature reserve (PR) Jurovský les (2 ha) situated in the pilot site area close to Jurova together of villages (park in Rohovce, park in Kráľovičove Kračany and park in Gabčíkovo).

# 3.10. Ecological network

The most relevant protected area under NATURA 2000 in our pilot site is Konopiská marches, which are connected to the channel Vojka-Kračany. Within the pilot site there is also Čiližské močiare protected under NATURA 2000. On the right side of the Bypass Canal, out of the pilot site (Head- and Tailrace Canal of Gabčíkovo Water Structure), the important protected area Dunajské luhy is situated (Fig. 3.15).

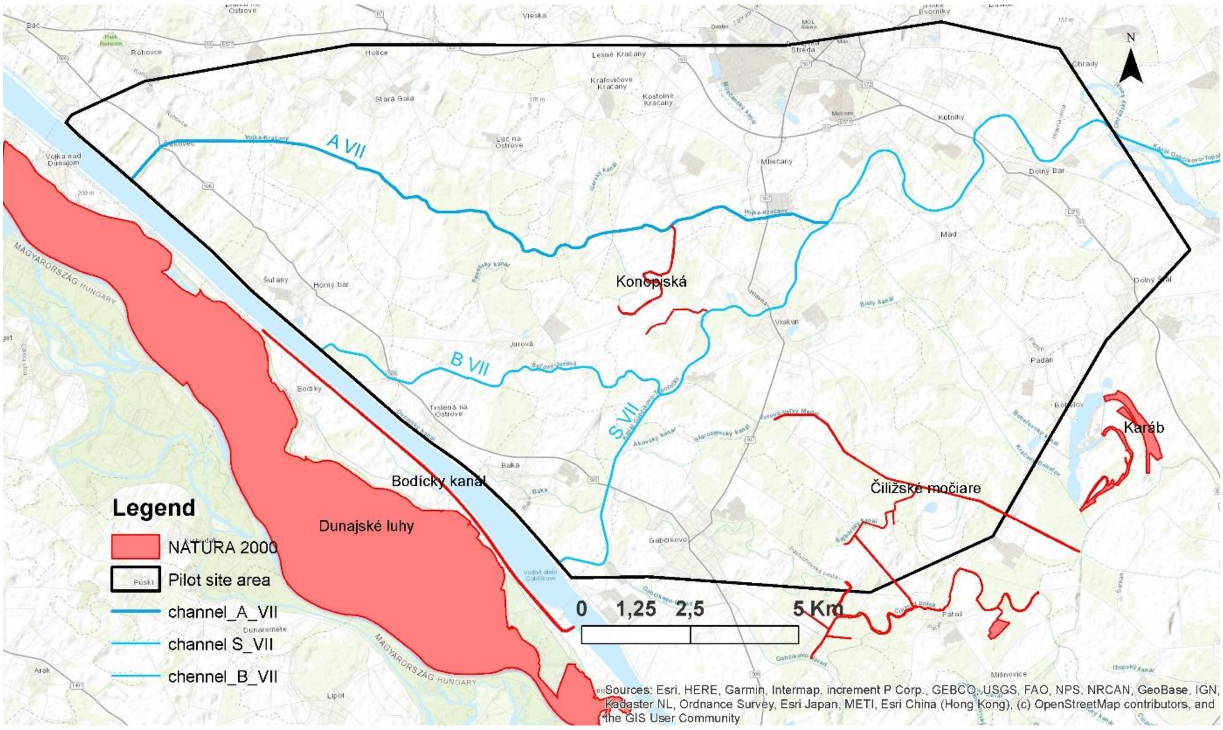


**Figure 3.15** NATURA 2000 protected areas within the pilot site (Database of WRI, source ŠOP SR)

# 3.11. Socio-economic conditions and main end-users

The pilot site area is situated in the Trnavský Kraj County and in the district of Dunajská Streda, where the density of population reaches around 110 inhabitants per km$^2$. There are two cities (Dunajská Streda and Gabčíkovo) and 18 villages located in the Dunajská Streda district. More than 50% of inhabitants of the Dunajská Streda district live in villages.

Channel Vojka-Kračany passes through extra-urban area of 6 villages and one town (Rohovce, Blatná na Ostrove, Holice, Lúč na Ostrove, Kráľovičove Kračany, Kostolné Kračany, Vrakúň, Povoda, and Dunajská Streda). Villages have around 1,000 inhabitants, while in the town of Dunajská Streda town there are more than 22,000 people.

There are the highest quality soil types in the area, so one of the dominant sectors is agriculture. Farms produce mainly cereals and fodder, but also vegetables and fruits. The effectively operated MAR system is necessary since there will be needed more water in the vegetation period for the agricultural plants because of greater differences between precipitation on one side and evapotranspiration on the other side.

# 4. Potential impacts of MAR on the environment

### 4.1.1. Impact on the microclimate

The impact of the MAR building on the microclimate will be minimal. After the construction, the water level along the entire channel will be raised, and the surface exposed to evapotranspiration may increase, which can raise the humidity in the vicinity of the channel.

A significant impact of the proposed activity on the atmosphere is not expected. During construction, there is a presumption of increased dust and exhaust emissions generated by material transport and working mechanisms. The location of the construction site and the surroundings of the road will be affected by dust and exhaust gases. Nonetheless, these effects are not significant and will last temporarily - during the construction work and will be tied to normal working hours.

### 4.1.2. Impact on the geology

During the construction of the three new sluices, we do not expect any influence on the geological conditions around the channel. After the sluices are put into operation, the sedimentation of fine-grained material from the suspension may increase. Nonetheless, this material should be transported downstream at the annual winter sluice opening.

### 4.1.3. Impact on the soil

The construction may require a temporary occupation of surrounding land. This area will be reserved for the deposition of a temporary landfill and for construction site equipment.

There is an assumption that the construction of sluices will always be in the vicinity of an accessible road, thus the construction is not expected to affect the quality and possible compaction of soils during the transport of materials and work equipment. Temporary compaction can occur in the immediate vicinity of sluices. The quality of soils could be endangered due to leaking oil and other substances from the working machines. Nonetheless, provided that the machines are in good technical condition, contamination can be eliminated by strict adherence to working procedures.

### 4.1.4. Impact on the water

#### 4.1.4.1 Impact on surface water

During construction, if not carried out during the winter sluice opening, it will be necessary to limit the inflow of surface water into the channel, which will temporarily affect the flow and surface water level in the channel. Wastewater generation and water use during construction should not occur.

During construction, in the channel, it is possible to assume short-term turbidity of surface water, but no significant change in the flow, quality, and quantity of surface water is expected.

During the operation phase, the water level in the channel will be higher, which is the expected result.

#### 4.1.4.2 Impact on groundwater

Due to the reduction of the surface water level during construction, groundwater drainage may occur through surface waters, as we assume the existence of mutual interaction at the construction site (the existence of groundwater recharge was proven by measuring flows in the Vojka-Kračany channel). Unless there is an unexpected accident (leakage of fuels and oils), groundwater contamination is not expected. Deterioration of groundwater quality either during the construction or operation phase is not expected as well. The impact on groundwater levels and thus on the groundwater level regime during the operation of the MAR should be positive - and thus groundwater resources should increase.

### 4.1.5. Impact on the landscape

The impact should be minimal, land use along the entire channel is mainly focused on agriculture and thus the sluices building will have a positive impact.

### 4.1.6. Impact on the cultural heritage

Not relevant because there are no cultural heritage locations within or near the channel Vojka – Kračany.

### 4.1.7. Impact on the biodiversity

During construction, the surrounding vegetation (grass, trees) may be removed, which will temporarily reduce the fauna usually associated with the respective environment. Construction will have the greatest impact on the aquatic fauna, as it will create another migration barrier in form of another sluice. On the other hand, after the construction, the water level in the stream will increase in the given sections, which can improve fauna and flora living conditions.

### 4.1.8. Impact on the protected areas

No negative impact on protected areas is expected. There could be a positive impact on Žitný Ostrov protected area of natural accumulation of water by increasing groundwater resources.

### 4.1.9. Impact on the ecological network

By building the first sluice in the channel, the surface and groundwater level regime in the adjacent Protected Area of European Importance “Konopiská” may be affected. As this is a wetland system, we can expect a positive impact.

### 4.1.10. Socio-economic impacts

The area for the construction of the sluices is located in the outskirts of the municipalities.

During construction, the potential negative effect will be the noise from construction mechanisms at the construction site and traffic noise generated by the increased frequency of material transport on the existing routes. These effects will be of a temporary nature and will be linked to normal working hours, so we assume that there will be no significant impairment of well-being and quality of life during construction.

Certain adverse effects caused by dust and mud removal on roads during rainy weather etc. can be expected during construction. These adverse effects can be at least partially eliminated by the construction contractor by appropriate work organization, and cleaning of machines on the way out.

We do not expect the creation of new jobs directly, but if there will be an intensification of agricultural activity, seasonal jobs in agricultural production may be created.

## 4.2. Cumulative impacts

If we consider all evaluated impacts of the MAR on the surrounding environment, we do not aspect any significant cumulative impact on the pilot site. As far as we know, there are no planned other similar projects or activities, which could have a cumulative impact on the planned recharge dam MAR type, for now.

Despite the above mentioned, what we can examine is the potential synergic impact on the environment by constructing three new sluices, in other words creating recharge dams. Construction of new sluices will increase water levels in the channel and have a positive effect on groundwater levels in the area. The higher groundwater level could have a stepwise positive effect on soil moisture, on agricultural production, and finally on the socio-economic situation.

## 4.3. Overview of recognized impacts

**Table 4.1** Overview of recognized impacts - Slovakia

| Grade | Description |
|---|---|
| -1 | Negative impact |
| 0 | There is no impact |
| 1 | Positive impact |

| *ENVIRONMENTAL COMPONENT* | | *IMPACT CHARACTERISATION* | | | |
|---|---|---|---|---|---|
| | | *DIRECT/ INDIRECT/ CUMULATIVE* | *SHORT-TERM/ LONG-TERM* | *POSITIVE/ NEUTRAL/ NEGATIVE* | *GRADE* |
| *Climate* | | *indirect* | *long-term* | *neutral* | *0* |
| *Geology* | | *indirect* | *short-term* | *neutral* | *0* |
| *Soil* | | *direct* | *short-term* | *neutral* | *0* |
| *Surface waters* | | *direct* | *long-term* | *positive* | *1* |
| *Groundwater* | | *direct* | *long-term* | *positive* | *1* |
| *Landscape* | | - | - | - | *0* |
| *Cultural heritage* | | - | - | - | *0* |
| *Biodiversity* | *Terrestrial habitats* | *indirect* | *short-term* | *neutral* | *0* |
| | *Water habitats* | *direct* | *long-term* | *neutral* | *0* |
| *Protected areas* | | *indirect* | *long-term* | *positive* | *1* |
| *Ecological network* | | *direct* | *long-term* | *positive* | *1* |
| *Population* | | *indirect* | *long-term* | *neutral* | *0* |

# 5. Conclusion and summary / Slovakia

The preliminary Environmental Impact Assessment evaluated influence on the environment by building three new sluices in channel Vojka – Kračany, i.e. creating recharge dam. The pilot area is agricultural land. It is located in the Slovak part of the Danube Basin, in the north-western part of the Pannonian Basin System. The sedimentary in-fill of the depression is represented by Neogene and Quaternary sediments. For the MAR scheme, Quaternary sediments are relevant, formed mostly by gravels and sandy gravels with favorable hydraulic conductivity coefficient and the transmissivity coefficient.

The creation of additional three sluices (i.e. recharge dams) in channel Vojka-Kračany has more or less neutral impact on climate, soil, geology, biodiversity, and population. After evaluation, it was concluded that there is no impact on cultural heritage and landscape at all. If we look at the positive impact, we assume long-term impact on surface water and groundwater level, which could positively affect the Žitný Ostrov protected area of natural accumulation of water and Kopaniská – an area protected by NATURA 2000.

# CONCLUDING REMARKS

The preliminary environmental impact assessment aimed to assess how the implementation of the MAR scheme in chosen pilot areas (Croatia, Hungary, Poland, Slovakia) will affect environmental components such as climate, geology, soil, landscape, cultural heritage, biodiversity, ecological network, groundwater and surface water, and ultimately human population as an indispensable part of the whole environment.

It was necessary to describe the type of MAR technology that will potentially be applied in the pilot area of each country as well as a possible variant solution. First, each country had to give a site description, proposed a MAR site in relation to other spatial interventions, as well as compliance with planned intervention with other spatial interventions. Then, detailed information about climate, geology, hydrogeological settings, soil, water, landscape, cultural heritage, biodiversity, protected areas, ecological network, socio-economic conditions, and main-end users were given. For each of these components potential impact of MAR on the environment has been assessed so that an overall conclusion for each country participating can be conducted.

Some of the highlights that run through the entire document are as follows:

- MAR will have neutral, minimal, or no impact on climate, geology, landscape, protected areas, biodiversity, surface, and groundwater in most of the pilot areas of all of the countries involved,
- In the pilot area in Croatia, a negative impact is expected for soil and terrestrial habitat of garrigue but since this habitat is widespread on the island, this impact is not significant,
- in the pilot area in Poland, threats to ichthyofauna were identified from the surface water withdrawal site on the Dunajec River but measures will be proposed to minimize this effect before implementing MAR.

But in general, this document has proven that implementation of MAR will have positive impacts on surface water bodies and groundwater bodies. So, there are more positive benefits of the implementation of this technology, than the negatives one such as:

**CROATIA** (*infiltration pond and aquifer storage recovery*)

- formation of the surface water reservoir,
- revitalization of old river beds in Korita
- increasing GW levels,
- improved water safety,
- stronger resilience of the water supply during dry summers,
- improved infrastructure and overall benefits for the local people as well as for the tourists that come on the island.

**HUNGARY** (*underground dam*)

- the rise in groundwater level,
- increased levels of water that can be used for irrigation,
- the water storage available for later uses and minimized water losses due to evaporation,
- benefits for local people and agricultural producers,

**POLAND** (*induced bank filtration and infiltration dams*)

- improved groundwater quality,

- increase in usable resources,

**SLOVAKIA** (*recharge dam*)

- long-term impact on surface water and groundwater level,
- positive effects on the protected area in the vicinity of potential MAR implementation.

This project has shown that the positive effects of MAR technology outweigh the negative and neutral effects on environmental components if any exist. There are many benefits of applying MAR technology, and what is somehow most important and what stands out the most is raising the quality of groundwater as well as raising the level of groundwater. This is especially important today because we are living in a time in which, there is increasing pressure from climate change on the environment and thus on human communities. The application of MAR technology will enable the creation of reservoirs of available quality water in conditions of increasing dry periods.

Considering biodiversity and protected areas, there are no significant long-term negative impacts of the application of this technology on habitats or species. On the contrary, this technology can revitalize old riverbeds by increasing groundwater levels.

Regarding the social component, MAR technology will increase the availability of quality water for the needs of the population in economic branches such as tourism (Croatia) or agriculture (Hungary). The potential application of MAR technology and the plant construction process itself can be an opportunity to create new jobs in certain locations.

The general conclusion that emerged from the assessment of the impact of the potential application of MAR technology on the components of the environment is that the technology in question is very useful and has almost no significant or long-term negative impacts on the environment. MAR technology is clean and it will enable the raising of the groundwater levels and quality of groundwater, thus making it available in periods when it would otherwise be scarce. The potential application of MAR technology will increase water availability and the resilience of human communities to climate change with minimal impact on biodiversity or protected areas of nature.

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