DEEPWATER-CE

WORKPACKAGE T3, ACTIVITY T3.5

D.T3.5.1 REPORT ON THE DESK ANALYSIS OF THE PILOT FEASIBILITY STUDY FOR MAR DEPLOYMENT IN POROUS AQUIFERS IN AREAS USED FOR AGRICULTURAL PURPOSES

REPORT D.T3.5.1.

Final version

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Lead Institution	PP6, Water Research Institute
Lead Author/s	Dana Vrablíková
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Contributors, name and surname	Institution
Dana Vrablíková	Water Research Institute
Andrea Vranovská	Water Research Institute
Alena Kurecová	Water Research Institute
Miriam Fendeková	Hydrofen s.r.o.
Andrej Šoltész	Slovak University of Technology
Michaela Červeňanská	Slovak University of Technology
Karol Kňava	Water Research Institute
Štefan Rehák	Water Research Institute
Peter Stradiot	Water Research Institute
Viliam Novák	Water Research Institute

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I. Introduction

The transnational decision support toolbox was developed on designating potentially suitable MAR locations in Central Europe within the DEEPWATER-CE project (output O.T2.1, DEEPWATER-CE, 2020b). Based on this toolbox, pilot sites with applicable MAR types can be identified (deliverables D.T3.3-6.1-5). Furthermore, a common methodological guidance for DEEPWATER-CE MAR pilot feasibility studies (deliverable D.T3.2.5) was proposed which can be used in combination with the transnational decision support toolbox to identify the potential of a MAR application. This report on the desk analysis of the pilot feasibility study for MAR deployment in*porous aquifers in areas used for agricultural purposes (D.T3.5.1)* shall give an overview on existing data for the feasibility assessment of the DEEPWATER-CE pilot site in *Slovakia*. Based on the existing data, the further steps for determining missing data for a comprehensive feasibility assessment are developed and documented in a pilot action design plan.

Based on methodology developed within DEEPWATER-CE project, to investigate the MAR suitable areas the general screening method was applied in the whole territory of Slovakia. The aim of screening applying selection criteria was to find suitable areas for a specific type of MAR (i.e. Recharge dam in Slovakia). Among others, the Zahorska Lowland as well as Podunajska Lowland were considered proper for potential MAR sites. In the areas which were selected as suitable ones from general screening, the specific selection criteria were applied. As before, the selection criteria were used to define a specific aspect of suitability - (i) climate exposure, (ii) hydrogeology/geology and (iii) sensitivity of MAR systems to extreme climate events. Specific selection criteria were applied in Zitny ostrov area (part of Podunajska Lowland).

Based on above-described methods applied in the territory of Slovakia, the originally planned pilot site in Zahorska Lowland was changed to Podunajska Lowland. The reason for change was that the Zahorska Lowland pilot area is characterised by low dense network of irrigation channels with low flows. The technical tools (sluices, barriers) for regulation of water flow in channels were removed due to opening the ways for fish migration. Regulation of flow in channels is a crucial point for the field measurements to create recharge dam and investigate interaction between surface water level and groundwater table. In Podunajska Lowland, there is denser network of functioning irrigation channels and existing technical tools for water flow regulation. Moreover, the soil sampling and measurements of soils/rocks hydraulic properties will provide input data for mathematical models calibration. From hydrogeological viewpoint, in both areas are similar porous aquifers, but in the Podunajska Lowland, the aquifers' hydraulic properties are better (gravels + sands) and climatic scenarios predict droughts in the Podunajska Lowland in the future.

The pilot area is roughly delineated by Samorin, Dunajska Streda and Gabcikovo towns and it belongs to medium MAR suitability according to restrictions of the following selection criteria: depth of groundwater table, hydrologic soil type, land use and regime type of the groundwater flow system. Otherwise, it will be considered as highly suitable area.

II. Data availability and sources

To follow the approved methodology of the site investigation and to fufill the aims of pilot site feasibility evaluation,the data set had to be compiled. The data will be used for pilot site characteristics as well as for description/input data to mathematical modelling of the area in order to investigate the possibilities of surface water infiltartion into groundwater.

The data set involves climatological, geomorphological, geological and hydrogeological,and hydrological data and soild properties as described in Tab. 1.

Table 1: Used data and their sources

Data description	**Data specification**	**Source of data**
Climatological data	daily precipitation	Slovak Hydrometeorological Institute, digital
	temperature – average, maximum, minimum daily	
	average daily water vapour pressure	
	daily mean wind speed	
	daily sunshine duration	
Geomorphological data	digital relief model	ZBGIS, digital
Geological and hydrogeological data	spatial distribution of hydraulic conductivity – from final reports of surveys	State Geological Institute of Dionýz Štúr, paper
	groundwater tables in boreholes - weekly step	Slovak Hydrometeorological Institute, digital
Hydrological data	water levels in channels – weekly step	Slovak Hydrometeorological Institute, digital
Soil properties	physical characteristics of soil	Field work
	hydraulic conductivity	Field work and laboratory measurements
	soil bulk density	Soil sampling and laboratory measurements

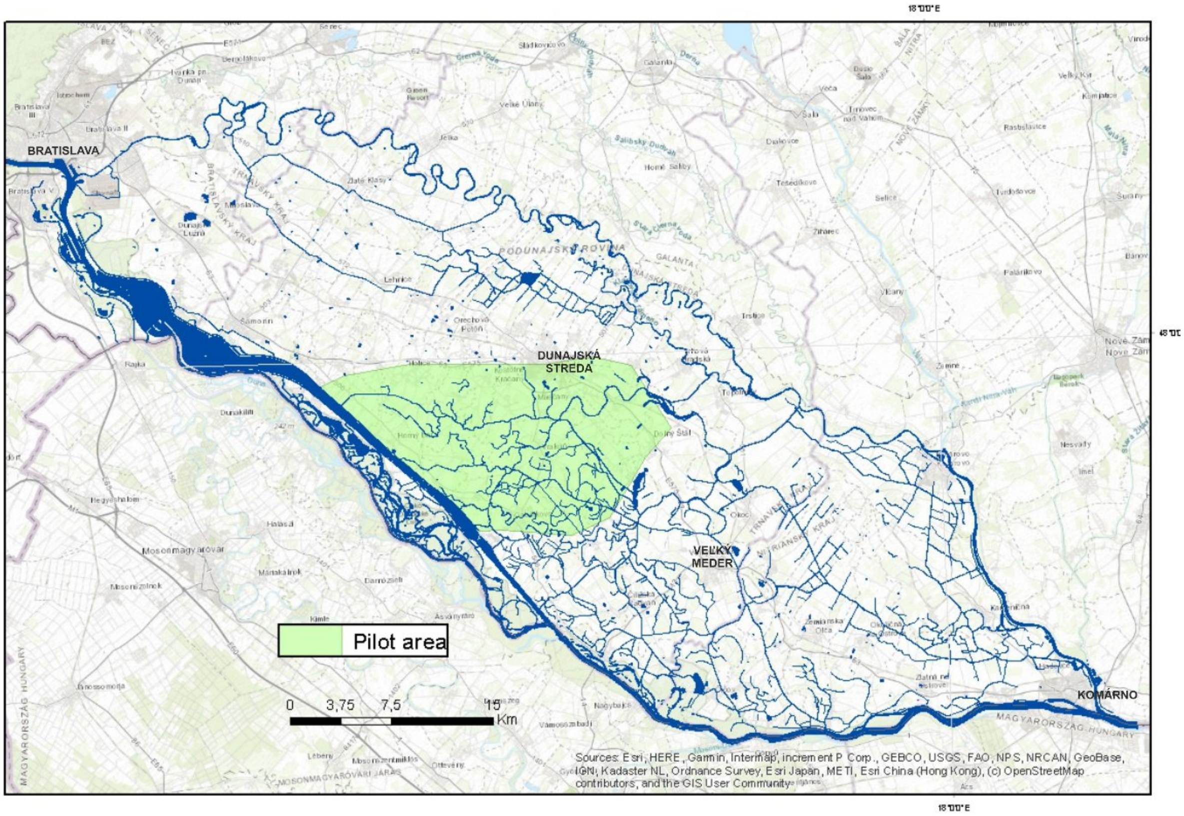
III. Pilot site characterization based on existing data

3.1 Surface topography – Geomorphology

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. The territory belongs geographically to the Podunajska (Danube) Lowland. According to the geomorphologic division (Landscape Atlas of SR, 2002), the pilot area is situated in the geomorphologic unit called Danube Plain (Podunajská rovina) and is a part of Čiližská mokraď sub-unit. The Žitný ostrov has an elliptical shape, its length is 84 km, the width ranges between 15 and 30 km, and the total area is 1635 km^2 (Benková et al.,2005). With its dimensions, the Žitný ostrov is the largest river island in Europe. The pilot site area is situated in the middle part of the Žitný Ostrov and it covers around 226 km^2 (see Fig.1.).

The topography of the pilot site area is similar to the whole Žitný ostrov, i.e.a lowland area with low slope and small differences between elevations above sea level. The highest point on the Žitný Ostrov area is located near Šamorín (134 m above sea level), and the lowest is the area at Komárno (105 m a.s.l.) (Dušek & Velísková, 2017). 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 most common soil types in the area arechernozems, mollic fluvisols.and fluvisols. According to the texture classification, soils are mostly loamy, clayey - loamy and sandy – loamy (Landscape Atlas of SR,2002).



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Fig.1. Pilot site area in Žitný Ostrov

3.2 Climatic conditions

The climatic conditions of the area are determined primarily by geographical factors, by its latitude, longitude and altitude. According Konček´s climate classification scheme, the Žitný Ostrov (Fig. 2, left) area is situated mostly in warm region (Climate Atlas of Slovakia, 2015). Pilot site area is situated in 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. 2, right). The average air temperature in summer (April to October) ranges from 19 to 20°C. There are annually in average 18-20 tropical days and more than 70 hot days and there are more than 1900 hours of sunshine per year. 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).

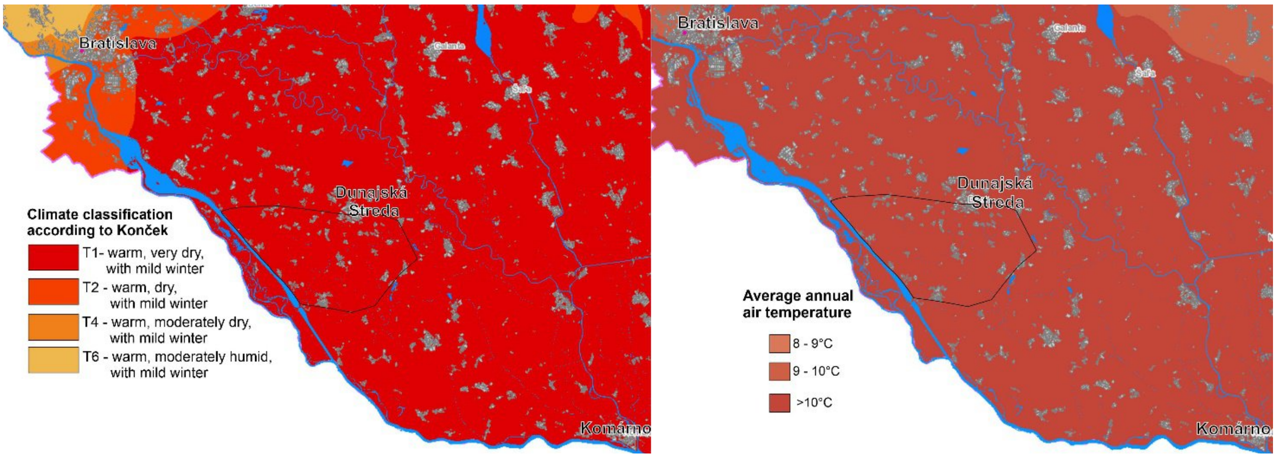


Fig. 2: Left: Climate classification according to Konček; Right: Average annual air temperature (Climate Atlas of Slovakia, 2015)

Total annual precipitation (for the period 1981-2010) vary between 600 – 551 mm in the major part of the pilot area, and between 550 – 522 mm in the southern part of our study area (Fig. 3, left). These amounts are the lowest in Slovakia and are typical for areas in the south of Slovakia. Total precipitation in the summer period (April-October) vary in the range 350 – 307 mm. The lowest values are typical for winter, ranging between 40 and 21 mm. The average number of snowy days in the winter season (November-April)vary 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, right) (Climate Atlas of Slovakia, 2015).

From an agricultural point of view, the district belongs to the suburban region of Bratislava, to the maize agricultural production area and to the lowland warm agricultural natural area (Blažík et al., 2011).

The area is located in the region where climate change in Slovakia has been manifested in recent decades, the climate has changed from warm and dry to warm and very dry compared to the second half of the 20th century (Mello et al., 2010).

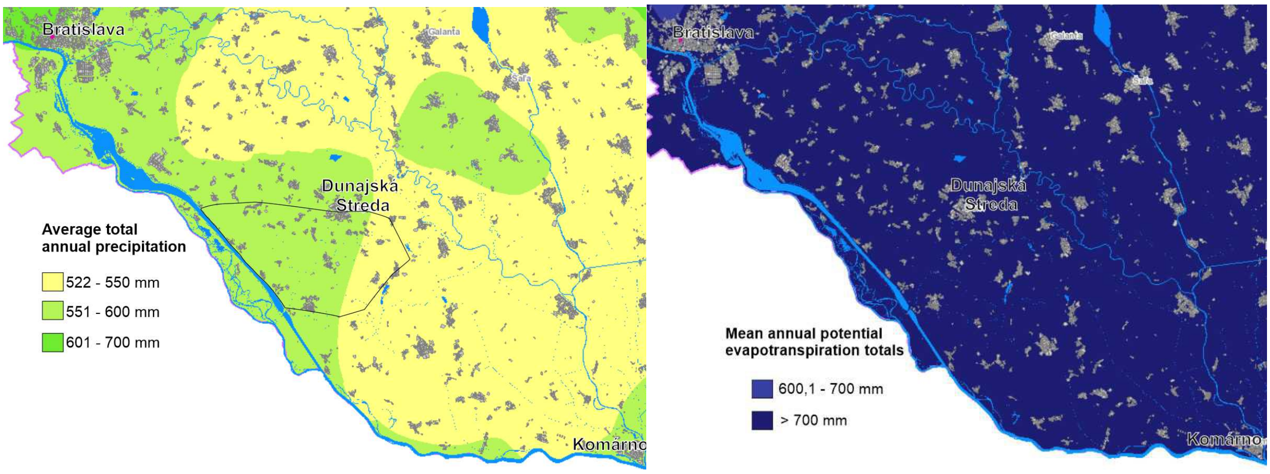


Fig. 3: Left: Average total annual precipitation; Right: Mean annual potential evapotranspiration totals (Climate Atlas of Slovakia, 2015)

3.3 Land use and potential sources of surface and groundwater contamination

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.

Žitný ostrov is one of the best areas for agricultural production due to favourable soil and climatic conditions. As the result, majority of the original vegetation (such as.floodplain forests (oak/elm/ash; willow-poplar), peatland (alder,reedbeds)) was removed (Blažík et al., 2011).

The study area is mostly covered by non-irrigated arable land (more than 80% - see tab. 2.; Fig.4.). 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.4). 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 area is occupied by broad-leaved forest (1.19%) (tab.2; Fig.4).

The main point sources of surface water pollution are comprised of industrial plants and wastewater treatment plants outlets. Based on the database of integrated monitoring of pollution sources (IMZZ) there are four landfills located close to Lúč na Ostrove, Horný Bar, Jurová and Vrakúň.

Act No 305/2018 Coll. 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 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. 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 close to Jurova together of villages (park in Rohovce, park in Kráľovičove Kračany, park in Gabčíkovo). Marshes, which also belong to territories of the European importance can be found in the wider surroundings of the pilot site (Čiliž, Konopiská).

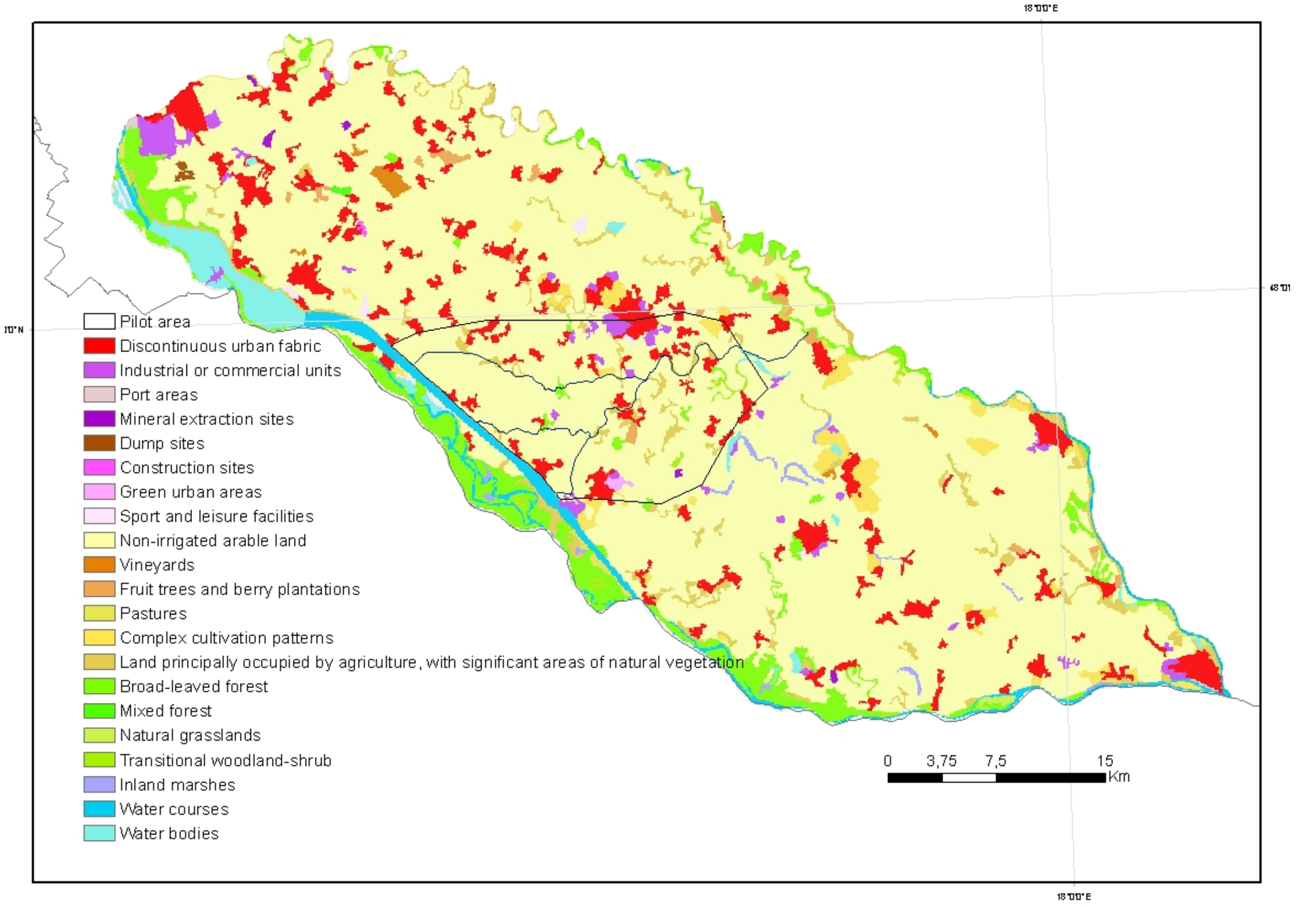


Fig.4. Land use in Žitný ostrov area according to Corine, 2018 (web1)

Tab. 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

Based on the water balance of Slovakia, hydrogeological rayon (region) Q 052 (Quaternary of the south-western part of the Danube Lowland), i.e. the pilot site area is in good balance status. The total usable amount of groundwater in this rayon with an area of 1897.80 km^2 reached 18,523.7 l.s^{-1} in 2019 and the consumption reached 2,423.73l.s^{-1}.The water is used mostly for public water supply (2154.31l.s^{-1}) and agriculture (53.16l.s^{-1}for animal production, 127.95l.s^{-1}for crop production and irrigation). The pilot site is located in the sub-region of the Váh River Basin (1439.70 km^2), for which the usable amount of groundwater in 2019 was determined to 7856.50 l.s^{-1} and the known consumption reached 1220.57 l.s^{-1}. The sub-region is still in a good balance status. Within the pilot area, the groundwater is used in four localities (tab.3) for which the usable groundwater amount in 2019 was determined to 4838.82 l.s^{-1}, total consumption volume reached 653.45 l.s^{-1}and water was used especially for public water supply and agricultural production (Belan et al., 2020).

Tab. 3 Groundwater balance table in four localities of the pilot site area (Belan et al., 2020)

Name of locality	District	Usable groundwater amount			Evaluation of usage		
		Cat.	Amount (l.s-1)	Quality	Consumption (l.s-1)	Usage	Balance status
8 Dunajská Streda	DS	B C1	115.50 184.00	B V	95.82	V1	satisfying 3.13
10 Baka	DS	C1	1500.00	V	0.91	V1	good 1648.35
11 Gabčíkovo	DS	B C1	2.33 3000	V,CA	1.00 472.30	V1	good 6.34
13Vrakúň	DS	B II.	26.99 10.00		1.29 0.95	V1-2	good 16.51
dispersed local sources	DS	II.	950.00	O	64.83	V1-2	

Explanations:
DS – Dunajska Streda (district)
Categories (B, C1 II.) were defined based on rules for classification of groundwater supplies according to the Decree of the Ministry of Environment of the Slovak Republic 141/2000 Coll.

- Category B represents groundwater sources and supplies evaluated on minimum 2 years monitoring of their quality, quantity, assessment of interrelation between groundwater and surface water, and ecological conditions.
- Category C1 represents groundwater sources and supplies evaluated on minimum 2 years monitoring of their quantity, basic assessment of their quality, geological and hydrogeological conditions.
- Level II. represents usable amounts of groundwater evaluated on the base of reliable archive data (i.e. monitoring shorter than 2 years, hydrogeological surveys with long-term pumping tests, short-term exploitation).

Usable groundwater amount – Quality:

- B -bacteriological/biological pollution
- V -quality meets standards of Norm STN
- CA -chemical/inorganic pollution
- O - quality was not assessed

Evaluation of usage –Usage:

- V1 – source is not used or partially used with well documented usable groundwater sources based on hydrogeological surveys, quality meeting STN for drinking water, the source is accessible and protectable
- V2 – source is not used or partially used with well documented usable groundwater sources of worse quality (drinking water treatment is needed) or unsuitable from the access or protection viewpoint

3.4 Hydrology

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 building the Gabčíkovo hydro-power water structure (VD Gabčíkovo). The channel network of Žitný Ostrov consists of six main, partially interconnected channels: Gabčíkovo-Topoľníky channel, Chotárny channel, Čalovo-Holiare-Kosihy channel, Aszód-Čergov channel, Čergov-Komárno channel, and Komárňanský channel. The total area covered by the current drainage system is 1469 km^2. The area of drainage with a built-up channel network is 1252 km^2. The total length of the channel network is almost 1000 km. Its density is about 1 km/1.25 km^2. The most important channels in the drainage system are the Chotárny and Gabčíkovo-Topoľníky channels, which flow into the Little Danube (Dušek & Velísková, 2017). 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 west- southern 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 Hrusov Reservoir.

According to the SR Government Regulation No 211/2005 Coll. the Gabčíkovo – Topoľníky channel and also its tributaries, channels Vojka – Kračany and Šuľany – Jurová 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. Slovakia has an exception for this water body according to the Article 4(4) for an extension of the deadline to reach good chemical and ecological status beyond 2027.

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 Pre-Quaternary groundwater body SK2001000P Intergranular groundwater body of the central part of the Danube Basin and its folders and reaches bad chemical ($NO3^-$) status with a high degree of reliability, and good quantitative status. The results of groundwater monitoring in 2019 show overcoming of limit concentrations of iron and manganese (compared to limits values in the Regulation of the Ministry of Health of the Slovak Republic No 247/2017 Coll.). These higher concentrations influence only organoleptic properties of the water and they do not represent any danger for health.

Directive 2007/60/EC on the assessment and management of flood risks (EU Floods Directive, FD) entered into force on 26 November 2007. Article 7 of the Floods Directive FD requires the Member States to prepare flood risk management plans for all areas identified as being at potentially significant flood risk (APSFR). Since the Danube River Basin is an international one, the flood risk management plan is coordinated on the international level by the ICPDR - International Commission for the Protection of the Danube River.

The first Flood Risk Management Plan for the Danube River Basin District (2015) was based on information received from the ICPDR Contracting Parties until 10 November 2015 and published under the title Flood Risk Management Plan for the Danube River Basin District by ICPDR in 2015. Besides the text of the report it also contains maps of (1) flood hazard and (2) flood risk, assessed from several points of view, e. g. population or economic activities.

The first preliminary evaluation of the flood risk for Slovakia was done by the Ministry of Environment of the Slovak Republic in 2011, and the updated version was published in December 2018 (Anon, 2018; https://www.minzp.sk/voda/ochrana-pred-povodnami/manazment-povodnovych-rizik). Within the flood risk assessment process in Slovakia, important floods between 1997 and 2017 were identified, the protection measures at the Slovak part of the Danube River were described and preliminary evaluation of flood risk in the partial Danube River Basin was performed. The list of identified areas in risk is given in Tab. 4, location of main Slovak streams with flood hazard and flooding scenarios is in Fig. 5.

Table 4 Areas in flood risk within partial River Basin Districts

Partial River Basin District	Total number of areas	Number of areas with water courses/parts of water courses at		
		existing	existing and potentially possible	potentially possible
		important flood risk		
Dunajec and Poprad	5	4	1	0
Morava	23	16	7	0
Dunaj/Danube	1	0	1	0
Váh	75	44	18	13
Hron	21	21	0	0
Ipeľ	15	14	1	0
Slaná	11	10	0	1
Bodrog	23	16	5	2
Hornád	19	18	0	1
Bodva	2	1	1	0

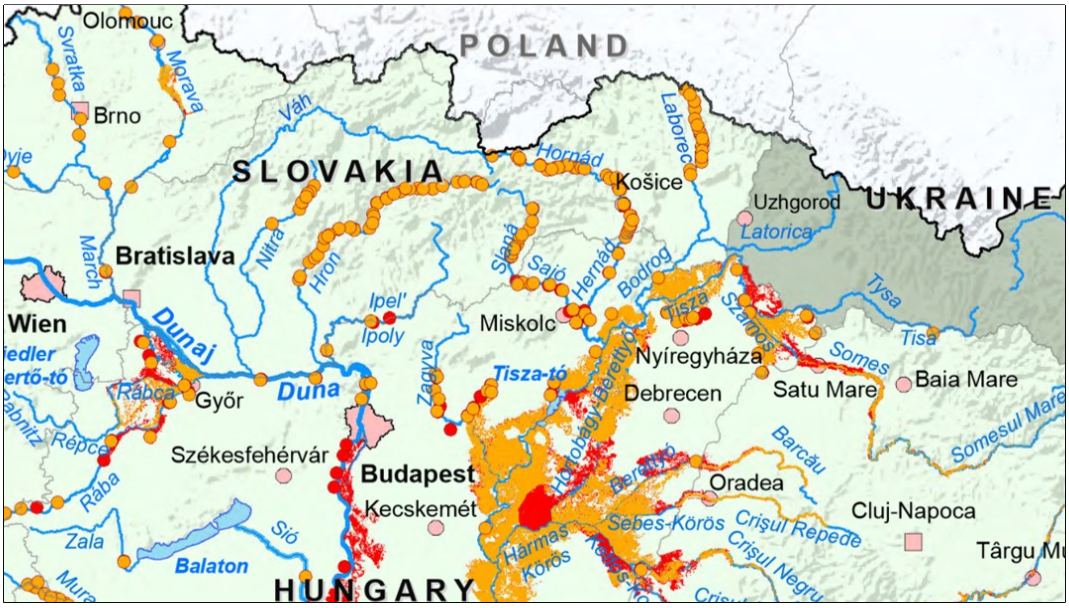


Fig. 5 Flood Hazard and Flooding Scenarios – Detailed view on Slovakia (Flood Risk Management Plan for the Danube River Basin District, 2015)

Within the pilot site area there exists the area in Baka and Gabčíkovo with important flood risk in the Partial Danube River Basin District (Fig.6). 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

During floods, the water from the Baka - Gabčíkovo channel in cadastral area of Baka village inundates as a result of prolonged rainfall, when the groundwater table rises above ground level. At Q5 flow, water flows before the confluence with the Baka channel and covers the adjacent land up to the family houses. At Q10 flow, water from the channel is overflowed on the left side from rkm 2.17 and floods the land to family houses. At Q50 flow, the water rises in rkm 2.2 on the left side, in front of the bridge on both sides and behind the bridge also on both sides of the channel and floods the land near the family houses. With Q100 flow, water is spread around as in Q50 flow (Fig. 7). At Q1000 flow, the water from the channel inundates both sides up to the land of the family houses.

The Gabčíkovo - Topoľníky channel flows in cadastral areas of Gabčíkovo and Baka villages. The floods are the result in long-lasting precipitation, when the groundwater table rises above the ground level. In this channel, the water gently rises at Q5 flow on the right side and floods the agricultural land. At Q10 flow, the water rises in rkm 28.00 to the right and floods the agricultural land. At Q50 flow, water from the channel rises in rkm 26.5 and floods the agricultural land. At Q100 the water rises in rkm 26.5 and floods on the right and left side and at Q1000 from rkm 26.5 the water continuously floods the agricultural land on both sides of the channel (Anon, 2018;https://www.minzp.sk/voda/ochrana-pred-povodnami/manazment-povodnovych-rizik).

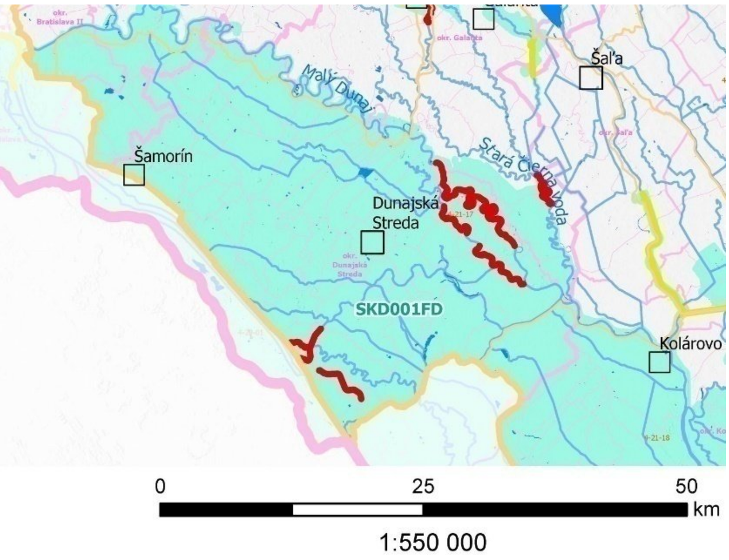


Fig. 6: Territory within the pilot site area with existing important flood risk (Anon, 2018)

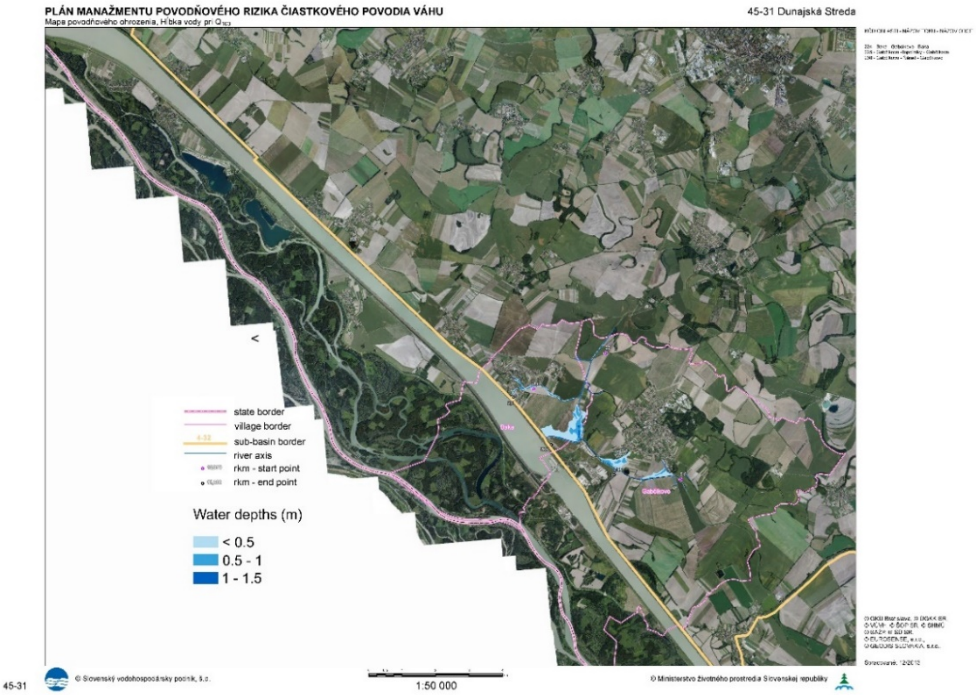


Fig. 7: Map of Flood Hazard for Q100flow in pilot site area (Anon, 2018)

3.5 Geology

The pilot site is located in the Slovak part of the Danube Basin, occurring in north-western part of the Pannonian Basin System. Geomorphologically, the Danube Basin is approximately equivalent to the Danube Lowland area. The shape of the Slovak part of the Danube Basin is the result of complex process associated, with polyphase back-arc rifting, post rift thermal subsidence and basin inversion (Šujan et al., 2021). The complicated development manifests itself in several, tectonically different depocenters (depressions). The largest, and deepest of them is the Gabčíkovo-Győr depression, which is tectonically bordered by the Malé Karpaty Mts. in the west, by the Trasdanubian Range in the east and by the Blatné, Rišnovce and Komjatice depressions in the North (Vass, 2002). The Gabčíkovo-Győr depression represents the study area for the pilot site.

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). In the deep structure of the basin the Neogene sediments discordantly overlie the Palaeozoic granitoid rocks (Fusán et al., 1987), and Neogene intrusive and extrusive volcanic rocks (e.g. the buried Kráľová volcanic field; Hrušecký, 1999) Deposition in the Gabčíkovo-Győr depression started with the late Badenian Báhoň formation, and was associated with the 2nd syn-rift phase. The sediments are represented by inner to outer shelf calcareous mudstones and sandstones of the epicontinetal Central Paratethys Sea. The deposition continues with shelf break-slope mudstones and brackish deltaic sandstones of Sarmatian age ranked to the Vráble Formation (3rdsyn-rift). At the end of the Sarmatian a pronounced erosional unconformity is recorded, and most likely connected, with the cessation of marine seaways into the area and onset on the extensive Lake Pennon. This process is most likely controlled by the transition from the 3rd to the 4th and last basin syn-rift phase. Thus, the beginning of the late Miocene (Pannonian), it is still affected by rifting, what resulted into deposition of deep basin calcareous mudstones, turbidite sandstones, and shelf break-slope mudstones of the Ivanka Formation. These are overlain by the sandy deltaic deposits of the Beladice Formation, which include thin lignite layers. The upper Miocene deposition ends with the sedimentation of Volkovce and the Pliocene Kolárovo formations, which mark the onset of thermal subsidence and basin inversion, respectively. These formations are dominated by alluvial mudstones, with rare sand and gravel channel-belt units (Šujan et al., 2016, 2018, 2021) (Fig.8).

The upper Miocene and Pliocene sediments are covered by 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 the thickness up to 50 m are represented by coarse gravels, sandy gravels and coarse-grained sands. The upper-most Pleistocene - Würm sediments have the thickness 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. Specific type of sediments are the recent anthropogenic deposits occurring in the urban areas.

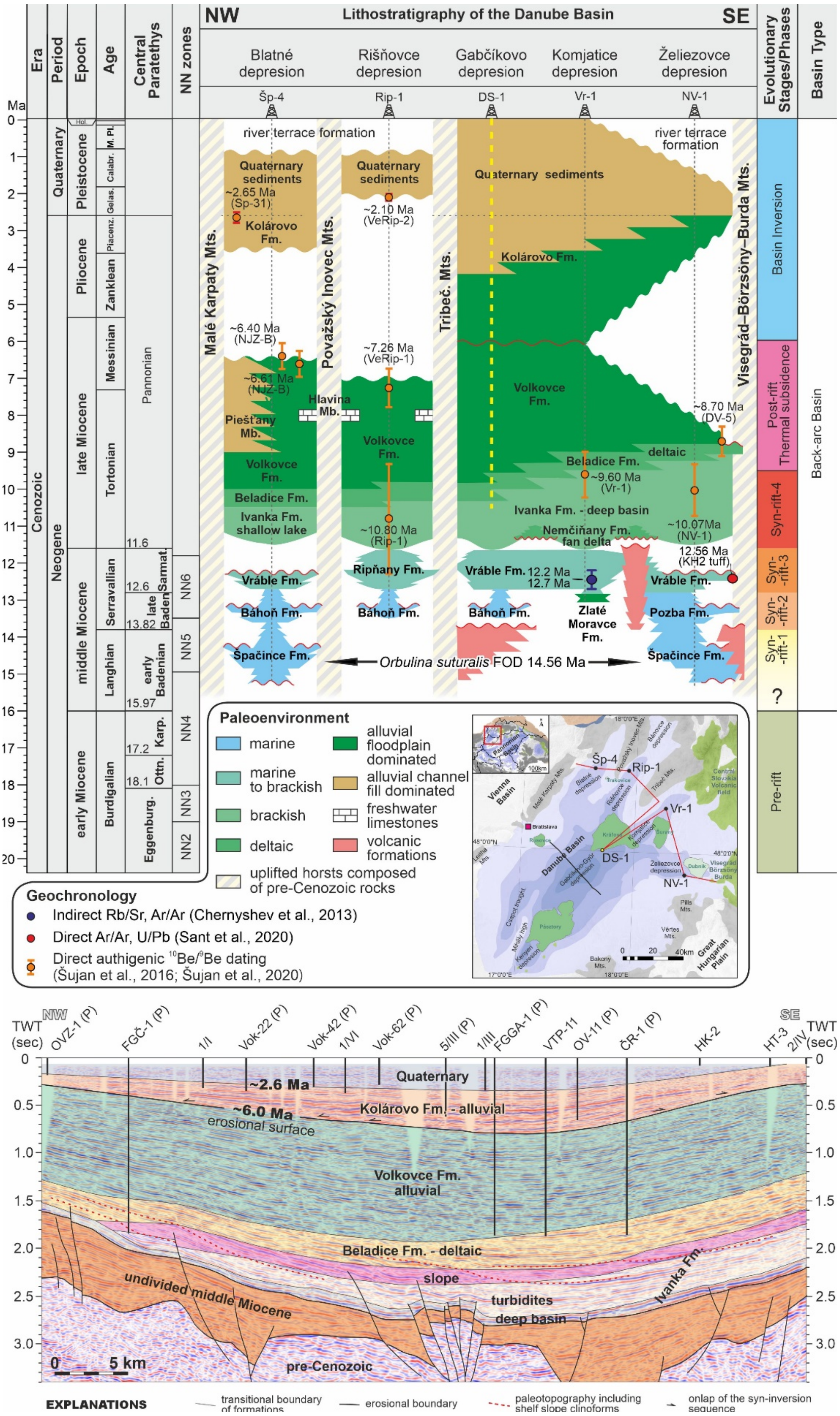


Fig. 8: Lithostratigraphic scheme of the Danube Basin and Seismic line 551/82-83 showing basin fill on the central Gabčíkovo-Győr depression according Šujan et al.,2021

3.6 Hydrogeology

The pilot site is the part of the hydrogeological rayon (region) *Q 052 Quaternary of the south-western part of the Danube Lowland* (Šuba & Mihálik, 1998). According to the Common Implementation Strategy of the Water Framework Directive (2000/60/EC) a distinction was made between Pre-Quaternary groundwater bodies and overlying Quaternary groundwater bodies in the process of groundwater bodies delineation in Slovakia. Third layer of geothermal groundwater bodies was also produced from existing hydrogeological data. The upper two layers of groundwater bodies differ from the geothermal one since they contain fresh water.

Due to complicated geological settings in the Danube basin, all three layers of groundwater bodies can be identified within the wider surroundings of the pilot site area. The upper-most groundwater body is the Quaternary groundwater body *SK1000300P Intergranular groundwater body of Quaternary sediments of the central part of the Danube Basin* (Decree of the government No. 282/2010 Coll., time version valid since January 1, 2020) with the area of 1668.112 km^2. Prevailing groundwater aquifers are alluvial and terrace gravels, sandy gravels and sands. Neogene aquifers in the area belong to Pre-Quaternary groundwater body *SK2001000P Intergranular groundwater body of the central part of the Danube Basin and its folders* (Decree of the SR Government No. 282/2010 Coll., time version valid since January 1, 2020) with the area of 6248.370 km^2. Prevailing groundwater aquifers are limno-fluvial sediments, mostly sands, gravels and clays. Agricultural land, including arable land, grassland, pastures and permanent crops plantations, shares 83,38 % of total groundwater body area, rest of groundwater body area land cover is represented by forests, semi-natural land, surface water tables and artificial surfaces. The third layer implies geothermal waters which belong to geothermal groundwater body *SK300240PF Geothermal waters of the Central depression of the Danube Basin* (Decree of the SR Government No. 282/2010 Coll., time version valid since January 1, 2020) covering the area of 3426.870 km^2. The main aquifers of the groundwater body are Neogene sands and gravels.

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, being 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 the 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. Larger thickness of loamy sediments with 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 already in 1959 within the hydrogeological investigation of the Žitný ostrov done by Bujalka and Drobáň. The average values of the hydraulic conductivity in the area between Čilistov and Gabčíkovo were estimated on 1.15*10^{-3} – 2.31*10^{-3} m.s^{-1}, in a few cases 3.47*10^{-3} m.s^{-1}. Later on, Jakubec (1967) estimated the average value of the hydraulic conductivity of the surface layer up to 30 depth on 3.0*10^{-3} m.s^{-1}and the conductivity of the zone deeper than 30 m on 2.8*10^{-4} m.s^{-1}. Benková et al. (2005) estimated the average values of the hydraulic conductivity coefficient in the wider area of the pilot site on 2.91*10^{-3} m.s^{-1} and the transmissivity coefficient on 2.96*10^{-2} m^2.s^{-1}. The same authors also investigated the change in hydraulic conductivity with the depth of the well screen location. They concluded, that increasing depth (0 – 25 m, 25 – 50 m, 50 – 100 m) lowers hydraulic conductivity – only within one order span. Finally, Némethyová et al. (2017) estimated the value of the hydraulic conductivity coefficient in well S-1, drilled within the pilot site at Horný Bar village to the depth of 15 m reaching coarse gravel water bearing aquifer. Resulting value was 5.619*10^{-3} m.s^{-1},and the value of the transmissivity coefficient was $3.65*10^{-2}$ $m^2.s^{-1}$, values were estimated using the method of grain size distribution curve.

Neogene sediments, mostly gravels, sandy gravels and sands of the Pannonian, Pontian, Dacian and Roman ages belong also to the important groundwater aquifers. They were found in the Žitný ostrov by more shallow wells (45 – 280 m), but also by deep wells (1000 – 2500 m). Neogene sediments do not occur on the surface. Benková et al. (2005) estimated values of the hydraulic conductivity coefficient for gravels in the central part of the Žitný ostrov on $1.44*10^{-3}m.s^{-1}$ and the transmissivity coefficient on $2.00*10^{-2}m^2.s^{-1}$, for sands the respective average values reached $2.08*10^{-4}m.s^{-1}$(hydraulic conductivity coefficient) and $3.59*10^{-3}m^2.s^{-1}$ (transmissivity coefficient).

Geothermal water was found in Gabčíkovo by the well FGGa-1 (Franko et al., 1984). The well was drilled in 1982 to the depth of 2582 m. As the aquifers, the Pontian sands were identified. The exploitation interval is situated at the depth of 1122–1926 m. The free outflow from the well reached 10 $l.s^{-1}$ of geothermal water with the temperature of 52 °C on the wellhead. Geothermal water is of Na-HCO_3 chemical type.

The Quaternary sediments have mostly the phreatic groundwater table, presence of clayey layers in Neogene sequences is the reason for occurrence of several horizons of Artesian groundwater. However, occurrence of aquifers in Neogene sediments is not regular and their interconnection is complicated, causing distinct anisotropy of filtration properties in the vertical and also in horizontal directions. Well yields of the Neogene aquifers are not high, they can reach from 0.1 up to several litres per second (Benková in Maglay, et al., 2017).

Chemical composition of fresh groundwater in the area of Žitný ostrov generally depends on (Benková et al., 2005):

- Chemical composition of the Danube (initial water)
- Length of infiltration pass of groundwater from the Danube River into Quaternary sediments, place and time of infiltration
- Character and intensity of the Little Danube (Malý Dunaj) and Váh Rivers influence
- Point and diffuse pollution sources, character of the land use
- Sources of iron and manganese in the rock environment
- Degree of bicarbonates content in Quaternary sediments.

Locally, the chemical composition of Quaternary groundwater within the pilot site depends on all mentioned factors, except of the Little Danube and Váh Rivers influence.

Groundwater in Quaternary sediments of the evaluated area can be generally characterized as fluviogenic water having origin of its chemical composition in infiltrating water from the surface water courses. The main cations are calcium and magnesium, values of iron and manganese contents are often increased. The main anions are bicarbonates and with lower values of sulphates. Presence of nitrites and nitrates indicates the anthropogenic pollution. Groundwater is of middle to high mineralization. The basic distinct Ca-HCO_3 and basic non-distinct Ca-(Mg)-HCO_3 chemical types prevail. There are four monitoring wells of the groundwater quality observation situated in the pilot site area: 6032 Gabčíkovo (with 2 observation depth levels labelled as 603291 and 603292), 6033 Mliečany (with 2 observation depth levels labelled as 603391 and 603392), 7312 Kostolné Kračany (with 2 observation depth levels labelled as 731291 and 731292) and 7336 Vrakúň (with 3 observation depth levels labelled as 733691, 733692 and 733695). Results of groundwater quality monitoring in the four wells within the period 2017 and 2018 (Ľuptáková et al., 2019) showed good water quality, according to inorganic compounds, over-limit values were measured for organic compounds in Vrakúň (PAU), Mliečany (anthracene) and Gabčíkovo (anthracene) in a few cases. As an example, results of chemical analysis of groundwater from the well S-1 at Horný Bar sampled in November and December 2017 (Némethyová et al., 2017) are given. Groundwater had weak alkali to alkali reaction with pH value 7.41 to 7.74, increased mineralization of 546 – 590 $mg.l^{-1}$, high electric conductivity of 860 to 862 $\mu S.cm^{-1}$. Groundwater temperature reached 12.9 – 13.0 °C. Chemical type of groundwater was estimated as basic, non-distinct Ca-Mg-HCO_3 to Ca-HCO_3 type (the value of A_2 Palmer index reached 56.93 – 58.17 c.z %), with an increased content of sulfate ions. The content of manganese was also increased. Concentrations of all monitored organic compounds were within the limits of the Resolution of the Ministry of Health of Slovakia No. 247/2017 Coll.

Neogene groundwater can be characterized as groundwater of petrogenic origin - carbonatogenic - of distinct A_2 type with the mineralization between 306.47 and 1059.7 $mg.l^{-1}$, the average value of mineralization makes 530.0 $mg.l^{-1}$. The continuous change in the chemical type of groundwater with the increasing depth was proven - from the Ca-(Mg)-HCO_3 type to Na-HCO_3 type (Bottlik et al., 2013). There are not monitoring wells on the groundwater quality of the state monitoring network located in the area of interest.

The main source for groundwater recharge in the area is the surface water of the Danube River. Water from the Danube infiltrates into the alluvial sediments and flows downward as groundwater through the Danubian Lowland, nearly in parallel with the Danube River. General flow direction is from the northwest to the southeast, even from the west to the east. In the lower part, where the slope of the river and the surrounding area decreases to one quarter of its gradient at Bratislava, the groundwater flows back into the Danube River via its own river branches, the Danube tributaries, and the drainage channels. All this occurs because of the lowered permeability, and lowered aquifer thickness downstream from Gabčíkovo. While the groundwater regime mainly depends on the river water regime, this dissipates with the distance from Danube. The influence of climatic conditions (precipitation, evapotranspiration) on groundwater table fluctuation is not important close to the river bed, however, the influence is more important for Quaternary aquifers in larger distances from the river (central part of the Žitný ostrov).

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. It was put into operation in 1992. The waterworks consists of the Čuňovo Dam, Hrušov water reservoir (headwater installations) with an area of 40 km^2, the bypass channel (headwater channel and tailwater channel), and the series of locks on the bypass channel (hydropower plants and navigation locks). The Hrušov water reservoir fills left-hand seepage channel, which is the water supply source for channel network of the Žitný Ostrov. There are six main partially interconnected channels, intersected by smaller ones.

Before the Gabčíkovo Waterworks started its operation, the decreasing trend in all groundwater monitoring objects was observed along the Danube River course in the alluvial plain between Bratislava and Medveďovo. The largest decreasing trends of groundwater table were observed in the upper part - between Bratislava and Kalinkovo. The operation of the Gabčíkovo Waterworks changed the decreasing trends into increasing ones in the area of Bratislava, in the upper part of the Žitný ostrov and in the direction towards the Little Danube. However, the decrease in groundwater table occurred in the area of Gabčíkovo (Mucha et al., 2004). At present, the groundwater depth in the wider surroundings of the pilot area varies between 4.5 – 7.0 m below 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).

The huge thickness of permeable Quaternary sediments in the Žitný ostrov allows to accumulate the largest amounts of groundwater reserves in Slovakia. 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 water source Gabčíkovo consists of 13 hydrogeological wells HAŠ-1 to HAŠ 13, which were drilled to the depth of 85 – 90 m during the period 1976 – 1984 (Fatulová, 1976; 1984). The amount of 3000 $l.s^{-1}$ was approved as usable groundwater amount of the water source Gabčíkovo, from which 473.3 $l.s^{-1}$ was used in 2019 (Slivová et al., 2020), see Tab. 3.

3.7 Aspects of existing infrastructure

Existing water supply infrastructure is highly influenced by structures (channels), which were built in the past, and pilot site area is highlighted in Fig.1. The primary drainage channel for collecting internal water of this region is the Gabčíkovo-Topoľníky channel 28.825 km long and its accumulation area covers 32 024 ha. The discharge capacity of the channel is up to 15.0 $m^3.s^{-1}$. It is mouthed – as it was mentioned above - into Klátovský branch and flowed into the Little Danube. It has three drainage channels which are located inside of the MAR area of interest:

- Vojka-Kračany channel
- Šuľany-Jurová channel and
- Trstená-Baka channel.

First two channels are more suitable for the MAR purposes because of installed control sluices. The Vojka-Kračany channel is 18.200 km long. There are five control sluices built along the channel to accumulate the water and control the surface water level regime during the vegetation period (artificial conditions). The sixth sluice is built up at the mouth of the channel into the primary Gabčíkovo-Topoľníky channel. The Šuľany-Jurová channel is 9.90 km long and there are two sluices built along the channel, as well. The third one (Trstená-Baka channel) is the shortest one – 2.469 km long – and there are not any sluices along the channel.

The most important aspect for the MAR project is the fact that all mentioned channels are supplied with water from the seepage channel of the Hrušov reservoir; i. e. with groundwater of high quality. This fact is so interesting because the water is supplied over the year. In winter time the sluices are pulled up to be protected against the frost (natural conditions) and they are put into operation in the spring time again (mostly in April or May).

The existing infrastructure of irrigation channels with water flow regulation tools (sluices) is the limiting factor for creation of a recharge dam MAR type. Due to this fact, this area was selected as a pilot site area.

3.8 Regulatory limitations

In Slovakia, there are no special regulations valid concerning MAR systems. The Ministry of Environment of the Slovak Republic is responsible for legal and administrative organisation of water policy. Directorate for Water Protection of the Ministry is responsible for implementation of water policy. There are institutions established by the Ministry, which participate in water policy implementation, namely: Water Research Institute (WRI), Slovak Hydrometeorological Institute (SHMU), Slovak Water Management Enterprise, Water Management Construction Bratislava, State Geological Institute of Dionýz Štúr, Slovak Environmental Inspection, Slovak Environmental Agency, as well as State Nature Conservation Agency. All these institutions together with regional and local environmental offices and municipalities share duties and responsibilities in various areas of water resources administration, monitoring, assessment, research and protection.

In case of MAR system installation/creation (e.g. in Slovak pilot site, i.e. recharge dam on existing channels), the Slovak Water Management Enterprise, state enterprise, has to be addressed. Water courses network in Slovakia is managed by this company that ensures maintenance of water courses and waterworks, cares for water quality and quantity, manages flood protection and navigation, etc. When abstracting surface water or groundwater for various purposes (e.g. irrigation), the state water management office i.e. Regional Environmental Office, Water Department (Office) has to provide approval. Permission to water abstraction (e.g. for irrigation) is issued in accordance with the Water Act (364/2004 Coll.) by the Office. The permission for groundwater abstraction is needed in case when water abstraction from one spring or the sum of groundwater abstraction from one groundwater body per one consumer exceeds 15 000 m^3 per year or 1 250 m^3 per month.

The water management office determines in permission the purpose, range, timeline and conditions for surface water or groundwater abstraction. The permission is issued for 10 years, in case the conditions have not been changed, the Office can prolong the permission. In permitting process of groundwater abstraction the Office must take into account the Resolution of the Ministry of Environment of SR on approval of final report on calculation of groundwater usable amount.

All water abstraction must meet the requirements of the Water Framework Directive goals implemented in the Water Act (364/2004 Coll.), i.e. to reach good water status. This comprises the water status monitoring. The surface water and groundwater monitoring is done in accordance with EC Directives, particularly the Water Framework Directive (2000/60/EC), Groundwater Directive (2006/118/EC) and Nitrates Directive (91/676/EEC). Monitoring is performed by Water Research Institute, Slovak Hydrometeorological Institute, Slovak Water Management Enterprise and State Geological Institute of Dionýz Štúr according to their competencies.

Surface water monitoring is performed in accordance with the Act No 364/2004 Coll. (Water Act); Act No 201/2009 Coll. (on state hydrological service and state meteorological service); Act No 7/2010 Coll., (on flood protection) and Government Regulation No 269/2010 Coll. (on requirements to achieve good status of waters), Government Regulation No 167/2015 Coll. (on environmental quality standards in the field of water policy), Government Regulation No 201/2011 Coll. (on technical specifications on chemical analyses and monitoring of waters); Government Regulation No 354/2006 Coll. (on drinking water standards) in accordance with Decree No 418/2010 Coll. of the Ministry of Agriculture, Environment and Regional Development of the Slovak Republic (on occurrence, monitoring and assessment of quantity and quality of surface water and groundwater).

Groundwater monitoring relates to item 4 of Collection of the Slovak Republic; Act No 364/2004 Coll (Water Act); Act No 201/2009 Coll. (on state hydrological service and state meteorological service); Act No 569/2007 Coll. (Geological Act); Act No 7/2010 Coll., (on flood protection); Government Regulation No 416/2011 Coll. (on assessment of chemical status of groundwater body) and Decree No 418/2010 Coll. of Ministry of Agriculture, Environment and Regional Development of the Slovak Republic.

When building MAR sites there are many aspects, which have to be covered – aquiring the land for a MAR site, administration of various interests, solving the conflicts of interests, evaluation of natural conditions, technical solutions, water demand and water supply. i.e. all aspects mentioned in feasibility study framework, so the team of professionals or company/companies could be involved in MAR system construction.

IV. Pilot action design plan

4.1 Aims

Referring to previous statements, the pilot site in Slovakia was planned to be located in a porous aquifer with the purpose of water use for agricultural production. Based on field investigation it was revealed that the selected pilot area in Zahorska Lowland (as originally stated in AF) has low dense network of small irrigation channels with limit technical tools for regulation of water flow. Podunajska Lowland was found as alternative pilot area with similar conditions, which has denser network of channels with much better infrastructure possibilities to reach the project goals.

The **aims of a desktop analysis for the Slovak pilot site area located in Podunajska Lowland** are to characterise the site from geological, hydrogeological, meteorological and sensitivity to extreme climate events viewpoints and to evaluate the water demand vs. water supply for agricultural purposes to be able to assess potential location/necessity of MAR scheme. Specifically, desktop analysis deals with:

- Collection of archive data (meteorological, climatological, geological, hydrogeological) in order to cover all necessary investigation to reach the project goal
- Evaluation of the archive data sufficiency in order to plan the field work investigation properly to gain the remaining information/data.

All the data/information will be used to assessment and quantifying the possibilities of aquifer recharge by

- assessment of soil hydraulic properties
- modelling of the surface water and groundwater tables interaction
- assessment of lateral range of infiltrated surface water impact on groundwater table based on data of investigated hydraulic conductivity of soil
- quantifying the volume of surface water infiltrated in groundwater i.e. quantifying the potential infiltrated water into groundwater for further uses
- overview of surface water quality for agricultural purposes and for infiltration into groundwater
- proposal of scenarios for technical regulation of water flow in channels to ensure groundwater recharge in the pilot area by surface water retention.

The works related to pilot site investigations and modelling will be carried out by the Water Research Institute (PP6) in cooperation with the Slovak University of Technology.

The archive data collected for the pilot site have been found in geological and hydrogeological supporting documents (maps, reports including data from more than 100 drills) and additional information on geochemistry of the waters. Moreover, the data on meteorology, climatology and hydrology were collected:

- daily precipitation in 2010 – 2019 (i.e.10 years) in Gabčíkovo station
- groundwater table in daily step in 2010 – 2019
- daily flow rate in channel - profile Gabčíkovo-Topoľníky in 2010 – 2019
- climatological data in 2010 and 2011 in Gabčíkovo station (average daily temperature, max. and min. daily temperature, average daily water vapour pressure, daily mean wind speed, daily sunshine duration, daily precipitation)
- water level from 32 wells (in the years 2008, 2010, 2018)

These data were provided by the State Hydrometeorological Institute and Geofond of State Geological Institute of Dionyz Stur. Moreover, the data on water demand will be collected from agricultural producers via questionnaires in cooperation with the Slovak Agrarian Chamber. These data will be used in cost-benefit analysis of MAR system.

Furthermore, pilot site field investigation was started in autumn 2020 and will continue by summer 2021. The field measurements will be comprised of the water flow and water level measurements in channels;

geometry of channels; soil sampling; measuring of soil properties and groundwater table in adjacent wells. Using mobile sampling equipment for soil sampling and groundwater table measurements, the lateral influence of surface water level fluctuation on the groundwater table will be investigated. Moreover, the experiment on assessment of the potential volume of infiltrated water into geological environment is planned, i.e. accumulation of the water between two sluices (creating recharge dam) and measuring the decrease of surface water level in time to evaluate the infiltrated volume of water.

Laboratory measurements to determine hydraulic conductivity of water-saturated soil by the method of variable hydraulic gradient, soil bulk density and its vertical distribution~~;~~ and calculation of soil water retention curves will be carried out.

Results of field and laboratory measurements will be used as input data to HYDRUS 2D and MODFLOW models. The measurements will provide data for model set up, boundary conditions and determine initial condition for numerical modelling of the surface and groundwater flow interaction. These data will be used for calibration of HYDRUS-2D and MODFLOW models (meteorological and climatological data, data of surface water levels, flows in channels, groundwater tables, and soil and rocks hydraulic properties).

4.1.1 Planned geological & hydrogeological and soil studies

Within this desktop analysis there will not be elaborated any special geological or hydrogeological studies. The information on geology and hydrogeology gathered from archive data of the State Geological Institute of Dionyz Stur involved in geological/hydrogeological reports, investigation and drills will be used for pilot site area characterisation.

In order to gain more precise information on hydraulic conductivity of soils to evaluate the amount of potentially infiltrated water, the additional soil sampling and soil properties measurements will be conducted in pilot site area (in embankments of channels and their neighbourhood). For this purpose a mobile sampling equipment for soil sampling and groundwater table measurements will be used. The aim of soil hydraulic conductivity measurements is to investigate the lateral influence of surface water level fluctuation to groundwater table and potential volume of infiltrated water from the recharge dam.

Soil properties measurements

The aim of the field research is to investigate the hydraulic conditions of the rocks surrounding of the channels and in the channels (bottom and banks) that allow recharging the groundwater. Soil hydraulic conductivity is an important parameter for identification of the soil type. Knowing specific soil type is the crucial input parameter to HYDRUS-2D model. Finally, the methods will be used to determine hydraulic conductivity of soil - the Auger hole method and Guelph permeameter, or by Decagon instrument (all performed in the field). Laboratory measurements of hydraulic conductivity of soil (K_s) using soil samples sampled in the field will be the next step.
Soil water content measurements will be done by the method:

- FDR sensor up to 1m depth (10, 20,30, 40, 60, 100cm)
- Capacitance method (at depths as above)

Gravimetric method will be used for sensors calibration and verification of their results. Evaluation of soil parameters by the drilling set up to the groundwater table depth is also going to be performed.

Water level/flow in channels & groundwater table

Field measurements will deal with natural state (no technical interference) and artificial state (using sluices to increase water level in channels, i.e. creating recharge dam) of water level and discharge regime in a part of Žitný ostrov region. These measurements will provide data on boundary and initial condition for numerical modelling of the surface and groundwater flow interaction, calibration of model related to surface water levels as well as for scenarios creation of possible groundwater recharge in pilot area via technical control. For discharge measurements FLO-MATE and FLOW-TRACKER devices will be used. The upcoming field measurements of water level and discharge regime in the channel system of the pilot area described above will start in the spring time before initialising control sluices (probably end of April) and then in June 2021 after closing regulatory sluices. Results of measurements will be evaluated in the summer 2021 and they will be used for validation of the numerical model.

Water chemistry

Based on archive data the water chemistry of surface water will be assessed, i.e. quality of the irrigation water for agricultural purposes in accordance with the Governmental Decree 269/2010 Coll., amendment 2. According to this Decree the irrigation water is defined by limits in accordance with technical standard STN 757143 which correspond to 1st quality level. i.e. water suitable for irrigation. The technical standard distinguishes among 3 classes of water for irrigation:
1st class – suitable for irrigation
2nd class – conditionally suitable for irrigation
3rd class – unsuitable for irrigation.

All above-mentioned information will provide background knowledge for field work planning, modelling of conditions in pilot site and assessing the suitability of potential MAR location.

4.1.2 Planned numerical modelling

Field measurements and archive data will provide information to set up boundaries and determine initial condition for numerical modelling of the surface and groundwater flow interaction. They will be used for calibration of models based on meteorological and climatological data, data on surface water levels, flows in channels, groundwater tables, and soil and rocks hydraulic properties. HYDRUS -2D and MODFLOW models will be used to verify the natural conditions and prepare trends for the future.

MODFLOW model with GMS

MODFLOW is a computer program that numerically solves the three-dimensional groundwater flow equation for a porous medium by using a finite-difference method (Harbaugh et al., 2000). MODFLOW uses a modular structure. The modular structure consists of a Main Program and a series of highly independent subroutines called "modules." The modules are grouped into "packages." Each package deals with a specific feature of the hydrologic system, which s simulated, such as flow from rivers or flow into drains etc. (McDonald, Harbaugh, 1988).

The MODFLOW model will be created in the Groundwater Modelling System (GMS) software, which allows us to use the conceptual model approach.

In addition to the Basic package, which handles several administrative tasks for the model, the following packages will also be used (the list may not be complete):

- River package, which simulates the effects of flow between surface-water features and groundwater systems. Input data: hydraulic conductance of the stream-aquifer interconnection (in GMS per unit length) calculated from the thickness of the riverbed, width of the river and hydraulic conductivity of the riverbed material; the water level in the stream; the elevation of the bottom of the streambed.

- Recharge package, which is designed to simulate regularly distributed recharge (most commonly precipitation) to the groundwater system. Input: recharge flux (in units of length per unit time).

In the Basic package, the IBOUND will be used to represent the Dirichlet -the first-type boundary condition with specified head, specifically a combination of IBOUND, which is used to identify specified head boundaries, and STR, which gives the head at those boundaries (the measured groundwater table in boreholes).

HYDRUS-2D

The HYDRUS model is a mathematical, deterministic model simulating the transport of water, heat and various dissolved substances in variably saturated porous media (soil) (Šimunek, et al., 2013). Model HYDRUS can be applied as one dimensional (HYDRUS ZMENY VYUŽÍVANIA PÔDY OKRESU DUNAJSKÁ STREDA A VYBRANÉ DOPADY TRANSFORMAČNÝCH PROCESOV-1D), as well as two and three dimensional (HYDRUS- 2D/3D).

Those models can estimate infiltration, evapotranspiration, plant water uptake, surface runoff and groundwater recharge as well. The groundwater recharge calculation by water in channels is the purpose of this project.

This issue has to be formulated as three-dimensional transport of water from channels to aquifer. It can be solved simple and sufficiently as two-dimensional infiltration of water from channels into aquifer, to model infiltration from channels through their bottom and banks. Two-dimensional approach is simpler, and can lead to more exact results (Radcliffe and Šimunek, 2010). This approach allows involving channel bottom sediments and soil variability in vertical dimension into calculation.

The input data into HYDRUS-2D model are - hydro-physical characteristics of soil (saturated/unsaturated hydraulic conductivities, soil water retention curves); properties of plants (leaf area index-LAI, roots mass distribution); and climatic characteristics at standardised height above the field surface (air temperature, air humidity, wind velocity). Then, changing of groundwater table position during aquifer recharge by infiltration from channel can be calculated by the model HYDRUS--2D.

Both models will be used to pilot site modelling, performed by the Water Research Institute (HYDRUS-2D) and the Slovak University of Technology (MODFLOW). This kind of modelling enables double-checking of groundwater table fluctuations; reveals the influence of infiltrated surface water to groundwater table and provides higher reliability of results. After calibrating the models, predictions of potential volume of infiltrated water (i.e. managed aquifer recharge) in variable surface water level conditions can be assessed in the future.

V. Summary and Conclusions

The pilot site in Slovakia was planned to be located in porous aquifer with the purpose of water use for agricultural production. Originally planned in AF, Zahorska Lowland, was changed to Podunajska Lowland due to similar geological and hydrogeological conditions with much better technical tools to regulate the flow in irrigation channels. i.e. creating the recharge dam MAR site.

The aims of desktop analysis of pilot site area located in Podunajska Lowland were fulfilled. Within this analysis there were summarised relevant available archive data. These data were used for pilot site area characterisation, mainly characteristic of its geomorphology, climatic conditions, land use, hydrology, geology and hydrogeology. Aspects of existing infrastructure and regulatory limitations were also considered. Within this desktop analysis there have not been elaborated geological or hydrogeological studies. The information on geology and hydrogeology to characterise the pilot site were collected from archive data of the State Geological Institute of Dionyz Stur involved in geological/hydrogeological reports, investigation and drills. Specifically, desktop analysis dealt with collection of archive data in order to cover all necessary investigation to reach the project goals, and with evaluation of the archive data sufficiency in order to plan the field work investigation properly to gain the remaining needed information/data.

To gather all necessary data for modelling, the additional fieldwork measurements and soil sampling have been performed. Moreover, more precise information on soil hydraulic conductivity in order to evaluate the amount of potentially infiltrated water is needed, so the additional soil sampling and soil properties measurements will be done in pilot site area. For this purpose a mobile sampling equipment for soil sampling and groundwater table measurements has been used. Consequently, we performed laboratory measurements on the samples to investigate soil hydraulic properties. The aim of soil hydraulic conductivity measurements is to investigate the lateral influence of surface water level fluctuation to groundwater table and potential volume of infiltrated water from the recharge dam.

Field measurements and archive data provide information to set up boundaries and determine initial condition for numerical modelling of the surface and groundwater flow interaction. They will be used for calibration of models (meteorological and climatological data, data on surface water levels, flows in channels, groundwater tables, and soil and rocks hydraulic properties). HYDRUS-2D and MODFLOW models have been used to prepare trends of groundwater table fluctuation for the future.

Desktop analysis is a prerequisite step in proper planning of the work, looking for suitable technical solutions and successful feasible construction of MAR systems.

VI. Literature

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