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**UNIVERSITY "SS. CYRIL AND METHODIUS" IN SKOPJE**  
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**ХИДРОГЕОЛОШКО МОДЕЛИРАЊЕ ЗА РАЗГРАНИЧУВАЊЕ НА ЗАШТИТНИ  
ЗОНИ КАЈ ПОДЗЕМНИ ВОДНИ ТЕЛА**  
**HYDROGEOLOGICAL MODELING FOR DELINEATION OF PROTECTION  
ZONES FOR GROUNDWATER BODIES**

Doctoral thesis

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## List of Abbreviations

°C	Degree Celsius
A-A'	Profile lines
B-B'	Profile lines
C-C'	Profile lines
CDI	Community Development Initiatives
CWS	Community Water Supply
DI	Dorsch International Consultants GmbH
E	East
EPA	US Environmental Protection Agency
GPS	Global Positioning System
GW	Groundwater
GWPZ	Groundwater Protection Zone
Hd	Dynamic Water
Hs	Static Water
i	Hydraulic gradient
K	Hydraulic conductivity
km <sup>2</sup>	Kilometer square
l/c/d	Liter per capita per day
l/s	Liter per second
m asl	Meters above sea level
m bgl	Meters below ground level
m/s	Meter per second
m <sup>2</sup>	Meter square
m <sup>3</sup> /d	Cubic meters per day
m <sup>3</sup> /s	Cubic meters per second
mg/l	Milligram per liter
mm	Millimeter
n [%]	Effective porosity
N	North
NCWS	Non-Community Water Supply
NGO	Non-Governmental Organization
NNW	North North West
NW	North West
PVC	Polyvinyl Chloride

Q	discharge [l/s]
R	Radius depression cone [m]
RWC	Regional Water Company
RWSSP-VI	Rural Water and Sanitation Support Programme phase VI
s	Drawdown
S	South
SDC	Swiss Agency for Development and Cooperation
SE	South East
SSE	South South East
T	Transmissivity
WHPA	Well Head Protection Area
WL	Water Level

## ABSTRACT

This doctoral thesis deals with hydrogeological modeling for the definition of groundwater protection zones in the southern well fields of Ferizaj (Varosh, Begracë and Gërlicë), with the aim of ensuring a sustainable and safe supply of drinking water for the local population. Given the vital importance of groundwater as a main source of drinking water and their sensitivity to anthropogenic pollution, the study aims to develop a numerical model of groundwater flow, which serves as a basis for the scientific delineation of protection zones according to the legislation in force.

The research includes the analysis of the geographical, climatic, geological, and hydrogeological characteristics of the study area, as well as the assessment of the hydraulic parameters of the aquifer (hydraulic conductivity, transmissivity, and effective porosity). The data were collected through preliminary documentary studies, field measurements of groundwater levels, pumping tests, and hydro-chemical analyses. On this basis, a conceptual model and then a computer model of groundwater flow were built, which were calibrated by comparing the calculated levels with those measured in the field.

The modeling results enabled the definition of Zone I (strict protection around the well), Zone II (based on the 50-day isochrone of water travel time) and Zone III (aquifer capture/recharge zone). For each well field, the spatial boundaries of these zones were identified, taking into account the direction of groundwater flow and local hydrogeological conditions. An assessment of the aquifer's sensitivity and a risk analysis from potential sources of pollution, including agricultural, infrastructural and industrial activities, were also carried out.

The thesis concludes with concrete recommendations for protective measures and sustainable management of water resources, emphasizing the need for control of activities within protective zones, continuous monitoring of water quality and integration of groundwater protection into spatial planning. The developed model represents an important tool for decision-making and can serve as a methodological basis for similar projects in other regions.

# 1 INTRODUCTION

## 1.1 Background

Water is an important and essential component of this universe and plays a vital role in the proper functioning of the Earth's ecosystems. Nowadays, water pollution is one of the global challenges that society must address in the 21st century, aiming to improve water quality and reduce human and ecosystem health impacts. With the rapid development of economies and industries, heavy metals pollution control has attracted considerable attention and still remains a serious perennial problem. Clean drinking water plays a very important role in the health of a community. Community access to clean drinking water can be improved by protecting drinking water sources and managing them to avoid contamination. While groundwater is in general more protected by nature from contamination than surface water, groundwater resources can be extremely difficult to clean up once they become polluted. This makes the protection of groundwater resources from initial contamination extremely important. Groundwater has, under natural conditions, mostly no adverse effects on human health and is therefore preferable as drinking water from any other source. It is for this reason in the public interest to protect groundwater from contamination or other interference to minimize public health risks and to conserve this valuable natural resource. Water is a primary resource for the presence of life on earth and access to clean water is critical for humans and the ecosystem. Nonetheless, during the last decades water quality has been negatively influenced by a continuously increasing population, rapid industrialization, increasing urbanization, and careless utilization of natural resources. Nowadays, water pollution is a serious issue because it affects our lives and is expected to get worse over coming decades. Organic matter, nutrients, pharmaceutical and personal care products, biocides, heavy metals, dyes, radionuclides, plastics, nanoparticles and pathogens are among the pollutants of major concern. Heavy metal ions are among the most released contaminants, and for this reason they are particularly worrisome. Heavy metals pollution control has attracted considerable attention and still remains a serious perennial problem, because they have high toxicity, stability in water media and posing a serious threat to human health and ecological systems. The sources of these pollutants can be natural and anthropogenic. Natural sources include the interactions with metal containing rocks, normally present in the environment, and volcanic eruptions. Anthropogenic sources include those associated with industrial (e.g., fossil fuel combustion, metal processing), agricultural (pesticides) and domestic activities. Pathogenic microbiological constituents (such as bacteria, viruses, parasites and worm eggs which cause water-borne diseases) frequently occur in areas with

insufficient sewage water treatment facilities in place. Water is monitored for such components on a regular basis to avoid adverse health effects of the population, and treatment facilities for pathogenic microbiological constituents nowadays are in place at most water sources. The effectiveness of water treatment for such components, however, highly depends on the presence of organic compounds and clay particles. The treatment of water for components such as nitrate, organic chemicals, metals, fertilizers, pesticides, etc. is very costly and also not always effective. Therefore the prevention of the occurrence of such pollutants in a source water area plays a key role in helping to protect the drinking water. Groundwater protection zones are defined in order to prevent contamination by substances and organisms hazardous to human health. Groundwater protection can, however, only be effective if land use development and land use planning take the needs for groundwater protection into consideration. Therefore appropriate actions must be considered in the early planning stages of groundwater development projects. For existing drinking water abstraction facilities restrictions for human activities have to be defined in order to minimize health risks. The allowance of activities in drinking water catchment areas has to be based on the principle of prevention of groundwater contamination and avoidance of adverse health effects. Zhang et al. [1] reported that to delineate wellhead protection zones is the key measures and core contents for groundwater protection, and it is also one of the foundations of decision-making for planning and management department. He presents their work about the urban water supply in Longkou city which is mainly from groundwater. The groundwater protection countermeasures for protection zones were put forward. It can give guidance for water resources management, land use, environmental protection and urban planning in Longkou city in the future. The method which he presents is also suitable for groundwater wellhead protection zones delineation in other places. Burgess et al. [2] has reviewed methods and experience gained in delineating GPZs for around 1000 groundwater sources in England and Wales. According to him, the large numbers of sources within a diverse number of hydrogeological settings has led to a structured approach to selecting the GPZ method appropriate to each groundwater source. By systematically examining the functional zoning and sustainable management of groundwater, the study which is focused on the planning area of Jining City establishes an evaluation index system for groundwater functional zoning by analyzing key factors such as resource supply function, geo-environmental stability function, and ecological environmental protection function, were developed by Chen et al. [3]. Gallyamov et al [4] article reveals the features of designing sanitary protection zones for underground water intakes for oil fields in Western Siberia using GIS technologies. The purpose of the first SPZ belt is to protect water wells and structures from accidental or

intentional contamination and damage, therefore, the first SPZ belt is limited to the territory of the site of water wells, treatment and water supply facilities. The size of the second SPZ belt was determined provided that bacterial contamination entering the captive aquifer beyond the border of the second belt does not reach the water intake during the survival time of microorganisms  $T_m$ , and the size of the third SPZ belt — based on the conditions of stable composition of pollutants in the water for the entire period of operation of the water intake. The task of establishing three zones of the water intake SPZ is to calculate the dimensions of the SPZ boundaries and apply these boundaries to the topobase of the area taking into account the general plan of the designed construction object. The appropriate division of underground drinking water source protection zones is a low-cost method of preventing water source pollution and ensuring a supply of safe drinking water, said Li et al. [5]. The Quinn et al. [6] report documents the creation of a numerical model of groundwater flow for Camp Ripley and hydrologically related areas to the west and southwest. The model relies on a hydrogeological conceptual model built on the findings of a University of Minnesota-Duluth drilling and sampling program conducted in 2001. Because of the site's stratigraphic complexity, a geostatistical approach was taken to handle the uncertainty of the subsurface correlation. The U.S. Geological Survey's MODFLOW code was used to create the steady-state model, which includes input data from a variety of sources and is calibrated to water levels in monitoring wells across much of the site. A scheme to ensure the protection of drinking water sources comprising the new pumping field supplying Esperanza and Rafaela cities in Santa Fe Province, Argentina, is presented by Del et al. [7]. The authors report that a 5–10-m radius was adopted for delineating the wellhead operational zones. To define the microbiological and surveillance zones, the fixed radius and Wyssling methods they applied, taking into account the groundwater travel time of 50 and 100 days, respectively. The results have shown that appropriate radii might be 70 m for the microbiological protection zone and 100 m for the surveillance zone. These values were obtained taking into account a pumping rate of approximately 60–70 m<sup>3</sup>/h. According to Nikiel et al. [8] an alternative method for the delineation of protection zones is the analytical elements method (AEM), which gives solutions like those obtained using FDM/FEM modelling methods with a relatively low degree of complexity. Groundwater protection must be a high priority in zones where contamination can easily enter the aquifer and affect a spring or pumping well used for the drinking water supply of a large population. The challenge of protection zoning is to identify these zones and assign them high priority, said Goldscheider et al. [9]. In their study Siarkos et al. [10] presents an assessment of the possible impacts of potential point sources of pollution on the groundwater quality in the watershed of N. Moudania. Next, the practice

implemented to delineate the wellhead protection zones is presented. This is a numerical modeling process that consists of a) the simulation of groundwater flow in the aquifer of N. Moudania by applying the three-dimensional finite difference model MODFLOW and b) the delineation of protection zones for the domestic water-supply wells by applying the particle tracking post-processing package MODPATH. Finally, suggestions are given for the control and management of the identified potential point sources of pollution, especially if they are located within the protection zones of the examined water-supply wells. Both size and geometry of WHP zones are controlled by several geological and hydrogeological parameters, which entail a synergetic effect. Within the parameters mentioned above, there are such as 1) pumping discharge; 2) aquifer thickness; 3) accessible porosity; 4) flow direction and the hydraulic gradient; 5) hydraulic conductivity; 6) the hydraulic connectivity of an aquitard. Nikulenkov et al. [11] said research shows all six factors perceptibly influence the results. The results from the study of Siarkos et al. [12] show that land use changes are always more expensive than implementing agroenvironmental measures. One aspect of German groundwater protection is the possibility to delineate up to four wellhead protection zones in the recharge area of a drinking-water well. Recent scientific investigations have shown gaps especially with regard to (a) the importance of the 50-days line, (b) the behaviour of micro-organisms and (c) the mobility and persistence of man-made pollutants said Schleyer et al. [13]. In his study, Ahmadi et al. [14] focused on the investigation of the drawdown cone and influence radius as two characteristics of the influence zone. Goodarzi et al. [15] in their study, evaluated the performance of the MODFLOW and WhAEM models in determining the protection zone of drinking wells for travel times of 2, 5, and 10 years. According to the results, the zones calculated by WhAEM model are always less than the zones calculated by MODFLOW model. In other words, the calculated zone by WhAEM does not consider some parts of the protection zone, which was calculated by the MODFLOW model in the upstream. This will increase the risk of contaminants entering the upstream side of wells. However, as WhAEM model is a user-friendly model and if there is no accurate information on the status of regional hydrogeology, with less cost and time consumption, the model performance is better than the MODFLOW model. Therefore, the WhAEM and MODFLOW models are efficient tools for the determination of the protection zone of drinking wells, which is essential in water resource management.

## **1.2 Statement of the problem**

In the study area of the Toplluha River catchment, groundwater research began in 1973 through piezometers and drilled wells. The aim of the research at the beginning was the use of groundwater for drinking, as well as in agriculture for irrigation. Since 2000, this water has been used only for drinking purposes, where several additional wells were built. Most of the city of Suhareka and some surrounding villages are supplied with drinking water through these unprotected underground wells. Their productivity is considered to be 20 l/s per well, where currently there are 5 wells in use meeting the water supply needs of approximately 17,000 inhabitants.

Although it seems that the area has enough potential to meet such a large and uncontrolled abstraction, it is evident that in the long term, with ever-increasing demand due to population growth, climate change, industrialization, changing standard of people's livelihoods and related decline. The amount of recharge will result in a drop in the groundwater level. The decrease in the level of underground water associated with the uncontrolled use of surface water for irrigation can disrupt the hydrological and ecological balance of the area.

In the study area of the Nerodime River catchment, groundwater research began in 2005, which also has the same destination, i.e., drinking water supply. A total of 14 wells and piezometers have been drilled in this aquifer, of which 6 wells are in use with a total capacity of 21.5 l/s, supplying drinking water to approximately 14,000 inhabitants.

So, it is necessary to model the groundwater flow of the above areas to project the risk of such an uncontrolled withdrawal into the hydrological system, in order to propose the necessary actions to mitigate such a problem, and also for the protection and efficient and sustainable resource management.

So, these models can be used as a tool for water resource managers to assess the regional effects of changing stresses on the steady state system. Furthermore, it improves the understanding of the groundwater system and the regional effects of different groundwater use alternatives on the water resources of the watershed.

## **1.3 Research objective**

General and specific objectives will be used during the study

## **1.4 General objective**

The general objective is to develop a numerical groundwater flow simulation model that best fits the natural groundwater system of the Nerodime and Toplluha catchments.

## **1.5 Specific objectives**

The specific objectives of the study are:

- Measuring the level of groundwater and determining the direction of movement,
- Calculation of hydrogeological parameters,
- Geological assessments of the study area,
- Preparation of the hydrogeological model,
- Using the calibrated method, the groundwater balance will be assessed,
- Based on the modeling of underground water, the second and third protection zone will be calculated
- 

## **1.6 Materials & Procedures**

To achieve the intended objective, appropriate methods were followed in three stages. The main stages of the activities are presented as pre-field, fieldwork, and post-field stages. By following these structured stages, the project ensures systematic planning, thorough data collection, and rigorous analysis, ultimately leading to reliable and actionable results.

### **1.6.1 Pre Field work**

At first, data will be collected in a desk study from all relevant stakeholders. This includes general conditions such as location of the study area, topographic maps, climatic information and land use. Understanding groundwater requires an idea of water flows above ground. Thus, hydrological data mainly on rainfall as well as location and characteristics of rivers in the study area are necessary. The water supply system for which the water source protection will be established must be understood. Is the water coming from a borehole, a spring or another source and how much is abstracted? Projections of future population data help to understand the future water demand and water abstraction for a well field.

Also, geological and hydrogeological information can be gathered through a desk study. Information on lithology and aquifer characteristics should always be included from literature in addition to field work. Especially maps, cross-sections and borehole-logs contain important information and save costly and timely investigations.

### **1.6.2 Field work**

No water source protection zone can be modelled without understanding the situation in the field. It gives the modeller a general understanding of how the model area will look like and helps to put desk study information into perspective. Several field visits are needed to combine desk study knowledge with the situation on the ground. Field work, however, is often necessary to gather information that could not be obtained through the desk study.

The extent of the field work depends on the quality and quantity of the desk study information. Some information such as hydro-meteorological or general geology must mainly be obtained through existing data from geological institutes and meteorological agencies, since obtaining such information from the field would exceed the scope of the study.

Other information such as borehole logs, pumping test results, water supply data, hydrogeological characteristics etc. are often available in the respective institutions and if not must be obtained in the field. Here, a careful desk study is relevant to ensure full utilisation of existing data.

A significant and indispensable dataset are several borehole water level measurements. Measuring the water level gives an insight into the groundwater level and its flow direction and is a key component for setting up and calibrating the model. In Kosovo, these values are often not available and thus a major part of the field study is to measure water levels in piezometer boreholes and private wells in the entire study area. If necessary, new boreholes must be drilled to gather groundwater level data, understanding of the lithology, and aquifer characteristics through pump tests. Groundwater levels must be gathered several times per year to understand seasonal variations. Further, fieldwork is also necessary to gather information on potential pollution sources.

### **1.6.3 Post Field work**

After the completion of the first and second phase, the acquired data will be processed and analyzed. Based on the data obtained, the necessary databases for modeling will be prepared. These data are presented schematically through the block diagram below.

## **1.7 Material Required**

- GIS software,
- AutoCAD software,
- Surfer software,
- Rock Works software,
- Aquifer Test software,

- Global Mapper software,
- Digital Elevation Model,
- Geology Map,
- Hydrogeology Map,
- Global Positioning System(GPS) –DEVICE,
- DEEP Meter

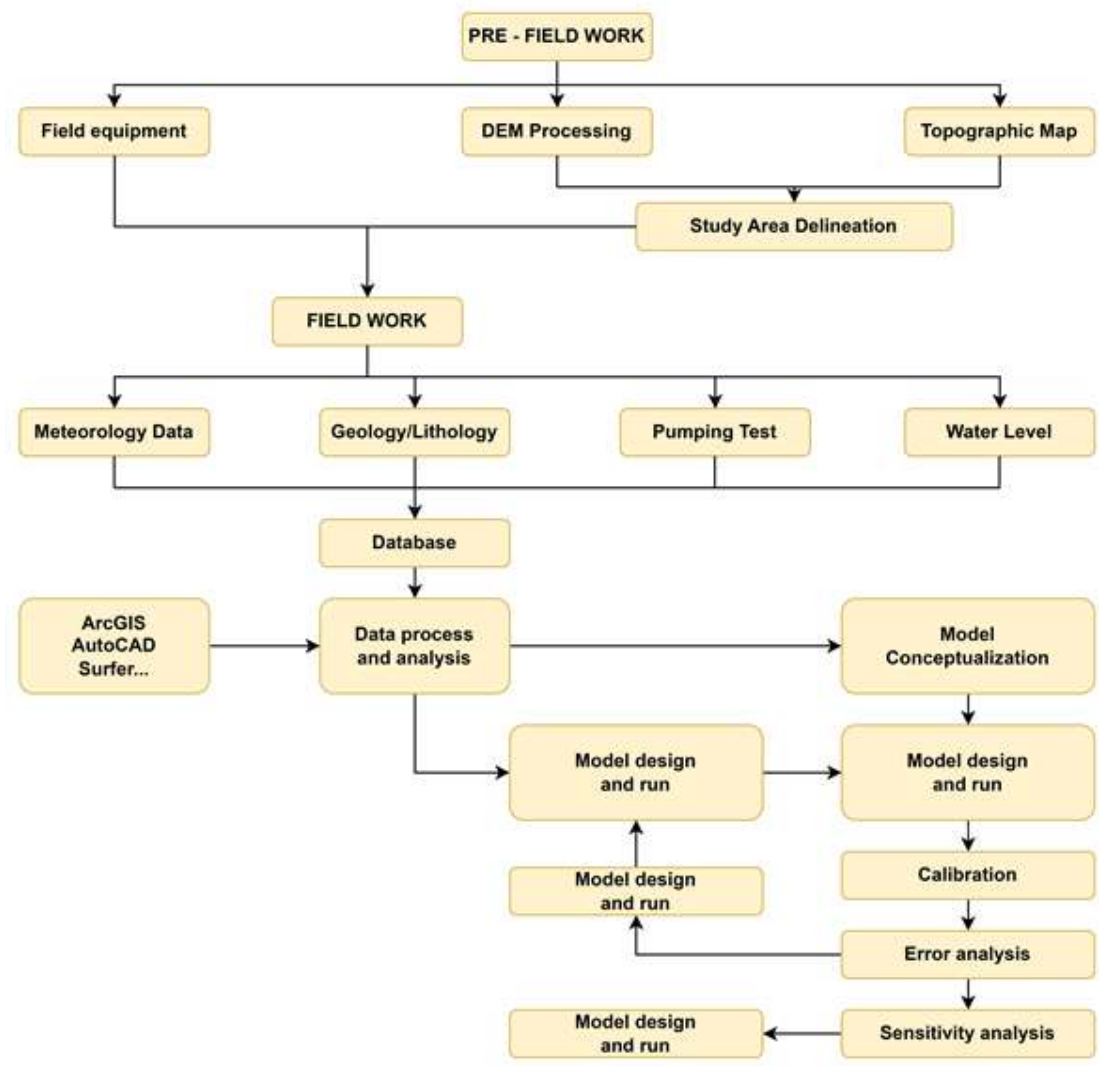


Figure 1: Methodology of Doctoral Thesis

## 1.8 Thesis outline

The research is sub divided in to nine chapters, and the contents are summarized briefly as:

### *Chapter 1: INTRODUCTION*

- Background information on the study

- Objectives and significance of the research
- Scope and limitations

***Chapter 2: GENERAL GEOGRAPHIC CHARACTERISTICS***

- Location and boundaries of the study area
- Physical geography (topography, climate, vegetation, etc.)
- Human geography (population, land use, infrastructure)

***Chapter 3: GEOLOGY***

- Geological formations and structures
- Types of rocks and their properties
- Historical geology of the area

***Chapter 4: HYDROGEOLOGY***

- Description of aquifers and their properties
- Groundwater flow systems
- Recharge and discharge areas

***Chapter 5: MATHEMATICAL GROUNDWATER MODEL***

- Development of the groundwater model
- Model parameters and calibration
- Simulation results and their interpretation

***Chapter 6: HYDROCHEMISTRY***

- Chemical composition of groundwater
- Sources and processes affecting groundwater chemistry
- Analysis of water quality data
- Results of vulnerability assessment

***Chapter 7: POLLUTION RISK FOR THE AQUIFER***

- Identification of potential pollution sources
- Risk assessment methodologies
- Impact of pollution on groundwater quality

***Chapter 8: PROPOSED DELINEATION OF PROTECTION ZONES***

- Criteria for delineating protection zones
- Design and implementation of protection zones
- Policy recommendations for groundwater protection

This structure ensures a thorough exploration of the topic, from fundamental geographic and geological information to advanced assessments and practical recommendations for groundwater management and protection.

## **2 GENERAL GEOGRAPHIC CHARACTERISTICS**

### **2.1 Geographic Position of the Explored Region**

The study area is located in the region Ferizaj/Uroševac covering the municipality of Ferizaj/Uroševac, and parts of the municipality Kačanik/Kaçanik, all positioned in the in the southern part of Kosovo.

The average height in the municipality is 850 m asl.

It is the crossroads of important roads connecting to Pristina in the north, to Skopje in the south, to Prizren and Peja in the west and to Gjilan/Gnjilane in the east.

Distance to these cities are:

to Pristina: 38 km

to Skopje: 48 km

to Gjilan//Gnjilane: 32 km

to Prizren: 70 km.

The model area “Southern Ferizaj wellfield” has an extent of 20 km East-West and 10 km North-South, covering 214 km<sup>2</sup>. It comprises the watershed of the Nerodime River and in the south some smaller area of the northern part of Lepence River’s watershed. In the south the area is limited by a geologic fault line, close to Kačanik/ Kačanik. Figure 2 shows the geographic position of Ferizaj/Uroševac municipality with surrounding municipalities.

The municipality of Suhareka/Suvareka is located in the southern part of Kosovo. It has boarders to the municipality of Prizren/Prizreni, Rahovec/Orahovac, Malisheva/Malishevo, Lipjan/Lipljane, Shtime/Stimlje, Ferizaj/Uroševac and Shterpce/Strpce. The Coordinates N 42° 15'– National Park "Sharri" (south), N 42° 30' – Berisha’s mountains and Javori (north) are limiting it’s N-S extend. W 20° 45'- municipality of Rahovec/Orahovac and W 21° 00'- Jeerci’s mountains, Guri I Dellocit are limiting the municipality to east and west Figure 3.

The municipality Suhareka/Suvareka is surrounded of high mountains; to the north-west the Pagarusha mountains and the Temeqine mountains with altitudes of 796 m.a.s.l to 828 m.a.s.l; to the north the Caraleva mountains with altitudes of 922 m - 1.048 m, to the east the Jezerci mountains of 1.677 m altitude, and to the south-east the mountains of Sharr of 2092 m altitude (dera e Pashes). To the west the valley of Prizren/Prizren opens up. The average altitude in the municipality is 455 m. the city of Suhareka/Suvareka has an altitude of 400 m. The surface of this municipality is 361 km<sup>2</sup> and covers 3.3% of the territory of Kosovo.

15.074 ha or 41.7 % of the municipalities surface of 36.099 ha, are covered with forests; 19.373 ha or 53.7 % are agricultural lands and 1.652 ha or 4.6% others.

Several important roads connecting the capital city Pristina to the regional city Prizren/Prizreni continuing to Albania are crossing the municipality.

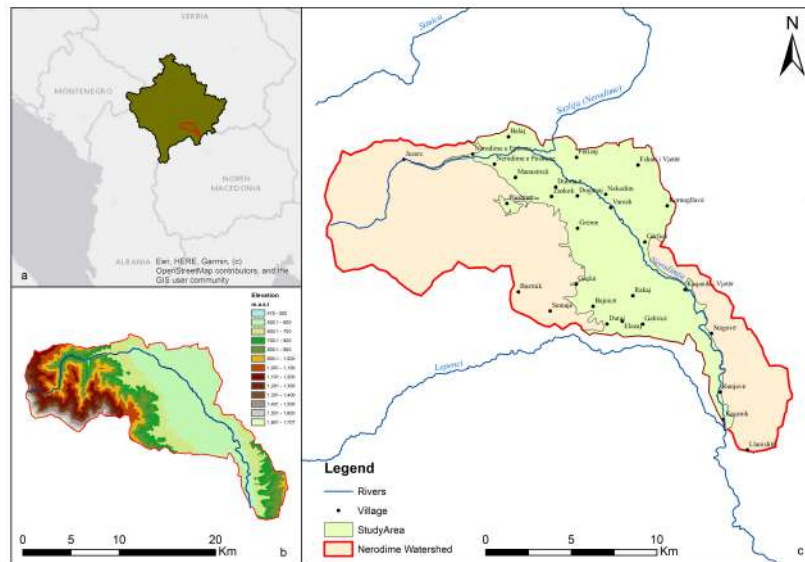


Figure 2: Geographic position of Ferizaj/Uroševac with surrounding municipalities.

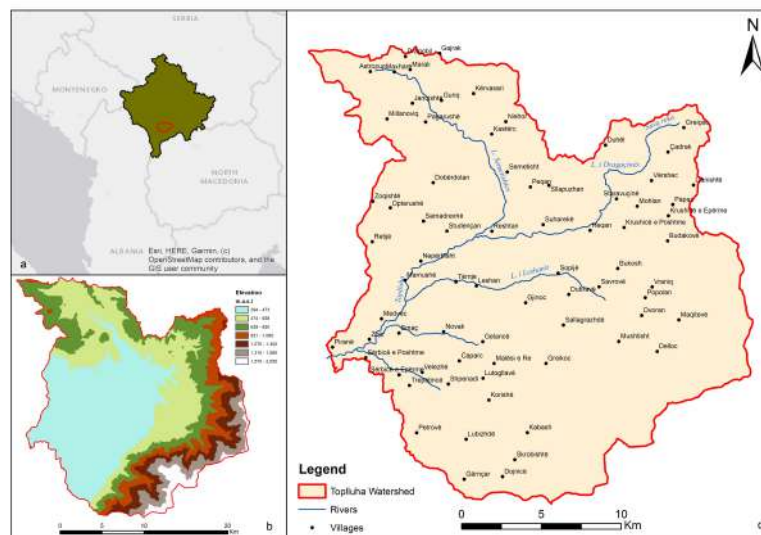


Figure 3: Geographic position of Ferizaj/Uroševac with surrounding municipalities.

## 2.2 Climatic Conditions

Both regions are characterized by an average continental climate, with relatively hot summers and moderately cold winters. For analyses of climatic parameters, the data from the “Hydro meteorological Yearbook 2012-2022” of the Ferizaj/Uroševac and Prizren/Prizreni weather stations have been used.

### 2.2.1 Temperature

Ferizaj/Uroševac is characterized by hot summers and cold winters. The long-term average shows that the temperature in January is  $-0.65\text{ }^{\circ}\text{C}$ , while the average temperature in August is  $+21.81\text{ }^{\circ}\text{C}$ . The comparison between the long-term averages (2012–2021) and the data from 2022 shows that temperatures during most months of 2022 were generally slightly higher than the long-term average, particularly during spring and summer. Winter months were closer to the long-term average values. The graph from the Ferizaj/Uroševac weather station showing the long-term average air temperatures (2012–2021) and the values for 2022 is presented below in Figure 4.

Suhareka/Suvaroka also is characterized by hot summers and cold winters. The two-year average shows a temperature in January of  $-0.8\text{ }^{\circ}\text{C}$ , while the average temperature in August is  $+22.9\text{ }^{\circ}\text{C}$ . The comparison between the two-years-averages and data from 2018 indicates temperatures in spring and autumn 2018 were slightly warmer than the two-year average. In summer 2018, temperatures were cooler than on average. The graph from the Suhareka/Suvaroka weather station is shown below in Figure 5.

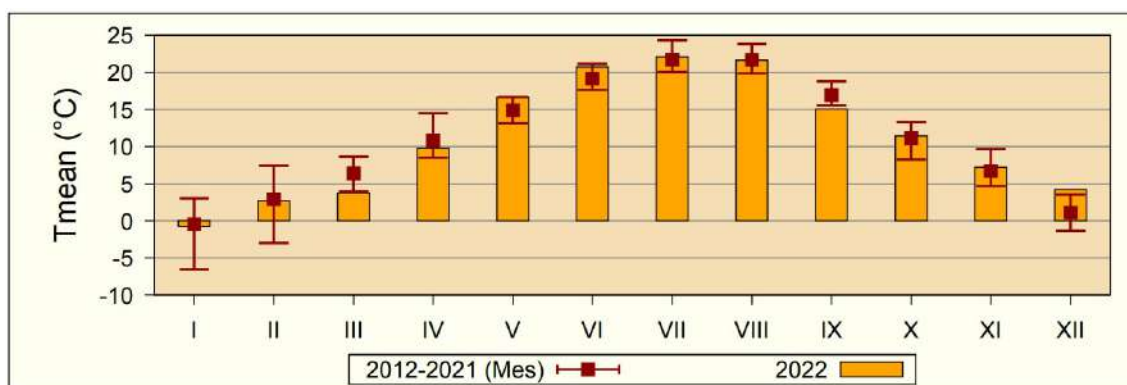


Figure 4: Monthly Temperature values for the study area of Ferizaj/Uroševac.

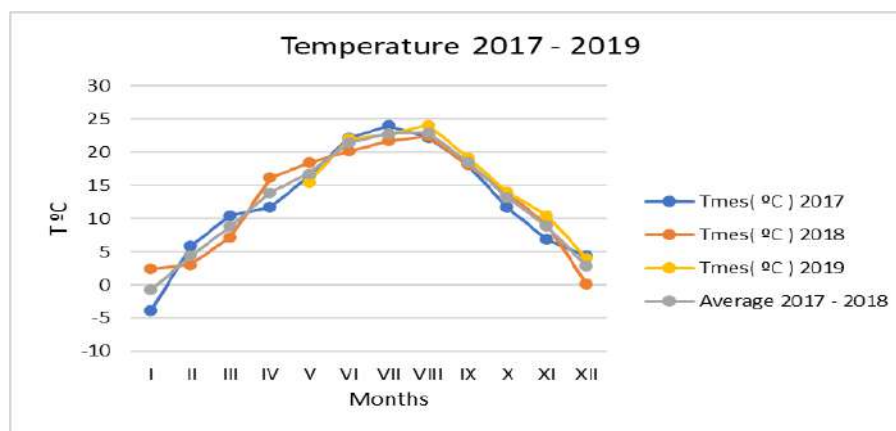


Figure 5: Monthly Temperature values for the study area of Suhareka/Suvaroka

### 2.2.2 Rainfalls

The rainfall for long-term averages (2012–2021) and the year 2022 is shown in Figure 6. The driest month in the long-term average is August with about 44 mm of precipitation. In November, the precipitation reaches its peak, with an average of about 63 mm. Precipitation varies by around 19 mm from the driest to the wettest month. In 2022 the wettest month was June with over 200 mm of precipitation, while the driest month was August with around 30 mm of rain. Especially the summer of 2022 was much wetter compared to the long-term average.

The rainfall averages over six years and the annual rainfall of years 2014 to 2019 is shown in Figure 7. Precipitation reaches its peak in November with an average of 93.2 mm while the driest month December shows 45.5 mm. In 2019 highest precipitation was in June with 139.2 mm while the lowest precipitation happened in March with 12.3 mm of rain.

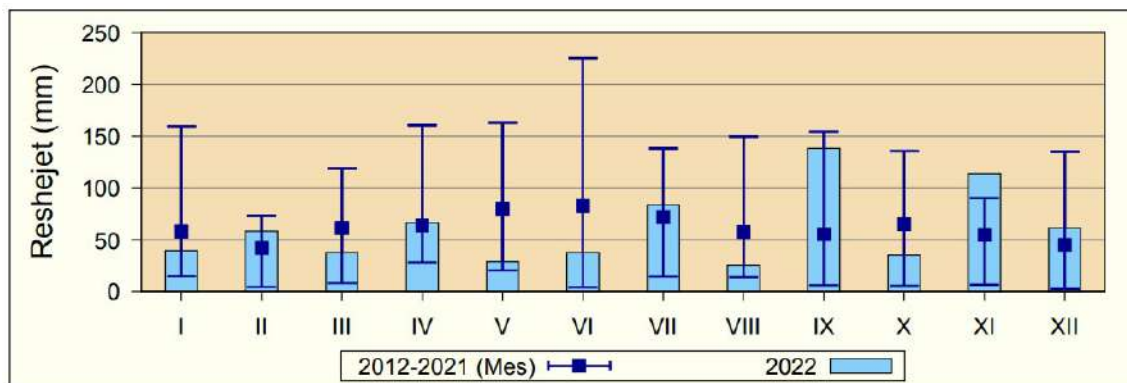


Figure 6: Monthly rainfall values of 2018 for the study area of Ferizaj/ Uroševac.

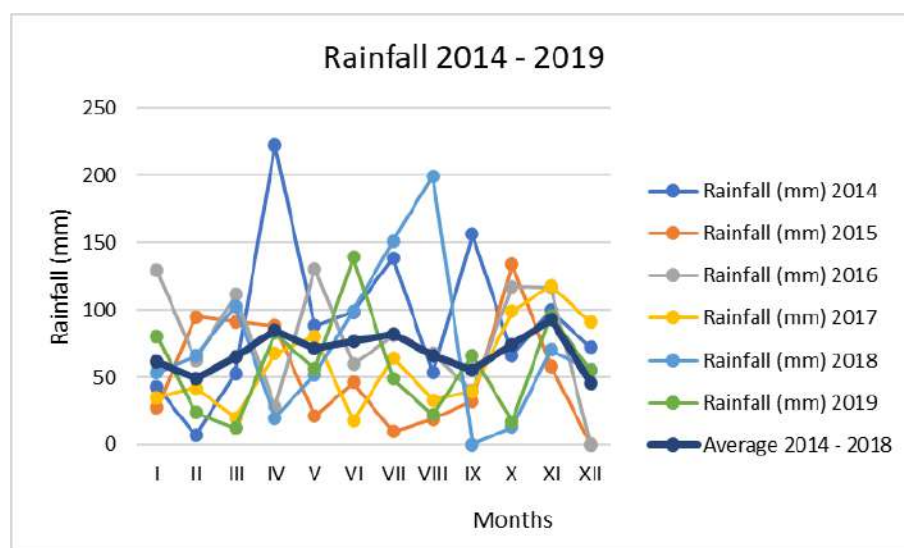


Figure 7: Monthly rainfall values of 2018 for the study area of Suhareka/Suvareka

### 2.2.3 Winds

The most frequent winds in the region of Ferizaj/Uroševac are those from the north-west with 226 degrees while the rarest are those from south, east, and north. Figure 8 shows a wind-rose for the study area.

The most frequent winds in the region of Suhareka/Suvareka are those from the north-east while the rarest are those from north-west. Figure 9 shows a wind-rose for the study area.

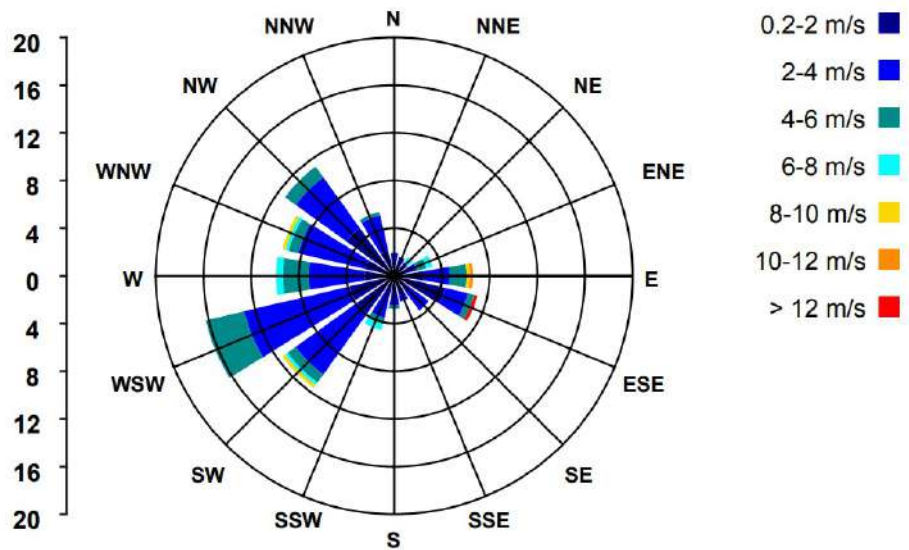


Figure 8: Wind rose for the Study area of Ferizaj/Uroševac.

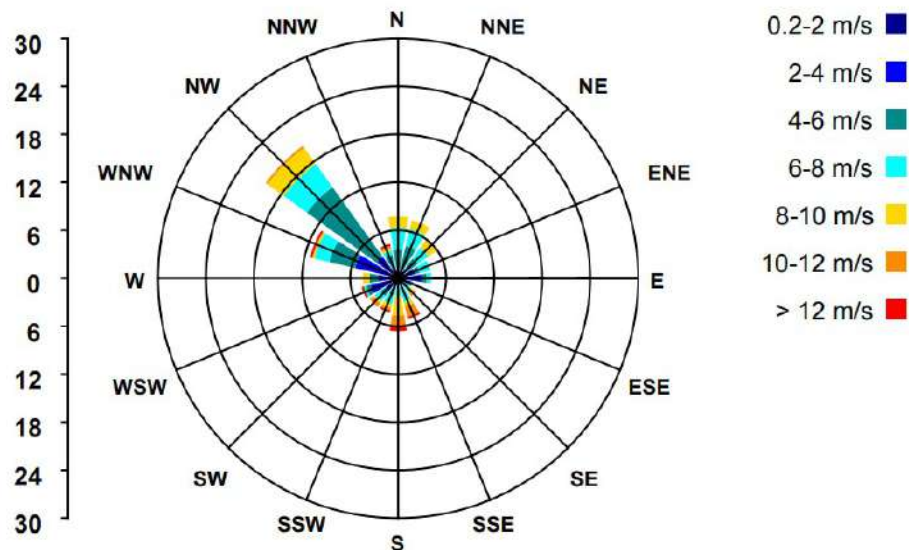


Figure 9: Wind rose for the Study area of Suhareka/Suvareka

### **2.3 Hydrographic Features of Ferizaj**

The surrounding area south of Ferizaj/Uroševac is considered as the southern end of the “Kosovo Basin” and connects it to Morava area. The region borders the Sharr Mountain in its southwest, Karadak and Anamorava to its east, and the Drenica Mountains to its northwest.

Numerous rivers and streams run through the municipality’s territory. The main river is Nerodime, coming from North crossing through the town of Ferizaj/Uroševac and continuing its flow further to south. The river is covered within the city. The altitude of the river in Ferizaj/Uroševac is 580 m asl.

Nerodime River is an important branch of the Lepence River, tributary of the Adriatic basin. The Nerodime River source is at the southern foot of Nerodime Mountain, at an altitude of 1,200 m, with an average discharge rate of 0.9 m<sup>3</sup>/sec. The length of the Nerodime River is 29 km; the catchment area covers 255 km<sup>2</sup>. According to measurements in May 2007 the discharge rate is 0.848 m<sup>3</sup>/sec. In August, the yield reduced to 30 l/s (Komuna e Ferizajit, 2017).

The Nerodime River is a weak stream due to a Bifurcation, an important geographic phenomenon, separating its water towards the Mediterranean and towards the Black Sea. The bifurcation is located 1 km northwest of Ferizaj/Uroševac, close to a location called “Nika’s Mill” (first described in 1321) (Komuna e Ferizajit, 2017).

Another river in the region of Ferizaj/Uroševac is the Pleshina River, which joins the Nerodime close to the village Gërlicë/Grlica.

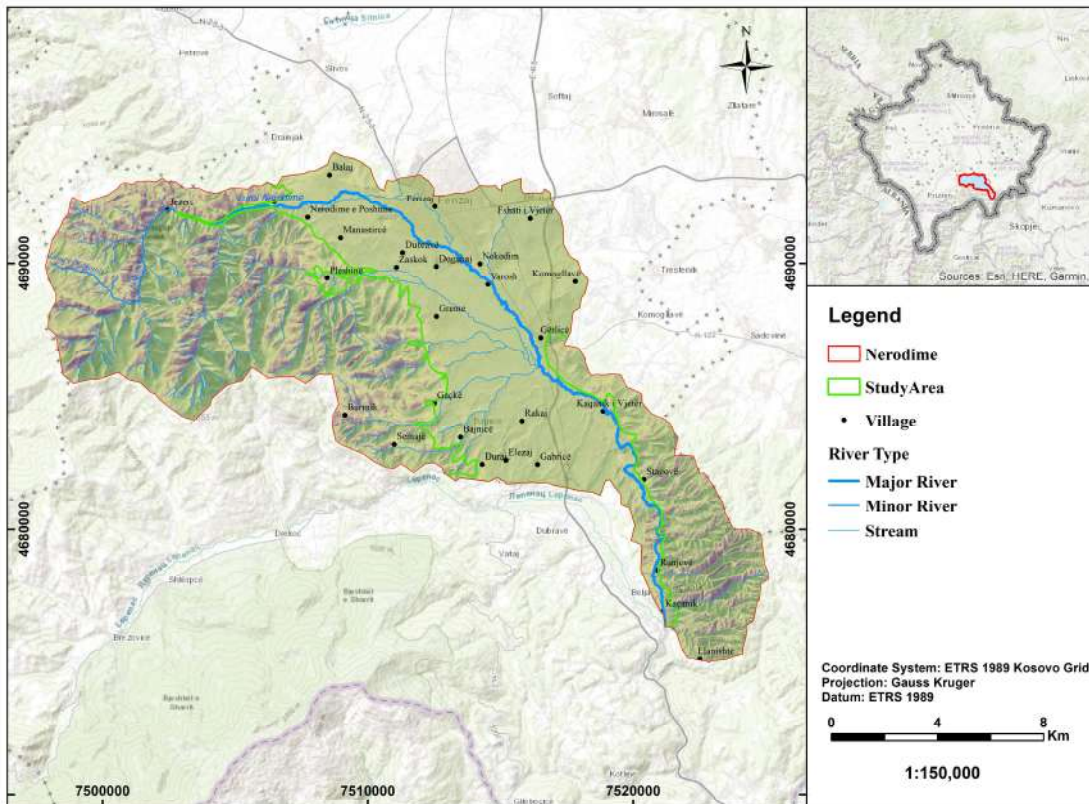


Figure 10: Hydrographic map for the Study area of Ferizaj/Uroševac.

## 2.4 Hydrographic Features of Suhareka

The municipality of Suhareka/Suvareka has a well-developed hydrographic network with a large number of rivers (streams) that pass through the territory of the municipality.

Small rivers with characteristic mountain stream patterns show a large oscillation of the quantity over the year. During the dry season in most of these rivers small amounts of water pour down the river beds, in some cases the surface remains dry while during the rainy season these river beds often cause local floods.

To the exception of the rivers Čërrnaleva, Topilla and Bllaca, all other rivers have their source in the territory of the municipality of Suhareka/Suvareka.

The largest river in the municipality and the main hydrographic artery is the Toplluha River. Its largest tributary is the Semetisht River. Toplluha is one of the left tributaries of the river Drini i Bardhë. The surface of the Toplluha basin is 510 km<sup>2</sup>, while the length of the river is 15.5 km.

More than 50% of the surface of the basin is arable land, about 30% meadows and pastures, 10% mountains; the rest is infertile land.

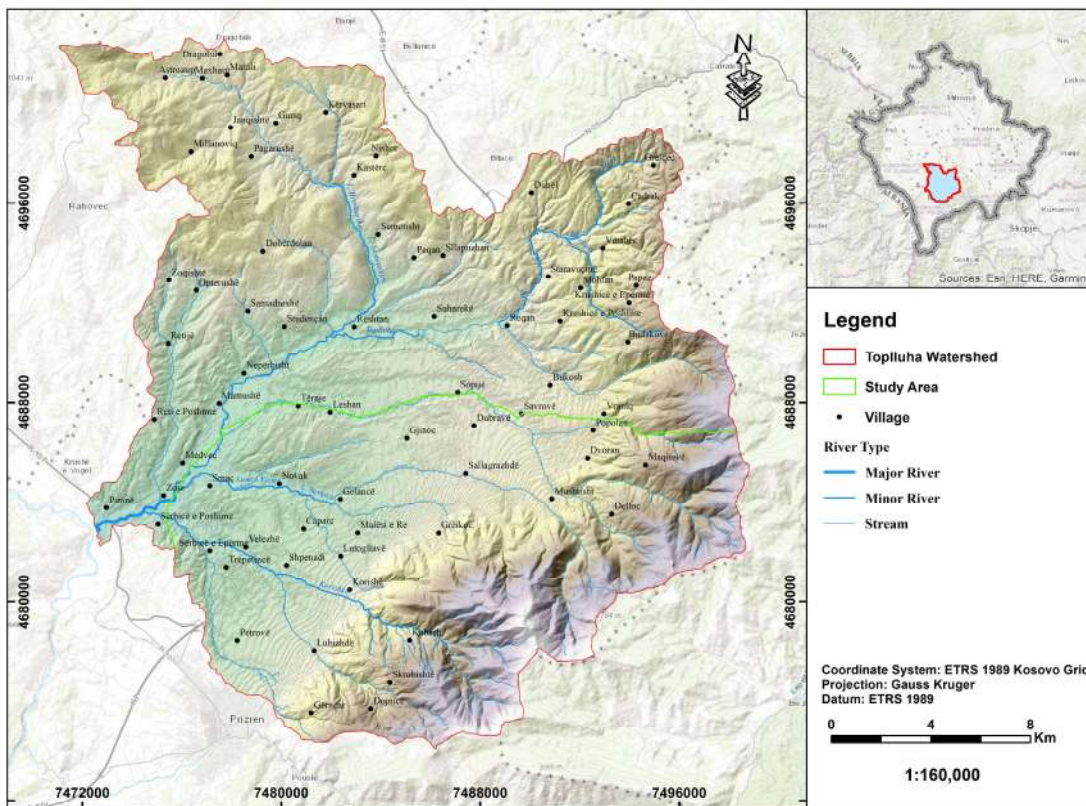


Figure 11: Hydrographic map for the Study area of Suhareka/Suvaraka

## 2.5 Geomorphological Features of Ferizaj

The study area is mainly at an altitude of over 500 m asl. Approximately half of the area are plains below 600 m asl and mainly used for crop production. The majority of settlements, roads, economic and other facilities are in these plain areas, covering about 6% of the Ferizaj/Uroševac region.

The region is part of the Kosovo Plain, subdivided in the plains of Jezerc, Nerodime in the west, and the plains of Zllatar, Rahavica further to the east. In the southeast is the Morava Valley. The study area represents the connection from Pristina in the North to Kačanik/Kaçanik in the South. Ferizaj/Uroševac city is at the southern tip of the Kosovo Plain and connects to the Morava valley in the South. The highest peaks in the mountainous regions east of the plains reach to over 1000 m asl. while more than 2000 m asl. are reached in the mountains west of the model area (see Figure 12).

The mountainous area is mainly covered by forests; a large protected forest area is in the north-western mountains.

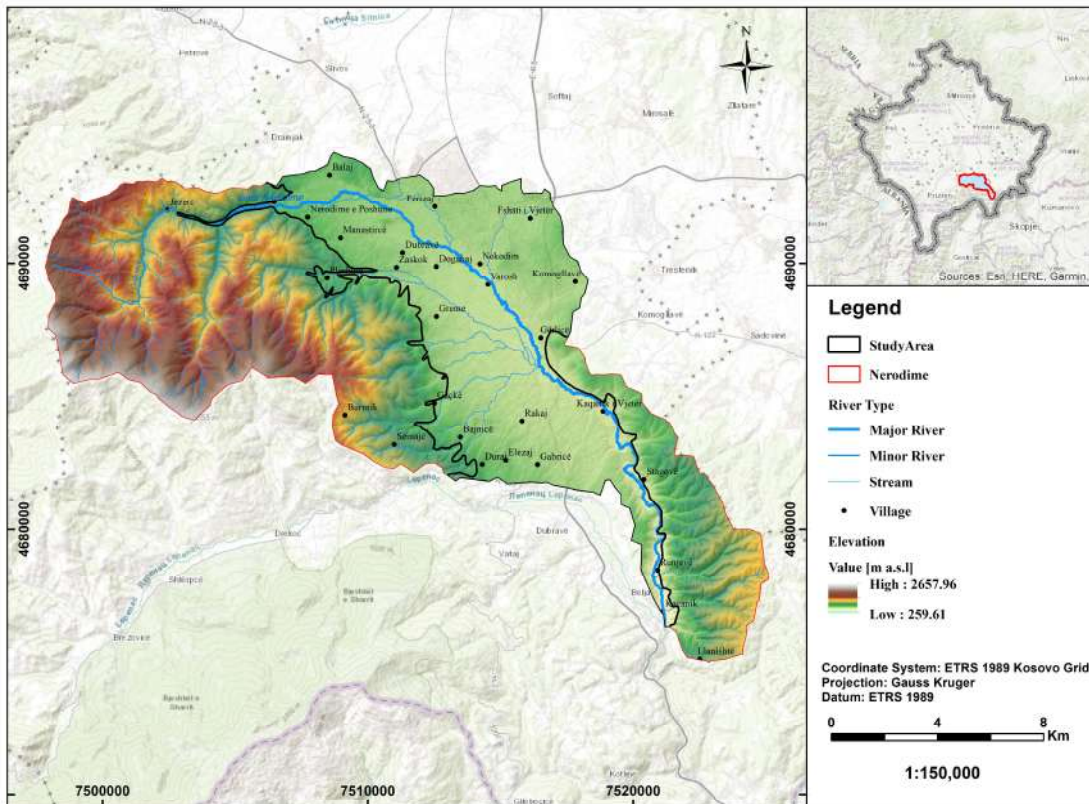


Figure 12: Geomorphology map for the Study area of Ferizaj/Uroševac.

## 2.6 Geomorphological Features of Ferizaj Suhareka

From a morphological point of view, the territory is characterized by a diverse relief, where the areas with lower altitudes (about 259.61 m above sea level) lie mainly in the central and western part of the basin, forming relatively flat alluvial plains and valleys. In contrast, the eastern and southeastern parts are dominated by mountainous areas with pronounced slopes and heights reaching up to about 2657.96 m, which is reflected on the map through darker shades of colors (brown and red). This pronounced hypsometric gradient directly affects hydrological processes and the dynamics of surface runoff. The hydrographic network appears well developed, with a main river that crosses the basin in the dominant direction and a system of branches (main and secondary branches) that contribute to the drainage of the entire surface. The largest branches are concentrated in areas with more rugged relief, where the steepness of the terrain favors the formation of fast flows and linear erosion. Meanwhile, in the lower parts, the flows have a calmer character and a tendency for sediment deposition.

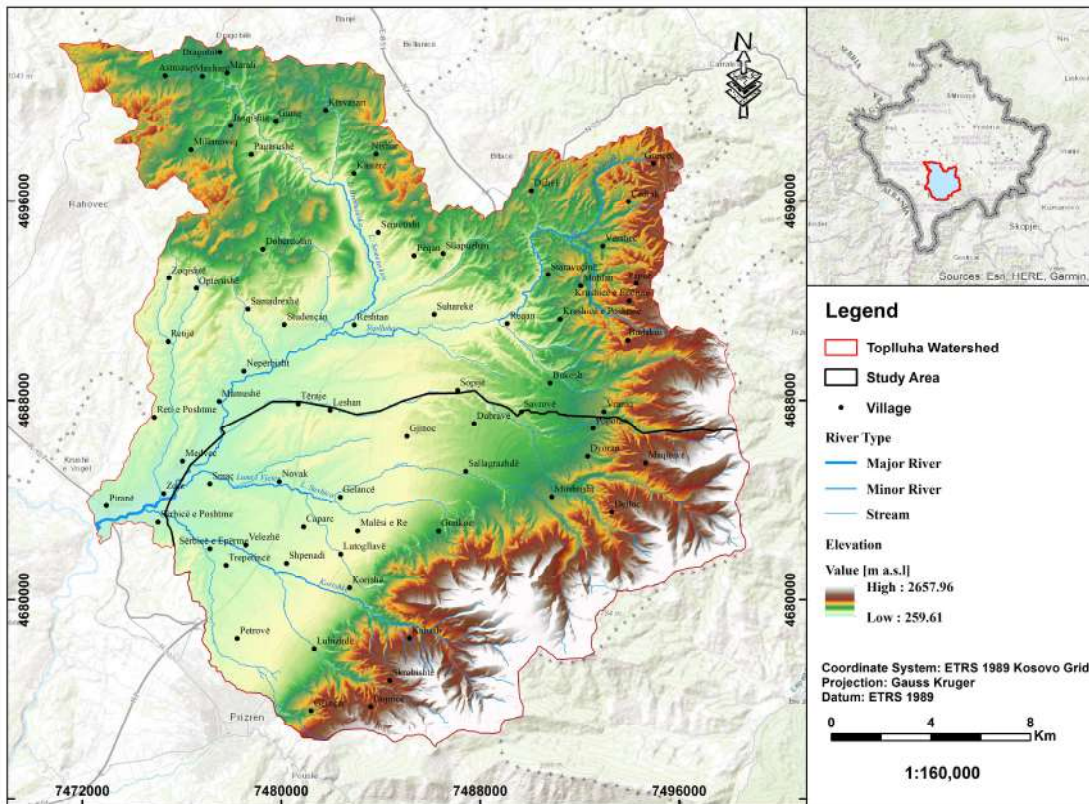


Figure 13: Geomorphology map for the Study area of Suhareka/Suvareka

### **3 GEOLOGY**

#### **3.1 Geology Overview of Ferizaj**

The principal geologic structures like fault lines and geologic formations strike NW-SE and are shown in Figure 14. The area is part of the External Vardar Subzone bordering the Central Vardar Zone to the east. The main plains containing the studied aquifers are part of Kosovo Basin, an intramountain basin, created since the Neogene, collecting mainly silty and clay as well as coarser alluvial river sediments. Tectonic activity decreased since Quaternary.

##### ***Lower Palaeozoic Schists***

Epidote schists extend to the western end of the study area, striking NW-SE and show a foliation dipping with approximately 50 degrees. These rocks are represented by thin schists with marble intercalations. These schists strike over 7–8 km with a width of 2-3 km.

##### ***Mid-Palaeozoic Schists***

Epidote and Muscovite green schists with thin foliation strike like the other formations NW-SE in the eastern mountainous region of the study area. They appear in intermittent alternation with earlier rocks at the surface.

##### ***Lower and Middles Triassic Marbles and Limestones***

In the South, on top of the Upper-Palaeozoic schist, smaller areas of Upper Triassic marbles and limestones appear. In the West in the mountainous area, Lower Mesozoic calcareous rocks are overlaying the Palaeozoic rocks in a smaller area of an intramountainous basin. The Triassic limestones are partly underlying the Pliocene sediments of the Kosovo Basin. They are striking NNW-SSE direction. These limestones are exposed at the south-eastern region of the study area striking in parallel to metamorphic rocks. Its layers are folded and overturned.

##### ***Middle- Upper Jurassic Carbonate Rocks, Marble and Calcschist***

Superposed on the Triassic formations in the West smaller areas in the mountains are built of Middle- and Upper Jurassic rocks like marble and calcschists.

##### ***Cretaceous Marlstone, Limestone and Siltstones***

Geographically dividing the Palaeozoic and Mesozoic metamorphic rocks to the West (as described above) and the Neogene and Quaternary sediments to the East, is a belt of Cretaceous marlstone, limestone and siltstone up to 4 km wide, striking NNW-SSE. These rocks show a Flysch-character, indicating the subduction and orogenesis (Overthrusting and upward movements leading to the mountain arcs).

##### ***Pliocene***

During the late Miocene and early Pliocene, tectonic movements formed the Kosovo Basin, a Graben structure striking again NNW-SSE. Thick layers of lignite are witnessing a rich vegetation cover. These sediments cover in discordant structure the older Pliocene and

Mesozoic sediments. The lignite accumulated together with sands, clays, sands and gravel up to 400 m thickness and is of large economic importance. These sediments form the main parts of the studied aquifer.

#### ***Lake sediments of the Quaternary***

The lake sediments in the Kosovo Basin are products of glacial processes on the surrounding mountainous area. However, these lake sediments are not consistent over the study area.

#### ***River Terraces of Quaternary***

Along the rivers, terraces developed from deposited gravel and sand containing lentils of various conglomerates and clay lentils as well. These formations are mainly found as bed and right and left of the recent rivers.

Figure 14 shows the geology in the study area. In addition, in Annex 3 an A0 map of the geology is provided. The legend for the geology can be found in the digital and printed version of the A0 map. The source is the Geological Map of Kosovo (KPMM, 2006a).

### **3.2 Tectonic of Ferizaj**

The study area and surrounding areas are characterized by extensive tectonic-magmatic activity, in particular during the alpine orogenesis (see Figure 14). A large number of folds and fault lines structures are observed. A main Fault line is providing the bed of Nerodime River, striking NNW-SSE through the city of Ferizaj/Uroševac.

The tectonic setup of the area is very complex. It is worth to mention the breaking up of a relative stable continental crust since the Triassic as part of the opening Thetis ocean. During Mid-Jurassic continuing to the Cretaceous period, subduction processes occurred and lead to the creation of various basins, depressions as well as to the folding and over thrusting of the layers and to mountain arcs. Thus, the ocean was closed again. During the Neogene period, the creation of basins became most prominent; in study area large layers of lacustrine sediments have been formed.

The source of the tectonics is the Tectonic Map of Kosovo (KPMM, 2006c).

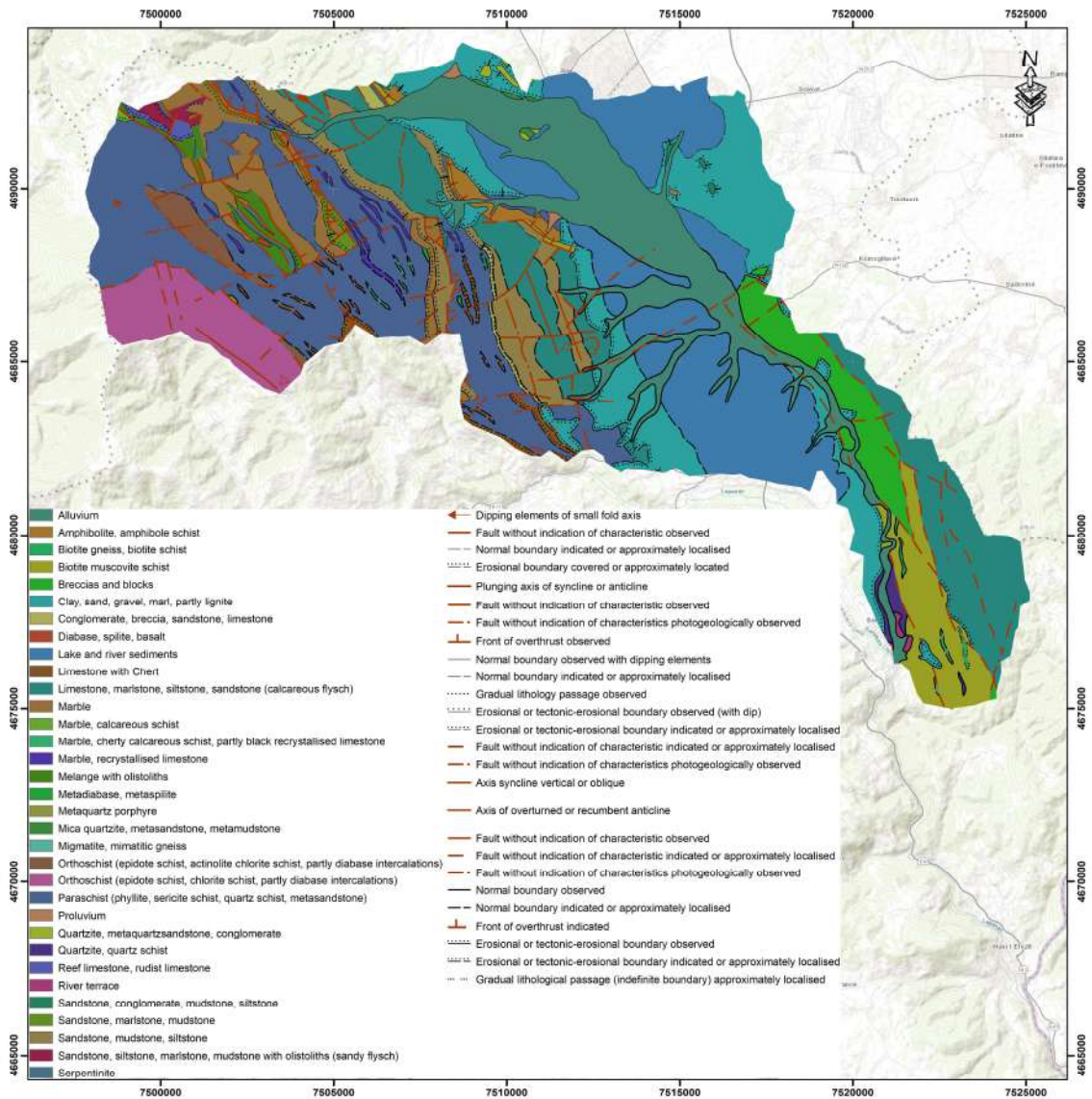


Figure 14: Geology of the Ferizaj Wellfield.

### 3.3 Geology Overview of Suhareka

The main geological structures such as tectonic faults and the extension of geological formations in the NW-SE direction are shown in Figure 15. The area is part of the Sharr - Korab area that borders the Ophiolitic Belt area to the west. The main plains containing the studied aquifers are part of the Peja - Prizren Basin, an inland basin, created since the Neogene, collecting mainly silt and clay, as well as coarse sediments of rivers. Tectonic activity has been declining since the Quaternary.

**Paleozoic (Pz)** - Upper Paleozoic formations spread in the south-eastern part of the study area in the form of a belt of several kilometers long, extending northwest. The geological formations of the Paleozoic are diverse and are represented by shales, quartzites, sandstones, limestones, greywacke and conglomerates. The sediments are represented by clays, phyllites, mikashists, albitsericitic, albite-chlorite, actinolytic rocks, as well as metamorphosed quartz conglomerates. Paleozoic formations are intensely wrinkled, and exhibit differentiated behavior towards tectonic stresses, where competent formations wrinkle while incompetent ones break tectonically.

**Triassic (T)** - Triassic formations are also widespread in the south-eastern part of the study area embedded in Jurassic lentil formations represented mainly by massive limestone and dolomite. The limestones are tectonically destroyed, with cracks and fissures. The density of this networking fissures may favor erosion and karst processes which, in turn, serve as a passageway for groundwater. These formations are part of the Ostrovica Melange.

**Jurassic (J)** - Jurassic formations are represented by the Strallor formation, a heterogeneous diabase-formation containing layers of soft limestone, extending over several kilometres and several meters thick. They are very heterogeneous and are represented by sandstones, siltstones, limestones, marls, clays, diabase and serpentinites. They are intensely tetanized and form relief with slopes above 15° slope. Ultramafic rocks, serpentinite and serpentinitized peridotites, meet in the southwestern part of the Ostovica Melange. These are tectonically destroyed and eroded at the surface.

**Pliocene (Pl)** - Pliocene formations are spread in the north-western part of the study area with an extension of about 10 km. In terms of stratigraphy, two horizons are to be distinguished:

1. Lower Pliocene sediments
2. Middle and Upper Pliocene sediments

Here the presence of Upper Pliocene sediments associated with various formations such as clays, gravels, sands, etc. stands out.

**Quaternary (Q)** - Quaternary sediments are quite widespread in both plain and undulating parts. Neogene (Pleistocene and Holocene) sediments are represented by glacial and fluvio-glacial deposits while in the mountainous areas alluvial formations are more dominant.

(source: Geological Map of Kosovo (ICMM, 2006a); Geology of Kosovo (Elezaj, Z. and Kodra, A. 2007-Prishtina/Pristina); Karakterizimi Sasior dhe Cilesor I Resurseve Hidrike në Basenin e Dukagjinit, Kosove (Çadraku, H. 2014-Tiranë)).

### **3.4 Tectonic of Suhareka**

The study area and the surrounding areas are characterized by a wide tectonic-magmatic activity, which represents a neotectonic unit with a predominant upward trend (see Figure 8). The natural boundaries of these area are the old faults separating Koritnik from the Sharr Mountains, reactivated during the neotectonic stage. The fault following the Lumbardh valley of Prizren/Prizreni is quite pronounced. Of particular importance is the lateral fault of Prizren/Prizreni in the northern part of the Sharr block, separating it from the Dukagjini Lowland.

This fault becomes visible on the slopes of Koritnik, where the amplitude of the neotectonic movement is over 2000 m. The length of the Prizren/Prizreni fault is about 30 km.

The study area belongs to the Prizren/Prizreni plain, a Syncline of the Dukagjini lowland.

The plain is connected in the west to the massif of Pashtrik Mountains, to the south with the massif of Sharr Mountains and the Mushtisht block and to the North and Northeast with the massif of Rahovec and Budakova. The lateral parts of the Prizren/Prizreni plain are limited by faults that are expressed in relief. The Prizren/Prizreni fault shows vertical displacements during the neotectonic stage up to 1500 m.

(source: Tectonic Map of Kosovo (ICMM, 2006c); Geology of Kosovo (Elezaj, Z. and Kodra, A. 2007-Prishtina/Pristina).

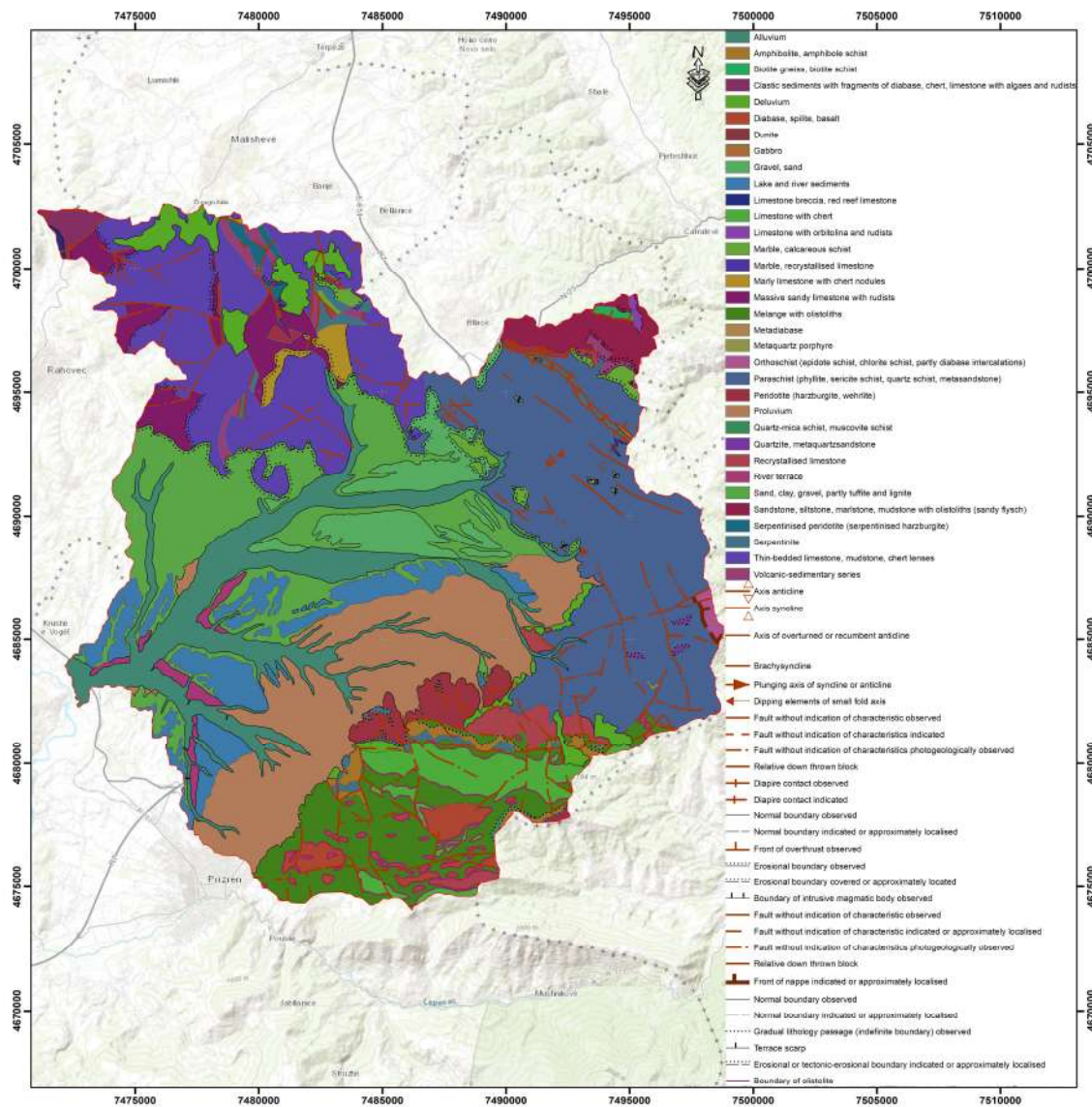


Figure 15: Geology of the Suhareka Wellfield.

## 4 HYDROGEOLOGY

### 4.1 Overview of the Hydrogeology of Ferizaj

The study area comprises the surface watershed of the Nerodime River north of village Stagovë/Stagovo including the norther part (left-hand side) of the Lepence watershed.

The hydrogeological map (see Figure 16) shows an aquifer in the Valley of Nerodime River. It constitutes the southern tip of a large aquifer filling the underground of the plain from Mitrovicë/Mitrovica in the North over Pristina and Ferizaj/Uroševac city to the southern end of the study area.

The porous aquifer with very high to medium hydraulic conductivity ( $K > 10^{-5}$  m/s) consists of coarsely grained Holocene and Pleistocene unconsolidated sediments. To the sides and edges of the aquifer, moderately productive porous aquifers with medium to low hydraulic conductivity ( $K = 10^{-5}$  m/s to  $10^{-9}$  m/s) consists of coarsely to fine grained Pleistocene and Neogene unconsolidated sediments and Palaeogene consolidated sedimentary rocks. At the riverbeds the Alluvium provides the youngest sediments. The less permeable upper part is made of fine clastic silt /clay, whereas the more permeable lower parts are of coarsely clastic sands and gravel. Some Pleistocene lacustrine sediments are built of gravelly silts and clayey gravels as well as sands. The Neogene sediments filling the lower parts of the Cenozoic basin are mainly Pliocene clastic depositions of clay, sand, gravel, marlstone, limestone, sandstone and conglomerate.

To the West the study area is covering a mountainous area build of Palaeozoic schists, Triassic and Jurassic limestones and other calcareous rocks. These rocks have to be considered as karstic rocks and fissures rocks. The hydraulic conductivity of these rocks is very low ( $K = 10^{-9}$  m/s) even though the karstic parts may be considered of good permeability. Karstic areas may have dedicated conductivities for groundwater; however, these flows are ignored during the present study.

The source of the hydrogeology is the Hydrogeological Map of Kosovo (KPMM, 2006b). The cross sections indicated in the figure will be shown and described in the chapter below.

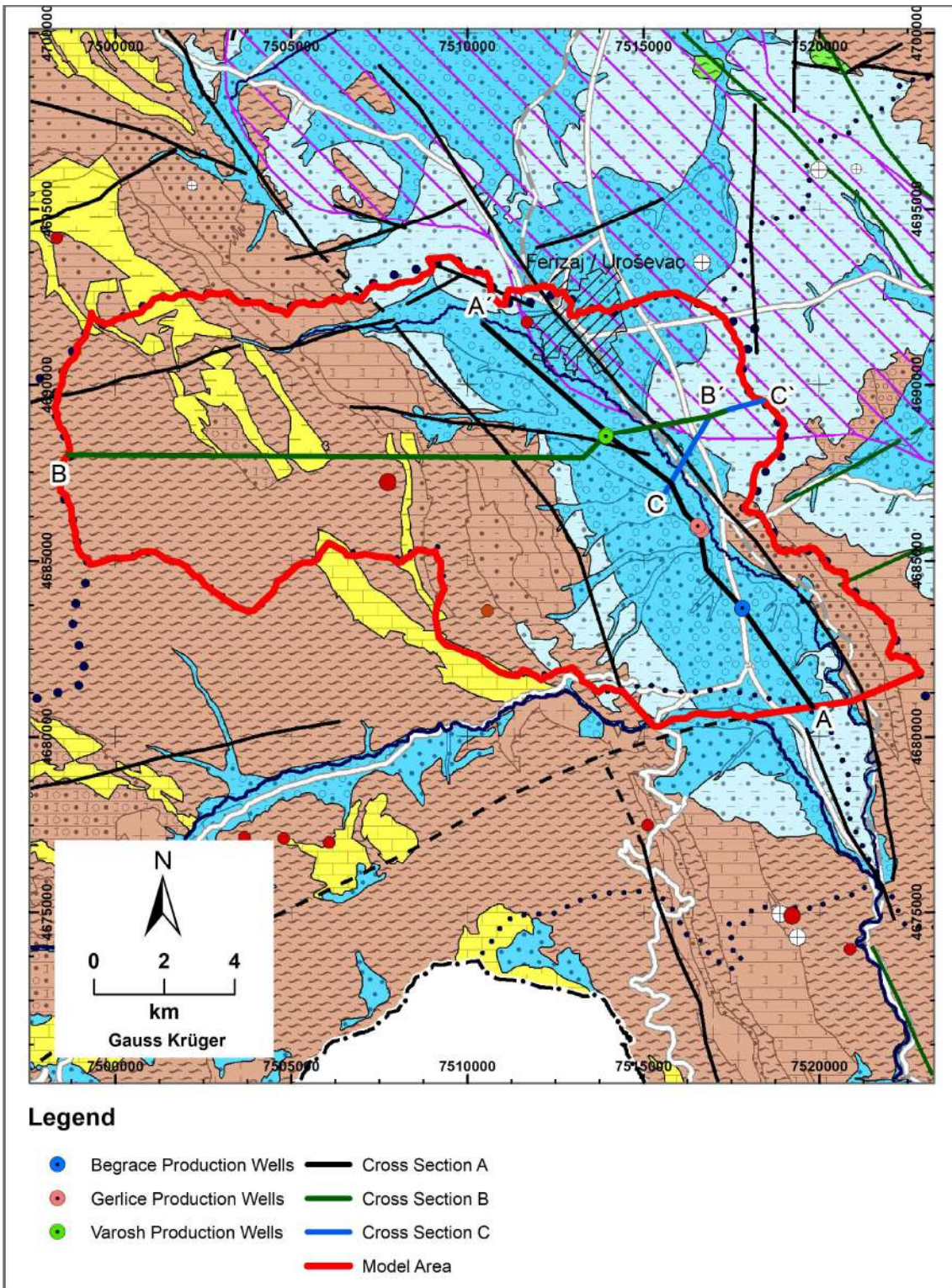


Figure 16: Hydrogeological map of the Ferizaj Wellfield

## 4.2 Overview of the Hydrogeology of Suhareka

The study area is part of the Toplluha river catchment area west of the village Gelancët. This area belongs to the sub-plain of Prizren/Prizreni and has an extension from Pirana to Drini i Bardhe in the west to the hills and mountains around it. The plain consists mainly of :

- Alluvial (Holocene) deposits such as: silt, clay, sand, and gravel,
- Neogene deposits of conglomerates, sand and clay.

The main permeable layer of Quaternary deposits are a water-saturated mix of gravels and sands and form a wide aquifer. These deposits with good permeability crop out at the surface near the Drini i Bardhe River in the south-west and south-east of the plain, progressively covered in the east by clay and silt deposits.

At the area of the Toplluh catchment 3 layers with different thickness aquifers were distinguished:

Table 1: Thickness of aquifer layers in the Toplluh catchment (Source: Simiç, M. Periç, J.)

Aquifer	Thickness [m]	Elevation [m.a.s.l]
A	16	375-391
B	11	351-362
C	17	320-337

Surface waters of the Drini I Bardhe and Suhareka Rivers infiltrate into the gravel aquifer in their eastern part, where the gravel aquifer is in contact with the rivers.

The main direction of groundwater movement is from east to southwest, i.e., from the mountains to the river Drin and then to Lake in Fierza.

The gravel aquifer at central part of the Drin river plain is unconfined, while below the village Greikoc it becomes confined.

The groundwater surface in the wellfield of Greikoc – Suhareka/Suwareka are about 6 m to 10 m below surface (equal to approx. 300 masl) though it has been exploited since several decades.

### **Porous unconsolidated aquifer**

#### **a) Quaternary Holocene (Alluvial) sediments (Gravel, sand, and clay)**

This aquifer has a high permeability. The aquifer has a high hydrogeologic productivity as well. There is a good hydraulic connection between surface water (rivers) and groundwater. The filtration coefficient ranges above  $>10^{-5}$  m/s. Groundwater is usually cold and of medium hardness. The water resources of this complex are large, and they can be exploited through drilling wells, where the capacity of such wells range from 5 to 50 l/s.

These Quaternary Holocene sediments constitute the aquifer exploited by the studied wells.

### **b) Quaternary alluvial fan and fluvial-glacial (Pleistocene) sediments**

Quaternary alluvial fan (former name: “proluvial”) sediments, fluvial-glacial sediments, composed of gravel, sand, clay conglomerates, etc. These sediments have reduced connection and interaction of surface water and groundwater and contain water of low hardness.

In this hydrogeologic unit, water resources come in the form of springs, drilled well exploitation in general is limited to the fluvial-glacial deposits.

### **Fissured and Karst aquifers**

#### **a) Aquifer in Neogene conglomerates, sandstones, clays and siltstones**

The Neogene conglomerates, sandstones, and other compacted sediments provide a medium to low permeability. The average value of the filtration coefficient ranges from  $10^{-5}$  to  $10^{-9}$  m/s under a confined regime. The productivity of these aquifers is less than the Alluvial sediments, however still good. Drilled wells often show artesian characteristics with yields around 0.1 to 4 l/s and from equipped wells from 10-15 l/s.

The deep location of the aquifers of 300-400 m b.g.l. leads to a higher mineralization.

#### **b) Karst with high water permeability**

The Upper Cretaceous and the Middle Triassic limestones usually have a high permeability and are fissured and karstified. In these units a significant number of aquifers have not yet been exploited.

In a larger scale, the filtration coefficient in this unit ranges from  $10^{-3}$  to  $10^{-4}$  m/s and is of good physico-chemical quality, however the risk of contamination of karst aquifers remains high. The exploitation by drilled wells is hardly feasible rather the catchment of springs is common.

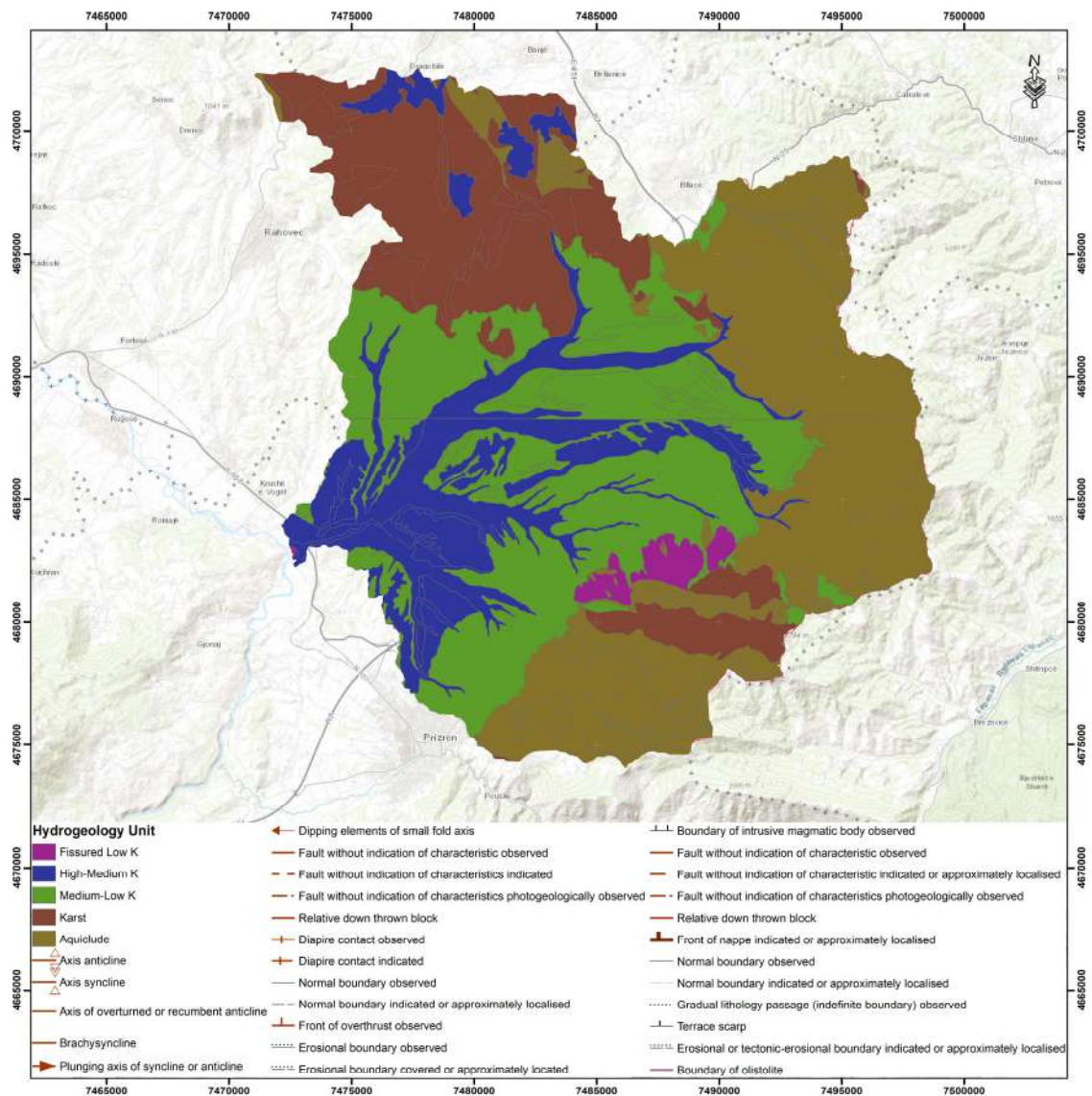


Figure 17: Hydrogeological map of the Suhareka Wellfield

### 4.3 Overview of Wells for Hydrogeological Investigations at Ferizaj

In order to understand the hydrogeology several wells were investigated as described below. Table 2 gives an overview of these wells.

Investigations in 2005 of the aquifers south of Ferizaj/Uroševac provided the evidence of a productive sedimentary layer. The drilling in Varosh/Varoš Selo to a depth of 174 m bgl. produced a yield up to 12 l/s. In total 4 wells have been drilled from 2005 to 2009 to further investigate the aquifer (Varosh, Greme, Gerlice, and Begrace) (Pruthi 2005, 2009a, 2009b, 2013).

In the study area some 14 drilled wells have been implemented. 6 wells are actually used as production wells to supply drinking water.

The wells Varosh 1 and Varosh 2 supply the villages Varosh/Varoš Selo and 50% of Nerodime resulting in a total of 4680 inhabitants.

Wells Begrace 1 and Begrace 2 supply the village Begracë/Belograc and Kačanik I Vjetër/ Stari Kačanik with a total of 4233 inhabitants.

The wells Gerlice 1 and Gerlice 2 supply the villages Gërlicë/Grlica and Komogllava/ Kamena Glava, with a total of 4933 inhabitants.

The wells Varosh 1, Varosh 2, Gerlice 1, Gerlice 2, Begrace 1 and Begrace 2 are in operation during 2019. The position of wells and piezometers are shown in Figure 43.

The preparation of the present study for the delineation of groundwater protection areas of the wellfields led to the drilling of further observation wells. Its drill logs have been providing further information of the hydrogeology. The project RWSSP VI realized 2 piezometer wells (P1 and P2; executed by Aqua Drill, 2019). The 244 mm diameter drilling provided samples showing granulometry and the pumping tests contributed to the further determination of hydraulic conductivities. In both piezometers, a 160 mm diameter pipe was installed to measure water levels. An "airlift" test was performed to estimate maximum debits.

Table 2: Wells used for hydrogeological investigations

Well Name	Code	Y-Pos	X-Pos	Drilling year	Description	Data Source
Varosh P1	VaP1	4688579	7513949	Sep, 2005	Piezometer	Pruthi, 2005
Varosh 1	Va1	4688564	7513943	Jul, 2005	Production Well	Pruthi, 2005
Varosh 2	Va2	4688524	7513925	Jul, 2006	Production Well	Pruthi, 2005
Greme P1	GrP1	4688030	7513410	Jun, 2012	Piezometer	Pruthi, 2013
Greme P2	GrP2	4687900	7513492	Jul, 2012	Piezometer	Pruthi, 2013
Greme 1	Gr1	4688030	7513410	May, 2013	Production Well	Pruthi, 2013
Begrace 1	Be1	4683638	7517796	Jul, 2009	Production Well	Pruthi, 2009b
Begrace 2	Be2	4683674	7517803	Jul, 2008	Production Well	Pruthi, 2009b
Gerlice 1	Ge1	4685869	7516649	Nov, 2008	Production Well	Pruthi, 2009a
Gerlice 2	Ge2	4685810	7516607	May, 2008	Production Well	Pruthi, 2009a
Gerlice 3	Ge3	4685818	7516602	Nov, 2008	Production Well	Pruthi, 2009a
Gerlice 4	Ge4	4685983	7516536	May, 2009	Production Well	Pruthi, 2009a
Piezometer 1	P1	4686332	7516543	Apr, 2019	Drilled for this study	Aquadriill, 2019
Piezometer 2	P2	4686264	7516386	Apr, 2019	Drilled for this study	Aquadriill, 2019

### 4.3.1 Drilling Profiles and Equipment of Varosh Wells

#### *Piezometer Varosh P1 (VaP1)*

The well provides the following lithological, hydrogeological and technical parameters (see Table 3 and Figure 18):

Table 3: Lithology of Varosh P1.

Depth [m bgl]	Lithology
0.00 - 5.00 m	Organic material
5.00 - 13.00 m	Brekzia of rocks (quartz, shale) - conglomerate reddish-white
13.00 - 18.00 m	Grained sand - medium grain, with reddish clay
18.00 - 44.00 m	Angular fragments of rocks and quartz, reddish-brown
44.00 - 50.00 m	Angular fragments of rocks and quartz, clayey, brownish grey
50.00 - 65.00 m	Clay with singular gravel, light brown
65.00 - 69.00 m	Clay with singular gravel, grey sealed
69.00 - 75.00 m	Gravel and ballast, clayey, light brown
75.00 - 78.00 m	Clay grained sand
78.00 - 85.00 m	Clay-coated sand, brown sealed
85.00 - 93.00 m	Sandy clay gravel, clay, brown sealed
93.00 - 113.00 m	Gravel sand (with quartz), clay, light brown
113.00 - 130.00 m	Pieces of rocks and quartz (blue) sealed blue
130.00 - 140.00 m	Partially clayey gravel, sealed brown
140.00 - 143.00 m	Sandy clay, brown sealed
143.00 - 172.00 m	Sandy (quartz) gravel, clayey, brown
172.00 - 174.00 m	Clay, yellow

The well is equipped with 160 mm PVC pipes at the full depth of 174.0 m. From 18.00 – 24.00 m; 30.00 – 48.00 m; 66.00 – 74.00 m; 86.00 – 98.00 m; 110.00 – 134.00 m and 146.00 – 168.00 m, horizontal slotted filters are installed. The angular space from 10.0 – 174.0 m is filled by a gravel filter of 3.0 – 8.0 mm grain size. From 0.00 to 10.0 m, a clay and cement mix has been placed, for the protection of the well from penetrating surface waters. Above, a concrete slab to +0.5 m above surface is installed.

Location: Varosh, Ferizaj  
 Y= 7 513 949  
 X= 4 688 579  
 Z= 551.235  
 Drilling date: 09.2005  
 Driller: AquaDrill  
 Diameter of drilling : 244 mm.

## Varosh P1

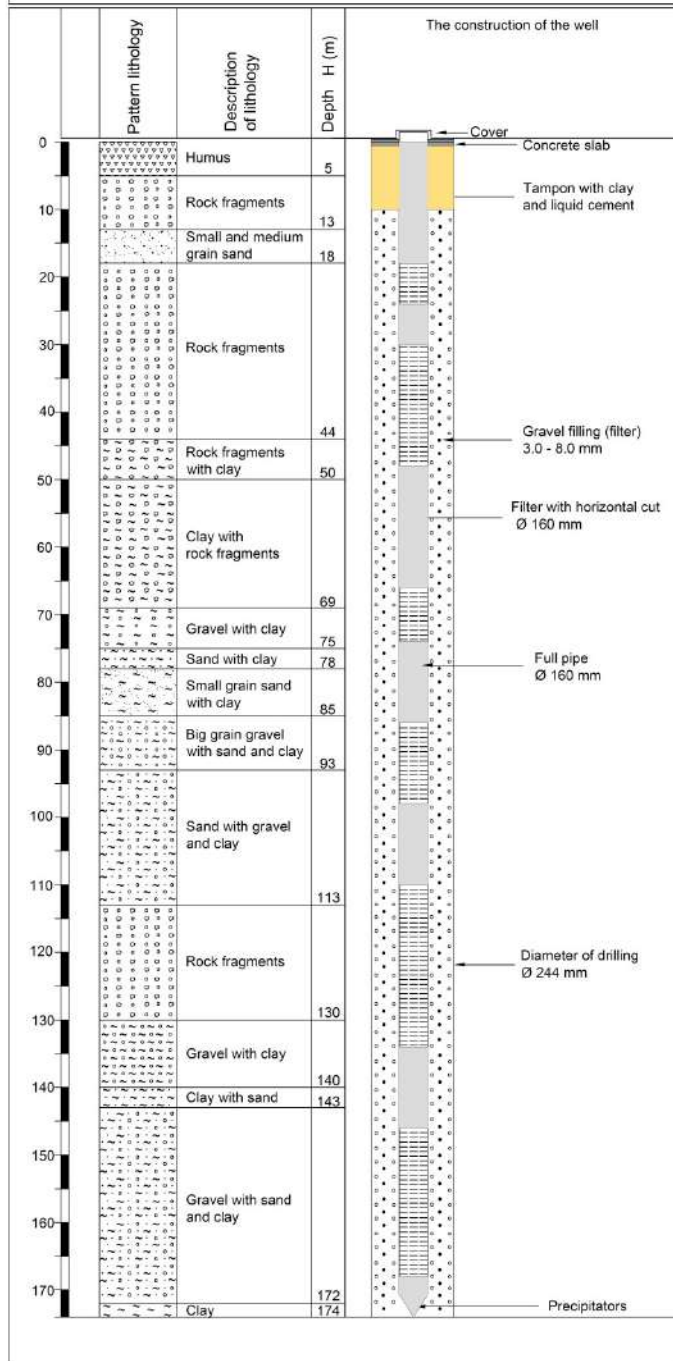


Figure 18: Profile of well Varosh P1.

### **Well Varosh1 (Va1)**

The well provides the following lithological, hydrogeological and technical parameters (see Table 4):

Table 4: Lithology of Varosh 1.

Depth [m bgl.]	Lithology
0.00 - 5.00 m	organic material
5.00 - 13.00 m	Angular fragments of rocks (quartz, shale) - conglomerate reddish-white
13.00 - 18.00 m	Grained sand - medium grain, with reddish clay
18.00 - 44.00 m	Angular fragments of rocks and quartz, reddish-brown
44.00 - 50.00 m	Angular fragments of rocks and quartz, clayey, brownish grey
50.00 - 65.00 m	Clay with clumps of rocks, light brown
65.00 - 69.00 m	Clay with clumps of rock, grey sealed
69.00 - 75.00 m	Gravel and ballast, clayey, light brown
75.00 - 78.00 m	Clay grained sand, closed color
78.00 - 85.00 m	Clay-coated sand, brown sealed
85.00 - 93.00 m	Sandy, clayey gravel, brown sealed
93.00 - 113.00 m	Gravel sand (with quartz), clayey, light brown
113.00 - 130.00 m	Pieces of rocks and quartz (blue) sealed blue
130.00 - 140.00 m	Partially clayey gravel, sealed brown
140.00 - 143.00 m	Sandy clay, brown sealed
143.00 - 170.00 m	Sandy (quartz) gravel, clayey, brown

### **Well Varosh 2 (Va2)**

The well provides the following lithological, hydrogeological and technical parameters (see Table 5):

Table 5: Lithology of Varosh 2.

Depth [m bgl.]	Lithology
0.00 - 2.00 m	Clay (organic)
2.00 - 6.00 m	Rounded pieces (up to 5-6 mm) of different rocks with sand, light brown color
6.00 - 7.00 m	angular pieces (up to 10 mm) of different rocks (quartzite dominates), light yellow
7.00 - 12.00 m	Angular fragments of rocks and quartz (conglomerate), with powdered sand, light brown (light brown)
12.00 - 18.00 m	Rounded rocky, sandy and clayey patches, light brown
18.00 - 44.00 m	Mostly quartz pieces, poorly rounded, light reddish color
44.00 - 100.00 m	Coarse-grained rock fragments (conglomerate) of calcareous, sandy, light brown color
100.00 - 120.00 m	Poorly rounded piece of different rocks, with quartz, light grey
120.00 - 172.00 m	Gravel sand (sandstones) with muskovite (sericite) with different rock grains (quartz dominates), light to green

The well is equipped with 280 mm PVC pipes over the total length of 172.0 m. At 18.00 – 24.00 m; 30.00 – 48.00 m; 66.00 – 74.00 m; 86.00 – 98.00 m; 110.00 – 134.00 m and 146.00 – 168.00 m, horizontal slotted filters are mounted. At 15.0 – 172.0 m gravel filter (grain sizes 3.0 – 8.0 mm) is filling the annular space. From 0.00 to 15.0 m, a clay and cement mix has been placed. A concrete slab of +0.5 m is covering the well above surface.

#### 4.3.2 Drilling Profile and Equipment of Greme Wells

##### *Piezometer Greme P1 (GrP1)*

The well provides the following lithological, hydrogeological and technical parameters (see Table 6):

Table 6: Lithology of Greme P1.

Depth [m bgl.]	Lithology
0.00 - 3.00 m	Clay, dark chestnut
3.00 - 10.00 m	Gravelly sandy and dusty, poorly clayey, light brown colour
10.00 - 13.00 m	Sandy gravel, poorly clayey, reddish-brown
13.00 - 16.00 m	Grain gravel (partially rounded rock fragments, up to 5-7 cm in size), white to light brown.
16.00 - 23.00 m	Rounded pebbles (sandstones) of sandy clay, yellowish brown
23.00 - 33.00 m	Sand gravel, poorly clayey, light brown
33.00 - 36.00 m	Clay with sand and gravel, light brown
36.00 - 40.00 m	Sandy gravel, poorly clayey, pale brown
40.00 - 60.00 m	Sandy clay, yellowish brown
60.00 - 73.00 m	Clay sand gravel, light grey
73.00 - 80.00 m	Sandy clay, olive grey
80.00 -100.00 m	Grained sand, light brown
100.00 -106.00 m	Grained sand, pale yellow
106.00 -121.00 m	Sandy gravel grains, poorly clayey, olive grey
121.00 -127.00 m	Sand (partially rounded) gravel, clayey, light brown colour
127.00 -145.00 m	Coarse grained sandy, clay, brown to dark green.
145.00 -158.00 m	Sandy gravel, light brown
158.00 -164.00 m	Sandy gravel, poorly clayey, brow to dark green
164.00 -172.00 m	More gravelly sand, clayey, yellow in dark brown

The well is equipped with 176 mm PVC pipes (10 bar) over the length 172.0 m. At 12.0 – 16.0 m; 24.0 – 33.0 m; 36.0 – 40.0 m; 54.0 – 60.0 m; 86.0 – 90.0 m; 100.0 – 114.0 m; 118.0 – 121.0 m; 129.0 – 133.0 m; 145.0 – 149.0 m; 153.0 – 157.0 m and 161.0 – 165.0 m, horizontal slotted filters are mounted. At 10.0 – 172.0 m gravel filter has been installed with grain sizes 3.0 – 8.0 mm. From 0.00 to 10.0 m, a clay and cement mix has been placed. Above, a concrete slab of +0.5 m is installed above the surface.

***Piezometer Greme P2 (GrP2)***

The well provides the following lithological, hydrogeological and technical parameters well (see Table 7):

Table 7: Lithology of Greme P2.

Depth [m bgl.]	Lithology
0.00 - 4.00 m	Clay, light brown
4.00 - 8.00 m	Medium gravel (partially rounded shells), pale yellow.
8.00 - 14.00 m	Quartz gravel grains (partially rounded), white to grey
14.00 - 20.00 m	Clay with coarse gravel and sand, brown in reddish brown
20.00 - 30.00 m	Gravel with silt and sand, yellowish-yellow
30.00 - 37.00 m	Medium sandy gravel, light yellow in light brown.
37.00 - 42.00 m	Sand, silty, yellow
42.00 - 44.00 m	Clay gravel, light brown.
44.00 - 50.00 m	Coarse gravel with clay, light brown
50.00 - 59.00 m	Gravel, sand, clayey, light brown
59.00 - 70.00 m	Clay with a little sand and gravel, greyish green
70.00 - 87.00 m	Sandy clay, light brown
87.00 - 106.00 m	Sandy gravel, slightly clayey, light brown
106.00 - 110.00 m	Sandy clay, greyish green
110.00 - 133.00 m	Dusty sand, light grey
133.00 - 144.00 m	Partially rounded quartz fragments and shades, white to reddish
144.00 - 160.00 m	Sand with little gravel, olive grey
160.00 - 178.00 m	Partially rounded quartz fragments and shades, white to reddish

The well is equipped with PVC pipes (10 bar) with a diameter 175.0 mm in a length of 178.0 m. At 10.0 – 14.0 m, 30.0 – 34.0 m, 88.0 – 106.0 m, 110.0 – 114.0 m, 140.0 – 144.0 m and 152.0 – 176.0 m, horizontal slotted filters are mounted. At 8.0 – 178.0 m gravel filter has been installed with grain sizes 3.0 – 8.0 mm. From 0.00 to 8.0 m, a clay and cement mix has been placed, for protection of the well from penetrating surface waters. Above, a concrete slab to +0.5 m above the surface is installed.

### ***Well Greme1 (Gr1)***

The well provides the following lithological, hydrogeological and technical parameters (see Table 8):

Table 8: Lithology of Greme 1.

<b>Depth [m bgl.]</b>	<b>Lithology</b>
0.00 - 3.00 m	Clay, light brown colour
3.00 - 5.00 m	Gravel, clayey, greyish green
5.00 - 10.00 m	Thick sand, dark brown
10.00 - 13.00 m	Medium gravel with quartz, yellow in the dark brown
13.00 - 25.00 m	Gravel sand, clay, brown
25.00 - 31.00 m	Grain grains, slightly clayey, yellow
31.00 - 47.00 m	Plastic clay, with clippings of rocks, yellow
47.00 - 56.00 m	Gravelly sand, light brown
56.00 - 82.00 m	Clay with clumps of rocks, light greyish green
82.00 - 91.00 m	Sandy clay and rock fragments, light yellow to dark brown
91.00 - 106.00 m	Gravel with fine sand, light brown to reddish brown
106.00 - 136.00 m	Sandy gravel, light grey
136.00 - 141.00 m	Plastic sand with light sand, light greyish green
141.00 - 151.00 m	Sandy gravel, poorly clayey, yellowish in yellow brown
151.00 - 156.00 m	Gravel clay, yellow in dark brown
156.00 - 160.00 m	Quartz sandy gravel, light grey
160.00 - 168.00 m	Powdered quartz granular granules of dark brown colour
168.00 - 172.00 m	Clay with partially rounded fragments of different rocks, brown

The well is equipped with 280 mm PVC pipes (10 bar) with a length of 172.0 m. At 24.0 – 28.0 m; 44.0 – 56.0 m; 92.0 – 96.0 m; 104.0 – 108.0 m; 112.0 – 120.0 m; 124.0 – 132.0 m; 144.0 – 148.0 m; 156.0 – 160.0 m and 164.0 – 168.0 m, horizontal slotted filters are mounted. At 10.0 – 172.0 m a gravel filter of 3.0 to 8.0 grain size is installed. From 0.0 to 10.0 m, a clay and cement mix has been placed. Above, a concrete slab of +0.5 m is installed.

### **4.3.3 Drilling Profile and Equipment of Begrace Wells**

#### ***Well Begrace1 (Be1)***

The well provides the following lithological, hydrogeological and technical parameters (see Table 9):

Table 9: Lithology of Begrace 1.

Depth [m bgl.]	Lithology
0.00 – 2.00 m	Clay, dark brown color
2.00 – 4.00 m	Sandy clay, brown
4.00 – 10.00 m	Gravel clay, dark brown
10.00 – 14.00 m	Partially rounded quartz fragments, friendly shades, green shades, light color
14.00 – 19.00 m	Partially rounded fragments of quartz, friendly shades, etc., dark brown braided
19.00 – 25.00 m	Clay sand, closed brown
25.00 – 29.00 m	Gravel with gravel, grey-green
29.00 – 32.00 m	Relatively rounded, gravelly gravel with different quartz and rocks, light color
32.00 – 34.00 m	Sandy and clay, yellow
34.00 – 49.00 m	Gravel, sandy, light brown
49.00 – 61.00 m	Sandy clay, light yellow
61.00 – 95.00 m	Gravel, sandy, light brown
95.00 – 113.00 m	Sandy clay, light yellow
113.00 – 115.00 m	Quartz grains, peels, etc., partially rounded, grey to yellow
115.00 – 120.00 m	Sandy clay, yellow to grey
120.00 – 126.00 m	Sandy, grey gravel
126.00 – 130.00 m	Plastic sandy clay
130.00 – 137.00 m	Dusty sand, with quartz shards, light green and light grey
137.00 – 139.00 m	Plastic clay, light green
139.00 – 143.00 m	Angular fragments of quartz and various rocks, grey
143.0 – 145.00 m	Plastic clay, light yellow
145.00 – 154.00 m	Gravel sand with ballast and gravel, with quartz, etc., grey to yellow
154.00 – 160.00 m	Plastic clay, light grey

The well is equipped with 280 mm PVC pipes (10 bar) over a total length of 160.0 m. At 25.0 – 32.0 m; 34.0 – 40.0 m; 42.0 – 49.0 m; 63.0 – 95.0 m; 113.0 – 115.0 m; 120.0 – 126.0 m; 130.0 – 136.0 m; 139.0 – 143.0 m; 145.0 – 150.0 m and 152.0 – 154.0 m, horizontal slotted filters are mounted. At 10.0 – 160.0 m a gravel filter of 3.0 to 8.0 mm grain size is installed. From 0.00 to 10.0 m, a clay and cement mix has been placed. Above, a concrete slab to +0.5 m above the surface is installed.

#### ***Piezometer Begrace 2 (Be2)***

The well provides the following lithological, hydrogeological and technical parameters (see Table 10):

Table 10: Lithology of Begrace 2.

Depth [m bgl.]	Lithology
0.00 - 3.00 m	Plastic clay, light yellow
3.00 - 4.00 m	Plastic clay, with gravel granules, light yellow
4.00 - 17.00 m	Partially rounded and angular pieces of quartz and quartz - conglomerate, light brown
17.00 - 22.00 m	Highly clayey, light yellow gravel
22.00 - 28.00 m	Partially rounded and angular fragments of quartz, calcite, micaceous shales, serpentinites, granite - gneisses etc, brown to green
28.00 - 40.00 m	Plastic clay, places - sandy places, light yellow
40.00 - 44.00 m	Medium gravel, slightly clayey, yellowish-yellow
44.00 - 51.00 m	Partially rounded and angular fragments of gabrodiabas quartz, conglomerate, olive grey
51.00 - 54.00 m	Coarse gravel, clayey, yellowish-brown
54.00 - 58.00 m	Partially rounded and angular fragments of quartz, gabbro-diabase, slightly clayey, yellowish-grey
58.00 - 61.00 m	Medium grained, clayey, yellowish gravel
61.00 - 70.00 m	Rounded and angular pieces of quartz, gabbro, etc. - clayey places, olive grey
70.00 - 73.00 m	Angular pieces of quartz and various rocks, dusty - clayey, light brownish yellow
73.00 - 76.00 m	Clay, with a little sand, smooth yellow
76.00 - 85.00 m	Fine sand and coarse gravel, highly clayey, pale yellow
85.00 - 90.00 m	Clay with a little sand and gravel, light yellow
90.00 - 100.00 m	Gravel sand, highly clayey, dark brown
100.00 - 105.00 m	Fine sand and gravel, clayey, dark brown
105.00 - 108.00 m	Plastic clay with a little sand and gravel, light yellow
108.00 - 113.00 m	Different rounded and angular pieces of quartz and different rocks, yellow
113.00 - 119.00 m	Gravel and sand gravel, slightly clayey, light brown
119.00 - 125.00 m	Plastic clay with a little sand and gravel, yellowish green
125.00 - 128.00 m	Slightly sandy clay, light brown
128.00 - 130.00 m	Sandy clay and gravel, olive grey
130.00 - 133.00 m	Low-plastic plastic clay, yellowish-green
133.00 - 145.00 m	Clay with a little sand, yellowish green
145.00 - 147.00 m	Light sandy clay, light grey

The well is equipped with 175 mm PVC pipes (16 bar) over a total length of 144.0 m. At 12.0 – 19.0 m; 22.0 – 28.0 m; 38.0 – 44.0 m; 50.0 – 54.0 m; 56.0 – 60.0 m; 70.0 – 72.0 m; 78.0 – 82.0 m; 90.0 – 94.0 m; 100.0 – 104.0 m; 113.0 – 118.0 m; 128.0 – 130.0 m and 140.0 – 142.0 m, horizontal slotted filters are mounted. At 10.0 – 144.0 m a gravel filter of 3.0 8.0 mm size is installed with grain sizes 3.0 – 8.0 mm. From 0.00 to 10.0 m, a clay and cement mix has been placed, for protection of the well from penetrating surface waters. A concrete slab to +0.5 m above the surface is installed.

#### 4.3.4 Drilling Profile and Equipment of Gerlice Wells

##### *Well Gerlice 1 (Ge1)*

The well provides the following lithological, hydrogeological and technical parameters (see Table 11).

Table 11: Lithology of Gerlice 1 well

Depth [m bgl.]	Lithology
0.00 - 2.00 m	Clay, brown
2.00 - 6.00 m	Large size gravel (with quartz), white
6.00 - 10.00 m	Sand, large light greenish grey
10.00 - 12.00 m	Gravel (with quartz), white to yellow
12.00 - 16.00 m	Sand with parts of clay, light greyish green
16.00 - 27.00 m	Small gravel
27.00 - 34.00 m	Coarse gravel, light olive grey

The well is equipped with 280 mm PVC pipes (16 bar) in the total length 30.0 m. At 7-12 m and 16 – 27 m, horizontal slotted filters are mounted. At 6.0 – 34.0 m gravel filter has been installed with grain sizes from 3.0 – 8.0 mm. From 0.00 to 6.0 m, a clay and cement mix has been placed. A concrete slab to +0.5 m above the surface is installed.

##### *Well Gerlice 2 (Ge2)*

The well provides the following lithological, hydrogeological and technical parameters (see Table 12]):

Table 12: Lithology of Gerlice 2

Depth [m bgl.]	Lithology
0.00 - 2.00 m	Clay, brown enclosed
2.00 - 16.00 m	Grain grains, light grey
16.00 - 26.00 m	Grained sand, green grey

26.00 - 30.00 m	Clay sand more clay, greyish green
30.00 - 33.00 m	Plastic clay, light grey
33.00 - 36.00 m	Fine sand, light grey
36.00 - 56.00 m	Light sandy, light greyish clay
56.00 - 67.00 m	Grained sandy clay, light greenish brown
67.00 - 78.00 m	Clay, light grey
78.00 - 80.00 m	Grain grains, light grey
80.00 - 91.00 m	Clay with a little sand, light grey
91.00 - 98.00 m	Clay, light grey
98.00 - 100.00 m	Gravel and sand ballast, highly clayey, light grey
100.00 - 105.00 m	Grained sandy clay, grey in color
105.00 - 110.00 m	Sandy clay, light greyish green
110.00 - 124.00 m	Clay dust sand, greenish grey
124.00 - 133.00 m	Angular and partially rounded fragments of different rocks - sandstone, shales, quartz, etc. (conglomerate), light grey
133.00 - 146.00 m	Sandy gravel gravels and very quartz, light grey
146.00 - 153.00 m	Plastic clay with a little sand, olive grey
153.00 - 158.00 m	Sandy gravel, light olive grey
158.00 - 165.00 m	Slightly sandy, olive grey clay
165.00 - 171.00 m	Sandy gravel and lots of quartz, light grey
171.00 - 182.00 m	Sandy clay, olive grey
182.00 - 183.00 m	Clay, brown to olive grey
183.00 - 184.00 m	Clay with pieces of peat (lignite), olive grey to black

The well is equipped with 175 mm PVC pipes (10 bar) and a total length of 184.0 m. At 6 - 16 m; 124 – 146 m and 153 - 171 m, horizontal slotted filters are mounted. At 5.0 – 182.0 m gravel filter has been installed with grain sizes 3.0 – 8.0 mm. From 0.00 to 5.0 m, a clay and cement mix has been placed. A concrete slab to +0.5 m above the surface is installed.

### ***Well Gerlice 3 (Ge3)***

The well provides the following lithological, hydrogeological and technical parameters (see Table 13):

Table 13: Lithology of well Gerlice 3

<b>Depth [m]</b>	<b>Lithology</b>
0.00 - 2.00 m	Clay, grass
2.00 - 16.00 m	Coarse gravel, light grey
16.00 - 26.00 m	Grains of sand, greyish green
26.00 - 30.00 m	Clay sand with clay, greyish green

The well is equipped with 280.0 mm PVC pipes (16 bar) in a total length of 30.0 m. At 8 - 16 m and 20 - 24 m, horizontal slotted filters are mounted. At 6.0 – 30.0 m a gravel filter has been installed with grain sizes from 3.0 – 8.0 mm. From 0.00 to 6.0 m, a clay and cement mix has been placed. Up to +0.5 m above the surface a concrete slab has been installed.

***Piezometer Gerlice 4 (Ge4)***

The well provides the following lithological, hydrogeological and technical parameters (see Table 14).

Table 14: Lithology of Gerlice 4.

Depth [m bgl.]	Lithology
0.00 - 2.00 m	Clay, closed brown
2.00 - 7.00 m	Grey sand, grey to yellow
7.00 - 13.00 m	Powdered sand with gravel and chalk pieces, yellow in light brown
13.00 - 17.00 m	Sandy clay and rock shards, light grey in color
17.00 - 21.00 m	Clay, gravel
21.00 - 93.00 m	Sandy clay, light grey in color
93.00 - 100.00 m	Sandy clay, green
100.00 - 112.00 m	Fine sandy clay, light greyish green
112.00 - 124.00 m	Angular fragments of different rocks, light grey
124.00 - 151.00 m	Granular fragments of clayey, greyish-green rock
151.00 - 155.00 m	Gravel clay, green (green)
155.00 - 196.00 m	Fragments of rock, clay, green
196.00 - 200.00 m	Fine rock fragments, green
200.00 - 204.00 m	Quartz gravel, grey to white
204.00 - 237.00 m	Clay, yellow
237.00 - 241.00 m	Rounded fragments of different rocks, partly clayey, light grey
241.00 - 244.00 m	Sand and gravel clay, grey
244.00 - 254.00 m	Sandy clay, yellowish-grey
254.00 - 256.00 m	Sandy clay, small grains, yellow

The well is equipped with 225.0 mm PVC pipes (10 bar) in a total length of 265.0 m. At 100 – 103 m; 112 – 118 m; 144 – 147 m; 155 – 161 m; 167 – 173 m; 185 – 188 m; 192 – 195 m; 199 – 205 m and 237 – 240 m, horizontal slotted filters are installed. The annular space from 90.0 – 256.0 m was filled by a gravel filter of 3.0 – 8.0 mm grain size. From 0.00 to 90.0 m, a clay and cement mix has been installed. A concrete slab from surface to +0.5 m above surface was placed.

### ***Piezometer 1 (P1)***

The well in Gërlicë/Grlica was drilled by the RWSSP VI applying specification in order to allow a later transversion to a production well. The Piezometer 1 in Gërlicë/Grlica was drilled at 244 mm diameter and equipped with 160 mm PVC pipes. The annular space between 2.0 m and 32.0 m depth is equipped with a gravel filter of 3.0 to 8.0 mm. From 2.0 m to the surface a plug of fine sand – cement mix was installed. The development and the later pumping test of the piezometer was realized by the airlifting over 24 hours.

The lithology was analyzed through samples taken from the cuttings during the drilling with a tri-cone drill head (Aquadri, 2019), (see Table 15).

Table 15: Lithology of Gerlice Piezometer 1.

<b>Depth [m bgl.]</b>	<b>Interval [m]</b>	<b>Sample [%]</b>	<b>Lithology</b>
0.00 – 1.00	1.00	60	Light brown clay
1.00 – 3.00	2.00	65	Brown gravel, clay
3.00 – 5.00	2.00	50	Sand with fine gravel
5.00 – 7.00	2.00	50	Brown plastic clay
7.00 – 14.00	7.00	50	Gravelly clay with light brown sand
14.00 – 18.00	4.00	57	Brown plastic clay
18.00 – 21.00	3.00	50	Blue sandy clay & ash
21.00 – 27.00	6.00	55	Grey sand, gravel blue
27.00 – 32.00	5.00	60	Brown plastic clay

The piezometer well was equipped as given below:

- 0.00 - 4.00 full PVC pipes,
- 4.00 - 8.00 screen pipes, (PVC filters),
- 8.00 - 12.00 full PVC pipes
- 12.00 - 16.00 screen pipes, (PVC filters),
- 16.00 - 24.00 full PVC pipes,
- 24.00 - 28.00 screen pipes, (PVC filters),
- 28.00 - 32.00 full PVC pipes, partially with holes lower end with pump sump

### ***Piezometer 2 (P2)***

The well in Gërlicë/Grlica was drilled by the RWSSP VI applying specification in order to allow a later transversion to a production well. The Piezometer 2 in Gërlicë/Grlica was drilled at 244 mm diameter and equipped with 160 mm PVC pipes. The annular space between 2.0 m and 32.0 m depth is equipped with a gravel filter of 3.0 to 8.0 mm. From 2.00 m to the surface a plug of fine sand – cement mix was installed. The development and the later pumping test of the piezometer was realized by the airlifting over 24 hours. The lithology was analyzed through samples taken from the cuttings during the drilling with a tri-cone drill head. Lithology is given below. (Aquadrill 2019) (see Table 16).

Table 16: Lithology of Gerlice Piezometer 2.

Depth [m bgl.]	Interval [m]	Sample [%]	Lithology
0.00 – 2.00	2.00	60	Light brown clay
2.00 – 13.00	11.00	65	Gravelly clay with brown sand
13.00 – 20.00	7.00	60	Gravel, clay with brown pebbles
20.00 – 30.00	10.00	55	Clay, blue
30.00 – 32.00	2,00	60	Blue plastic clay

The piezometer well was equipped as given below:

- 0.00 - 4.00 full PVC pipes,
- 4.00 - 8.00 screen pipes, (PVC filters),
- 8.00 - 20.00 full PVC pipes
- 20.00 -28.00 screen pipes, (PVC filters),
- 28.00 -32.00 full PVC pipes, partially with holes lower end with pump sump

#### **4.4 Overview of Wells for Hydrogeological Investigations at Suhareka**

Investigations of the aquifers of Grejkoc provided the evidence of a productive sedimentary layer in 1988. The drilling in Grejkoc to a depth of 75.2 m bgl. produced a yield up to 5 l/s - 10 l/s. In total 7 wells have been drilled from 1988 to 2009 to further investigate the aquifer. In the study area 7 drilled wells have been implemented in the Quaternary Holocene aquifer. 5 wells are actually used as production wells to supply drinking water.

The wells Pusi Atit 1 – Pusi Atit 5 supply the villages:

- Suhareka/Suvareka,
- Shiroka,
- Leshan,
- Ternej,
- Gelanc,

- Gjinoc,
- Highway Suhareka/Suwareka and Prizren/Prizreni

resulting in a total of 17 000 inhabitants.

The well EB1 and the well EB1/1 have been in operation during 1988-1989 only. Since then, these have been serving as piezometers.

All operating wells coordinates and their construction year are given in Table 17.

Table 17: Wells used for hydrogeological investigations

Well Name	Code	Y-Pos	X-Pos	Drilling year	Description	Data Source
PusiAtit1	Well1	7483766.75	4682749.58	2017	Pumping well	WC Suhareka
PusiAtit2	Well2	7483946.45	4682630.02	1988	Pumping well	WC Suhareka
PusiAtit3	Well3	7484180	4682537	2010	Pumping well	WC Suhareka
PusiAtit4	Well4	7484391.17	4682267.12	2010	Pumping well	WC Suhareka
PusiAtit5	Well5	7484572.58	4682465.03	2010	Pumping well	WC Suhareka
EB 1	Pz1	7483766.75	4682749.58	1988	Piezometer	WC Suhareka
EB 1/1	Pz2	7483768.34	4682742.04	1988	Piezometer	WC Suhareka
Baqevc1 *	B1	7488003.31	4683728.42	2013	Pumping well	WC Suhareka
Baqevc2 *	B2	7488031.34	4683763.42	2013	Pumping well	WC Suhareka

\* Bagevc 1 & 2 are outside the study area. These served as information to establish the Hydrogeologic map.

#### 4.4.1 Drilling Profiles and Equipment of Pusi Atit Wells

##### *Well EB-1*

The tables below (see Table 18) provide the lithological, hydrogeological and design of the well EB-1.

The well is equipped with 400 mm PVC pipes to the full depth of 75.2 m.

From 29.5 – 39.5 m; 55.5 – 71.5 m; horizontal slotted filters are installed.

The angular space from 16.5 – 75.2 m is filled by a gravel filter of 4.0 – 8.0 mm grain size.

From 0.0 to 16.5 m, a clay and cement mix has been placed, as plug to avoid an infiltration of surface waters. Above, a concrete slab to +0.5 m above surface is installed.

Table 18: Lithology of well EB-1.

Depth [m bgl]	Lithology
0.0 - 1.0 m	Humus
1.0 - 10.0 m	Clay with sand, partly with gravel
10.0 - 30.0 m	Coarse sand with clay
30.0 - 34.0 m	Coarse sand with gravel and clay
34.0 - 38.0 m	Aleurite <sup>1</sup> with sand and gravel
38.0 - 65.0 m	Medium and coarse sand
65.0 - 75.20 m	Fine clay sand

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<sup>1</sup> Aleurite is a loose fine clastic sedimentary rock, which is intermediate by its composition between the sands and clays; it consists primarily of the mineral grains (quartz, feldspar, mica, and others) of the size of 0.01-0.1 millimetres; see: “<http://mining-enc.com/a/aleurite/>”

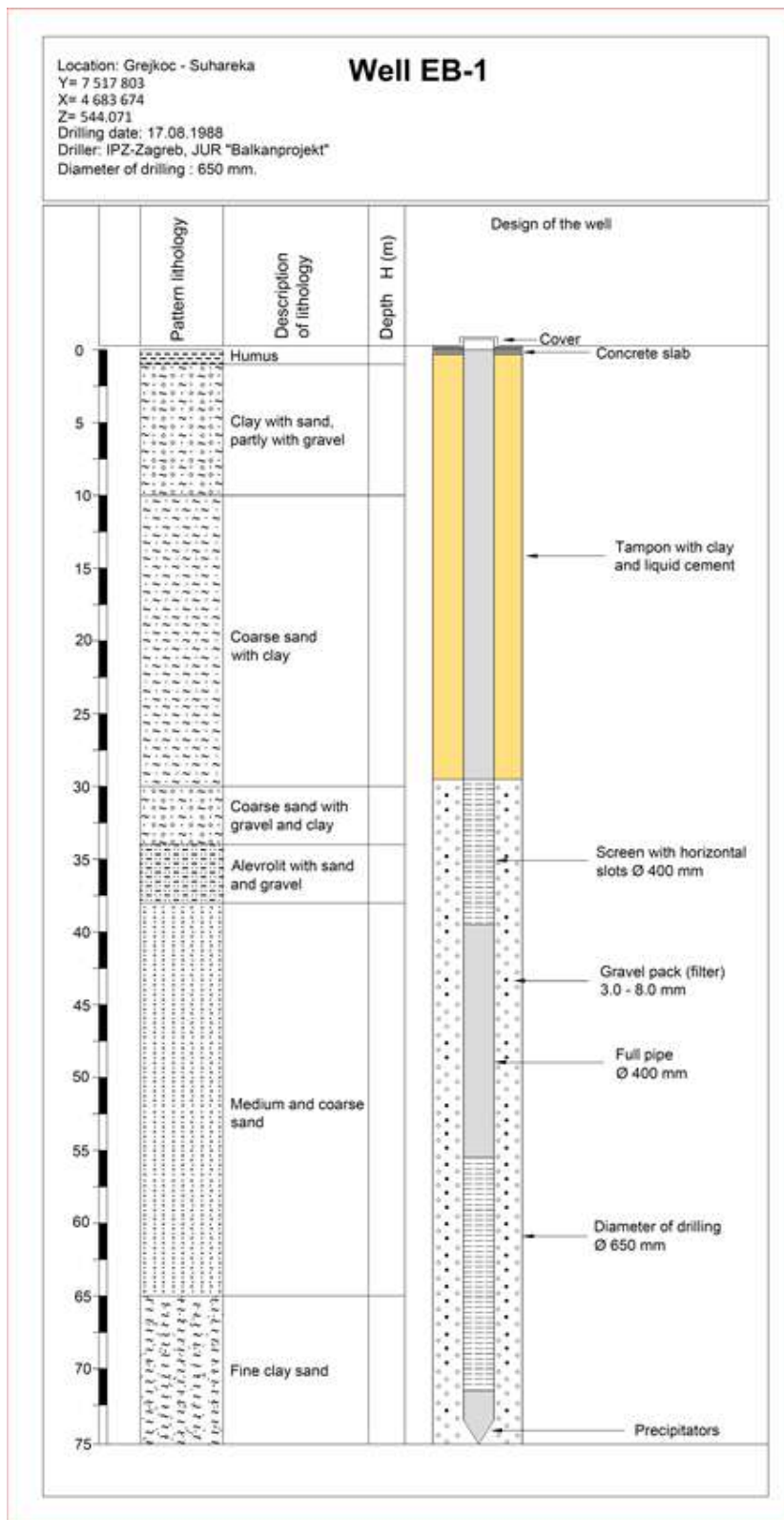


Figure 19: Profile of well EB-1

### ***Well EB-1/1***

The tables below (Table 19) provide the lithological, hydrogeological and design of the well EB-1/1.

The well is equipped with 400 mm PVC pipes at the full depth of 75.6 m.

From 31.5 – 43.5 m; 55.5 – 57.5 m and 59.5 – 71.5 m, horizontal slotted filters are installed.

The angular space from 20.0 – 75.6 m is filled by a gravel filter of 4.0 – 8.0 mm grain size.

From 0.0 to 20.0 m, a clay and cement mix has been placed, as plug to avoid an infiltration of surface waters. Above, a concrete slab to +0.5 m above surface is installed.

Table 19: Lithology of well EB-1/1.

<b>Depth [m bgl]</b>	<b>Lithology</b>
0.0 - 1.5 m	Humus and marshy clays
1.5 - 8.0 m	Clay gravel with clay particles
8.0 - 28.0 m	Fine and medium gravel
28.0 - 31.0 m	Medium-grained gravel with the same petrographic composition as the upper part is clayey
31.0 - 44.0 m	Fine gravel sand grains (grains up to 2 mm in size) almost clean
44.0 - 55.0 m	Medium-grained and coarse-grained sand, mostly quartz, almost pure
55.0 – 56.0 m	Fine gravel, slightly clayey
56.0 – 58.0 m	Fine-grained and medium-grained clayey gravel
58.0 – 59.0 m	Blue-gray clay
59.0 – 67.0 m	Sand with medium and coarse gravel, slightly clayey
67.0 – 73.5 m	Medium grain quartz sand
73.50 – 75.6 m	Clayey sand gravel

### ***Well 5***

The tables below (see Table 20) provide the lithological, hydrogeological and design of the Well 5.

The well is equipped with 254 mm PVC pipes at the full depth of 102.0 m.

From 30.0 – 36.0 m; 42.0 – 48.0 m; 54.0 – 66.0 m; 72.0 – 84.0 m and 90.0 – 96.0 m, horizontal slotted filters are installed.

The angular space from 30.0 – 102.0 m is filled by a gravel filter of 7.0 – 8.0 mm grain size.

From 0.0 to 30.0 m, a clay and cement mix has been placed, as plug to avoid an infiltration of surface waters. Above, a concrete slab to +0.5 m above surface is installed.

Table 20: Lithology of well 5.

Depth [m bgl]	Lithology
0.0 - 4.0 m	Silt with Clay
4.0 - 10.0 m	Marshy deposits
10.0 - 30.0 m	Clay with fossils
30.0 - 55.0 m	Sandy little bit clay
55.0 - 60.0 m	Sandy
60.0 - 67.0 m	Large sized sand
67.0 – 69.0 m	Clay with fossils
69.0 – 83.0 m	Large sized sand
83.0 – 90.0 m	Clay
90.0 – 98.0 m	Gravel
98.0 – 114.0 m	Conglomerate

## Well 6

The tables below (see Table 21) provide the lithological, hydrogeological and design of the Well 6.

The well is equipped with 254 mm PVC pipes at the full depth of 120.0 m.

From 30.0 – 36.0 m; 42.0 – 48.0 m; 54.0 – 66.0 m; 72.0 – 84.0 m; 90.0 – 96.0 m and 102.0 – 120.0 m, horizontal slotted filters are installed.

The angular space from 30.0 – 120.0 m is filled by a gravel filter of 7.0 – 8.0 mm grain size.

From 0.0 to 30.0 m, a clay and cement mix has been placed, as plug to avoid an infiltration of surface waters. Above, a concrete slab to +0.5 m above surface is installed.

Table 21: Lithology of well 6.

Depth [m bgl]	Lithology
0.0 - 6.0 m	Silt with Clay
6.0 - 10.0 m	Silt
10.0 - 35.0 m	Clay with Silt
35.0 - 55.0 m	Medium sand
55.0 - 60.0 m	Sand
60.0 - 70.0 m	Gravel
70.0 – 72.0 m	Clay
72.0 – 85.0 m	Gravel
85.0 – 90.0 m	Clay
90.0 – 98.0 m	Gravel

98.0 – 102.0 m	Clay
102.0 – 120.0 m	Conglomerate

#### 4.5 Cross Section of the Ferizaj Wellfield

Based on the geologic map, the hydrogeological map and the drilling information a 3-Dimensional setup of the study area has been deduced. In order to show the vertical dimension, hydrogeological cross sections have been developed and are shown in a reduced scale here below (Figure 20; Figure 21; Figure 22).

##### *Cross Section A-A`:*

A cross section expands from North to South over 16 km length in the middle of the basin approximately in the centre of the aquifer. This hydrogeological cross section provides an estimation of the maximum thickness of the aquifer from north to south. The underlying Mesozoic Limestones are considered as Aquiclude and form the basis of the aquifer. The thickness of the Cenozoic aquifer is estimated to 200 m to 250 m. Its bottom is starting at about 320 m asl to 400 m asl while the surface is at 600 m asl. to 550 m asl. The cross section shows two main layers of sand and gravel and three main layers of (sandy) clay, further some lentils of sand and gravel in the clay layers. This set up is a simplified interpretation of the results of the drilling profiles. The continuous extent of these layers isn't proofed yet. However, knowing that theses sand and gravels have been sedimented by the river Nerodime and its precursors, it has to be considered that these layers (located through individual drillings) are interconnected, as sedimentation by a meandering river was continuous. Drilling profiles of Begrace 1 and Begrace 2, Gerlice 2, as well as Varosh 1 and Varosh 2 are showing several thin layers of clay, of gravel and of sand. These thin layers are considered to be lentils with smaller and therefore insignificant extend and are of no importance to the aquifer model. More detailed cross section requires further geophysical and geological investigation.

### ***Cross Section B-B'***

A cross section West-East over 19 km has been developed on the base of the geological, the hydrogeological map and the drilling profiles. The Western part of the cross section provides an interpretation of the geological map (for detailed location, see Figure 16). The hydrogeological model is considering the western part containing Mesozoic and Palaeozoic rocks as Aquiclude. The eastern part shows the cross section of the aquifer. It provides a hydrogeological interpretation of the drilling profiles and the hydrogeological map. As described for cross section A-A', the sand and gravel-layers are intercalated with mainly clay layers and are frequently interrupted with (hydrogeological insignificant) lentils. The main tectonic fault line as provided by the tectonic map is reflected in the cross section as red line. The exact location and the effects in the sedimentary layers of the aquifer have been estimated and simplified. For detailed description, please check cross section A-A'.

### ***Cross Section C-C'***

This E-W cross section provides a detailed interpretation of the profile results of S4; S7; S6. Common points of cross section A-A' and C-C' are S4 and of B-B' and C-C' are S6 and S7. The main tectonic fault lines as provided by the tectonic map are reflected in the cross section as red lines. The exact location and the effects in the sedimentary layers of the aquifer have been estimated and simplified. For detailed description, please check section A-A'.

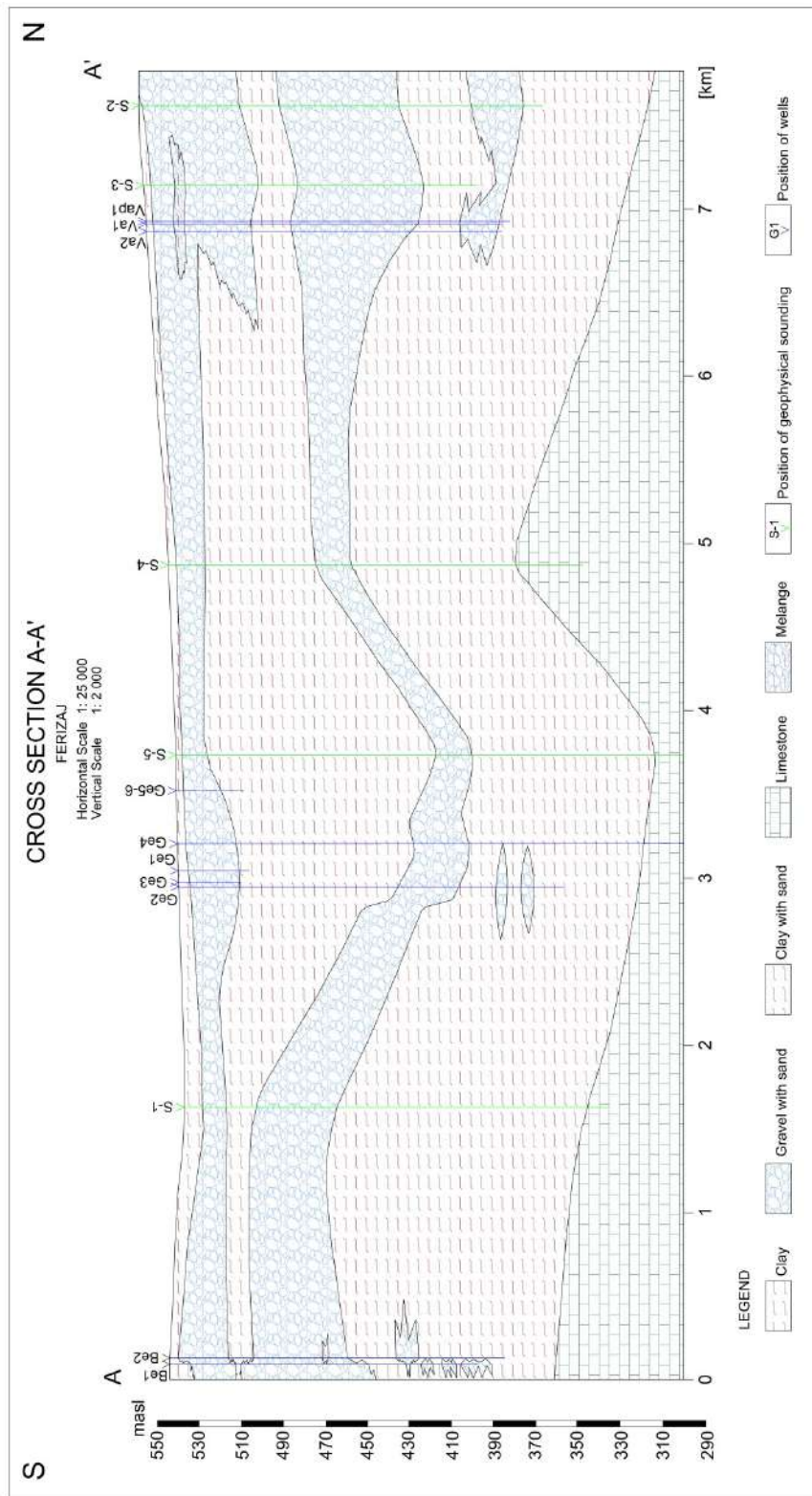


Figure 20: Short version of Cross Section A.

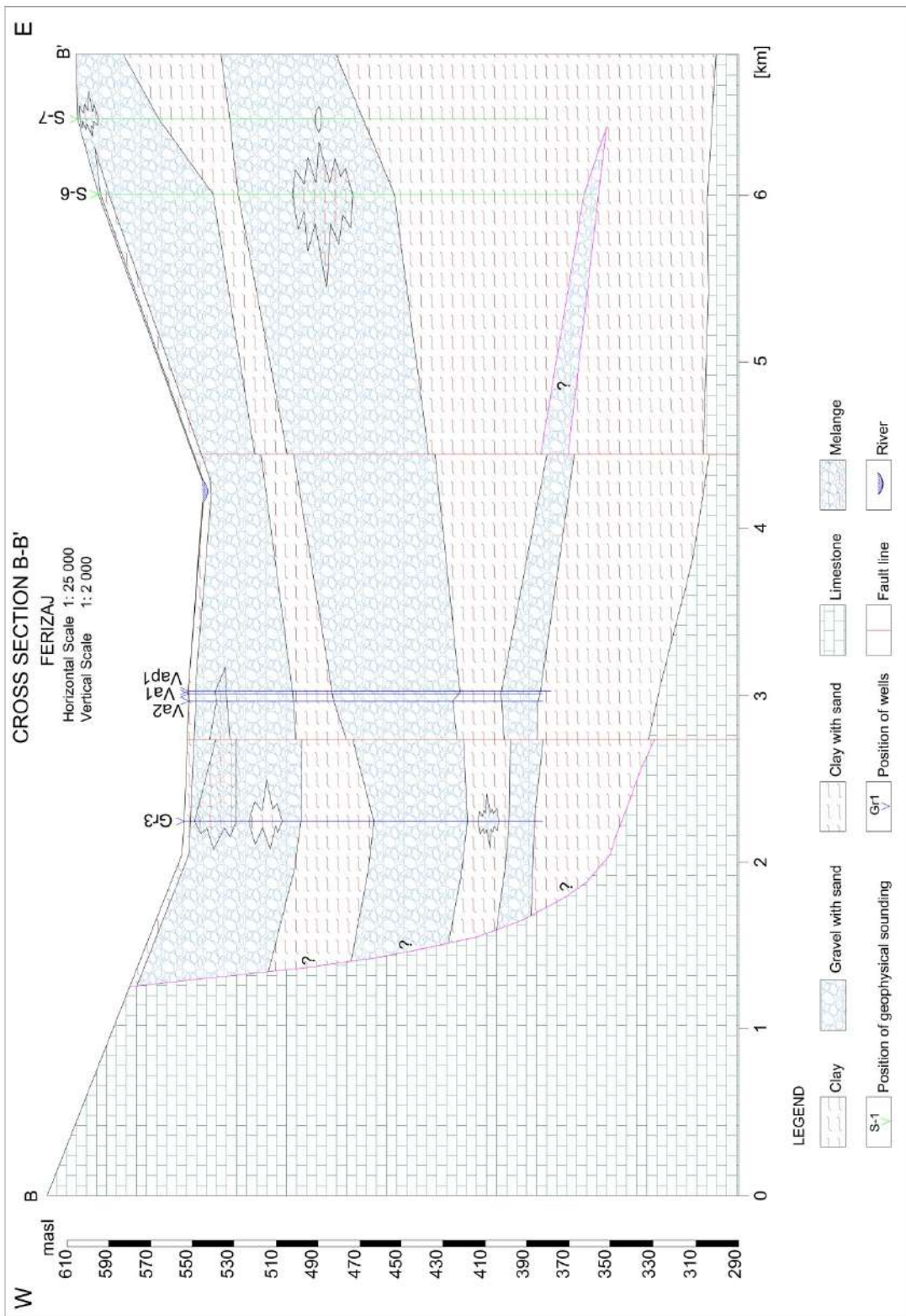


Figure 21: Short version of Cross section B

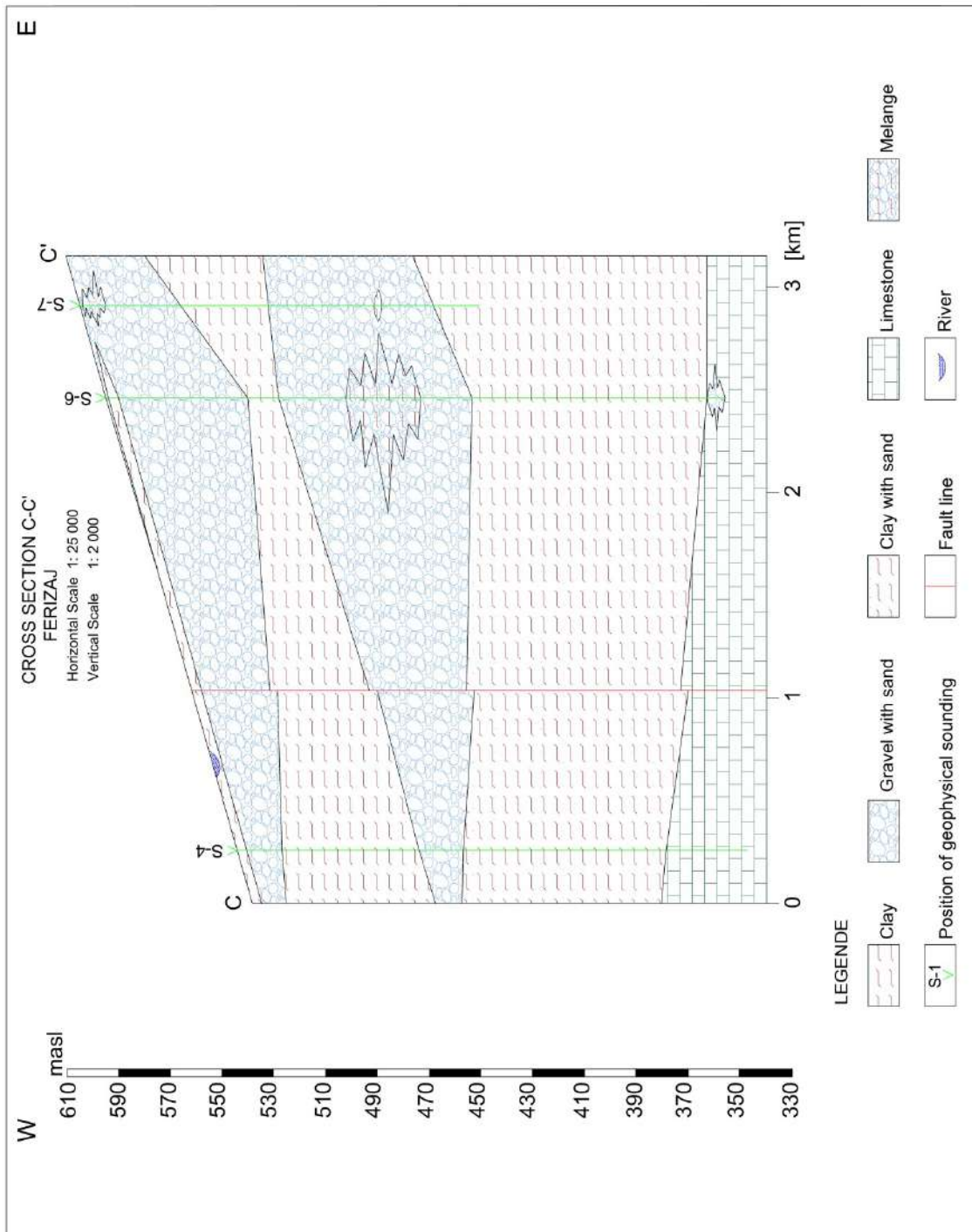


Figure 22: Short version of cross section C.

#### 4.6 Cross Section of the Suhareka Wellfield

Based on the geologic map, the hydrogeological map and the drilling information a 3-Dimensional setup of the study area has been deduced. The positions of the profiles are presented in the geological and hydrogeological map above.

In order to show the vertical dimension, hydrogeological cross sections have been developed (Figure 23; Figure 24; Figure 25).

##### *Cross Section A-B:*

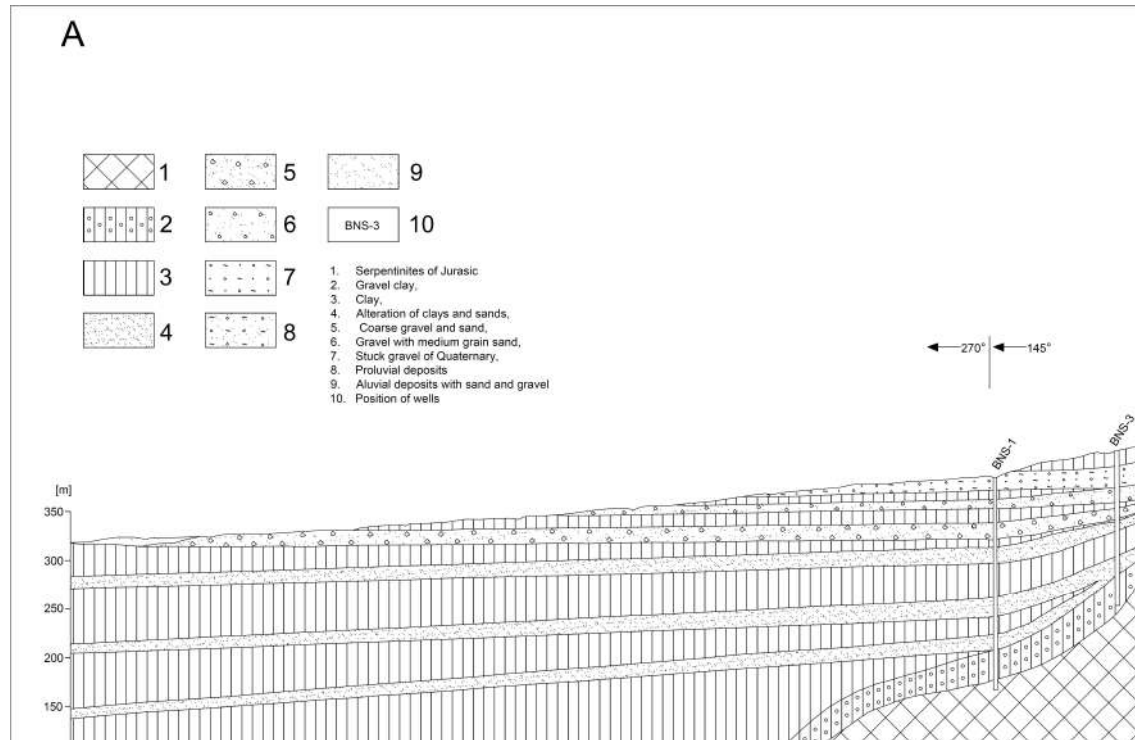


Figure 23: Cross Section A-B (Source: Simić, M. Perić, J.).

**Block Diagram:**

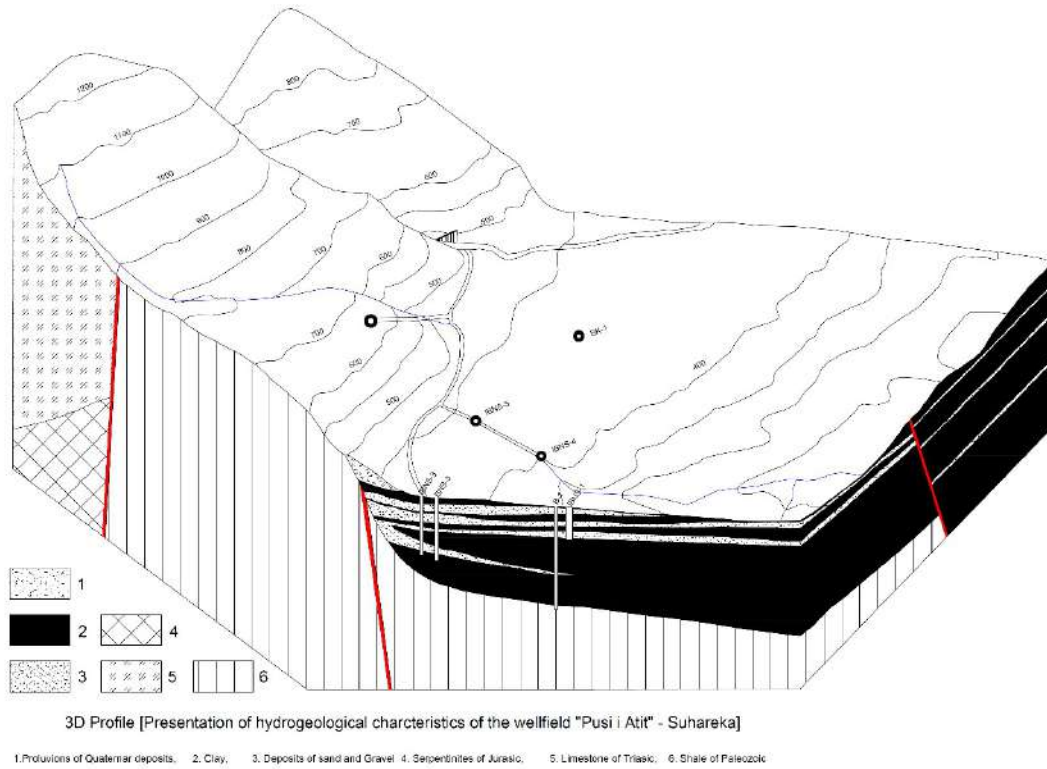


Figure 24: Block diagram (Source: Simić, M. Perić, J.).

**Cross Section C-D:**

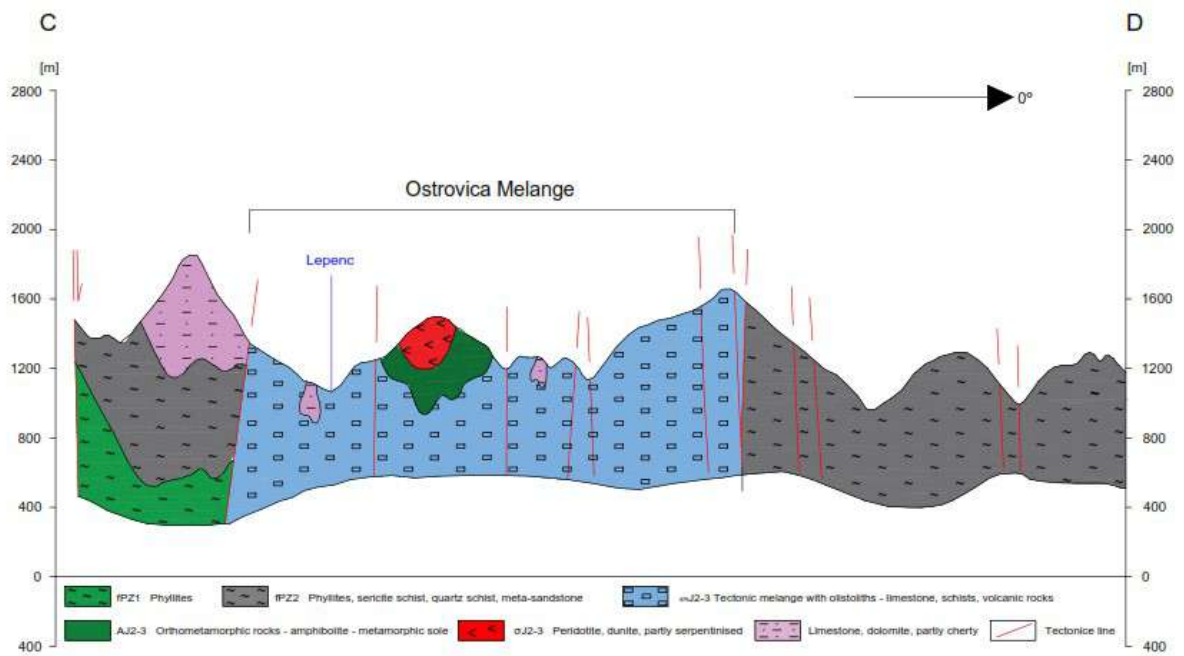


Figure 25: Cross section C-D

#### 4.7 Hydrogeological Parameters of Ferizaj Wellfield

All wells have been investigated during their construction period and the below shown hydraulic parameters have been deducted by RWSSP VI from the received data.

Data from existing pumptests were evaluated to calculate Transmissivity and Hydraulic Conductivity using the Logan formula (Logan 1964) widely used in the pump test evaluation. These values were validated by solving the pumptests with AQTsolve by applying the Cooper-Jacob (Cooper & Jacob 1964) approach for the pump tests for which constant flow values were available. The validation showed very similar results and thus the values calculated with the Logan formula are used in this report. They are shown in Table 22 and further down in Figure 27 and Figure 28.

Table 22: Hydraulic parameters of the wells.

Name	Pumping rates $Q_a$ [l/s]	Drawdown s [m]	Transmissivity T [m <sup>2</sup> /s]	Hydraulic Conductivity K [m/s]
Gerlice 2	4.2; 9.9	2.34; 7.72	1.6E-03	2.1E-05
Gerlice 4	3.2; 5.4; 6.8	1.9; 9.86; 16.55	5.0E-04	2.3E-05
Gerlice 3	4.8; 8.6; 11.4	3.26; 8.88; 15.6	8.9E-04	3.2E-05
Gerlice 1	4; 7; 11.5	3.62; 7.61; 15.65	8.9E-04	2.8E-05
Varosh P1	3.0; 6.25	0.98; 3.21	2.4E-03	2.7E-05
Varosh 1	5; 9.5; 18	2.14; 5; 11.56	1.9E-03	2.4E-05
Varosh 2	6; 12; 20	3.39; 8.66; 13.19	1.9E-03	3.0E-05
Greme P1	4; 7.1; 8.6	6.89; 15.15; 19.77	5.3E-04	9.8E-06
Greme P2	3.2; 5.6; 8.7	6; 12.02; 20.58	5.2E-04	7.5E-06
Greme 1	4; 7; 9.5	4.97; 9.17; 13.24	8.8E-04	1.4E-05
Begrace 2	3; 6	1.96; 4.92	1.5E-03	3.3E-05
Begrace 1	2.2; 4; 8	0.7; 1.73; 4.53	2.2E-03	2.2E-05
Piezometer 1	1.1	3.93	3.5E-04	1.7E-05
Piezometer 2	2.25	4.89	5.6E-04	2.0E-05

For each well, a specific diagram describing the specific drawdown [ $Q_a$ ] during production was produced. All diagrams are attached in Annex 3.

The specific drawdowns vary

from 0.42 [l/s/m] in Greme P1, Greme P2 and Gerlice 4  
to 3.0 [l/s/m] in Varosh P1 and 3.14 [l/s/m] in Begrace 1.

In general, pump tests are carried out in three stages of pumping rates with subsequent measurement of the recovery of the groundwater level. From the order of the lowering at the end of a pumping stage and the associated delivery rate follows a performance curve per pumping test, which gives conclusions about the specific lowering.

The capacity of a well is the product of the filter surface area and the inlet velocity of the groundwater. While the filter jacket area can be calculated, the maximum inlet velocity can only be estimated empirically.

Unconfined aquifer:

$$[\text{Capacity } Q_f] = [\text{Diameter well } \emptyset] * \pi * [\text{water-filled length of well } H] * v_{\max}$$

where  $v_{\max}$  is the maximum velocity of water entering the well.

According to the Sichard formula, the maximum entering velocity for groundwater from the aquifer is

$$v_{\max} = \sqrt{(K) / 15}$$

To estimate the optimum well performance,  $[Q_{\text{opt}}]$ , parameters  $Q_f$  and  $Q_a$  are determined.  $Q_f$  as a function of the well diameter and  $Q_a$ , is measured during the pumping test. Both values are drawn to a graph. The most favourable well capacity  $Q_{\text{opt}}$  is given when the capacity is equal to the water flow:

$Q_f$  and  $Q_a$  are graphically plotted for various drawdowns  $s$  as  $s \rightarrow Q_f$  and  $s \rightarrow Q_a$  in a common figure.  $Q_{\text{opt}}(s)$  is read for the intersection of both lines.

An example is given in Figure 26 for well Varosh 1. The aquifer thickness ( $H$ ) in this example is given as 88 m (sum of all filter length of the equipped well), diameter  $\emptyset$  is 600 mm; while  $K$ ,  $Q_a$ ;  $Q_f$  and  $s$  are taken from the pumping test data. The resulting  $Q_{\text{opt}}$  is  $0.024 \text{ m}^3/\text{s}$  at a drawdown  $s = 26 \text{ m}$ . This example shows that the potential yield ( $0.024 \text{ m}^3/\text{s} = 24 \text{ l/s}$ ) of well Varosh 1 is far beyond the actual pumping rate of  $6.5 \text{ l/s}$ .

However, such determination is not required at the present study and therefore not calculated for all wells.

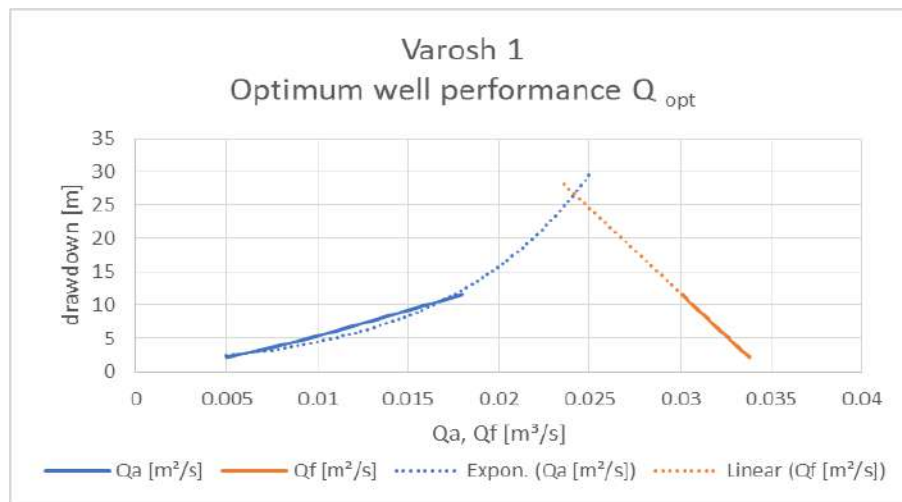


Figure 26: Optimum well performance, example for Varosh 1

#### 4.7.1 Hydraulic Conductivity

Hydraulic conductivity (synonym: Coefficient of Permeability or K-value) is a measure of a sediment’s or rock’s capacity to transport water. Table 23 shows representative values of hydraulic conductivity for various unconsolidated sedimentary materials, sedimentary rocks and crystalline rocks.

Table 23: Representative of K-values for unconsolidated sedimentary materials.

Unconsolidated Sedimentary Materials	
Material	Hydraulic Conductivity (m/s)
Gravel	3E-4 to 3 E-2
Coarse sand	9E-7 to 6E-3
Medium sand	9E-7 to 5E-4
Fine sand	2E-7 to 2E-4
Silt, loess	1E-9 to 2E-5
Till	1E-12 to 2E-6
Clay	1E-11 to 4.7E-9
Unweathered marine clay	8E-13 to 2E-9
Sedimentary Rocks	
Rock Type	Hydraulic Conductivity (m/s)
Karst and reef limestone	1E-6 to 2E-2
Limestone, dolomite	1E-9 to 6E-6
Sandstone	3E-10 to 6E-6
Siltstone	1E-11 to 1.4E-8
Salt	1E-12 to 1E-10
Anhydrite	4E-13 to 2E-8
Shale	1E-13 to 2E-9

Source: Domenico and Schwartz 1990.

The hydraulic conductivity was calculated from pumping tests at the production wells and the piezometers. Table 23 provides an overview of the calculated values in the study area.

In order to obtain an overview and to allow an objective estimation of an average value to apply in further calculations, a histogram shows the distribution of identified values of the hydraulic coefficient. Further, to identify local trends for variations of the hydraulic conductivity, all values are displayed on a map, while the symbol size indicates the local value (see Figure 27).

The obtained values for hydraulic conductivity (K) of the production wells, all located within the sedimentary porous aquifer, are varying from  $2.2E-5$  m/s to  $7.8E-4$  m/s and therefore perfectly meet the representative values given in Table 23 for sands and for gravel. As for the hard rock of the study area, no well tests have been available and K values are to be estimated. In general, values of the given marbles, limestones and schists are varying from  $6E-6$  m/s to below  $1E-9$  m/s. Karstic limestones may show values up to  $1E-2$  m/s, but variation of their yield is large. In order to evaluate the required protection areas, these karstic processes may be disregarded. Karstic sources are not constant and for the evaluation of the protection areas their lowest yield (which is zero) is of interest.

It is evident that the wells providing the highest K values, most probably are within the most recent river valleys with unconsolidated gravel and coarse sands (Figure 27).

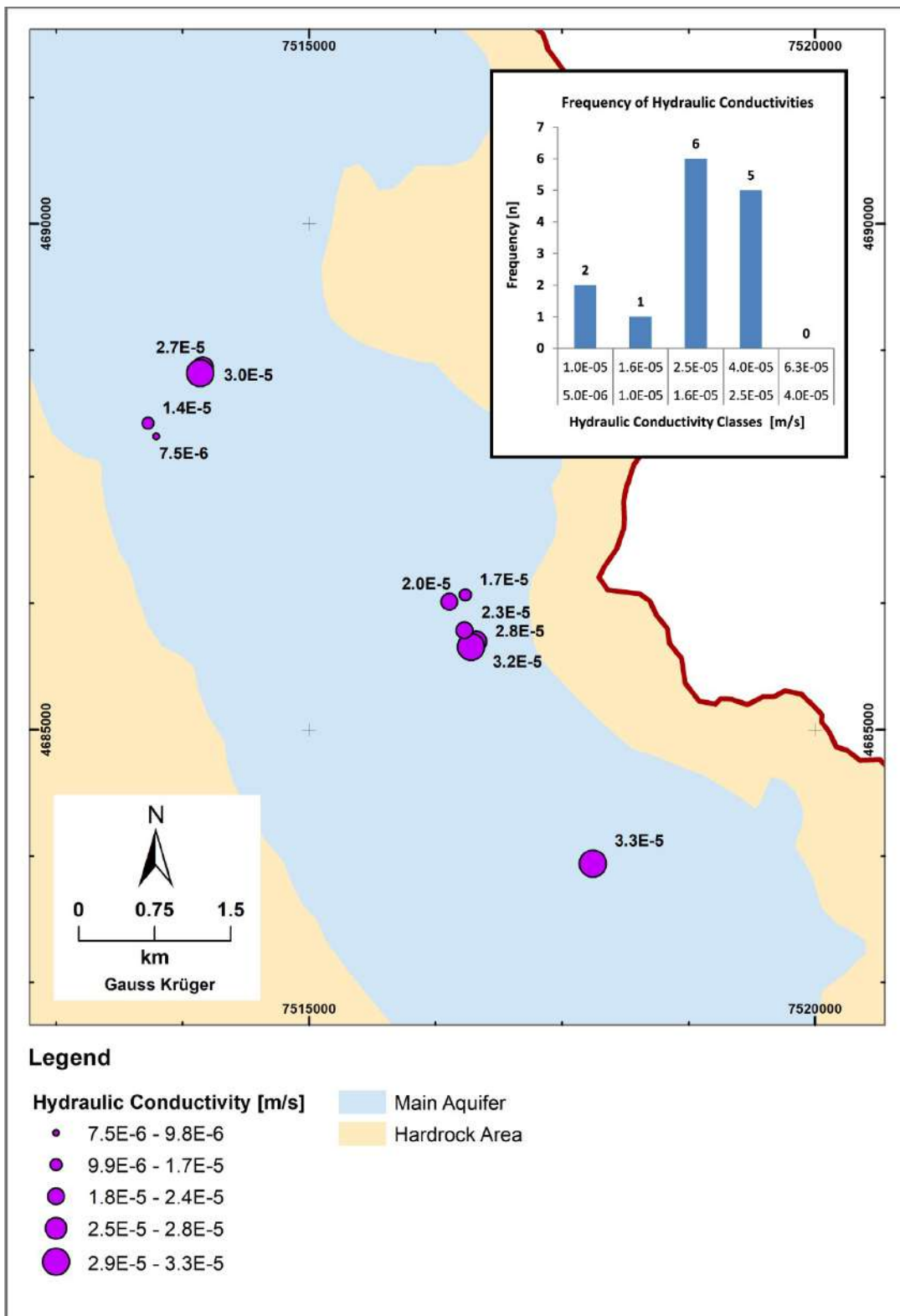


Figure 27: Histogram of hydraulic conductivities and local distribution of values

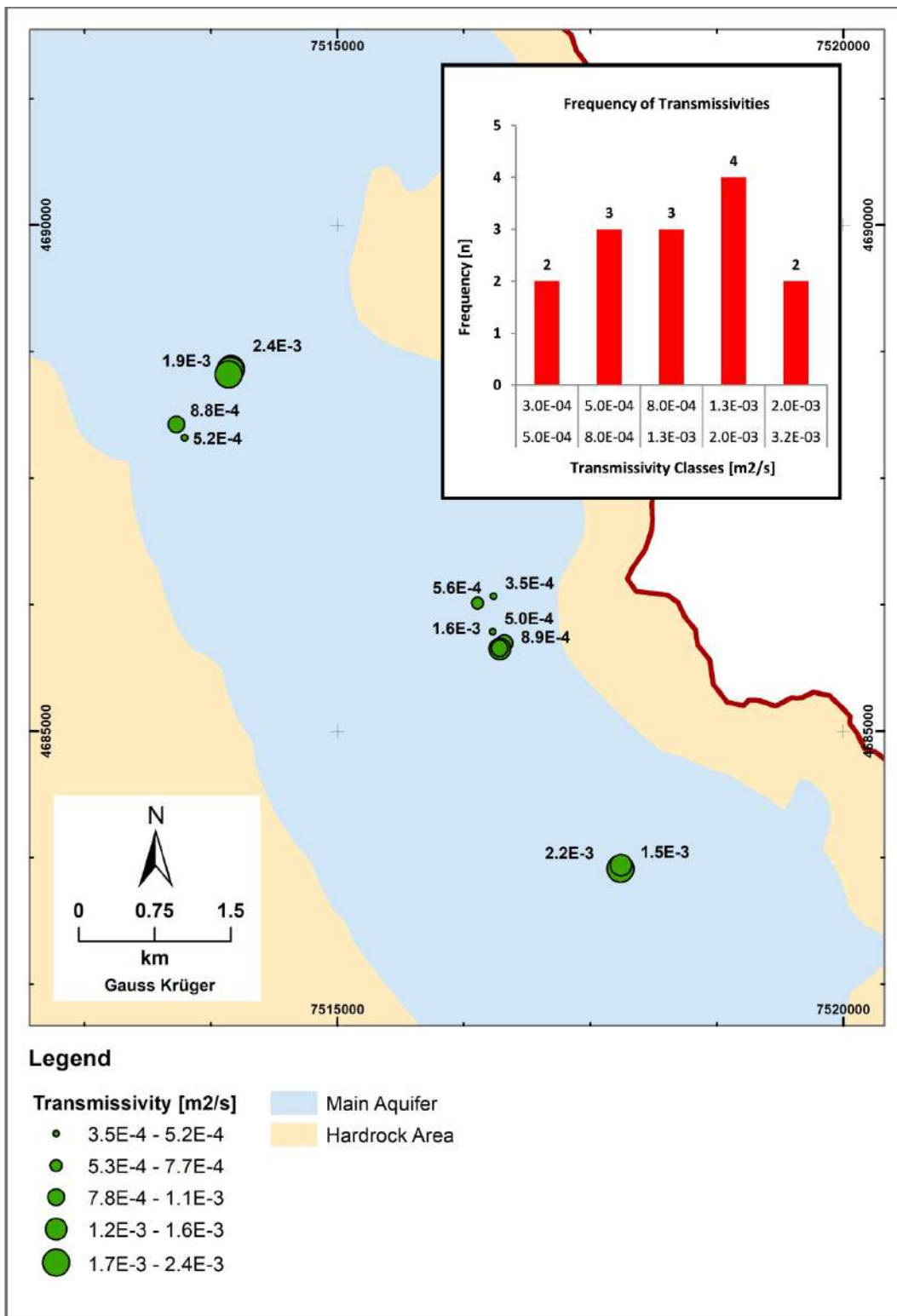


Figure 28: Histogram of Transmissivity and local distribution of values

#### 4.7.2 Transmissivity

Transmissivity is the rate of flow under a unit hydraulic gradient through a unit width of aquifer of given saturated thickness. The transmissivity of an aquifer is related to its hydraulic conductivity as follows:

$$T=K*m$$

where T is the transmissivity, K is the hydraulic conductivity and m is the aquifer thickness.

To define the (active) aquifer thickness, detailed data for the 3-dimensional extension of the aquifer is required. In order to simplify calculation, facilitate further calculation of the aquifer behaviour, the length of the slotted filter pipes and the gravel pack are as well as the information from the cross sections are used as parameter “aquifer thickness” (l). Figure 28 provides an overview on the various transmissivities identified in the study area. Values are distributed between 3E-4 to 3.2E-3 m<sup>2</sup>/s.

#### 4.7.3 Porosity

Porosity is the percentage of open space within unconsolidated sediments or rocks, e.g. the space between grains in a sediment or sedimentary rock but also space within fractures in rocks.

Porosity is expressed as a percentage calculated from the volume of open space in a rock compared with the total volume of rock. Unconsolidated sediments, like the alluvial sediments, tend to have higher porosity than consolidated sediments and rocks. Some representative values are given in Table 24.

The effective porosity is the volume of pore space that will drain in a reasonable period of time under the influence of gravity. Effective porosity is always less than total porosity, sometimes (as in the case of clays) much less. Gravels and sands tend to have values of effective porosity in the range of 5-25% ( $n_{eff}=0.05-0.25$ ) while shales, shists and limestones are of 0.1-14% ( $n_{eff}=0.001-0.14$ ). Important to the calculation of the aquifer is the effective porosity. The later described computer model starts with an approximate value of 0.1 for aquifer areas and 0.01 for the hard rock area.

Table 24: Representative values for porosity and effective porosity.

Lithology	Indicative range of values	
	n (%) (total porosity)	n eff. (%) (effective porosity)
Granite and gneiss	0.02 - 2	0.1 – 2*
Basalt	5 - 30	0.1 – 2*
Quartzite	0.5 - 2	0 – 2*
Shales	0.1 – 7.5	0.1 – 1*
Schists and slates	0.1 – 7.5	0.1 – 2*
Limestone and dolomite	0.5 - 15	0.5 – 14*
Chalk	0.5 - 45	0.5 – 15*
Sandstone, siltstone	3 – 38	3 – 25
Volcanic tuff	30 -40	5 – 15
Gravels	15 - 25	5 – 25
Sands	15 - 35	5 – 25
Silts	30 - 45	5 – 15
Loams, loess and clays	40 - 70	0.1 – 3

\*depends on fractures, fissures. Source: Adapted from Freeze and Cherry 1979.

#### 4.8 Hydrogeological Parameters of Suhareka

During the construction, all production wells have been tested and resulting data have been recorded and transmitted to the RWSSP VI team. (SOAL, 2010)

In order to verify and confirm the hydraulic parameters, further pumping test have been implemented during the hydrogeological research phase 2019 (Aqua Drill, 2019) by the project. 3 exploitation wells have been tested in order to calculate the hydraulic parameters and the correlation between the previous parameters. The project RWSSP VI realized testing wells (Well1, Well4 and B2; executed by Aqua Drill, 2019).

The standard Step Test with 3 increasing pumping rates have been run. Pump rate and draw down in in 3 different wells and the water level of near-by wells have been measured. In general, pump tests are carried out in three stages of pumping rates with subsequent measurement of the recovery of the groundwater level. Pumping phases of 8 hours have been applied and hydraulic parameters have been calculated for each well. Tables 25, 26, 27 and diagrams at Annex 5 show the hydraulic parameters for each well.

At well B2 the testing started with the first phase with a pump capacity of 2 l/s continuing with the second phase 4 l/s and the third phase 6 l/s, but during the testing we stopped at the second phase because the groundwater level began to fall below 48 m depth and the pump was located at a depth of 55 m.

Data from pump tests were evaluated to calculate Transmissivity and Hydraulic Conductivity using the Logan formula (Logan 1964) widely used in pump test evaluation.

Table 25: Hydraulic parameters at well 1 during a pumping test.

Testing parameters	Well 1				Piezometer Pz1	Piezometer Pz2
	Q (l/s)	Q(m <sup>3</sup> /d)	S (m)	q = Q/S	S (m)	S (m)
First drawdown	5.40	466.56	2.92	1.85	0.60	0.28
Second drawdown	10.10	872.64	5.70	1.77	1.50	1.08
Third drawdown	15.00	1296.00	9.56	1.57	2.12	1.71

Parameters	K [m/d]	K [m/s]	T [m <sup>2</sup> /d]	T [m <sup>2</sup> /s]	R [m]
First drawdown	2.58	2.98E-05	166.49	1.93E-03	47.84
Second drawdown	2.47	2.86E-05	159.52	1.85E-03	91.42
Third drawdown	2.19	2.53E-05	141.26	1.63E-03	144.28

Table 26: Hydraulic parameters at well 4 during a pumping tests.

Testing parameters	Well 4				Well 5
	Q (l/s)	Q (m <sup>3</sup> /d)	S (m)	q = Q/S	S (m)
First drawdown	5.00	432.00	1.66	3.01	No impact
Second drawdown	10.00	864.00	3.71	2.70	No impact
Third drawdown	15.00	1296.00	5.89	2.55	No impact

Parameters	K [m/d]	K [m/s]	T [m <sup>2</sup> /d]	T [m <sup>2</sup> /s]	R [m]
First drawdown	3.83	4.44E-05	271.17	3.14E-03	33.17
Second drawdown	3.43	3.97E-05	242.67	2.81E-03	70.13
Third drawdown	3.24	3.75E-05	229.28	2.65E-03	108.22

Table 27: Hydraulic parameters of the well B2 during a pumping test.

Testing parameters	Well B2				Well B1
	Q (l/s)	Q(m <sup>3</sup> /d)	S (m)	q = Q/S	S (m)
First drawdown	2.00	172.80	4.22	0.47	No impact
Second drawdown	4.30	371.52	12.23	0.35	1.43

Parameters	K [m/d]	K [m/s]	T [m <sup>2</sup> /d]	T [m <sup>2</sup> /s]	R [m]
First drawdown	0.67	7.72E-06	42.67	4.94E-04	35.17
Second drawdown	0.49	5.72E-06	31.65	3.66E-04	87.78

with:

Q            Quantity (Yield)

S	Drawdown
q	Specific Drawdown
K	Coefficient of Hydraulic Conductivity
T	Transmissivity
R	Radius of Influence

For each well, a specific diagram describing the specific drawdown [q] during production was established. All diagrams are attached in Annex 3.

The specific drawdowns vary

from 0.35 [l/s/m] in Baqevc B2

to 3.01 [l/s/m] in Well 4

These data are typical for wells in this aquifer, however showing a lower performance of well B2. the Hydraulic parameters of the aquifer. In the same manner the results of the calculation of the permeability vary.

#### 4.8.1 Hydraulic Conductivity

Hydraulic conductivity (synonym: Coefficient of Permeability or K-value) is a measure of a sediment's or rock's capacity to transport water.

The resulting hydraulic conductivity parameters of the above described pumping tests provide typical values for Sand-, Silt-, and Till aquifers (Table 28 shows representative values of hydraulic conductivity for various unconsolidated sedimentary materials, sedimentary rocks and crystalline rocks.):

Well 1	from	2.53E-05 m/s	to	2.98E-05 m/s
Well 4	from	3.75E-05 m/s	to	4.44E-05 m/s
Well B2	from	5.72E-06 m/s	to	7.72E-06 m/s

Further, the values resulting from the pumping tests correspond to indications given by the Hydrogeologic map (see Annex 3) ranging at the upper end for the so called "Intergranular porosity aquifer with medium to low permeability":  $K [m/s] = 10^{-5} - 10^{-9}$  and at the lower end of the "Intergranular porosity aquifer with very high to medium permeability":  $K [m/s] > 10^{-5}$ .

Table 28: Representative of K-values for unconsolidated sedimentary materials.

<b>Unconsolidated Sedimentary Materials</b>	
<b>Material</b>	<b>Hydraulic Conductivity (m/s)</b>
Gravel	3E-4 to 3 E-2
Coarse sand	9E-7 to 6E-3
Medium sand	9E-7 to 5E-4
Fine sand	2E-7 to 2E-4
Silt, loess	1E-9 to 2E-5
Till	1E-12 to 2E-6
Clay	1E-11 to 4.7E-9
Unweathered marine clay	8E-13 to 2E-9
<b>Sedimentary Rocks</b>	
<b>Rock Type</b>	<b>Hydraulic Conductivity (m/s)</b>
Karst and reef limestone	1E-6 to 2E-2
Limestone, dolomite	1E-9 to 6E-6
Sandstone	3E-10 to 6E-6
Siltstone	1E-11 to 1.4E-8
Salt	1E-12 to 1E-10
Anhydrite	4E-13 to 2E-8
Shale	1E-13 to 2E-9

(Source: Domenico and Schwartz 1990)

#### 4.8.2 Transmissivity

Transmissivity is the rate of flow under a unit hydraulic gradient through a unit width of aquifer of given saturated thickness. The transmissivity of an aquifer is related to its hydraulic conductivity as follows:

$$T=K*m$$

with

- K        Coefficient of Hydraulic Conductivity
- T        Transmissivity
- m        Aquifer thickness

To define the (active) aquifer thickness, detailed data for the 3-dimensional extension of the aquifer is required. In order to facilitate and to simplify calculation of the aquifer behavior, the length of the slotted filter pipes and the gravel pack are as well as the information from the cross sections are used as parameter for the aquifer thickness. To evaluate the above pumping test following values for m [aquifer thickness] have been applied.

Well P1	64,5 m
Well 4	70,7 m
Well B2	64,0 m

The resulting transmissivities [T] are distributed between 4.3 E-4 to 2.9 E-3 m<sup>2</sup>/s.

In order to achieve an realistic starting point the average of the obtained Transmissivity values have been averaged.

As the hard rock area of the study area has not been tested its hydraulic conductivities however, its geology is well known, an estimated average of the permeability of Sandstone, limestone and karstic rocks of 3 E-4 m<sup>2</sup>/s has been applied for the modelling.

#### 4.8.3 Porosity

Porosity is the percentage of open space within unconsolidated sediments or rocks, e.g. the space between grains in a sediment or sedimentary rock but also space within fractures in rocks.

Porosity is expressed as a percentage calculated from the volume of open space in a rock compared with the total volume of rock. Unconsolidated sediments, like the Holocene (alluvial) sediments, tend to have higher porosity than consolidated sediments and rocks. Some representative values are given in Table 29.

The effective porosity is the volume of pore space that will drain under the influence of gravity. Effective porosity is always less than total porosity, in the case of clays it is more than one dimension less. Gravels and sands tend to have values of effective porosity in the range of 5-25% with an effective porosity  $n_{eff}=0.05-0.25$ . Shales, shists and limestones are of 0.1-14% porosity and effective porosity is  $n_{eff}=0.001-0.14$ . Important to the calculation of the aquifer is the effective porosity.

The later described computer model starts with an approximate value of 0.1 (consolidated sands and gravels) for aquifer areas and 0.01 (igneous rocks) for the hard rock area.

Table 29: Representative values for porosity and effective porosity.

Lithology	Indicative range of values	
	n (%) (total porosity)	n eff. (%) (effective porosity)
Granite and gneiss	0.02 - 2	0.1 - 2*
Basalt	5 - 30	0.1 - 2*
Quartzite	0.5 - 2	0 - 2*
Shales	0.1 - 7.5	0.1 - 1*
Schists and slates	0.1 - 7.5	0.1 - 2*
Limestone and dolomite	0.5 - 15	0.5 - 14*
Chalk	0.5 - 45	0.5 - 15*
Sandstone, siltstone	3 - 38	3 - 25
Volcanic tuff	30 - 40	5 - 15

Gravels	15 - 25	5 – 25
Sands	15 - 35	5 – 25
Silts	30 - 45	5 – 15
Loams, loess and clays	40 - 70	0.1 – 3

\*depends on fractures, fissures.

(Source: Adapted from Freeze and Cherry 1979)

#### 4.9 Groundwater Levels Observations at Ferizaj Wellfield

Since 2018, the RWSSP VI started the investigation of the Ferizaj well fields. Besides the production wells, numerous observation wells have been identified in the field (see Figure 29). Such observation wells most of the time constitute private owned shallow open wells, in rare cases equipped with pumps.

Observation wells have been mapped and a topographical survey initiated by the RWSSP VI provided the absolute topographic level (meter above sea level), (see Annex 5).

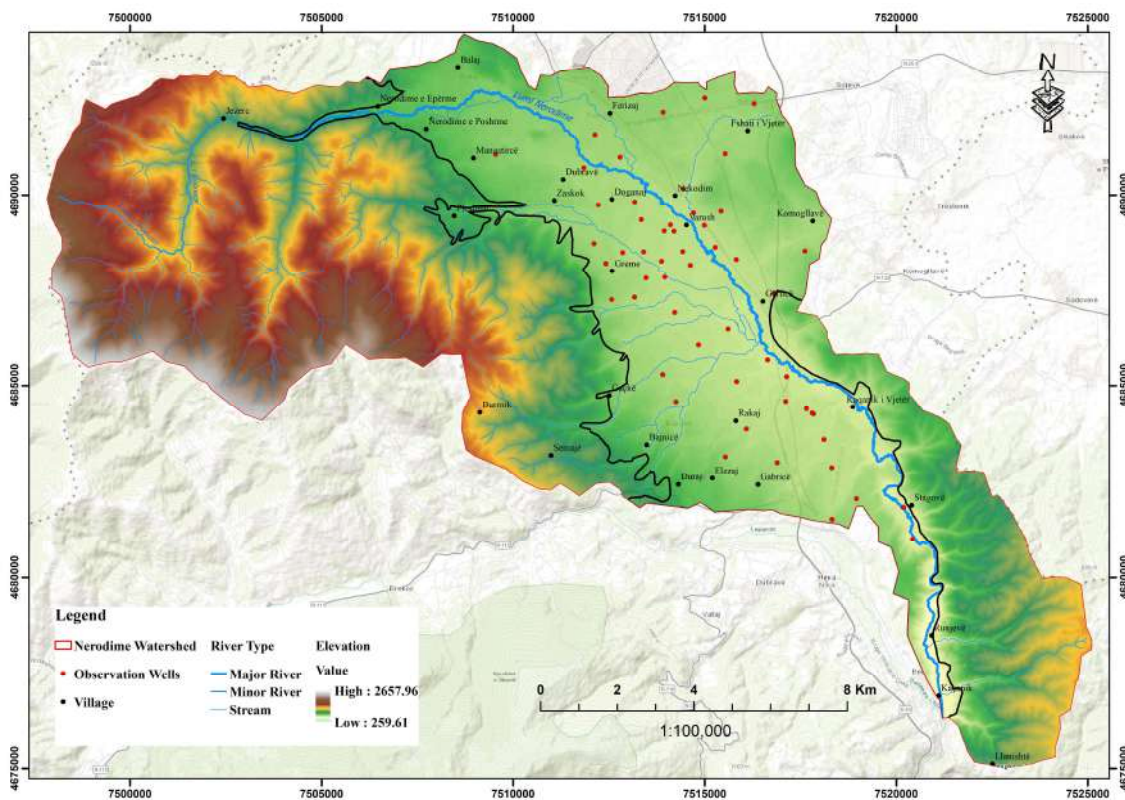


Figure 29: Overview map of identified observation wells.

#### 4.10 Groundwater Levels Observations at Suhareka Wellfield

Since 2019, the RWSSP VI started the investigation of the Pusi Atit well field. Besides the production wells, numerous observation wells have been identified in the field (see Figure 30). Such observation wells most of the time constitute private owned shallow open wells, in rare cases equipped with pumps.

Observation wells have been mapped and a topographical survey initiated by the RWSSP VI provided the absolute topographic level (meter above sea level), (see Annex 6).

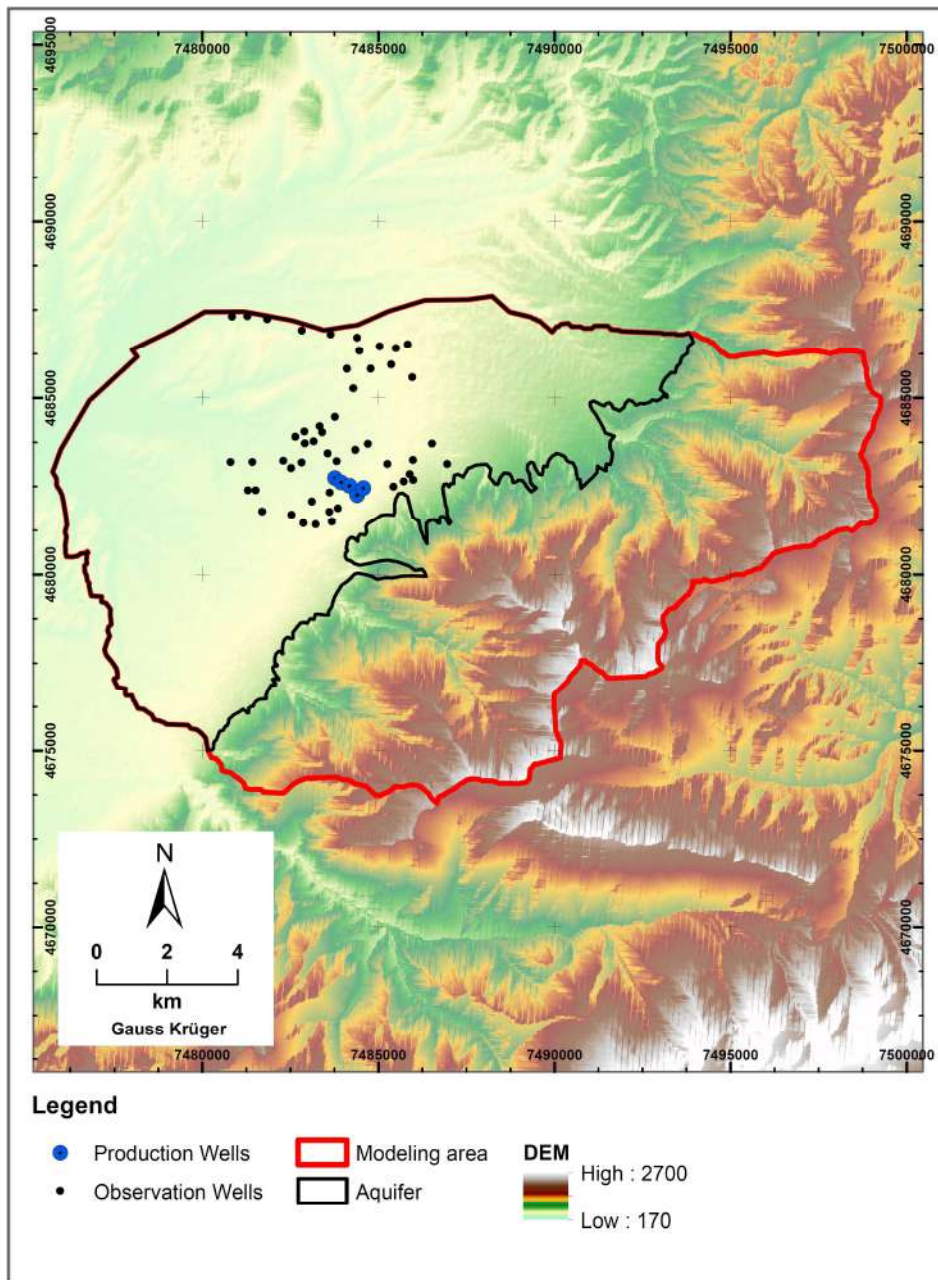


Figure 30: Overview map of identified observation wells.

## **5 MATHEMATICAL GROUNDWATER MODEL**

### **5.1 The Conceptual Model of Ferizaj Wellfield**

For the delineation of the groundwater protection areas of the wells, and the quantification of the water budget a 2-dimensional steady-state groundwater flow model assuming average flow conditions was designed. As the well drawdown in the alluvial aquifer is small compared to the total thickness of the alluvial aquifer confined aquifer conditions were assumed.

#### **5.1.1 Model Area**

The model area (equal to the study area) comprises the total catchment area of the Nerodime River including the valley with the alluvial sediments and the hard rocks of the surrounding mountains. This approach guarantees a feasible estimation of the groundwater inflow from the mountain area into the alluvial aquifer.

The boundary in the West, North, and East is defined by the watershed, while the boundary in the south follows the course of the river Lepence entering the Nerodime valley from the West.

#### **5.1.2 Boundary Conditions**

The boundary conditions are orientated on the natural hydraulic boundaries (see Figure 31). The watershed of the Nerodime River is simulated as a no flow boundary. The southern boundary within the alluvial is a fixed head boundary following the observed groundwater head contour line for average groundwater flow conditions. The river reaches within the alluvial are simulated by a leakage boundary, while the rivers and wells in the hard rock area are simulated as drains. This means that in the first case effluent and influent conditions can be simulated, while in the second case only an outflow of groundwater into the rivers respectively into the drains is possible.

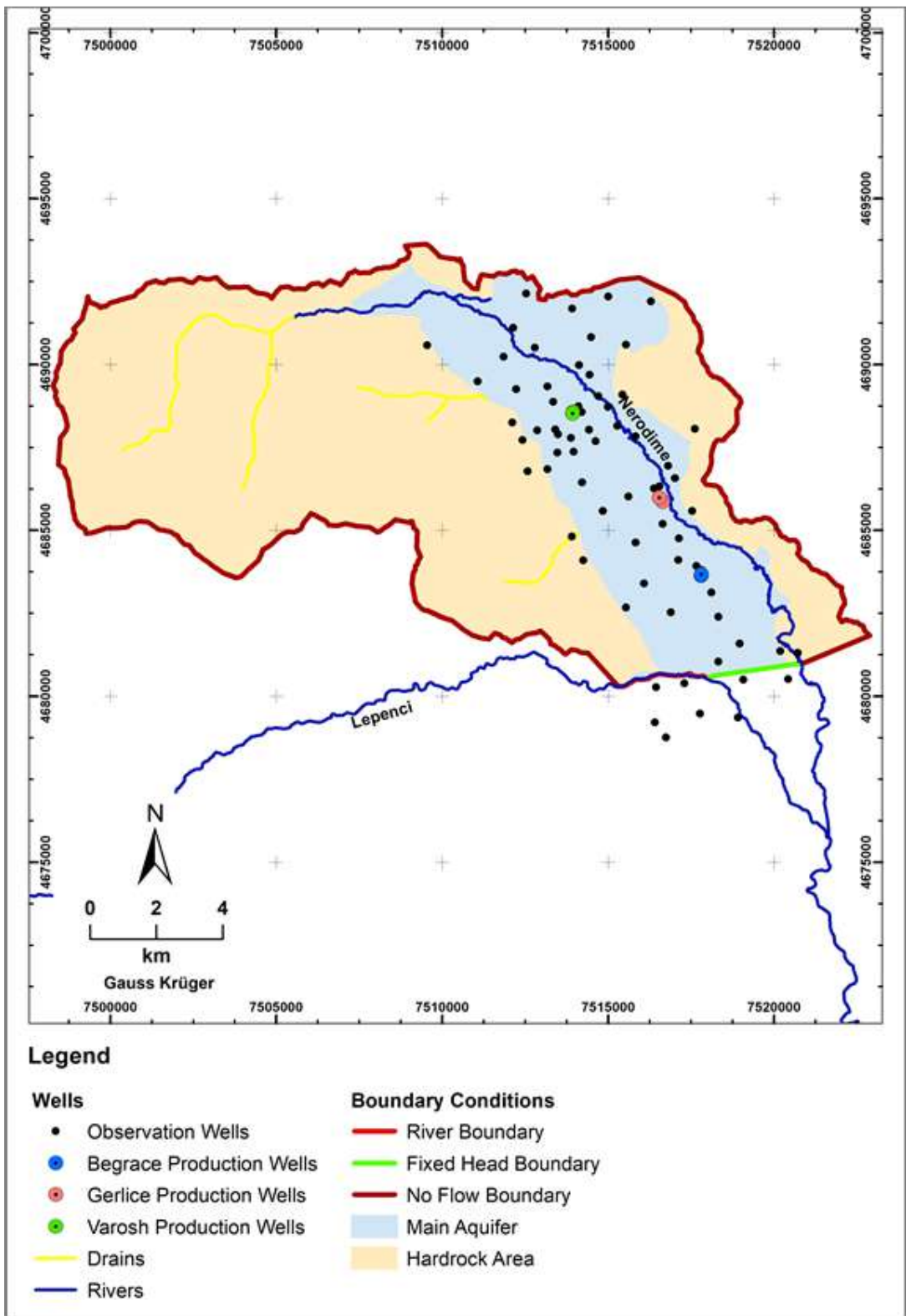


Figure 31: Boundary conditions of the model.

## 5.2 The Computer Model and Input Parameters

### 5.2.1 Description of the Computer Model

For the numerical computation of groundwater flow the program Modflow (USGS, 2005) was used. Pre- and post-processing was done with Processing Modflow Version 8.0 (SimCore).

The delineation of the catchment areas and the corresponding 50-day isochrones of the production wells were calculated with the advective transport model PMPATH.

### 5.2.2 Input Parameters

Table 30 gives an overview of the input parameters of the model. The chapters below describe these values in more detail.

Table 30: Input Parameters for the modelling.

Parameter	Value	Unit
Extent of the modelled area Easting	24700	m
Extent of the modelled area Northing	13350	m
Number of Rows	287	-
Number of Columns	510	-
Number of cells	146370	-
Cell Size	50 x 50 (10 x10)	m
Number of Layers	1	-
Aquifer thickness	250	m
Initial Hydraulic Head	530	m asl.
Transmissivity of Aquifer	1.0E-03	m <sup>2</sup> /s
Transmissivity of Hard Rock	2.0E-04	m <sup>2</sup> /s
Effective Porosity Aquifer	0.1	-
Effective Porosity Hard Rock	0.01	-
Recharge in Aquifer	3.0E-09	m/s
Recharge in Hard Rock	1.0E-09	m/s
Well Abstraction	4.5E-02	m <sup>3</sup> /s
Drainage	2.5E-02	m <sup>3</sup> /s

### ***Grid***

A finite difference grid with 146 370 square cells with a constant cell size of 50 x 50 m over an area of about 330 km<sup>2</sup> was selected for the flow model. There are 510 cells in the x-direction (west to east) and 287 in the y-direction (north to east). The number of active cells is 4.76E+10 corresponding to a model area of 210 km<sup>2</sup>. This discretization gives a clear-cut idea of the groundwater flow field in the entire area. The grid is more detailed around the wells to increase modeling accuracy. Therefore, cells in the well field area are scaled down to 10 m x 10m.

### ***Layer and Aquifer thickness***

For this model 1 layer was sufficient. Whereas the top of the layer represents the ground level and the bottom of the layer represents the bottom of the aquifer. GPS data from field survey were gathered during the measurement campaign and are used for the ground level.

Based on the cross sections the average aquifer thickness is 250 meters.

### ***Heads at fixed head boundary***

The initial head at the fixed head boundary was chosen to be 530 m asl.

### ***Transmissivity***

Chapter 4.7.1, Figure 27 and Figure 28 describe the hydraulic conductivities and the transmissivities in the aquifer. Since a homogenous underground is assumed two different values were estimated: one for the alluvial aquifer and one for the hard rock area. Based on the above mentioned chapters the values were calculated as average values. These values will be adapted during calibration for the best fit. For the model, only the transmissivity is used as hydraulic conductivity is calculated internally.

As a starting value (before calibration) the following transmissivities are used for the model.

Transmissivity - alluvial	9.8 E-4 m <sup>2</sup> /s
Transmissivity - hard rock	2.0 E-04 m <sup>2</sup> /s

### ***Effective Porosity***

There are no laboratory values available so far for effective porosities, so that the effective porosity has to be estimated. Similar as for transmissivity, one value was chosen for each the alluvial aquifer and the hard rock area.

The literature values provide a wide range of values for each type of rock (see Table 24, 29).

For the computation of the 50-day isochrone an effective porosity of  $n_f = 0.1 = 10\%$  for the alluvial aquifer, and  $n_f = 0.01 = 1\%$  for the hard rock aquifer was assumed.

### **Well Abstraction**

The size of the water source protection zone also depends on the abstraction rate of the production wells. In general water source protection zones are calculated with the abstraction rate for which a permit was issued. However, in Ferizaj/Uroševac this is not the case.

One possibility is to use the current abstraction rates of the wells. This might however change in the future due to changing demands. To ensure a long lasting solution it was decided to use a design demand for the year 2034 based on census data and design water consumption figures used for water supply design.

Table 31 gives an overview of the data and assumptions. For the three wells-fields the total consumption is calculated based on the census 2034 population data and distributed to the existing production wells which have a pump installed. This results in modelling of a total 6 wells with a total abstraction of 45 l/s. If, in the future these values will be exceeded, the water source protection zone has to be recalculated.

Table 31: Overview of the data and assumptions for the three wells-fields

Well name (RWSSP VI)	Varosh1	Varosh2	Gerlice 1	Gerlice 2	Gerlice 3	Gerlice 4	Begrace 1	Begrace 2	Total
Pump installed	Yes	Yes	Yes	No	No	Yes	Yes	Yes	
Design flow [l/s]	6.5	N/A	5.5	N/A	N/A	3.0	6.5	8.5	21.5
Supplied Villages	Varosh/Varoš Selo, 50% Nekodim		Gërlicë/Grlica, Komogllavë/ Kamena Glava			Kačanik i Vjetër/ Stari Kačanik, Begracë/ Belograc			
Inhabitants 2034	6,224		6,775			5,813			18,812
Total Design flow 2034 [l/s]	15		16			14			45
Design flow 2034/ modelled flow [l/s]	7.5	7.5	8.0	0.0	0.0	8.0	7.0	7.0	45

### ***Recharge***

The groundwater recharge from precipitation was estimated from precipitation data, computation of evapotranspiration, and the analysis of streamflow records from gauging stations of the rivers. The estimates are shown in Table 32.

### ***River Leakage***

The river leakage was not known a priori, it was estimated during the calibration process of the model. For the river hydraulic conductance, a value of  $5E-4$  m<sup>2</sup>/s was estimated.

### ***River Drains***

The rivers and creeks in the hard rock area were modelled as drain nodes with a very high conductance to guarantee that they are perfectly hydraulically connected to the aquifer. For the drain hydraulic conductance a value of  $0.2$  m<sup>2</sup>/s was estimated.

## **5.3 Calibration**

Due to the limited data available a simple calibration strategy was applied. Within the model area two homogenous zones were defined. Zone 1 corresponds to the alluvial, zone 2 to the hard rocks. For each zone the transmissivity of the aquifer and the groundwater recharge from precipitation was estimated. Table 32 shows the average and the range of the model parameters transmissivity and groundwater recharge from precipitation.

Table 32: Overview on Transmissivity and recharge applied

<b>Parameter</b>	<b>Unit</b>	<b>Average value</b>	<b>Min. value</b>	<b>Max. value</b>	<b>Best fit calibration</b>
Transmissivity - alluvial	m <sup>2</sup> /s	9.8 E-4	3.5 E-4	2.4 E-3	1.0 E-3
Transmissivity - hard rock	m <sup>2</sup> /s	2.0 E-4	1.0 E-5	3.0 E-4	2.0 E-4
Gw-recharge - alluvial	m/s	4.0 E-9	2.0 E-9	6.0 E-9	3.0 E-9
Gw-recharge - hard rock	m/s	1.5 E-9	0.5 E-9	2.0 E-9	1.0 E-9

The leakage factor respectively the hydraulic conductance for the rivers and drain nodes were kept constant during the calibration process.

During the calibration process transmissivity and groundwater recharge were varied within the given ranges. The simulation results were compared with measured head data from observation wells in the alluvial sediments. Observation data from the hard rocks were not available, so that a classical calibration of the groundwater heads in this zone was not possible. However, the simulated head distribution is plausible and according to the hydrogeologist's experience a realistic scenario. It is controlled by the drainage network.

The values for the best parameter fit are displayed in Table 33 (Column: best fit calibration). Figure 32 shows the corresponding scatter plot ( $h_{\text{calculated}}$  versus  $h_{\text{observed}}$ ). It can be seen that the deviation between the calculated and observed heads is quiet good taking into account the simple zonation approach of the model in only two hydrogeological zones.

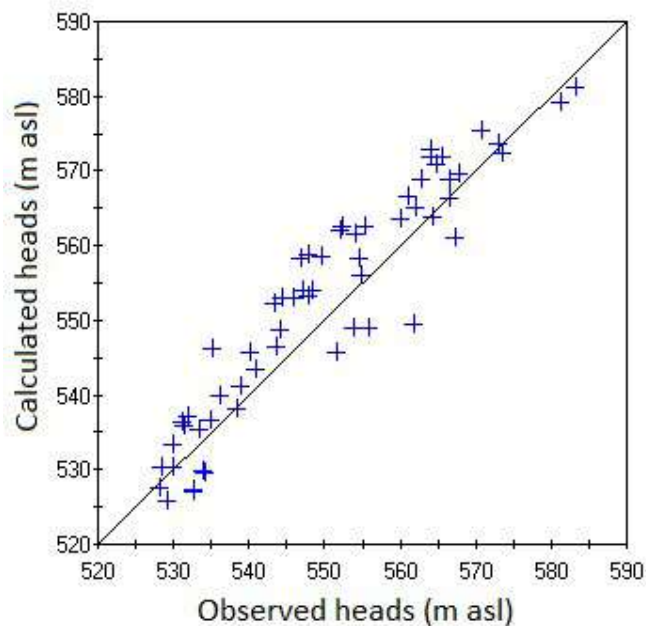


Figure 32: Scatter plot as comparison of calculated and observed piezometric heads.

The calculated variance of the fit is  $33.19 \text{ m}^2$  (the variance is defined as the mean squared error between observed and calculated heads).

Figure 33 shows the piezometric head distribution in the alluvial aquifer for steady state conditions. It can be seen that the groundwater dynamic within the aquifer is strongly dependent from the inflow from the hard rocks and the Nerodime River which acts as gaining river, that means that the groundwater discharges into the river.

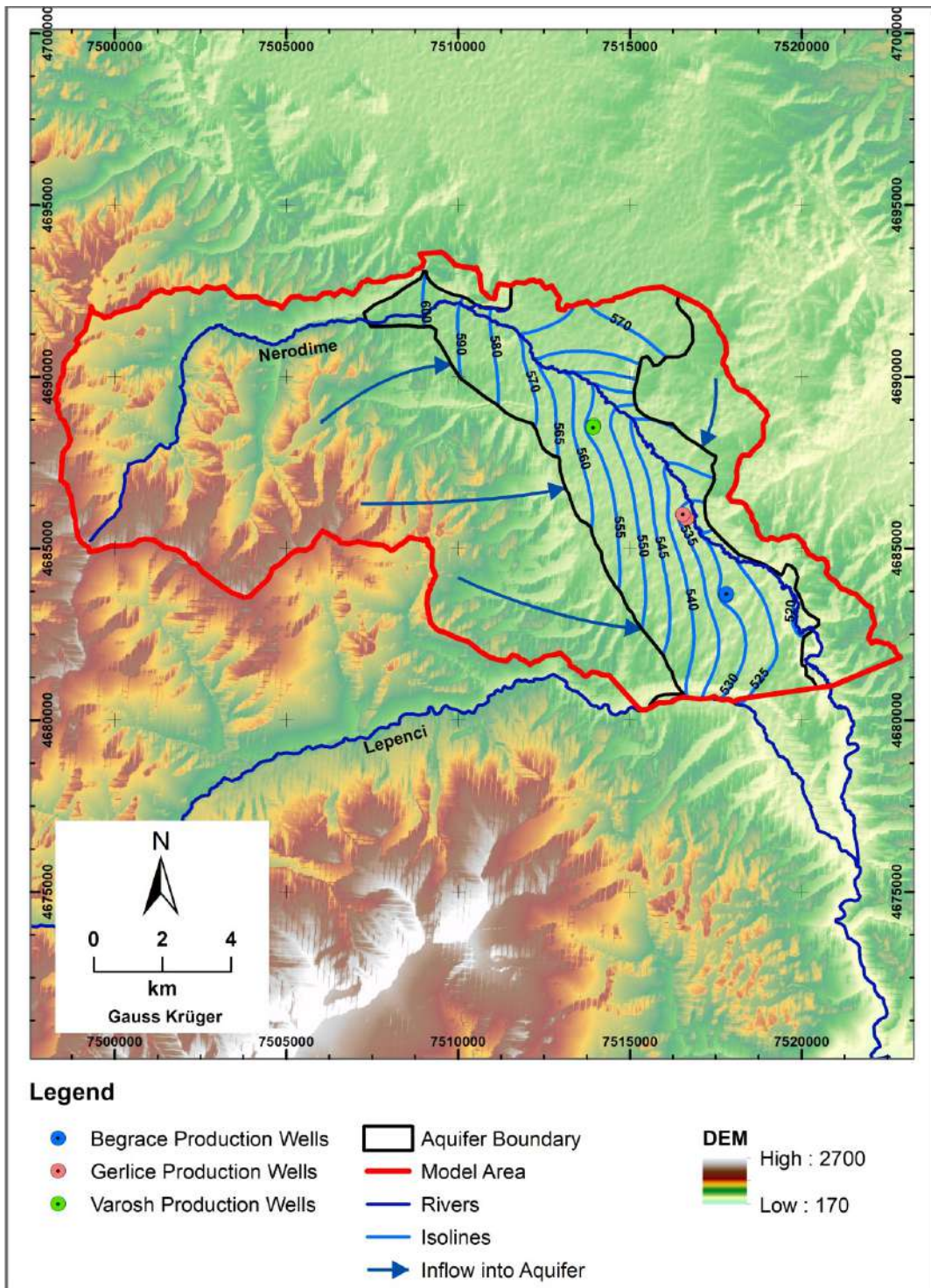


Figure 33: Piezometric head distribution in the alluvial aquifer for steady state conditions.

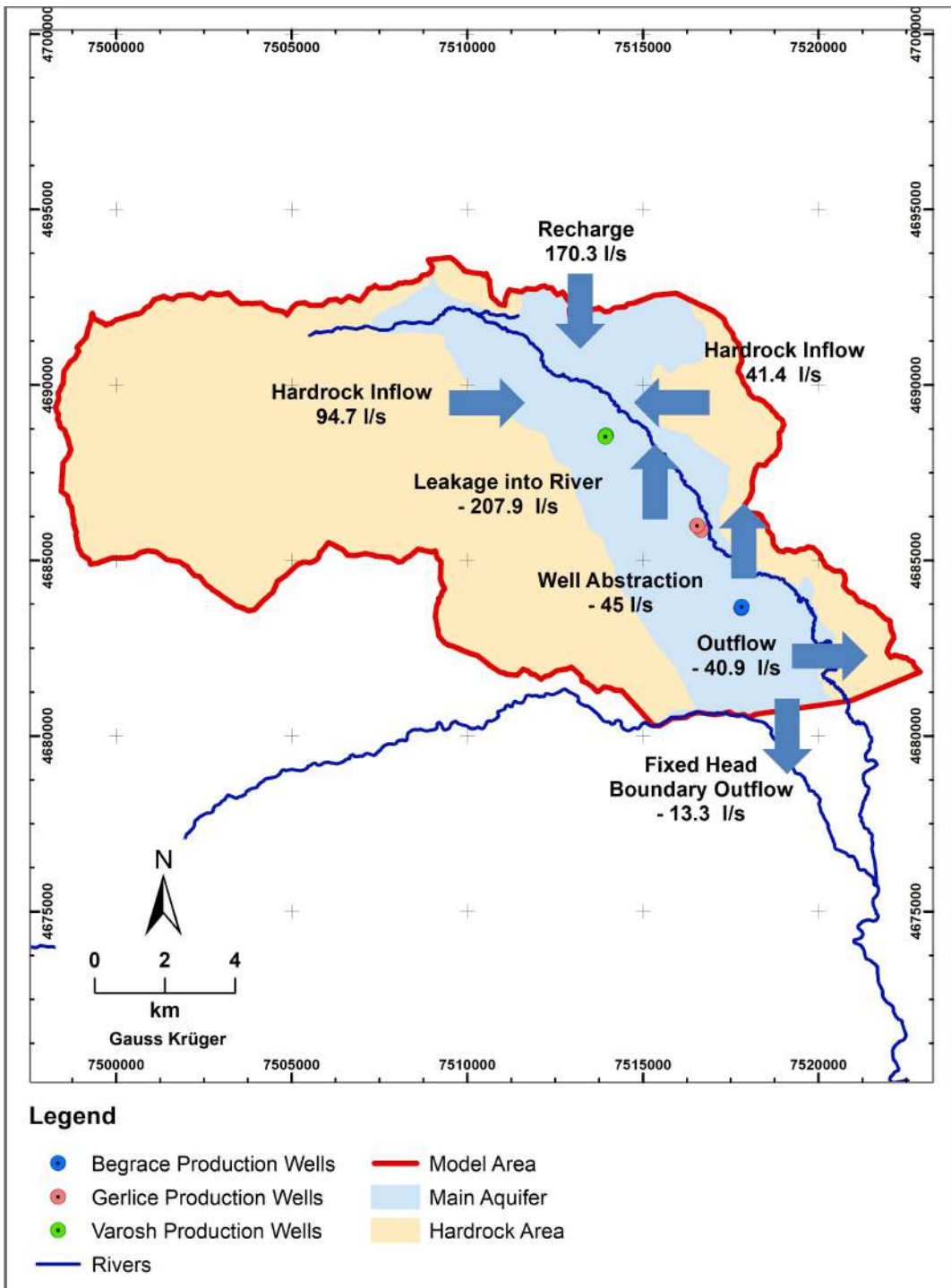


Figure 34: Water balance calculated by the model.

The water budget is shown in Figure 34. It shows the steady state water balance for the alluvial aquifer for average conditions. The arrows show the in- and outflows. Inflows are positive, outflows are negative.

## **5.4 Results**

On the basis of the calibrated groundwater flow model the groundwater protection areas of the wells were calculated.

The following information is necessary when interpreting the maps.

- Zone I does not have to be calculated. It simply is the line 10 m around the well (MESP 2017). It is indicated as a black line in the following maps.
- Zone II is based on the 50-day isochrone and is calculated by the model. The 50-day isochrone as calculated by the model is shown in blue color. In Article 12, paragraph 2, Administrative Instruction (MESP 2017) indicates that Zone II must be at least 100 m from the well. Thus, this 100 m minimum line is indicated in addition to the 50-day isochrones in red color.
- Zone III is based on the entire catchment of the well and is calculated by the model. This catchment boundary, as calculated by the model, is indicated as dotted blue line in the below figures.
- In Article 14, paragraph 3, the Administrative Instruction (MESP 2017) indicates that Zone III must be at least 500 m from Zone I. Thus, this 500 m minimum line is indicated in addition as a red dotted line. Whenever the catchment is more than 500 m from the well, the blue and the red dotted lines are identical.
- In addition, the Administrative Instruction states in Article 14, paragraph 2, that if the catchment area of the well is not known, Zone III shall be the 200-day isochrones. Therefore, the 200 day isochrones is also indicated as orange line in the following figures. However, because the catchment could be calculated, this line is purely informative.

### **5.4.1 Varosh Production Wells**

The Varosh wells are located approximately 45 meters from each other. Therefore, both wells have a separate 10 meter line. Also two separate 50-day isochrones are calculated. Both 50-day isochrones have an approximate diameter between 40-50 meters. The 50-day isochrones are therefore of less extension than the 100 m minimum line (see Figure 35).

The catchment of the wells is overlapping and creates a single area extending towards the flow of the groundwater towards west. Its length is approximately 2.7 km and its width is roughly 1.2 km. In the eastern part, the catchment is below 500 as indicated by the 500 m minimum line in Figure 36.

The 100 m minimum line is enclosing some private homes to the West. The catchment area encloses mainly agricultural areas. However, villages at the Eastern and Western end are enclosed. Further, and more important, the street crossing the catchment area from North to South accommodates some commercial infrastructure towards West.

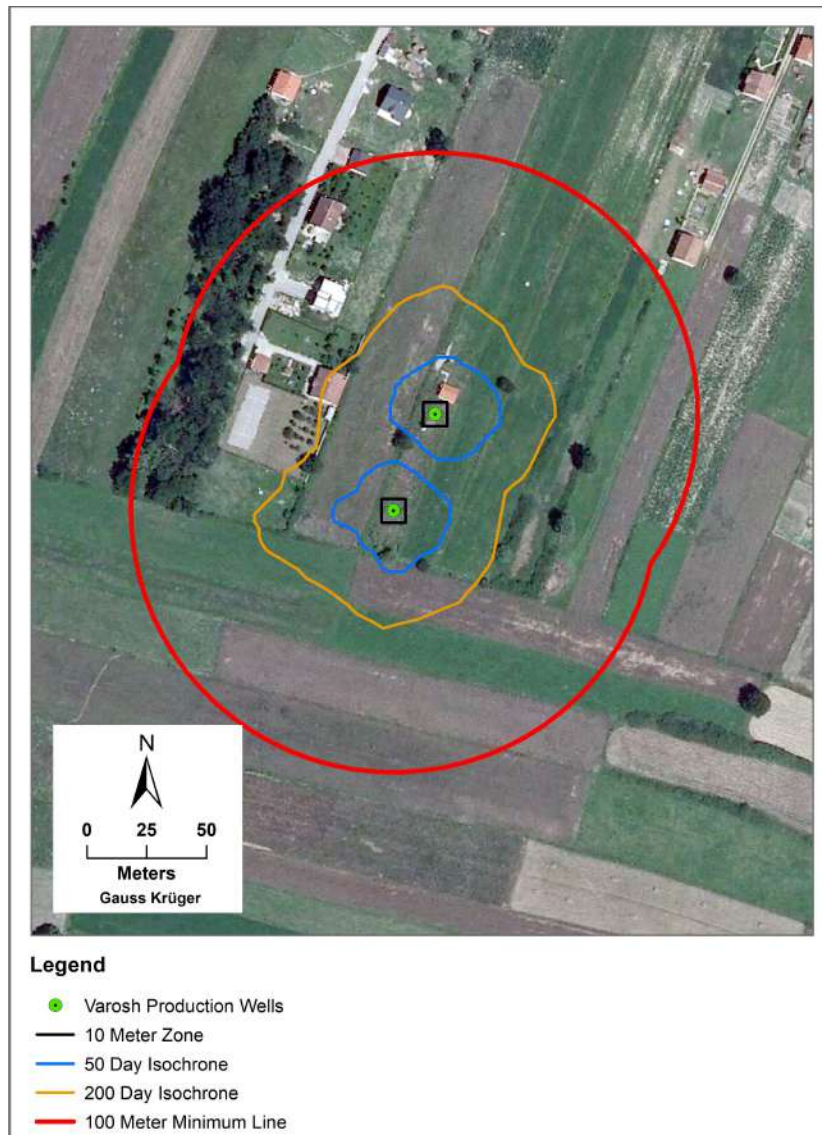


Figure 35: Modelled lines for Zone I and II for Varosh wells.

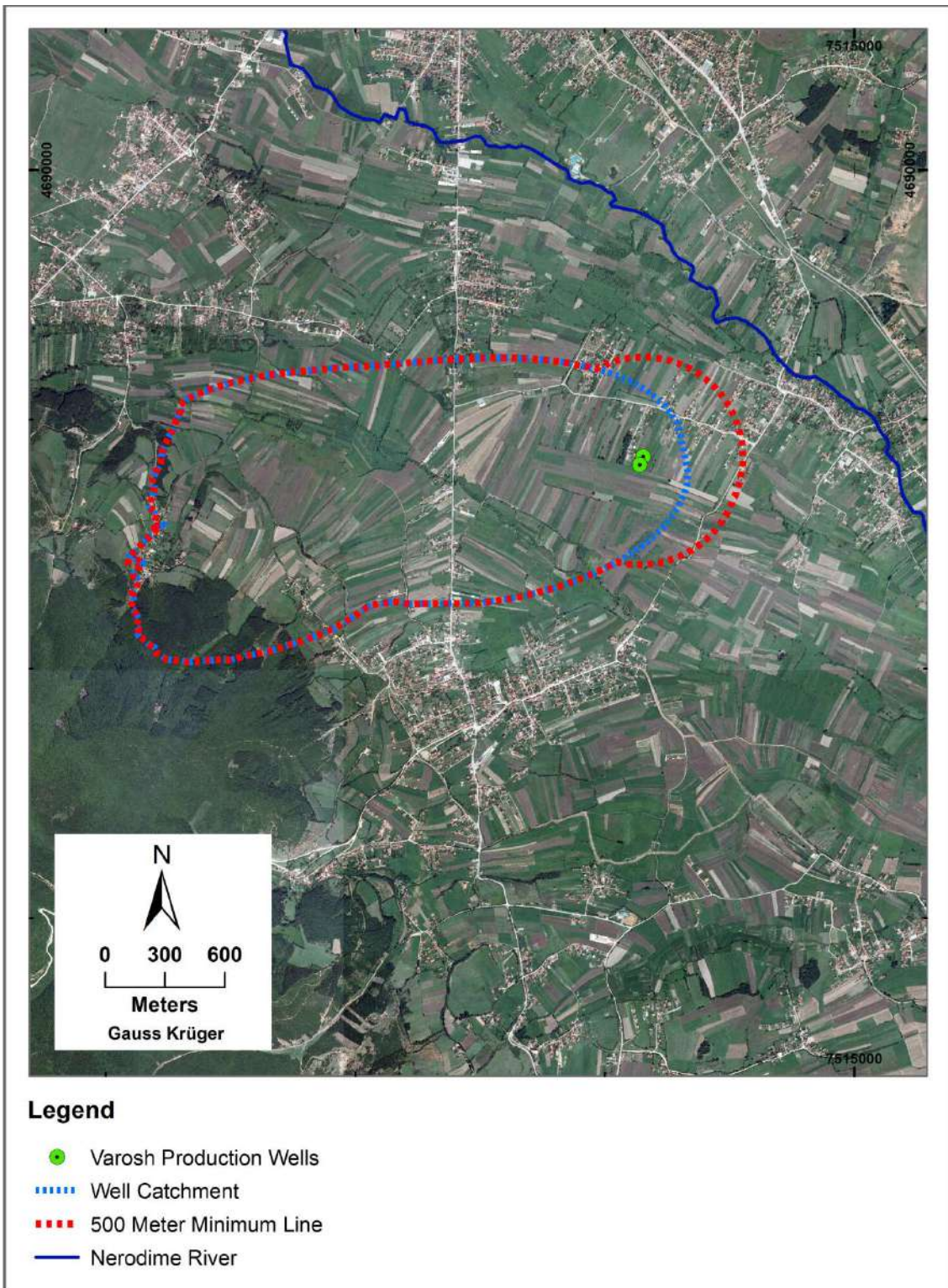


Figure 36: Modelled lines for Zone III for Varosh wells.

#### **5.4.2 Begrace Production Wells**

The Begrace production wells are located approximately 37 meters from each other. Therefore, both wells have separate 10 meter zones.

Two separate 50-day isochrones are calculated. Both 50-day isochrones have a diameter of approximately 35-45 meter. The 50-day isochrones are therefore of less than the 100 m minimum line (See Figure 37).

The catchment of both wells is overlapping and therefore creates a singular area extending towards the groundwater flow towards West. The area has a length of approximately 2.5 km and its width is 1.2 km. In the eastern part, the catchment is below 500 as indicated by the 500 m minimum line in Figure 38.

The 100 m minimum line is enclosing some private homes to the North and a petrol station to the West as well as some car/lorry parking spots to the South.

The Catchment area encloses some commercial (petrol station, restaurant, car repair, etc.) areas as well as some villages towards West. Further some farms are located inside the area.

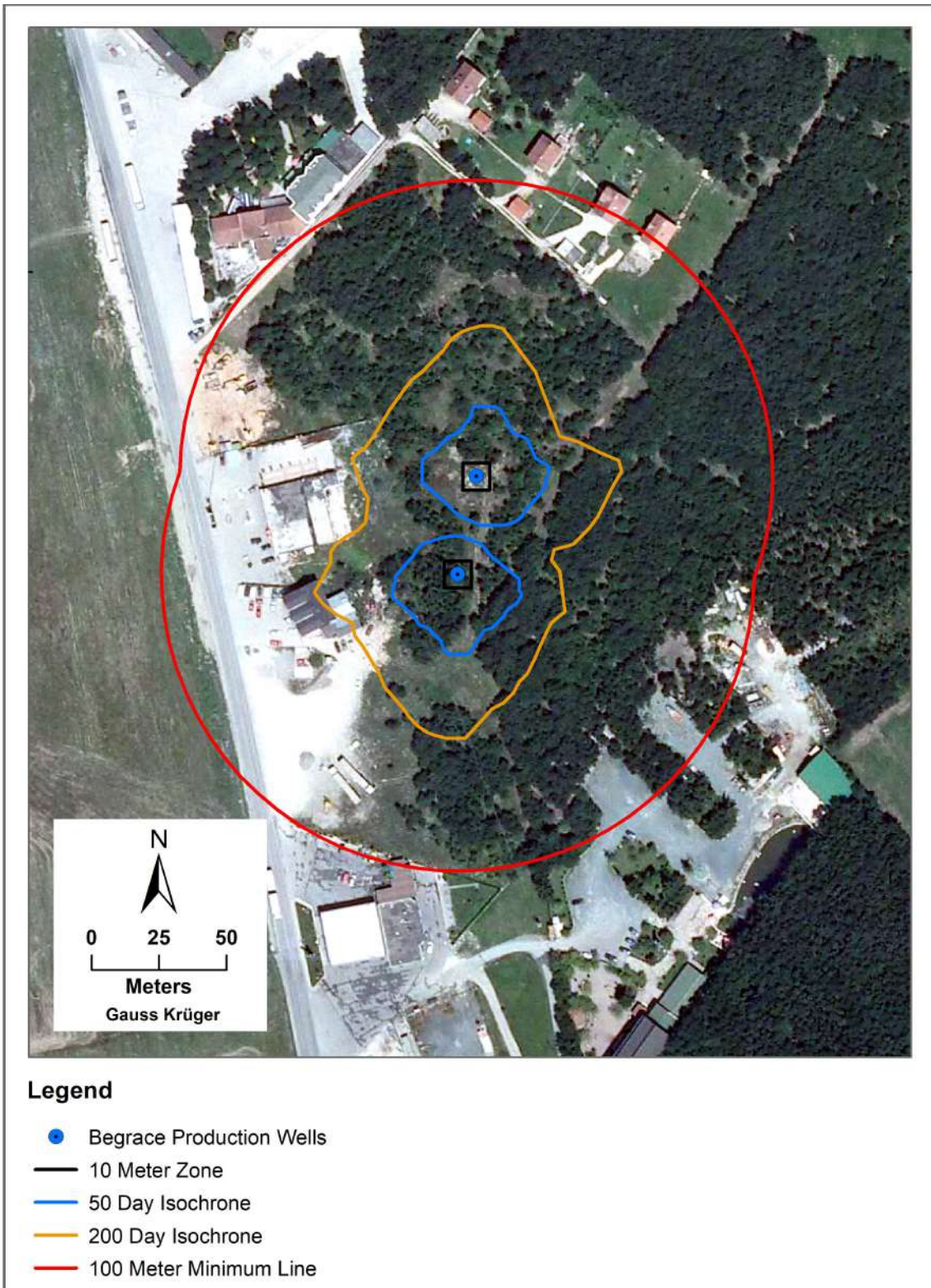


Figure 37: Modelled lines for Zone I and II for Begrace wells.

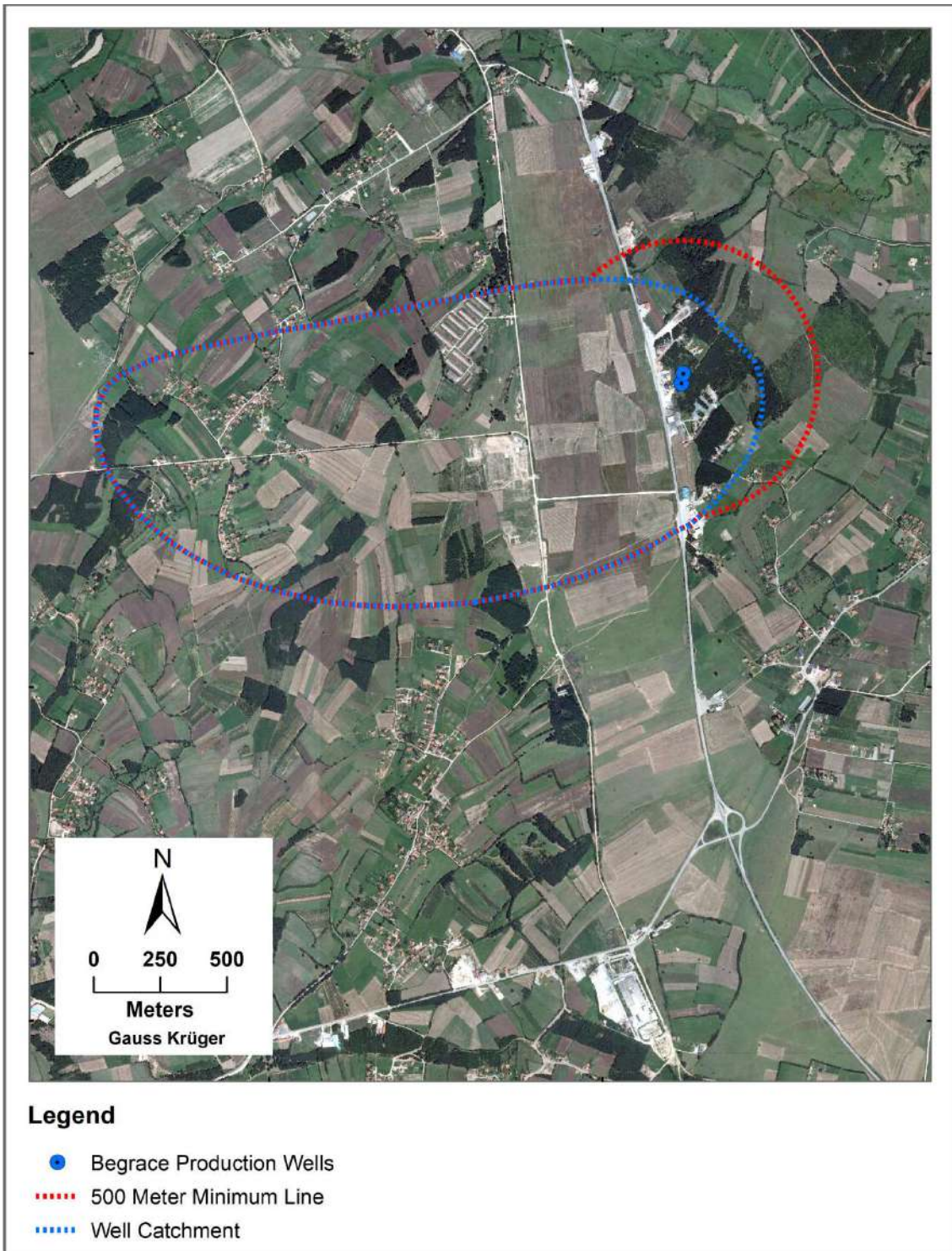


Figure 38: Modelled lines for Zone III for Begrace wells.

### **5.4.3 Gerlice Production Wells**

The Gerlice production wells are located approximately 165 meters from each other. Both wells have their separate 10 meter zones.

Two separate 50-day isochrones are calculated. Both 50-day isochrones have a diameter of approximately 40-50 m. The 50-day isochrones have a smaller diameter than the 100 m minimum line (see Figure 39).

The catchments of the wells are overlapping. Therefore, they create a singular area extending towards the groundwater flow towards west. Its length is approximately 2.5 km and its width about 1.2 km. In the eastern part, the catchment is below 500 as indicated by the 500 m minimum line in Figure 40.

The 100 m minimum line is enclosing agricultural areas only. The catchment area encloses some villages towards West and a public swimming pool to the East. Further the catchment area encloses some petrol stations in the east.

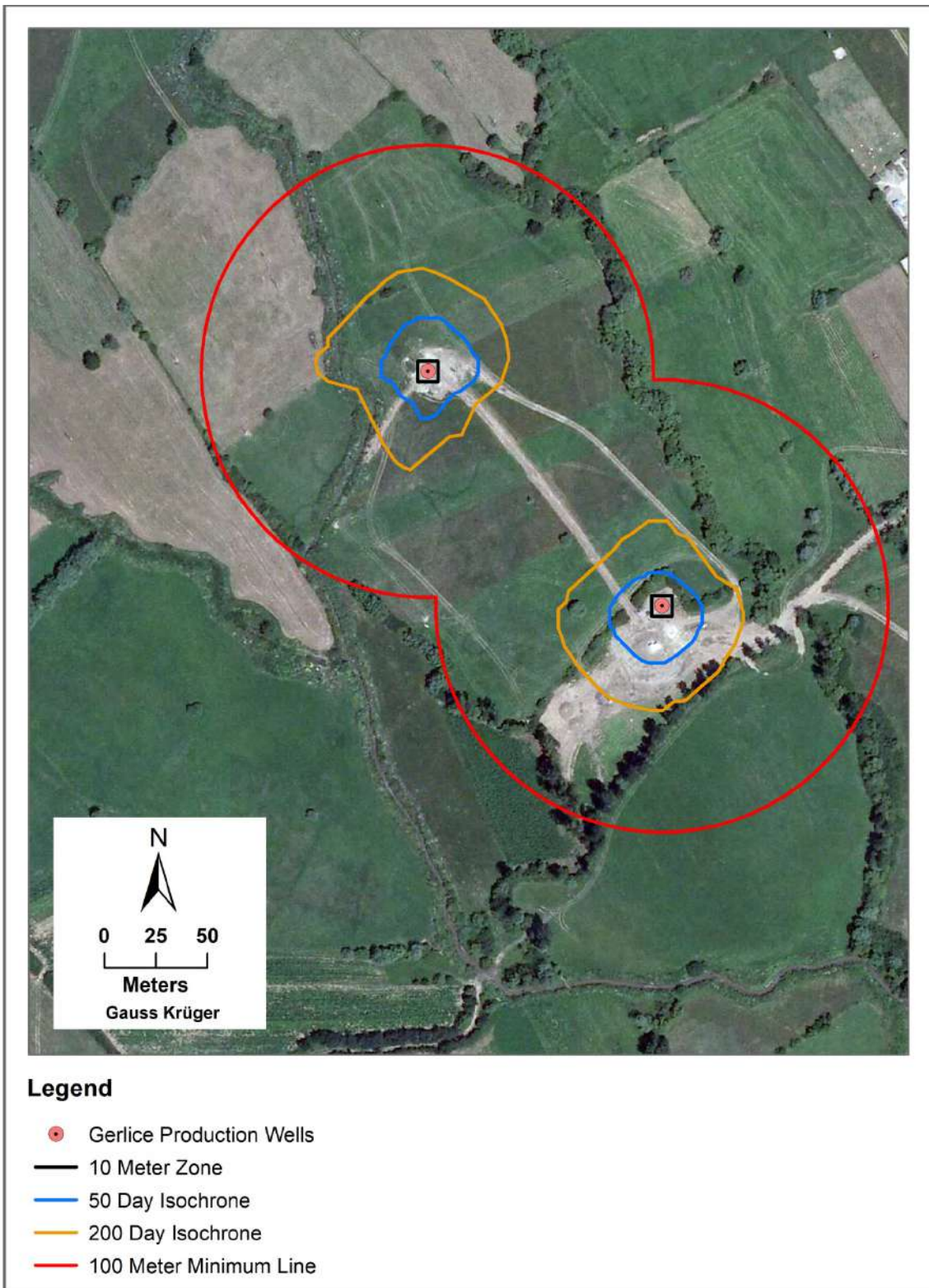


Figure 39: Modelled lines for Zone I and II for Gerlice wells.

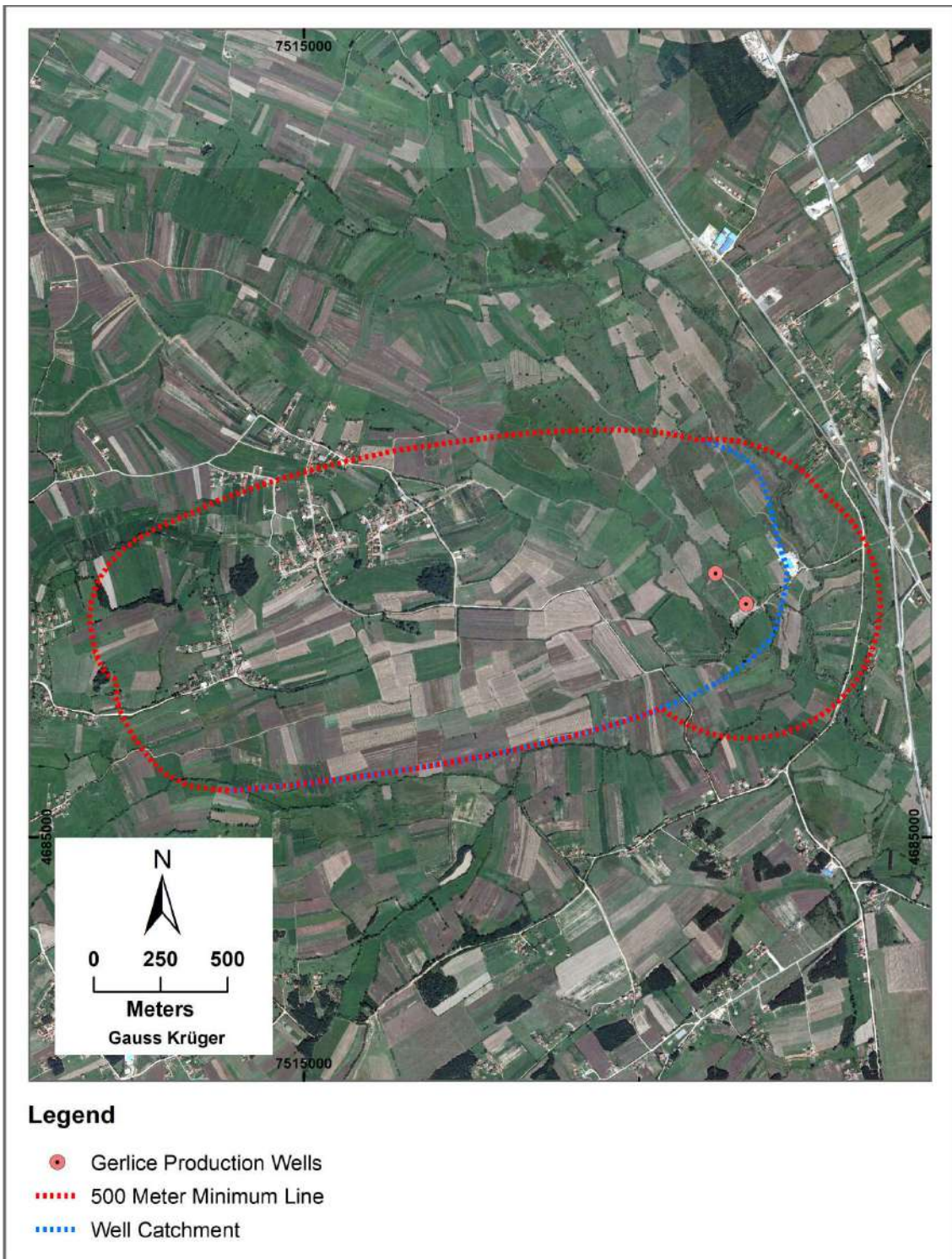


Figure 40: Modelled lines for Zone III for Gerlice wells.

## **5.5 The Conceptual Model of Suhareka Wellfield**

For the delineation of the groundwater protection areas of the wells, and the quantification of the water budget a 2-dimensional steady-state groundwater flow model assuming average flow conditions was designed. As the well drawdown in the alluvial aquifer is small compared to the total thickness of the alluvial aquifer confined aquifer conditions were assumed.

### **5.5.1 Model Area**

The model area (equal to the study area) comprises the total catchment area of the Toplluga River including the valley with the alluvial sediments and the hard rocks of the surrounding mountains. This approach guarantees a feasible estimation of the groundwater inflow from the mountain area into the alluvial aquifer.

The boundary in the northwest is defined by the River, while the boundary in the northeast and southwest is defined by the surface watershed.

### **5.5.2 Boundary Conditions**

With the used Modflow software, each cell requires a so-called IBOUND array that defines whether a cell is active, inactive or provides a constant head. Active cells are used in the aquifer area of the model. Groundwater levels and flow are calculated in such cells. Inactive cells are used outside the aquifer area, where there no groundwater flows is expected.

The boundary conditions are orientated on the natural hydraulic boundaries (see Figure 41).

The model boundaries are either inactive or constant head cells. To simulate the inflow and outflow of the model area active parts of model boundaries are set to a constant head. Initial hydraulic head remains fixed throughout the simulation in constant head cells.

The western boundary within the alluvial sediments is a “constant head” boundary following the observed groundwater head contour line for average groundwater flow conditions.

Further to the edges of the model area, rives constitute a boundary condition when applying the modelling software. Therefore, riverbeds within the alluvial sediments are simulated by a “leakage boundary”, while the rivers in the hard rock area are simulated as “drains”. This means that in the first case effluent and influent conditions are simulated, while in the second case only an outflow of groundwater into the rivers respectively into the drains is possible.

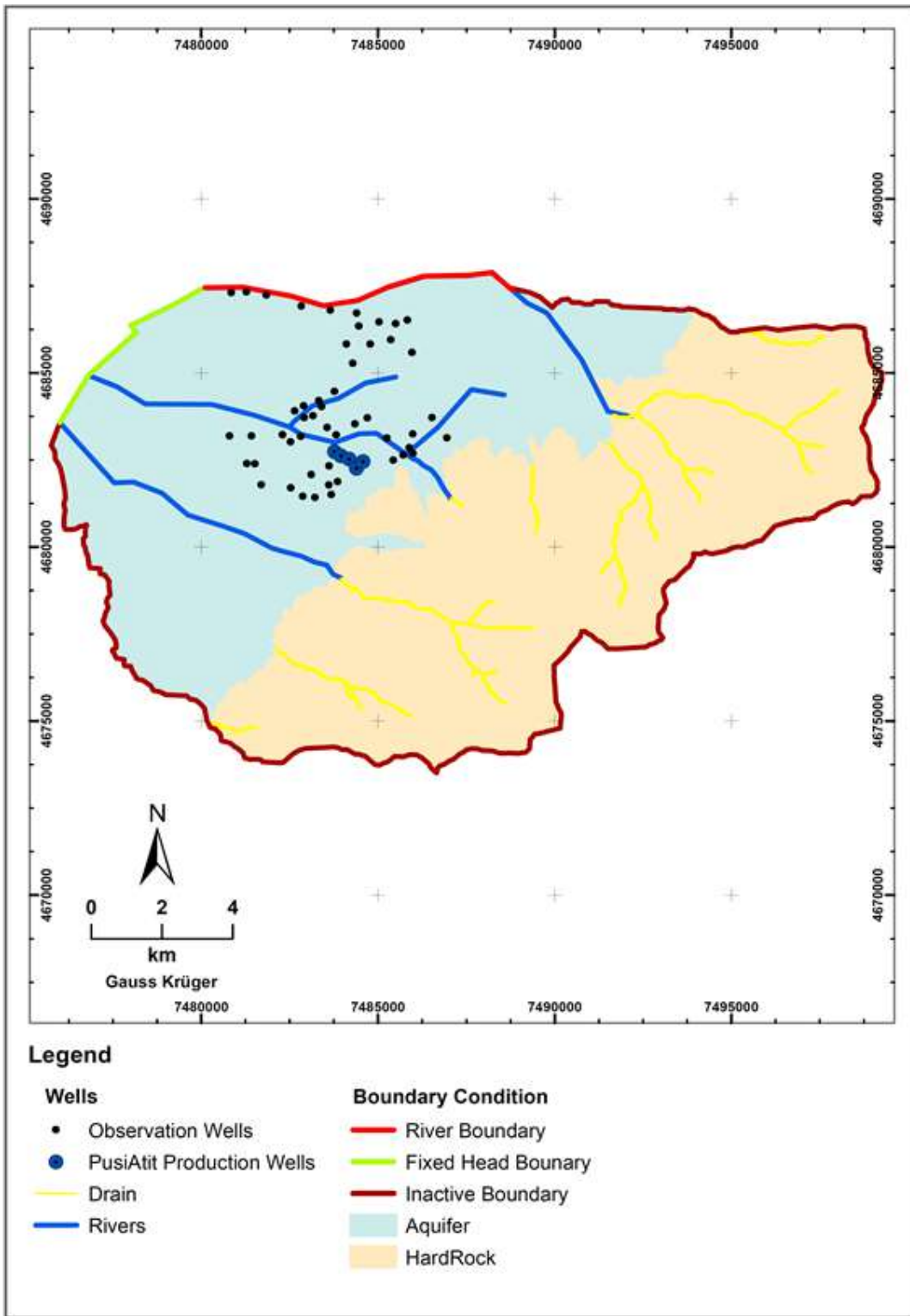


Figure 41: Boundary conditions of the model.

## 5.6 The Computer Model and Input Parameters

### 5.6.1 Description of the Computer Model

For the numerical computation of groundwater flow the program Modflow (USGS, 2005) was used. Pre- and post-processing was done with Processing Modflow Version 8.0 (SimCore).

The delineation of the catchment areas and the corresponding 50-day isochrones of the production wells were calculated with the advective transport model PMPATH.

### 5.6.2 Input Parameters

Table 33 gives an overview of the input parameters of the model. The model setup is a single layer model. All below parameters are referring to the layer. The chapters below provide more details on the values.

Table 33: Input Parameters for the modelling.

Parameter	Value	Unit
Extent of the modelled area Easting	23900	m
Extent of the modelled area Northing	15250	m
Number of Rows	325	-
Number of Columns	498	-
Number of cells	161850	-
Cell Size	50 x 50 (10 x10)	m
Number of Layers	1	-
Aquifer thickness	100	m
Initial Hydraulic Head	300	m asl.
Transmissivity of Aquifer	1.2E-03	m <sup>2</sup> /s
Transmissivity of Hard Rock	3.0E-04	m <sup>2</sup> /s
Effective Porosity Aquifer	0.1	-
Effective Porosity Hard Rock	0.01	-
Recharge in Aquifer	4.3E-09	m/s
Recharge in Hard Rock	1.4E-09	m/s
Well Abstraction	7.5E-02	m <sup>3</sup> /s

(For more details on the above values please check the below paragraphs)

### ***Grid***

A finite difference grid with 161 850 square cells with a constant cell size of 50 x 50 m over an area of about 404 km<sup>2</sup> was selected for the flow model. There are 498 cells in the x-direction (west to east) and 325 in the y-direction (north to east). The number of active cells is 2.33E+08 corresponding to a model area of 233 km<sup>2</sup>. This discretization gives a clear-cut idea of the groundwater flow field in the entire area. The grid is more detailed around the wells to increase modeling accuracy. Therefore, cells in the well field area are scaled down to 10 m x 10m.

### ***Layer and Aquifer thickness***

For this model one layer is sufficient. Whereas the top of the layer represents the surface level and the bottom of the layer represents the bottom of the aquifer. GPS data from field survey were gathered during the measurement campaign and are used to define the surface level.

Based on the cross sections the average aquifer thickness is 100 meters.

### ***Initial hydraulic heads***

Modflow software requires the definition of hydraulic heads as starting values in steady state simulations. The initial heads are plotted in the constant head cells and are representing the actually measured values from the field surveys.

### ***Transmissivity***

Since a homogenous underground is assumed for each of the two units: the porosity aquifer and the hard rock area; two different values were estimated: one for the alluvial aquifer and one for the hard rock area. Based on the above-mentioned chapters the initially applied values were calculated as average from values obtained by the pumping tests. These values will be adapted during calibration for the best fit. For the model, only the transmissivity is used while the hydraulic conductivity is calculated internally.

As a starting value (before calibration) the following transmissivities are used for the model.

Transmissivity - alluvial	1.4 E-03 m <sup>2</sup> /s
Transmissivity - hard rock	3.0 E-04 m <sup>2</sup> /s

### ***Effective Porosity***

There are no laboratory values available so far for effective porosities, so that the effective porosity has to be estimated. Similar as for transmissivity, one value was chosen for each the alluvial aquifer and the hard rock area.

The literature values provide a wide range of values for each type of rock (see Table x).

For the computation of the 50-day isochrone an effective porosity of  $n_f = 0.1 = 10\%$  for the alluvial aquifer, and  $n_f = 0.01 = 1\%$  for the hard rock aquifer was assumed.

### ***Well Abstraction of Pusi Atit production wells.***

The size of the water source protection zone also depends on the abstraction rate of the production wells. In general water source protection zones are calculated with the abstraction rate for which a permit was issued. However, in Suhareka/Suvareka this is not the case. Abstraction rates had to be estimated due to a lack of reliable data and information.

One possibility to estimate is the application of the current abstraction rates of the wells. This might however change in the future due to changing demands.

The total consumption of the wellfield is calculated based on the maximum yield defined during the construction. This results in modelling of 5 identical wells with a total abstraction of 75 l/s. Table 34 gives an overview of the data and assumptions for the studied production wells. In case these values would be exceeded in future, the water source protection zone has to be recalculated.

Table 34: Overview of the data and assumptions for the production wells

Well name (RWSSP VI)	Pusi Atit P1	Pusi Atit P2	Pusi Atit P3	Pusi Atit P4	Pusi Atit P5
Pump installed	Yes	Yes	Yes	Yes	Yes
Design flow [l/s]	15	15	15	15	15
Supplied Villages	Suhareka, Shiroka, Leshan, Ternej, Gelanc, Gjinoc, Highway Suhareka and Prizren				
Design flow = modelled flow [l/s]	15	15	15	15	15

### ***Well Abstraction of other production wells in the study area***

The first runs of the model provided incoherent results and calibration attempts failed. Deeper investigation provided the existence of further wells inside the study area.

In cooperation with the Water Company, a total of 12 additional production wells within the modeling area with a total production capacity of 71 l/s have been identified.

The below shown Table 35 provides an overview of the additional wells data. Locations are shown on Figure 43.

Table 35: Additional wells

Well name (RWSSP VL)	Design flow / modelled flow [l/s]	Y – Gaus Krüger	X – Gaus Krüger
Komuna e Mamushes	12	7478932	4684756
Novake	15	7480729	4683822
Malesi e Re	3	7484665	4680294
Sopijë	10	7488970	4687341
Savrovë	3	7490955	4686137
Maçitevë	4	7496179	4684943
Mushtisht	13	7491665	4682768
Baqevc 1	3	7488441	4683221
Baqevc 2	3	7488469	4683256
Baqevc 4	5	7488541	4683337

### ***Recharge***

The groundwater recharge from precipitation was estimated from precipitation data, computation of evapotranspiration, and the analysis of surface flow (rivers) records of gauging stations. The estimates are shown in Table 36.

Groundwater recharge is a hydrologic process, where parts of the precipitation infiltrates into the ground to refill the groundwater resource. This recharge is estimated using the different formulae of Bhattacharya, of Krishna Rao, of Chaturvedi, of Sehgal, of Radhakrishna and of Datta et al.(A.K Ghosh, 2016).

The average groundwater recharge of the below formulae ( $[158.5 + 112.75 + 163.22 + 265.67 + 85.1 + 44.87] / 6$ ) is 138.35 mm (4.39E-09 m/y). This is near to the value of 158.5 mm and 163.22 mm calculated from respective Bhattacharya’s and Chaturvedi’s formulae. Thus, these can be taken into consideration. This is expressed in millimeter (mm). The recharge value is a first estimate, used to start the modelling process. However, the groundwater recharge is adapted (variated) during the calibration process. The finally applied values are shown in Table 37.

Table 36: Relationship of Rainfall (P) and Groundwater Recharge (G)

	Precipitation (mm/y)	Precipitation (m/y)
Average 2014 - 2019	825.88	2.62E-08

	GW recharge (mm/y)	GW recharge (m/y)
Bhattacharua's formula (1954)	158.50	5.03E-09
Krishna Rao's (1970)	112.75	3.58E-09
Chaturvedi's (1973)	163.22	5.18E-09
Sehgal's (1973)	265.67	8.42E-09
Radhakrishna's (1974)	85.10	2.70E-09
Datta et al.'s (1980)	44.87	1.42E-09

### ***River Leakage***

The river leakage was not known a priori, it was estimated during the calibration process of the model. From earlier models and from estimates based on the surrounding rocks, a hydraulic conductance of  $5E-4 \text{ m}^2/\text{s}$  was estimated.

### ***River Drains***

The rivers and creeks in the hard rock area were modelled as drain nodes with a very high conductance to guarantee an unhindered runoff in the area with a common high gradient and a good connection with the underground. For the drain the hydraulic conductance was estimated to a value of  $0.2 \text{ m}^2/\text{s}$ .

## **5.7 Calibration**

Due to the limited data available a simple calibration strategy was applied. Within the model area two homogenous zones were defined. Zone 1 corresponds to the alluvial, zone 2 to the hard rocks. For each zone the transmissivity of the aquifer and the groundwater recharge from precipitation was estimated. Table 37 shows the average and the range of the model parameters transmissivity and groundwater recharge from precipitation.

Table 37: Overview on Transmissivity and recharge applied

Parameter	Unit	Start value f. Model	Min. value	Max. value	Best fit calibration
Transmissivity - alluvial	$\text{m}^2/\text{s}$	1.71E-03	4.3E-04	2.9E-03	1.2E-03
Transmissivity - hard rock	$\text{m}^2/\text{s}$	3.05E-04	1E-05	6E-04	3E-04
Gw-recharge - alluvial	$\text{m}/\text{s}$	2.45E-09	1.43E-09	8.49E-09	4.3E-09
Gw-recharge - hard rock	$\text{m}/\text{s}$	1.10E-09	0.7E-09	2.5E-09	1.4E-09

The leakage factor respectively the hydraulic conductance for the rivers and drain nodes were kept constant during the calibration process.

During the calibration process transmissivity and groundwater recharge were varied within the given ranges. The simulation results were compared with measured head data from observation wells in the alluvial sediments. Observation data from the hard rocks were not available, so that a classical calibration of the groundwater heads in this zone was not possible. However, the simulated head distribution is plausible and according to the hydrogeologist's experience a realistic scenario. It is controlled by the drainage network. The values for the best parameter fit are displayed in Table 38 (Column: best fit calibration). Figure 42 shows the corresponding scatter plot ( $h_{\text{calculated}}$  versus  $h_{\text{observed}}$ ). The deviation between the calculated and observed heads as plotted in the figure is showing a satisfying correlation considering the simple zonation approach of the model in only two hydrogeological zones.

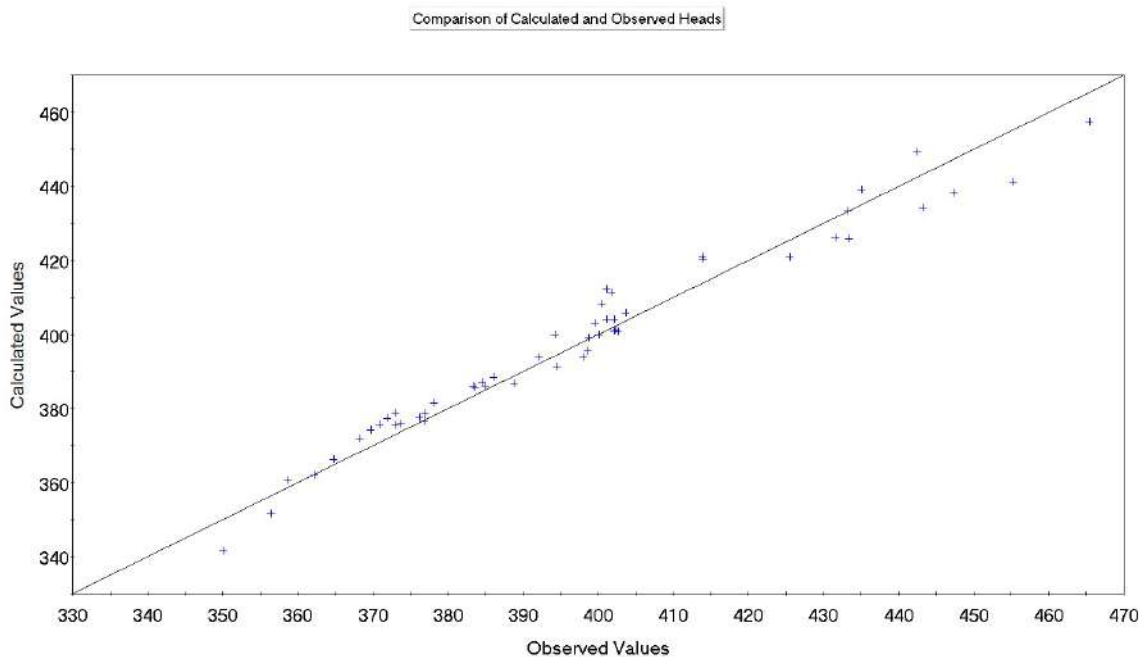


Figure 42: Scatter plot as comparison of calculated and observed piezometric heads.

The calculated variance of the fit is  $26.6 \text{ m}^2$  (the variance is defined as the mean squared error between observed and calculated heads).

### ***Modelled groundwater surface***

Figure 43 shows the piezometric head distribution in the alluvial aquifer for steady state conditions. The groundwater surface of the alluvial sediments shows a strong relation to the hard rock areas. These hard rock areas provide an important inflow to the alluvial aquifer. As expected, the abstracting wells show a clear depression cone in groundwater surface.

### Modelled groundwater surface

The water budget is shown in Figure 44. The steady state water balance for the alluvial aquifer for average conditions is showing. The arrows show the in- and outflows. Inflows are positive, outflows are negative.

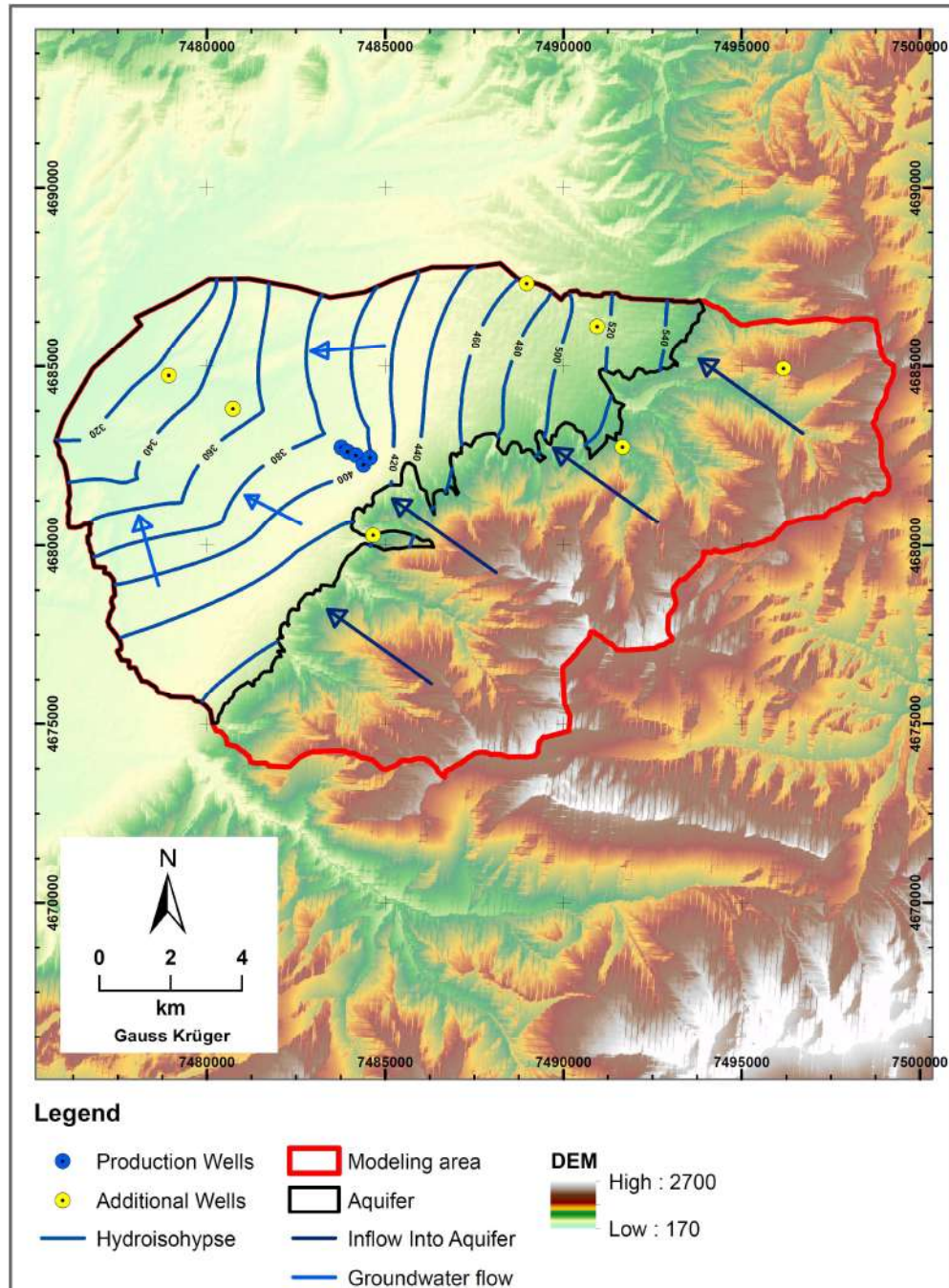


Figure 43: Piezometric head distribution in the alluvial aquifer for steady state conditions.

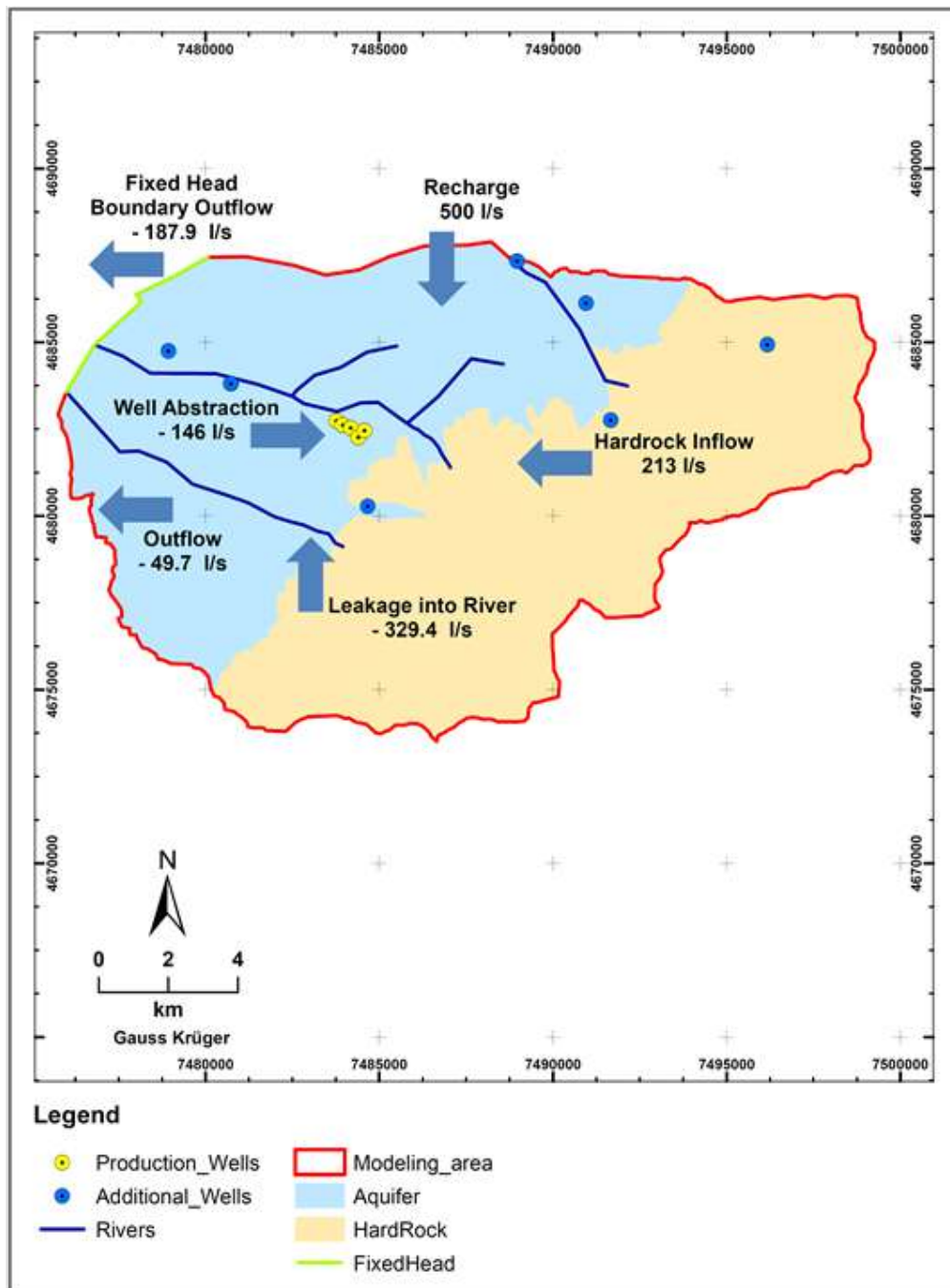


Figure 44: Water balance calculated by the model.

## 5.8 Results

On the basis of the calibrated groundwater flow model the groundwater protection areas of the wells were calculated.

The following information is necessary when interpreting the maps.

- Zone I does not have to be calculated. It consists of the line 10 m around the well (MESP 15/2017). It is indicated as a black line in the following maps.

- Zone II is based on the 50-day isochrone and is calculated by the model. The 50-day isochrone as calculated by the model is shown in blue color. In Article 12, paragraph 2, Administrative Instruction (MESP 15/2017) indicates that Zone II must be at least 100 m from the well. Thus, this 100 m minimum line is indicated in addition to the 50-day isochrones in red color.
- Zone III is based on the entire catchment of the well and is calculated by the model. This catchment boundary, as calculated by the model, is indicated as dotted blue line in the below figures.
- In Article 14, paragraph 3, the Administrative Instruction (MESP 15/2017) indicates that Zone III must be at least 500 m from Zone I. Thus, this 500 m minimum line is indicated in addition as a red dotted line. Whenever the catchment is more than 500 m from the well, the blue and the red dotted lines are identical.

In addition, the Administrative Instruction states in Article 14, paragraph 2, that if the catchment area of the well is not known, Zone III shall be the 200-day isochrones. Therefore, the 200 day isochrones are also indicated as orange line in the following figures. However, because the catchment could be calculated, this line is purely informative.

#### **5.8.1 Pusi Atit Production Wells**

The Pusi Atit wells are located approximately 200 - 400 meters from each other. Therefore, all wells have a separate 10-meter line. Also, separate 50-day isochrones are calculated. All 50-day isochrones have an approximate diameter between 75-85 meters. The 50-day isochrones are therefore of less extension than the 100 m minimum line (see Figure 45).

The catchment of the wells is overlapping and creates a single area extending towards the flow of the groundwater towards east. Its length is approximately 5 km and its width is roughly 2.5 km (see Figure 46).

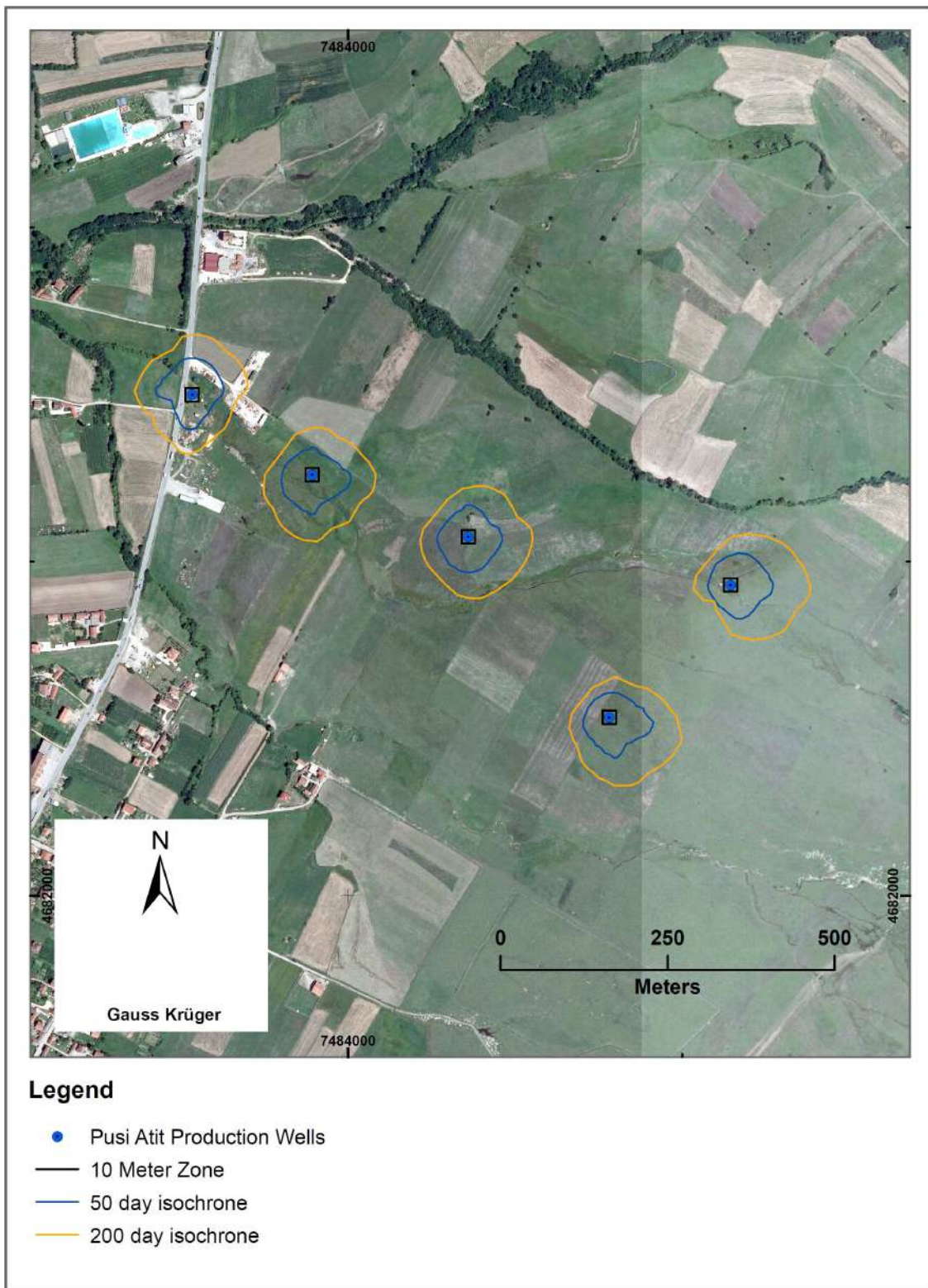


Figure 45: Modelled lines for Zone I and II for Pusi Atit wells.

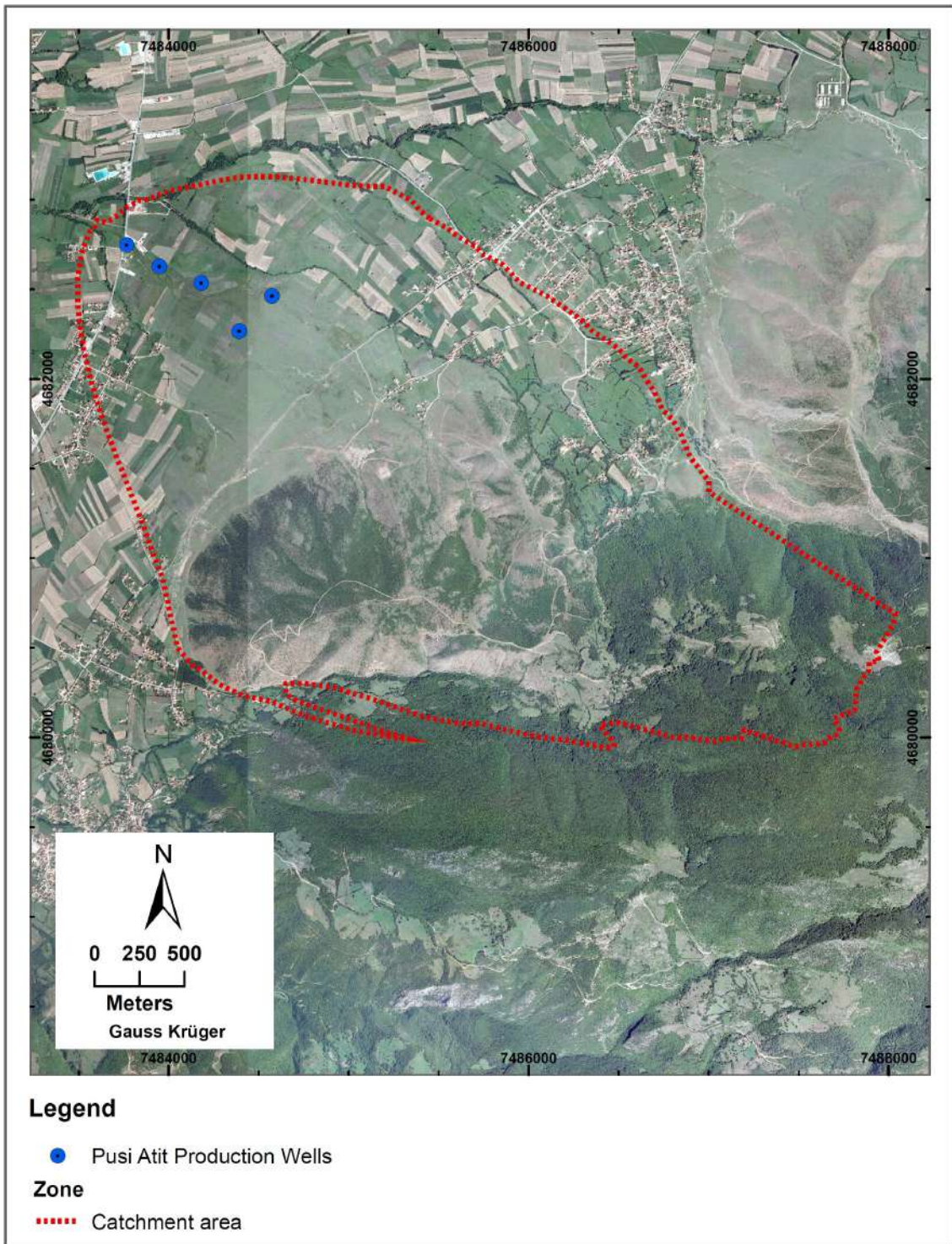


Figure 46: Modelled lines for Zone III for Pusi Atit



## 6 HYDROCHEMISTRY

### 6.1 Hydrochemistry of Ferizaj Wellfield

The hydrochemical description of the aquifer is established through the evaluation of data from the Varosh wells in since December 2016 and for Begrace and Gerlice wells since November 2018. All data was provided by the RWC. For Greme wells, no data have been available during the study period.

The parameters determining the groundwater quality in the aquifer comply to standards in force in Kosovo and are within the permissible values for drinking water in Kosovo.

**Colour:** No data available

**Turbidity:** Based on the water samples analysed no turbidity was detected (0 NTU) or the remark “acceptable” is mentioned by the laboratory.

**Odours:** The water from the aquifer does not provide any odours and is therefore classified “acceptable”.

**Taste:** No data available.

**pH value:** The pH index varies for all wells from pH 6.82 to pH 7.63 which indicates a slightly alkaline water environment for the wells analyzed by the RWC.

The Vaorsh wells show a variation between pH 6.82 and pH 7.63. The peak of pH 7.63 was analyzed in July 2018, while values of later analysis remained lower. A minimum value of pH 6.8 was analysed in March 2019. All values remain inside the limits from 6.5 to 8.5.

The Gerlice wells show variation from pH 7.03 to pH 7.58 during the analysed period from 2018 to 2019.

The Begrace wells show variation from pH 7.02 to pH 7.52, very similar to the Gerlice wells during the analysed period from 2018 to 2019.

#### **Hardness & Mineralization:**

The aquifer of the wells in the Southern Ferizaj wellfields show values for electrical conductivity from 287 to 532  $\mu\text{S}/\text{cm}$ . This is corresponding to a hardness of approximately 3.2 to 5.9 mval/l (equal to 11.8 to 16.5  $^{\circ}\text{dH}$ ). The groundwater is to be classified as “medium to hard”.

These values of electrical conductivity provide an indication for low to medium mineralized waters for all analyzed wells. All values remain below the maximum permissible value of 2500  $\mu\text{S}/\text{cm}$ .

In Varosh/Varoš Selo, the wells show the largest variation from 293 to 532  $\mu\text{S}/\text{cm}$ , where the maximum peak occurred in May 2019. The maximum is following a peak in Ammonium

concentration and a low peak of pH some weeks earlier. This might indicate a contamination occurred in the early months of 2019 in the area of the Varosh/Varoš Selo wells or could be explained by a very dry spring season increasing the Ion-concentration due to reduced quantities of available water. However, no complaints for bad quality of water have been recorded during that period.

In Gërlicë/Grlica the values vary from 318  $\mu\text{S}/\text{cm}$  to 503  $\mu\text{S}/\text{cm}$  and show a similar pattern to the values in Varosh/Varoš Selo.

In Begracë/Belograc the variation reaches from 287  $\mu\text{S}/\text{cm}$  to 396  $\mu\text{S}/\text{cm}$ . The water produced in Begracë/Belograc is of relatively low salinity and to be classified as medium hard.

**Oxydability (O<sub>2</sub> consumption):**

The oxygen consumption per liter in the wells analysed by the water utility for Varosh/Varoš Selo vary from 0.16 to 0.88 mg/l O<sub>2</sub>, for the Gerlice wells from 0.48 to 0.96 mg/l and for the wells in Begracë/Belograc from 0.4 to 0.72 mg/l. All values are below the prescriptive limit of 5 mg/l O<sub>2</sub> and proof a good quality of groundwater.

**Ammonium:** The content of the ammonium in the groundwater ranges from 0.01 mg/l to 0.15 mg/l, whereby the values do not exceed the permissible maximum of 0.5 mg/l for drinking water.

In Varosh/Varoš Selo, the content varies from 0.01 to 0.12 mg/l, in Gerlice the wells from 0.01 to 0.15 mg/l and in Begracë/Belograc from 0.01 to 0.09 mg/l Ammonium.

In nature, ammonium is primarily produced during the degradation of proteins. It is released as an end product during the bacterial rotting of dead biomass. In water, ammonium is first oxidized by bacteria to nitrite and then to nitrate. The peak in Varosh/Varoš Selo may be result of natural or anthropogenic contamination near the wells in spring 2019.

**Nitrites:** The concentration of nitrites in the wells range from 0.001 mg/l to 0 mg/l. The results show that nitrites do not exceed the maximum permissible value. The values reach to a maximum of 0.095 mg/l in Varosh/Varoš Selo in December 2018 and decrease further on while in Begracë/Belograc and Gërlicë/Grlica the values do not increase to more than 0.05 mg/l in May-June 2019.

The increase in nitrite composition is certainly due to the fertilization of the soil with chemical fertilizers in the vicinity of the water source. The permissible value of 0.5 mg/l is not exceeded in any of the samples.

**Nitrates:** Nitrates have not been analysed in none of the samples. It is recommended to verify the Nitrate content in these wells as soon as possible.

**Iron:** The iron concentration in the water sources of this source is in the range 0.01-0.22 mg/l. All values remain below the permissible limit of 0.2 mg/l.

**Manganese:** The concentration of the manganese in the wells ranges from 0.01 to 0.039 mg/l. The Manganese concentration did not exceed the permissible maximum values 0.05 mg/l for drinking water.

**Bacteriological analyses:** Samples taken from the wells since 2017 have been according to the norms for bacteriological parameters in Kosovo. In summertime 2019 a slight increase in bacteria counting remained below the permissible limit. However, such values indicate the urgent need to protect well against pollution.

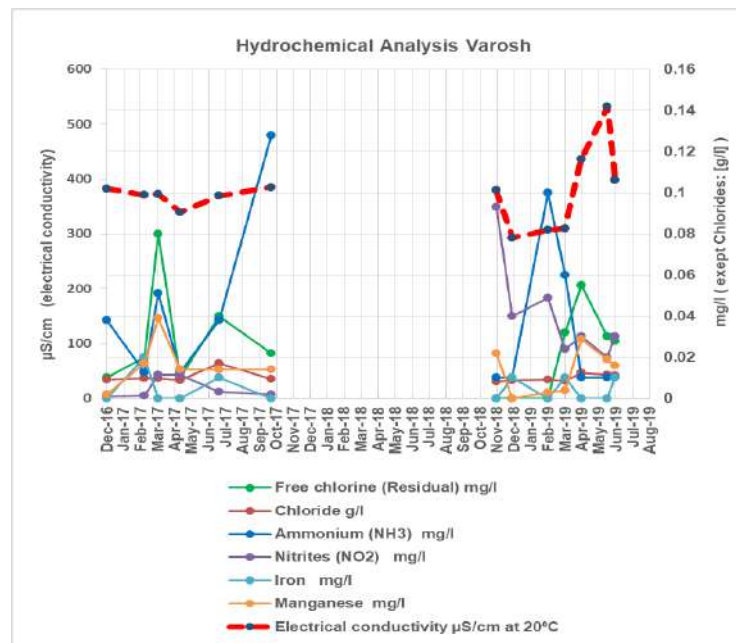


Figure 48: Hydrochemical data of the Varosh wells.

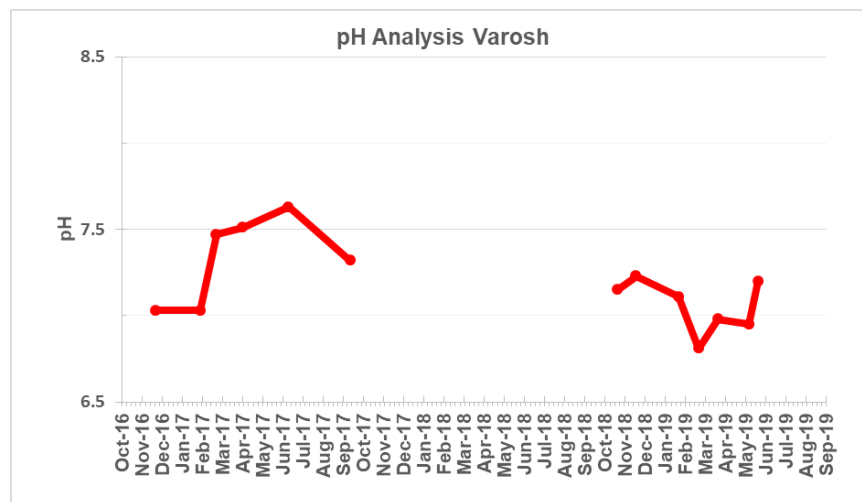


Figure 49: pH values of Varosh water samples.

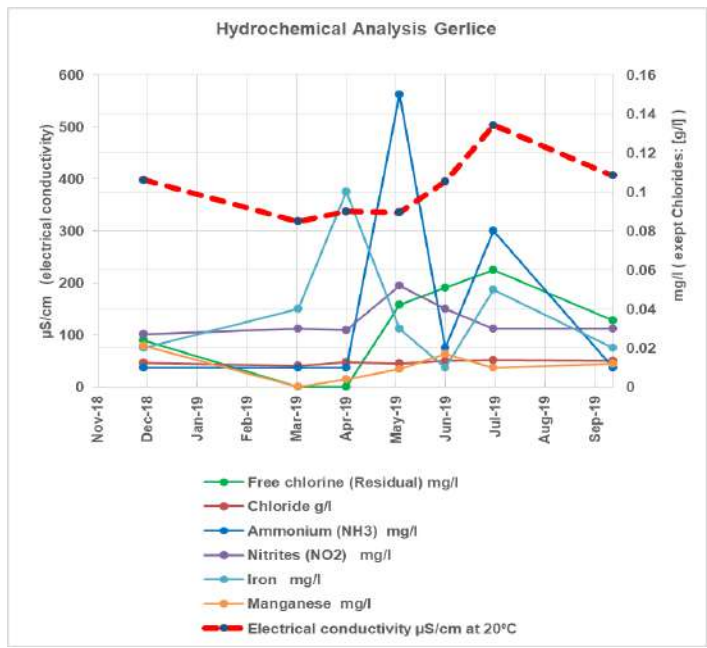


Figure 50: Hydrochemical data of the Gerlice wells.

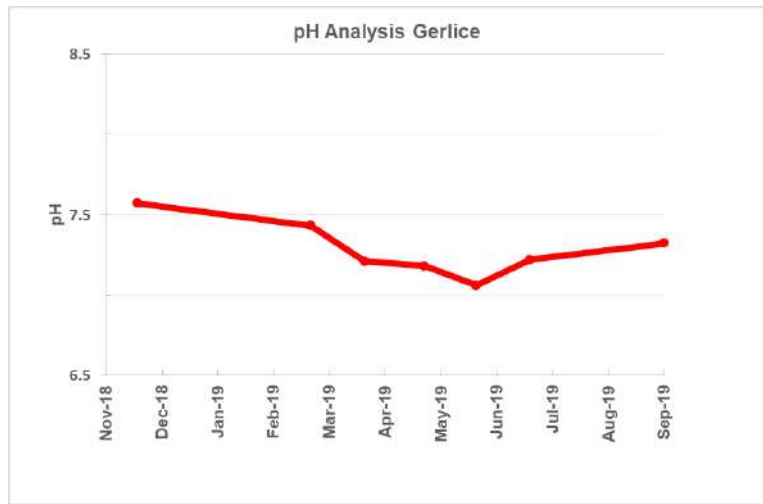


Figure 51: pH values of Gerlice groundwater samples.

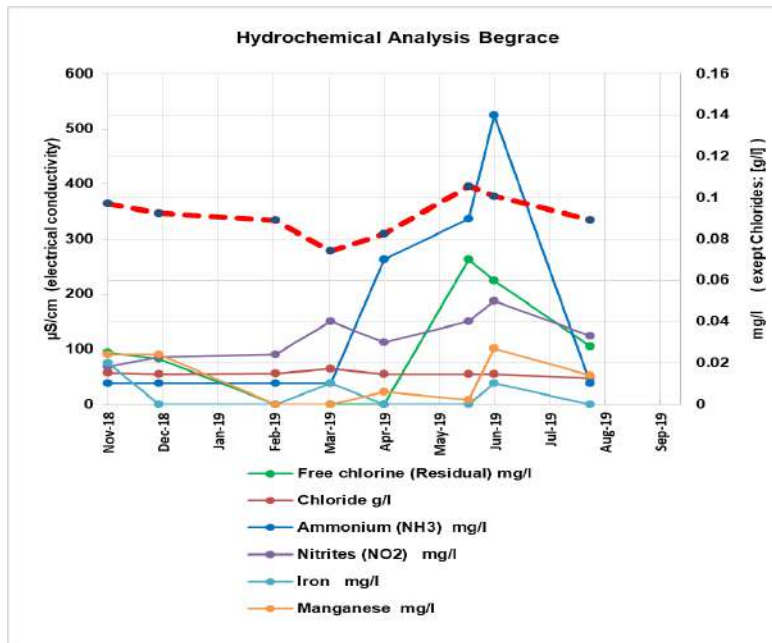


Figure 52: Hydrochemical data of Begrace water samples.

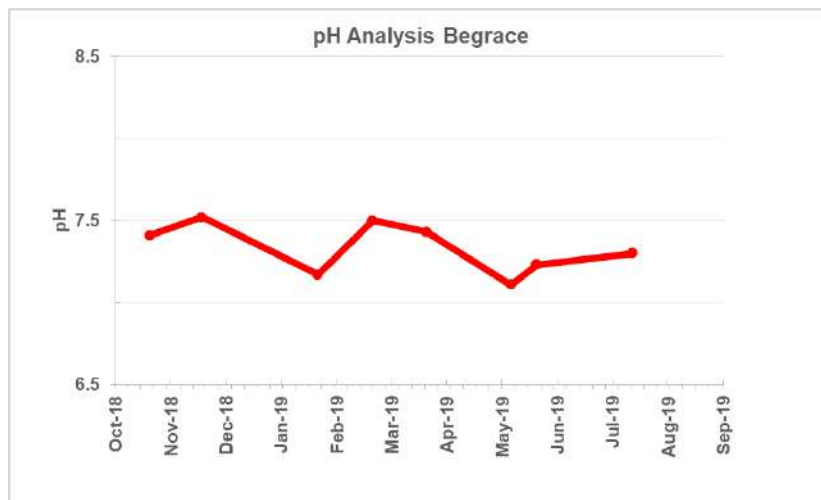


Figure 53: pH values of the Begrace water samples.

## 6.2 Hydrochemistry of Suhareka Wellfield

The aquifer was described by evaluating data since May 2017 from wells in the study area. All data were provided by the RWC Hidroregijoni Jugor. During the investigation period, no data were available for wells in Baqevc, however on the request of the RWC, analyses were successfully performed in these wells.

The parameters determining the quality of the groundwater in the aquifer do not meet the standards applicable in Kosovo. The Manganese content exceeds the threshold, all other values remain within the permissible values for drinking water in Kosovo.

**Color:** The analysis results have shown that the water is colorless.

Turbidity : water samples of 2017 have exceeded the threshold value. However, the value declined during the following years and complies to the standards.

**Smell:** Aquifer water has no aroma and is therefore classified as "acceptable".

**Taste:** Aquifer water has no taste and is therefore classified as "acceptable".

**PH value:** The pH index varies for all wells from pH 7.58 to pH 8.43 indicating a slightly neutral water environment for the wells analyzed by the RWC.

**Hardness and mineralization:** The aquifer in Suhareka/Suvareka shows an electrical conductivity from 523 to 782  $\mu\text{S}/\text{cm}$ . This corresponds to a hardness of approximately 3.2 to 5.9 mval/l (equivalent to 11.8 at 16.5° dH). The Groundwater is classified as "medium to hard".

These electrical conductivity values provide an indication of low to moderate mineralized water for all wells analyzed. All values remain below the maximum allowable value of 2500  $\mu\text{S}/\text{cm}$ .

**Nitrite:** The concentration of nitrite in wells varies from 0.01 mg/l to over 0.02 mg/l and therefore do not exceed the maximum value of 0.5 mg/l<sup>2</sup>.

The increase in nitrite composition most probably results from over-fertilizing the soil with near the water source.

**Nitrates:** Nitrates have been identified below 0.5 mg/l and therefore do not exceed the permissible standard of 50 mg/l.

**Iron:** The concentration of iron in these water resources is in the range 0.02-0.19 mg/l. All values remain below the allowable limit of 0.2 mg/l.

**Manganese:** The concentration of manganese in wells varies from 0.04 to over 0.5 mg/l. Concentrated manganese exceeded the maximum allowed values of 0.05 mg/l for drinking water.

Pesticides and fertilizers from agriculture containing manganese enrich the soil. Seeping rainwater dissolves the mineral from soil and transports it into the aquifer.

In oxygen-poor groundwater, an increased concentration of manganese and iron often occurs. In this case sensory impairments in terms of taste and appearance occur. This can have a particularly negative effect when washing laundry. Dark stains on textiles are the result of manganese and iron. An acute health hazard does not exist, however.

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<sup>2</sup> The value for Nitrite was given by Email by Adem Morina on 25/11/2020

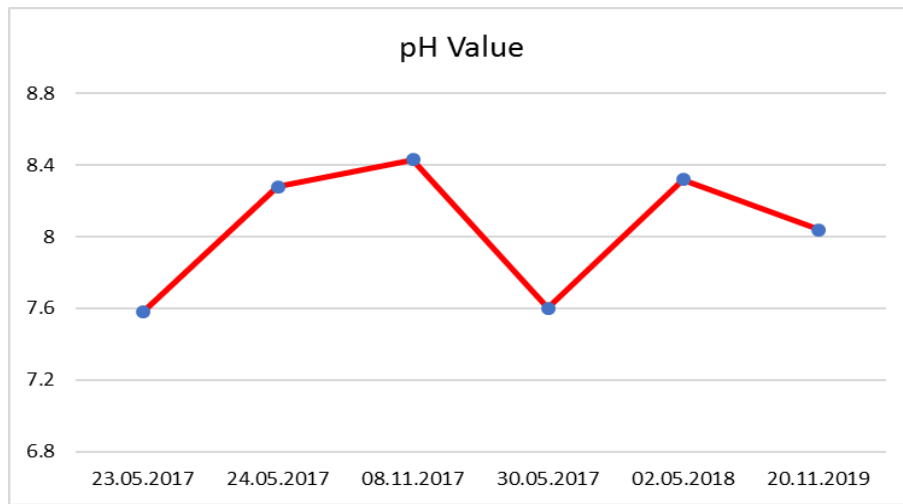


Figure 54: pH value of wells from 2017 to 2019

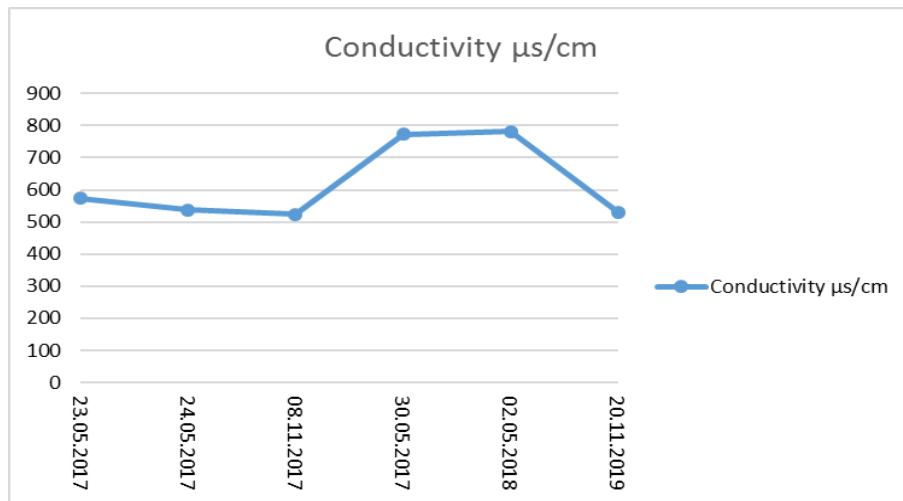


Figure 55: Conductivity values from 2017 to 2019

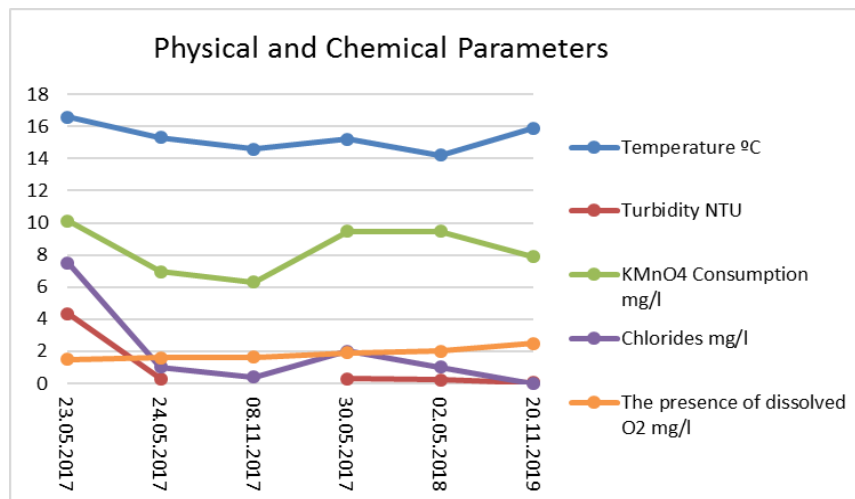


Figure 56: Physical and chemical parameters between 2017 and 2019

Table 38: Physico-chemical analysis of wells

PLACE OF TAKE THE SAMPLE "PUSI ATIT" - SUHAREKA								
Parameters	Units	Date:	23.05.17	24.05.17	08.11.17	30.05.17	02.05.18	20.11.19
		Standards	Results	Results	Results	Results	Results	Results
<i>Temperature °C</i>	°C	8-12	16.6	15.3	14.6	15.2	14.2	15.9
<i>Turbidity NTU</i>	NTU	1	4.36	0.28		0.29	0.21	0.05
<i>PH Value</i>	PH	6.5 - 9.5	7.58	8.28	8.43	7.6	8.32	8.04
<i>KMnO4 Consumption mg/l</i>	mg/l	n.a.	10.11	6.95	6.32	9.48	9.48	7.9
<i>Chloride mg/l</i>	mg/l Cl	200	7.5	1	0.4	2	1	-
<i>Ammonia</i>	mg/l NH4	0.1	0.07	<0.05	0.02	<0.05	<0.05	<0.05
<i>Nitrites</i>	mg/l NO2	0.5	0.01	0	<0.02	<0.02	<0.02	<0.02
<i>Nitrates</i>	mg/l NO3	50	<0.5	<0.5	<0.5	<0.5	<0.05	-
<i>Iron</i>	mg/l Fe	0.3	0.19	0.02	0.25	<0.05	<0.05	0.02
<i>Manganese</i>	mg/l Mn	0.05	0.04	0.11	<0.5	<0.5	<0.5	<0.5
<i>Conductivity µs/cm</i>	µs/cm	1500	573	537	523	773	782	531
<i>Dissolved O2 mg/l</i>	mg/l	3	1.5	1.61	1.63	1.91	2.01	2.5

## **7 POLLUTION RISK FOR THE AQUIFER**

### **7.1 Wastewater**

The wastewater transport systems and wastewater treatment in the study area is limited. Inhabitants of the city of Ferizaj/Uroševac are connected to a sewerage system. Outfall of the sewer system is the Nerodime River. Other villages are either connected to smaller sewerage systems with outfalls to the close by rivers or are collecting the sewer in septic tanks. Such septic tanks are leaking into the groundwater and faecal sludge is discharged to the next receiving river as well. Wastewaters outfalls to the rivers are untreated. All other commercial and industrial infrastructure are not connected to public sewer systems. It has to be considered that most probably all their sewer have their outfall to the Nerodime as well.

Outfalls are contaminating the Nerodime and contributing rivers. The untreated sewage outfall causes environmental problems beyond the Nerodime river, as soil and groundwater resources are contaminated by infiltration.

### **7.2 Surface Water**

The main surface water is the Nerodime River crossing the study area from north to south, continue the journey to the Aegean Sea via the Lepence and Vardar Rivers.

The water quality of Nerodime has to be considered as polluted. Most probably villages along the river do not have sewage treatment facilities and therefor pour the sewage into the river. During the field visit the river provided a typical dark grey colored water and the typical sewage smell (see Figure 57) as well as dumpsites in or at the river (see Figure 58 and Figure 59).

It is highly recommended to connect all industrial, commercial sites as well as all houses to a sewerage system. The sewer system has to transport the sewage in controlled channels or pipes towards a treatment station or at least to an outfall without any connection to a drinking water resource. It is urgent to avoid all inflow of untreated sewage into the river. Further, it is highly recommended to clean up the dump sites at the river.

The Nerodime River is listed exemplary in the list of pollution sources under ID 8.



Figure 57: Example of Polluted Nerodime River



Figure 58: Example of Polluted Nerodime River



Figure 59: Example of Polluted Nerodime River

### **7.3 Possible Pollution Point Sources**

The present study comprehends a survey of the land surface of the study area within the catchment of the wells and a few hundred meters outside of the catchment area.

All publicly accessible places have been surveyed; private land was surveyed where possible and allowed by the landowner. Subsurface pollution sources have not been identified, however, may be present and covered by landfill or vegetation. Further investigation is recommended in case records provide hints for covered potential polluting spots. The below description of potential pollution sources contains mainly waste dumps and commercial infrastructure.

Waste dumps observed in the study area are wild and illegal. No official waste dump site was discovered during the study period,

Commercial infrastructure includes restaurants, farms, petrol stations, small and medium companies and scrapyards. Especially scrapyards are providing a high risk for underground contamination and groundwater contamination. None of the scrapyards provide sealed paving or surface water collection systems, connected to a sewerage pipeline or treatment. Oil spill and other chemical substance are infiltrating the underground. Depending on their position,

these car scrapyards have to be displaced or the ground has to be protected against any intrusion of oils and other chemicals.

Table 39 gives an overview of the possible pollution point sources described in the following chapter.

Table 39: List of potential pollution sources

Pollution Name	ID	Catchment	Y-Pos	X-Pos
Farm	1	Varosh	4685560	7517028
Scrapyards next to Autoservice Luani	2	Varosh	4686063	7517053
Meli petrol station	3	Varosh	4686131	7513821
Shabani furniture company	4	Varosh	4685847	7517375
Scrapyards and garage te Luta	5	Gerlice	4688155	7516248
INNOIL recycling station	6	Gerlice	4688458	7515358
GARKKO recycling company	7	Gerlice	4688242	7514244
Nerodime River	8	Gerlice	4688200	7516482
Promoplast company	9	Gerlice	4685791	7517075
Petrol station Veda/Gena market	10	Gerlice	4685602	7517645
Veda petrol station	11	Gerlice	4685496	7517756
Nerodime River near Gërlicë/Grlica	12	Gerlice	4685333	7517971
Ballkan Petrol	13	Begrace	4685191	7517897
Auto Color Vllezrit Osmani	14	Begrace	4686541	7516991
Restaurant Evropa and Petrol Pump	15	Begrace	4687850	7516075
Auto Color Mani	16	Begrace	4689121	7513017
Auto Service Malsia	17	Begrace	4689784	7513028
Pro Metal	18	Begrace	4689916	7513029
Highway	19	Begrace	4686973	7513091
Old Farm	20	Begrace	4685215	7513619

### 7.3.1 Varosh Wells Catchment

The chapter below describes four potential pollution sources which are located inside the catchment of the Varosh wells. See also Figure 60.

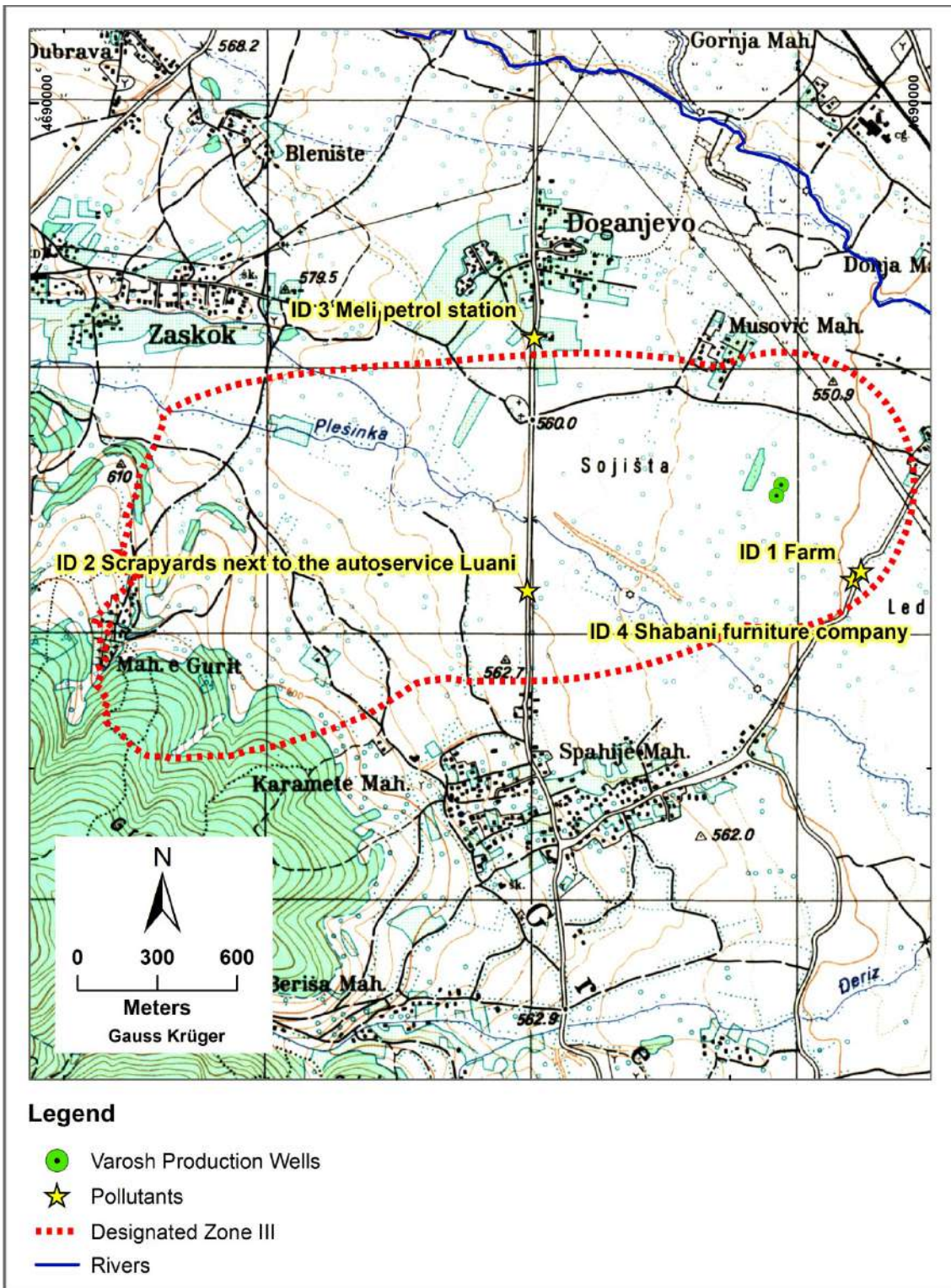


Figure 60: Potential Pollution Sources in the Varosh Wells Catchment.

### 7.3.2 Gerlice Wells Catchment

The chapter below describes eight potential pollution sources which are located inside the catchment of the Gerlice wells. See also Figure 61.

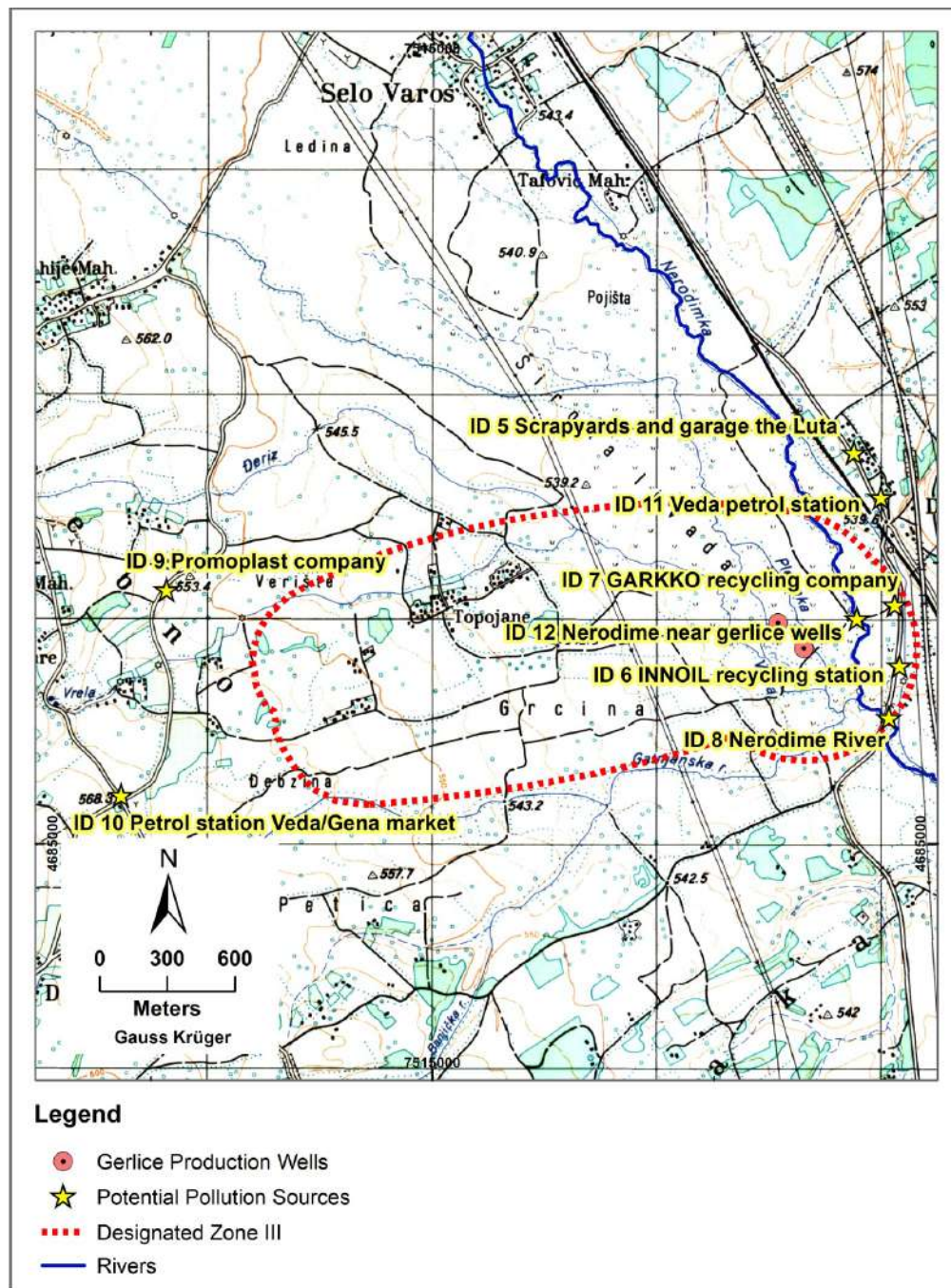


Figure 61: Potential Pollution Sources in the Gerlice Wells Catchment.

### 7.3.3 Begrace Wells Catchment

The chapter below describes eight potential pollution sources which are located inside the catchment of the Begrace wells. See also Figure 62.

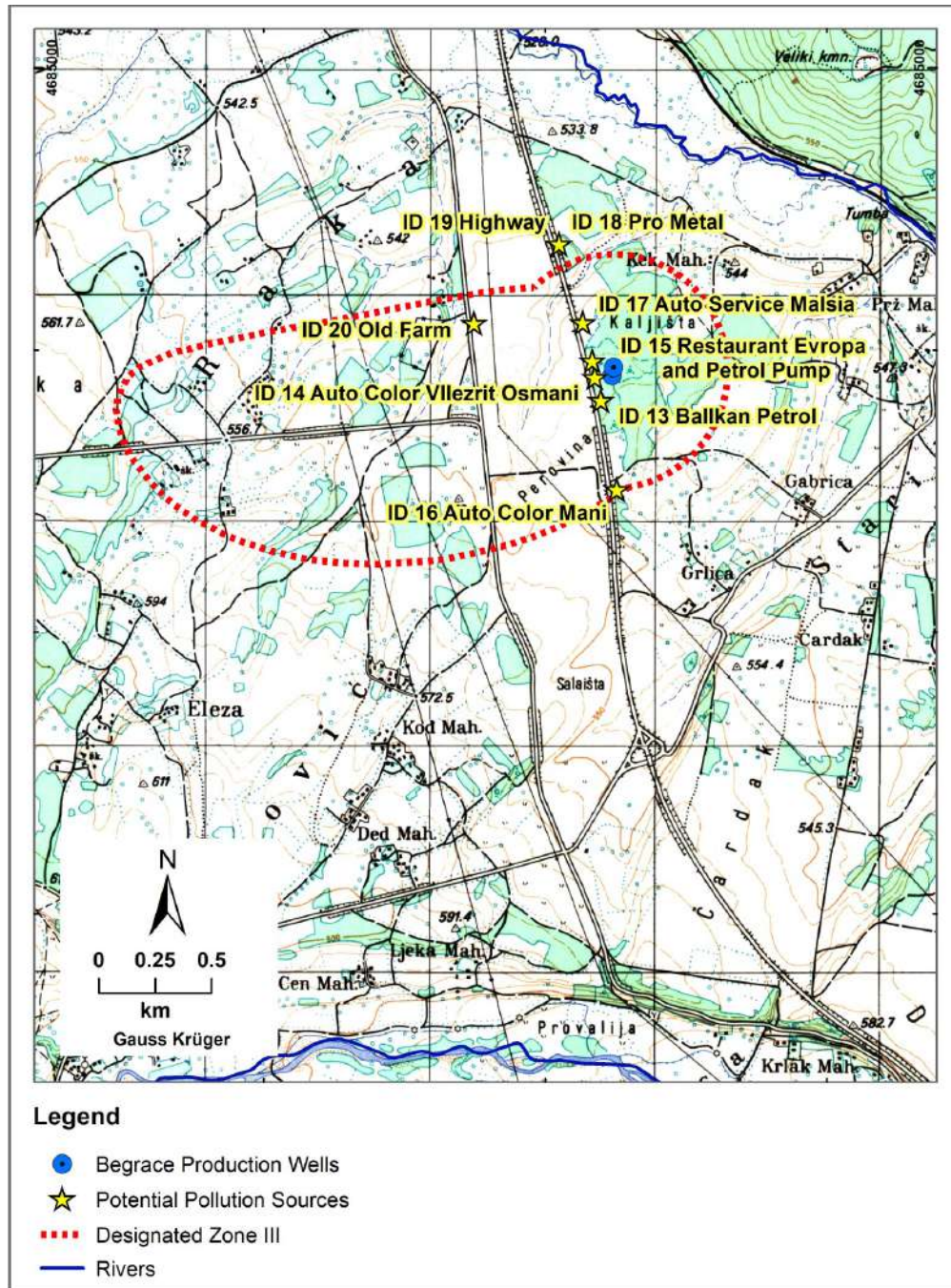


Figure 62: Potential Pollution Sources in the Gerlice Wells Catchment.

### 7.4 Possible Pollution Point Sources of Suhareka Wellfield

The study area within the catchment of the wells and a few hundred meters outside of the catchment area was surveyed for potential sources of pollution. All publicly accessible places

have been surveyed; private land was surveyed where allowed by the landowner. Subsurface pollution sources have not been identified, however, may be present and covered by landfill or vegetation. Further investigation is recommended in case records provide hints for subsoil or hidden potential polluting spots. The below description of potential pollution sources contains mainly commercial infrastructure.

Such commercial infrastructure includes restaurants, farms, petrol stations, companies and scrapyards. Especially scrapyards present a high risk for underground contamination and groundwater contamination. None of the scrapyards is equipped with sealed paving or surface water collection systems nor connected to a sewerage pipeline or treatment. Oil spill and other chemical substance are infiltrating the underground. Depending on their position, these car scrapyards have to be displaced or the ground has to be protected against any intrusion of oils and other chemicals.

Table 40 gives an overview of the possible pollution point sources described in the following chapter.

Table 40: List of potential pollution sources

Pollution Name	ID	Catchment	Prot. zone	KRef - X	KRef - Y
Building materials and concrete objects	1	Pusi Atit	II	4683311.04	7483347.95
Petrol station	2	Pusi Atit	III	4683505.31	7483365.73
Gabions and gravel	3	Pusi Atit	Out	4683888.14	7483468.03
Auto Parts and Service	4	Pusi Atit	Out	4683907.8	7483607.39
Cylinders, building materials	5	Pusi Atit	Out	4684060.21	7483960.56
Natural fertilizers	6	Pusi Atit	Out	4683927.95	7484509.28
Greenhouse	7	Pusi Atit	II	4682967.21	7484142.74
Commercial plant nursery	8	Pusi Atit	III	4682296.46	7484187.4
Farm	9	Pusi Atit	III	4682796.46	7484036
Serpentinite mine	10	Pusi Atit	III	4682235.47	7484650.66
Metal worker	11	Pusi Atit	(III)	4683159.85	7485421.88
Business "New Born"	12	Pusi Atit	II	4683200.08	7483317.18
Business "Vëllezërit Gashi"	13	Pusi Atit	II	4683151.25	7483307.18
Business "Kamila Chocolate"	14	Pusi Atit	III	4682183.94	7483862.27
Cemetery	15	Pusi Atit	III	4682026.4	7483806.66
New business	16	Pusi Atit	III	4681897.54	7483831.1
New construction	17	Pusi Atit	III	4682239.55	7483823.65
Rami Plast and Euro fix	18	Pusi Atit	III	4682674.19	7483141.97

Eighteen individual points for potential pollution source have been identified. Each location has been documented by a brief description, coordinates, and some photographs.

### 7.4.1 Potential point pollution sources of the Protection Zone I

The Protection Zone I comprises the area of the wellhead, its housing and the area to a distance of 10 m from the wellhead. Inside this area no pollution source has been identified. However, this area requires an intensive protection. Fences with locked gates and signpost are required. Such fences are installed, however do have several openings or holes and gates have not been completely locked.

### 7.4.2 Potential point pollution sources of Protection Zone II

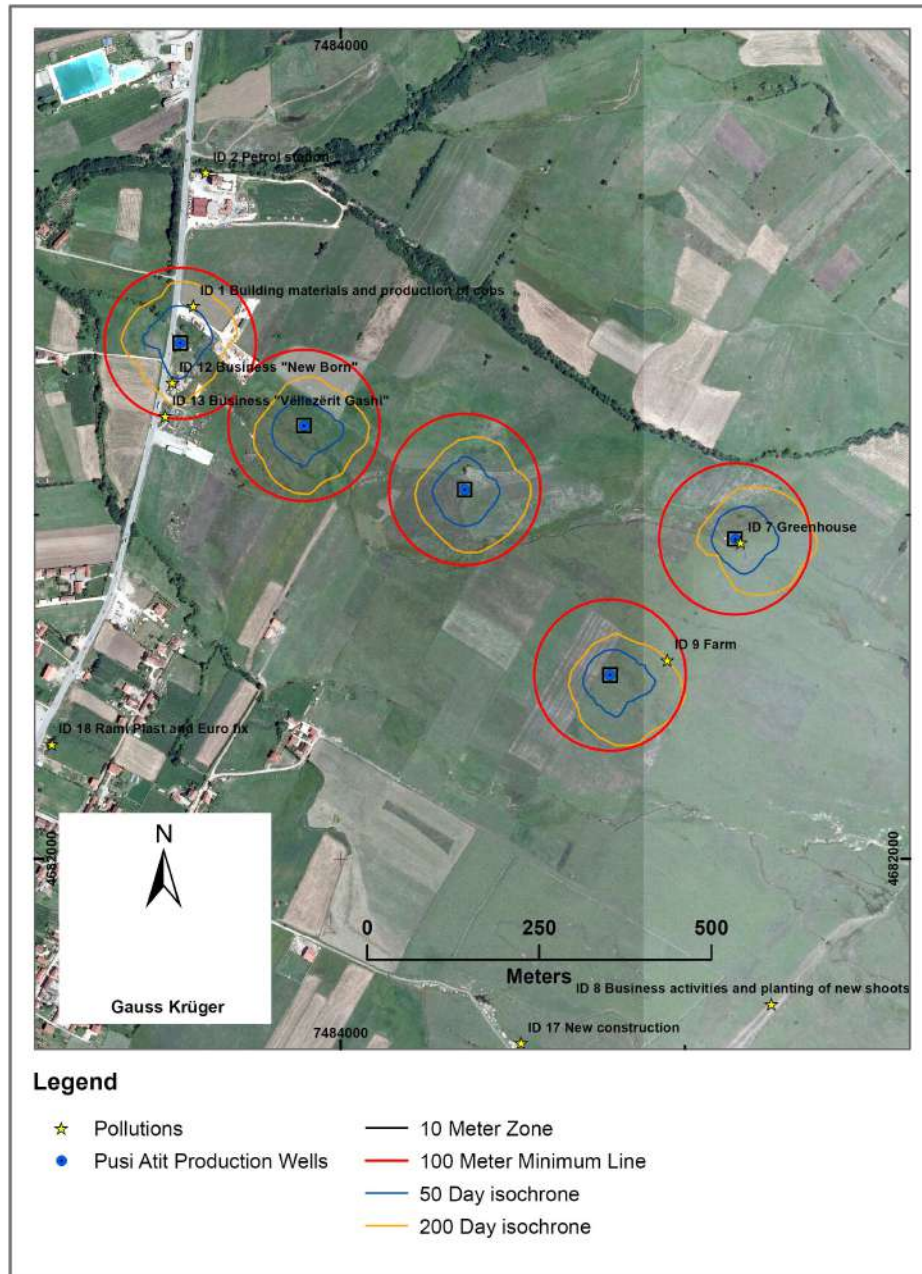


Figure 63: Potential Pollution Sources inside the Protection Zone II of the Pusi Atit wellfield



## **8 PROPOSED DELINEATION OF PROTECTION ZONES**

In this chapter we propose the designated Zone I, Zone II and Zone III for the Varosh, Begrace, Gerlice, Pusi i Atit wells as a recommendation for implementation. The term “designated” is used since it is the final responsibility of the municipality to implement such protection zones into legal land use planning and permits.

### **8.1 Designated Protection Zones of the Ferizaj Wellfield**

The delineation the minimum protection area resulting from the modelling of the aquifer as described in the chapter 5.4 represents the minimal extend to fulfil hydrogeological conditions for protection. However, the Kosovar law provides further minimal conditions to define the minimum area for protection zones.

The Protection Zone I comprises the area of 10 m radius around the well head.

The Protection Zone II is defined by the 50-day isochrone, Further, Article 12, paragraph 2, Administrative Instruction (MESP 2017) indicates that Zone II must be at least 100 m from the delineation of protection Zone I. Therefore, a buffer of 100 m around protection Zone I is to be considered as minimum extend of protection Zone II (100 m minimum line). In case the modelling provides a 50-day isochrone smaller than the 100 m minimum line the designated Zone II reaches to the 100 m m minimum line.

The Protection Zone III defined by the entire catchment of the well. Further, the protection Zone III requires a minimum distance of 500 m from the well head (Article 14, paragraph 3 of the Administrative Instruction (MESP 2017)). Therefore, a circle of 500 m around the well head has to be defined as minimum extend of the protection Zone III (recharge area). This delineation is called “500 m minimum line”. Wherever the modelled recharge area is of larger extent than the 500 m minimum line, the minimum protection Zone III extent is defined by the modelled recharge area.

The resulting designated protection zones as proposed in this report are given in:

The below figures for the designated protection zones.

Figure 65, Figure 66 and Figure 67 for the Varosh wells.

Figure 68, Figure 69 and Figure 70 for the Gerlice wells.

Figure 71, Figure 72 and Figure 73 for the Begrace wells.

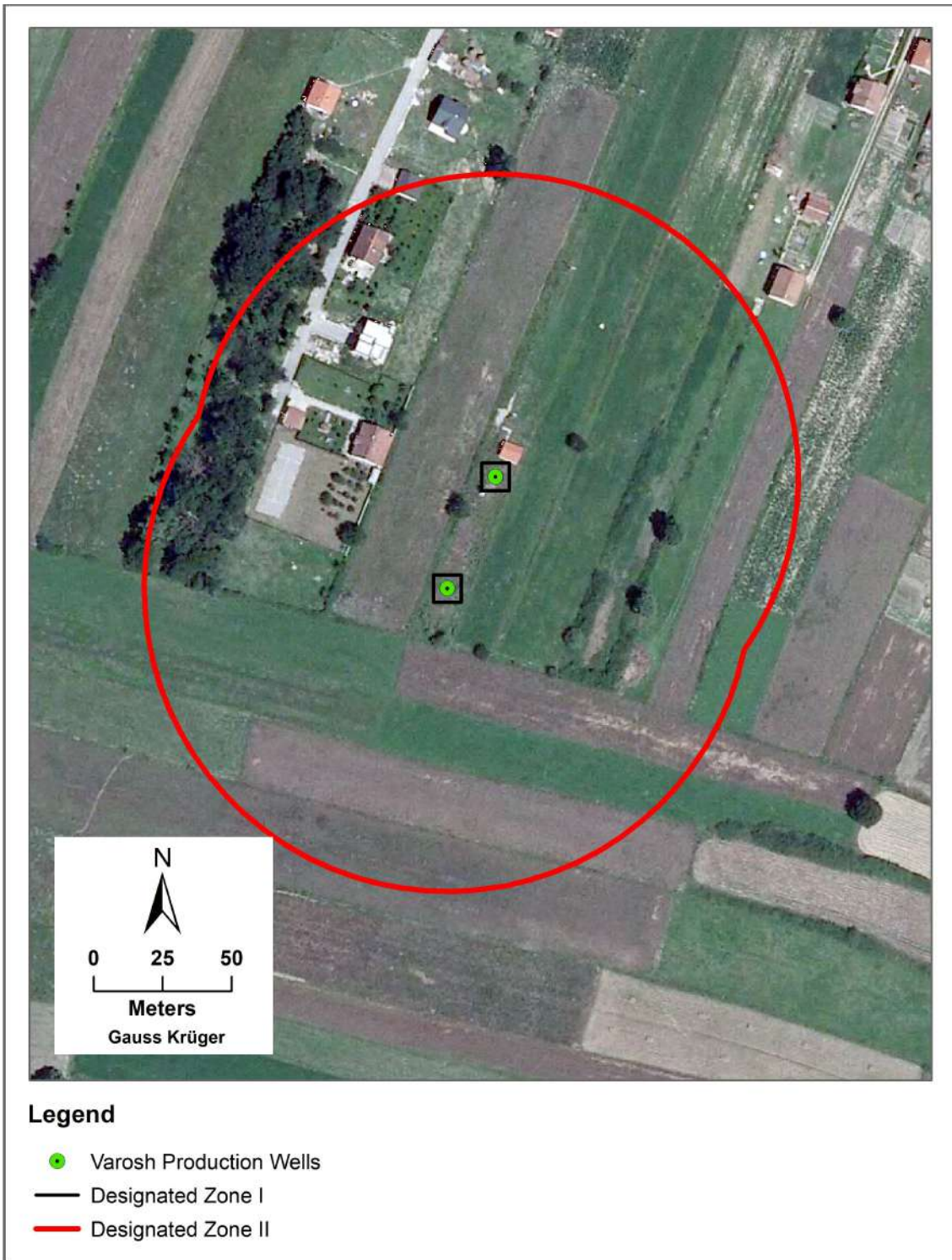


Figure 65: Designated Zone I and II for Varosh wells.

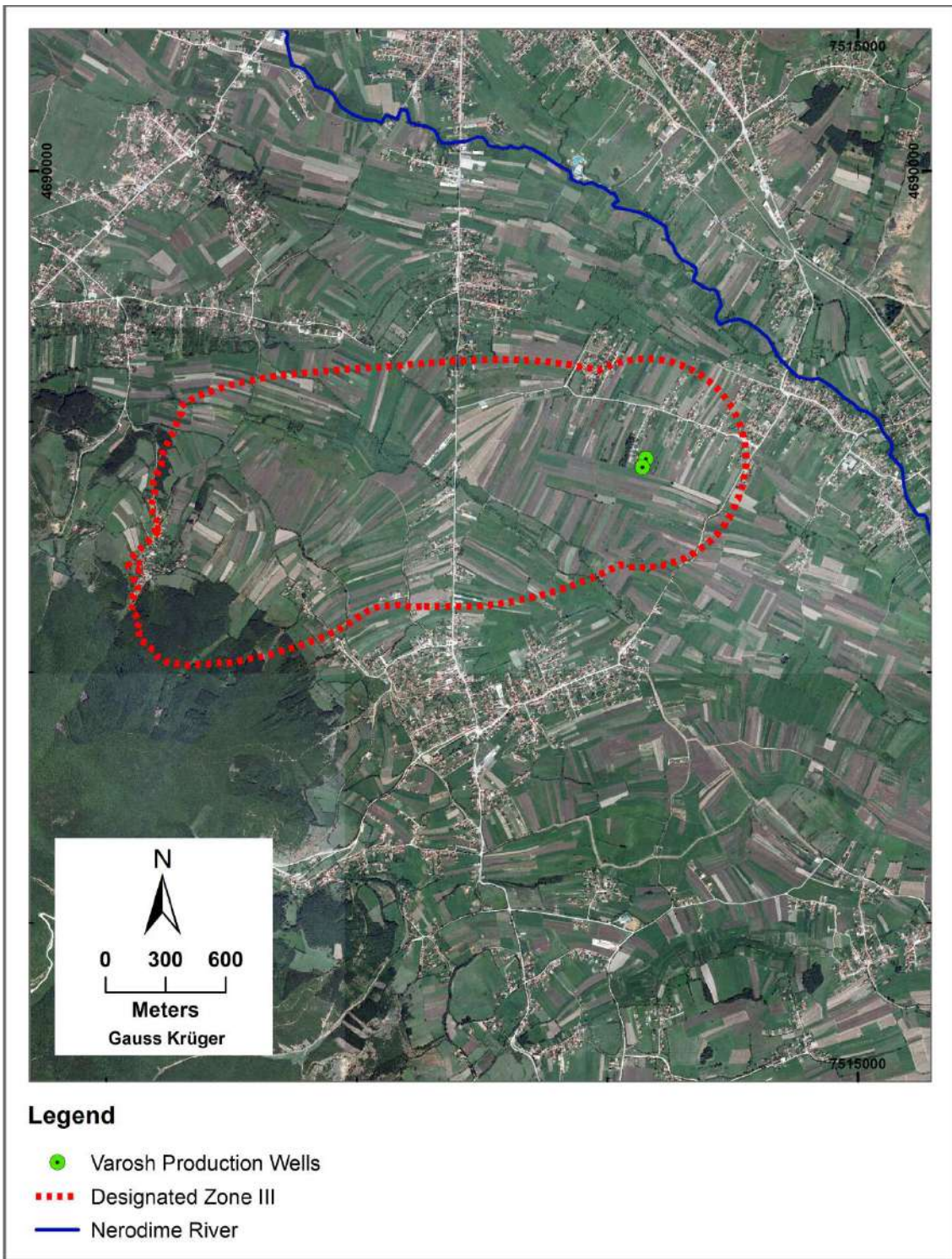


Figure 66: Designated Zone III for Varosh wells with ortophoto as background.

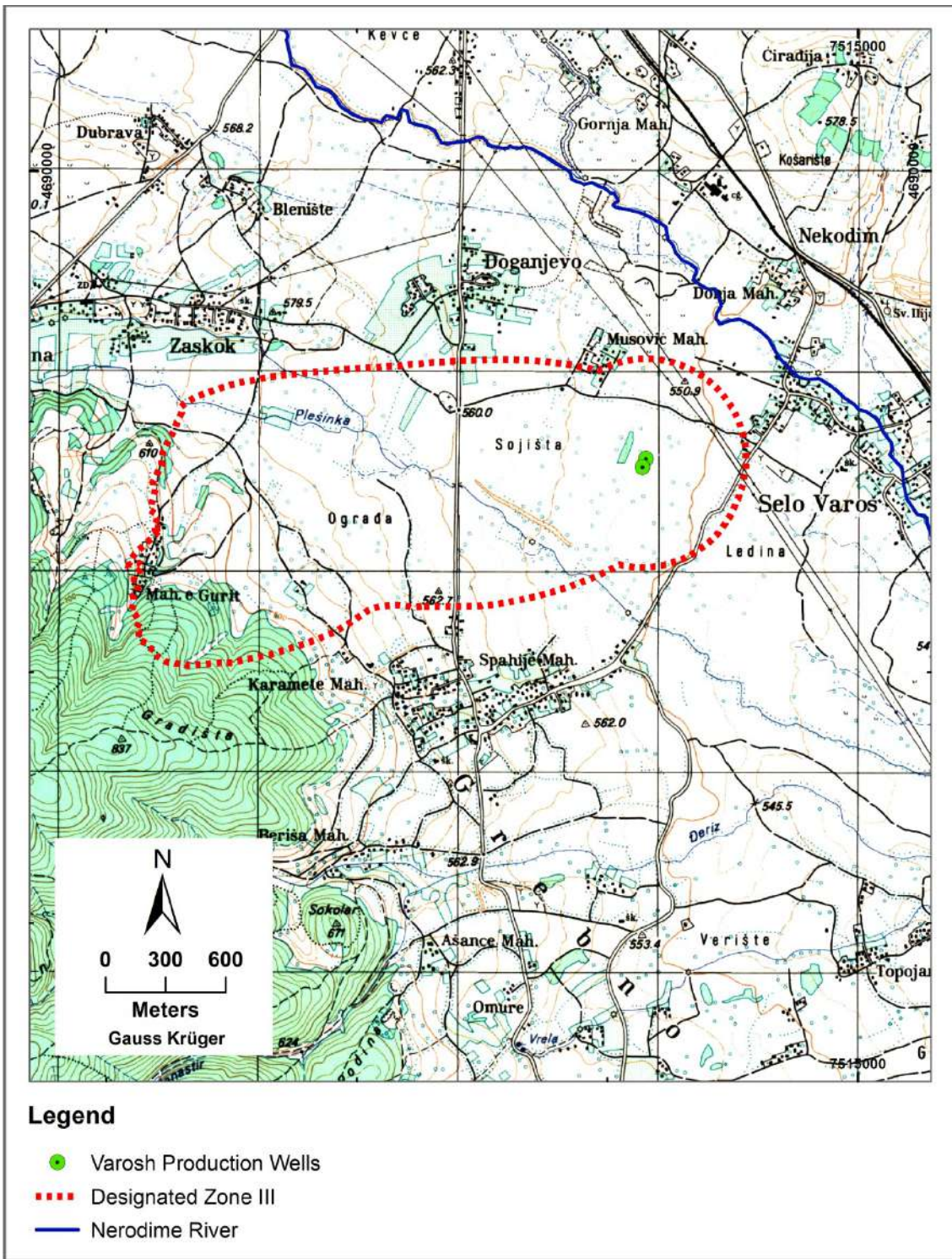


Figure 67: Designated Zone III for Varosh wells with topographic map as background.

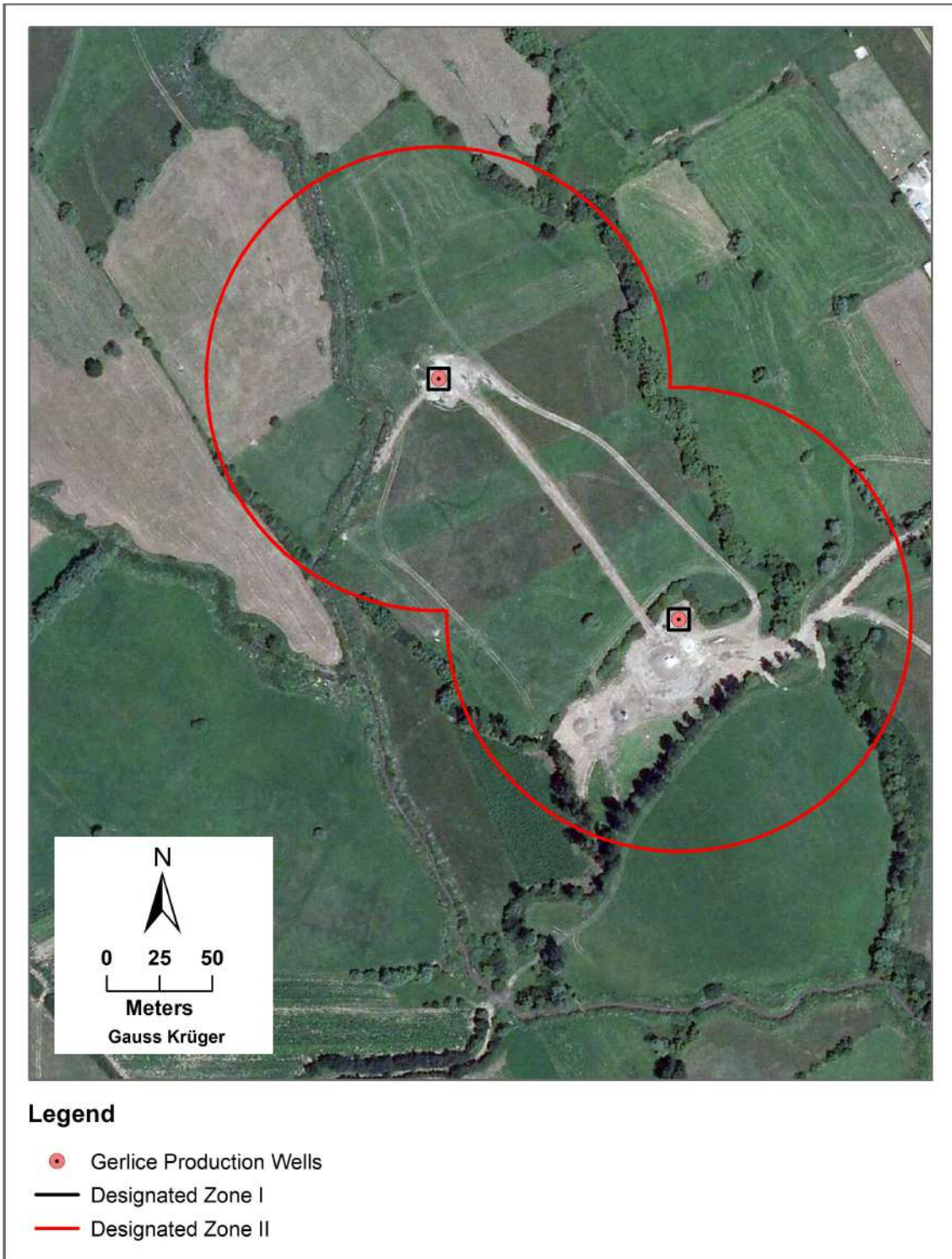


Figure 68: Designated Zone I and II the Gerlice wells.

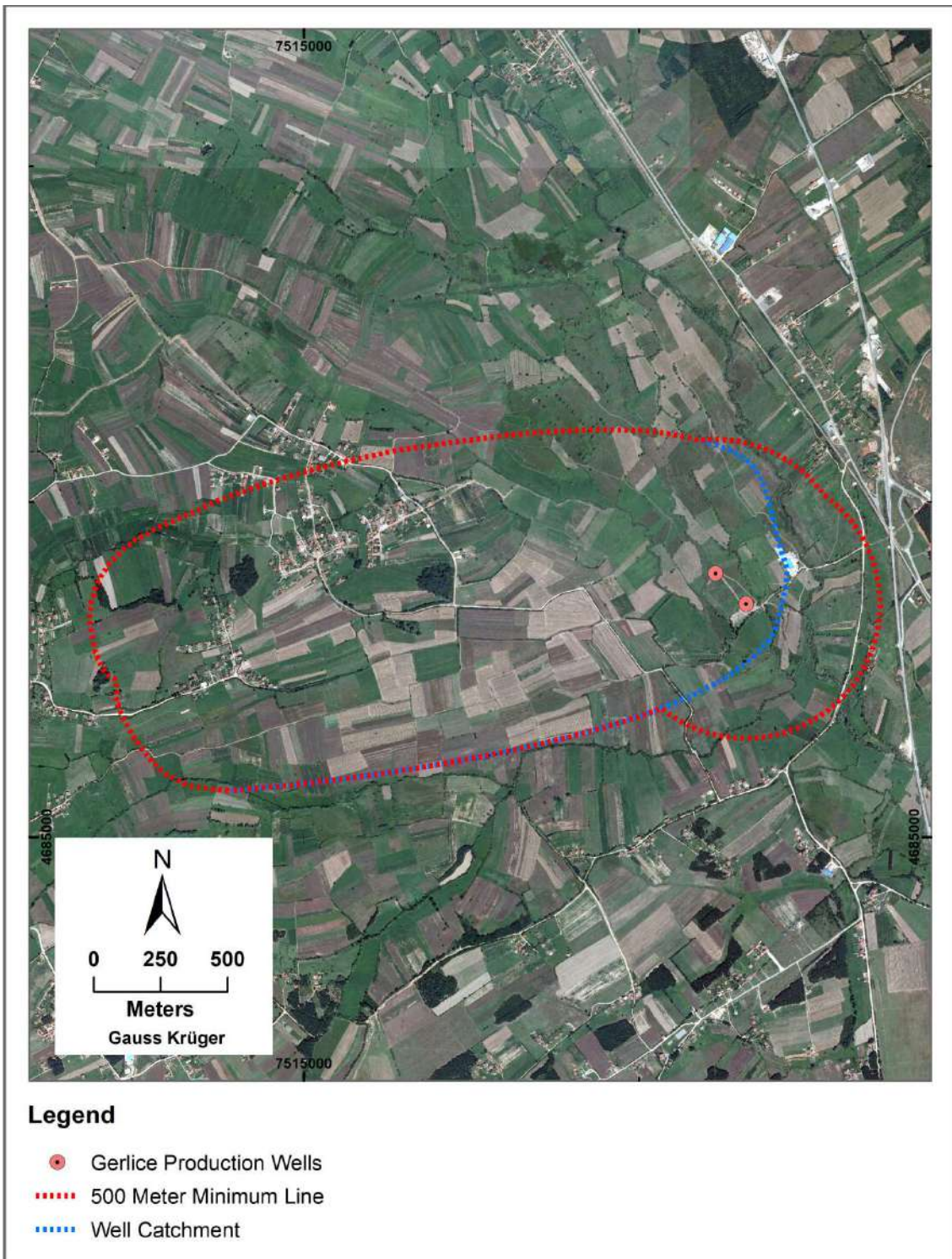


Figure 69: Designated Zone III for Gerlice wells with ortophoto as background.

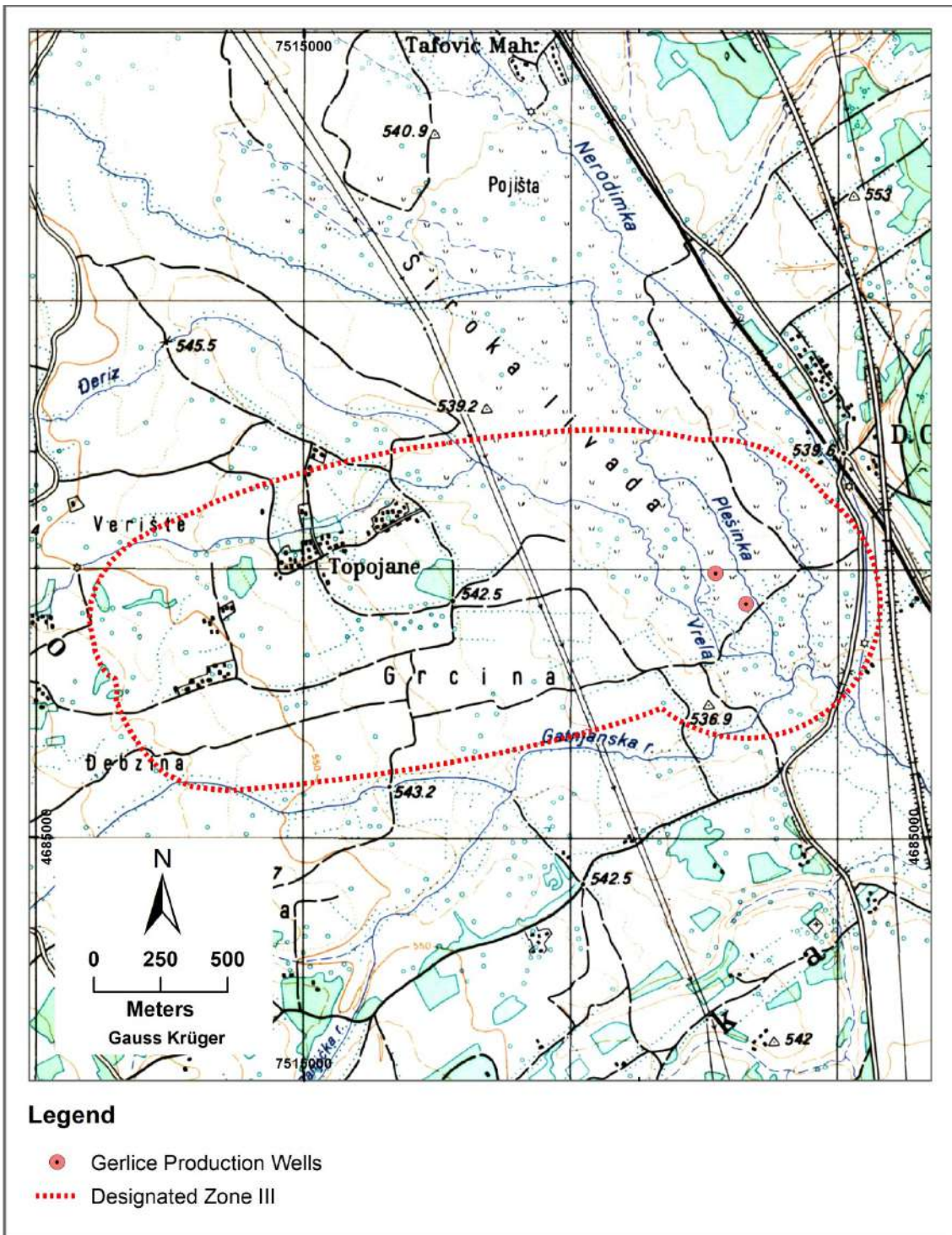


Figure 70: Designated Zone III for Gerlice wells with topographic map as background.

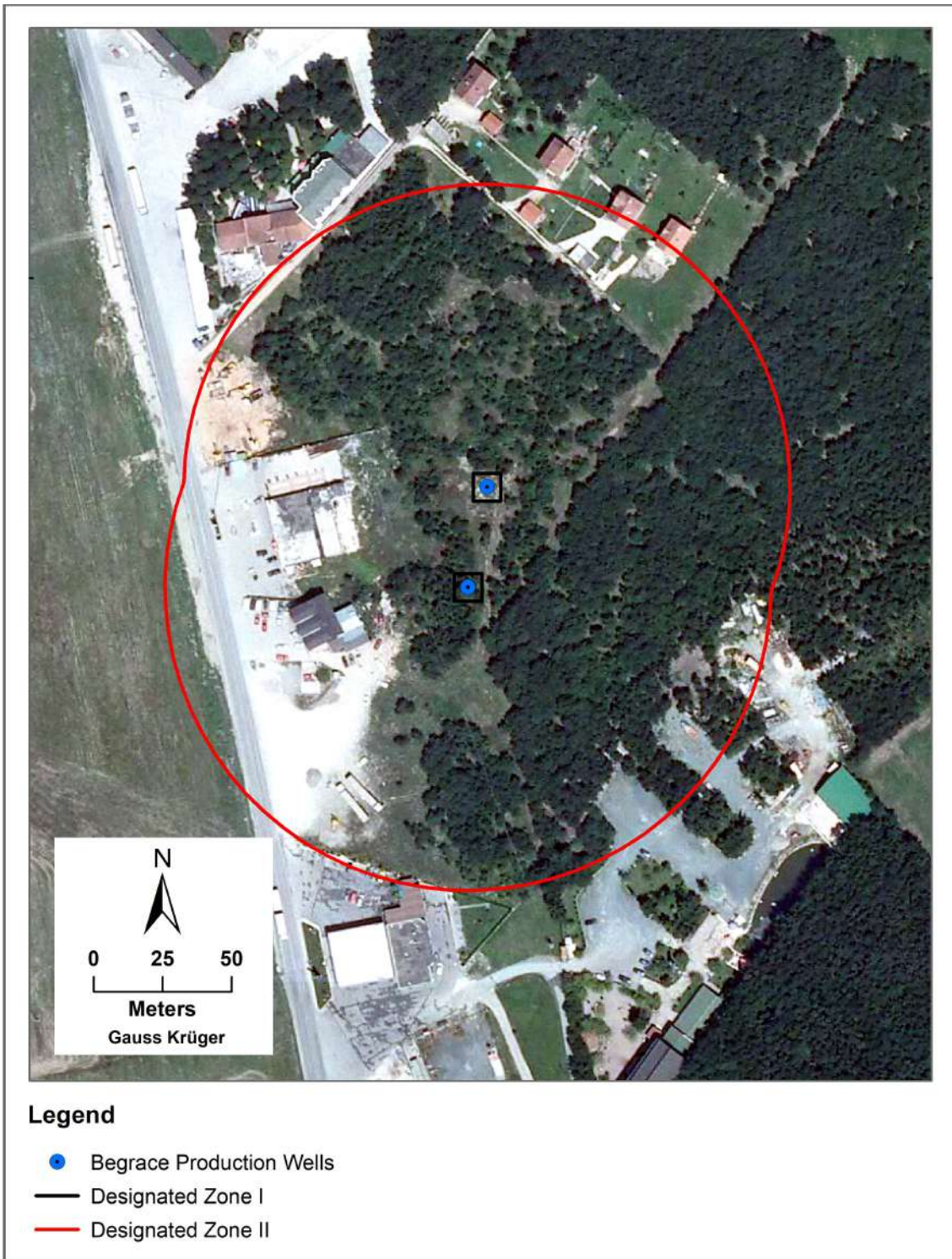


Figure 71: Designated Zone I and II for Begrace wells.

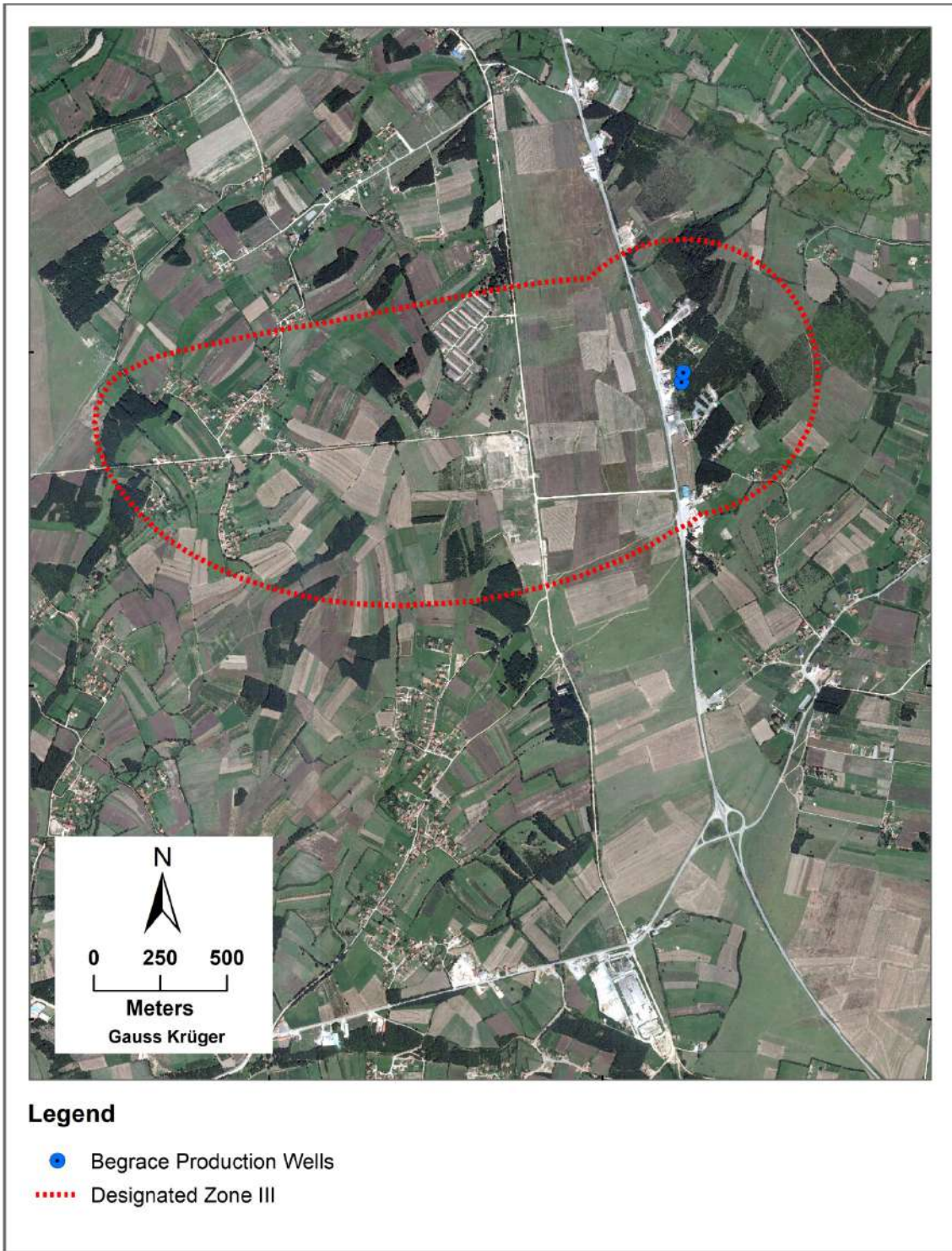


Figure 72: Designated Zone III for Begrace wells with orthophoto as background.

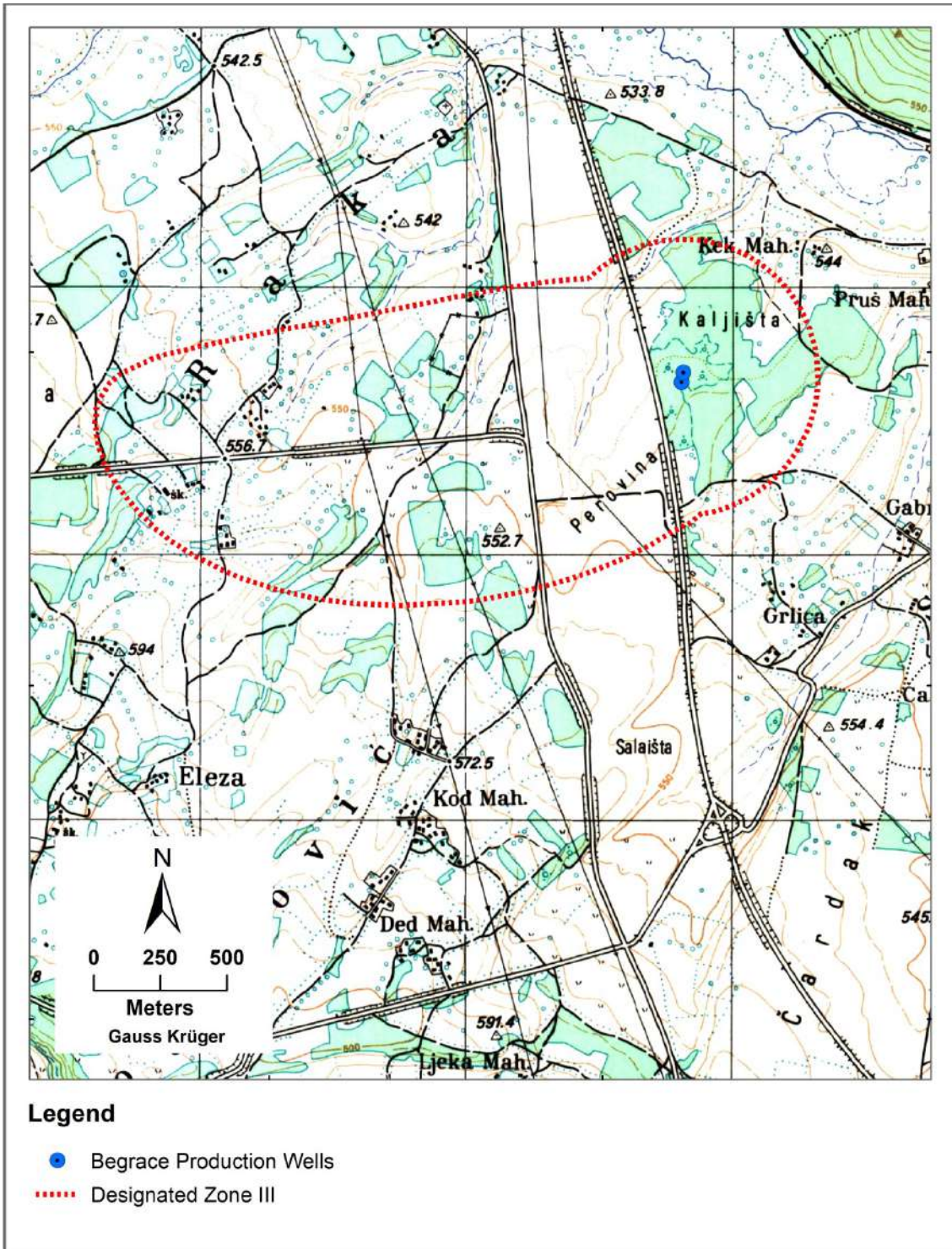


Figure 73: Designated Zone III for Begrace wells with topographic map as background.

## 8.2 Designated Protection Zones of the Suhareka Wellfield

The delineation the minimum protection area resulting from the modelling of the aquifer as described in the chapter 5.8 represents the minimal extend to fulfil hydrogeological conditions for protection. However, the Kosovar law provides further minimal conditions to define the minimum area for protection zones.

The Protection Zone I comprise the area of 10 m radius around the well head.

The Protection Zone II is defined by the 50-day isochrone, Further, Article 12, paragraph 2, Administrative Instruction (MESP 2017) indicates that Zone II must be at least 100 m from the delineation of protection Zone I. Therefore, a buffer of 100 m around protection Zone I is to be considered as minimum extend of protection Zone II (100 m minimum line). In case the modelling provides a 50-day isochrone smaller than the 100 m minimum line the designated Zone II reaches to the 100 m m minimum line.

The Protection Zone III is defined by the entire catchment of the wells. Further, the Protection Zone III requires a minimum distance of 500 m from the well head (Article 14, paragraph 3 of the Administrative Instruction (MESP 2017)). Therefore, a circle of 500 m around the well head has to be defined as minimum extend of the protection Zone III (recharge area). This delineation is called “500 m minimum line”. Wherever the modelled recharge area is of larger extent than the 500 m minimum line, the minimum protection Zone III extent is defined by the modelled recharge area.

The resulting designated protection zones as proposed in this report are given in:

The below figures for the designated protection zones.

Figure 74, Figure 75 and Figure 76 for the Pusi Atit wells.

It has to be annotated the information of the Director of the Department of Water of the MESP, that the 100 m minimum line and the 500 m minimum line for the Protection Zone II rep. III should not apply in the (given) case of a digital modelling of the aquifer groundwater flows. The present report has to follow the Administrative Instruction 15/2017 in its recommendation and therefore does not designate the Protection Zone ignoring the 100 m respective 500 m line specification.

However, the municipality should reflect in their decision-making process the option to follow the information given verbally by the MESP and to refer to the digital groundwater modelling only and to ignore the 100 m and 500 m minimum line specification.

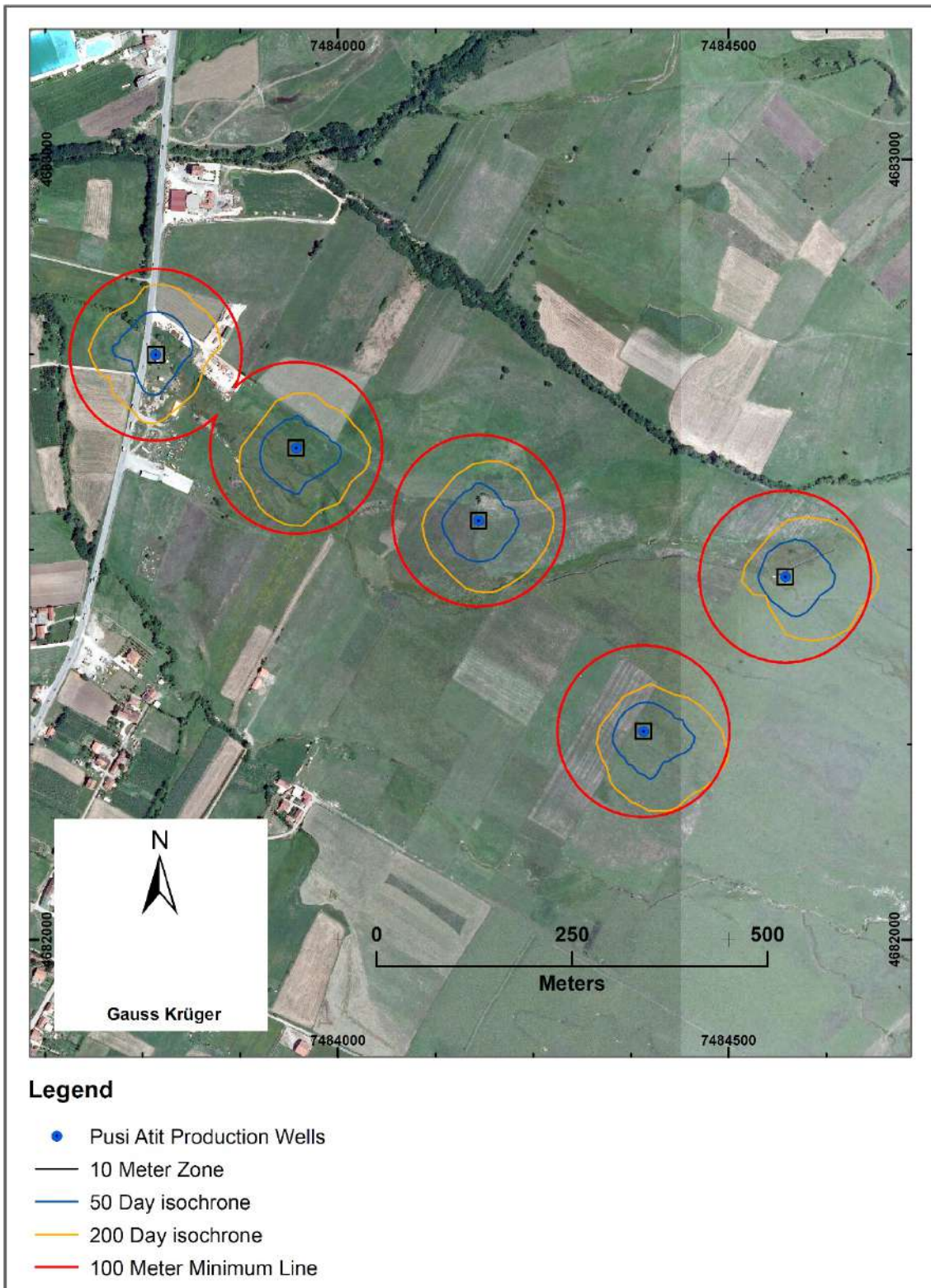


Figure 74: Designated Zone I and II for Pusi Atit wells.

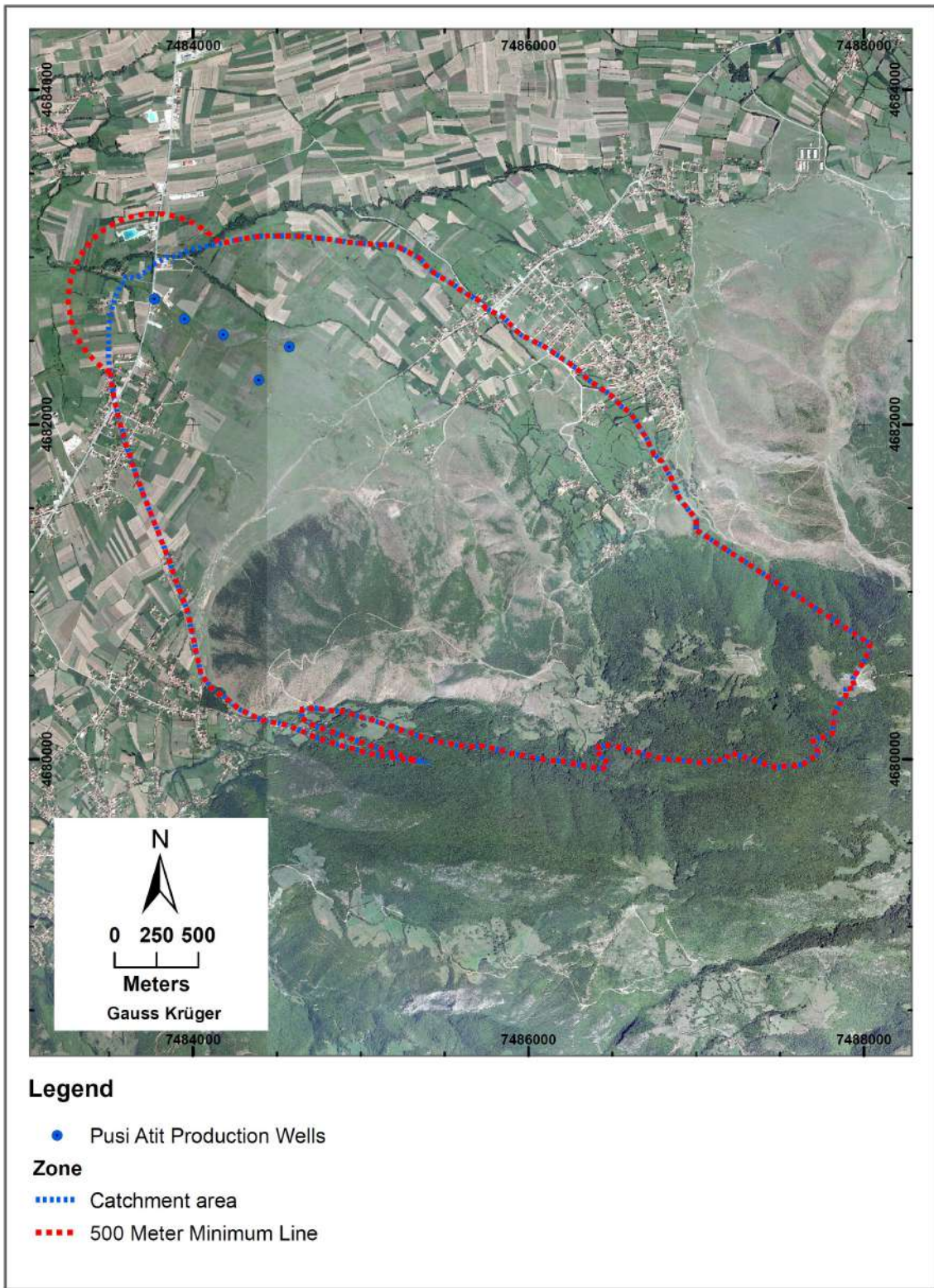


Figure 75: Designated Zone III for Pusi Atit wells with orthophoto as background.

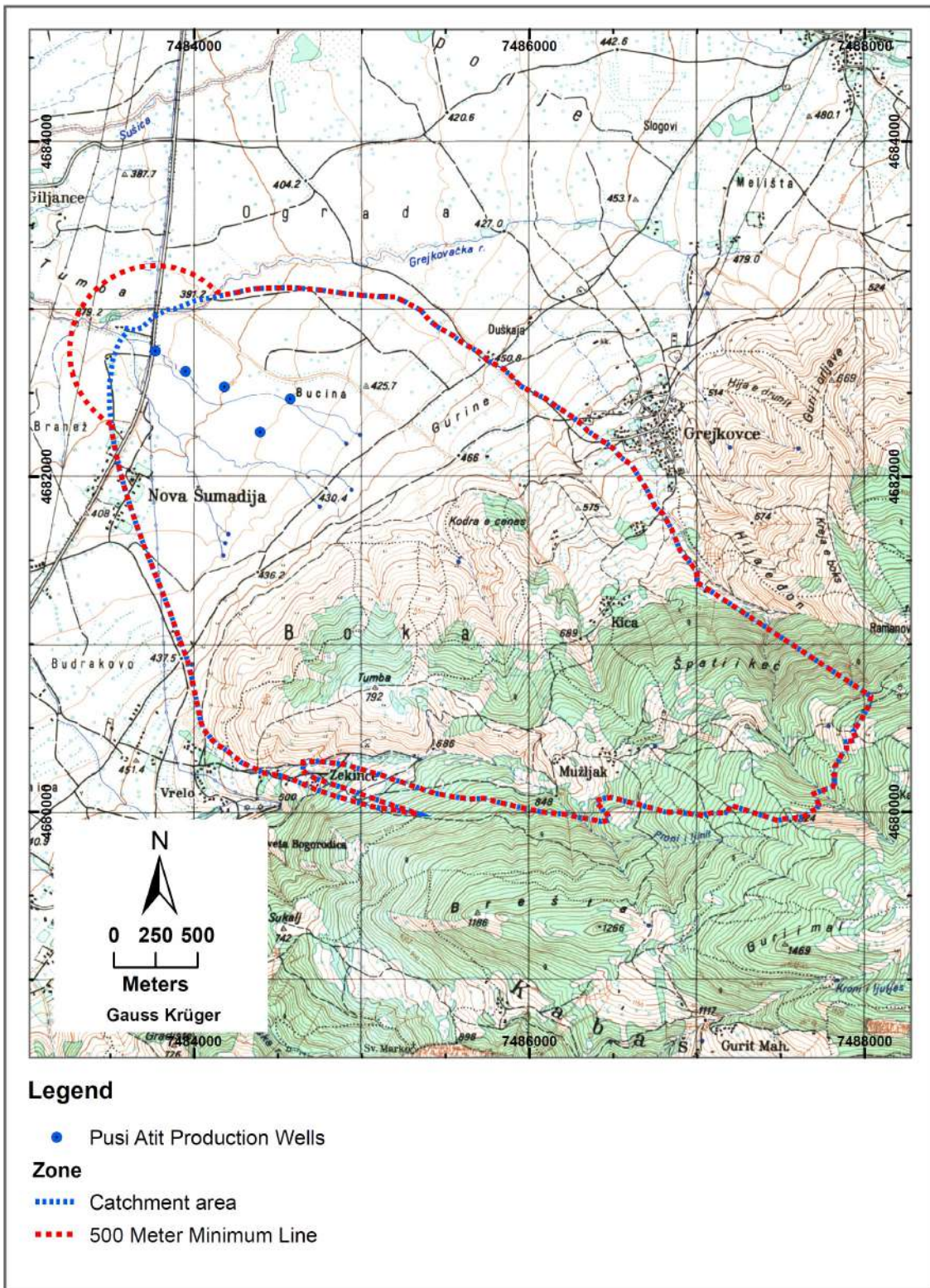


Figure 76: Designated Zone III for Pusi Atit wells with topographic map as background.

### 8.3 Distribution of pollution sources in the protection zones

The potential pollution sources as identified in chapter 7 require individual studies in order to define the detailed minimum measures in order to comply with the legal regulations, once the protection areas are defined by the law and the protection areas become implemented by the municipality.

General recommendations to comply with regulations are developed below. To facilitate the overview on activities and pollutions sources, the below matrix shows the distribution of potential pollution sources and their respective attribution to a designated zone (see Table 41 and Table 42).

Table 41: Matrix of pollution sources in protection zones II and III.

Wells	Zone II	Zone III	Outside but close to the protection zone
Varosh	-	ID 1, ID 2, ID 4	ID 3
Gerlice	-	ID 7, ID 12, ID 6, ID 8	ID 5, ID 11, ID 9, ID 10
Begrace	-	ID 20, ID 14, ID 16, ID 13, ID 15, ID 17, ID 19	ID 18

Table 42: Matrix of pollution sources in protection zones II and III.

Wells	Zone II	Zone III	Outside but close to the protection zone
Pusi Atit	ID1, ID7, ID12, ID13	ID2, ID8, ID9, ID10, ID11, ID14, ID15	ID3, ID4, ID5, ID6

### 8.4 Protective Measures for Protection Zones I

Zone I is a strictly protected area designated for strict and direct protection. No other activities than those needed for water resources operation are allowed in this zone. Only employees that are authorized by the owner are allowed to enter the zone. Therefore, a fence at least 10 m from the well heads is required. The fence may be larger if further infrastructure e.g. pump station is very near the wells.

The fence has to be complete (without any holes) and a locked entry door is required. A proper casing prevents the contamination of the wells. At the fence, a signpost informing the public about the restriction needs to be installed at the fence.

## **8.5 Protective Measures for Protection Zones II**

In Zone II it is prohibited to conduct construction works, construction of facilities and conduct activities which may damage the water supply infrastructure and pollute water sources.

Therefore, the following measures have to be considered for the named potential pollution source:

- Approach all owners of private wells and explain restriction of the newly defined protection zone. Enforce the stop of exploitation of private wells;
- Enforce the expulsion of all waste types in the area and control in regular frequency the area for illegal waste deposits;
- Approach the present industrial and crafts units (if identified) and enforce their relocation outside the protection area;
- Implement very well visible signpost explaining the restrictions and run frequent controls for transportation of chemicals, liquid fuels, oils and other hazardous substances on main roads crossing the area. ;

## **8.6 Protective Measures for Protection Zones III**

In Protection Zone III, also named sanitary protection zone it is prohibited the execution of works, construction of facilities and activities that may pollute water sources.

Therefore, it's recommended to:

- Investigate all constructions for septic tanks. As direct or indirect discharge of wastewater into the aquifer is prohibited, the owners have to be informed to ensure the guaranteed proofing of their septic tanks and to apply regular emptying by qualified service providers;
- Further investigate that industrial and commercial units are not using harmful and hazardous substances to water;
- Enforce regular and frequent control of road transport of hazardous substances under law;
- Enforce the control of compliance to petrol stations etc. relative to transport liquid fuels, oils and other hazardous liquids, unless special measures are taken which prevent the infiltration of these fluids on groundwater;

- Control the agricultural sites (greenhouses etc.) for compliance to the restriction for open storage and use of hazardous chemicals for water that are used for the protection and growth of plants and to destroy harmful weed;
- Investigate the gravel and cement industries for compliance to the restriction for exploitation of mineral resources, unless it is proven that this activity is not harmful for groundwater quality on the source as well as the exploitation of gravel except the separation specifically protected and controlled ones.

## CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER WORKS

This doctoral thesis deals with hydrogeological modeling for the definition of groundwater protection zones in the southern well fields of Ferizaj (Varosh, Begracë and Gërlicë), with the aim of ensuring a sustainable and safe supply of drinking water for the local population.

The research includes the analysis of the geographical, climatic, geological, and hydrogeological characteristics of the study area, as well as the assessment of the hydraulic parameters of the aquifer (hydraulic conductivity, transmissivity, and effective porosity).

The data were collected through preliminary documentary studies, field measurements of groundwater levels, pumping tests, and hydro-chemical analyses.

The modeling results enabled the definition of Zone I (strict protection around the well), Zone II (based on the 50-day isochrone of water travel time) and Zone III (aquifer capture/recharge zone). For each well field, the spatial boundaries of these zones were identified, taking into account the direction of groundwater flow and local hydrogeological conditions. An assessment of the aquifer's sensitivity and a risk analysis from potential sources of pollution, including agricultural, infrastructural and industrial activities, were also carried out.

The thesis concludes with concrete recommendations for protective measures and sustainable management of water resources, emphasizing the need for control of activities within protective zones, continuous monitoring of water quality and integration of groundwater protection into spatial planning.

The developed model represents an important tool for decision-making and can serve as a methodological basis for similar projects in other regions.

The field of application and its limitations are linked to the fact that, for full verification, the proposed methodology must undergo critical review regarding its applicability. Namely, the possible conditions for groundwater contamination over time are variable. This means that in other regions the methodology should be subjected to appropriate verification through continuous monitoring of groundwater quality and quantity, in line with principles developed in European and other directives.

Possible further research is related to the following aspects:

- creating similar models as those developed for the analyzed areas, but also for neighboring regions;

- analyzing influential factors for susceptibility to groundwater contamination using established methods, such as the so-called DRASTIC method;
- conducting more detailed statistical analyses of all input parameters during modeling, which would help minimize subjectivity in the model and optimize the predicted results.

Author hopes that presented analyses will also serve as a practical tool for integrating methodologies in a Balkan country, and to ensure sustainable use of groundwaters in a future.

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## **Annex 1: Groundwater Protection in Kosovo**

Aquifers present the main source for drinking water supply. Representing a share of about 70 % of the actual provision of drinking water, this resource requires specific protection against any kind of pollution. Groundwater protection has become a national priority in Kosovo and is focusing preventing over rehabilitation. To protect the resource, several protection areas are defined at the surface, preventing pollution by limiting the number of possible activities within these areas. These protection areas serve as protective buffer around the wells capturing groundwater for human consumption.

The definition of groundwater protection zone refers to several disciplines like hydrogeology, economy, sociology, etc. and is a complex process demanding specific technologies and administrative procedures. The fact that activities inside the protection areas are limited and new defined protection areas interfere into the usufruct of the land, the definition of the protection zones remains a delicate act for researchers, geologist and administrators.

### **Delineation of Groundwater Protection Zones in Kosovo**

In the following the three groundwater protection zones are described. According to the Kosovar law of sanitary protected areas prohibited activities are listed for each area. This report covers only excerpts of the law and is not complete.

#### **Protection Zone I**

Area 1 is a strictly protected area designated for strict and direct protection around the water source and installation facilities. It protects the water source from discharges and pollutants that can directly affect the water by human activities.

No other activities then those needed for water resources operation are allowed in this zone. Only employees that are authorized by the owner are allowed to enter the zone.

According to Article 6 of the Kosovar law of sanitary protected areas the fence needs to be at least 10 m from the object of water supply to prevent bacteriological water pollution. The fastest way to contaminate groundwater is through the well, it provides a direct path for the contaminated water to travel from the surface to the aquifer. A proper casing prevents the contaminated water from seeping along the outside of the casing and entering the well.

#### **Protection Zone II**

Area 2 is a limited protective area. The surface of this area shall be sufficient to provide protection from movements of microbial and chemical contaminants, and other types of pollutants. It is prohibited to conduct construction works, construction of facilities and conduct activities which may damage the water supply infrastructure and pollute water sources.

For delineation of groundwater protection Zone II the calculated travel time of water is important. According to the law in Kosovo the travel time is 50 days. Water inside the protection Zone II reaches the well in less than 50 days.

#### **Protection Zone III**

The third protective are covering the area between the outer boundary of the second protective area to the hydrogeological watershed of the well field. This area represents the recharge area on land surface and is called protection Zone III. In this area the execution of works, construction of facilities and activities that may pollute the water source are prohibited.

## **Kosovar regulations for land use in protection zones**

### **Groundwater Protection Zone I**

No other activities are allowed except those intended for infrastructure maintenance and operation of the water supply system. Cultivation of grass without the use of fertilizers and other chemical preparations is allowed.

### **Groundwater Protection Zone II**

In Zone II it is prohibited to conduct construction works, construction of facilities and conduct activities which may damage the water supply infrastructure and pollute water sources, in particular:

- Execution of works, construction of facilities and conduct activities of GWPZ 3
- Construction of new settlements and the construction of sewerage, unless the discharge of water sewage pipes is controlled and secured;
- Construction of sports and recreational facilities without water discharge sewage;
- Construction and exploitation of recourses and wells which are not used for public supply;
- Excavations on the aquifer, except in a short period and under the control of groundwater quality;
- Collection and storage of all waste types
- Construction and the work of industrial and crafts units;
- Construction and work of the railway stations, of buses and terminals, unless special measures are taken of which pollution of source is prevented;
- Construction and use of storage of substances hazardous to water
- Construction of animals and poultry farms, except of cases up to 10 heads of livestock and poultry for individual households for their own use, if it is well built and I operation non-dischargeable water sewage, respectively non dischargeable septic tank;
- Construction and use of the pipe for transporting chemical, liquid fuels oils and other hazardous liquids;
- Road transportation of chemicals, liquid fuels, oils and other hazardous substances;
- The drillings for oil, gas and other hazardous substances, as well as mineral waters;
- Raw mineral exploitations
- Exploitation of gravel

- Digging and construction activities that will weaken the geological protective strata;
- Any other activities for that may have negative consequences to water source.

### **Groundwater Protection Zone III**

In Zone III, also named sanitary protection zone it is prohibited the execution of works, construction of facilities and activities that may pollute water sources, in particular:

- Direct and indirect discharge of wastewater into the aquifer, as well as wastewater untreated in the ground, including emptying and cleaning of vehicles for the transfer of faeces;
- The work and construction of industrial and crafts units which can be harmful and hazardous substances to water
- Road transport of hazardous substances under law;
- The work and construction equipment for cleaning polluted water and solid waste incineration;
- Direct and indirect discharge of polluted waters treated on the ground
- Construction and use of pipe for transport of chemicals, liquid fuels, oils and other hazardous liquids, unless special measures are taken which prevent the infiltration of these fluids on groundwater;
- Conduction research drillings for oil, gas and other hazardous substances, and mineral waters, unless special measures are taken to prevent infiltration of leakage of these substances on groundwater;
- Open storage and using of hazardous chemicals for water that are used for the protection and growth of plants and to destroy harmful weed;
- The construction and work of animals and poultry farms unless special measures are taken to prevent the contamination of groundwater;
- Construction of new cemeteries or expansion of existing ones;
- Exploitation of mineral recourses, unless it is proven that this activity is not harmful for groundwater quality on the source;
- Exploitation of gravel except the separation specifically protected and controlled ones;
- And other activities for which is verified that may have negative consequences on the water source.

## **Annex 2: Groundwater Protection in other Countries**

Protection against pollution of aquifers and definition of protection zone of wells or well fields, in different countries is provided by different laws and ways.

### ***USA***

The responsibility for groundwater protection lies at State level. However, the 1986 Federal Safe Drinking Water Act Amendments direct all States to develop a Well Head Protection Program (WHPP) Plan for both public community (CWS) and public non-community (NCWS) water-supply wells. Following these amendments, the States had to propose a WHPP Plan that had to be approved by the U.S. Environmental Protection Agency (EPA) . The delineation of Well Head Protection Areas (WHPA's) is one component of the WHPP. Other components of the WHPP Plan include pollution-source inventories, development and implementation of best management practices to protect groundwater, integrated land use planning, and education to promote public awareness of each person's role in protecting groundwater resources.

The methodology to be used for the delineation of Well Head Protection Areas is laid down in the 'Guidelines for the Delineation of Wellhead Protection Areas' (EPA 1987). This guideline gives the States, i.e. the implementing authorities, flexibility to choose an appropriate approach for the delineation policy. The guideline proposes as operational goals:

- To provide a remedial action zone (in order to protect the well from unexpected contaminant release),
- To provide an attenuation zone (in order to bring the concentrations of specific contaminants down to desired levels by the time they would reach the wellhead and
- To provide a well field management zone.

As criteria for the delineation of groundwater protection zones the guideline uses:

- Distance,
- Drawdown,
- Travel time,
- Flow system boundaries and
- The capacity of the aquifer to assimilate contaminants.

This criteria catalogue is the main difference to many other systems, which are based on travel times only. Moreover, the EPA guideline does not propose the use of a certain zoning system, unlike in most other countries. It leaves this decision to the implementing authority. This procedure is applied in very different manners throughout the different states and even counties.

The guideline only specifies that for the delineation of protection zones 'appropriate thresholds' have to be chosen, representing the limits above or below which a criterion will cease to provide the desired level of protection.

The guideline proposes using the following methods for the delineation process:

- Arbitrary fixed radius method,
- Calculated fixed radius method,
- Simplified variable shapes,

- Analytical methods,
- Hydrogeologic mapping
- Numerical flow/transport models.

The guideline does not propose individual restrictions on land use and human activities as in guidelines of other countries. The responsibility for these definitions lies at State level.

### ***Europe***

In 2000, the European Union adopted the Water Framework Directive on waters, which provides a new approach for management and protection of surface and underground waters. The European Parliament has issued a number of Directives dealing with water protection issues. These Directives have to be adopted by and integrated into the legal framework of the member states within a specified time period.

The Water Framework Directive aims to create a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater in order to among others (1) prevent a further deterioration and to protect and enhance the status of aquatic systems, (2) promote the sustainable water use, and (3) ensure the progressive reduction of pollution of groundwater as well as prevent its further pollution.

Usually three (3) to four (4) sanitary protection areas of groundwater resources are defined, based on the distance and time travel criteria (TOT), with simple mathematical methods, analytical methods and numerical modelling.

### ***Germany***

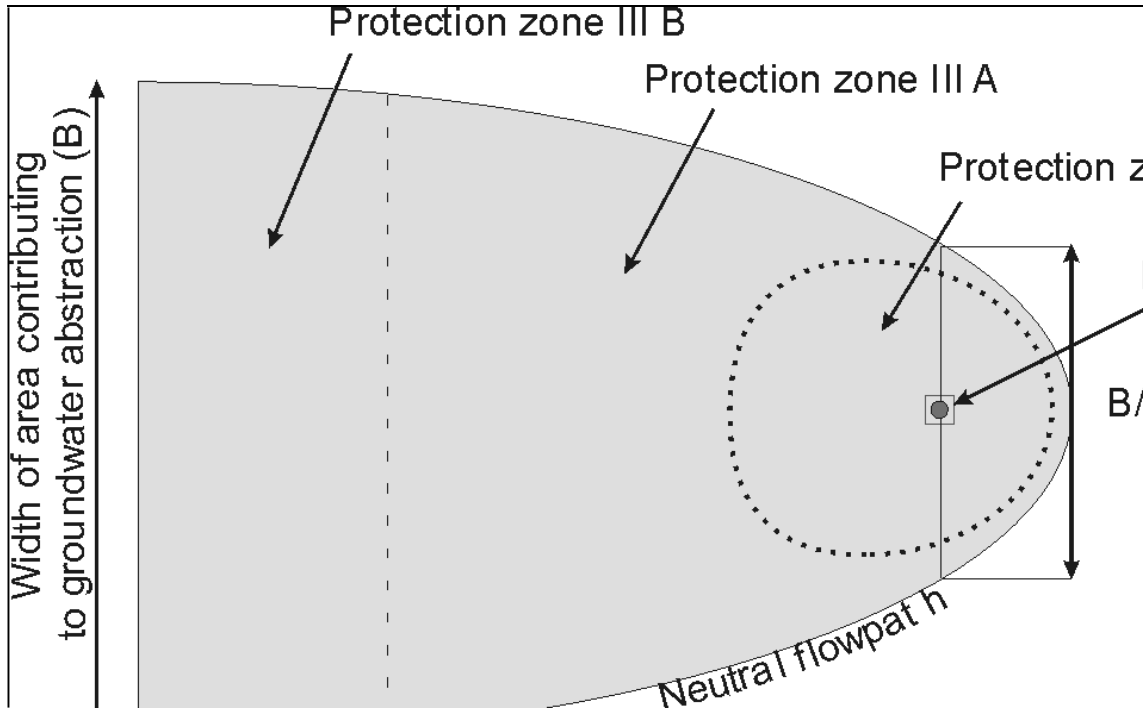
The establishment of groundwater protection zones was enacted in Germany already in 1957 in the frame of the German Water Act (§ 19 Wasserhaushaltsgesetz). Apart from this national law, every German state has commonly established its own more detailed water law. Regulations for groundwater protection have been issued by the DVGW and by the individual states in different forms. The methodology used for the delineation process and the definition of the zones is more or less the same in all states.

In general, it is distinguished between three different zones:

Zone I – The immediate protection zone is defined by a distance of at least 10 m from the water well, not less than 20 m in the upstream direction of a spring and at least 30 m in the case of a karst aquifer. It provides against direct contamination at the well itself.

Zone II – The inner protection zone is defined by the 50-day isochrone but has to be not less than 100 m from the well or spring. It provides against contamination particularly from pathogenic microbiological constituents and from other contamination which may be hazardous.

Zone III – The outer protection zone encompasses the entire contribution zone of the groundwater catchment area (may be subdivided into zones III A and IIIB, see below). It provides protection against contamination affecting water over long distances such as radioactive substances or chemicals which are not or not easily degraded.



German Zoning System

For the delineation of the 50-day isochrone (i.e. the outer boundary of zone II), the German guideline W 101 specifically names the use of hydraulic models as standard method. The determination of this boundary has to be based on the average daily discharge rate or the maximum daily discharge rate. The extension of Zone II upstream from the well should be in no case less than 100 m or 50 m in cases where circumstances warrant such a decision.

Zone III may be subdivided into sub-zones III A and III B. In case of porous rock aquifers with groundwater flow velocities of less than 10 m/day, the boundary between Zone III A and III B should be located approximately 2 km upstream of the well. Distance should be greater if flow velocities are higher.

**Switzerland**

The delineation of groundwater protection zones as well as a number of other measures aiming at the protection of surface and groundwater resources are laid down in the Water Protection Act (Gewässerschutzgesetz, 1991) and the Water Protection Ordinance (Gewässerschutzverordnung, 1998). The Guidance for Groundwater Protection defines the process of protection zone delineation.

Whereas the federal government is responsible for the federal laws and regulations, the districts (Kantone) are responsible for the issuance of the ordinance and the implementation of restrictions and permissions. However, the owner (municipalities or companies) of the water supply facility is responsible for conducting the required hydrogeological study, for paying for the administrative procedure and for paying compensations.

The Zoning System:

- In general, the guidance distinguishes different levels of protection of groundwater by defining

- Endangered areas where a protection is required for safeguarding exploitable groundwater resources (Gewässerschutzbereich Au, if of relevant extractable amount and fulfilling quality standards),
- Endangered areas where Protection zones for groundwater quality restoration have to be established because water abstraction facilities are already affected by pollution (Zuströmbereich Zu).
- Conservation areas (Grundwasserschutzareale) for the protection of important groundwater resources, which are presently not being used as drinking water resources but might be in the future.
- Protection zones S1, S2 and S3 (Grundwasserschutzzonen) for the protection of existing water abstraction facilities used for domestic water supply,
- Other areas with no or exploitable groundwater resources of little importance. Here few restrictions for human activities are required.

Three elements are necessary for the administrative procedure to issue a groundwater protection zone ordinance: a hydrogeological report, a protection zone plan and a protection zone rule. What is required from hydrogeological reports has to be justified by the level of potential pollution threat. The protection zone plan shows the boundaries of the zones S1, S2 and S3 as they were determined by hydrogeological investigations (hydrogeological boundaries) and the practical boundaries, following natural boundaries or boundaries of landownership.

The groundwater protection zones are (except for karst aquifers):

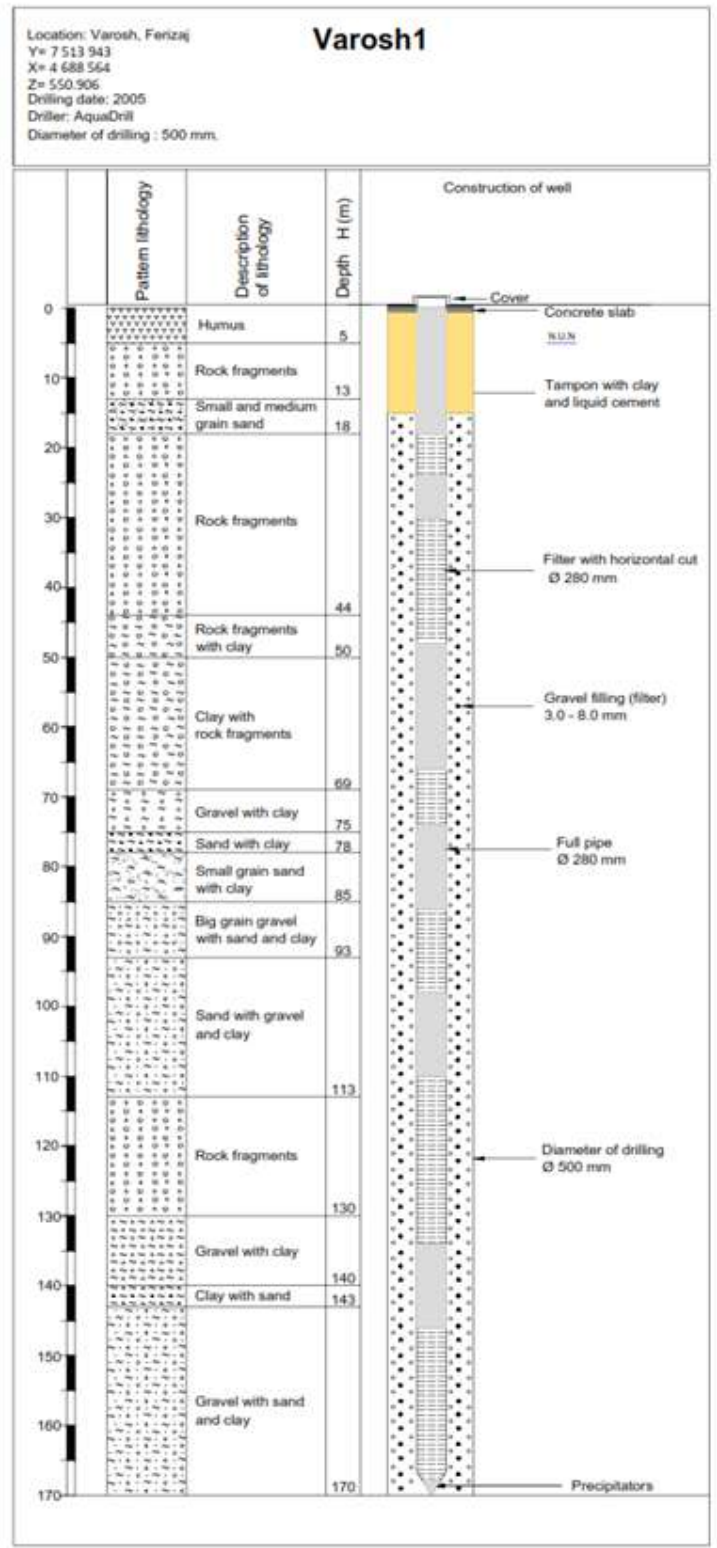
Zone S1 – The immediate protection zone is defined by a distance of at least 10 m from the water well. In the case of spring captures using drainage tubes, a distance of 10 m should be maintained from the entire drainage tube. The area should be protected by a fence.

Zone S2 – The inner protection zone, defined by the 10-day travel time in the saturated zone of the aquifer,

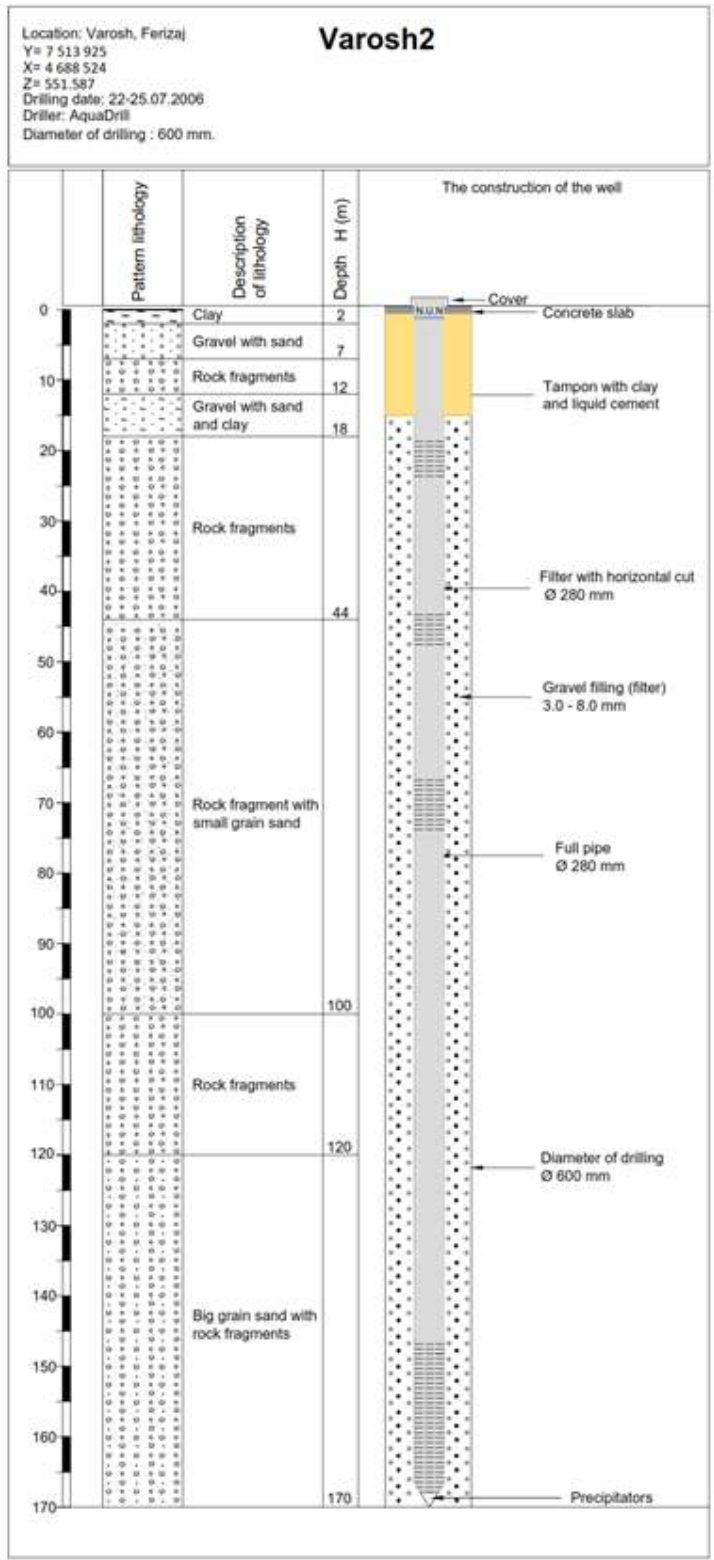
Zone S3 – The outer protection zone encompasses a zone where, in the case of unconsolidated rocks, the distance from the outer boundaries of zones S2 to S3 is at least as large as the distance from the outer boundaries of zones S1 to S2.

For the delineation of the extent of zone S2 the daily maximum allowable water abstraction (according to the abstraction license) and low water level conditions have to be used. The average flow velocity is considered as representative flow velocity for determining travel times. The distance from the outer boundary of zone S1 to the outer boundary of zone S2 has to be at least 100 m.

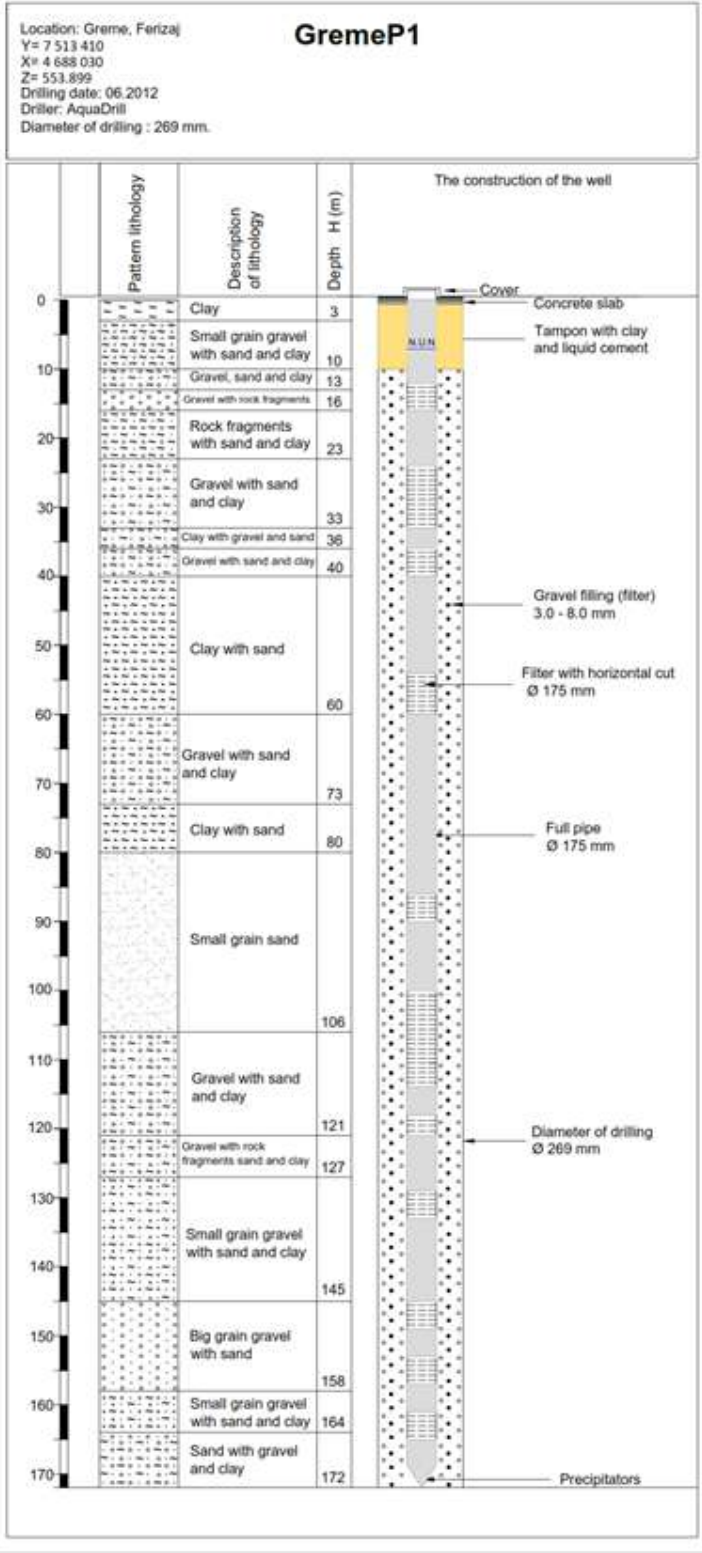
### Annex 3: Log wells at Ferizaj Wellfield



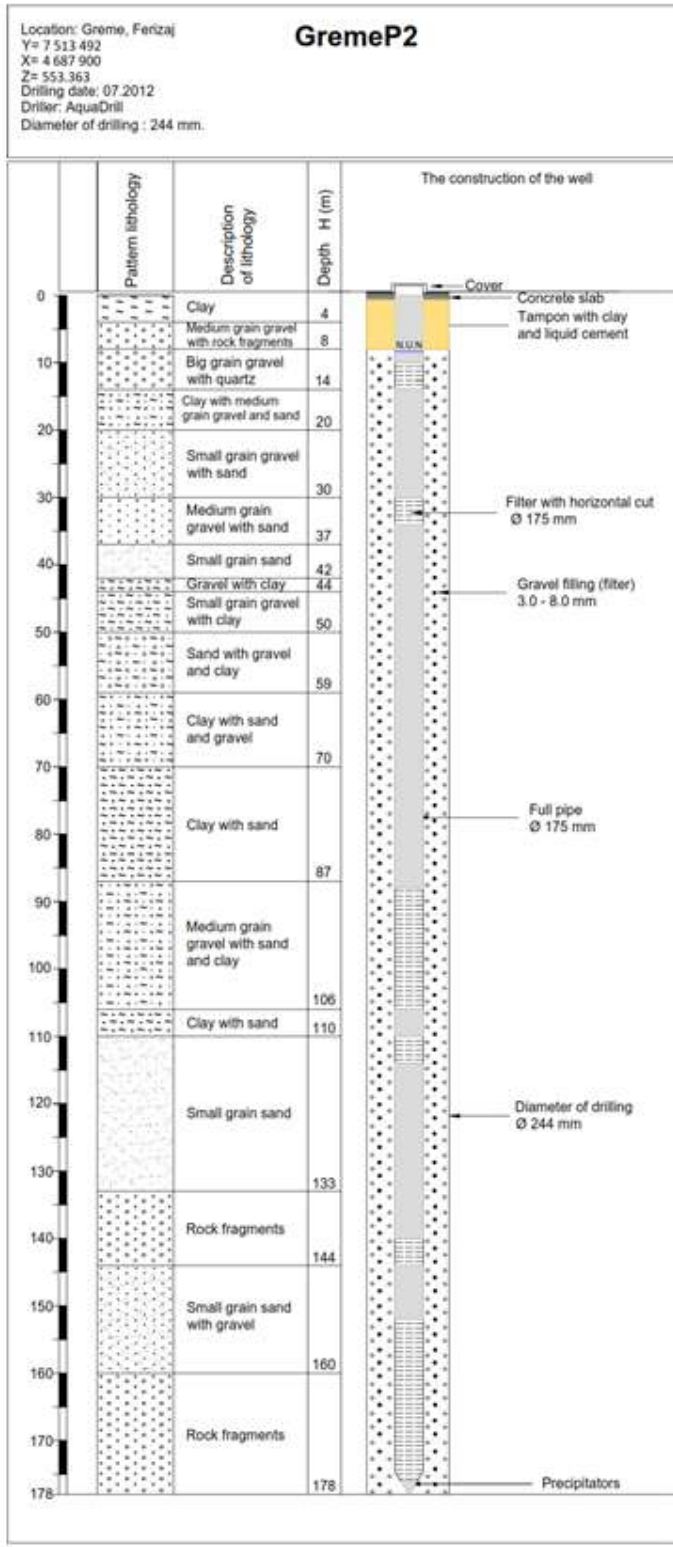
Profile of Varosh 1



Profile of Varosh 2.



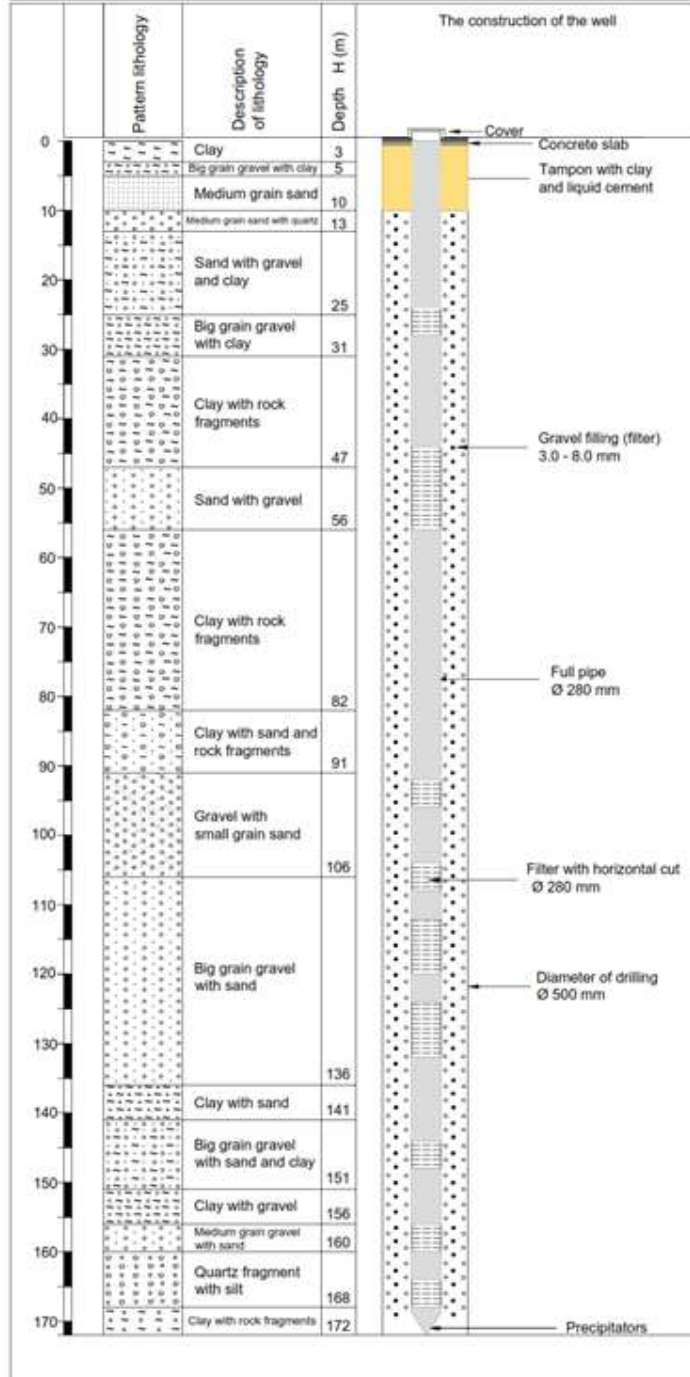
Profile of Greme P1



Profile of Greme P2

Location: Greme, Ferizaj  
 Y= 7 513 410  
 X= 4 688 030  
 Z= 553.899  
 Drilling date: 05.2013  
 Driller: AquaDrill  
 Diameter of drilling : 500 mm.

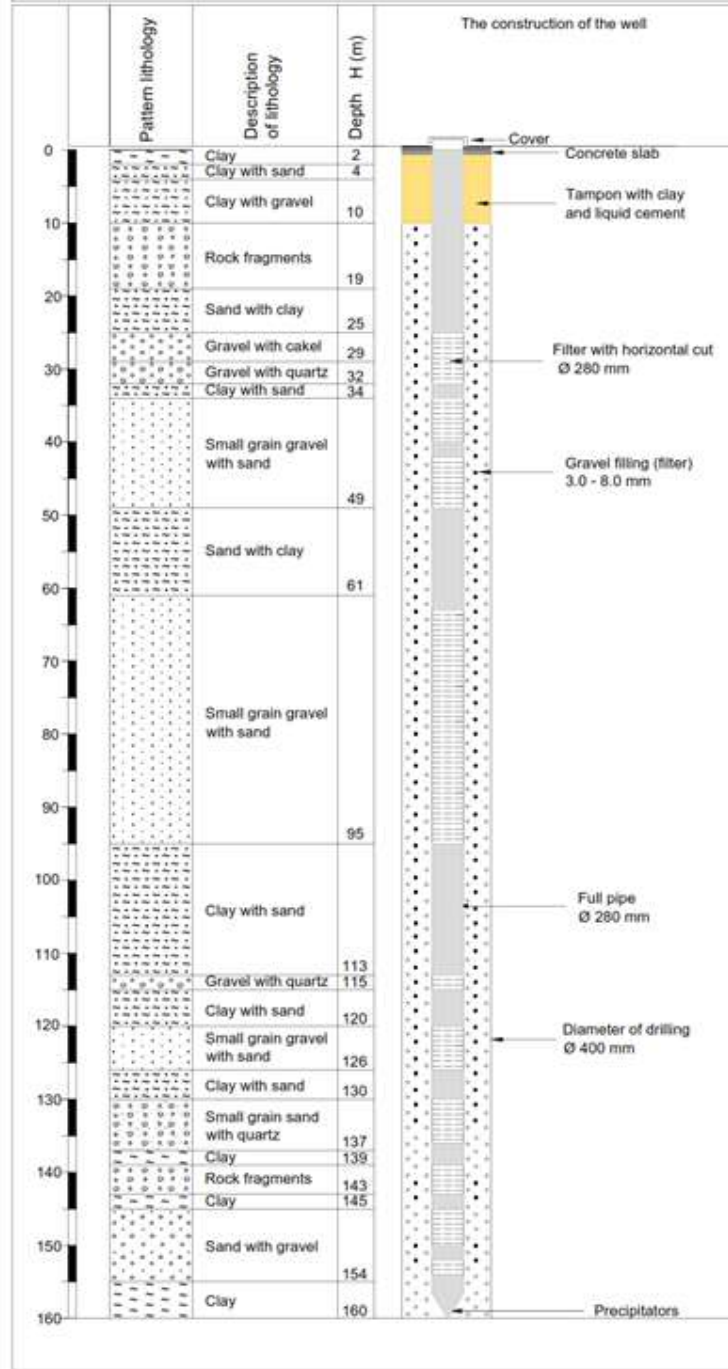
## Greme1



Profile of Greme 1

Location: Begrace, Ferizaj  
 Y= 7 517 796  
 X= 4 683 638  
 Z= 544,281  
 Drilling date: 07.2009  
 Driller: AquaDrill  
 Diameter of drilling : 400 mm.

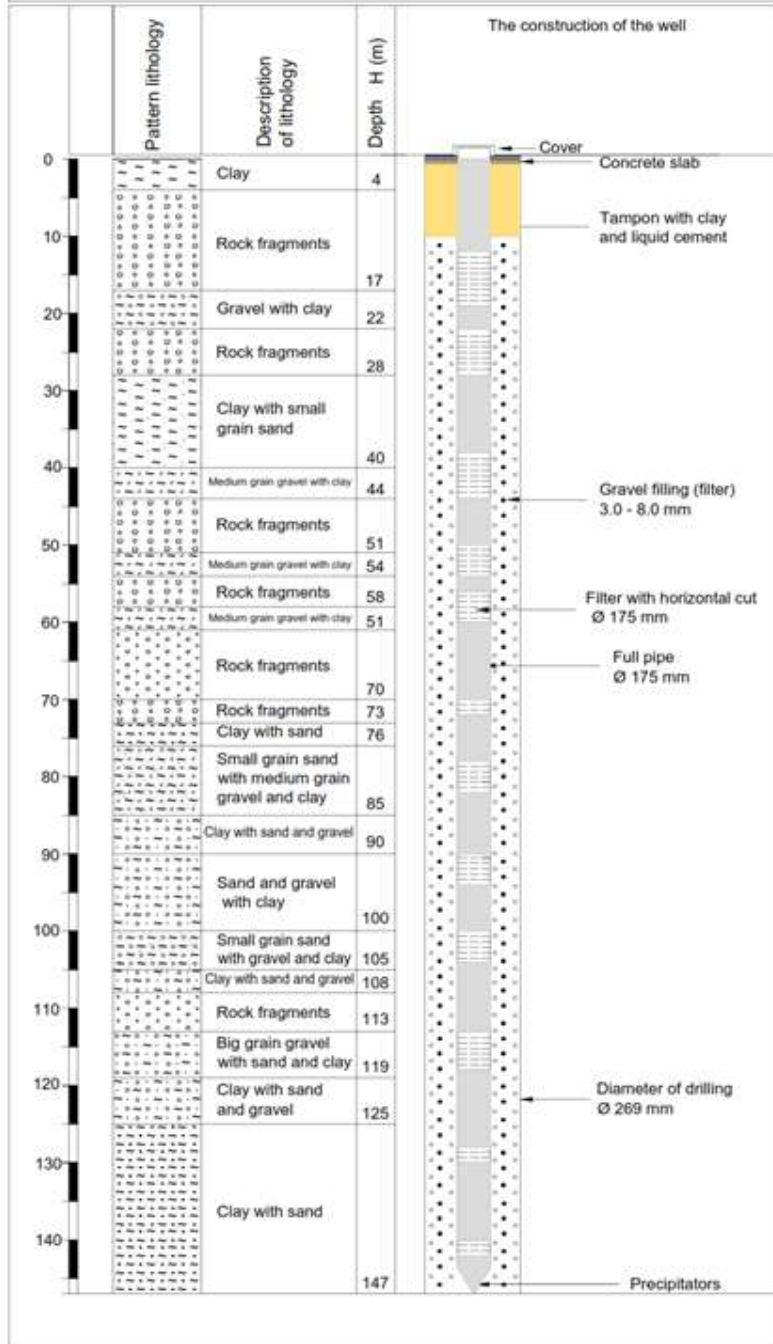
# Begrace1



Profile of Begrace 1

Location: Begrace, Ferizaj  
 Y= 7 517 803  
 X= 4 683 674  
 Z= 544.071  
 Drilling date: 07.2008  
 Driller: AquaDrill  
 Diameter of drilling : 269 mm.

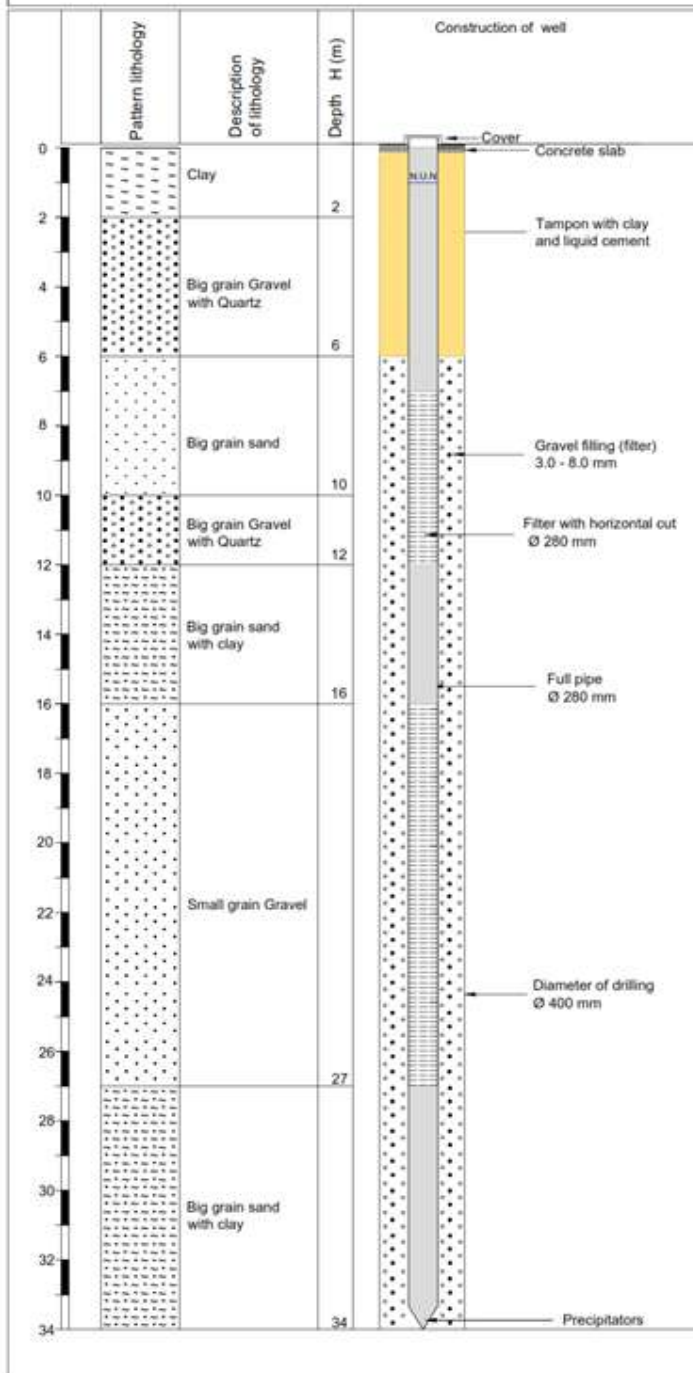
## Begrace2



Profile of Begrace 2

Location: Gerlice, Ferizaj  
 Y= 7 516 649  
 X= 4 685 869  
 Z= 530.982  
 Drilling date: 11.2008  
 Driller: AquaDrill  
 Diameter of drilling : 400 mm.

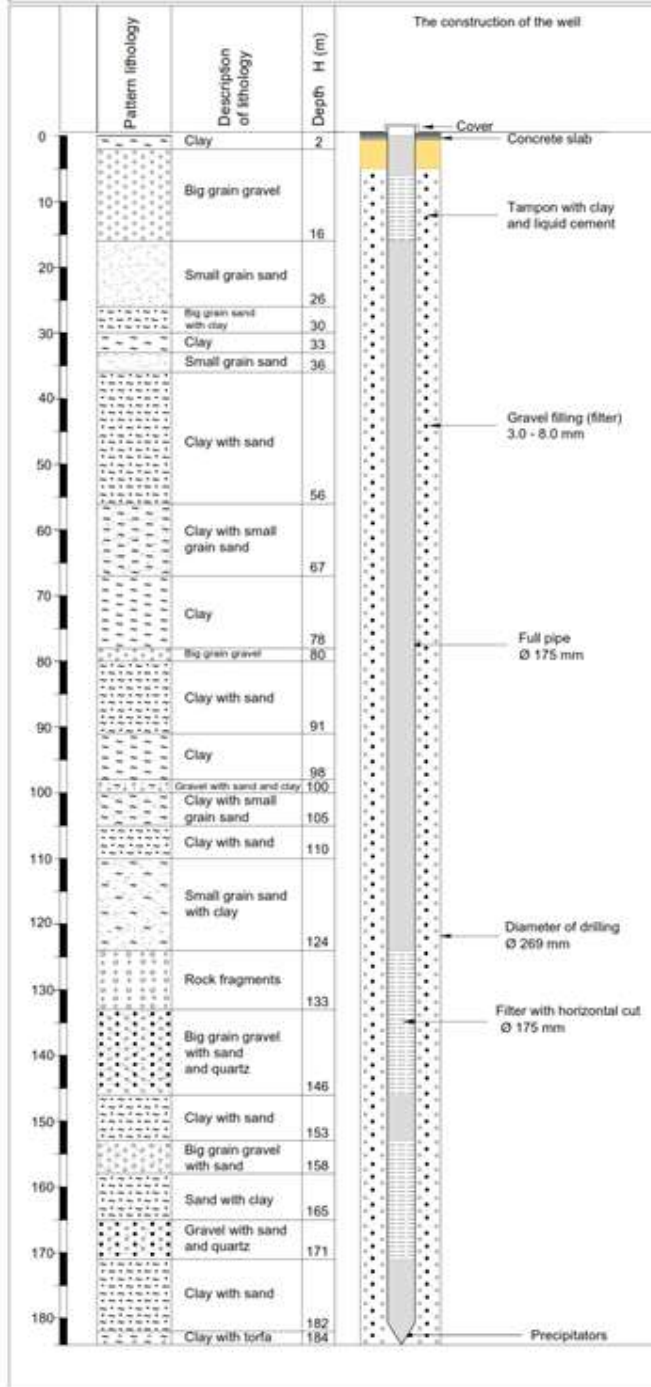
# Gerlice1



Profile of Gerlice 1

Location: Gerlice, Ferizaj  
 Y= 7 516.607  
 X= 4 685.810  
 Z= 530.842  
 Drilling date: 05.2008  
 Driller: AquaDrill  
 Diameter of drilling : 269 mm.

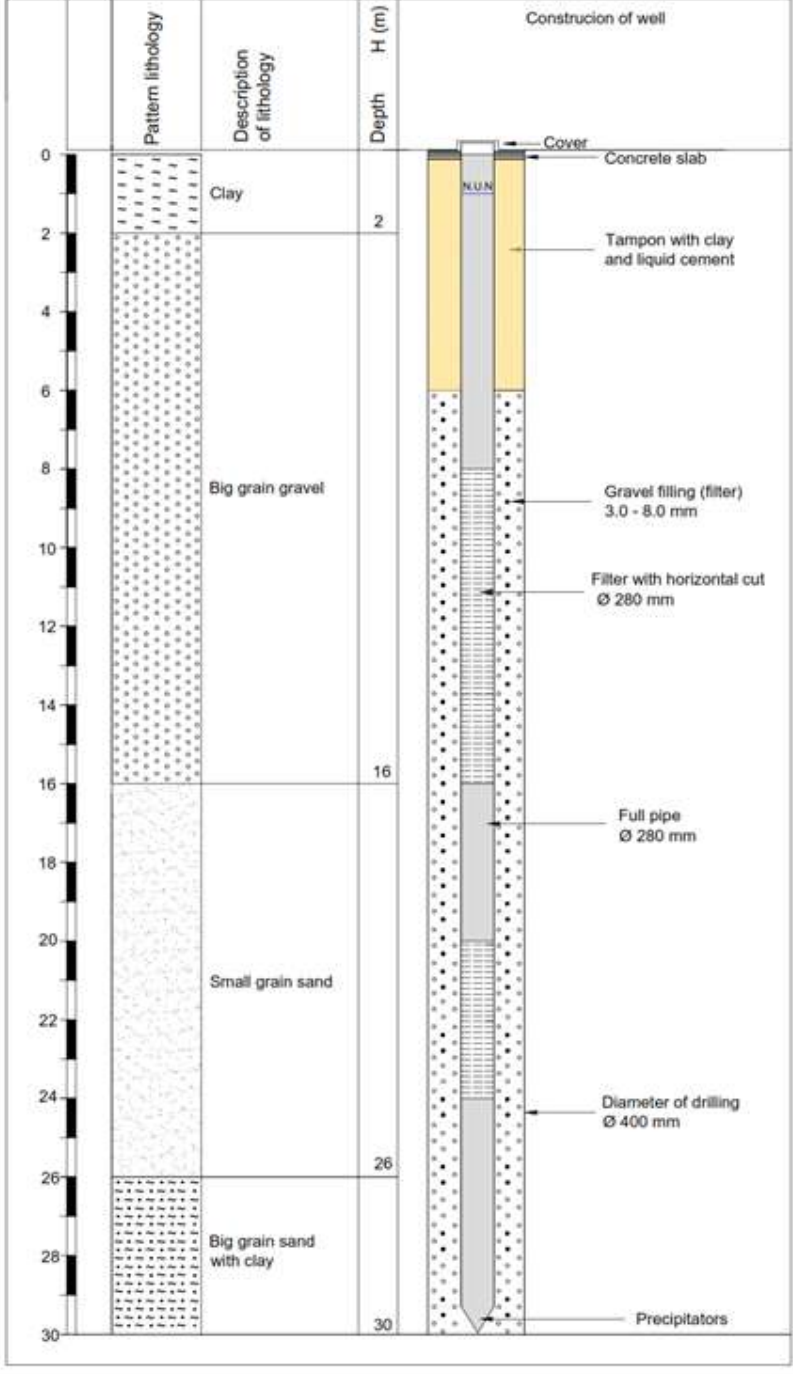
## Gerlice2



Profile of Gerlice 2

Location: Gerlice, Ferizaj  
 Y= 7 516 602  
 X= 4 685 818  
 Z= 531.035  
 Driller date: 11.2008  
 Driller: AquaDrill  
 Diameter of drilling : 400 mm.

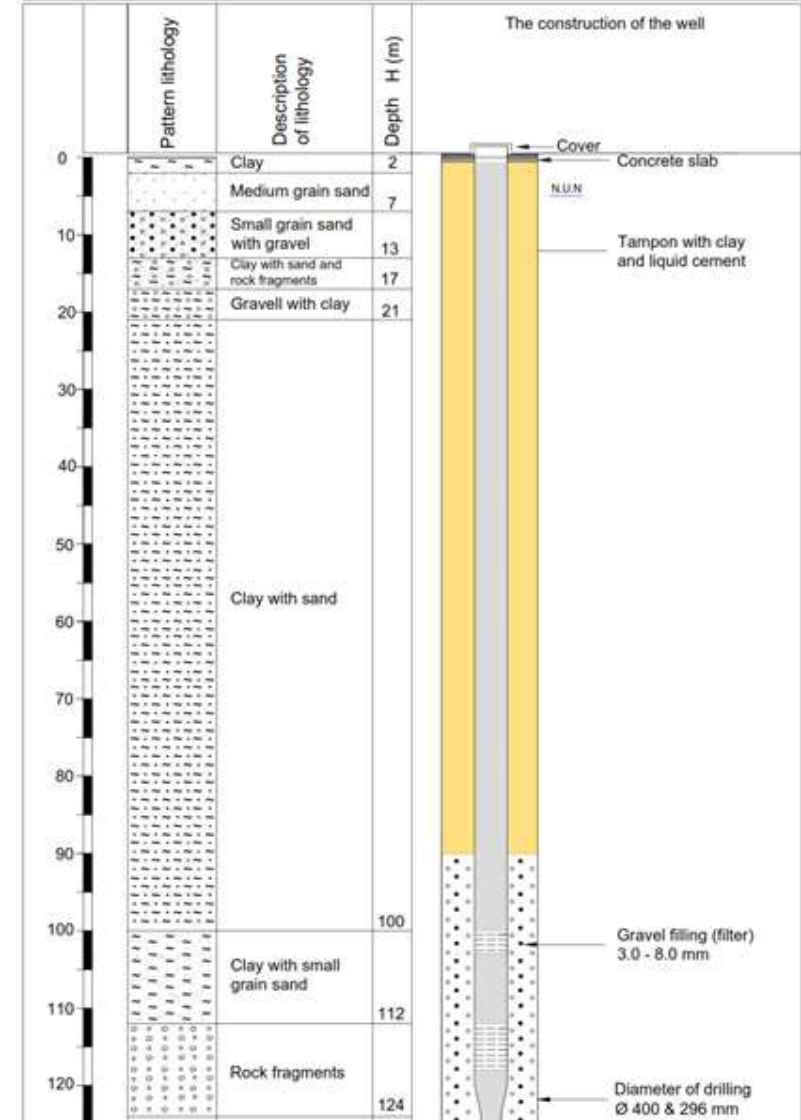
### Gerlice3

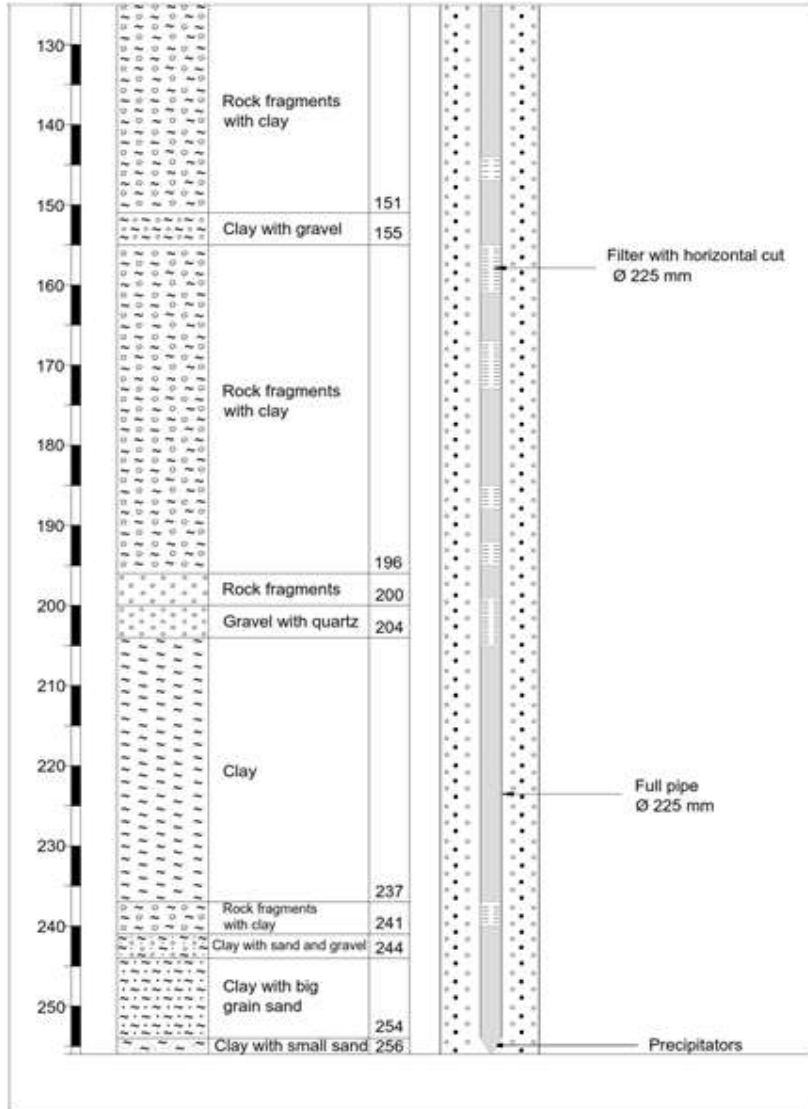


Profile of Gerlice 3

Location: Gerlice, Ferizaj  
 Y= 7 516 536  
 X= 4 685 983  
 Z= 531.932  
 Drilling date: 05.2009  
 Driller: AquaDrill  
 Diameter of drilling : 400/296 mm.

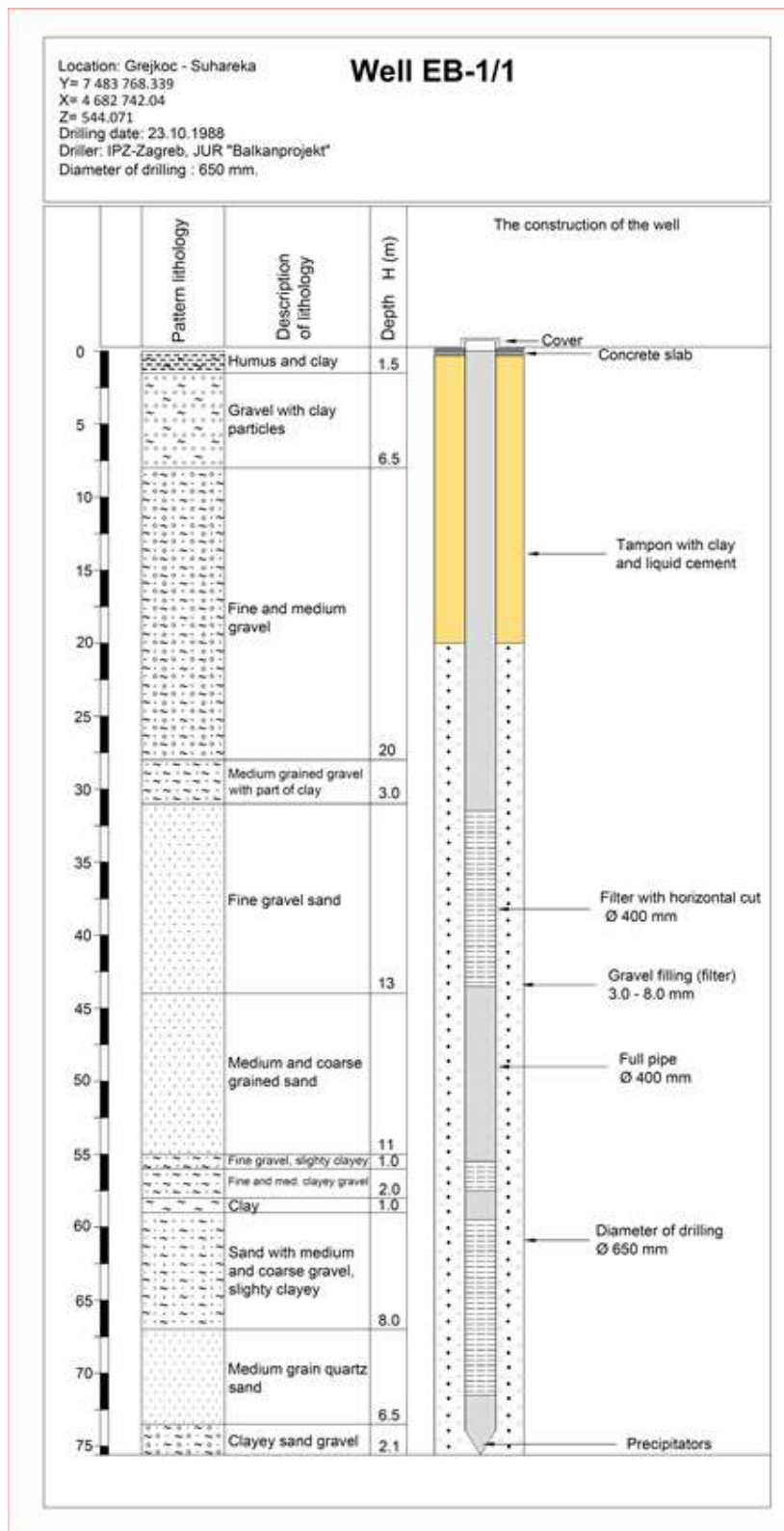
## Gerlice4





Profile of Gerlice 4

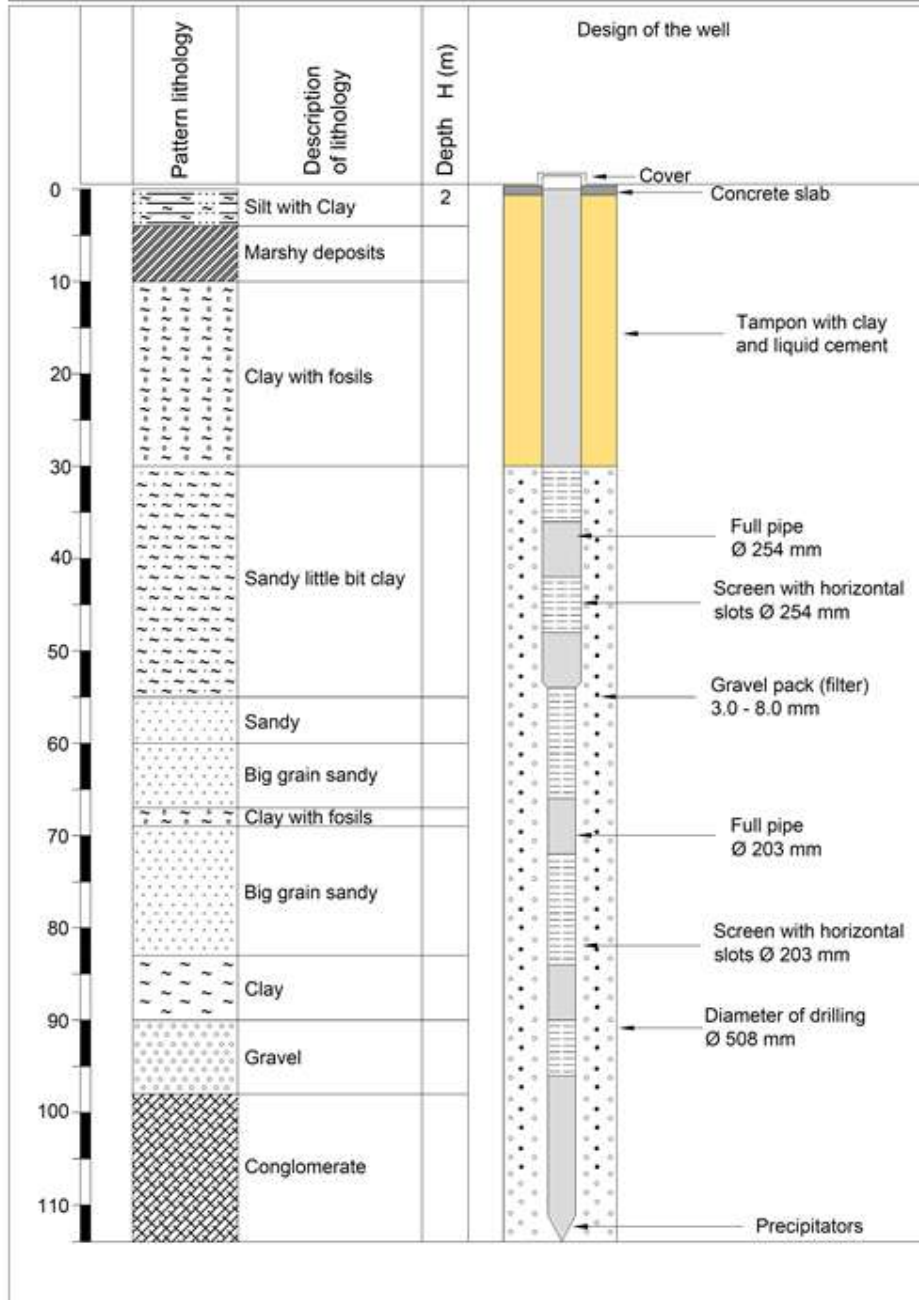
## Annex 4: Log wells at Ferizaj Wellfield



Profile of well EB-1/1

Location: Grejkoc, Suhareka  
 Y= 7 513 925  
 X= 4 688 524  
 Z= 551.587  
 Drilling date: 09-2010  
 Driller: SOAL  
 Diameter of drilling : 508 mm.

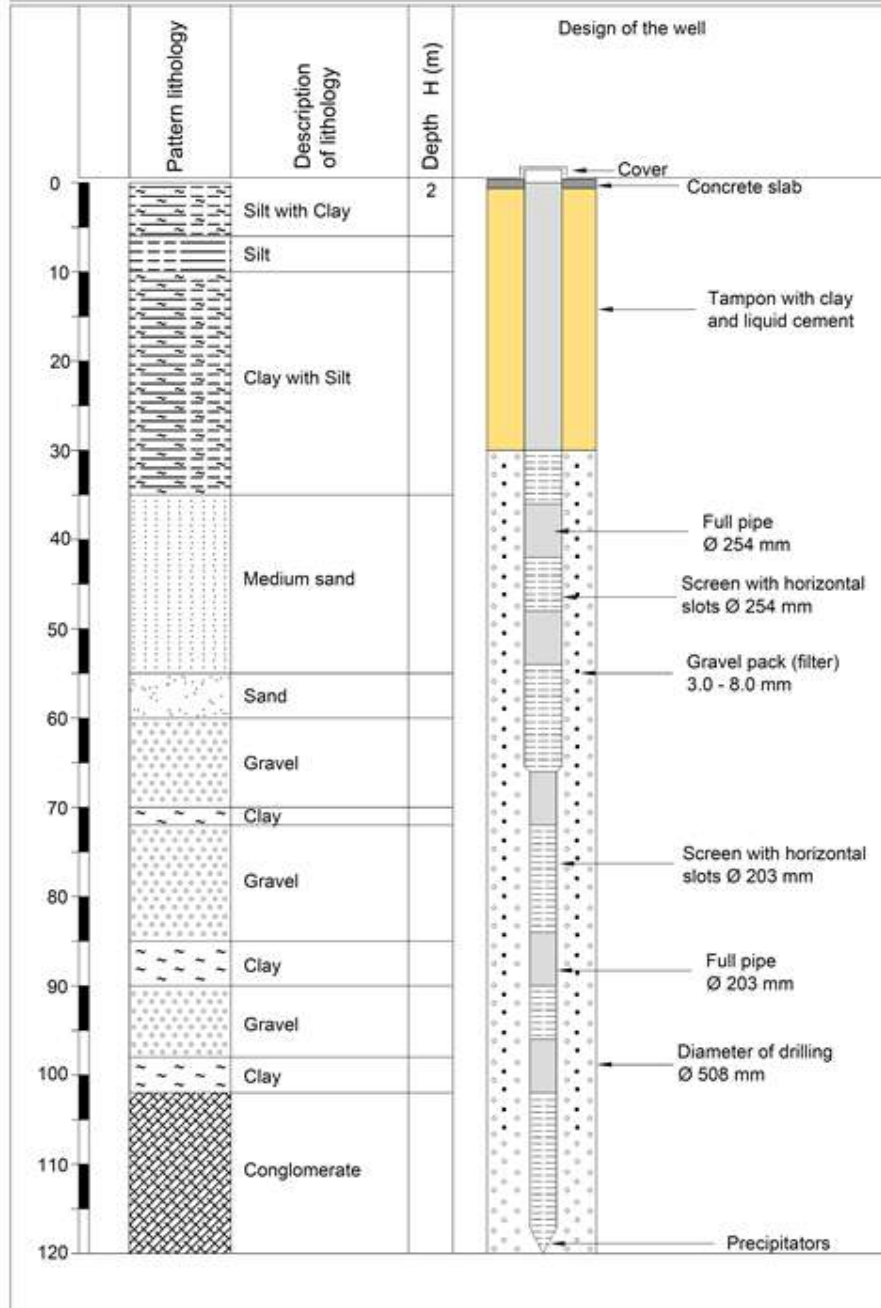
## Well 5



Profile of Well

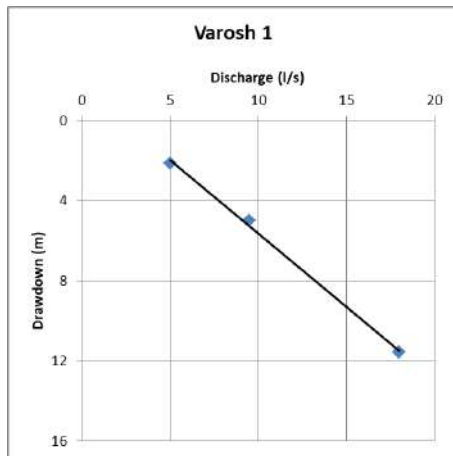
Location: Grejkoc, Suhareka  
 Y= 7 513 925  
 X= 4 688 524  
 Z= 551.587  
 Drilling date: 10-2010  
 Driller: SOAL  
 Diameter of drilling : 508 mm.

## Well 6

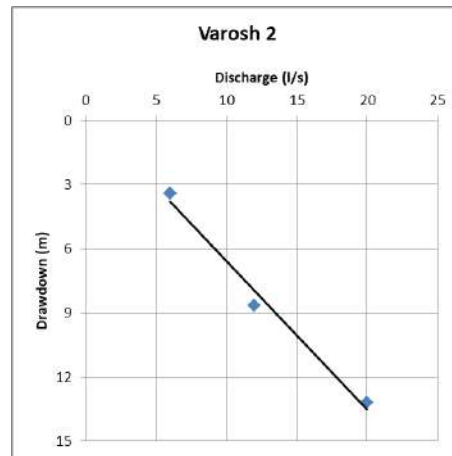


Profile of Well 6

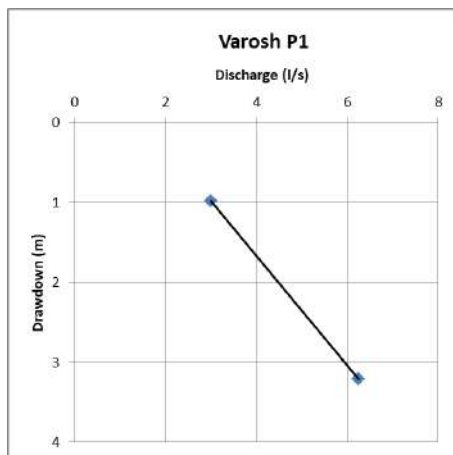
## Annex 5: Specific drawdown of production wells at Ferizaj Wellfield



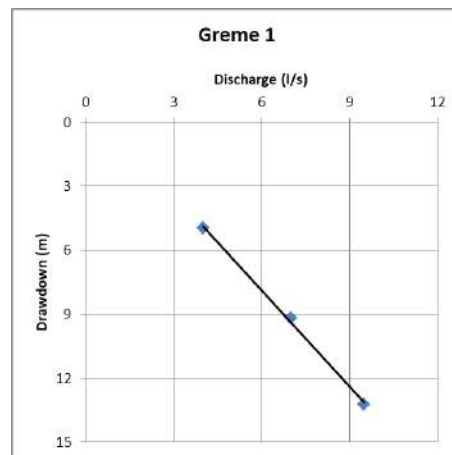
Specific Drawdown of Varosh 1



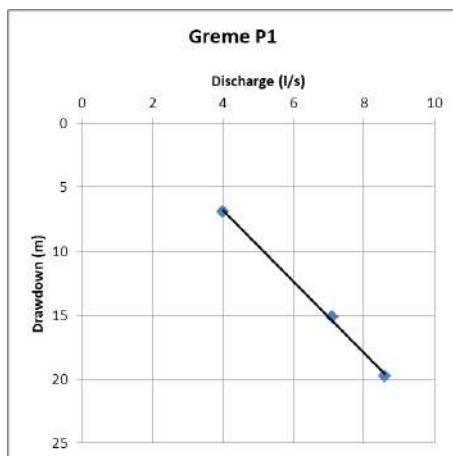
Specific Drawdown of Varosh 2



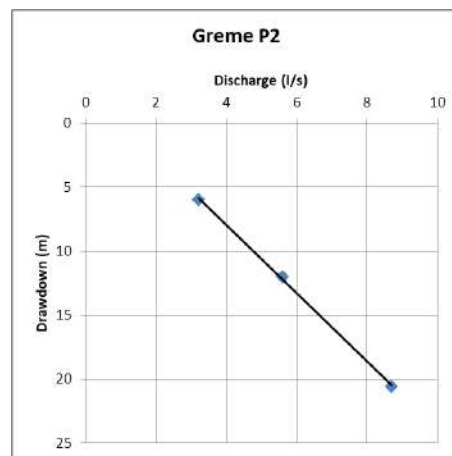
Specific Drawdown of Varosh P1



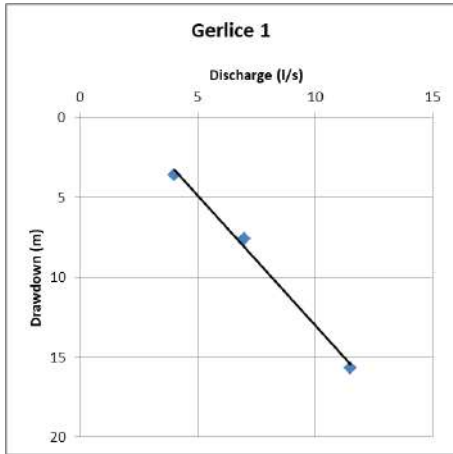
Specific Drawdown of Greme 1



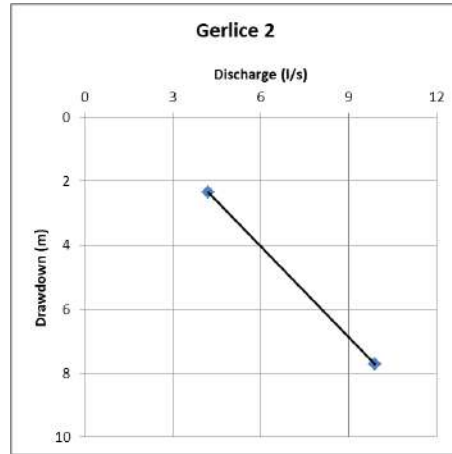
Specific Drawdown of Greme P1



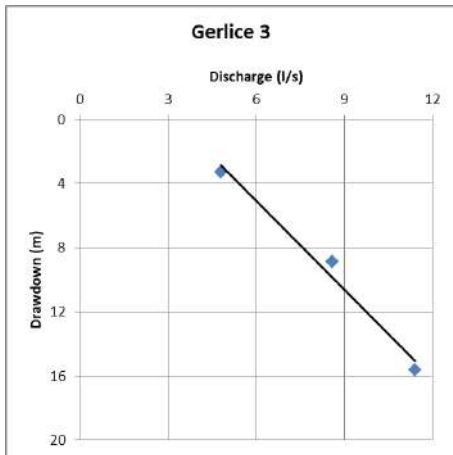
Specific Drawdown of Greme P2



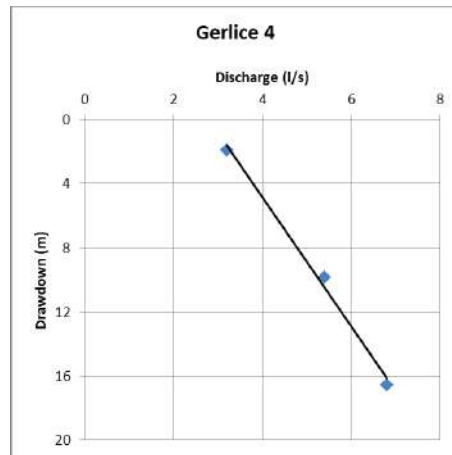
Specific Drawdown of Gerlice 1



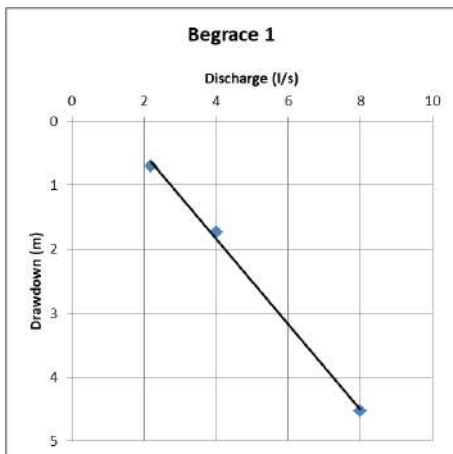
Specific Drawdown of Gerlice 2



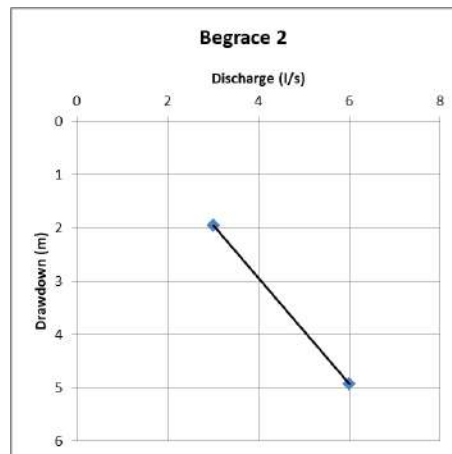
Specific Drawdown of Gerlice 3



Specific Drawdown of Gerlice 4



Specific Drawdown of Begrace 1



Specific Drawdown of Begrace 2

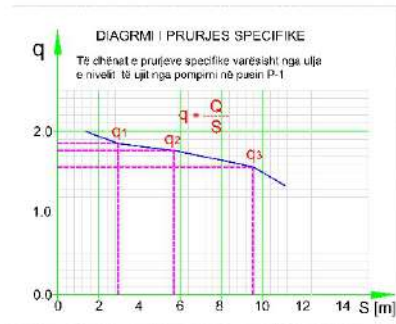
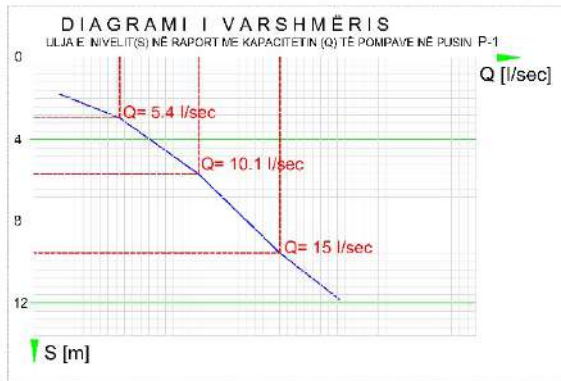
## Annex 6: Inventory of observation wells and water levels at Ferizaj Wellfield

Name	X	Y	Elevation m asl.	Water Level m asl.	Water Level m bgl.	Date
VaroshP8	7514202	4688570	550.06	547.86	2.20	8-May-19
VaroshP11	7514994	4688721	546.03	540.22	5.81	8-May-19
VaroshP12	7514428	4688036	547.99	545.97	2.02	8-May-19
VaroshP14	7514627	4687684	545.35	543.44	1.91	8-May-19
VaroshP22	7514707	4689047	547.56	544.10	3.46	8-May-19
VaroshP26	7515430	4689095	562.85	561.75	1.10	10-May-19
VaroshP31	7515275	4688151	542.97	540.87	2.10	10-May-19
VaroshP34	7514438	4689690	558.55	554.92	3.63	10-May-19
VaroshP36	7514127	4689980	557.84	554.73	3.11	10-May-19
FerizajP1	7512794	4690504	562.75	560.01	2.74	11-May-19
GremeP3	7512113	4688248	576.91	570.71	6.20	11-May-19
GremeP4	7512422	4687728	585.52	572.97	12.55	11-May-19
GremeP6	7512861	4688011	562.45	560.98	1.47	11-May-19
GremeP7	7513347	4688875	556.68	554.05	2.63	11-May-19
IliriasP1	7511072	4689491	592.93	583.33	9.60	11-May-19
DoganajP2	7512226	4689260	575.68	564.93	10.75	11-May-19
DoganajP4	7513173	4689342	557.67	555.32	2.35	11-May-19
NikadinP4	7514488	4690824	570.75	566.50	4.25	14-May-19
Fshati I VjeterP3	7515536	4690596	564.96	562.93	2.03	14-May-19
Gerlic P1	7517020	4686576	540.12	534.86	5.26	14-May-19
Gerlic P2	7516806	4686944	543.20	538.45	4.75	14-May-19
VaroshP40	7515827	4687833	540.64	539.04	1.60	14-May-19
KomogllaveP7	7517619	4688055	562.39	553.86	8.53	16-May-19
GerliceP5	7517532	4685586	530.90	528.45	2.45	16-May-19
Kaqanik I VjeterP1	7518116	4683125	542.05	533.83	8.22	16-May-19
Kaqanik I VjeterP2	7518319	4682397	550.57	529.87	20.70	16-May-19
GremeP9	7512574	4686779	595.24	581.37	13.87	17-May-19
GremeP10	7513471	4687346	562.30	552.42	9.88	17-May-19
GremeP11	7513964	4687368	549.80	547.90	1.90	17-May-19
GremeP12	7513172	4686842	567.67	562.14	5.53	17-May-19
GremeP15	7514218	4686447	549.51	546.91	2.60	17-May-19
GremeP17	7515611	4686017	541.23	535.28	5.95	17-May-19
GremeP18	7514839	4685584	549.88	547.24	2.64	17-May-19
GaqkëP1	7513904	4684816	565.37	564.43	0.94	17-May-19
GaqkëP2	7514249	4684101	573.63	567.26	6.37	17-May-19
RakajP4	7515833	4684628	546.57	543.69	2.88	17-May-19
RakajP5	7516645	4685192	537.21	531.24	5.97	17-May-19
RakajP6	7517113	4684111	538.69	533.34	5.35	17-May-19
KogjajP3	7516894	4682530	565.75	536.30	29.45	18-May-19
KogjajP5	7515540	4682674	579.84	555.77	24.07	18-May-19
VaroshP2	7514107	4688738	550.83	548.45	2.38	18-May-19
VaroshP4	7513876	4687788	550.41	549.61	0.80	18-May-19
GremeP1	7513410	4688039	553.90	552.26	1.64	18-May-19
BegraceP1	7517840	4683785	543.26	532.69	10.57	18-May-19
BegraceP2	7517807	4683809	543.17	532.60	10.57	18-May-19
BegraceP3	7517658	4683922	542.53	534.28	8.25	18-May-19

Name	X	Y	Elevation m asl.	Water Level m asl.	Water Level m bgl.	Date
VaroshP1	7513949	4688579	551.24	544.34	6.90	18-May-19
RakajP2	7516087	4683395	556.16	551.56	4.60	17-May-19
RakajP1	7517139	4684758	535.13	530.03	5.10	16-May-19
Piezometer 1	7516543	4686332	533.18	531.53	1.65	20-May-19
Piezometer 2	7516386	4686264	533.28	531.88	1.40	20-May-19
varosh 1	7513943	4688564	550.91	542.91	8.00	20-May-19
varosh 2	7513925	4688524	551.59	548.29	3.30	20-May-19
gremel	7513410	4688030	553.90	548.93	4.97	20-May-19
gerlice 1	7516649	4685869	530.98	527.02	3.96	20-May-19
gerlice 2	7516607	4685810	530.84	528.99	1.85	20-May-19
begrace 1	7517796	4683638	544.28	532.72	11.56	20-May-19
begrace 2	7517803	4683674	544.07	531.13	12.94	20-May-19
Bibaj 1	7516294	4691904	572.17	564.17	8.00	21-Aug-19
Bibaj 2	7515002	4692050	571.37	565.57	5.80	21-Aug-19
Ferizaj2	7513918	4691683	577.63	567.88	9.75	21-Aug-19
Ferizaj3	7512530	4692140	580.28	573.60	6.68	21-Aug-19
Ferizaj4	7512138	4691107	570.01	566.49	3.52	21-Aug-19
Ferizaj5	7511852	4690232	568.62	564.12	4.50	21-Aug-19
Ferizaj6	7509546	4690580	601.72	595.42	6.30	21-Aug-19
KV1	7518965	4681585	542.48	529.23	13.25	21-Aug-19
KV2	7520424	4680520	586.58	569.18	17.40	21-Aug-19
KV3	7520714	4681306	513.54	510.54	3.00	21-Aug-19
KV4	7520194	4681361	535.27	516.04	19.23	21-Aug-19
KV5	7518323	4681046	568.94	528.10	40.84	21-Aug-19
KV6	7519072	4680501	526.87	518.04	8.83	21-Aug-19
KV7	7518912	4679355	521.29	513.86	7.43	21-Aug-19
KV8	7517770	4679474	574.18	571.70	2.48	21-Aug-19
KV9	7516746	4678762	641.80	637.23	4.57	21-Aug-19
KV10	7516409	4679214	667.94	658.56	9.38	21-Aug-19
KV11	7516449	4680269	556.52	556.05	0.47	21-Aug-19
KV12	7517298	4680388	539.96	536.56	3.40	21-Aug-19

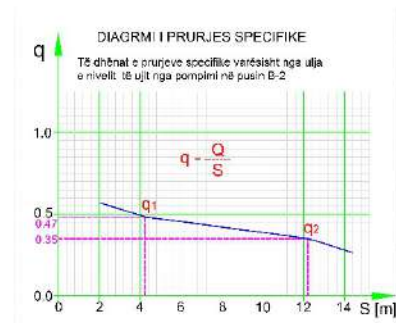
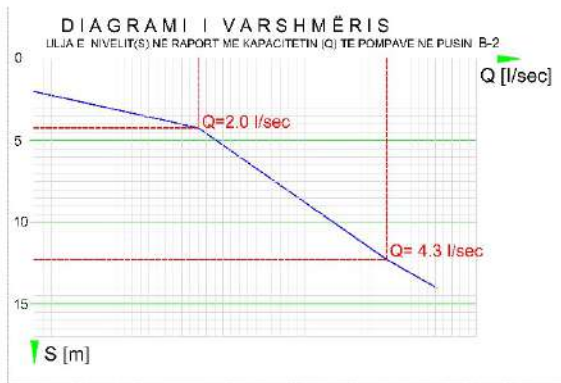
## Annex 7: Specific drawdown of production wells at Suhareka Wellfield

## PUSI P-1



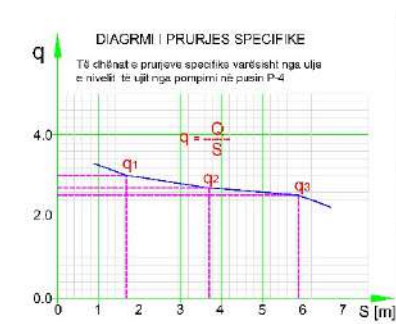
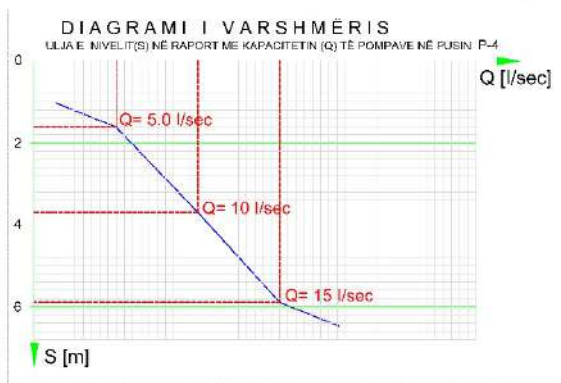
Specific Drawdown of Well 1

## PUSI B-2



Specific Drawdown of Well B-2

## PUSI P-4



Specific Drawdown of Well 4

## Annex 8: Inventory of observation wells and water levels at Suhareka Wellfield

Name	Gaus	Gaus	Elevation Gaus	NUN [m]	H [m]	WL [m]	GWL ASL
Pz-2	7483768.339	4682742.04	387.1087	14.42	0.3	14.12	372.9887

Grejkoc1	7483824.544	4683209.422	388.2427	2.88	0.7	2.18	386.0627
Grejkoc2	7484354.181	4683529.44	398.2607	4.65	0.6	4.05	394.2107
Grejkoc3	7484708.655	4683701.401	403.3887	4	1.15	2.85	400.5387
Grejkoc4	7485259.83	4683125.766	417.8847	4.15	0.3	3.85	414.0347
Grejkoc5	7485724.391	4682640.031	450.9857	8.25	0.5	7.75	443.2357
Grejkoc6	7485437.107	4682487.869	440.9227	8.2	0.7	7.5	433.4227
Grejkoc9	7485997.998	4682680.429	463.6077	9.15	0.85	8.3	455.3077
Grejkoc13	7486958.937	4683127.991	472.3857	7.77	0.85	6.92	465.4657
Grejkoc14	7486533.847	4683708.157	449.2247	7.47	0.8	6.67	442.5547
Grejkoc15	7485987.944	4683242.379	440.1487	5.84	0.8	5.04	435.1087
Grejkoc16	7485895.264	4682842.912	451.8207	5.02	0.7	4.32	447.5007
Leshan 1	7483654.183	4686799.887	386.3017	2.05	0.35	1.7	384.6017
Leshan 2	7482836.267	4686910.829	376.9327	4.15	0.95	3.2	373.7327
Leshan10	7481850.293	4687232.638	365.4507	4.1	0.85	3.25	362.2007
Ta3	7480854.322	4687303.945	359.8827	10.36	0.55	9.81	350.0727
Ta4	7481284.16	4687322.085	359.5877	3.45	0.3	3.15	356.4377
Gelance1	7483772.092	4684463.487	393.7157	1.8	0.3	1.5	392.2157
Gelance2	7483335.476	4684200.811	387.5127	4.6	0.7	3.9	383.6127
Gelance3	7482904.409	4684051.353	383.8307	7.72	0.8	6.92	376.9107
Gelance4	7482646.919	4683900.911	373.5677	4.55	0.7	3.85	369.7177
Gelance5	7482528.84	4683015.227	379.2187	3.23	0.8	2.43	376.7887
Gelance6	7482304.774	4683219.268	373.2777	5	0	5	368.2777
Gelance7	7483408.693	4684026.216	385.7897	3.33	0.9	2.43	383.3597
Gelance8	7483166.648	4683767.506	380.5267	3.22	0.85	2.37	378.1567
Gelance9	7482920.486	4683710.045	376.2757	5.23	0.8	4.43	371.8457
Gelance10	7482823.852	4683168.891	372.8317	2.3	0.3	2	370.8317
Gelance11	7483568.798	4683427.204	387.2687	2.45	0.2	2.25	385.0187
MR1	7483622.156	4682324.623	400.2537	6.2	0.5	5.7	394.5537
MR2	7483861.425	4681873.213	405.0277	3.2	0.9	2.3	402.7277
MR3	7483618.211	4681777.115	407.5107	6.1	0.8	5.3	402.2107
MR4	7483684.894	4681497.501	414.0317	11.2	0.85	10.35	403.6817
MR5	7483222.762	4681417.894	412.3387	10.8	0.6	10.2	402.1387
MR6	7483118.686	4682070.286	400.0777	2.85	0.8	2.05	398.0277
MR7	7482874.016	4681450.885	409.4797	7.9	0.8	7.1	402.3797
Lutogllave1	7482541.481	4681691.797	402.4077	4.62	0.85	3.77	398.6377
Caparce1	7481704.29	4681781.498	388.7437	Vderdhje	0	0	388.7437
Caparce2	7481520.104	4682384.876	377.9657	2.65	0.9	1.75	376.2157
Caparce3	7481297.195	4682387.634	376.2377	3.4	0.15	3.25	372.9877
Caparce4	7480805.804	4683186.672	361.8797	3.98	0.8	3.18	358.6997
Caparce5	7481426.552	4683184.006	368.0917	4.05	0.75	3.3	364.7917
Topliqan1	7484401.953	4686710.492	411.7207	13.83	0.85	12.98	398.7407
Topliqan2	7484463.87	4686337.723	411.7357	12.87	0.75	12.12	399.6157
Topliqan3	7484114.807	4685821.142	404.8797	5.55	0.75	4.8	400.0797
Topliqan4	7484292.217	4685270.721	407.8377	7.45	0.75	6.7	401.1377
Gjinovc1	7484789.348	4685824.401	413.2497	12.18	0.65	11.53	401.7197
Gjinovc2	7485372.111	4685944.924	424.5127	10.65	0	10.65	413.8627
Gjinovc3	7485040.829	4686455.826	416.2237	15.88	0.8	15.08	401.1437
Gjinovc4	7485506.729	4686410.736	434.3157	9.55	0.75	8.8	425.5157
Gjinovc5	7485837.901	4686516.585	438.4757	7.75	0.9	6.85	431.6257
Gjinovc6	7485968.158	4685581.865	436.1157	3.5	0.6	2.9	433.2157

Name	Gaus	Gaus	Elevation Gaus	H [m]	NUN [m]	WL [m]	GWL ASL
Pz-2	7483768.339	4682742.04	387.1087	0.3	22	21.7	365.4087
Grejkoc1	7483824.544	4683209.422	388.2427	0.7	2.7	2	386.2427
Grejkoc2	7484354.181	4683529.44	398.2607	0.6	3.8	3.2	395.0607
Grejkoc3	7484708.655	4683701.401	403.3887	1.15	3.4	2.25	401.1387
Grejkoc4	7485259.83	4683125.766	417.8847	0.3	3.4	3.1	414.7847
Grejkoc5	7485724.391	4682640.031	450.9857	0.5	7.2	6.7	444.2857

Grejkoc6	7485437.107	4682487.869	440.9227	0.7	7	6.3	434.6227
Grejkoc9	7485997.998	4682680.429	463.6077	0.85	8.15	7.3	456.3077
Grejkoc13	7486958.937	4683127.991	472.3857	0.85	9.4	8.55	463.8357
Grejkoc14	7486533.847	4683708.157	449.2247	0.8	7.5	6.7	442.5247
Grejkoc15	7485987.944	4683242.379	440.1487	0.8	4.55	3.75	436.3987
Grejkoc16	7485895.264	4682842.912	451.8207	0.7	5.32	4.62	447.2007
Leshan 1	7483654.183	4686799.887	386.3017	0.35	2.78	2.43	383.8717
Leshan 2	7482836.267	4686910.829	376.9327	0.95	4.32	3.37	373.5627
Leshan10	7481850.293	4687232.638	365.4507	0.85	4.1	3.25	362.2007
Ta3	7480854.322	4687303.945	359.8827	0.55	10.5	9.95	349.9327
Ta4	7481284.16	4687322.085	359.5877	0.3	3.45	3.15	356.4377
Gelance1	7483772.092	4684463.487	393.7157	0.3	1.54	1.24	392.4757
Gelance2	7483335.476	4684200.811	387.5127	0.7	4.7	4	383.5127
Gelance3	7482904.409	4684051.353	383.8307	0.8	7.6	6.8	377.0307
Gelance4	7482646.919	4683900.911	373.5677	0.7	3.86	3.16	370.4077
Gelance5	7482528.84	4683015.227	379.2187	0.8	3.5	2.7	376.5187
Gelance6	7482304.774	4683219.268	373.2777	0	6.32	6.32	366.9577
Gelance7	7483408.693	4684026.216	385.7897	0.9	3.22	2.32	383.4697
Gelance8	7483166.648	4683767.506	380.5267	0.85	3.22	2.37	378.1567
Gelance9	7482920.486	4683710.045	376.2757	0.8	5.25	4.45	371.8257
Gelance10	7482823.852	4683168.891	372.8317	0.3	2.22	1.92	370.9117
Gelance11	7483568.798	4683427.204	387.2687	0.2	2.15	1.95	385.3187
MR1	7483622.156	4682324.623	400.2537	0.5	6.25	5.75	394.5037
MR2	7483861.425	4681873.213	405.0277	0.9	2.55	1.65	403.3777
MR3	7483618.211	4681777.115	407.5107	0.8	4.9	4.1	403.4107
MR4	7483684.894	4681497.501	414.0317	0.85	9.65	8.8	405.2317
MR5	7483222.762	4681417.894	412.3387	0.6	8.47	7.87	404.4687
MR6	7483118.686	4682070.286	400.0777	0.8	3	2.2	397.8777
MR7	7482874.016	4681450.885	409.4797	0.8	5.95	5.15	404.3297
Lutogllavel	7482541.481	4681691.797	402.4077	0.85	3	2.15	400.2577
Caparce1	7481704.29	4681781.498	388.7437	0		0	388.7437
Caparce2	7481520.104	4682384.876	377.9657	0.9	2.62	1.72	376.2457
Caparce3	7481297.195	4682387.634	376.2377	0.15	3.32	3.17	373.0677
Caparce4	7480805.804	4683186.672	361.8797	0.8	3.9	3.1	358.7797
Caparce5	7481426.552	4683184.006	368.0917	0.75	4.18	3.43	364.6617
Topliqan1	7484401.953	4686710.492	411.7207	0.85	13.92	13.07	398.6507
Topliqan2	7484463.87	4686337.723	411.7357	0.75	12.98	12.23	399.5057
Topliqan3	7484114.807	4685821.142	404.8797	0.75	5.57	4.82	400.0597
Topliqan4	7484292.217	4685270.721	407.8377	0.75	7.55	6.8	401.0377
Gjinovc1	7484789.348	4685824.401	413.2497	0.65	12.08	11.43	401.8197
Gjinovc2	7485372.111	4685944.924	424.5127	0	10.7	10.7	413.8127
Gjinovc3	7485040.829	4686455.826	416.2237	0.8	16.08	15.28	400.9437
Gjinovc4	7485506.729	4686410.736	434.3157	0.75	9.62	8.87	425.4457
Gjinovc5	7485837.901	4686516.585	438.4757	0.9	7.9	7	431.4757
Gjinovc6	7485968.158	4685581.865	436.1157	0.6	3.7	3.1	433.0157

## **Annex 9: Pollution point sources at Ferizaj Wellfield**

### ***ID 1: Farm***

A farm with two hangars behind a fenced area has been identified. No information on actual production and operations has been made available. A larger stock of manure at the northern border of the farm constitutes a potential harm to the groundwater. Manure cannot be stored without a proofed underground cover and a secured collection of all effluents. Further information on the operation of the farm has not been provided. However, due to the location inside the 500 meter line, commercial animal farming and stables for commercial livestock farming have to be excluded in case infiltration of excrement appears possible.

A work plan has to be developed with the owner. A re-location of the manure stocks and the eventual livestock outside the protection zone is advisable.



Farm (ID 1).

### ***ID: 2 Scrapyards next to the Auto-Service Luani***

At the northern end of Greme/Grebno, a garage including a car scrapyard was identified. The surface is paved, however, cannot be considered sealed. It remains unclear if a drainage system is installed and connected to a treatment system.

The scrapyard is of danger to groundwater and soil. Protective measures like a complete impermeable cover including a drainage system to a treatment unit is required.



Car scrapyard near Auto Service Luani (ID 2).

***ID 3: Meli Petrol Station***

The Meli petrol station at the road from Ferizaj/Uroševac to Greme/Grebno represents a risk for groundwater contamination (active since 2014). Petrol reservoirs below surface leakages at the filling point may lead to intrusion of fuel substance into the underground and into the aquifer. Potential protection measures and alternatives have to be developed and proposed to the owner.



Meli Petrol Station (ID 3).

***ID 4: Shabani Furniture Company***

Near Varosh/Varoš Selo, the Shabani furniture company is producing furniture on site. Furniture production in general comprises treatment with paints and wood protection chemicals. Most of such chemical are harmful to groundwater and cannot be tolerated in groundwater protection areas I; II and III.

Detailed investigation on the presence and use of such harmful substances and protective measures are recommended. The commercial activity needs to limit to activities according to the protection zone conditions.



Shabani furniture company (ID 4).

***ID 5: Scrapyards and garage Te Luta***

In Gërlicë/Grlica a car scrapyard covering around ¼ hectare filled with around 75 old cars inside the village is installed on a green area. Neither protection nor drainage system is installed, while engines are manipulated.

The scrapyards are of danger to groundwater and soil. Protective measures like a complete impermeable cover including a drainage system to a treatment unit is required.



Scrapyards and garage Te Luta (ID 5).

***ID 6: Innoil recycling station***

The Innoil Company south of Gërlicë/Grlica is recycling oil. Any oil handling or transformation for commercial activities is excluded in groundwater protection zones. The oil recycling is not permitted in water protection zones. The use of machines further presents a risk to the groundwater resource due to potential oil, petrol and or thinner leakages.

The site requires detailed investigation on real pollution risks, already occurred pollution and on potential protection measures.



Innoil recycling station (ID 6).

***ID 7: Garkko Recycling Company***

The Recycling Company Garkko Plasticas in the area of Gërlicë/Grlica is transforming plastic waste. No further details to the commercial activity are known about the processes on this site.



Garkko Recycling Company (ID 7).



Plastic material discovers outside Garkko Recycling.

ID 8 refers to the Nerodime River as described above!

***ID 9: Promoplast Company***

Promoplast is a plastic transforming company. The site wasn't inspected, external observations are provided. The company doesn't show any signs of pollutant materials storage or handling. Further investigation is required to exclude potential pollutant risk to groundwater.



Promoplast Company (ID 9).

***ID 10: Veda Petrol station***

A petrol station at the southward road at Gërlicë/Grlica represents a risk for groundwater contamination. Petrol reservoirs below surface and unsealed pavement at the filling point will lead to intrusion of fuel substance into the underground and into the aquifer. The site requires an investigation on the actual contamination (active since 2011 approximately). Potential protection measures and alternatives have to be developed and proposed to the owner.



Veda Petrol station (ID 10).

***ID 11: Petrol Station VEDA GENA market***

The Veda Gena petrol station at road south of Greme/Grebno represents a risk for groundwater contamination. Petrol reservoirs below surface and unsealed pavement at the filling point will lead to intrusion of fuel substance into the underground and into the aquifer. The site requires further investigation on the actual contamination. Potential protection measures and alternatives have to be developed and proposed to the owner.



Petrol Station VEDA GENA market (ID 11).

***ID 12: Nerodime River near Gërlicë/Grlica***

Close to the wells and the abandoned swimming bath, a bridge is crossing the Nerodime River. This site is used to dump all kind of waste into the riverbed. Obviously, waste is flushed away during high water, most probably during autumn and winter months. No identification of toxicity of the waste was possible during the site visits. However, water quality of the Nerodime River is obviously of bad quality (organoleptic and visual analysis).



Waste dump at the Nerodime river, close to Gerlice wells.



Domestic and commercial waste dump.

***ID 13 – Balkan Petrol Station***

A petrol station neighbouring the Begrace production wells represents a potential hazard to groundwater. Petrol reservoirs below surface may leak as well as spills and leakages at the filling point may lead to infiltration of fuel into the underground contaminating the aquifer. Potential protection measures and alternatives have to be developed and proposed to the owner.



Ballkan Petrol Station (ID 13).

***ID 14: Auto Color Vllezrit Osmani***

The Auto Color Vllezrit Osmani Company is handling and using toxic liquids (paint and thinner). Any handling or storing for commercial activities is excluded in groundwater protection zones. The handling of such toxic liquids is not permitted in water protection zones.

The site requires detailed investigation on real pollution risks, already occurred pollution and on potential protection measures.



Auto Color Vllezrit Osmani (ID 14).

***ID 15: Restaurant Evropa and Petrol Station***

The Evropa petrol station and restaurant at road running at the East of the production wells represent a risk for groundwater contamination. Petrol reservoirs below surface and unsealed pavement at the filling point will lead to intrusion of fuel substance into the underground and into the aquifer. The site requires urgent further investigation on installed reservoirs, pipes and on the actual contamination. Potential protection measures and alternatives have to be developed if possible and proposed to the owner. However, the proximity to the production wells most probably will lead to an exclusion of the activities of the petrol station.



Petrol Station (ID 15).



Evropa Hotel (ID 15).

***ID 16: Auto Color Mani***

The Auto Color Mani Company is handling and using toxic liquids (paint and thinner). Any handling or storing for commercial activities is excluded in groundwater protection zones. The handling of such toxic liquids is not permitted in water protection zones.

The site requires detailed investigation on real pollution risks, already occurred pollution and on potential protection measures.



Auto Color Mani (ID 16).

***ID 17: Auto Service Malesia***

At the northern part of the road running next to the production wells, a car repair service Malesia is located. The surface is paved however, cannot be considered sealed. It remains unclear if a drainage system is installed and connected to a treatment system.

The car repair is of danger to groundwater and soil. Protective measures like a complete impermeable cover including a drainage system to a treatment unit is required.



Auto Service Malesia (ID 17).

***ID 18: Pro Metal***

Next to the road running close to the production wells, and in the North, slightly outside the catchment area, a metal working site presents a potential risk for groundwater pollution. Classified metal debris and domestic machinery is collected. Such commercial activities would be excluded in water protection zones II, the operation of machines further presents a risk to the groundwater resource due to potential oil, petrol and or thinner leakages. Probably, no protection against pollutant infiltration neither drainage system is installed on site. Though already outside the catchment area of Begrace wells, this site requires further investigation on real pollution risks, already occurred pollution and on potential protection measures. In case the production of the wells would be increased, the catchment area might include this site and would require action. Therefore, preventive measures are recommended.



Pro Metal (ID 18).

***ID 19: Highway***

The highway connecting Pristina and Skopje is crossing the catchment area of the Begrace wells. Transport of chemicals of each kind on highways is common. To avoid contaminations from regular traffic as well as from accidents, the marginal strips have to be sealed and each spill of rain water and of accidentally spilled liquids has to be collected in channels. The collected water and chemicals have to be transported to a treatment station. Regular work procedures have to be installed or alternative transport by pipeline to a treatment station is applied. A hazard urgent reaction work plan is urgently required.



Highway near Begrace wells (ID 19).

***ID 20: Old Farm***

An older farm of about 15 chicken houses behind a large fenced area has been identified. No information on actual production and operations has been made available.

In case production continues, specific basins and protections collecting all spilled liquids (also rainwater) have to be installed in order to avoid any infiltration. Solid waste and chemical products potentially harmful to ground water cannot be stored on the area.

Manure cannot be stored without a proofed underground cover and a secured collection of all effluents. In case the farm is abandoned, some hydrochemical investigation are required analysing the potential remains of earlier effluents infiltrating into the ground. A work plan need to be established in order to follow up implementation of measures on site.



Animal Farm near highway (ID 20).

## **Annex 10: Pollution point sources at Suhareka Wellfield**

### ***ID 1: Building materials and production of concrete objects***

At a distance of 20-30 meters to the production well N°1 are two commercial companies located. The first one is selling and therefore also storing construction materials. The second company is producing prefabricated concrete objects on site. No detailed information on production and maintenance procedures have been disclosed.

It is recommended to assess both companies for use or handling of any chemicals hazardous to water and soil. Further handling of lubricants, fuels etc. for machines and lorries has to be investigated and strictly prohibited. Waste of the commercial products has to be stored outside the Protection zone II.



Building materials and production of cobs (ID 1).

***ID 7: Greenhouse***

Between the wells Pusi Atit 4 and Pusi Atit 5, a group of eight greenhouses for the production of different vegetables are installed.

Greenhouses in Protection Zone II have to be assessed and strictly monitored. Inside the Protection Zone II. Art. 13 of the Administrative Instruction MESP-No. 15/2017 excludes all use of chemical fertilizers, pesticides, herbicides and insecticides. Any production in these greenhouses has to be monitored for the strict obedience to the restrictions.

Greenhouses inside the Protection Zone III have to comply to the restrictions of Art. 15 of the Administrative Instruction MESP-No. 15/2017, indicating that all processing, storage or manipulation of chemicals, fuels, oils, and other substances hazardous to water are prohibited. Therefore, these greenhouses need to be monitored and all use of chemicals hazardous to water (many pesticides, herbicides, insecticides, and some fertilizers are toxic and hazardous to water) has to be restricted.



Greenhouse (ID 7).

***ID 12: Business "New Born"***

The abandoned commercial site "New Born" requires an investigation for abandoned hazardous goods. No further information was available during the study period.



Business "New Born" (ID 12).

***ID 9: Farm***

A farm to the South of the Pusi Atit wellfield at the border of the Protection Area II has been identified. However, no information on actual production and operations has been made available. Further assessment is required. All restrictions of Protection Zone III have to be prohibited and monitored. Manure shall not be stored without a sealed underground cover and a secured collection of all effluents. In case the farm is abandoned, some hydro chemical investigation are required analyzing the potential remains of earlier effluents infiltrating into the ground.



Farm (ID 9).

***ID 13: Business "Vëllezërit Gashi"***

The Vëllezërit Gashi company around 100 m South of the well Pusi Atit 1 located at the border of the Protection Zone II is producing a variety of stone products. The surface on site has no sealed pavement nor any drainage system deferring liquid spills to a closed drainage system.

An in-depth assessment of this company is required. According to the Art. 15 of the Administrative Instruction MESP-No. 15/2017 no storage or handling of hazardous substance (like paints, thinners, oils etc.) is allowed inside the Protection Zone III.



Business "Vëllezërit Gashi" (ID 13).

***ID: 2 Petrol station***

The Edita petrol station at the road Suhareka/Suwareka – Prizren/Prizreni is at a distance of 150 meters to the production well N°1. Though the location of the petrol station is a few meters beyond the Protection zone III boarder, a specific assessment of the infrastructure is required. It has to be verified the location of the fuel reservoirs (in general sub-soil reservoirs). Location and depth of the sub-soil reservoirs may influence the groundwater, and though being outside the surface recharge area, a direct flowline from the lower end of the reservoirs may enter the production wells. Further the filling point may produce runoff of contaminated rain or stormwaters which will be conducted into the recharge area and therefore infiltrate inside the protection area.

The local administration in cooperation with the owner and according to §1.4 of the Art.14 of the Administrative Instruction MESP-No. 15/2017, the above-mentioned risk have to be assessed and protection measure need to be installed if required.



Petrol station (ID 2).

***ID 6: Natural fertilizers***

All over the agricultural parts of the recharge area of the Pusi Atit wells, natural fertilizer are applied. These do not present any risk nor infraction of the regulation as far as these do not enter to the Protection Zone II.



Natural fertilizers (ID 6)

***ID 8: Commercial activities and plant nursery***

At around 1 km south of the Pusi Atit wells a group of barracks and greenhouses for the production of different vegetables are installed.

Greenhouses inside the Protection Zone III have to comply to the restrictions of Art. 14 of the Administrative Instruction MESP-No. 15/2017, indicating that all processing, storage or manipulation of chemicals, fuels, oils, and other substances hazardous to water are prohibited. Therefore, the greenhouses need to be monitored and all use of chemicals hazardous to water (many pesticides, herbicides, insecticides, and some fertilizers are toxic and hazardous to water) has to be restricted.



Business activities and planting of new shoots (ID 8)

***ID 10: Serpentinite mine***

The abandoned serpentinite mine south of the well field consists a pollution risk. In general any exploitation of mineral resources is prohibited unless it is proven that it is not harmful for groundwater quality (see §11 Art.14 of the Administrative Instructions 15/2017 MESP). Further the abandoned site requires an investigation on abandoned hazardous wastes.



Serpentinite mine (ID 10)

***ID 11: Metal worker***

A metal working company next to the border of the catchment area near the Grejkoc Street constitutes a potential risk for groundwater resources. No visible protection from infiltration of spilled or stored liquids and other chemicals neither drainage system are installed on site. Though already outside the catchment area of Pusi Atit wellfield, this site requires further assessment on effective pollution risks, already occurred pollution. Potential protection measures have to be discussed and with the owner and implemented where required. The local administration has to check if any §1.2 of the Art.14 of the Administrative Instruction MESP-No. 15/2017 has to be applied, restricting any operation of metal processing workshops.



Metal worker (ID 11)

***ID 14: Business "Kamila Chocolate"***

At about 1 km south of Well N°4, a commercial company Kamila Chocolate produces nutriture. As such, this does not pose a major risk to groundwater and is in accordance with § 1.4. Art 14 of the Administrative Instructions 15/2017 MESP. However, the company owner should be informed by an official letter about the regulations related to water resources protection. Further, the company is not allowed to store any kind of hazardous to groundwater liquids like oils and certain paints.



Business "Kamila Chocolate" (ID 14).

***ID 15: Cemetery***

The graveyard around 800 m south of the Pusi Atit well N° 4 within the Protection Zone III remains is maintained and continues to receive further bodies.

An existing graveyard has to be tolerated inside the Protection Zone III according to the relevant legislation. However, no extension nor new construction of graveyards is allowed (see §1.10 Art. 15 of the Administrative Instruction MESP-No. 15/2017). The municipality has to inform the cemetery board accordingly and should propose new cemetery locations outside the Protection Zone III.



Cemetery (ID 15).

***ID 16: New business***

Close to the cemetery a new building has been erected for obviously commercial use. During the study period no further information of this construction has been obtained. Further observation is required.



New business (ID 16).

***ID 17: New construction***

At about 1 km south of Well N°4, a new construction site for a private commercial or industrial building is emerging. Further assessment is required.



New construction (ID 17).

***ID 18: Rami Plast and Euro fix***

Within the catchment area at about 800 south-east of well N° 1 the commercial company Rami Plast produces plastic doors and windows. As such, this does not pose a major risk to groundwater and is in accordance with Art 14 of the Administrative Instructions 15/2017 MESP. However, the company owner should be informed by an official letter about the regulations related to water resources protection. Further, the company is not allowed to store any kind of hazardous to groundwater liquids like oils and certain paints.



Rami Plast and Euro fix (ID 18).

***Pusi Atit Wells located outside Protection Zone III requiring specific assessment.***

***ID 3: Gabions and gravel***

At Grejkoc Street around 500 m outside the Protection zone III a production site for gravel, rocks, and the production of gabions creates an indirect risk for the Pusi I Ati wellfield. Though located outside the recharge area a contamination risk at the direct neighboring requires a specific assessment and later monitoring. Further the Grejkovc river crosses the recharge area. Any hazard to the river would infiltrate in the recharge area of the Pusi I Ati well field. Chemical products and paints have to be assessed and storage requires specific security measures against infiltration or drainage.



Gabions and gravel (ID 3).

***ID 4: Auto Parts and Service***

At Grejkoc Street around 500 m outside the Protection zone III, an unnamed garage including a car scrapyards has been identified. The work site is covered by unsealed pavement and it remains unclear if a drainage system is installed and connected to a treatment system. At close distance, the Grejkoc river crosses the recharge area. Any hazard to the river would infiltrate in the recharge area of the Pusi I Ati well field. Chemical products, fuel and oils have to be assessed and storage requires specific security measures against infiltration or drainage.



Auto Parts and Service (ID 4).

***ID 5: Cylinders, building materials.***

At Grejkoc Street around 500 m outside the Protection zone III, a metal works site has been identified. The absence of pavement and drainage systems create a risk though outside the protection Zone III. At close distance, the Grejkovc river crosses the recharge area. Any hazard to the river would infiltrate in the recharge area of the Pusi I Ati well field. Chemical products, fuel and oils have to be assessed and storage requires specific security measures against infiltration or drainage.



Cylinders, building materials (ID 5).