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Chapter 7 Geology and Groundwater

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7 Geology and Groundwater

7.1 Introduction

This chapter reports findings of the assessment of the potential geology and hydrogeology impacts of the Project during both the construction and operational phases.

The assessment of the Project has been undertaken primary through a desk-based study using available information relating to geology, geomorphology, and hydrogeology. The methodology included assessment of groundwater vulnerability and determination of groundwater pollution hazards and risks as explained in Chapter 7.3.6, Chapter 7.3.7 and Chapter 7.3.8, respectively. The final assessment of impact significance took into consideration the results of vulnerability and hazards/risk assessment. The assessment of impacts must be taken with caution, as the more detailed investigations of the project area may increase the impact significance.

Where appropriate, this chapter also identified proposed mitigation measures to minimise or control likely adverse effects arising from the project.

This chapter should be read in conjunction with the following chapters:

Chapter 1	Introduction
Chapter 2	About the Project
Chapter 3	Detailed Project description
Chapter 4	Policy, legislative and institutional context
Chapter 5	Assessment methodology
Chapter 8	Surface waters
Chapter 17	Cumulative impacts
Chapter 18	Residual impacts
Chapter 19	ESMP

7.2 Baseline Conditions

7.2.1 Geomorphology

The project area belongs to the carbonate platform of the outer Dinarides, with the exception of the northernmost part of Konjic that belongs to the Bosnian flysch zone, a younger group of formations from the carbonate platform of the outer Dinarides.

The geomorphological structure of the terrain along the project area is diverse and morphologically uneven, due to the very complex composition of geological formations, complex tectonic relations, and different behaviour of rock masses in the surface zone of decay. The motorway route runs along hilly and mountainous areas.

In general, about 40% of the investigated area belongs to the hilly-mountainous terrain over 500 m asl (e.g., Prenj, Cvrsnica, Cabulja mountains). Only about one third of the terrain is located at the altitudes up to 200 to 500 m asl, and the rest is slightly hilly and flat terrain.

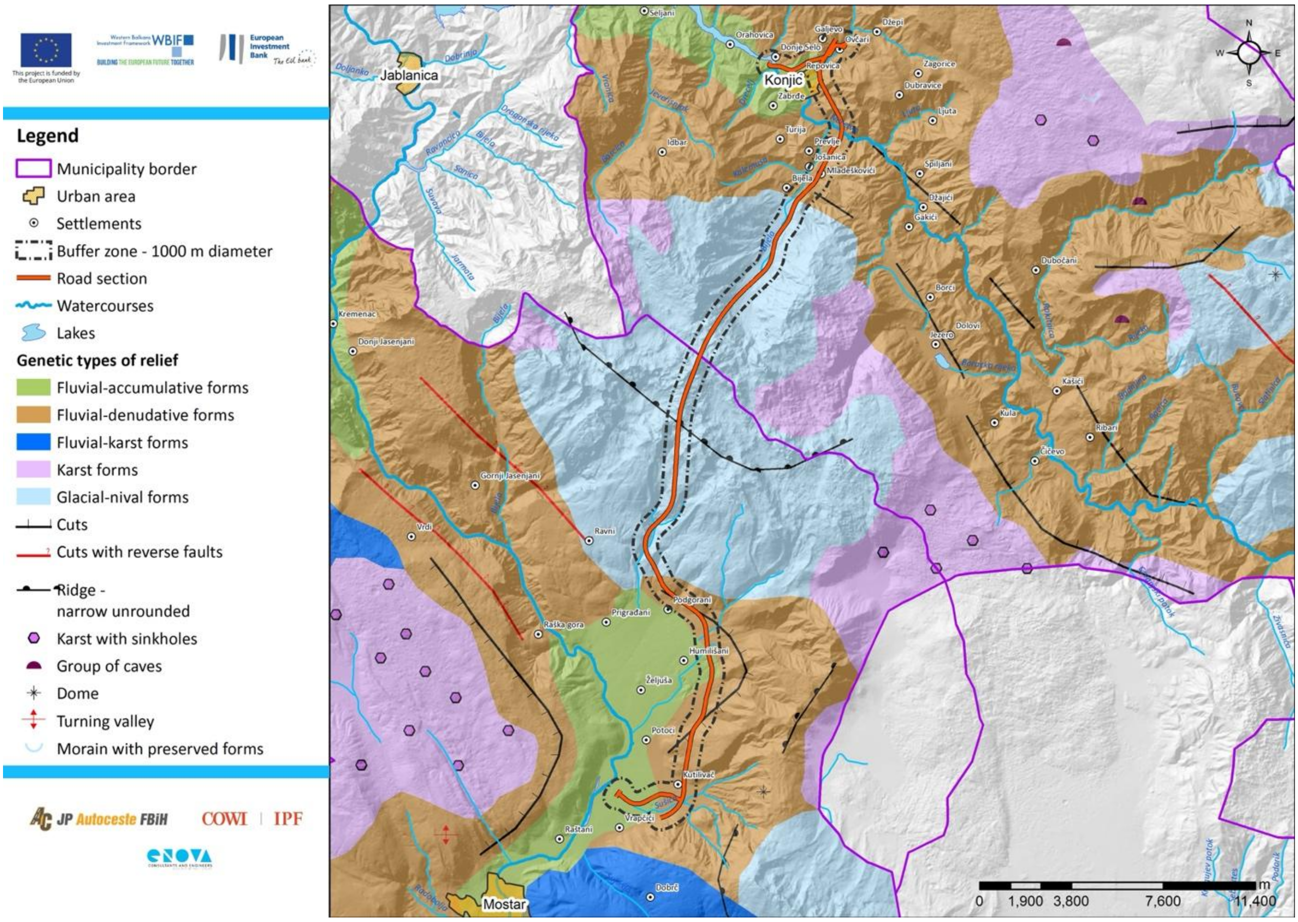

Figure 7-1: Genetic types of the terrain in the Project area

According to the genetic types, two categories of terrain, depending on the characteristics of tectonic activity, are determined, as follows[1]:

- Geomorphological units in neotectonics descent phase:
  - fluvial-accumulation terrain
- Geomorphological units in phase of tectonic uplift:
  - gravitational-deluvial terrain
  - erosion-denudation terrain
  - karst-erosion terrain
  - glacial-nival terrain.

The fluvial-accumulation terrain was created by fluvial-accumulation processes in the valleys of the river flows of Tresanica between Bradina and Konjic, and Neretva and Bijela. This category includes alluvial and terrace plateaus, terrace sections, alluvial cones, torrential sediments, fluvioglacial and limnoglacial surfaces, as well as other forms related to the fluvial regime. Of particular interest are the fluvioglacial terraces in the riverbeds of the Neretva and Bijela,

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[1] Environmental Impact Study, Section: Konjic (Ovcari) - Mostar North, Zagrebinspekt, Mostar, September 2016.

which are clearly observed as relics of old terraces formed by the deposition of glacial moraine material from the surrounding mountains. A feature of this relief is the grassy terrain intersected by a secondary network of occasional and permanent streams.

The gravitational-deluvial terrain has a small territorial distribution. It is located in the foothills of mountain massifs or steeply slopes of the mountains Borasnica and Prenj, and in the river valleys of Bijela and Neretva. The feature of this terrain is the steeply slopes leaning against the rocky base, with a uniform slope built of accumulated crushed material, mostly of limestone and dolomite composition. On the slopes, screes are sometimes found in the form of spacious fan-shaped and conical alluvial cones, active osulines or landslides, and sometimes osulin mantles that cover most of the slopes.

The erosion-denudation terrain has a relatively small presence along the motorway route in the area of the middle course of Bijela. This category of terrain is characterised by morphological fragmentation. It is composed of crystalline shales of low crystallinity of Lower Triassic sediments. Slopes are often with a steady fall.

The karst-erosion terrain is bare karst without any vegetation. This category of terrain includes the area of the mountain Prenj, and it occupies about 40% of the project area. It is built of carbonate rocks, limestone and dolomite of Triassic, Jurassic, and Cretaceous age. This terrain is characterised by a very specific structure. The slopes are very steep, gorge and canyon type. All karst phenomena can be observed in the limestone terrains. The most common forms are sinkholes and smaller bays, ravines, ravines and abysses. Unlike limestone, dolomites are subject to the processes of physical decomposition by grusification. In the areas of the plateau where limestones are mainly present, sinkholes have a high frequency of occurrence, so that certain parts of the terrain have all the characteristics of karst with sinkholes ("*boginjavi" karst*).

The glacial-nival terrain has a very limited distribution in the valley of the river Bijela and on the slopes of Prenj, outside the project area. These are areas with slightly steep slopes formed during the accumulation processes of moraine material from the old Upper Pleistocene glaciers.

The motorway passes through three distinct geomorphological units Bjelasnica, Prenj and Velež, which differ significantly in terms of geological and structural-tectonic characteristics as follows:

> Mountain Bjelasnica in this area is bordered by the Neretva River in the southwest and Tresanica in the northwest, whose valleys are also the most important geomorphological forms in this part of the mountain. The terrain that rises above the axis of the motorway in the northeast direction gradually passes into karst relief, which is very pronounced in the upper part of the mountain Bjelasnica. No major surface and underground karst formations are registered in the motorway zone.
> In geomorphological terms, Prenj is a very young mountain, formed about 18 million years ago. It covers the large area of about 400 km^2. Prenj is

bordered from all sides, except in the southeast, by the canyons of the Neretva River.

> In the motorway zone, Mount Velež is bordered by the Bijelo polje field and the Neretva River in the west. The terrain that rises above the Bijelo polje field in the east direction gradually transforms into karst relief, which is very pronounced on the Velež plateau. In the zone of the motorway axis that is laid along the westernmost slopes of Velež, no major surface karst forms are registered. Of the underground karst forms, it is important to mention the cave from which the spring Bosnjaci drains, which was formed in fluvioglacial sediments deposited in the Bijelo polje field.

Geomorphology of Prenj karst terrains

Karst is a unique natural environment dominated by carbonate rocks, mostly limestone, with dolomite rocks occupying a secondary position. Due to their exceptional fracturing, solubility, significant porosity, and the presence of open karst channels and caverns, carbonate rocks accumulate a considerable amount of groundwater. Therefore, underground springs dominate in karst environments. The direct consequence of this is a very rare and disintegrated surface drainage network or its complete absence. Where karst and non-karst areas meet, streams emerge at springs, where vast karst groundwater is drained. These springs are of high yield, sometimes even tens of m^3/s of water.

There is no sharp boundary between karstified and non-karstified rocks at depth. The transitional zone below which highly karstified rock is not expected is called the *base of karstification*. In the area of the external Dinarides, which includes the Prenj massif, the base of karstification ranges to a depth of 250 m, as proven by geophysical testing.

The process of karstification creates and conditions specific morphology or karst phenomena on both the surface and underground limestone rocks. Among the morphological forms, only the following are exclusively characteristic of karst: karren, sinkholes, uvalas, shafts, caves, dry valleys, karst fields, and karst surfaces.

Hydrogeological phenomena are also, as geomorphological forms, phenomena that occur only in karst terrains. These include karst springs, estavelles, resurgences, and sinkholes. They are equally important for determining the hydrogeological and hydrological characteristics of karst.

Karst springs are places of outflow and drainage of karst groundwater. The outflow can be constant or intermittent. The places of their emergence are usually "broken" due to the nature of limestone rocks and their porosity. They are generally distributed along the contact of karst and impermeable rocks. Such are the springs that drain the Prenj massif: Salakovac, Sanica, Bijela, Crno vrelo, etc.

Sinkholes are forms that arise at the points where surface waters flow into the underground. Their formation is crucially influenced by fissure systems, larger faults, interbedded fractures, and the chemical-mechanical action of water. They are most common along intermittent river channels and in places closer to the lower-lying erosion base. Sinkholes are classified according to the nature of occurrence into those with constant and intermittent water intake. Such are the sinkholes on the Prenj massif: Jezero, Jezerce, Veline bare, etc.

The circulation of groundwater in karst occurs in a completely different way than in non-karst terrains. Unlike other geological environments, it is very difficult to determine the laws according to which circulation and accumulation of groundwater occur in karst.

The speed of groundwater movement in the Dinaric karst varies within quite wide limits. Based on the analysis of a large number of dye tracing experiments, *"it has been determined that these limits are from 0.002 to 55.2 cm/s"*. The circulation rate changes with changes in the hydrological conditions on the surface of the terrain, i.e., with changes in the regime in the aquifer. In dry periods, when the water table is low, circulation in karst collectors is very slow. At that time, water moves in the form of slow and completely isolated underground streams, sometimes staying for a long time in siphonic accumulations of the underground. Therefore, it takes much longer for a colored water wave to travel from a sinkhole to a spring than during floods and high hydrological activity.

The underground drainage system in karst is similar to the surface drainage system. It is a well-developed system with main conduits and a lower-order network. This network does not drain the surface but the porous volume of the collector. In dry periods, most of this system is dry, and only flows that represent underground extensions of permanent surface flows and *basal karst flows* survive. They are connected at the end to the absolute or main erosional base. Basal flows usually end with large karst springs. The main transit of water takes place through conductors of large dimensions. Privileged or dominant directions of groundwater circulation in karst are most often predisposed by forms of fractured tectonics. Large fault zones are usually filled with clay material and do not represent a suitable zone for the development of karstification. In that case, accompanying tectonics play a key role in forming privileged directions of circulation. Individual karst forms are most often associated with lower-order tectonic elements, the so-called accompanying tectonics.

The Prenj catchment area consists of gentle folded structures with a large range. The axes of the folds generally dip towards the southeast with statistical elements of a 140/14° dip. The folds in the block are fractured with two clear systems of faults.

The first system with an azimuth range of 160-340° has a pronounced reverse, and partly gravitational, character of block movement. The second fault system has an azimuth range of 45-225°. Field research has shown that predominantly horizontal movement of blocks occurred along these faults.

Tension fractures and shear fractures are the most common in the fissure system. Relaxation fractures are less represented and are usually parallel to bedding surfaces. Both families of fractures are often heavily karstified, and surface karst phenomena are oriented parallel to these families.

In the narrow zone of the tunnel corridor, significant mechanical discontinuities with penetrative character, significant bedding surfaces, faults, and three families of fractures are present (the third family is subparallel to faults with an azimuth range of 45-225°).

These elements of the structure are important for assessing the excavation conditions and the stability of underground structures[2]:

> Relatively gentle inclinations of layers, along with a relatively homogeneous composition, suggest that frequent and unpredictable shifts of different lithological units are not expected (with the exception of deposits T1 and partially T22).
> Steep and sub-vertical dip angles of shearing fractures, faults, and tension cracks in combination with ss (secondary stress) fractures indicate the possible occurrence of instability (in the crown) along with the appearance of underground pressures that may have different characteristics. On the other hand, it is favourable that in the deep parts of the rock mass, fractures outside of fault zones are not relaxed, meaning they are compressed.
> Relatively steep dip angles of faults suggest the possibility of passing through tectonically damaged rock mass over a relatively short distance, since no structures of foliation are indicated in the tunnel's path.

The mountain massif of Prenj belongs to the external Dinarides, which have a northwest-southeast direction. The relief of this area is polygenetically shaped on the eroded Mesozoic carbonate plate of the external Dinarides, which is lithologically composed of over 7,000 meters thick deposits of Mesozoic limestone and dolomite formed under conditions of long-lasting shallow marine sedimentation from the Upper Triassic to the Paleogene.

Morphogenetically, the wider mountain area of Prenj is dominated by a lowland, karst, and periglacial relief developed on eroded carbonate rocks. The micro-tectonically cracked carbonate base of this area, dominated by pure limestone, favored the development of karst relief and specific underground karst hydrogeology. The higher areas of the mountain massifs and ridges in this area are polygenetically shaped by Quaternary glacial, periglacial, and slope processes on Mesozoic carbonates.

Occurrences of polygonal karst, sinkholes with narrow eroded ridges, are common in this area. They are characterised by a high density of deep funnel-shaped and basin-shaped sinkholes that are shaped by a combination of snow corrosion, mechanical destruction from frost, ice, and solifluction flow of shallow

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[2] Geotechnical investigation works on the route on the section Konjic-Mostar north (Prenj tunnel), Documentation of investigation works, Winner Project d.o.o. Sarajevo, 2016.

regolith of mountain carbonate soils. Active slope processes occur on the steeper rocky sides of eroded sinkholes, and their narrow bottoms are filled with sharp-edged colluvial deposits. Relatively shallow, bowl-shaped sinkholes, mostly oval and circular in shape, are widened by lateral corrosion. They are prevalent at altitudes above 1,500 meters above sea level and, due to the impermeable base, some are filled with small mountain lakes and periodic pools, such as Jezerce (1,650 m above sea level) and Jezero (1,500 m above sea level) on Prenj.

Bare karst is intersected by **screes** shaped by linear corrosion of snow, water, and rain along cracks on the exposed carbonate base. In this area of karst, scree of different shapes (mesh, bowl-shaped, ribbed, etc.) and depths prevail, from millimeter-shallow groove-like depressions separated by sharp corroded edges (bee cells) to several meters deep grooves (gullies). The more exposed areas of Prenj, above 1600 meters above sea level, are characterised by a pronounced density of scree occurrences that form extensive scree slopes of decameter and occasionally hectometer surfaces.

Sinkholes of various surface dimensions (from several hectares to several square kilometers) and shapes (bowl-shaped, funnel-shaped, basin-shaped) are shaped by subcutaneous corrosion at the contact of the soil horizon with the carbonate rocky base in the micro-tectonically cracked near-surface epikarst zone. The pronounced density of these Quaternary exokarstic depressions is geomorphologically related to the fault zones and cracks of the lower terrains of mountain surfaces, low plateaus, and pediments. These are mostly funnel-shaped sinkholes with steep sides and a narrow bottom filled with Quaternary deposits. They are covered with dense beech, spruce, and fir forests, so the snow cover lasts in them for a long time. On the massif of Prenj, there is a density of 54 sinkholes per square kilometre.

The density of sinkholes is particularly pronounced in areas where the lithological substrate consists of weathered Jurassic limestone, while it is less pronounced in dolomites. However, sinkhole density is not a true indicator of karstification in a given area, as the dimensions of sinkholes and underground endokarstic forms are primarily neglected. Terrain where sinkholes of kilometers in surface area and hectometers in depth have developed (one occurrence per km^2) is less karstified than terrain with more sinkholes of decametric dimensions (dozens of occurrences per km^2).

One of the largest sinkholes spatially is located in Zakantar on Mount Prenj at an altitude of around 1,600 meters above sea level. It represents a circular karstic depression about 60 meters deep with a diameter of over 500 meters. It was reshaped by corrosion, periglacial, derazial, and pedogenic processes in the Holocene on Jurassic limestone.

7.2.2 Geology

7.2.2.1 Geological and lithostratigraphic features

Geological characteristics of the terrain in the narrow and wider area of the motorway were examined based on the results of geological research conducted so far for the purposes of the development of study-technical documentation, impact studies, source protection studies and analysis of all other available sources, official state documents, documentation and published papers on the performance of geological and hydrogeological surveys of the area where the subsection of the motorway is planned.

Geological map of the terrain with the marked position of the motorway on the Konjic (Ovcari) – Prenj Tunnel – Mostar North subsection is given on Figure 7-2.

The rocks of Mesozoic and Cenozoic age, that is of Triassic, Jurassic, Cretaceous, Paleogene, Neogene and Quaternary deposits, participate in the geological structure of the terrain that belongs to the project area.

Triassic

The Triassic is widely distributed, especially in the north-eastern and north-western part of Prenj, in the south-western parts of Bjelasnica, and sporadically on the western slopes of Velez. Almost all stages of the Lower, Middle and Upper Triassic are found in these terrains.

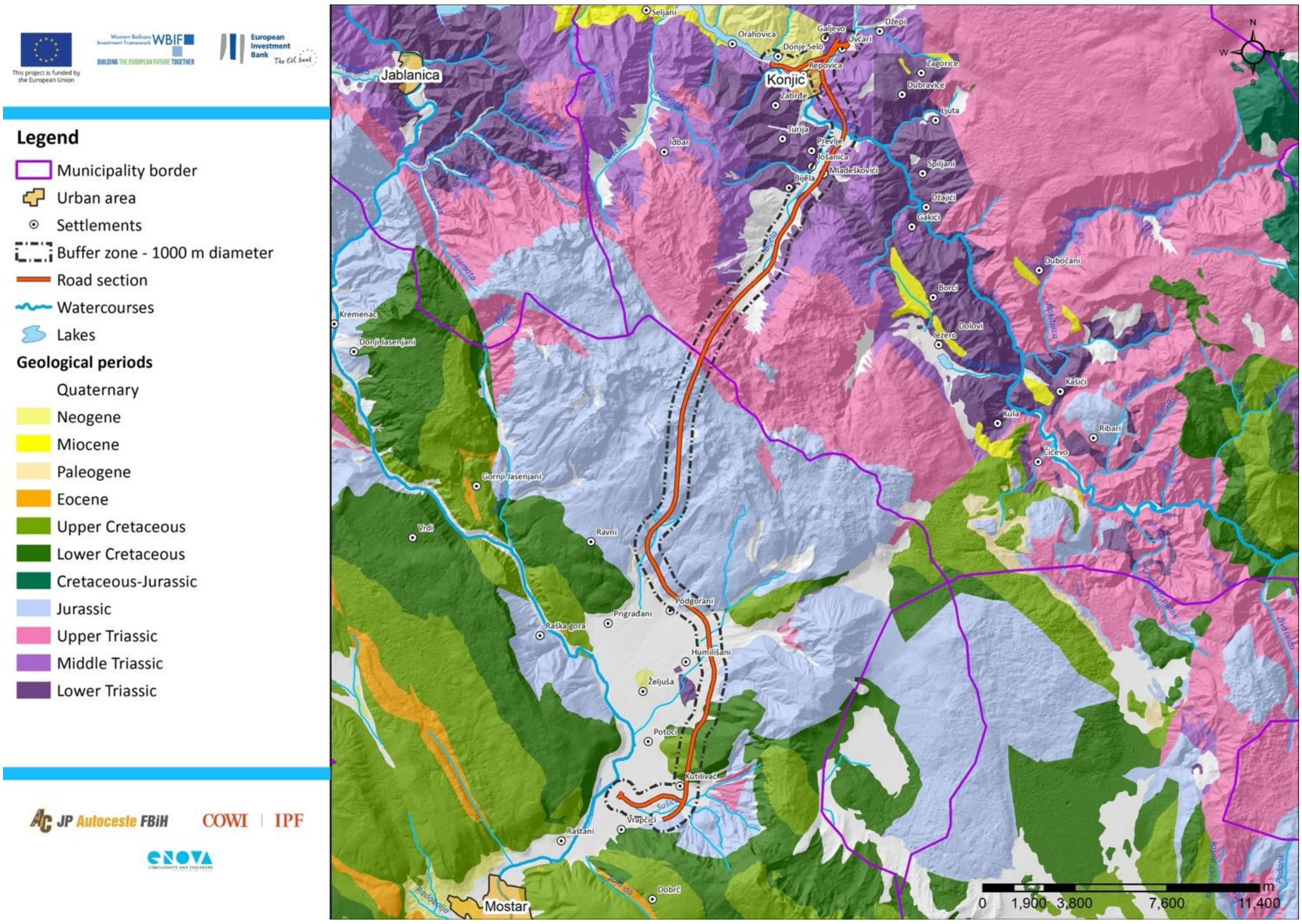

Figure 7-2: Geological map of the project area

Lower Triassic

The sediments of Lower Triassic were found in the area that gravitates to the Bijela valley to the south of Konjic, near Jablanica, and small batches of these deposits were found near the village of Lisani in Bijelo polje. In the Konjic region, the Lower Triassic sediments are represented by shale sandy marls, clay siltstones, silt claystones, sandy limestones, limestone sandstones and metamorphosed quartz-muscovite sandstones. They are grey-green, grey and reddish brown. The total thickness of the Lower Triassic sediments in this area does not exceed 400 m.

Seissian (T^1_1) sediments were discovered east of Jablanica. They are represented by sandstone, sandy limestones with layers of clay and marly limestones. They are gray and reddish. The thickness of these sediments is about 200 m.

Figure 7-3: Lower Triassic sediments south of Konjic

Sandy marls, marly limestones and limestones belonging to the Campilian ($T^2{}_1$) strata of the Lower Triassic lie concordantly over the described sediments. They are grey, grey-green, and purple. These deposits have been found in the vicinity of Jablanica, where they are about 260 m thick. A similar development of the Lower Triassic sediments was recognised in Bijelo Polje near the village of Lisani. Thickness of these deposits is about 150 m.

Figure 7-4: Campilian strata of the Lower Triassic in Sanica Valley near Jablanica

<u>Middle Triassic</u>

Limestones, brecciated limestones, dolomites, and volcanic-sedimentary formation are found to create layers over sediments of the Lower Triassic. The Middle Triassic is represented by Anisian and Ladinian strata.

Anisian strata ($T_2{}^1$) is found in the vicinity of Konjic in the southwestern part of Bjelasnica, the valley of Konjicka Bijela, Idbar, Sanica and Sistica. They are composed mainly of massive dolomites and subordinate limestones. An important feature of dolomites is that they are often intensely grusified. Anisian strata is from 50 to 250 m thick in these terrains.

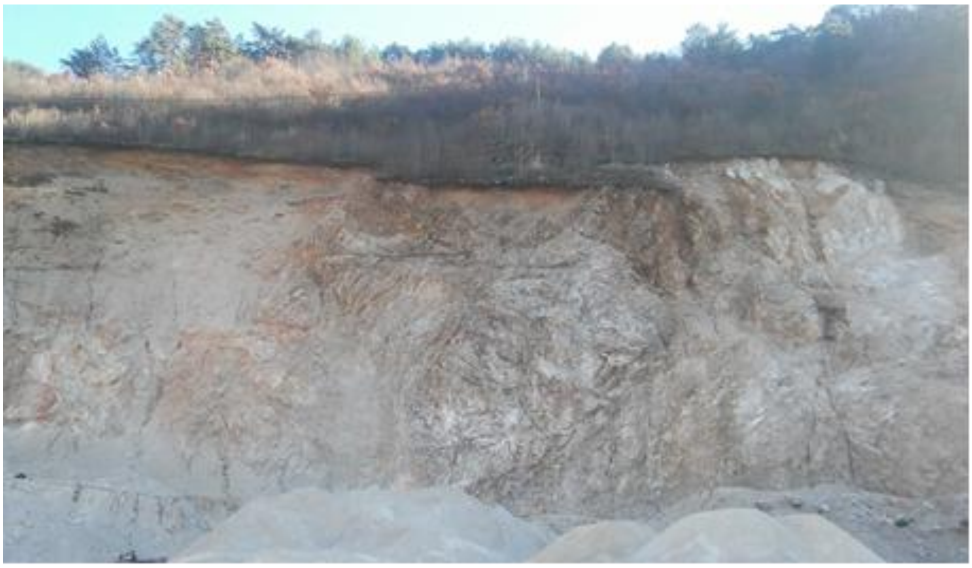

Figure 7-5: Anisian dolomites in Ovcari near Konjic

Lower Anisian strata ($^1T_2^1$) is found only in the area of Konjic, Zlatar, Paklena and Orahovica. The series of sediment lies concordial over Lower Triassic layers. In the lower sections these sediments are represented with black, plate-type and occasionally bituminous limestones whose thickness varies from 0-10 m. Over these are the grey and light grey massif dolomites, usually disintegrated into dolomite gruss. Next in the column are light grey and white layers of dolomites. Dolomites that lie over plate-type limestones, most probably partially belong to the Upper Triassic age. Thickness of these sediments in this part is around 180 m.

Ladinian stage (T_2^2) is more widespread in the basin of Konjicka Bijela, Idbar and Sanica. It consists of dolomites, limestones, and volcanic-sedimentary formations. Ladinian strata is around 300 m thick.

Gabbro ($\boldsymbol{U}T_2^2$) represented by gabbro-magmatic rocks is found in the lower course of river Doljana near Jablanica. These rocks form the south border of Jablanica gabbro massif. Those are the rocks of grey-greenish colour with visible traces of biotite.

Diabases ($\beta\beta T_2^2$) are discovered at Rujiste and left bank of Konjicka Bijela where they exist in contact with werfen. These rocks exerted metamorphic changes to surrounding sediments.

Middle-Upper Triassic ($T_{2,3}$)

The Middle-Upper Triassic was found on large areas at Prenj, in the basin of Konjicka Bijela, Idbar, Sanica, Sistica and Mostarska Bijela. It is built mostly of dolomite with rare limestone inlays. Their thickness is around 400 m.

Upper Triassic (T_3)

The Upper Triassic is only found at Prenj, where it is represented by limestones with megalodons of total thickness of about 400 m.

Figure 7-6: Dolomites and limestones of the Middle-Upper Triassic on Prenj (photographed from Bijela)

A part of *Norik and Ret* ($T_3^{2,3}$) on the Bjelasnica slopes are represented mainly by massif and banked limestones, rarely dolomites. Their thickens is from 600-800 m. In the area of Prenj and Boracka Draga, they are represented with 400 m thick banked and massif limestone, and occasionally dolomites.

Jurassic

The Jurassic is largely distributed in the central part of Prenj, and in the terrain that gravitates to the Neretva Valley between Glogosnica and Grabovica. Almost all stages of the Lower, Middle and Upper Jurassic are found in these terrains.

According to BGM sheet Mostar, the Lower Jurassic (J_1) lies concordantly over the limestone and dolomite of the Upper Triassic. It was found at Prenj, in the region of Sivadija, Zakantar, Rujiste, Kute, the upper part of the Mostarska Bijela course and other localities. It is built mostly of limestone with thin layers of dolomite with a total thickness of about 280 m.

The Middle Jurassic (J_2) lies continuously over the Lower Jurassic, and it is recognised in almost all of the aforementioned localities. It consists of oolitic limestones with smaller inner layers of dolomite limestones and dolomites. The Middle Jurassic sediments thickness is approximately 300 m thick limestones.

The Upper Jurassic (J_3) is found in two substages; Oxfordian-Kimeridgian ($J_3^{1,2}$) and Kimeridgian-Portland ($J_3^{2,3}$).

Oxfordian-Kimeridgian are found at Prenj in the areas of Vucji Kuk and Obalj, Vjetrena Brda and Galica Prenj, Konjska Dubrava, in the area of Zijemlje and in the Neretva valley southwest from Salakovac. They are mostly composed of limestone with a total thickness of about 250 m.

Kimeridgian-Portland strata have been found at Prenj above Podgorani and in Ravne, in the Mostarska Bijela basin, between Glogosnica and Grabovica, around Rujiste and in the Neretva valley southwest from Salakovac. They consist of approximately 300 m thick dolomites and limestones.

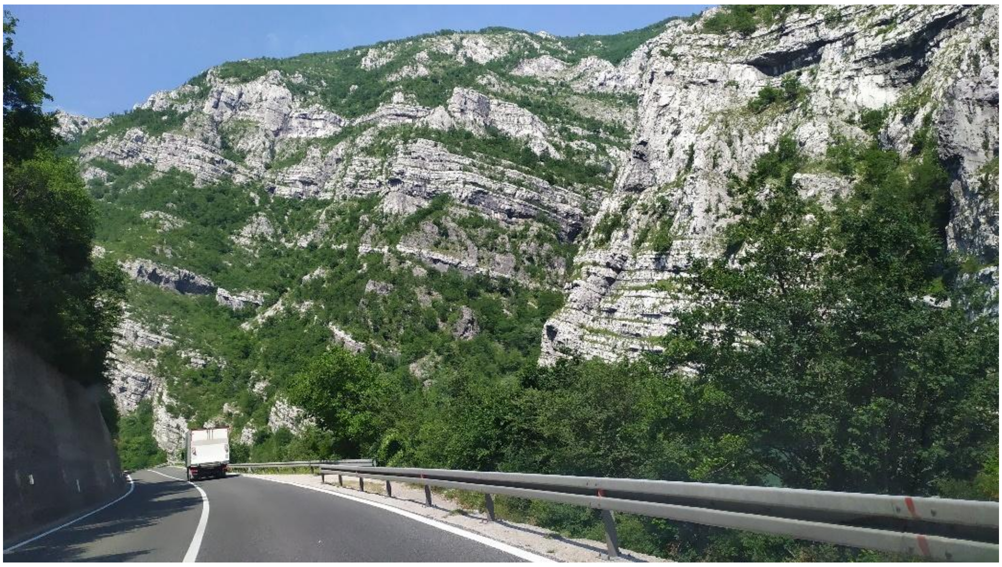

Figure 7-7: Upper Jurassic in Neretva Valley

Cretaceous

The Cretaceous is largely widespread in the southwestern part of Prenj, in the area of Rujiste, and the western parts of Velez. Both Cretaceous substages are found in these terrains; Upper and Lower Cretaceous.

The Lower Cretaceous (K_1) lies concordantly over the Jurassic sediments. It was found at Velez in the terrains between Vrapcici and Donje Zijemlje, at Prenj, in the area of Prigradjani, and in the area of Cabulja. It is built mostly of limestone with dolomite interlayers with a total thickness of about 700 m.

The Lower Cretaceous in the southwestern parts of the terrain is mostly divided into lower (${}^{1}K_1$) and upper (${}^{2}K_1$) parts. The lower parts, found in the area of Stajski Gvozd and Donja Grabovica, are represented by limestones and less often by dolomites with a total thickness of about 280 m. The upper parts follow the lower Cretaceous development at these sites, and they are primarily composed of about 350 m thick limestone.

The Upper Cretaceous has been recognised at Velez and Prenj. On the southwestern slopes of Velez, the Upper Cretaceous appears above Kute, on Plocno and on Sljemen, and at Prenj, from Salakovac through Jasenjani to

Glogovo. The Upper Cretaceous is mostly divided into Cenomanian, Turonian and Santonian.

Figure 7-8: Upper Cretaceous in Neretva Valley

Cenomanian (K_2^1) concordantly lays over the Lower Cretaceous and is represented by grey and brown limestones and dolomites. It can be found in Cabulja, Sljemena, Jasenski Gvozd, Jasenjan and Dreznice. Thickness of these sediments is around 250 m.

Cenomanian and Turonian ($K_2^{1,2}$) in the area of Gornje Zijemlje are represented by 250-500 m thick limestones with interlayers of dolomites.

Turonian (K_2^2) lays over the Cenomanian sediments in the area of Cabulja, Jasenjan, Jasneki Gvozd, Salakovac, Plocno, Sljemena and western slopes of Velez. It is represented with banked limestones and subordinate dolomites. It is mostly divided into lower (${}^1K_2^2$) and upper (${}^2K_2^2$) parts. Their thickens is around 1000 m.

Turonian-Santonian (K_2^{2+3}) is found as a thin layer from Salakovac over Jasenjani to Dreznica and on Porim. It is represented by 450 m thick banked massif limestones.

Turonian-Santonian ($K_2^{2,3}$) is found on the southwest slopes of Velez and on Cabulja. It is represented by 250 m banked limestones.

Paleogene

The Paleogene deposits lay discordant and transgressive over the Upper Cretaceous sediments (Turonian and Santonian). They are discovered in several isolated zones of dinaric direction. The following members are important: alveolinids-numulitids limestones, clastic Eocene sediments and limestone breccias with Eocene clastics.

Alveolinids-numulitids limestones ($E_{1,2}$) are found in the area of Goranci. They are represented by layered banked and often massif limestones. The thickness of these sediments is around 200 m.

Clastic Eocene sediments ($E_{2,3}$) are presented as a thin flysch zone in the area of Goranci. They are made of sandstones, marls, marly-sandy limestones, and conglomerates. Their thickness is around 100 m.

Breccias with Eocene clastics (E) are found in the area of Jasenjani, Dreznica and near Salakovac. They are represented with limestone breccias, sandstones, marls, marly-sandy limestones. Their thickness is around 200 m.

The Middle and Upper Miocene ($M_{2,3}$) is found in Dzepe. It is composed of coarse-grained conglomerates and breccia and sand-marly limestones. The lower parts ($^{1}M_{2,3}$) are found in Borci and in the Neretva valley, downstream from Konjic. They are represented by thick layered breccias and conglomerates with interlayers of sandstones and sandy-marly limestones. The thickness of these sediments is 50 m. The upper parts ($^{2}M_{2,3}$) are separated in Borci and are made from marl, carbon rich marl and marlstone. The thickness of this sediment is up to 50 m.

Neogene

Neogene (N) was found in Bijelo Polje near Mostar, and also near Konjic, in Borci and around Jablanica lake. These deposits lie discordantly and transgressively over older Mesozoic (Triassic, Jurassic, and Cretaceous) deposits.

In the Ovcari area and on the right bank of the Tresanica valley, layers of breccia, that is conglomerates of breccia and sandstone are found. The total thickness of Neogene in Konjic basin is around 150 m.

The lowest members of the Neogene in the Mostar basin are limestone conglomerates, sandstones and clays that constitute the floor layer of the coal strata. The total thickness of the Neogene in the Mostar basin is estimated at about 800 m.

Quaternary

Quaternary is represented by various sediments, and the most widespread are glacial deposits (moraines), fluvioglacial materials, deluvium, alluvium, and talus.

Glacial deposits - moraines (gl) were registered at Prenj and Velez. They are made of slightly rounded pieces of limestone. The most important moraines are near Klenova Draga, Gornja Grabovica, Bijela, Obalje, Borac and Velika Poljana. In addition to the moraine material, funnel-shaped depressions were found, which constitute cirques (Poljice and Gruce at Prenj), glacial waves (Klekova Draga, Velika Draga and waves from Poljica to Bijela).

Figure 7-9: Glacial sediments in the Konjicka Bijela valley

Limnoglacial sediments (lgl) are found in the area of Boracko Lake. They are represented by white dolomite and limestone sands, gravels and crushed layered material

Fluvioglacial sediments (fgl) were registered near Jablanica, and in the Neretva Valley all the way to Salakovac, and in Bijelo Polje. They include pebbles and unrounded pieces of rocks that are usually tightly bound as conglomerates, and occasionally unbound. They are occasionally 60 m thick (Jablanica)

Deluvial sediments (d) are more widespread around Prigradjani, then in Donje and Gornje Zijemlje, and numerous other localities on smaller areas. They are composed of pieces and debris material originating from the rocks that make outer edges of these fields and are transported via rivers and erosion of surrounding terrains.

Fluvial-deluvial sediments (el-dl) are made of crushed-sandy-clayish material of 1 m thickens. Since the alignment is mainly covered by grass and forest vegetation, the layers of geological substrate in the area of Ovcari Interchange are almost completely hidden except for parts where basic rocks (Triassic dolomites and Miocene clastics) rises or where fluvioglacial and proalluvial-alluvial sediments are developed.

Alluvial strata (al) are deposited along the Neretva, Idbar, Tresanica, Konjicka Bijela, Mostarska Bijela and Dreznica riverbeds. They are composed mainly of gravel and sand with variable clay content, with less than 10 m thickness.

Talus and talus breccia (s) are found on the slopes of Prenj and Velez. They are composed of pieces and debris from rocks deposited on steep slopes, as well as of pieces of limestone rocks of different granularity deposited on the slopes of

Prenj that are mixed with clay. In case of breccia, sediments are bound with limestones.

Figure 7-10: Talus breccia in the Konjicka Bijela valley

7.2.2.2 Tectonic features

The motorway on the subsection Konjic (Ovcari) – Prenj Tunnel – Mostar North is laid in the following structural-tectonic units: Spiljani-Konjic, Konjic-Glavaticevo, Cvrsnica-Prenj, Dreznica-Porim and Velez-Cabulja (Figure 7-11).

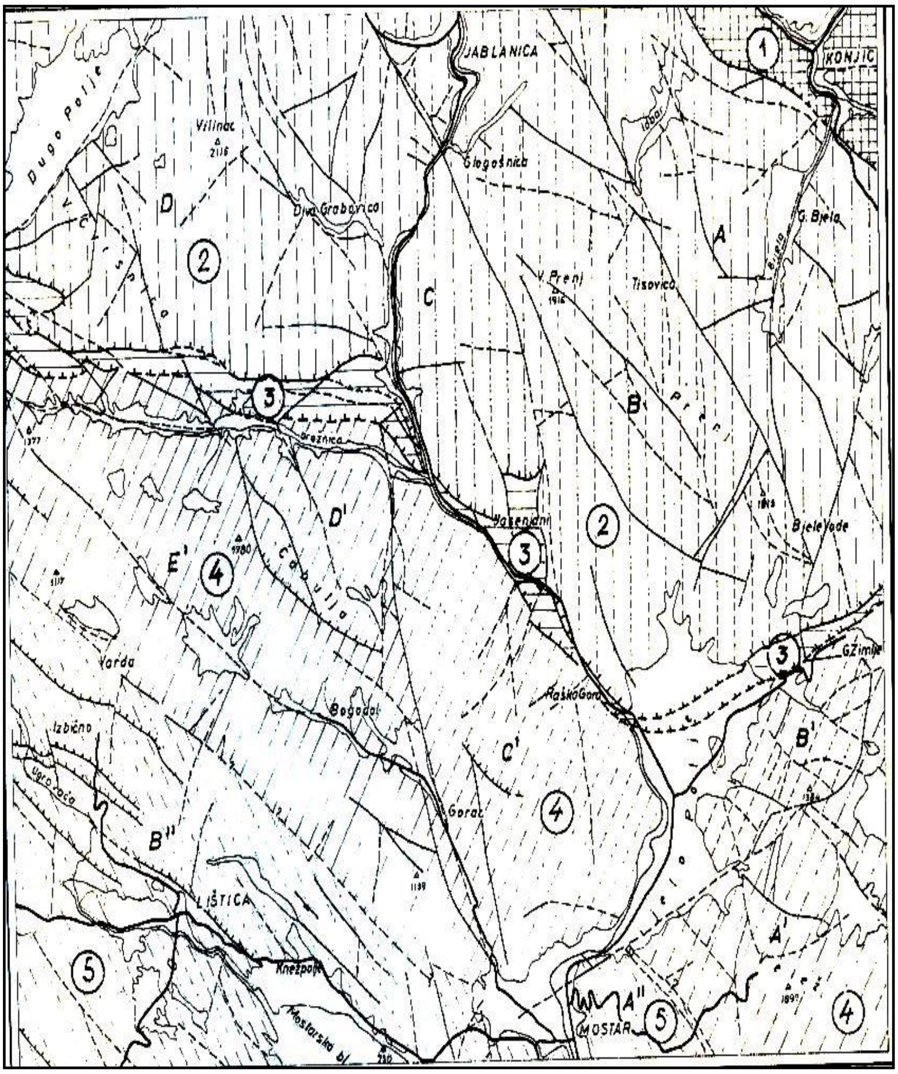

Figure 7-11: Generalised tectonic map of the Sheet Mostar[3]

(Legend for BGM Sheet Mostar)
1. Tectonic unit Konjic-Glavaticevo; 2. Tectonic unit Cvrsnica-Prenj (A. Block Idbar-Bijela-Sivadija. B. Block Jablanica-Prenj. C. plasa-Jesenski Gvozd. D. Block Cvrsnica); 3. Tectonic unit Dreznica-Porim. 4. Tectonic unit Velez-Cabulja (A' Block Velez. B' Block Zimlje-Potoci. C' Block Raska Gora. D' Block Cabulja. E' Block Bogodol-Rosne Poljane); 5. Tectonic unit Udreznje-Mostar (A". Block Opine-Mostar. B". Block Knespolje – Listica)

The Spiljani-Konjic tectonic unit is found inside structural-facial unit Bjelasnica. The geological structure of this block includes mainly dolomites and dolomitic limestones, rarely Middle Triassic-Anisian limestones.

The Konjic - Glavaticevo tectonic unit was registered on the far northeastern slopes of Prenj along the Neretva River. It is characterised by a specific development of the Lower and Middle Triassic that does not occur in other parts of the terrain. The Lower Triassic was developed in the facies of sandstones, marls, sandy and marly limestones partly covered by bituminous limestones,

[3] Archive data of Institute for geology of FBiH, prof.dr. Ferid Skopljak

and then dolomites of the Middle Triassic. The southwestern border of this unit has not been documented with certainty, but it is assumed to be a dislocation that stretches from Ulog and Glavaticevo, across Boracko Lake, the confluence of Bijela into Neretva, to the lower course of Idbar, from where it probably goes further towards Prozor. This dislocation has a reverse character, because the sediments of the Lower Triassic to the southwest of Konjic partly overthrust the Middle and Upper Triassic formations.

The Cvrsnica - Prenj tectonic unit is built of sediments from Triassic, Jurassic and Cretaceous era and gabbro rocks have also been found. The northern boundary of this tectonic unit is the previously described dislocation to the southwest of Konjic. The southern boundary of this tectonic unit is a dislocation plateau through which the Cretaceous and Jurassic sediments of the Cvrsnica and Prenj mountains in the area of Dreznica, Salakovac and Zijemlje overthrust the Eocene and Upper Cretaceous deposits. The deepest discovered parts of this tectonic unit are represented by Lower Triassic sediments. Within this tectonic unit, tectonic blocks were found that rotated separately: a) Idbar block - Bijela - Sivadija, b) Jablanica block - Prenj, and c) Plasa block - Jasenski Gvozd.

a) The Idbar - Bijela - Sivadija block is separated from the southwestern part of the terrain by a large fault that stretches from Zijemlje in the southeast through Bijele Vode, Otis, Zelena Glava and Tisovica to the source area of Idbar and further to the northwest. This fault has a Dinaric direction of extension, and in some places, Zelena Glava and Jezerce, the inverse south-eastern position of the Triassic sediments towards the Jurassic ones is observed. In Bijele Vode and other places, this fault has a vertical character. This fault brough about the rotation of this block, so that the northwest wall was rising, while the area around Zijemlja was relatively stationary. The arrangement of Jurassic sediments on the south-western and north-eastern walls of the fault points to the horizontal movement of these two walls, and partly also the overthrusts, which speaks of the faulting at the time of folding. The border of this block in the southeast is the Baktijevica-Grusca fault, which also separated the Prenj tectonic unit from the Velez tectonic unit.

b) The Jablanica - Prenj block in the northeast borders the Idbar - Bijela - Sivadija block along the aforementioned large dislocation, while in the southwest, it is separated by a fault that extends from Donja Jablanica and Glogosnica along the Mostarska Bijela valley. This fault brought the Triassic sediments in the northeast wall into contact with the Jurassic and Cretaceous sediments in the southwest. Here, as in the previous case, there was a significant shear of the southeast wall in the south-southeast direction, and partly a rotation of this block, and thus the northwest wall is elevated more.

c) Plasa - Jasenski Gvozd block at Prenj is bordered by the aforementioned fault Donja Jablanica - Glogosnica - Mostarska Bijela valley in the northeast and the Neretva River in the southwest up to the area above Jasenjani, where this block is in contact with the tectonic unit Dreznica - Porim.

The Dreznica - Porim tectonic unit is formed by Upper Cretaceous and Eocene sediments. The Upper Cretaceous is represented mainly by limestones, and the Eocene by flysch deposits. It is small in size and represents a narrow belt along the edge of Prenj, from Jasenjani via Salakovac to Porim. The whole unit is intersected by vertical faults. The northern boundary of this unit towards the Cvrsnica-Prenj unit is tectonic, along which Jurassic and Cretaceous sediments have overthrust the Eocene and Upper Cretaceous. The southern boundary is also tectonic, as the Cretaceous sediments of this unit overthrust older sediments.

The Velez-Cabulja tectonic unit, i.e. Zijemlje-Potoci block. This block is isolated by a large fault that stretches from Gornje Zijemlje, across Kuti and probably further along the perimeter of Bijelo Polje to Mostar. The north-western wall of this block has been rotated, so the north-eastern parts ascended, and the southwestern ones descended, bringing the Upper Cretaceous sediments into contact with the Upper Triassic. This block is bordered on the northwest by a presumed vertical fault south of Lisani, along which its southwestern parts are also lowered, as indicated by the Lower Triassic sediments in Lisani, which certainly form deeper parts of the Velez anticline.

7.2.2.3 Seismic activity

In the wider project area, there are 45 locations where the earthquakes of different magnitudes were recorded between 1904 and 2001. 5 earthquakes were recorded in the 21st century, 6 earthquakes in the period 1999-1991, 9 in the period of 1979-1970, 5 in the period of 1969-1960, etc.

The largest number of earthquakes in BiH occur at depths of 0 to 10 km, while earthquakes of the highest magnitude (Treskavica and Banja Luka zones) occur at depths of 10-20 km[4]. Based on the seismotectonic map of Bosnia and Herzegovina, 27 earthquakes of various magnitudes and depths were recorded in a wider area with a radius of 10 kilometers from the section.

Table 7-1: List of recorded earthquakes in wider area around the planned section

Intensity (MCS)*	Magnitude	Depth	Location	No. of earthquakes
IV	3,0 – 3,5	10-20 m	Hodbina, Polog	2
V	3,5 – 4	10 m	Mostar, Potoci, Blagaj, Hodbina, Buna	14
VI	4 – 4,5	10-20 m	Mostar, Jasenica, Hodbina, Podvelez, Polog	7
VII	4,5 – 5	5-10 m	Mostar, Hodbina	2
VIII	6,5 – 7	12-20 m	Jasenica, Blagaj	2

* Intensity on MCS scale (Mercalli-Cancani-Sleberg); IV (light), V (moderate), VI (strong), VII (very strong), VIII (severe)

[4] Prof.dr. Hazim Hrvatovic, Identification and assessment of geological hazards-earthquakes (Identifikacija i procjena geoloskih hazarda/zemljotresa), 2010.

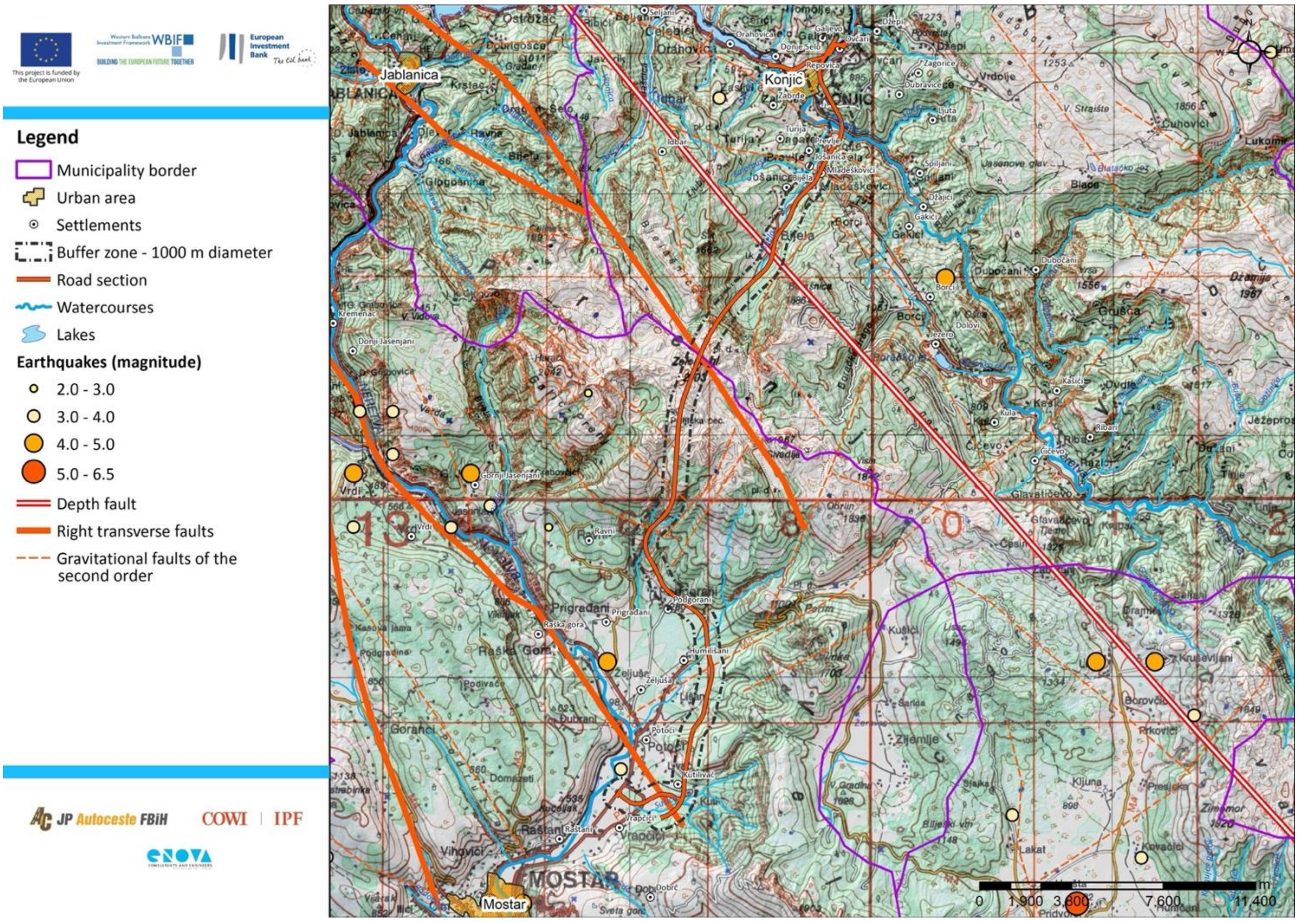

Figure 7-12: Seismotectonic map of wider area around the planned route[5]

This area is the borderline between internal and external Dinarides, above which rise the mountain ranges of Dinara, Vitorog, Radusa, Velez, Bjelasnica, Lelija, Zelengora and others. At the foot of these mountains are lowlands and karst fields. The tectonic movement and growth of the mountains generate faults and cracks.

Three earthquakes were registered in the past in the close proximity to the alignment:

> In 1970, a 4.2 magnitude earthquake6 hit the south part of the section, near the Zeljusa settlement,
> In 1965, a 3.8 magnitude earthquake hit the settlement Turije near Konjic,
> In 1931, a 3.9 magnitude earthquake hit the settlement Vrapcici on the Mostar side.

The earthquakes of this magnitude are usually felt by people but cause no damage to structures.

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[5] Prof.dr. Hazim Hrvatovic, Identification and assessment of geological hazards-earthquakes (Identifikacija i procjena geoloskih hazarda/zemljotresa), 2010.
[6] Richter Magnitude Scale

7.2.3 Geophysics

For the purpose of determining the geotechnical conditions for the construction of the Prenj Tunnel, the geophysical research of the terrain was carried out[7]. The aim was to identify and define the karstification zones per depth of the Prenj massif, as well as significant fault zones that may cause the water intrusion in the tunnel construction zone. Geophysical investigations were carried out using the method of reflective seismicity covering minimum depth of 1000 m, that is the minimum 10 m below the level of the tunnel. Four seismic reflection profiles with a total length of 3000 m were identified and defined (Figure 7-13).

The summary of results relevant for this ESIA is presented below:

- The karstification base along the tunnel is at the depth of 150 – 250 meters from the surface of the terrain, which is in accordance with the usual depth of karstification in the Herzegovinian karst. Infiltration and movement of groundwater is performed within this zone, while deeper groundwater penetration to the tunnel level is possible here and there along the faults and fractures, which are occasionally present. This means that the characteristic of the terrain is as such that the risks of groundwater intrusion, as well as possible groundwater pollution during construction of the tunnel, are reduced to a minimal and acceptable level.
- The positions of the main fault R1 and the accompanying faults relevant to the alignment of the tunnel are determined together with the intersection points with the tunnel. This allows for more accurate positioning (forecasted chainage) of possible periodical water penetration sections along the tunnel.

[7] Results of geophysical, hydrogeological and hydrological investigation in the framework of supplemental detailed geological, engineering-geological, geotechnical, geophysical, hydrological and hydrogeological research and investigation on the section Konjic (Ovcari) – entrance to the Prenj Tunnel, Winner Project, 2022

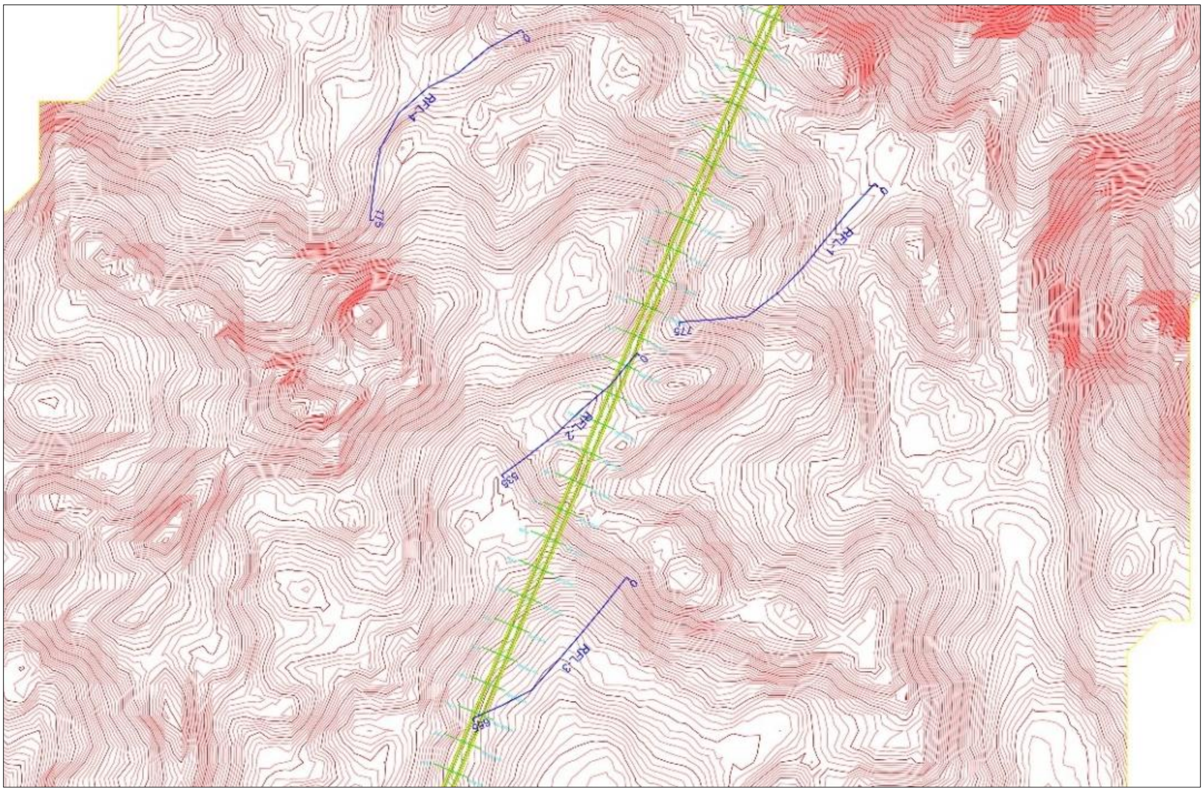


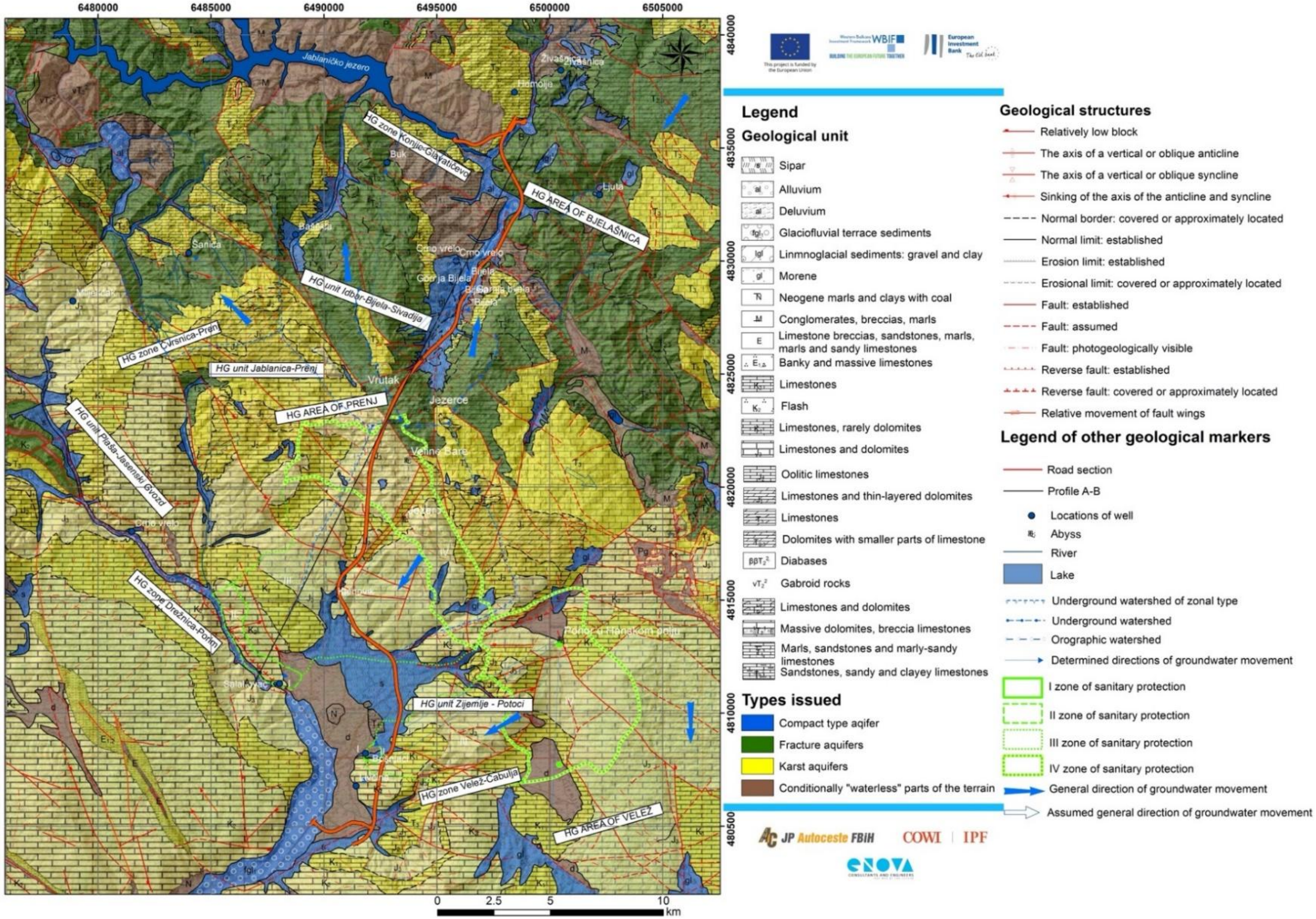
Figure 7-13: Position of geophysical profiles relevant to the alignment of the Prenj Tunnel

There is no indication of presence of unfavourable lower Triassic clastic sediments in the tunnel zone. Absence of these waterproof but weak clastic rocks deeper under the tunnel level means that the **tunnel excavation will be dominantly in compact and solid nonkarstified limestones and dolomites with an overlayer**, which is in places deeper than 1,000 meters.

7.2.4 Hydrogeology

7.2.4.1 Hydrogeology map of the Project area

Figure 7-14 is representation of the complex hydrogeological relations in the project area. The map should be use for understanding of hydrogeological setting described in the following chapters. The full-scale, high-resolution map will be also made available as a separate file. Map was obtained from the Project of supplemental detailed geological, engineering-geological, geotechnical, geophysical, hydrological and hydrogeological research and investigation on the section Konjic (Ovcari) – entrance to the Prenj Tunnel.



The map was made according to the author's originals OGK SFRJ 1: 100 000, sheets Prozor K33-12, Sarajevo K34-1, Mostar K33-24, Kalinovik K34-13

Figure 7-14: Hydrogeology map

7.2.4.2 Types of aquifers in the project area

The following types of aquifers can be found in the project area (Figure 7-14):

> confined aquifers
> karst aquifers
> karts-fracture aquifers
> fracture aquifers and
> conditionally "dry" terrains.

Confined aquifers are formed inside the rocks of intergranular porosity. This aquifer type is abundant in the valleys of Neretva, Konjicka Bijela, Bascica, Tresanica, Ravancica, Mostarska bijela, Dubrava and Bijelo Polje filed. In the project area, confined aquifers are formed inside the glacial, fluvioglacial, and alluvial sediment. A confined aquifer of limited distribution is formed inside limnoglacial sediments of Boracko filed.

A confined aquifer is recharged by precipitation from the whole catchment area, surface streams, water from water reservoirs on the Neretva River, and water from karst aquifers. In the period of high flow, when the water level in limestone aquifers is high, a karst aquifer drains in form of temporary or permanent springs of higher or lower yield. Part of the water from the karst aquifers directly infiltrate in a confined aquifer without previous discharge to the surface. In this manner, a confined aquifer is directly connected to a karst aquifer and its variable water levels directly depend on the variations in a karst aquifer. A confined aquifer in glacial sediments is recharged by rainfall and water from karst aquifer.

Karst aquifers are the most abundant aquifers in this area. They are developed inside limestones, dolomite limestones and dolomites of Mesozoic age (mainly Jurassic or Cretaceous). The limestones have the largest presence, less present are the dolomite limestones, while the pure dolomites are very rare. Almost all important hydrogeological phenomenon are related to presence of limestones which are highly karstified, both on the surface and underground. Most of the Prenj, Bjelasnica (section that concerns the motorway), Velez and Cabulja massifs are composed of limestone rocks.

A karst aquifer is replenished directly by rainfall through many different karst formations. Through cracks and fissures, rainwater infiltrates underground to move further through karst channels inside the limestone mass. Aquifers are mainly shattered because rock karstification is not the same in all parts of the massif and karts caverns are not unique on a larger area.

A karst aquifer in the area is discharged through many temporary and permanent springs such as: Konjicka Bijela, Bascica, Sanica, Mlijescak, Crno vrelo, Salakovac, Bosnjaci, Livcina and others. A number of springs is submerged under several reservoirs on the Neretva River. The springs yields vary from few l/s in low flow season to tens of m^3/s in high water season.

Karst-fracture aquifers and fracture aquifers are represented by fewer formations comparing to the number of karst aquifers. They are mainly found in dolomite limestones, limestones, and dolomites of Triassic age. These aquifers are mainly found on the northeast wing of main fault, around Konjicka Bijela, in the Neretva valley up to Konjic, as well as on the slopes of Bjelasnica. The water from these aquifers is usually in direct corelation with water from karst aquifer due to the complex structural-tectonic and hydrogeological relations in this area, and they are hard to be distinguished.

These aquifers are discharged through a number of permanent and temporary springs of which the most important are Ljuta, Zivasnica, Homolje, Buk and sources around Borac, etc. The springs yields vary from few l/s in low flow season to several m^3/s in high water season.

The conditionally ”dry” terrains are mainly composed of:

- Lower Triassic sediments,
- Magmatic rocks of Middle Triassic,
- Flysch Paleogene sediments,
- Sediments of Neogene age,
- Impermeable sediments of Quaternary age.

They very often represent a barrier to groundwater movement in this area and cause surface spring discharge.

The Lower Triassic sediments are represented with sandstones, marl, clay, marly limestones, etc. They are found southwest from Konjic, in the area of Konjicka Bijela, around Jablanica, near Lisani and Borac.

The magmatic rocks of Middle Triassic are found around Jablanica (gabrro), on Rujiste, and Konjicka Bijela (diabases).

The flysch Paleogene sediments are represented by sandstones, marl, marly limestones and breccia. They can be found around Jasenjanin. Dreznice and Salakovac. In the Neretva valley, downstream from Konjic, in the area of Borac and Dzepe, Paleogene (Miocene) sediments are represented by different conglomerates of breccia, sand and marly limestones, marly, sandstones and coals.

The Neogene sediments are represented in Bijelo Polje field near Mostar, near Konjic, in Borci and around Jablanicko lake. They are represented with conglomerates, sandstones, clay, marl and coals.

The impermeable sediments of Quaternary are composed of limnoglacial and deluvial sediments.

7.2.4.3 Hydrogeological zoning

In relation to the geomorphological, geological, and structural-tectonic characteristics of the terrain in which the subsection of the Konjic (Ovcari) – Prenj Tunnel – Mostar North motorway, including Konjic Bypass, is laid, three major hydrogeological areas can be distinguished:

- Hydrogeological area Bjelasnica,
- Hydrogeological area Prenj, and
- Hydrogeological area Velez.

Within the defined hydrogeological areas, hydrogeological zones and lower-order hydrogeological units can be distinguished.

Hydrogeological area Bjelasnica

The hydrogeological area Bjelasnica is demarcated by the river Neretva in the southwest, and the river Tresanica in the northwest. It is dominantly made of limestones, dolomite limestones and dolomites. This karst aquifer is mainly discharged through the Ljuta spring.

Figure 7-15: Spring Ljuta near Konjic

The Ljuta spring (Q_{max}=11 m^3/s) is formed at the contact point of upper Triassic permeable limestones and less permeable Middle Triassic dolomites. The spring is located to the east of Konjic, above the village of Ljuta at the elevation of 366 m a.s.l. The spring is a contact, fracture spring – it flows from the cave with the ascending flow mechanism. According to available data from multiannual observation, the yield of the Ljuta spring is Q=1.5 -11 m^3/s[8]. The spring is partly captured for the purposes of water supply to Konjic.

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[8] Sliskovic, I. et. al (1983). Study on hydrogeological zoning and groundwater balance of fracture and karst-fracture rocks of BiH, Geoinzenjering, Sarajevo.

South of Konjic two more important drinking water sources are found – Zivasnica (438 m a.s.l.) and Homolje (541 m a.s.l.) springs. Zivasnica is a fracture spring with descending flow mechanism that drains from the dolomites and limestones of Middle Triassic age. According to available data, the abundance of the spring is Q=0,005-0,015 m^3/s. The spring is captured for the purposes of water supply to Konjic. Homolje is a contact spring with ascending flow mechanism that also drains from the dolomites and limestones of Middle Triassic age. The spring yield is Q=0,0001-0,001 m^3/s and is captured as a public drinking fountain.

The groundwater of the hydrogeological area of Bjelasnica is distinctly and exclusively of *hydrocarbonate-calcium-magnesium* (HCO3-Ca-Mg) and *hydrocarbonate-magnesium-calcium (HCO3-Mg-Ca)* type.

Hydrogeological area Prenj

The hydrogeological area Prenj is bordered on all sides by the canyons of the Neretva River, except in the southeast. Its peaks reach heights of 2,100 m a.s.l., while the Neretva canyons are cut at the altitudes up to 100-300 m a.s.l., which constitutes an extremely large difference in altitude, and thus also steep gradients of groundwater flow that had a strong impact on karst formations on this mountain. The mountain is mostly made of carbonate rocks (limestones and dolomites), and the karstification is especially pronounced with a large number of surface and underground karst forms; sinkholes, pits, abysses, caves and karst springs.

In the area of Prenj, three hydrogeological zones can be distinguished:

1. hydrogeological zone Konjic-Glavaticevo,
2. hydrogeological zone Cvrsnica-Prenj and
3. hydrogeological zone Dreznica-Porim.

1) The Konjic – Glavaticevo hydrogeological zone is found on the far north-eastern slopes of Prenj along the Neretva River. It is characterised by a specific development of impermeable deposits of the Lower and Middle Triassic that does not occur in other parts of the terrain. The southwestern border of this zone has not been documented with certainty, but it is assumed to be a dislocation that stretches from Ulog and Glavaticevo, across Boracko Lake, the confluence of Bijela into Neretva, to the lower course of Idbar, from where it probably goes further towards Prozor. In this hydrogeological zone, due to the geological composition of the terrain, which is dominated by watertight sediments of the Lower Triassic, there is not a single major occurrence of groundwater sources.

2) The Cvrsnica – Prenj hydrogeological zone is contoured from the south with previous zone Konjic-Glavaticevo, while its south border is a dislocation plateau through which the Cretaceous and Jurassic sediments of the Cvrsnica and Prenj mountains in the area of Dreznica, Salakovac and Zijemlje overthrust the Eocene and Upper Cretaceous deposits This zone is built of sediments from Mesosoic age, while magmatic rocks (diabases) have also been found. The deepest discovered parts of this hydrogeological zone are represented by Lower

Triassic impermeable sediments. Within this hydrogeological zone, the following hydrogeological units have been defined:

a) Idbar – Bijela – Sivadija,
b) Jablanica – Prenj, and
c) Plasa – Jasenski Gvozd.

a) The hydrogeological unit Idbar – Bijela – Sivadija is separated from the southwestern part of the terrain by a large fault that stretches from Zijemlje in the southeast through Bijele Vode, Otis, Zelena Glava and Tisovica to the source area of Idbar and further to the northwest. The border of this hydrogeological unit in the southeast is the Baktijevica-Grusca fault, which separates the Prenj hydrogeological area from the Velez hydrogeological area.

In hydrogeological terms, most of this hydrogeological unit is made of permeable rocks of cavernous-fissure porosity (carbonate deposits of the Middle and Upper Triassic). The Middle Triassic carbonate rocks most likely constitute the aquifer of this hydrogeological unit. Apparently, the aquifer is formed in a syncline-type structure with the floor layer composed of the Lower Triassic impermeable deposits, and water-permeable carbonate deposits of the Middle-Upper and Upper Triassic are found above the aquifer. This syncline structure generally sinks to the northeast, and the direction of its plunging mainly determines the location of the aquifer discharge. The aquifer is almost regularly discharged in contact with the watertight deposits of the Lower Triassic or in locations where the aquifer was revealed by erosion, as is the case in the valleys of Konjicka Bijela and Idbar (Bascica). The boundary of the aquifer formed in the carbonate rocks of Middle Tirassic can almost be drawn connecting the points of flow of the largest karst springs in this unit (elevation of 420-550 m a.s.l.). The yield of these springs is estimated at Q_{max}=2.5 m^3/s.

The aquifer formed in this hydrogeological unit is discharged at the springs of Konjicka Bijela, the largest ones being the Bijela (465 m a.s.l), Gornja Bijela (465 m a.s.l.) and Crno Vrelo (457 m a.s.l.) springs, and at the springs of Idbar, the largest ones being the Bascica (555 m a.s.l) and Buk (420 m a.s.l.) springs. The aquifer formed in this block is partly discharged at small springs in the Sistica basin, the larger ones being in the area of Boracko Lake and the village of Borci; Draganica vrelo, Milakovac and other smaller springs.

Figure 7-16: Gornja Bijela spring in Bijela near Konjic

Gornja Bijela is a fracture spring with ascending flow mechanism. It has a secondary flow from the moraine material, and primary flow from the Middle Triassic – Anisian dolomites and limestones. The spring yield is Q=0,01-0,1 m^3/s. The spring is captured for the purposes of water supply to Konjic.

Crno Vrelo is a fracture spring with ascending flow mechanism. It also has a secondary flow from the moraine material, and primary flow from the Middle Triassic – Anisian dolomites and limestones. According to available data, the abundance of the spring is Q=0,01-0,1 m^3/s. The spring is captured for the purposes of water supply to Glavaticevo settlement.

Bascica is a contact spring with descending flow mechanism. It flows from the Middle Triassic – Anisian dolomites and limestones. According to available data, the abundance of the spring is Q=0,01-0,1 m^3/s. The spring has not been captured.

The Buk spring is located in Orahovica. It is a contact spring with descending flow mechanism. It flows from the Middle Triassic – Anisian dolomites and limestones. According to available data, the abundance of the spring is Q=0,1-1 m^3/s . The spring is partly captured for the purposes of water supply.

The Draganica Vrelo spring is located near the Boracko Lake. It is a diffuse spring with ascending flow mechanism. It flows from the Middle Triassic – Anisian dolomites and limestones. According to available data, the abundance of the spring is Q=0,001-0,01 m^3/s. The spring is captured for the purposes of water supply.

The Milakovac spring is located in Borci. It is a fracture spring with descending flow mechanism. It flows from the Middle Triassic – Anisian dolomites and limestones. According to available data, the abundance of the spring is Q=0,001-0,01 m^3/s. The spring is captured for the purposes of water supply.

The groundwater of this hydrogeological unit that is discharged at these sources and karst springs is distinctively of hydrocarbonate – calcium – magnesium (HCO3-Ca-Mg) type.

b) <u>The Jablanica – Prenj hydrogeological unit</u> in the northeast borders the Idbar – Bijela – Sivadija hydrogeological unit along the aforementioned large dislocation, while in the southwest, it is separated by a fault that extends from Donja Jablanica and Glogosnica along the Mostarska Bijela valley.

In the Jablanica – Prenj hydrogeological unit, two hydrogeological units were evidently formed; one in the northwest and the other in the southeast, as indicated by different hydro-chemical water types and the abundance of the sources. From the photogeological perspective, the border of these two hydrogeological units is likely in the direction of Bijela Mostarska – Idbar.

In hydrogeological terms, the north-western part of the hydrogeological unit Jablanica – Prenj is made of permeable rocks of karst and karst-fissure porosity (carbonate deposits of the Middle, Middle-Upper and Upper Triassic, and Lower and Middle Jurassic). According to the available data, the aquifer in this part of the hydrogeological unit Jablanica – Prenj is represented by the Middle-Upper Triassic carbonates, which are likely discharged at the Sanice spring in the most part.

Sanica (377 m a.s.l) is a fracture spring with ascending flow mechanism. It flows from a small "groundwater lake" from Middle-Upper Triassic dolomites and limestones. The Sanica spring yield is 0.39 m^3/s - 1.01 m^3/s[9]. The spring is captured for the purposes of water supply to Jablanica. The Sanica spring becomes turbid after intense rain or sudden snow melting. The groundwater that is discharged at this spring is of hydrocarbonate – calcium – magnesium (HCO3-Ca-Mg) type.

Protection zones have been established for the Sanica spring in accordance with existing legislation.

[9] Rimac, N. (2009). Hydrological analysis of the Sanica spring and determination of minimum biological flow, Federal Hydro-Meteorological Institute Sarajevo

Figure 7-17: Sanica spring near Jablanica

The groundwater in the north-western part of this unit is of hydrocarbonate – calcium – magnesium (HCO_3-Ca-Mg) type, and in the south-eastern part of this unit of hydrocarbonate – calcium (HCO_3-Ca) type, which indicates the existence of two separate groundwater reservoirs.

In hydrogeological terms, the south-eastern part of the hydrogeological unit Jablanica – Prenj is made of permeable rocks of cavernous-fissure porosity (carbonate deposits of the Middle and Upper Triassic, and Lower, Middle and Upper Jurassic). In this part of the hydrogeological unit, a very water-abundant aquifer was formed, which is discharged at the Salakovac springs (100 m a.s.l).

Figure 7-18: Salakovac springs

The Salakovac spring is located at the very contact point between the Jablanica – Prenj block and the tectonic unit Dreznica – Porim, which further complicates the hydrogeological relations. According to the protection study, the size of the catchment area of the Salakovac spring is 91 km^2 [10]. The groundwater from Prenj reaches the Neogene sediments of Bijelo Polje, where they turn west and pour out at Salakovacka vrela (Salakovac springs)[11]. Salakovac spring was the subject of extensive hydrogeological research and testing, especially because it is affected by losses from the HPP Salakovac reservoir, and because the spring has been captured for the purposes of the water supply system in Mostar.

According to the available documentation, there is no exact data on the abundance of the spring, because observations of the spring itself have never been conducted. Measurements were almost impossible to perform due to the diffuseness and partial immersion of the spring in certain hydrological situations[12]. Therefore, the yield was determined on the basis of measuring the flow of the Neretva River on the upstream and downstream profile (Salakovac and Mostar). Small, medium, and large waters of the Salakovac spring were estimated based on the difference in the flow of the Neretva River at the Salakovac and Mostar water meter stations: minimum waters in 20-year occurrence span Q_{min}=0.5 (m^3/s); medium water Q_{sr} =3.6 m^3/s; large water Q_{vv}

[10] Zavod za vodoprivredu (2022) Study on Protection of Salakovac Spring.
[11] Sliskovic, I. et al (1983) Study on hydrogeology zoning and balance of groundwater in fracture and karst-fracture rocks in BiH, Geoinzenjering, Sarajevo.
[12] Antunovic I. et al. (2007). Project on additional investiragtion works and development of Study and Project of Salakovac spring protection, Integra-consulting in Civil Engineering, Mostar.

> 20 m^3/s. This estimate applies to the period before the construction of the Salakovac reservoir.

According to the available data, the Salakovac spring shows large abundance oscillations, and therefore significant oscillations of groundwater levels in the aquifer can be assumed as well. In the analysis of groundwater level fluctuations on the example of the HPP Salakovac dam, it is understood that the minimum levels descend very deeply considering the river flow (sometimes below the river level), which clearly shows that groundwater circulation takes place in the direction parallel to the river [13].

c) Plasa – Jasenski Gvozd hydrogeological unit at the Prenj Mt. is contured by the fault Donja Jablanica – Glogosnica – Mostarska Bijela valley in the northeast and the Neretva River in the southwest up to the area above Jasenjani, where this unit is in contact with the hydrogeological zone Dreznica – Porim.

This unit is mainly made of limestones and minimally of dolomite limestones and dolomites of the Cretaceous and Jurassic age. These rocks are very permeable with karst porosity inside which an aquifer is formed. According to available data, this aquifer is mostly discharged at the occasional karst spring Crno vrelo and karst source Mlijescak near Aleksin Han. Maximum yield of Crno Vrelo is greater than 20 m^3/s although the spring dries up for 3-4 months a year[14]. The average yield of the Mlijescak spring is 0.85 m^3/s[15]. Both springs are submerged by the HPP Salakovac reservoir.

The structural position of the hydrogeological unit Plasa – Jasenski Gvozd in this part of Prenj caused the appearance of springs in the Neretva canyon, and probably separated the groundwater accumulation that is discharged at the Sanica and Salakovac springs.

3) The Dreznica – Porim hydrogeological zone is small in size and represents a narrow belt along the edge of Prenj, from Jasenjani via Salakovac to Porim. From the hydrogeological point of view, this zone is mostly made of permeable rocks of cavernous-fissure porosity (carbonate deposits of the Cretaceous) where an aquifer is formed. This aquifer, together with the aquifer formed in Plasa – Jasenski Gvozd block, is likely discharged at the karst spring Crno vrelo ($Q_{max.}$ > 20 m^3/s) that is situated in the hydrogeological unit Dreznica – Porim, which complicates the hydrogeological relations to the extent that they are impossible to solve at the current level of research and the state of the environment.

Considering that this hydrogeological zone overthrusts the Triassic carbonates, it cannot be ruled out that together they represent a very water-abundant aquifer that is discharged at the Crno vrelo spring (130 m a.s.l.). This is confirmed by the high abundance of this occasional karst spring that originates from the cave

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[13] Ivankovic, T. (1984) Hydrogeological issues of groundwater reservoirs in karst on an example of HPP Salakovac, Ph.D. thesis, Mining-geological Faculty Tuzla
[14] Sliskovic, I. et. al (1983) Study on hydrogeological zoning and groundwater balance in fracture and karst-fracture rocks in BiH, Geoinzenjering, Sarajevo.
[15] Ibid.

with the inverse cave passage slope, which has been partly speleologically explored.

It is also important to note that the aquifer in this hydrogeological zone may be pressurised. There are information indicating that before the construction of HPP Salakovac, after intense and prolonged rainfall, Crno vrelo sprayed water from the cave to the center of the Neretva riverbed. Nowadays, after intense rainfall, there is a long trail of muddy water in the reservoir, flowing from the spring to the lake.

Hydrogeological area Velez

The wider area along which the motorway is laid in this section is part of the hydrogeological zone Velez – Cabulja, i.e., the Zijemlje – Potoci hydrogeological unit. This unit is isolated by a large fault that stretches from Gornje Zijemlje, across Kuti and probably further along the perimeter of Bijelo Polje to Mostar. On the north-western side, the unit is limited by a fault to the south of Lisani.

In hydrogeological terms, the unit is characterised by relatively simple relations where the aquifer formed in the Jurassic and Cretaceous carbonate deposits is discharged in the west, at the Bosnjaci (Q_{max}=1.95 m^3/s, 140 m a.s.l.) and Livcina (Q_{max}=1.8 m^3/s, 95 m a.s.l.) springs. These karst springs appear at the contact point between aquifers and Neogene waterproof strata deposited in Bijelo Polje. The groundwater in the Zijemlje – Potoci block and the aforementioned springs is typically of the hydrocarbonate-calcium (HCO3-Ca) type.

Figure 7-19: Livcina spring

In July 2022, during construction of the water intake structure, a 250 m long cave channel is discovered inside the conglomerates and clay-gravel. This channel pointed the groundwater movement from the intensive karstification zone through the karstification zone of fluvio-glacial sediments to the contact zone of non-karstified rocks of Neogene age, and enabled discharge at the Bosnjaci spring. Along the cave channel, near the terrain surface, two sinkholes are found closer to the contact with a massif, where there is less possibility to find immediate roof sediment above the channel. The sinkhole Lazine has diameter of 3 m and depth of 2 m, while the sinkhole Jamurine is significantly larger and has diameter of 10 m and depth of 3.5 m[16].

The recharge zone of the Bosnjaci and Livcina springs is the area of karst with sinkholes (Montenegro plateau), the zone of intense karstification (the Plocno flatland of the Donje-Gornje Zijemlje depression), and zone od poor karstification (area of Malo and Veliko Rujiste).

The underground reservoir in the karst aquifer with free flow that is discharged at the Bosnjaci spring, is recharged by rain infiltration. The rain creates local temporary streams or flood the impermeable zones of Hansko polje, Gornje Zijemlje and Donje Zijemlje. Direct sinking of rainwater is observed in the area of karst with sinkholes (Montenegro plateau), the zone of intense karstification (the Plocno flatland of the Donje-Gornje Zijemlje depression), and zone od poor karstification (area of Malo and Veliko Rujiste).

7.2.4.4 Groundwater flow

In karst it is very difficult, sometimes impossible, to determine the exact distribution of caverns, karst channels and cracks that governs the directions of groundwater flow.

This section provides review of all known performed dye-tracer tests in the project area and conclusions about groundwater flow (direction and velocity) that are relevant for assessment of impacts on ground and surface waters.

The most recent dye-tracer tests were carried out by Winner Project in the period 2021-2022[17] in order to determine possibility of groundwater impact on the construction of the Prenj Tunnel as well as the impact of tunnel construction on the water sources used for the public water supply of Konjic, Jablanica and Mostar. Considering the configuration of the terrain and hydrogeological zones surrounding the project area, the dye was injected to abysses at four locations Jezerce, Jezero, Vrutak and Veline Bare. The results and maps presented in the following sections were taken from the Report prepared by Winner Project in 2022[18].

Dye-tracer test at the location of Jezerce

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[16] Civil Engineering Faculty Sarajevo, Institute for Geology (2003). Protection of the Bosnjaci spring – Mostar
[17] Results of geophysical, hydrogeological, and hydrological investigation in the framework of supplemental detailed geological, engineering-geological, geotechnical, geophysical, hydrological, and hydrogeological research and investigation on the section Konjic (Ovcari) – entrance to the Prenj Tunnel, Winner Project, 2022
[18] ibid.

The Jezerce abyss is located on the Prenj mountain, above the northern portal of the Prenj Tunnel, at an altitude of 1680 m a.s.l. The 10 kg of Na-fluorescein is injected in the sinkhole. The dye monitoring sites were established at four locations:

> Konjicka bijela sources (on both left and right arm);
> Konjicka Bijela stream, downstream from the sources; and
> Bascica spring (Idbar).

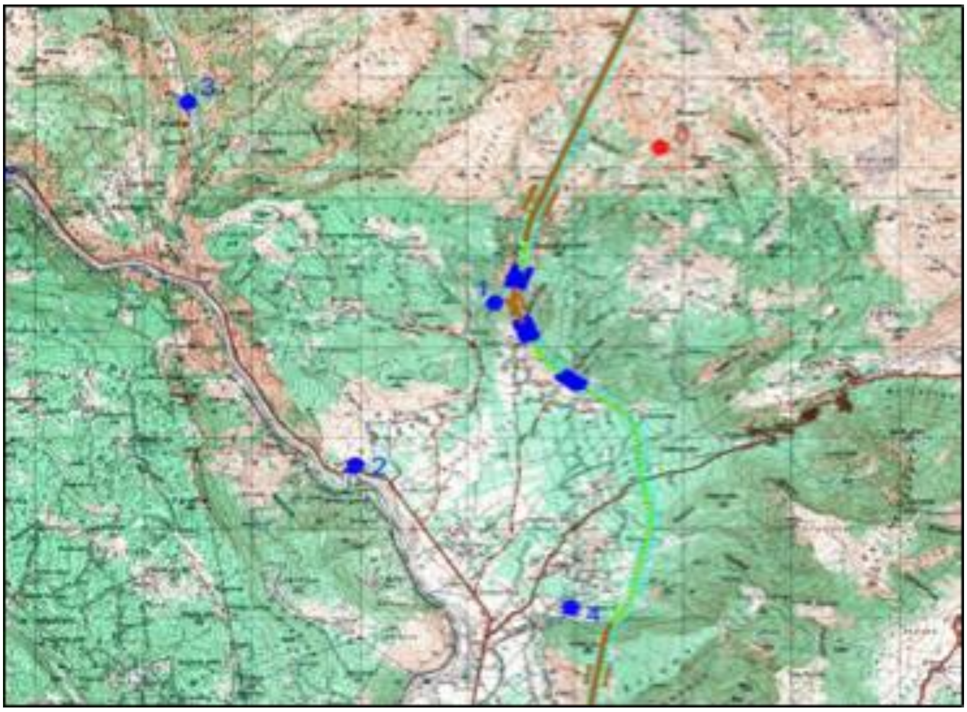


Figure 7-20: Place of dye injection at Jezerce (0) and monitoring locations (1-4)

The monitoring lasted for two months. The dye was recovered only from the Konjicka Bijela source (left arm) and from the Konjicka Bijela stream on the same day, 22 days after injection. The results confirmed the findings of the Austria-Hungarian geologists from the beginning of XX century.

Based on the test results, the fictious groundwater velocity between the Jezerce abyss and the Konjicka bijela source (left arm) is calculated to be 0.3054 cm/s. In case of rectilinear flow, the velocity would be 0.3001 cm/s (260 m/day).

Dye-tracer tests at the Jezerce abyss revealed the connection with Konjicka Bijela spring (left arm). The obtained fictious groundwater velocity is caused by the terrain geology (dolomites and limestones). Dolomites are less permeable, and water moves slower through cracks that are compacted and grussified (decomposed).

Since the underground connection with spring Bascica is not determined, it can be concluded that groundwater in the zone of Jezerce abyss moves north-east toward Konjicka Bijela, and not north-west toward Bascica. As a result, depending on the hydrological situation (quantity of precipitation), the groundwater may appear in the zone of south portal of the Prenj Tunnel in form of moist patches or water dripping.

Dye-tracer test at the location of Jezero

The Jezero abyss is located on the Prenj mountain, above the southern portal of the Prenj Tunnel, at an altitude of about 1520 m a.s.l. The test was performed with Na-fluorescein. The colour monitoring sites were established at four locations:

- Klenovik spring,
- Salakovacka springs,
- Mostarska Bijela stream, and
- Bosnjaci spring.

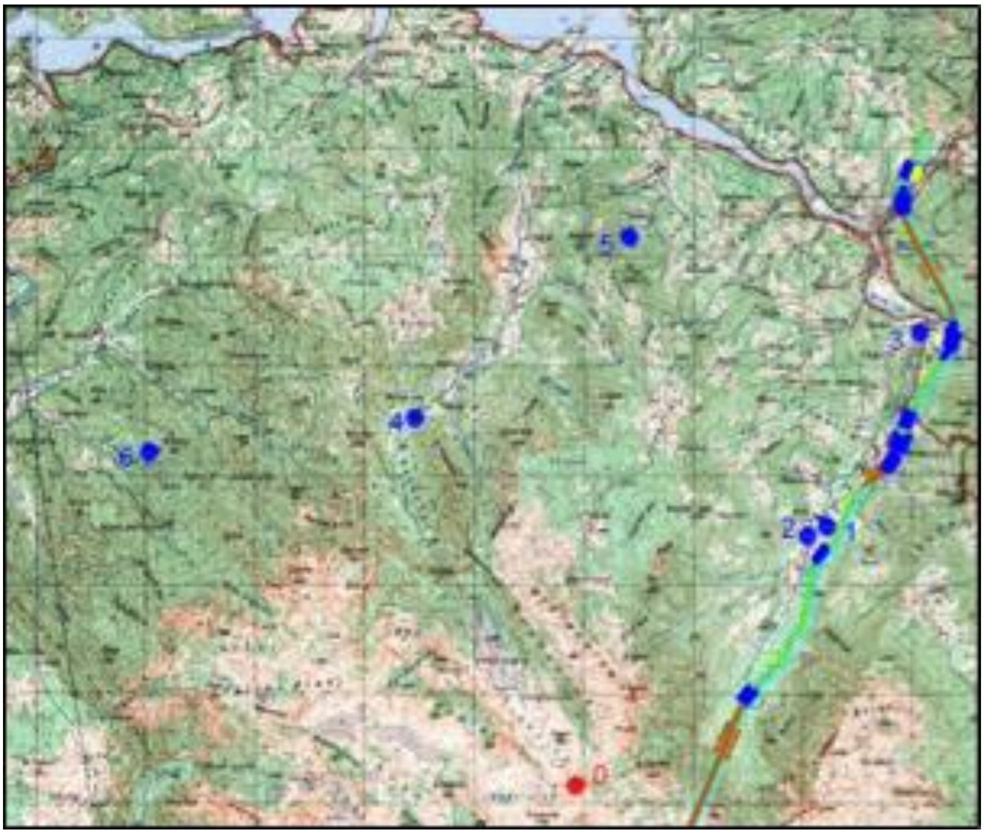


Figure 7-21: Place of dye injection at Jezero (0) and monitoring locations (1- 4)

The monitoring lasted for two months. The dye was recovered from the Salakovac sources on day 11 and lasted for total 12 days. The highest concentration was observed on the fifth day after the first appearance.

Based on the test results, the fictious groundwater velocity between the Jezero abyss and the Salakovac sources is calculated to be 0.964 cm/s (833 m/dan).

Dye-tracer tests at the Jezero abyss revealed direct hydraulic relation with Salakovac springs. The obtained fictious groundwater velocity is caused by terrain geology (Upper Jurassic limestones) as well as the altitude difference between the abyss and the source (around 1425 m).

The limestones of Upper Jurassic age in this area are very karstified with a branched network of underground channels and cracks along which groundwater moves.

The dominant direction of groundwater flow in this area is directed by two subparallel faults oriented northeast - southwest that are located between the Jezero abyss and the Salakovac springs. Since the dye is not recovered from the Klenovik spring, it can be concluded that the groundwater in the zone of Klenova draga flows under the elevation of the alignment, and not towards the south portal of the Prenj Tunnel.

Dye-tracer test at the location of Vrutak abyss

The Vrutak abyss is located on the Prenj mountain, west of the northern tunnel portal at an altitude of 1,500 m a.s.l. The abyss is found in the zone of the main fault. Na-fluorescein was injected in the sinkhole. The monitoring was established at six locations:

- Konjica Bijela springs (left and right arm),
- Konjicka Bijela stream,
- Bascica springs (Idbar),
- Buk spring, and
- Sanica spring.

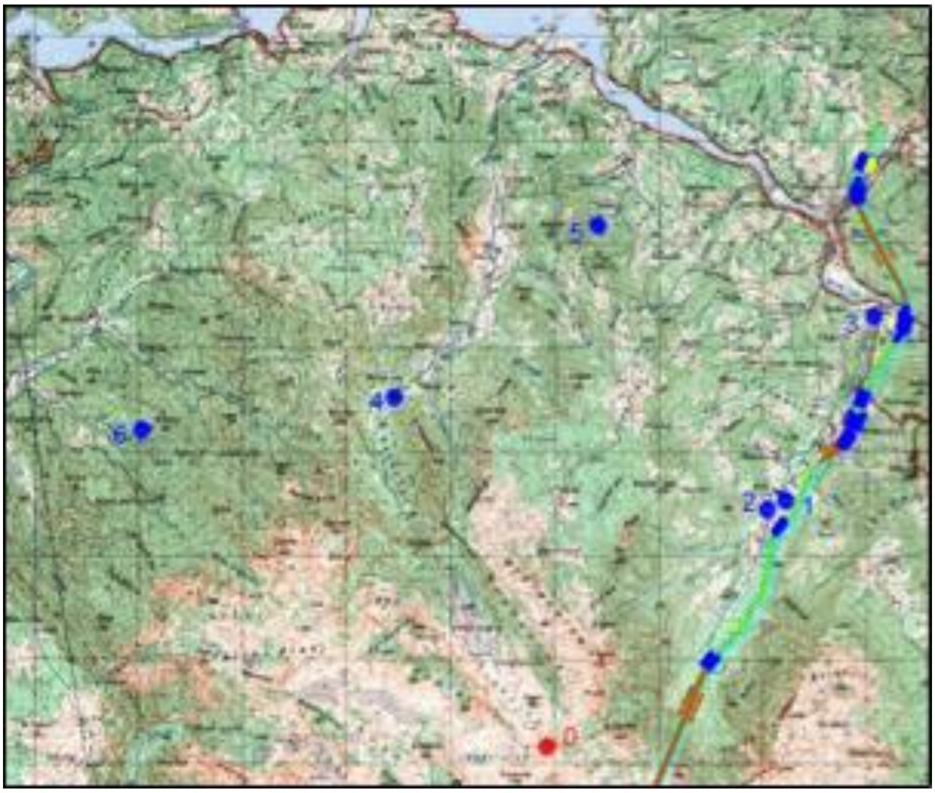


Figure 7-22: Place of dye injection at Vrutak (0) and monitoring locations (1-6)

The monitoring lasted for one months. The dye was first recovered from the Bascica spring, 14 days after the injection, and lasted for 16 days with maximum concentration on the day 12.

Next, the dye was recovered from the springs Sanica and Konjicka Bijela (right arm), 15 days after the injection. The dye in Sanica was visible for 10 days, and in Konjicka Bijela (right arm) for 13 days. The maximum dye concentration in Sanica was on the first day and in Konjicka Bijela (right arm) on the fifth day.

Finally, 23 days after the colouring, the colour was recovered from the springs Konjicka Bijela (left arm) and Buk. The dye in Konjicka Bijela spring (left arm) was visible for 5 days, and in the Buk spring for 6 days. Interestingly, the maximum concentration in both springs was observed on the third day in approximately equal concentrations.

Based on the test results, the fictious groundwater velocity between the Vrutak abyss and the monitoring points was calculated to be as follows: Sanica 0.766 cm/s; Bascica 0.611 cm/s; Buk 0.508 cm/s; Konjicka Bijela (right arm) 0.481 cm/s and Konjicka Bijela (left arm) 0.332 cm/s.

Dye-tracer tests at the Vrutak abyss revels complex hydrogeological relationship in this area. The Vrutak abyss is located on the main fault with Middle and Upper Triassic limestones and dolomites ($T_{2,3}$) in the northeaster and Central Jurassic limestones (J2) in the southwestern wing of the fault. This tectonic assembly and lithostratigraphic rock composition defines hydrogeological relations including position of Vrutak abyss and dye recovery locations (springs) and their position inside subbasins. Vrutak is located at the highest part of the Basice basin (Idbar), Sanica is in the Glogosnica sub-basin, and Buk is located on the borderline in between the Idbar subbasin in the west and Konjicka Bijela in the east.

The maximum fictitious groundwater velocity of 0.766 cm/s (662 m/day) is obtained between Vrutak and Sanica. Since the highest dye concentration was observed only a day after the first appearance, it clearly indicates that the circulation of groundwater is carried out in the epikarst zone (a thin zone near the karst surface). It is also a well-known fact that heavy rains and sudden snow melting cause turbidity in the Sanica spring which supports this conclusion. The dominant hydraulic connections are also established toward Bascica (Idbar) and Buk, while the water movement towards Konjicka Bijela are less pronounced and are expressed differently in different hydrological conditions.

Since the Vrutak abyss is found on the borderline between several sub-basins, and due to complex geological-tectonic terrain structure and hydrogeological relations, it can be concluded that underground bifurcation is present (movement of water from one basin to another under different hydrological conditions).

These results undoubtfully indicate that the groundwater from this area is mainly drained west and north toward the Neretva River, and not toward the Prenj Tunnel. This is particularly evident for groundwater moving through the epikarst zone. Since the Vrutak sinkhole is located in an area with underground bifurcation and where the main fault crosses the Prenj Tunnel route, it is expected that groundwater will appear along the fault zone in quantities dependent on hydrological conditions.

Dye-tracer test at the location of Veline Bare

The Veline Bare abyss is located on the Prenj mountain, east of the tunnel at an altitude of 1,560 m a.s.l. The abyss is found in the zone of the main fault. Na-fluorescein was injected in the sinkhole. The monitoring was established at four locations:

- Salakovac sources,
- Klenovik spring,
- Mostarska Bijela stream, and
- Bosnjaci spring.

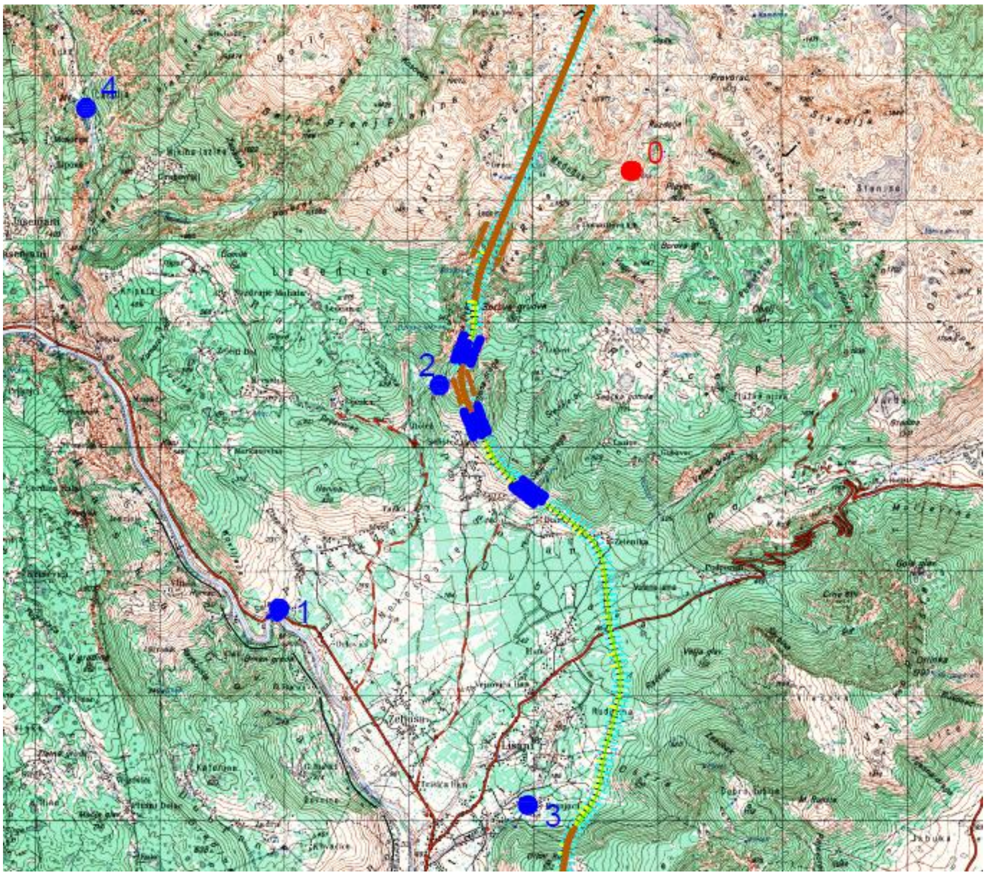


Figure 7-23: Place of dye injection at Veline Bare (0) and monitoring locations (1-6)

The monitoring lasted for one month. The dye was not recovered from any of the locations.

Dye-tracer test at the Veline bare abyss did not reveal underground connection with any of the four monitoring locations. The reason may be the low level of groundwater in the Prenj massif so that the dye remained trapped in underground caverns until the heavy rains feeds the underground systems and discharge the coloured water at the springs. It would be advisable to continue monitoring until the hydrological situation changes and precipitation drains the caverns. On the other hand, this result indicates that in the period of low and medium flows there is no significant groundwater flow in the Prenj Tunnel zone.

The following paragraphs present results of dye-tracer tests performed in the period 1980-2000.

Dye-tracer test in the Hansko polje field

In 1981, the dye-tracer test was carried in the framework of hydrogeological research of the Bosnjaci spring[19]. The Na-fluorescein dye was injected in an abyss in the Hansko polje field, located east from the tunnel alignment at an altitude of 840 m a.s.l. This test indicated direct connection between the abyss and the Bosnjaci spring, the temporary spring Livcina and the Buna spring (located 23 km from the abyss).

The dye was recovered from the Bosnjaci spring after 21 days, from Livcina spring after 22 days and from the Buna source after 13 days.

Based on the test results, the fictious groundwater velocity from abyss in the Hansko polje field to the springs Bosnjaci and Licina was calculated to be 0.7 cm/s (605 m/day), while the velocity to the Buna spring is 2 cm/s.

During the detailed hydrogeological research of the Bosnjaci spring in 1999, the tracer tests were carried out on the side of the spring, at the borehole NB-3 located 25 m from the spring. Na-fluorescein was injected to the borehole. The dye was recovered from the spring after 65 minutes so the calculated fictious groundwater velocity was calculated to be 0.65 cm/s. This velocity corresponds to the calculated groundwater velocity between the Hansko polje field and the Bosnjaci spring.

Dye tracer test at the Hansko polje filed reveals that the dominant direction of groundwater flow is from the Hanjsko polje field, over Donje Zijemlje toward Buna spring, while certain quantities of water are also discharged at the Bosnjaci and Livcina springs. The groundwater dominantly moves is the south-east direction along the normal fault that extends toward the Buna spring. A part of these waters drains at the Bosnjaci and Livcina springs via a perpendicular fault. The obtained fictious groundwater velocity of 0.7 cm/s (605 m/day) is influenced by the terrain geology, consisting of limestones of Jurassic and Cretaceous age that are full of faults and highly karstified.

The general information about historical dye-tracer tests in the area of Bosnjaci can also be found in the literature but without a detailed description. In the *Study on Protection of the Bosnjaci Spring*, prepared by the Civil Engineering Faculty in 2003, it is mentioned that "a part of water that flows from Donje Zijemlje to the Bosnjaci spring in the Bijelo polje field, drains toward temporary spring Livcina in the settlement of Livac (determined by dye-tracer

[82] Protection of the Bosnjaci Spring – Mostar. Civil Engineering Faculty of Sarajevo, Institute of Geology, 2003.

tests)….Groundwater that exists in karstified fluvioglacial rocks of the Bijelo polje field (the Bosnjaci settlement) moves from the village Gatali toward the Bosnjaci spring (determined by dye-tracer tests)."

Dye-tracer test in the zone of Salakovac springs

For the purpose of establishing connection between hydropower plant (HPP) Salakovac and the Salakovac spring, in1980-ies the tracer tests were carried out. The Na-fluorescein dye was injected in the abyss located 200 m upstream from the dam and in the piezometers found close to the HPP reservoir. The test results indicated direct connection with Salakovac spring (spring next to the mechanical house, middle springs on the "S" curve and most distant wells located downstream). The tests were carried out before the first rehabilitation of the abyss, after the first rehabilitation and after second rehabilitation The calculated fictious groundwater velocity between the abyss and the middle springs near the "S" curve was 6.33 cm/s before the first rehabilitation and 1.86 cm/s after second rehabilitation of the abyss[20].

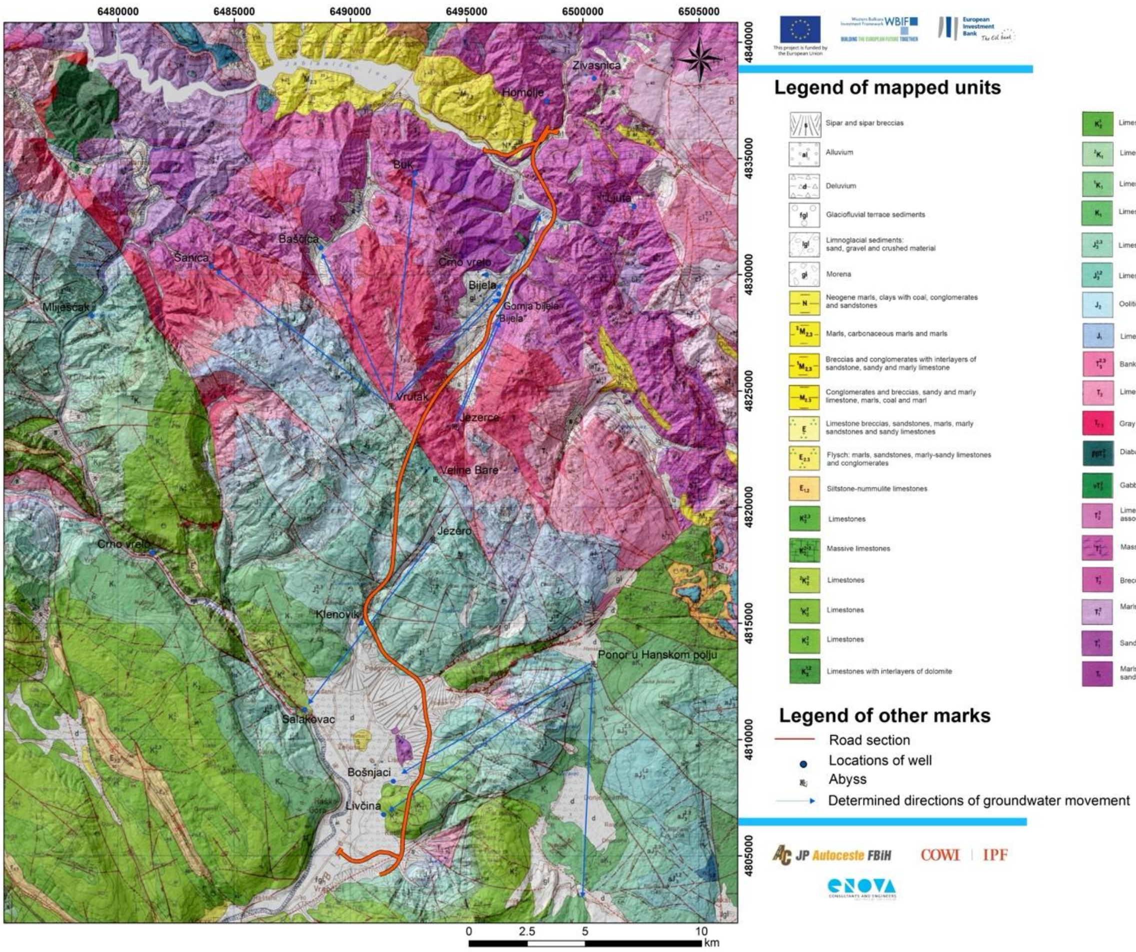
Dye tracer test revealed direct connection between HPP reservoir with Salakovac springs. The springs' yield is highly depended on the water level in the reservoir and the level-flow dependency curve is established. According to the Report prepared by Integra in 2007[21], when the reservoir is full and in the hydrological situation of extreme low flows in the basin, 0.5 m^3/s of water drains from the basin and 24.5m^3/s from the reservoir. This means that in unfavourable hydrological conditions of low flows, only 2% is drained from the basin. When the reservoir is full and in the situation of medium flows in the basin, 3.35 m^3/s or 13.4% of water drains from the basin and 21.65 m^3/s from the reservoir. In the situation of extreme high flows in the basin, hydrodynamic relationships are considerable different which impacts the direction of water flow. The hydrodynamic pressure in karst massif increases, so that both springs and the reservoir are fed from the basin.

The general direction of groundwater flow on the Prenj mountain (the wider area around motorway alignment) is conditioned by the position of the main Dinaric fault that extends in the direction northwest-southeast and secondary faults that are perpendicular to the main one. This fault zone in the northeast wing is represented by Upper Triassic limestones, and dolomites ($T_{2,3}$) and Middle Jurassic limestone (J_2) in the south-west wing. Thus, groundwaters of the north-east wing mainly gravitate towards Konjicka Bijela, Buk and Sanica in the direction of northwest, north and northeast, and not in the direction of the Prenj Tunnel. Groundwater of the southwest wing gravitate toward Salakovac and Crno Vrelo in the direction of southwest, and not in the direction of the Prenj Tunnel. Therefore, **this fault zone cause groundwater on the Prenj mountain to generally move toward Konjicka Bijela and Salakovac springs.** Since the groundwater flow in this area is under direct influence of hydrological situation, it cannot be excluded as a possibility that in the period of

[20] Integra Ltd. Mostar (2007). Project of additional investigative work and preparation of expert study and project of protection of water sources of the Salakovac springs.
[21] Ibid.

high flows, groundwater overflows from one basin to another and starts moving toward the Prenj Tunnel.

The map of the direction of groundwater movement determined by dye-tracer tests is given in Figure 7-24.



The map was made according to the author's originals OGK SFRJ 1: 100 000, sheets Prozor K33-12, Sarajevo K34-1, Mostar K33-24, Kalinovik K34-13

Figure 7-24: Determined direction of groundwater movement

7.2.4.5 Groundwater balance

Konjicka Bijela and Salakovac springs

According to the hydrological calculations performed by Winner Project[22], the average quantity of water that drains toward north portal of the Prenj Tunnel (in the area of Konjicka Bijela) is equal to 0.81 m^3/s, while the average quantity of water that drains toward south portal (in the area of Salakovac springs) is 3.35 m^3/s. Expressed in percentages, this makes 23.3% of water existing in the Prenj in the medium flow season. During the middle flow season, 4.16 m^3/s of water

[22] Results of geophysical, hydrogeological, and hydrological investigation in the framework of supplemental detailed geological, engineering-geological, geotechnical, geophysical, hydrological, and hydrogeological research and investigation on the section Konjic (Ovcari) – entrance to the Prenj Tunnel, Winner Project, 2022

flows from the part of Prenj massif around the area of Prenj Tunnel, that belongs to the basins of Konjicka Bijela and Salakovac springs. During the low flow season (2-yearly flows), 0.149 m^3/s drains towards the northern portal (Konjicka Bijela) and 0.5 m^3/s toward the southern portal (Salakovac springs).

The total maximum quantity of water, showing once in 2 years, that drains from the Prenj massif amounts to 95 m^3/s. 32.8 m^3/s or 34.5% of total amount of water that can be found on the Prenj Mt. in the high flow season drains from the basins of Konjicka Bijela and Salakovac springs.

In case of extreme high flows, the groundwater flow in the tunnel area will not significantly increase. That is because the groundwater flow is restricted by dimensions of underground karst caverns and channels, so the increased quantities of water in the basin will also generate increased surface flow from the Prenj area.

The quantity of water at Konjicka Bijela and Salakovac springs in the high flow season can be slightly increased compared to the above presented amounts. However, regardless of the quantity of water in the Prenj area at certain period of time, the karst channels though which these springs receive and drain water have limited permeability. This will limit the groundwater quantity that penetrates the tunnel tube, at the same time increasing the time needed for water to drain from the tunnel tube.

Regardless of possibility to get the high quantities of water in the Prenj area, the groundwater flow discharge from the Konjicka Bijela and Salakovac springs will not change significantly. The reason is limited capacity of the underground reservoir and karst conductors. The increase in surface flow in the Konjicka Bijela basin can be expected, but this will not have any significant impacts on the groundwater quantities.

The Prenj area has very scarce surface hydrography network, and the water dominantly flows underground toward two discharge points: the Konjicka Bijela and Salakovac springs. Several smaller springs can also be found in the area, but they are of smaller, almost negligible capacity. The Crno Vrelo spring is also found in this area, located west of the Salakovac springs and at the higher altitude.

Konjicka Bijela and Salakovac springs origin at two opposite sides of the Prenj Tunnel; Konjicka Bijela is found north and Salakovac springs south of the tunnel. Both springs discharge at several locations. The elevation of Konjicka Bijela springs is from 400-500 m a.s.l. and Salakovac springs from 90-100 m a.s.l.

According to the test results, highest groundwater flow is at the Salakovac springs and the Crno Vrelo spring found at elevations of 90 m a.s.l. and 115 m a.s.l., respectively. These two springs are most dominant points of groundwater discharge in the south section of Prenj.

Bosnjaci spring

The yield of Bosnjaci spring is determined based on a comparative analysis with the Radobolja spring that has very similar characteristics. The average annual flow is 0.325 m^3/s with maximum yield being 0.445 m^3/s and minimum being equal to 0.204 m^3/s [23].

The yield measurements were performed several times in different hydrological conditions. During September and October 1988, in the low flow period, the testing was performed in the hole that was dug in the zone of the main spring. For reduction in water level of 181 cm, the obtained yield was 0.24 m^3/s, while at the same time the spring discharge was 0.147 m^3/s.

The same testing was performed end of June-beginning of July 1999 in the period of low medium flow. For the reduction of 131 cm the obtained yield was 0.249 m^3/s. Before the test, the measured yield of the aquifer and the well near the spring was 0.201 m^3/s.

The comparative analysis of these two tests indicates the clear dependence of the spring yield and hydrological conditions.

In September and October 2022, during construction of the water intake structure on the Bosnjaci spring, the regular flow measurements were performed in an open channel. Depending on the hydrological conditions, the yield varied between 0.205-0.43 m^3/s.

7.2.5 Chemical Status of Groundwaters Along the Main Motorway Route

The latest report on the chemical status of groundwaters in FBiH was published in 2021[24]. The determination of chemical status of groundwaters was made in accordance with the criteria given in the Annex 8 of the *Decision on the characterisation of surface and groundwater, reference conditions and parameters for the assessment of water status and monitoring of waters and biotic characteristics of rivers in the water area of the Adriatic Sea*[25], which is aligned with the EU Water Framework Directive.

The monitoring was performed at the Bosnjaci and Salakovac springs but also at the Ljuta and Sanica springs for which it is determined that they will not be under the impact of the Project.

The general chemical status of all four springs is determined as “good”.

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[23] Civil Engineering Faculty in Sarajevo, Institute for Geology (2003). Protection of the Bosnjaci spring - Mostar.
[24] Report on the state of surface and groundwater quality in the water area of the Adriatic Sea in the FBiH for Year 2020 (Agency for Watershed of the Adriatic Sea, Mostar December 2021).
[25] Official Gazette of the FBiH No. 1/14

7.3 Assessment of Potential Impacts

7.3.1 Guidelines for Impact Assessment

During the analysis of the impact on groundwater, which was carried out in this chapter, the guidelines given in the Decision on the Implementation of the Plan of Special Features of Importance for the Federation of BiH "Highway on Corridor Vc" for a period of 20 years[26], that is, Article 2, point 4 and Article 20, which prescribe the conditions of use, arrangement, construction and protection of the area covered by the Plan, and promote the application of valid regulations in BiH and FBiH in the field of water protection. Article 20 states that special attention should be paid to water sources that are used or planned to be used for public water supply and their protection zones, whereby the protection zones are determined in accordance with the secondary legal act in the FBiH that prescribes the conditions for determining sanitary protection zones for water sources that are used or are planned to be used for drinking water, and on the basis of investigative hydrogeological works, and requests that drainage and protection solutions adapted to the requirements of the given level of water protection are defined through technical documentation.

In addition, in the definition of sanitary protection zones and the analysis of the impact and the definition of appropriate protection measures, the data and guidelines given in the recent Studies on the protection of the Salakovac and Bosnjaci water sources (Zavod za vodoprivredu Sarajevo, 2022), the *Decision on the protection of the Salakovac springs*, which was published in the Official the Gazette of the City of Mostar in 2023 (No. 14/23) and the Previous Water Consent issued by the Adriatic Sea Watershed Agency Mostar (No. UP/40-1/21-2-129/21 dated 15.3.2022)[27].

It should be noted that the Decision on the Protection of the Bosniaci water source is in the process of being adopted by the Council of Ministers, given that it is an inter-entity spring. The Konjicka Bijela water source, which is under the jurisdiction of the water supply company from Konjic, does not have a Protection Study or a Decision on the protection.

The same documentation was used during the analysis of the impact on surface water.

7.3.2 Overview of Potential Impacts

In the construction phase**,** two types of impacts can be expected:

- impact of groundwater on motorway construction, and
- impact of motorway construction on groundwater.

[26] Official Gazette of the FBiH, No. 100/ 17
[27] Studies and Decisions on protection can be obtained from City of Mostar i.e. water supply company Gospodarsko drustvo Vodovod d.o.o. Mostar

The main *impacts of groundwater on motorway construction* are related to the interference of tunnels construction with groundwater. Tunnelling beneath the groundwater table may cause changes in the state of stress and the pore water pressure regime. The groundwater inflow during tunnelling significantly hampers the tunnelling works, thus resulting in an increase in the construction costs. Also, the change in the pore water pressure regime during the tunnelling process can affect the tunnel stability. It puts the excavation face stability at risk and could cause a collapse of the tunnel cavity which is also a safety risk for workers.

The main *impacts of motorway construction on groundwater* resources are related to potential impact of construction works on groundwater flow, recharge, and quality.

During the tunnelling works, it is possible to encounter fractures or voids through which the groundwater is migrating and influence changes in the water flow regime. This in turn can impact the volume and quality of groundwater which is especially important if the water is feeding springs used for water supply.

Another potential impact on groundwater is the impacts from the blasting works. The significant blasting works are planned in this Project for creation of cuts and notches in rock masses, excavation of foundation pits for bridge piers and blasting works in tunnels. Blasting works can be linked to disturbance of groundwater courses, which is why they are considered in the impact assessment.

Unplanned released of emissions from the construction site in the immediate vicinity of springs can negatively impact the groundwater quality. These includes releases such as:

> Accidental spillages during e.g., change of machine oils and lubricants at the construction site, spillages from the storage site, etc.
> Wastewater from concrete batching plant and asphalt mixing plant,
> Sanitary waters from workers’ camps, and
> Inappropriate disposal of different types of wastes.

In the operation phase**,** the main impacts on groundwater resources are related to potential negative impact of motorway use on groundwater flow, recharge, and quality. These impacts are caused by permanent cutting the surface and underground streams by motorway structures and uncontrolled discharge of wastewater in the immediate vicinity of springs such as:

> intercepted surface run-off which is usually contaminated with fuel, oil and lubricants leakage, tyre ware, dust, wind-borne particles, different pollutants settling from the atmosphere and defrosting salts and gravel of small granulation used in winter maintenance activities,
> spill over of surface runoff not intercepted and treated by drainage system, usually occurring in case of floods,

> direct release of sanitary water from toll station and resting areas,
> accidental spill of hazardous material (e.g., oil and oil derivatives, hazardous chemicals, etc.) resulting from traffic accidents. This impact has been estimated as a lifelong Project impact.

The detailed assessment of potential impacts is given in the following chapter.

Here is to be noted that by polluting groundwaters, polluting substances can also reach open streams, and vice versa. For this reason, this chapter must be read in conjunction with *Chapter 8. Surface waters*.

7.3.3 Assessment of groundwater impacts on motorway construction

The great depth of karstification and the level of groundwater in many, especially karst areas, enables the construction of underground facilities above the groundwater level, where surface flows are limited and there is rapid infiltration of stormwater.

In the karst of Eastern Herzegovina, the base of karstification is located at depths of about 250 to 300 m, where the rock mass is the most intensively karstified and with the highest porosity from the surface to the depth of 20 m (epikarst zone).

Experiences in the excavation of traffic and hydraulic tunnels in the karst terrains of the Dinarides (examples from Montenegro, Herzegovina and Croatia) show that developed karst channels with dominant constant or intermittent groundwater flow are present in the immediate hinterland of karst springs. By cutting through those karst channels, the tunnel tube will drain groundwater and will often get flooded. This mostly happens during heavy rainfall and lasts until the rainfall stops.

When the tunnel excavations are at significantly higher elevations than the groundwater discharge zones, significant appearance of groundwater in the tunnel tubes are very rare. In such conditions, groundwater mainly appears in the form of dampening or throughfall, and rarely in the form of a weak leak. Zones with such groundwater occurrences coincides with pronounced fault zones in karst terrains. By cutting underground caverns and karst channels at elevations higher than the zone of groundwater discharge, tunnel tubes are mostly dry, and only during heavy rainfall does the groundwater occur in the form of dampening or throughfall.

In case of the Prenj Tunnel, the thickness of the overlying layer is up to 1350 m, and the elevation of the tunnel is below the assumed zone of karstification.

Based on the forecast hydrogeological profile of the terrain[28] along the route of the future Prenj Tunnel (Figure 7-25), the complete excavation of the tunnel will be through karstified limestones of Mesozoic age, except for the entrance portal, which will partly be in talus deposits.

Excavation of the Prenj Tunnel will predominantly be in rocks with karst type porosity, and a smaller part through rocks of karst-fissure porosity (Figure 7-25).

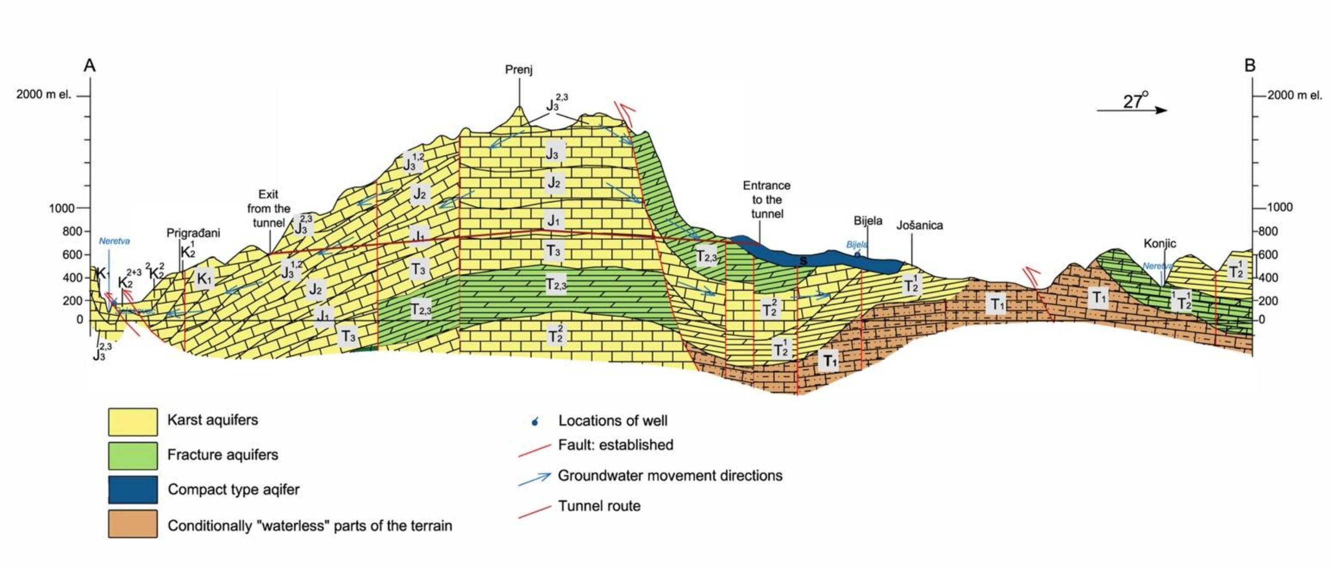

Figure 7-25: Prognostic hydrogeological profile of the terrain along the route of the future Prenj Tunnel[29]

Based on the available design documents and results of engineering and geological researches carried out so far for the purposes of designing the Prenj Tunnel, which were limited to portal zones and surface mapping of the terrain (without exploratory boreholes along the tunnel route), it can be concluded that <u>the elevation of the tunnel will be above the impermeable subgrade represented by Lower Triassic flysch sediments, which is a barrier to the movement of groundwater.</u> A conditional barrier to the movement of groundwater along the route of the tunnel is represented by dolomites of the Middle and Lower Triassic, especially in the zone of the entrance portal.

One third of the Prenj Tunnel excavation (entrance on the Konjic side) will be carried out in the north-eastern wing of the large fault whose groundwater gravitates towards the springs of Konjicka Bijela, Idbar and Sanica, as proved by groundwater dye-tracer tests (Figure 7-14). The remaining two-thirds of the tunnel excavation will be carried out in the southwestern wing of the large fault,

[28] Results of geophysical, hydrogeological, and hydrological investigation in the framework of supplemental detailed geological, engineering-geological, geotechnical, geophysical, hydrological, and hydrogeological research and investigation on the section Konjic (Ovcari) – entrance to the Prenj Tunnel, Winner Project, 2022
[29] Ibid.

whose groundwaters are dominantly gravitating to Salakovac springs and probably Crno vrelo spring (Figure 7-14).

The hydrogeological relations on the Prenj Mt. indicate that there should be no significant penetration of high-volume groundwater during excavation of the Prenj Tunnel. The groundwater penetration can be expected only in the main fault zone, where underground karst forms (caverns, pits, karst channels) are found. The groundwater may appear in the form of dampening, throughfall or weak leakage and only during periods of heavy rainfall and sudden melting of snow on the Prenj massif.

During the excavation of the Orlov Kuk Tunnel - T5, which is located in the hinterland of the Bosnjaci spring, underground karst channels carrying groundwater from the direction of Zijemlje towards Bosnjaci may be cut off. In the case of such a scenario, it is necessary to prevent the contamination of the groundwater of the Bosnjaci spring. If turbidity of groundwater occurs at the water source, it is necessary to stop the water supply for the village until the quality of the water is brought to the quality prescribed by law.

In the case of cutting off underground streams during tunnel excavation appropriate engineering measures should be implemented as explained in section 7.4.

7.3.4 Assessment of construction impacts on groundwater

The motorway route passes through the sanitary protection zones of two important and very sensitive sources, Salakovac and Bosnjaci, as well as in the immediate vicinity of the Konjicka Bijela source, where negative impacts on groundwater could occur during the construction phase.

The impact with highest probability of occurrence during the execution of the construction works is potential increase of **water turbidity at the source of drinking water supply**. Additionally, **accidental pollution** caused by activities on the construction site near the water sources is possible (although this can be mitigated through strict management of materials and pollution prevention plan).

It should be emphasised that this type of pollution (turbidity) is not permanent, so after the termination of the works, with the application of adequate measures for the protection of excavation, followed by proper drainage, this phenomenon would be reduced or would disappear completely.

Another potential impact on groundwater is the **impacts from the blasting works.** The assessment of this impact during the construction phase can only be given in general, based on experiential knowledge.

As the blasting works on the referenced section are expected for creation of cuts and notches in rock masses, excavation of foundation pits for bridge piers and blasting works in tunnels, it is rather common that blasting works are linked with disturbance of groundwater courses. However, under normal blasting conditions this is unlikely to expect.

The watercourses are formed in sufficiently porous and permeable rock mass, which enable unhindered access and flow of water. Reservoirs are mostly filled by atmospheric precipitation (rain, snow) seeping into the porous rock mass below the surface. The blasting can cause water turbidity on nearby springs/wells. This is a temporary phenomenon and can be considered a temporary nuisance. Vibration levels below 5 cm/s are insignificant and cannot cause damage to the well or aquifers.

Chapter 7.2.4.3 presents the hydrogeological zoning of the terrain of the wider area of the Konjic (Ovcari) - Prenj Tunnel - Mostar North motorway route, where three main hydrogeological areas are distinguished based on the geomorphological, geological, hydrogeological and structural-tectonic characteristics of the terrain, within which hydrogeological zones and lower order units are set aside. The following paragraphs refer to the assessment of impacts in relation to the previously presented hydrogeological reionisation of the terrain.

Hydrogeological area Bjelasnica

The start of the Konjic (Ovcari) - Prenj Tunnel - Mostar North motorway route is north of Konjic in the hydrogeological area of Bjelasnica. Through this hydrogeological area, the motorway route includes the Ovcari Interchange, then bypasses the town's urban settlement on the north-eastern side and crosses Tresanica and the industrial zone over the Viaduct No.3. Then the route continues to the southwest and with two tunnels T1 and T2, between which there is an embankment about 200 m long, bypasses Konjic, after which the route emerges above Gornje polje and crosses the Neretva River over the Viaduct No.4.

The hydrogeological area of Bjelasnica is characterised by rather simple relations, where groundwater from the Triassic outcrop is emptied at the Ljuta source. As the route of the motorway through this area is not in the catchment area of the Ljuta karst spring, which was previously confirmed by the groundwater tracer experiments using dye tracer[30], the construction and operation of the motorway will not have an impact on this spring. At the Ovcari side of the motorway, there are two sources of drinking water Zivasnica and Homolje, but the construction and operation of the motorway will not have an impact on them because their catchment areas are morphologically situated above and outside the axis of the motorway without possible mutual influence.

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[30] Results of geophysical, hydrogeological, and hydrological investigation in the framework of supplemental detailed geological, engineering-geological, geotechnical, geophysical, hydrological, and hydrogeological research and investigation on the section Konjic (Ovcari) – entrance to the Prenj Tunnel, Winner Project, 2022

Apart from the aforementioned sources used for water supply, there are no significant sources and wells used for water supply on the section of the motorway route through the hydrogeological area of Bjelasnica. There is a possibility that during the excavation of tunnels T1 and T2, which are located in this area, short-term minor water turbidity will appear at the sources located under the tunnel route on the right bank of the Neretva River. If there are wells in this area, short-term water turbidity is possible, provided that they capture groundwater from Triassic dolomites and dolomitic limestones from the massif through which the tunnels are made, and not groundwater from the Neretva alluvium. Whether there will be turbidity and to what extent, the previously described objects, depends on the current level of groundwater, in other words, whether it is a dry or rainy period of the year. This scenario is possible provided that the dolomites and dolomitic limestones are heavily faulted and cracked, which is unlikely.

It is suggested to conduct a field visit and record all hydrogeological phenomena in the zone of influence of the construction of this section of the motorway. A register of these phenomena can be made with the information on their baseline state. These actions are captured in the Environmental and Social Management Plan (Chapter 19.2, Measure 19.2.1).

In the section of the route after the exit from the T2 tunnel towards the right bank of the Neretva River, a number of small occasional intermittent sources appear draining groundwater from the southern slopes of Vrtaljica during the rainy season. The construction of the motorway will not affect these sources as they are not within the construction zone.

During the construction of the Konjic Bypass, which is a section of the motorway, there will be no impact on groundwater. There are no recorded sources of water supply in the area affected by the works, and the route mostly passes through impermeable Miocene sediments.

Hydrogeological area Prenj

After the motorway route, after crossing the left bank of the Neretva River, it continues south parallel to the village of Glavicine, then passes through the village of Lupoglav, where it crosses the regional road to Boracko Lake via the Viaduct No.5. The route continues south parallel to the valley of Konjicka Bijela over the eastern slope of the valley, where near the village of Mladeskovici is the Konjic South Interchange. Further, towards the south, the route continues in the embankment parallel to the village of Bijela, and then through the valley of Bijela to the slopes of the Prenj mountain, where the Prenj Tunnel begins.

From the Viaduct No.4 over the Neretva River to the Viaduct No.5 above the road to Borci, the motorway route is in a cut, or an embankment. On this section of the motorway, there will be no negative impact on groundwater due to the development of impermeable deposits of the Triassic in which there is not a single major occurrence of groundwater sources, and therefore no sources that are captured for the needs of the water supply to the population. In case of the existence of occasional sources or wells, which are located along the projected route, slight and sporadic water turbidity may occur, and only in periods of heavy rainfall, when due to a large amount of stormwater, material may be washed off from the cut or the embankment and transported towards lower elevations. In order to prevent the washing off of material from the motorway route to lower elevations, it is necessary to provide adequate protection by constructing water collectors with sedimentation tanks and separators.

Similar hydrogeological conditions exist in the construction zone of the Konjic South Interchange, where Triassic impermeable sediments are also present, so no impact of the motorway construction on groundwater is expected.

Further on, from the Konjic South Interchange to the entrance to the Prenj Tunnel, the motorway route was designed in an embankment along the eastern valley side of Konjicka Bijela. This section of the route passes over glacial (moraine) and talus deposits, which are built of slightly rounded pieces of limestone with crushed material and the presence of humus and clay particles. Groundwater flows much more slowly through such materials compared to karstified limestone. This variant of the motorway on the embankment is much more acceptable and more economical compared to the previous variant, which envisaged a route further east in the scree zone, where the upper section would be in the cut and the lower section in the embankment. In this way, the construction of a large number of retaining walls and geotechnical anchors required for the stabilisation of scree slopes was avoided.

As the route in the embankment follows the course of the Konjicka Bijela, it is necessary to ensure that there is no pollution of surface and groundwater during the construction and later during the operation of the motorway.

Four springs are located in the immediate vicinity of the route, of which two are captured for the water supply of Konjic (Bijela and Gornja Bijela), and two springs are used for local needs of about 30 households in the settlement of Gornja Bijela (Figure 7-26). Also nearby the route, there is a spring Streliste, which is captured for the needs of the company Igman Konjic, but it will not be endangered by the construction of the motorway (Figure 7-27).

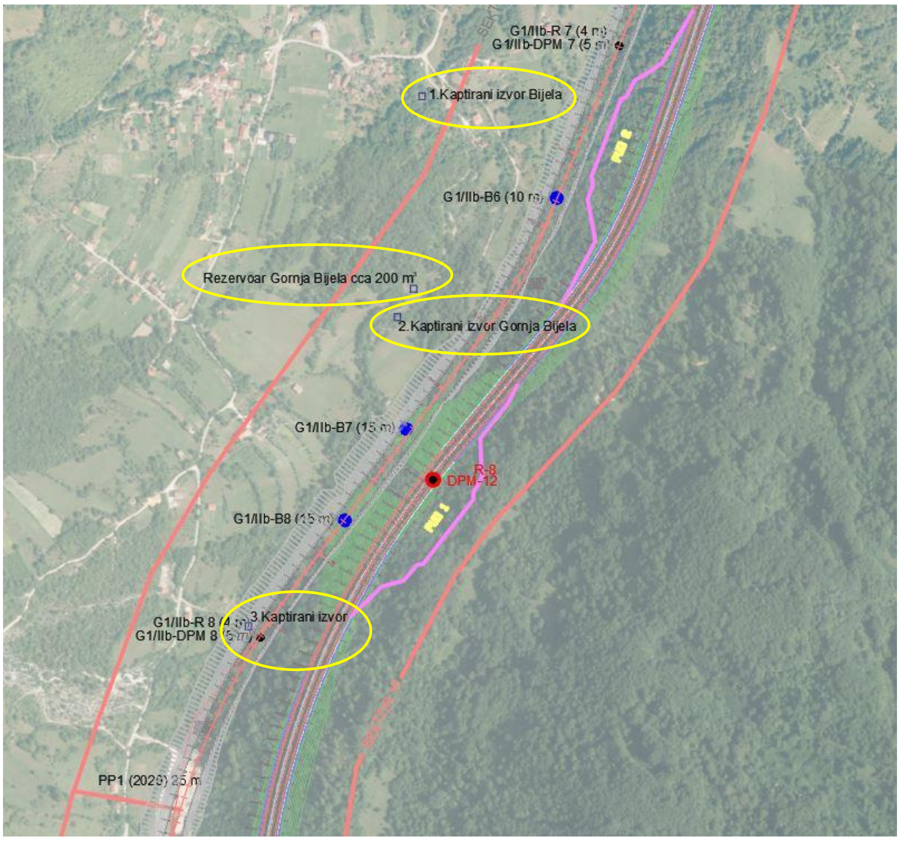

Figure 7-26: Position of the captured Bijela, Gornja Bijela and local springs (engl. "kaptirani izvor" = captured spring/water intake structure; "rezervoar" – reservoir)

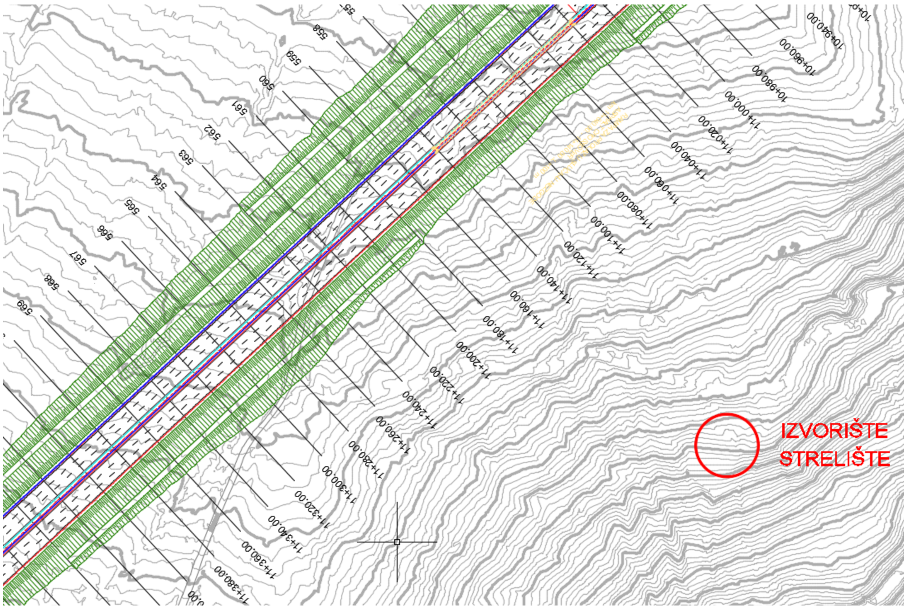

Figure 7-27: The position of the source of Streliste in relation to the position of the motorway

The captured spring Bijela is located about 240 m northwest of the route at 8+420 km, and the captured spring Gornja Bijela is located about 110 m northwest of the route at 8+800 km. The reservoir Gornja Bijela, with a volume of 200 m^3, is located about 70 m northeast of the Gornja Bijela spring.

The springs Bijela nad Gornja Bijela are captured for the water supply of Konjic and are managed by the Konjic Water Supply Company (Figure 7-28).

Figure 7-28: Captured Bijela spring

These springs have a secondary flow from moraine material, and a primary flow from Middle Triassic dolomites and limestone. They drain the Prenj massif, which belongs to the north-eastern wing of the great fault, as confirmed by dye-tracer tests in the Vrutak and Jezerce abysses (Figure 7-14)[31].

The springs used in the Konjic water supply system have not undergone detailed hydrogeological research and are not officially protected by sanitary protection zones. The absence of such information raises significant concerns regarding the protection of both the quantity and quality of the springs.

During the construction of the motorway and later during its operation, major negative impact on the springs of Bijela and Gornja Bijela are not considered likely because they drain groundwater coming from the Prenj massif. The route of the motorway through the valley of Konjicka Bijela to the Prenj Tunnel is designed on an embankment so that there will be no works on slope excavations and blasting that could affect groundwater. The construction works include the removal of humus material, possibly its replacement and the construction of an embankment. During these works, it is important to take all measures to avoid any unplanned discharge of oil or oil derivatives into the environment and minimise the risk of groundwater pollution. Additionally, regulation of the natural course of the river Bijela is planned for a length of about 600 meters, which will further ensure that the intake is not endangered (Figure 7-29). Any discharge of

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[31] Results of geophysical, hydrogeological, and hydrological investigation in the framework of supplemental detailed geological, engineering-geological, geotechnical, geophysical, hydrological, and hydrogeological research and investigation on the section Konjic (Ovcari) – entrance to the Prenj Tunnel, Winner Project, 2022

precipitation water from the asphalt surfaces of the motorway must be conducted downstream of the Crno Vrelo intake through pipes. These actions are captured in the Environmental and Social Management Plan (Chapter 19.2, Measure 19.2.4).

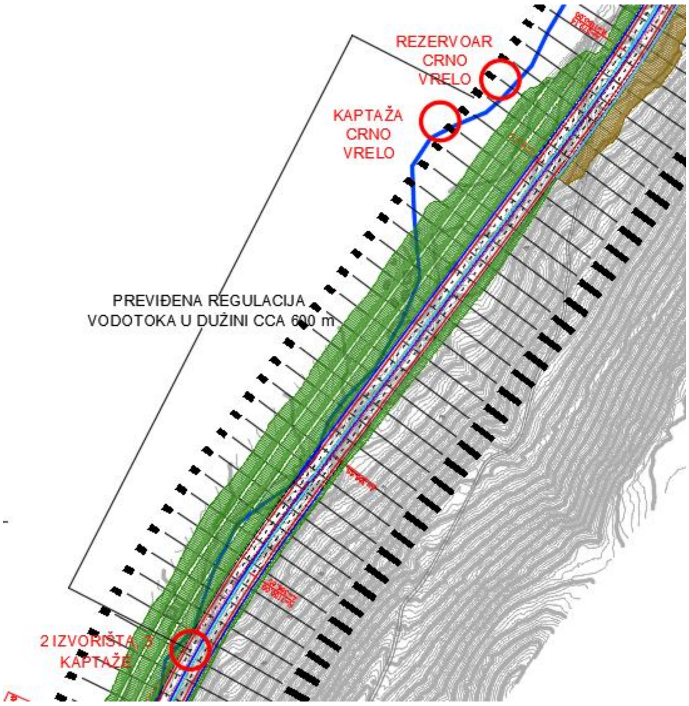

Figure 7-29: The regulation and position of the intake and reservoir are planned

To effectively treat collected precipitation water, the installation of oil and light liquid separators at strategic locations, following established engineering practices, will be required. In a ratio of 1/10, the water is purified according to EN858, and the rest overflows into the bypass. In the zone of the captured sources, separators with 100% purification will be used. In addition, a tanker truck is provided in case of incidents and spills of hazardous materials on the highway. So, in case of an incident, i.e., fuel spill from a tanker truck, the separators will detect that a concentrated liquid is coming and automatically close the float valve. This will cause all the liquid to divert into a specially designed 50 m^3 tank. The capacity of this tank is sufficient to collect and transport the liquid, as well as the liquid from the vehicle's own tank.

Treated stormwater has to be discharged out of the Bijela and Gornja Bijela springs' influence area. These actions are captured in the Environmental and Social Management Plan (Chapter 19.2, Measure 19.2.5).

The local spring captured for the needs of up to 30 households in the Gornja Bijela settlement is located on the very motorway route at 9+340 km. The water intake structure was built by the local population and is not managed by the Konjic Water Supply Company.

Figure 7-30: The position of the captured local spring

Figure 7-31: A captured source in the Suhi potok riverbed for the needs of the local population

Considering that the local source is located along the motorway route, with the technical solutions that will be implemented as part of the motorway, it is necessary to preserve these sources. The problem will be solved by designing culverts in the embankment or support structures that will protect the existing sources and intakes, thus preventing them from being disturbed.

In case of unforeseen circumstances, the local population will be connected to the Gornja Bijela reservoir for an alternative water source managed by the Konjic Water Supply Company. This action is captured in the Environmental and Social Management Plan (Chapter 19.2, Measure 19.2.4).

For the purposes of the construction of the Prenj Tunnel, it is planned to construct access roads to the entrance (north) and exit (south) portals. The access roads will serve for the transport of workers and equipment, as well as for the transport of materials needed for the construction of the tunnel.

The access road to the entrance portal (Figure 7-32) is planned along the Konjicka Bijela valley, and it will mostly use the routes of the existing roads. During the construction of this road, there will be no need for blasting, but existing roads will be widened and filled with buffer and compacted. Due to the proximity of the Bijela and Gornja Bijela springs, which is used for the water supply of Konjic, special attention should be paid to the protection of groundwater. The access road must be fully paved with asphalt an include standard solutions for collecting and treating runoff (gutters, drains, manholes, oil and grease separators). The discharge locations must be foreseen downstream from the Bijela and Gornja Bijela springs. This action is captured in the Environmental and Social Management Plan (Chapter 19.2, Measure 19.2.4).

Figure 7-32: View of the entrance portal of the Prenj Tunnel

The access road to the exit portal of the Prenj Tunnel was designed from the trunk road in Salakovac via Prigradjani and Klenova Draga. Two-thirds of the access road passes through III and IV sanitary protection zones of the Salakovac spring (Figure 7-33)[32]. According to the Rulebook on sanitary protection from 2012[33] Construction of transport roads is permitted in these zones, provided that standard protection measures are applied in IV zone, and standard measures are enhanced with additional protection in III zones. For the construction of access road, the route of the existing local roads will be used, which must be widened and finally asphalted. The route of the access road is

[32] Study on protection of the Salakovac spring City of Mostar, Zavod za vodoprivredu, December 2022; Decision on sanitary protection zones and protection measures for Salakovac spring (Off. Gazette of City of Mostar, No. 14/23); Study on protection of the Bosnjaci spring City of Mostar, Zavod za vodoprivredu, December 2022
[33] Rulebook on the method of setting the conditions for determining sanitary zones and on protective measures for water sources used for public water supply (Official Gazette of Federation BiH no. 88/12)

laid over talus deposits and diluvial drifts, which in this area are of significant thickness and, in addition to crushed material, contain clay admixtures, which is very important from the point of view of groundwater protection. As the access road is located in the sanitary protection zone of the Salakovac source, it is necessary to fully pave the road with asphalt and include standard solutions for collection and treatment of the run-off (gutters, drains, manholes, oil and grease separators). The run-off that will be discharged into the recipient must have the quality defined by law so that it does not affect the groundwater of the Salakovac source and must be discharged out of the protection zone III in like with the requirements stipulated by the Preliminary Water Consent[34]. This action is captured in the Environmental and Social Management Plan (Chapter 19.2, Measure 19.2.4).

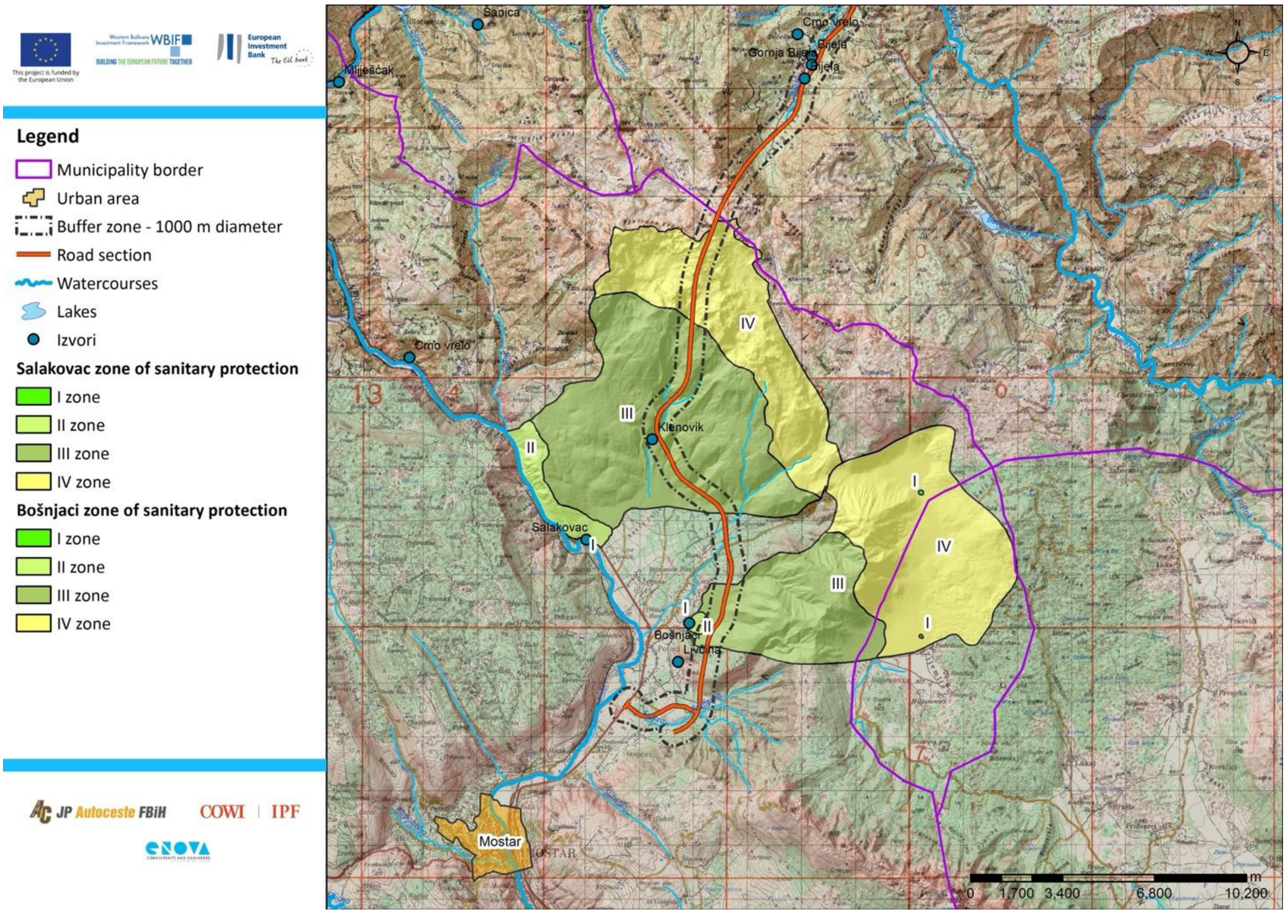

Figure 7-33: Sanitary protection zones of the Salakovac and Bosnjaci springs

Ending the route in the embankment, the motorway continues through the Prenj Tunnel for 12+400 km. With the Prenj Tunnel, the motorway route cuts through a large fault zone that divides the Prenj massif into a north-eastern wing built of

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[34] Previous water consent issued by the Adriatic Sea Watershed Agency (UP/40-1/21-2-129/21 dated 15.03.2022), paragraph 3.2.1: "In zones of high risk of water pollution, all water from the roadway collect and purify up to the level determined by the *Regulation on the conditions for the discharge of wastewater into natural recipients and the public sewage system* ("Official Gazette of FBiH", no. 26120, 96/20), without discharging treated wastewater within the high risk zone."

Triassic dolomites and dolomitic limestones and a southwestern wing built of Jurassic limestones (Figure 7-14). Roughly one third of the tunnel excavation was designed in carbonate rocks of Triassic age, and two thirds in limestones of Jurassic age. The dye-tracer tests carried out on Prenj established that groundwater from the north-eastern wing of the fault drains to the springs of Konjicka Bijela, Buk, Bascica and Sanica, while water from the southwestern wing is drained at Salakovac springs and probably at Crno vrelo spring (Figure 7-14). The results of the tracer experiments using dye tracer indicate that the circulation of groundwater from Prenj takes place in the epikarst and karstification zones.

As for the negative impact of the construction of the Prenj Tunnel on groundwater, it is only possible in the case of cutting off significant underground streams through which groundwater flows. Since the upper layer in the Prenj Tunnel is over 1,000 m, and the excavation is mostly done below the karstification zone, it is rather unlikely to expect such a scenario. Experiences in the excavation of similar tunnels in the karst terrains of the Dinarides demonstrate that karst channels with underground streams may appear in areas in the immediate vicinity of karst springs. Since the excavation of the Prenj Tunnel does not pass through the immediate vicinity of the karst springs, this scenario is also unlikely. The discharge of groundwater from the Prenj massif is mainly conditioned by the contact of permeable carbonate rocks with impermeable sediments located at lower elevations than the tunnel elevation, as well as along fault zones.

According to the available results of geological research, in the wider area of the motorway route through the Prenj massif, the Lower Triassic impermeable sediments are located well below the elevation of the tunnel (Figure 7-25), so the tunnel excavation will not be completed through the water-saturated zone, which is immediately located in the overlaying cover of the impermeable sediments. In the central part of the Prenj Tunnel, about 200 m below the elevation, there are dolomites of the Lower and Middle Triassic in the underlaying stratum of limestones, which, depending on the degree of faults and cracks, may represent a barrier to the movement of groundwater.

Nevertheless, the groundwater intrusion in the form of throughfall, seepage or rarely running water is to be expected along the fault, and especially along the main fault zone. In these cases, it is necessary to ensure that the run-off is adequately evacuated outside the tunnel so that they do not become polluted and, as such, get discharged into the environment. If the groundwater flow is cut off, it is necessary to provide the conditions for that water to continue its flow in the form of a bypass in order to reduce the impact of groundwater on the tunnel construction. For this activity, a water act is needed and the discharge will be performed according to the Water Permit.

About two-thirds of the excavation of the Prenj Tunnel is designed to be carried out through the IV sanitary protection zone of the Salakovac springs. Based on the previously described scenarios and the presented hydrogeological relationships along the route of the Prenj Tunnel, the excavation of the tunnel will not have an impact on the groundwater of the Salakovac spirings.

The dye-tracer tests at the Jezero abyss revealed the connection with the Salakovac springs and a fictitious groundwater velocity of 833 m/day was obtained. As the southern portal of the Prenj Tunnel is about 5.5 km away from the Salakovac springs in a straight line, any pollution from the tunnel can be transported by groundwater to the source in about a week. In order to prevent such a scenario from occurring, it is necessary to provide conditions for the receiving, draining and treatment of tunnel run-off and, after achieving the prescribed quality, their discharge into the recipient.

About 950 m southwest of the exit portal of the Prenj Tunnel, at an elevation of 470 m above sea level, there is the Klenovik spring. Given that its abundance is small in relation to the spatial position and the area it could drain, the works are not expected to affect its quality or quantity. This is supported by the fact that during the tracer experiments using dye-tracer test in the Jezero and Veline bare abysses, the dye did not appear on Klenovik[35].

Figure 7-34: Klenovik spring

After exiting the Prenj Tunnel, the road continues along an embankment about 100 m long, and then enters the Klenova Draga tunnel - T3A. From the tunnel, the route continues via the Viaduct No.8, whereupon it enters the Gradina tunnel - T4, which ends at a distance of about 300 m from the furthest houses of the village of Podgorani.

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[35] Assessed based on the flow speed provided in the Study on the protection of the Salakovac source, Zavod za vodoprivredu Sarajevo, December 2022

This is where the Viaduct No.9 over Badnjena Draga near Selista begins and runs parallel to the settlement. The route continues to the northeast of the settlement and extends along the ridges of the hills north of Podgorani, where the Viaduct No.10 over Seocka Draga begins, which is used by the route to cross into Dolac, north of Humilisani. Further on, the route continues in a slight semicircle around the Humilisani settlement over the slopes of Porim at a distance of about 800 m from the inhabited area. Here the route leaves the hydrogeological area of Prenj.

Tunnels T3A and T4, as well as the complete motorway route to Podgorani and Zelenika, were designed through karstified limestones of Jurassic age **within the III sanitary protection zone of the Salakovac source[36].** Between tunnels T3 and T3A, an embankment on scree material with good filtration characteristics was designed. In this area, during the period of heavy rainfall, surface torrential flows appear, emptying the limestone aquifers in the hinterland. Therefore, special attention should be paid to the embankment construction conditions so that there is no significant washing out and removal of the deposited material and thus water pollution. Since the base of the embankment has good filtration characteristics, any pollution is transferred much faster through the geological environment.

Tunnel T4 is located on the western side of the Klenova Draga canyon and its position does not affect the groundwater because it is located along the edge of the canyon and at the same time drains a very small area of the Prenj massif. During the construction of this tunnel, groundwater may occur in the form of dampening or throughfall, especially in the rainy season.

Tunnel T4 is positioned between two canyon valleys, Klenova and Badnjena Draga, which in this area represent local erosion bases for groundwater. For this reason, the construction of the tunnel is not expected to have an impact on groundwater, and especially not on the waters of the Salakovac source. If groundwater occurs, which cannot be in significant quantities, during excavation it is necessary to apply the previously described protection measures for the tunnels.

The construction of viaducts 8, 9 and 10 will not affect groundwater except in the possible situation of accidental releases when oil or oil derivatives may be spilled into the ground. Since there are occasional currents under these bridges in the period of high water, material may be washed away and carried away, so it is necessary to provide protection measures in these conditions, especially during the construction of the foundations of the supporting columns. First, oil collection tanks should be installed under machines. Second, if groundwater is pumped from foundation pits, it should be treated in oil and water separators before being discharged into the environment. Third, to prevent land erosion,

[36] Study on the protection of the Salakovac source, Zavod za vodoprivredu Sarajevo, December 2022 (pg. 76-85) and Decision on sanitary protection zones and protection measures for Salakovac source (Off. Gazette of City of Mostar, No. 14/23)

anti-erosion barriers should be installed. These actions are captured in the Environmental and Social Management Plan (Chapter 19.2, Measure 19.2.4). These activities are to be performed in line with the Water Permit.

The open route from Podgorani via Dolac and Humilisani is planned in a cut on the upper side and an embankment on the lower side through limestone and talus deposits. This section of the motorway route will have no impact on groundwater. The spoil disposal site at Gladno polje-Humilisani is located in this area, outside any designated water protection zone (Figure 7-35). On this section of the route, there are no sources of significant abundance that could be threatened by the works. At the same time, the scree contains crushed stone, humus, and clayey fractions, so the movement of groundwater through it is much slower than through carbonate rocks. On this section, the route leaves the III sanitary protection zone of the Salakovac source and thus the hydrogeological area of Prenj.

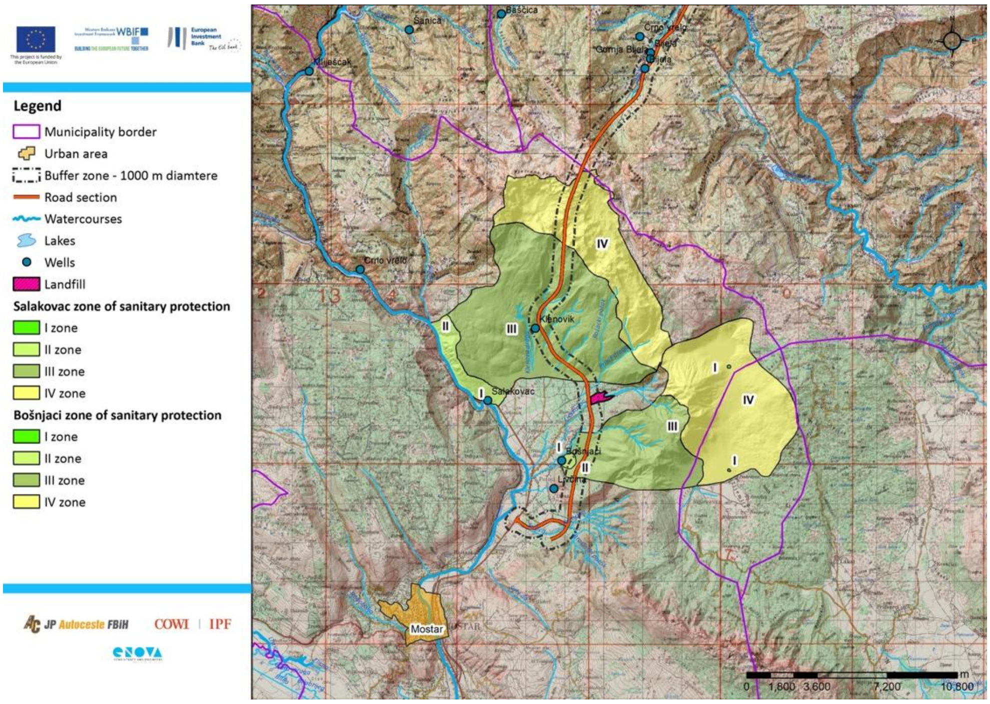

Figure 7-35: Humilisani spoil disposal site

Route of the motorway through the hydrogeological area of Velez

Below Humilisani, the route runs to the south and below Sljemen, it enters the Orlov kuk tunnel - T5, and then exits to the Kuti area, where the Mostar North Interchange has been designed. In this area, the route partly **passes through the III sanitary protection zone of the Bosnjaci source** (Figure 7-33)[37] in the form of cuts and embankments of insignificant height. To the entrance to the T5 tunnel, the route is laid over the scree, which are built of loosely rounded

[37] Study on protection of the Bosnjaci spring City of Mostar, Zavod za vodoprivredu, December 2022

pieces of limestone with crushed material and the presence of humus and clay particles. Just before entering the T5 tunnel, the route changes from scree to Upper Cretaceous limestone.

On this section, the route is designed in cuts and embankments, so there will be works on slope excavations and blasting that could affect the groundwater. During these works, it is important to take all measures to avoid any unplanned discharge of oil or oil derivatives into the environment, as well as water used in the phase of drilling boreholes. For this reason, it is necessary to take all measures to minimise the risk of groundwater pollution.

In the event that, during the construction of the motorway, a source gets polluted, it will be insignificant and short-term. However, an option for temporary disconnection of the source from the water supply network should be provided in the event of an incident. Groundwater will not affect the works during the construction of the motorway on this section of the route.

With the drainage project, it is necessary to ensure the collection, drainage, and treatment of stormwater from the future motorway. After the treatment of the stormwater, it is necessary to discharge it into the recipient Konjicka Bijela, which must be downstream from the Bosnjaci spring, so that there is no impact on the quality of the water from these sources.

Further on, the route continues through the T5 Orlov Kuk tunnel, whose entrance portal and about one-third of the tunnel length is located in the III sanitary protection zone of the Bosnjaci spring. The Bosnjaci spring is located about 850 m west of the entrance portal of the tunnel. Dye-tracer tests carried out in the catchment area of the Bosnjaci spring yielded a fictitious groundwater flow rate of about 600 m/day.

Tunnel T5 is the most sensitive location on the motorway route from the aspect of groundwater protection due to its proximity to the Bosnjaci spring. As the tunnel cuts through the limestone, karst channels and caverns can be expected to appear, which may be the underground streams of the Bosnjaci spring, as well as the occasional Livcina source, which is located in the immediate vicinity.

Therefore, it is necessary to pay special attention to collect the tunnel runoff, bring it out of the tunnel and treat it before discharging into the recipient. If caverns or karst channels appear, they should never be filled with excavated material or discharge point for tunnel runoff. In the event of an underground flow, it is necessary to create a bypass so that the groundwater can continue to circulate so that it does not exert pressure on the tunnel structure.

After exiting the tunnel, the motorway continues along an open route on the plains of Kuti, which ends before the Mostar North Interchange. There are no sources in this area, and no impact of the works on groundwater. Groundwater on this section of the route will not have an impact on the motorway and on the execution of works.

7.3.5 Assessment of impact on public springs

The Konjicka Bijela Spring are used for water supply in Konjic. This spring consists of two sources, Bijela and Gornja Bijela, which are located at a mutual distance of about 350 m, and the reservoir Gornja Bijela (Figure 7-14). The spring is officially not protected, and no sanitary protection zones have been established to date.

The motorway route passes (a) in the immediate vicinity of the two springs in the form of an open route embankment and (b) in form of a tunnel through the Prenj Mountain in the catchment area of the spring.

The motorway section along the Konjicka Bijela valley to the Prenj Tunnel is designed on an embankment, and the removal of humus and the construction of an embankment is foreseen as part of the construction work. Potential adverse impacts on the spring include impact on spring quality due to unplanned releases in the immediate vicinity of the spring.

One of the measures to reduce the impact of the motorway on this spring is the installation of waterproof foils before the embankment formation in order to prevent possible spills of harmful substances during the motorway construction phase and its subsequent exploitation. In order to reduce the impact of the motorway on this spring, it is necessary to ensure the collection, drainage and treatment of storm water from the future motorway. After the treatment of these waters, they should be discharged into the recipient, which must be downstream from the spring to prevent any impact on the spring water quality.

Dye-tracer test in the Prenj area (at the Jezerce and Vrutak abysses)[38] revealed the connection with Konjicka Bijela springs, where the dye appeared after 22 days. During the excavation of the Prenj Tunnel, attention must be paid to the drainage of tunnel water, as well as to the potential cutting of underground streams.

In the event of appearance of groundwater during the drilling of the tunnel, it should be collected and evacuated through a pipeline, or a bypass should be made so that it can continue flowing. In the event of appearance of caverns during excavation, tunnel water must not be allowed into them to prevent potential groundwater pollution.

In conclusion, the motorway route passes close to the Konjicka bijela springs (Bijela and Gornja Bijela) and its construction and use may have an impact on these springs. The appropriate mitigation measures are required to prevent and mitigate adverse impacts. The measures are captured in the Environmental and Social Management Plan (Chapter 19.2, Measure 19.2.4).

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[38] Results of geophysical, hydrogeological and hydrological investigation in the framework of supplemental detailed geological, engineering-geological, geotechnical, geophysical, hydrological and hydrogeological research and investigation on the section Konjic (Ovcari) – entrance to the Prenj Tunnel, Winner Project, 2022

The Sanica Spring is located about 11 km west of the motorway route. The spring is used for water supply to Jablanica (Figure 7-14). Sanitary water protection zones have been established for the Sanica spring, although no tracer tests have been carried out at the time, so that the catchment area, directions, and speed of groundwater flow have not been precisely determined.

For the purpose of designing the Prenj Tunnel[39], a dye-tracer test was carried out at the location of the Vrutak abyss, in the main fault zone (Figure 7-14). At the Sanica spring, the dye appeared 15 days after injection and lasted for another 10 days, with the highest concentration on the first day of appearance. Based on the dye test, a fictitious groundwater movement speed of 662 m/day was calculated. Since the highest concentration of dye appeared the day after the first appearance, it means that the circulation of groundwater takes place within the shallow zone of the karstified belt (epikarst). This is also supported by the fact that the Sanica spring shows high turbidity every time after a heavy rain or sudden melting of snow.

Based on the presented hydrogeological relations in the subject area, it can be concluded that the construction and exploitation of the Konjic (Ovcari) - Prenj Tunnel - Mostar North motorway will not have an impact on the Sanica spring.

The Salakovac Spring. The section from Prenj Tunnel to Mostar North with access roads is designed to pass through the III and IV sanitary protection zones of the Salakovac spring, which is used for water supply of the Mostar City.

In December 2022, the Water Management Institute from Sarajevo developed a *Report on the protection of the Salakovac spring* pursuant to the new *Rulebook on the method of defining the conditions for determining sanitary protection zones and protective measures for water springs for public water supply of the population* (Article 7)[40], which defines the establishment of SPZ boundaries for water springs in aquifers of karst porosity. Four SPZs have been determined for the Salakovac spring (Figure 7-14):

> protection zone I as a zone with the strictest bans and restrictions,
> protection zone II as a zone with strict bans and restrictions,
> protection zone III as a zone with moderate bans and restrictions,
> protection zone IV as a zone with preventive bans and restrictions.

A large section of the Prenj Tunnel passes through SPZ IV, around 7.5 km. The next 5 km of the section from Tunnel Prenj to Mostar North, which includes two tunnels and 3 viaducts/bridges, passes through SPZ III. A part of the access road that leads from the main road in Salakovac via Prigradani and Podgorani to the exit portal of the Prenj Tunnel passes through SPZ III for about 2.7 km. This access road is designed in a way that it also passes through SPZ II for about 1.5 km (Figure 7-14). According to the Decision on sanitary protection zones and protection measures for Salakovac spring, road construction is allowed in the II zone if standard and additional measures are applied.

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[39] Ibid.
[40] Official Gazette of the FBiH, no. 88/12

The dye-tracer test at the Jezero abyss on Prenj revealed a direct hydraulic connection with the Salakovac spring (Figure 7-24). A fictitious groundwater velocity of 833 m/day was calculated based on that result. Two sub-parallel faults running northeast-southwest located between Jezero abyss and Salakovac spring (Figure 7-24) are the main direction of groundwater movement in this area. Since the dye did not appear at the Klenovik spring, it can be concluded that the groundwater flows below the level of the motorway route and not towards the tunnel portal in the exit portal zone of the Prenj Tunnel (Figure 7-36).

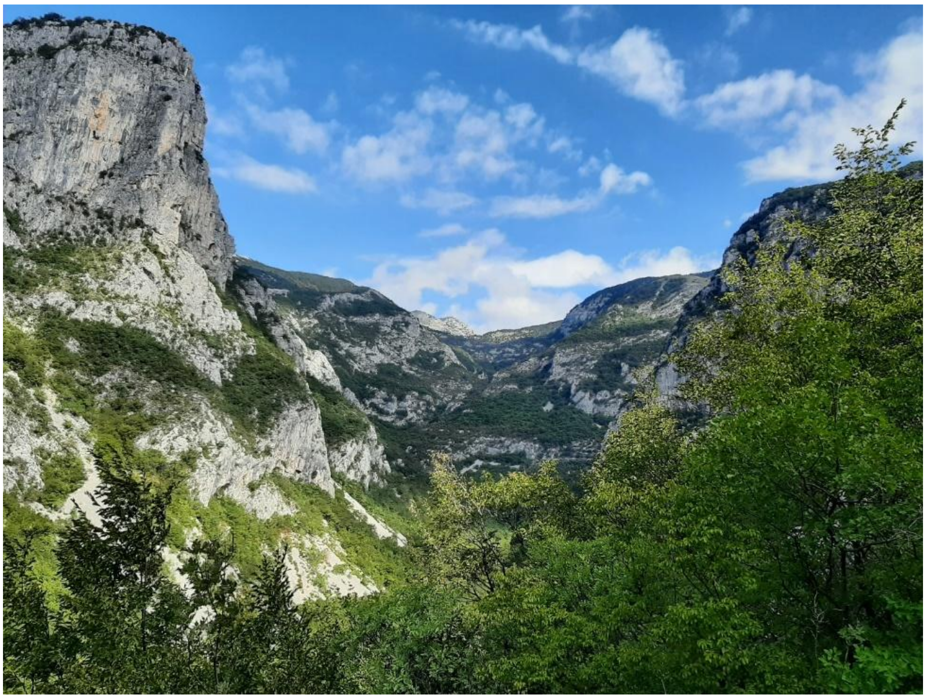

Figure 7-36: View of the exit portal of the Prenj Tunnel

Salakovac spring is located at an altitude of 100 m a.s.l. and it is the lowest spring where the groundwater of the Prenj massif is emptied. For this reason, it is to be expected that groundwater moves below the level of the Prenj Tunnel in the part belonging to the SPZ of the Salakovac spring, and tunnel excavation works will have no impact on the groundwater.

A connection with the Salakovac spring was not established by dye-tracer test performed at the Veline Bare abyss, which is located about 3 km to the north of the Jezero abyss (Figure 7-14).

The route of the access road to the exit portal of the Prenj Tunnel was designed for the most part over deluvial and talus sediments, which were built from various granulations of limestone fragments and rubble material with clayey fraction present as well. In order to minimise the negative impact of the access road on the Salakovac spring, it should be paved after widening, with proper drainage ensured. Drainage would include the collection and draining of storm water from the access road surface, its treatment to achieve a satisfactory quality, and discharge into the recipient located outside the SPZ.

According to the presented hydrogeological relations along the route of the Prenj Tunnel, the excavation of the tunnel and construction of access roads will not have an impact on the groundwater of the Salakovac spring.

The Bosnjaci Spring. One part of the motorway route will pass through the SPZ III of the Bosnjaci spring, which is used for water supply of the Mostar City (Figure 7-14).

In December 2022, the Water Management Institute from Sarajevo developed a *Report on the protection of the Salakovac spring* pursuant to the Article 7 of the new Rulebook on the method of defining the conditions for determining sanitary protection zones and protective measures for water springs for public water supply of the population[41].

About 2 km of the open route before the tunnel and about 600 m of the Orlov Kuk Tunnel were designed to pass through the SPZ III of the Bosnjaci spring (Figure 7-14). The remaining 1.6 km of the Orlov Kuk Tunnel does not enter the defined SPZs of the Bosnjaci spring.

On the part of the route that passes through the SPZ of the spring, construction of cuts, embankments and Orlov Kuk tunnel has been planned. These works can impact the groundwater of the Bosnjaci spring.

The Orlov Kuk Tunnel is the most sensitive location on the motorway route from the groundwater protection perspective due to its proximity to the Bosnjaci spring. Tunnel T5 penetrates limestone and one can expect the appearance of karst canals and caverns that may be the underground streams of the Bosnjaci spring and the Livcine spring, which is located in the immediate vicinity. This is why it is necessary to take care of the groundwater collection and evacuation from the tunnel tube, and its release into the recipient after it has been treated to reach a satisfactory quality (usually sedimentation only, to be confirmed with water quality test).

Still, if accidental spring pollution by sediments occurs during the motorway construction, it is expected that it will be minor and temporary. In this case, temporary disconnection of the spring from the water supply network should be foreseen.

In conclusion, the motorway route passes through the catchment area of the Bosnjaci spring, and its construction and use may have an impact on this karst spring. Appropriate mitigation measures are required.

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[41] Official Gazette of the FBiH, no. 88/12

7.3.6 Assessment of groundwater vulnerability

7.3.6.1 Methodology

Groundwater vulnerability can be defined as a set of characteristics of the environment that determine the level of sensitivity to surface pollution. The definition assumes that the geological environment (soil and rocks) can act as a natural filter and remove some pollutants that would otherwise pollute the groundwater.

For the purpose of this ESIA, the assessment of groundwater vulnerability in the karst aquifer is done using the EPIK method[42]. With the EPIK method, much greater emphasis is placed on the method of surface water infiltration, which is of crucial importance when it comes to the karst groundwater vulnerability.

The results of the assessment are groundwater vulnerability maps that single out areas with different degrees of vulnerability. The final maps provide end users with a clear picture of vulnerability of the aquifer to pollution, allowing easy comparison of vulnerability between different aquifers, or between parts of the same aquifer. Very high vulnerability corresponds to the aquifers where the groundwater level is at a shallow depth and where, due to the existence of large cracks (caverns), there is rapid infiltration of surface water with little possibility for purification due to the lesser contact time.

Four factors are mapped: E factor - epikarst, P factor - protective cover, I factor - infiltration and K factor - karstification.

E factor. The following substrates were used to determine the epikarst development level (E factor) of the subject area:

- Main geological map of the researched area on a scale of 1:100,000, obtained by compiling the papers "Prozor", "Sarajevo", "Mostar" and "Kalinovik",
- Topographical maps of the research area at a scale of 1:25,000,
- Satellite image of the terrain,
- Digital terrain elevation model (DEM) displayed as a "shaded relief map" using 3D analysis tools in GIS.

By analysing the geological map, the zones of presence of carbonate rocks were determined. Topographic maps were then analysed in correlation with the elevation model and the satellite image, based on which the epikarst zones where determined.

Factor E is divided into 3 categories that define the degree of vulnerability. Areas of sinkholes and open karst are defined as areas with developed epikarst of class E1. Class E2 includes karst terrains built of pure limestone and covered

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[42] Doerfliger, N., Zwahlen, F. (1997) EPIK: A new method for outlining of protection areas in karstic environment, Karst Waters and Environmental Impacts, Gűnay and Johnson (eds), Rotterdam

with low vegetation, and terrains built of carbonate rocks with admixtures, without vegetation cover. The third class E3 consists of the terrain parts where there are no carbonate rocks, i.e., non-karst.

P factor. The P factor map is a protective cover and the following substrates were used for its creation:

- Pedological maps (published by the Institute for Agropedology and the Faculty of Forestry from Sarajevo) at a scale of 1:100,000,
- Vegetation map (CORINE Land Cover, 2006) on a scale of 1:100,000,
- Satellite image of the terrain.

The pedological map made it possible to distinguish the soil type and thickness within the research area. Additional soil categorisation was performed using a vegetation map (CORINE Land Cover, 2006) and a satellite image of the terrain.

Four categories were defined (P1, P2, P3, P4) within this map, and thickness of the protective cover and composition of the vegetation were taken as criteria for the categorisation, in accordance with the criteria proposed by the author of the method:

- *P1 category* - terrains built from karstified limestone with fairly thin (< 20 cm) or missing soil cover. Vegetation is absent from these terrains or represented in the form of low vegetation and shrubland.
- *P2 category*- soils that are present on terrains built from dolomitic rocks and flysch formations. The thickness of these soils is over 20 cm. These terrains are covered with dense forests (upland areas) and meadows (plain areas).
- *P3 category* - terrains built from alluvial, glacial, deluvial and talus sediments with a clayey component present and total thickness exceeding 1 m. From the vegetative aspect, these terrains are mostly characterised as meadows and pastures.
- *Category P4* - terrains built from thick layers of impermeable sediments over 2 m thick with vegetative cover present.

I factor. The I factor mapping required the largest amount of time and effort. The following substrates were used to assess the infiltration conditions:

- Hydrogeological map on a scale of 1:100,000,
- Topographic maps on a scale of 1:25,000,
- Vegetation map (CORINE Land Cover, 2006) on a scale of 1:100,000,
- Digital elevation model (DEM),
- Terrain slope map was obtained through Slope analysis,
- Satellite image of the terrain.

As part of the calculation of this factor, the areas that belong to basins of sinkholes and plunging streams and zones were first defined. The defining was done using a topographic map and shaded relief obtained through the DEM model.

Parts of the research area that are outside the basins of sinkholes and plunging streams are further classified into two classes: class I3 for parts of the terrain in which karst aquifers are developed, as well as for parts of the terrain that are not built of carbonate rocks, but belong to the basin of karst springs or streams that pass through the karst terrains, and class I4 - the rest of the terrain outside the basins of sinkholes and plunging streams.

Terrains belonging to basins of sinkholes and plunging streams are classified in a different way. Zones immediately around sinkholes, plunging streams, as well as a group of sinkholes where surface water infiltration is pronounced were marked first. These zones are classified in class I1. The rest of the basins are classified depending on the forest cover and terrain slope. Class I2 includes forest areas with a terrain slope of over 35% and meadows, pastures, and arable areas with a slope of over 25%, while class I3 includes forested areas with a slope of less than 35% and meadows, pastures and arable areas with a slope of less than 25%.

On the basis of these criteria for determining classes for parameter I, the sinkhole zones on the Prenj massif, as well as the sinkholes for which the connection with the Bosnjaci and Livcine springs was established, were classified into category I1. Terrains with a slope of more than 25% are classified in category I2. Category I3 includes the remaining terrains belonging to the Prenj massif and the Bosnjaci and Livcine springs. Terrains located outside the basin of the Prenj massif, that is, the basins of Bosnjaci and Livcine are classified in category I4.

K factor. For the analysis of karstification degree, i.e., for the K factor mapping, the following substrates were used:

- Geological map on a scale of 1:100,000,
- Hydrogeological map on a scale of 1:100,000.

The analysis and classification of this factor used the data of hydrogeological and engineering geological surveys in the researched area that were mainly carried out for the purposes of an impact study, design of the subject motorway section and determining the SPZ of the Salakovac and Bosnjaci springs. Also, available data from earlier research in the wider area (research for the construction of hydro power plants on the Neretva River[43]) were used. This primarily refers to dye tests on groundwater and exploratory drilling.

The results of these surveys significantly advanced the classification, bearing in mind that it is possible to estimate the degree of surface karstification from these substrates, but when it comes to the development of underground karst phenomena, direct and detailed in situ research is practically irreplaceable.

According to the proposed methodology, karst systems with groundwater velocity greater than 15 m/h can be considered systems with a developed network of karst canals. Groundwater dye tests in the wider area of Prenj have

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[43] According to information from the study Additional engineering-geological works at the localities of Konjicka Bijela and Idbar for the purpose of defining the geotechnical conditions for tunnel construction (Phase I) (Winner Project d.o.o. Sarajevo, 2021), the research used data from surveys carried out for the need for the construction of HPP on the Neretva sublimated in the study entitled Energoinvest – Higrainzenjering Sarajevo, Faculty of Mining and Geology Belgrade, HPP on Neretva: Ljuta, Glogošnica, Konjic, Jablanica, Grabovica, Salakovac and Mostar

shown that groundwater velocity ranges from 0.33-0.96 cm/s (v_{sr}=0.66 cm/s), i.e., from 11.88-34.56 m/h (v_{sr}=20.376 m/h), which indicates the presence of a highly developed network of karst canals.

This is supported by the fact that the karst terrains of Prenj are drained through a small number of springs of considerable yield, which indicates the presence of karst canals of considerable dimensions that dictate the groundwater movement directions.

The first class K1 includes Mesozoic limestones (mostly Jurassic and Cretaceous), with the characteristic presence of sinkhole zones and wide fissures that were transformed into caverns, canals and the largest underground karst cave forms through the karstification process. Class K2 includes Mesozoic carbonate rocks with dolomite more prevalent than limestone. Other terrain-building rocks (non-karst) are included in the third class K3.

7.3.6.2 Mapping of groundwater vulnerability

The groundwater vulnerability assessment is performed through the protection index F, which is calculated for each field (polygon) in the research area applying an equation in which all four parameters are variable. Each of the classes has its weight value, with the lowest value indicating the greatest sensitivity to pollution. Standard values for EPIK parameters are shown in Table 7-2.

Table 7-2: Standard values for EPIK parameters

E parameter			P parameter				I parameter				K parameter		
E_1	E_2	E_3	P_1	P_2	P_3	P_4	I_1	I_2	I_3	I_4	K_1	K_2	K_3
1	3	4	1	2	3	4	1	2	3	4	1	2	3

The groundwater vulnerability map (Figure 7-37) using the EPIK method was obtained by combining all four factors in the formula:

$$F = \alpha Ei + \beta Pj + \gamma Ik + \delta Kl$$

where values 3, 1, 3 and 2 are used as weight coefficients α, β, γ and δ[44].

The relative weight coefficients (α, β, γ and δ) show the impact of each factor on the groundwater vulnerability level. Based on the influence of certain factors, one can conclude that the degree of epikarst development and the conditions of infiltration have the greatest influence on the vulnerability of groundwater in the karst. The F index value ranges from 9 to 34 and is divided into four classes:

$F \leq 19$	Very high vulnerability
$19 < F \leq 25$	High vulnerability

[44] Doerfliger N, Jeannin PY, Zwahlen F, 1999: Water vulnerability assessment in karst environments: a new method of defining protection areas using a multi-attribute approach and GIS tools (EPIK method), Environmental Geology 39 (2), 165-176.

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$F > 25$	Medium vulnerability
$F > 25$, $P=P_4$, $I=I_{3,4}$	Low vulnerability

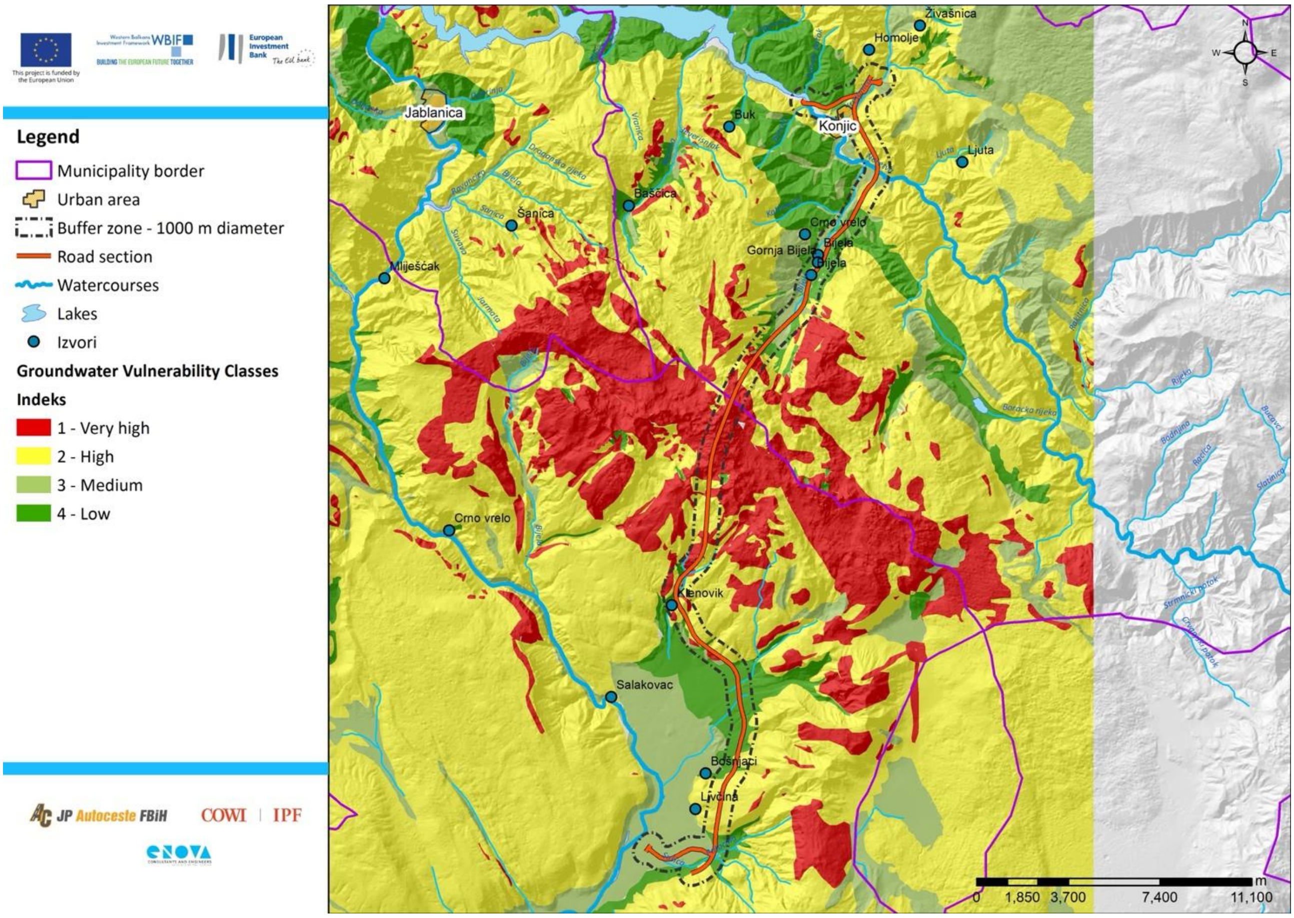

Figure 7-37: Vulnerability map

7.3.6.3 Assessment of groundwater vulnerability

Groundwater vulnerability in the motorway zone

Most of the motorway route is characterised by very high and high groundwater vulnerability. This is expected because the largest part of the terrain is built of carbonate rocks with developed karst aquifers.

In karst terrains where the epikarst development is evident and there are many karst forms (sinks, plunging streams, sinkholes, and caves), and where the infiltration of surface water is very intense, a **very high vulnerability** of groundwater has been defined and these terrains are marked in red on the map. These are terrains through which the Prenj Tunnel is built.

Terrains that are built of carbonate rocks with admixtures where karstification is not dominantly expressed and there is no vegetative cover are characterised by **high groundwater vulnerability.** This category also includes areas with pronounced karstification, but also with a vegetative cover. These terrains are **marked in yellow** on the map. These are terrains where the Ovcari Interchange was designed, as well as a part of the route from the junction to the

Neretva River, the section around Glavicina, a part of the route from the exit from the Prenj Tunnel to the Seocka Draga bridge and a part of the route before the entrance to the tunnel and the entire Orlov Kuk Tunnel.

Terrains with **medium groundwater vulnerability** include parts of the terrain in which the compacted aquifer type also exists. These are terrains with soil cover and a vegetation cover. This category includes areas built of moraines and talus, where clayey fractions are represented in a small proportion. These terrains are **marked in light green** on the map. A part of the motorway route from the M2 bridge to the Prenj Tunnel along the valley of Konjicka Bijela was designed within this category.

Conditionally arid parts of the terrain (flysch formations) from Triassic and Neogene are classified as terrains with **low groundwater vulnerability**. In these terrains, the epikarst is not developed, the soil provides good protection, and surface water infiltration is mostly diffuse, which is why the groundwater vulnerability is lower than in the previous classes. This category includes areas built of moraines and talus, where clayey fractions are represented to a significant extent. These terrains are **marked in dark green** on the map (Figure 7-37). A part of the route in the valley of Konjicka Bijela, a part of the entrance portal of the Prenj Tunnel, part of the route from Seocka Draga to the front of the Orlov Kuk Tunnel, as well as the open route after the Orlov Kuk Tunnel were designed on the terrain that has low vulnerability.

Groundwater vulnerability of the wider area

The EPIK method was developed to assess the vulnerability of groundwater in karst terrains. In karst terrains, there may be areas that are not made of carbonate rocks and within which there is no karst aquifer. Such areas can be drained on the surface and recharge the karst aquifer. The vulnerability mapping methodology does not particularly emphasise such hydrogeological relations, and therefore does not value them separately.

When analysing the groundwater vulnerability assessment, thickness of the zone above the aquifer and the amount of recharge were not considered. These parameters can play a very important role in assessing the groundwater vulnerability.

In one part of the project area, during the rainy season (autumn-spring), there is a compact aquifer within the moraine and talus sediments, which is hydraulically directly connected with the karst aquifer that is hypsometrically located below it. The sediments in the limestone roof layer are treated as a protective cover (P factor). In the analysis, only its thickness is considered but not its filtration characteristics.

According to the established methodology, the EPIK method is limited to a large-scale mapping. This is particularly pronounced when determining the factor E where an area occupied by one sinkhole (E1) and an area between two sinkholes (E2) should be defined in order to draw lines between E1 and E2, which is difficult when creating a map at a scale of 1:100,000.

By applying the EPIK method, it is almost impossible to obtain high and very high vulnerability for terrains with compact porosity, such as alluvial and glacial and talus sediments where groundwater is very vulnerable. In this case, medium vulnerability was obtained for these terrains.

The EPIK method requires a detailed assessment of karst characteristics, which is often difficult, expensive, and time-consuming because it includes field research, application of geophysical methods, hydrogeological and isotopic tests, analysis of hydraulic characteristics, and more. Registration of sinkholes and underground canals often requires the interpretation of high-resolution aerial and satellite images.

The groundwater vulnerability mapping of the subject area reveals a direct corelation between the distribution of groundwater vulnerability and the distribution of karst aquifers. The greatest importance in the groundwater vulnerability assessment have E and K factors, that is, the development level of the epikarst and the network of karst canals. By increasing the weight coefficients for these two factors (coefficients α and δ), the value of the protection index F increases, i.e., groundwater vulnerability generally decreases. Part of the terrain with a very high vulnerability class moves to a high vulnerability class. Part of the terrain of high vulnerability class moves to medium vulnerability class terrains, and part of the medium vulnerability class terrains moves to low vulnerability class. Still, the largest part of terrain retains their vulnerability class obtained with the originally adopted weight coefficients; these are the terrains purely built from karstified limestone.

Groundwater level in karst terrains varies significantly during the hydrological cycle (sometimes even above 300 m). Unfortunately, the EPIK method does not include this variation in the analysis of the groundwater vulnerability assessment. Pollutant can infiltrate and remain in the karst canals during the dry part of the year, and after the (sudden) increase in groundwater level, it can reach the groundwater.

As for the negative impact of the construction of the Prenj tunnel on groundwater, it is only possible if significant underground currents that circulate groundwater are intersected. However, it is expected that along the faults, especially along the main fault zone, there will be occurrences of groundwater in the form of dripping, seepage, or rarely flowing. In these cases, it is necessary to ensure that these waters are adequately evacuated from the tunnel to prevent their pollution and discharge into the environment. For this scenario, it is necessary to provide for the collection and pipeline disposal of tunnel water outside the tunnel, after prior treatment. In the event of an intersection of an underground current, it is necessary to provide conditions for that water to continue its flow by creating a bypass to reduce the impact of groundwater on the tunnel structure.

7.3.7 Assessment of groundwater pollution hazards

The term "hazard" is used to indicate possible sources of pollution brought about by human activity. According to the conceptual framework proposed by "The

European COST Action 620", hazard assessment is based on consideration of the degree of harm for each type of pollutant, without analysing natural features of the terrain. It does not take into account natural characteristics of the geological environment, but only the distribution of potential pollutants. Consideration of hazards primarily refers to three main types of land use: infrastructural, industrial, and agricultural.

For the purposes of this assessment, only the pollutants that will have an impact during the motorway construction were taken into account, without showing and analysing the existing environmental pollutants. At the same time, a 500 m wide corridor on both sides of the motorway axis was taken as the zone of influence because the motorway is treated as a linear pollutant.

According to the European Hazard Mapping Approach[45], the formula for the hazard score calculation reads:
$H_{azard\ score} = H \times Q_n \times R_f$
where:
$H_{azard\ score}$ – hazard score,
H – value denoting hazard severity,
Q_n - hazard ranking factor
R_f – reduction factor that reflects the probability of a pollutant spill substance (most often, value 1 is taken)

The main criterion for assessing the hazard severity (H) is toxicity of substances associated with individual pollutants and their characteristics such as solubility and mobility[46]. The hazard ranking factor (Q_n) serves to compare pollutants of the same type but with different capacities. Table 2 provides an overview of the hazard value, which reflects hazard severity and ranking factor for individual activities that generate pollutants.

Table 7-3: Tabular presentation of hazard severity value (H), hazard ranking factor (Q_n) and hazard score (H_{score})[47,48]

Activity	H - hazard severity	Q_n - hazard ranking factor	R_f - reduction factor	H_{score} - hazard
Tunnel excavation	25	1.2	1	30
Workers' camps	30	1.1	1	33
Spoil sites	35	1	1	35
Road (number of vehicles)	40	0.8	1	32
Tunnel (number of vehicles)	40	0.8	1	32

[45] De Ketelaere D., Hötzl H., Neukum C., Civita M. and Sappa G. (2004) Hazard analysis and mapping. In: cost action 620. Vulnerability and risk mapping for the protection of carbonate (karstic) aquifers. Final report cost action 620. European Commission, Brüssel, Luxemburg.
[46] Ibid.
[47] Ibid.
[48] Ravbar N. (2007) The protection of karst water, a comprehensive slovene approach to vulnerabilty and contamination risk mapping. Karst Research Institute at ZRC SAZU. Postojna – Ljubljana.

Activity	H - hazard severity	Q_n - hazard ranking factor	R_f - reduction factor	H_{score} - hazard
Construction of cuts and embankments	10	1	1	10
Concrete batching plant	30	1.2	1	36

The map of groundwater pollution hazards along the motorway route was obtained using satellite images where the polygons of the locations of potential polluters were drawn (Figure 7-38), and then hazard values were assigned to them according to the above equation while respecting the criteria provided in Table 7-3.

Based on the value of hazard severity (H) and the corresponding factors (Qn) for its ranking, surfaces were defined according to the level of hazard (table 3). According to the level of hazard, groundwater pollution hazard is grouped in six categories: very high, high, medium, low, very low and no hazard (Figure 7-38).

Table 7-4: Hazard level ranking[49]

Hazard score	Hazard index	Hazard level
0	0	No hazard
0 – 24	1	Very low
24 – 48	2	Low
48 – 72	3	Medium
72 – 96	4	High
96 – 100	5	Very high

Based on the level of hazard, the motorway route corridor is divided into two categories: very low and low hazard (Figure 7-38).

[49] Modified based on the work of *De Ketelaere D., Hötzl H., Neukum C., Civita M. and Sappa G. (2004) Hazard analysis and mapping. In: cost action 620. Vulnerability and risk mapping for the protection of carbonate (karstic) aquifers. Final report cost action 620. European Commission, Brüssel, Luxemburg*.

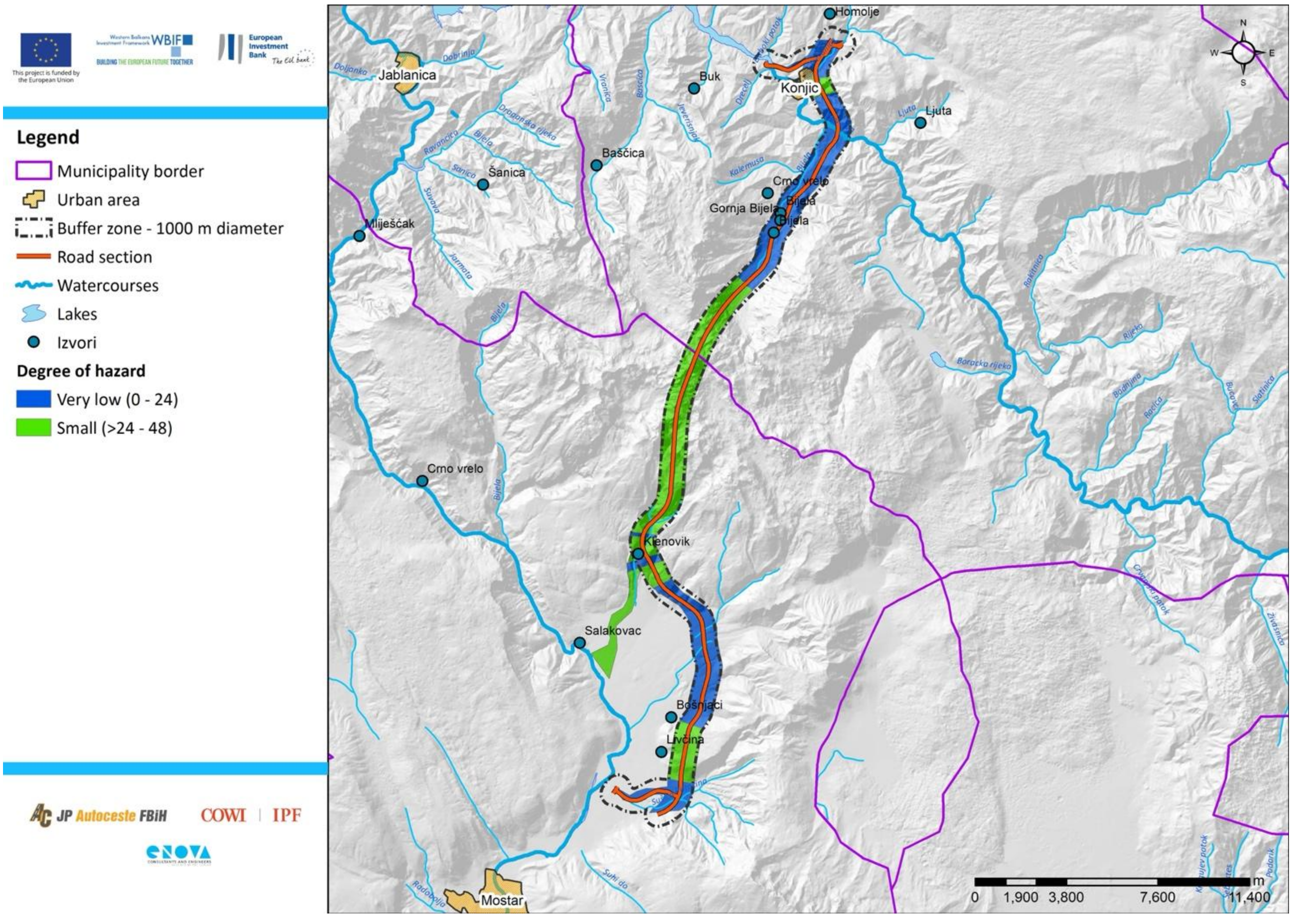

Figure 7-38: Map of groundwater pollution hazard

The part of the route where works on the construction of bridges, viaducts, cuttings and embankments, rest areas and interchanges, i.e., works on the open route are planned is **very low-hazard**. This category also includes the terrains covered by construction of the access road to the northern portal of the Prenj Tunnel, Konjic Bypas, as well as the connections of the Mostar North Interchange with the main road.

The part of the route where tunnel excavations will be carried out has **low hazard level**. This category also includes areas that will be used for landfills, concrete batching plants and workers camps.

The Prenj Tunnel is the longest structure on the motorway route and its excavation will take place in parallel on both sides. For this reason, the areas near the entrance and exit portals are also included in this category, because most probably this terrain will be used for the accommodation of personnel and equipment, possibly concrete bathing plant, storage, etc. The terrain covered by the access road to the southern portal of the Prenj Tunnel is also included in this category.

7.3.8 Assessment of groundwater pollution risk

The risk of groundwater pollution represents the probability that groundwater will be polluted by activities occurring on or near the terrain surface. The risk assessment itself consists of:

> Assessments of the vulnerability (sensitivity) of groundwater to pollution, taking into account only the natural protective capabilities of the geological environment;
> Hazard assessments of groundwater pollution risk, which do not consider natural characteristics of the geological environment, but only the distribution of potential pollutants.

Unlike hazard, which represents only a potential danger (pollutants) for groundwater, the natural vulnerability of the above-aquifer zone to pollution is also considered when assessing the risks.

Table 7-5 shows values of groundwater vulnerability and terrain hazards based on which the risk intensity was evaluated for each area.

Table 7-5: Diagram of risk intensity determination for the motorway route[50]

Vulnerability		
Vulnerability score	**Vulnerability index**	**Vulnerability level**
< 19	1	Very high
19 – 25	2	High
> 25	3	Medium
> 25 ($P=P_4$, $I=I_{3,4}$)	4	Low

+

Hazard		
Hazard score	**Hazard index**	**Hazard level**
0	5	No hazard
0 – 24	4	Very low
24 – 48	3	Low
48 – 72	2	Medium
72 – 96	1	High
96 – 100	0	Very high

=

Risk		
Risk score	**Risk index**	**Risk level**
1 – 4	2	High
5 – 7	1	Medium
≥ 8	0	Low

By overlaying the groundwater vulnerability map obtained by applying the EPIK method (Figure 7-37) with the hazard map of the same area (Figure 7-38), a groundwater pollution risk map is obtained (Figure 7-39). The resulting map shows the degree of risk intensity, i.e., the possibility of groundwater being polluted by the external factors.

[50] Modified based on the work of *De Ketelaere D., Hötzl H., Neukum C., Civita M. and Sappa G. (2004) Hazard analysis and mapping. In: cost action 620. Vulnerability and risk mapping for the protection of carbonate (karstic) aquifers. Final report cost action 620. European Commission, Brüssel, Luxemburg*.

According to the degree of groundwater pollution risk along the motorway route, the risk is grouped into three categories: high, medium, and low. Areas of high intensity of risk are the areas where a hazardous pollutants are discharged on terrains of high vulnerability.

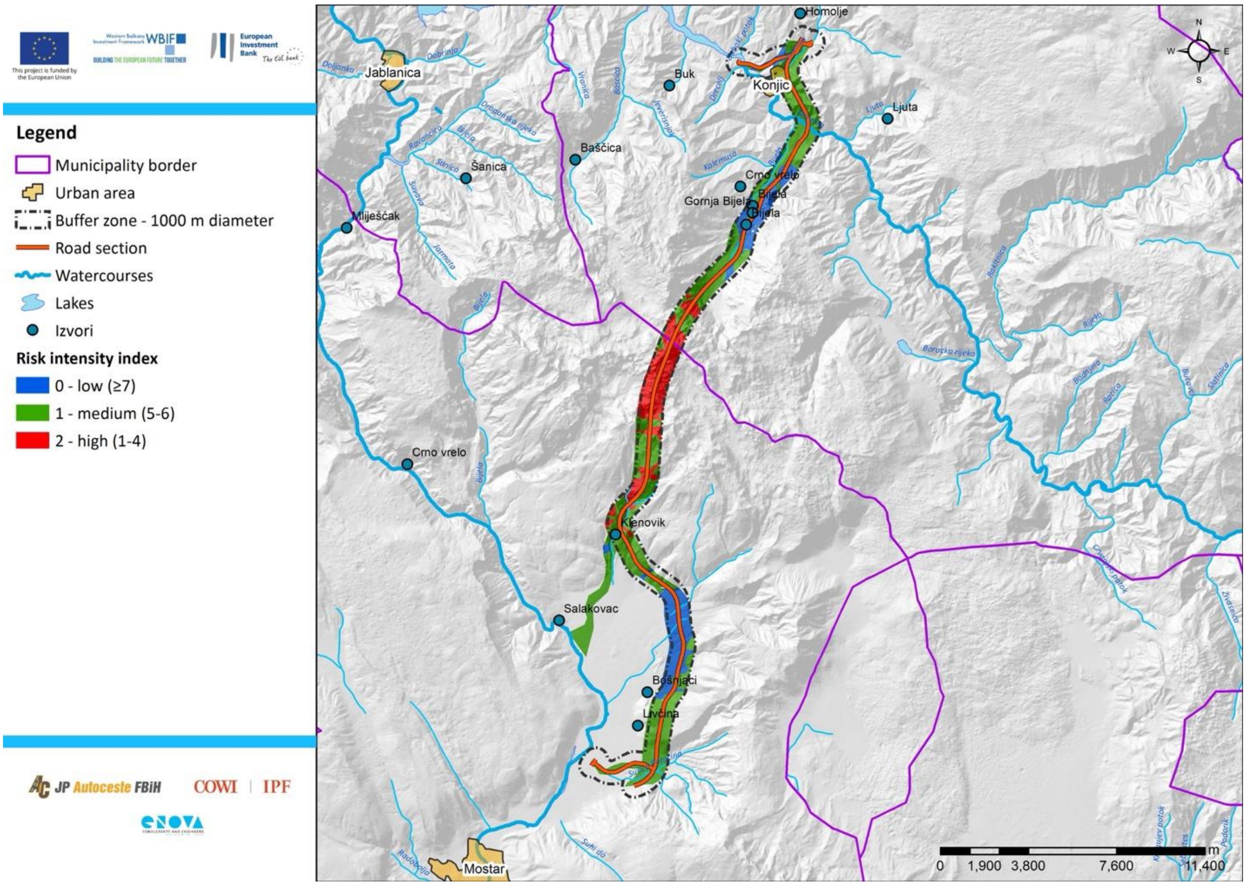

Figure 7-39: Map of groundwater pollution risk

There is a **high risk** of groundwater pollution in the terrains with exposed karst where the Prenj Tunnel will be drilled, as well as the terrains in the area of Klenova Draga. These are the terrains where most probably workers camps will be established.

Terrains made of karstified limestone rocks, where there is no very high groundwater vulnerability, as well as areas with medium and low groundwater vulnerability that are made of non-calcareous rocks bear **medium risk** of groundwater pollution. This risk category is the most represented.

Terrains that are made of non-calcareous rocks (moraines, talus, flysch, etc.) where works will be carried out on an open route in the form of cuts and embankments have **low risk** of groundwater pollution.

7.3.9 Conclusion on the assessment of potential impacts

The Konjic (Ovcari) - Prenj Tunnel - Mostar North motorway section mostly passes through the karst terrain of the Prenj massif. Surface and ground waters from Prenj move in a radial direction, i.e., they move towards the Neretva River, which surrounds the Prenj massif from all sides except from the southeast. More significant springs into which the Prenj aquifer empties are located at lower elevations of the terrain at the point of contact of karst aquifer and impermeable or less permeable rocks.

Along its route, the motorway passes through the catchment areas of 4 springs utilised for water supply: Bijela, Sanica, Salakovac and Bosnjaci. As the route will pass through their catchment areas, it is evident that the construction and operation of the motorway has the potential to have negative impact on groundwater quality, flow and recharge which can cause interrupted water supply. In addition, the intersection of water bearing fractures or dissolution cavities during tunnelling works could negatively impact the drilling works and general stability of tunnel structures.

Impacts of groundwater on motorway construction

The results of research about the hydrogeological relations on the Prenj Mt. carried out so far indicate that there should be no significant penetration of high-volume groundwater during excavation of the tunnel Prenj. The overburden of the Prenj tunnel is over 1,000 m thick, and the drilling will be performed below the karstification zone, which indicate low possibility to encounter high flow underground streams.

In general, groundwater from the Prenj Tunnel route flows in two directions, towards Konjicka Bijela to the north, and Salakovac springs to the south. Most likely, the main fault represents the watershed divide between these two directions and groundwater can be encountered along the fault. The groundwater in tunnels may appear in the form of dampening, throughfall or weak leakage and only during periods of heavy rainfall or sudden melting of snow on the Prenj massif. The similar water appearance can also be expected during excavation of the Orlov Kuk Tunnel, which is located in the hinterland of the Bosnjaci spring, and where underground karst channels carrying groundwater from the direction of Zijemlje towards Bosnjaci may be encountered.

Here is to be noted that the Prenj Tunnel and the Orlov Kuk Tunnel are in the area of high to very high groundwater vulnerability. At the same time the Prenj area is assessed to be under high risk of pollution as the works are carried out inside the aquifer zone but with low hazard level.

Therefore, groundwater that infiltrates in the tunnel should not be stopped at the point of penetration, but rather captured and drained out of the tunnel with pipes or channels. This phenomenon is a temporary and localised occurrence. The water from the tunnel may be loaded with suspended solids and other pollutants so special attention should be paid that it is not discharged untreated to riverbeds and does not pollute the surface waters. The tunnel can be sealed only after the tunnel has been built and all appropriate measures are taken so that the sealing of the penetration does not cause dangerous or harmful consequences for the workers in the tunnel and the environment.

If there is a possibility of additional capturing of potentially intercepted underground streams in the Prenj tunnel, the possibility of capturing those waters for the purposes of constructing the motorway or for water supply and later use in the maintenance phase of the motorway should be considered.

Impacts of motorway construction on groundwater flow and recharge

During the drilling of the Prenj Tunnel and the Orlov Kuk Tunnel, it is necessary to comply with measures to reduce the possible impact of the works on groundwater flow and recharge. In the case of cutting off underground streams (karst channels or caverns with water) the groundwater must be allowed to move in the same direction toward the springs which will at the same time reduce the pressure on the tunnel tube and prevent damage to the tunnel lining. This is ensured with construction of the groundwater bypass around the tunnel lining.

Impacts of motorway construction on groundwater quality

The motorway route passes through the sanitary protection zones of two important and very sensitive springs, Salakovac and Bosnjaci, as well as in the immediate vicinity of the unprotected Konjicka Bijela spring (Bijela and Gornja Bijela), where negative impacts on groundwater could occur during the construction phase.

Potentially the most pronounced negative impact of the motorway construction is on the quality of groundwater due to the hydrogeological properties of the terrain. These are predominantly carbonate rocks with high filtration coefficients, which results in the rapid penetration of polluted substances from the working surfaces, and later from the pavement construction into the base terrain and contact with groundwater, which is a significant resource.

The impact on groundwater quality during motorway construction is possible in case of excavation or blasting of the rock mass, erosion of material from cuts and embankments and in case of accidental spill. These impacts will not leave lasting consequences on the quality and quantity of groundwater. They may cause increased water turbidity or accidental pollution if occur/released in vicinity of the springs.

The Bosnjaci spring is also under possible impacts of construction of cuts and embankments as well as the Orlov Kuk Tunnel that will take place in the III water protection zone of this spring. An option for temporary disconnection of the source from the water supply network should be provided in the event of an accidental pollution or temporary turbidity until the quality returns into the legally prescribed limits.

In accordance with the above, it is necessary to control the quality of groundwater at every location that is potentially under risk of pollution in line with the Rulebook on drinking water safety[51].

The protection measures that will be prescribed in chapter 7.4 must be harmonised with prohibited and permitted activities and additional and standard protection measures for the III sanitary protection zone through which the motorway passes and which are given in the Studies on the protection of the Salakovac and Bosnjaci spurces (Zavod za vodoprivredu Sarajevo, December 2022) and the *Decision on sanitary protection zones and protective measures for the Salakovac source* (Official Gazette of the City of Mostar no. 14/23). The measures from the Studies and the Decision are harmonised with the *Rulebook on the way of establishing conditions for determining sanitary protection zones and protective measures for water sources for public water supply* (Official Gazette of FBiH, No. 88/12). These are the following protection measures in the III protection zone of the source:

Prohibition measures - the following activities are prohibited:

> Excavations in the aquifer
> Construction and operation of quarries and other material borrowing facilities
> Mining and other construction works that are not in the function of water supply, and which can disrupt the composition of aquifers
> Disposal of any solid, construction, communal and other waste
> Above ground or underground tanks
> Conveyors

It is allowed with standard and additional protection measures:

> Carrying out any activities that cause or promote soil erosion
> Construction of highways and roads reserved for motor traffic
> Construction of urban roads and related facilities (parking lots, bridges, tunnels,...)
> Road transport of chemicals, liquid fuels and other dangerous substances
> Allowed with standard protection measures: Landfills of industrial waste harmless to water quality at the source

All facilities within the third protection zone must have appropriate collection and drainage of wastewater by constructing a sewer that will be taken to the main sewer collector.

Impacts of motorway construction on springs used for water supply

The construction of the motorway will not have a physical impact on water supply to the local population in a sense of impact on water source structures.

[51] Rulebook on drinking water safety (Official Gazette of BiH 40/10, 43/10, 30/12, 62/17)

A possible exception to this is a local water source in the waterbed of Konjicka Bijela used by approx. 30 households. This water source will be preserved by building a supporting structure to protect the source as foreseen by the Preliminary Design. In case of unforeseen circumstances, households will be supplied with an alternative source of drinking water, most likely by connecting to a reservoir in Gornja Bijela, managed by the Konjic Water Supply Company.

The Bosnjaci spring is also under possible impacts of construction of cuts and embankments as well as the Orlov Kuk Tunnel that will take place in the III water protection zone of this spring. An option for temporary disconnection of the source from the water supply network should be provided in the event of an accidental pollution or temporary turbidity until the quality returns into the legally prescribed limits.

Impacts of motorway operation on groundwater quality

During the motorway operation, possible negative impacts on groundwater quality are the infiltration of storm water from the roadway structure and its direct discharge into the environment.

Slight and occasional water turbidity may occur in sections that are designed on embankments or cuts where in periods of heavy rainfall, due to a large amount of stormwater, material may be washed off from the cut or the embankment and transported towards waters at lower elevations. The project documentation developed so far foresees the controlled collection of storm water from the roadway, and its treatment to the required quality for discharge into the recipient in line with the conditions stipulated by the Preliminary Water Consent. In the spring area such as Bijela, Salakovac and Bosnjaci springs, immediate discharge of treated water shall be avoided, and the water is to be taken out of the influence zone/SPZ so that there is no impact on the quality of the spring water from these sources. More details on treatment facilities planned in SPZs are given in Chapter 8 Surface water.

It can be concluded that the complex works on the construction of the motorway will not have a major adverse impact on the groundwater in this area during the period of construction and subsequent operation of the motorway. The approach here was iterative to ensure that the level of investigation was commensurate to risks, as required by EBRD and EIB Policies. The entire route was assessed for potential to be impacted by construction and operations, including vulnerability of aquifers to impacts, likelihood of an incident leading to impacts etc. Main impacts are considered to be potential spills of fuels during construction, construction causing temporary high turbidity to spring or surface water or intersection of main flow cavity that could result in changes to water quantity or quality of springs that supply domestic water to villages. Of these the first two items are considered to have low risk and clearly the main risk is presented by change in spring water quality. Based on this the area around Prenj Mountain and specifically the catchment areas of the springs supplying water for villages was investigated in significant detail to assess this significant risk.

The results for the detailed analysis of this area are that while the Prenj Tunnel may encounter groundwater, especially at the main identified fault, the inflow of water is not considered to be significant except perhaps at time of substantial precipitation or rapid snow melt. Therefore, the overall impacts associated with issues related to groundwater are considered to be medium and can be managed through standard practices including pollution prevention plan, spill response plan and catchment and treatment of surface water runoff in line with issued water acts.

It must be noted that there is some uncertainty related to the assessment of impacts of motorway construction on groundwater, as well as the impact of groundwater on the motorway itself (as dealing with subsurface conditions is not an exact science). More detailed information will become available as construction activities begin and this may lead to new findings (including direct observation during tunnelling). Nonetheless, by following the suggested mitigation and prevention measures (contained in the Environmental and Social Management Plan) during construction, it is possible to minimise potentially negative impacts on these sensitive sources.

Table 7-6 provides a summary of potential impacts and assessment of their significance based on the evaluation of relevant facts.

Table 7-6: Summary of potential impacts on groundwaters and assessment of their significance before mitigation

Phase	Type of potential impact	Adverse/ Beneficial	Magnitude	Sensitivity	Impact evaluation	Significance (before mitigation)
Groundwater						
Pre-construction	Limited information on groundwater quality and quantity in the zone of motorway construction	Adverse	Moderate	Medium	**Moderate**	**Significant**
Construction	Intrusion of groundwater in tunnel tubes during excavation that can impact stability of the structure and cause the safety risk	Adverse	Moderate	Medium	**Moderate**	**Significant**
Construction	Impact on the direction of ground water flow and recharge by cutting the underground voids/streams by tunnelling	Adverse	Moderate	Medium	**Moderate**	**Significant**
Construction	Impact on groundwater quality due to: › direct release of intercepted tunnel drainage water without treatment	Adverse	Moderate	Medium	**Moderate**	**Significant**

Phase	Type of potential impact	Adverse/ Beneficial	Magnitude	Sensitivity	Impact evaluation	Significance (before mitigation)
	> turbidity caused by erosion and excavation or blasting of the rock mass > accidental spills in vicinity of the springs					
Operation	> Impact on groundwater quality resulting from release of treated run-off from the motorway surface in the proximity to the springs and their water protection zones	Adverse	Moderate	Medium	**Moderate**	**Significant**

7.4 Mitigation and Enhancement Measures[52]

7.4.1 Pre-construction phase

- Conduct a detailed inventory to identify all wells for public water supply, wells for individual water supply (drinking or other purposes), newly built wells for supplying construction locations with drinking or technical water, and piezometers installed at the referenced locations related to motorway construction. During the detailed list of wells, use data from the Groundwater cadaster of FBiH.[53]
  Note: Possible locations of piezometers are (i) in the area of the entrance portal of the Prenj Tunnel, in the valley of the Konjicka Bijela, at location of Rakov laz (700-750m a.s.l.), (ii) in the zone of the exit portal of the Prenj Tunnel - Podgorani region (400 m a.s.l.), and (iii) on the axis of the motorway in the hinterland of the spring "Bosnjaci" in Potoci. The predicted depth of the piezometer on the portals of the Prenj Tunnel is approximately 100 m, and in the hinterland of the source "Bosnjaci" approximately 60 m.
- Prepare the **Groundwater Monitoring Plan (GMP)** to cover baseline monitoring and monitoring in the construction phase The GMP shall include:
  - inventory of the wells with information on name, location, type and other available information on each well.

[52] The protection measures in the III sanitary 7-23protection zone of the Bosnjaci and Salakovac springs are formulated on the basis of the measures prescribed in the Studies on the protection of the Salakovac and Bosnjaci springs and the Decision on sanitary protection zones and protective measures for the Salakovac spring, which are harmonised with the *Rulebook on the method of establishing conditions for determining sanitary protection zones and protective measures for water sources for public water supply* (Official Gazette of the FBiH, No. 88/12), as well as conditions from the Preliminary Water Consent for the Konjic-Mostar North section issued by the Adriatic Sea Watershed Agency (UP/40-1/21-2-129/21 from March 15, 2022).
[53] Groundwater cadaster of FBiH is available at the Adriatic Sea Watershed Agency, Mostar

  - monitoring protocol including information on the frequency and method of sampling, sampling parameters, methods of analysis and reporting
  - response plan in case of contamination
  - risk management and remediation plan.

  The GMP shall be prepared in line with the rules set in the Rulebook on drinking water safety[54]. The monitoring programme during the construction shall include the construction period and the warranty period. Monitoring shall include both quality and groundwater level in the wells/piezometers.
- Conduct the baseline monitoring of water quality and levels in the wells/piezometers at all identified wells according to the GMP.
  Note: The frequency of sampling during the construction will depend on the dynamics of works progression.

7.4.2 Construction phase

a) Impacts of groundwater on motorway construction

- Establish systematic monitoring of water levels throughout a tunnel's lifetime (as described in Chapter 7.4.1)
- Do not discharge the groundwater that penetrates the tunnel tube to discovered caverns or karst canals as this may lead to groundwater pollution.
- Capture the groundwater that penetrates the tunnel tube and drained it out of the tunnel with pipes or channels. Horizontal passages and passages with smaller slopes are drained by ditches or channels, if necessary, also with use of pumps. The ditches or channels must be deep enough and positioned in a way not to endanger the safety of workers. Passages with larger longitudinal slopes are drained with pipes. Ditches, channels with pumps, and drainage pipes must be regularly cleaned and maintained in good condition. Drainage of the tunnel is performed in a way that it does not undermine the supports of protective structures, does not erode the tunnel walls or tunnel lining, does not wash away rock material in the excavation and does not damage devices and auxiliary traffic signals. The workplace, movement of workers, and traffic areas must stay dry and not under water.
- Treat the captured groundwater before discharging into the environment (usually settling only; to be decided based on results of water testing as stipulated by the *Regulation on the conditions for the discharge of wastewater into the environment and public sewage systems Official Gazette of the FBiH, No, 26/20 and 96/20*).
- The water from the tunnel may be loaded with suspended solids and other pollutants so the special attention should be paid that it is not discharged untreated near the spring Konjicka Bijela or in the water protection zones of Salakovac and Bosnjaci springs.
- The tunnel can be sealed only after the tunnel has been built and all safety measures are taken so that the sealing of the penetration does not cause

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[54] Rulebook on drinking water safety (Official Gazette of BiH 40/10, 43/10, 30/12, 62/17)

dangerous or harmful consequences for the workers in the tunnel and the environment.

b) Impacts of motorway construction on groundwater flow and recharge

- In case of cutting off underground streams (karst channels or caverns with water) during tunnel excavation, construct a bypass (migration flowpath) to its extension so that the groundwater continues to move and at the same time reduce the pressure on the tunnel tube and prevent damage to the tunnel lining.
- If the tunnel tube cuts through a cavern of larger dimensions, build a supporting structure (bridge in the tunnel) to bridge the cavern.
- When large caverns appear, avoid filling the caverns with any material as this will decrease permeability. Caverns and caves shall not be infilled without prior inspection and approval by an expert (hydrogeologist, karstologist or speleologist).

c) Impacts of motorway construction on groundwater quality

- Ensure continuous presence of hydrogeological engineers on the site, preferably with experience in similar projects, in order to take under strict control, the execution of works and groundwater monitoring and anticipate and prevent negative impact of motorway construction (excavation or blasting of the rock mass, erosion of material from cuts and embankments, accidental spills) on groundwater quality.
- Provide a special method of blasting so as not to disrupt the water flow regime in sections where the route passes through the areas of water pumping stations or near water facilities and according to the conditions of the Preliminary Water Consent. The following measures are proposed:
  - In accordance with the actual situation on the ground where the works will be carried out and the available data on the working environment, it is necessary to create a detailed Blasting Plan (Contractor of drilling and mining works),
  - Work on drilling mine holes and blasting should be planned in such a way that the diameter, depth, and geometric arrangement of the mine holes are carried out in a selective (gradual excavation) manner in the smallest possible volume up to the excavation depth provided for in the project (more frequent drilling and blasting within a certain period),
  - The filling of mine holes must be carried out with a system of millisecond non-electric detonators and connectors for surface blasting (DUAL MS), so that each mine charge - borehole has a separate detonation effect in the minefield activation system and with the minimum possible amount of explosives per mine hole, which prevents seismic (earthquake) reduces the effect to a minimum. In this connection, and against the planned depths of the mine holes, discontinuous filling can also be used (multiple detonators in one mining hole with intermediate plugs made of inflated material).

  - It is mandatory for the authorised company to apply measurement of the seismic impact with certified instruments for every blasting, with the preparation of a report after the measurement.
- Install waterproof foils before the formation of embankments to prevent further penetration of any spills of harmful substances into the ground both during the construction phase and later during the operation of the motorway.
- Do not drain tunnel runoff (water used for drilling mining holes) into open channels or caverns in order to avoid jeopardising the quality of groundwater. Instead, evacuate tunnel run-off outside the tunnel using a piping system and discharge it into the recipient after treating in sedimentation basins.
- Apply the he same measures as under item a).
- Monitor the quality of groundwater (see measures for pre-construction phase) in line with the Rulebook on drinking water safety[55].
- Save and protect the locally sourced water supply for up to 30 households in Gornja Bijela by constructing a supportive structure as envisaged by the Preliminary Design. In case of unforeseen circumstances, provide an alternative source of drinking water for households using this supply by connecting them to the Gornja Bijela reservoir.
- Undertake the regulation of the natural bed of the river Bijela, approximately 600 m in length, to further ensure that the Crno Vrelo catchment is not compromised.
- In the area of local spring captured for the need of up to 30 households in Gornja Bijela, provide the households using this source with an alternative source of drinking water by connecting them to the Gornja Bijela reservoir.
- To protect the Konjicka Bijela and Salakovac springs, fully pave the access roads with asphalt and equip with stormwater collection systems (gutters, drains, manholes). Treat the collected run-off in oil and grease separators up to the quality defined by the law. Discharge the treated run-off outside the zone of influence, downstream from the Konjicka Bijela spring, and outside of the III water protection zone of the Salakovac spring.
- Implement collection and treatment measures for tunnel run-off and captured groundwater from the Orlov Kuk tunnel (as described under item a)) and discharge treated water outside the III water protection zone of this spring.
- Ensure regular contacts with water utilities and agree on the option of temporary disconnection of the source from the water supply network in the event of an accidental pollution or temporary turbidity until the quality returns into the legally prescribed limits.
- To prevent accidental releases of oil and grease during construction of viaducts instal oil collection tanks under the machines. To prevent material washing away during construction of viaduct pillar foundation install anti-erosion barriers. In case of groundwater being pumped from foundation pits, ensure that these waters are treated in oil and water separators before discharge to the environment.

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[55] Rulebook on drinking water safety (Official Gazette of BiH 40/10, 43/10, 30/12, 62/17)

- Treat collected wastewater from concrete batch plants up to the quality defined by the law. Discharge the treated runoff outside the zone of influence of Crno Vrelo, Bijela and Gornja Bijela springs, and outside of the III water protection zone of the Salakovac and Bosnjaci springs.
- Apply all mitigation measures for surface waters defined in Chapter 8.4.

7.4.3 Operational phase

Impacts of motorway operation on groundwater flow and recharge

- Implement the measures for preventing the cut off of groundwater flow during tunnels construction as described under b)

Impacts of motorway operation on groundwater quality

- Design and construct closed system for controlled collection of storm water from the motorway surface, toll and rest areas, and its treatment in oil and grease separators and/or biological treatment units (for sanitary wastewater) to the required quality before discharge into the recipient.
- In the zone of captured sources, use grease and light liquid separators with 100% purification and plan a closed tank of 50-100 m^3 in case of an incident and spillage of hazardous substances on the motorway.
- Do not discharge treated water in the spring area. The water should be taken out of the influence zone so that there is no impact on the quality of the water from these sources. The water shall be discharged downstream from the zone of influence of the Bijela and Gornja Bijela springs[56] and outside the III sanitary protection zone of Salakovac and Bosnjaci springs. In case any new wells are identified during the pre-construction phase, treated water should not be discharged in their vicinity.
- Perform regular testing of treated storm water quality (before its discharge) in line with the Water Permit obtained for the Project.
- According to the conditions specified in the Preliminary Water Consent, it is envisaged to install warning signs for passage through the high-risk water zone, as well as signs indicating speed limits for vehicles and signs prohibiting stopping for vehicles carrying hazardous and water-damaging substances in high-risk zones[57].

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[56] Since the Bijela spring is not officially protected, water protection zones are not determined and thus it is difficult to make more precise definition of the „zone of influence‟ and discharge location.
[57] According to the definition in the Preliminary Water Consent, the area located within the III protection zone of the source falls within the high-risk zone where the implementation of standard and additional protective measures is required, while the area within the IV protection zone of the source is in the moderate-risk zone where the implementation of standard protective measures is necessary.