1.4.2. Tunnel Fatničko polje and Belećа reservoir (FP->BR)

At the time of the study, the tunnel was in the final stages of construction. The tunnel is much longer than DP->FP and has a steeper slope (S= 0.00166 or 0.166%) thus, when it is not surcharged (the flow in it is free surface), the regime is supercritical (FROUDE number larger than 1). Temporarily, the tunnel is not lined throughout its whole length and only the parts which are more susceptible to high leakage are lined with concrete. The roughness will therefore vary along its lined and unlined reaches. For the hydraulic analysis of its capacity, we have used an equivalent roughness value (i.e. average over its entire length). The plan view and cross section of this tunnel is presented in Figure 8.

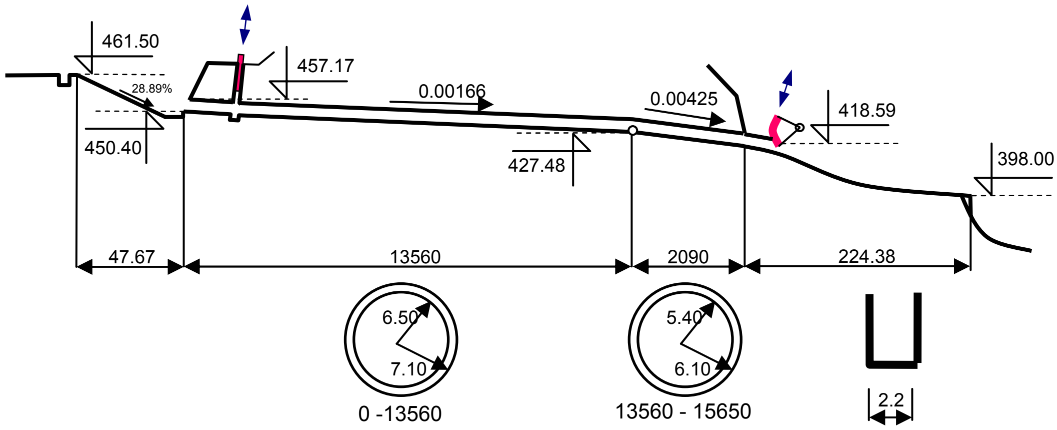
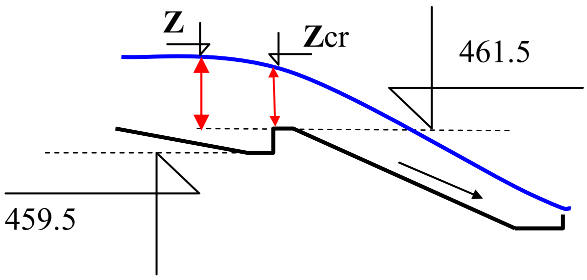


Figure 8. Longitudinal section of the tunnel between Fatničko polje and Belećа reservoir

Its capacity function will again consist of two parts:

1. **Free surface flow in the tunnel**: When the flow in the FP-BR tunnel is free surface, the flow regime in the tunnel is supercritical (FROUDE Number bigger than 1) and therefore water level in the tunnel will not affect the water level upstream from its entrance - inlet. Additionally, since the slope of the approaching channel is higher than critical, water level in it will not determine the stage-discharge relationship. The control section (with Froude number equal to 1) will be formed at downstream most part of the sedimentation tank, where there is an elevated channel invert, a sort of brad crested weir. The lower portion of the flow – discharge curve is calculated for both the control section (critical depth) and for the section a few meters upstream (which was used as a cross section for the stage measurement that were calculated and presented in Figure 9), by taking into account the gradually varied flow in the inlet channel with the normal depth in the tunnel as the downstream boundary condition (two different values for the friction factor in the tunnel were taken into account).
2. **Tunnel surcharged:** When the tunnel is surcharged its capacity is determined by its friction losses and it depends on the water level in Fatničko polje. Before the tunnel is made fully operational, it is suggested to perform a measurement of the friction of the tunnel in order to establish the real values which determine it capacity. Since this data was not yet

available, the analysis was again performed with two hypothetical Manning roughness factors (n= 1/60 $m^{-1/3}s$ and n= 1/80 $m^{-1/3}s$, whereas K=1/n). The results are shown in Figure 9 and have been used in the modelling work (following chapters).



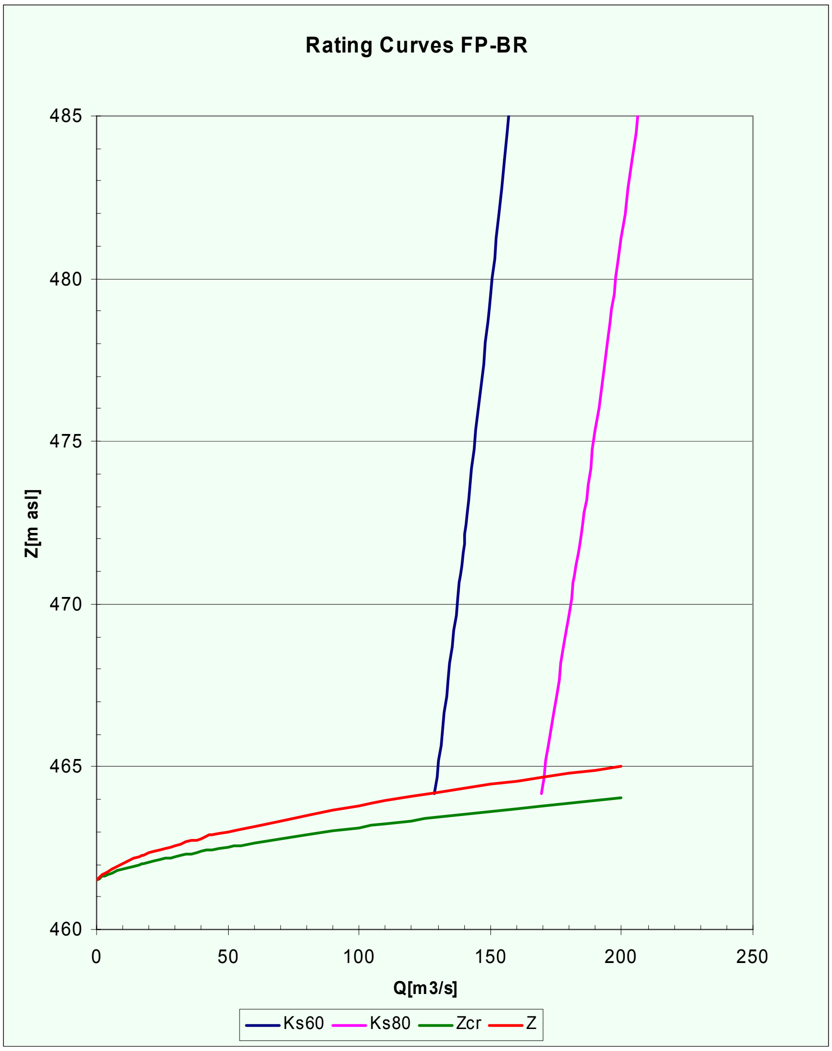


Figure 9. Capacity of the tunnel between Fatničko polje and Bileća reservoir

It is planned that the channel will have a flow regulation gate at is downstream end. Under the present operational management framework it is to be kept opened at all times.

1.5. Preceding studies and data sources relevant to this project

In addition to the references cited in the individual reports of modelling groups, in elaboration of the present study the following documents have been used:

a. documents relevant to data and modelling

- HIS-HET data base, i.e. data base containing data sets made available by HET Trebinje. In this data base the results of monitoring of hydrological, meteorological, hydrogeological and data related to operational management of the power plants that were kept in paper files have been compiled and digits by the Jaroslav Černi Institute from Belgrade.
- Additional data obtained form HET Trebinje (for the period between the years 2000 – 2003)
- Additional meteorological data obtained from the focal point for implementation of the UN convention on climate change

b. Projects, studies, published papers and proceedings

In elaborating this study the following reports and publications were available to the authors:

- Water Management Master plan for Trebišnjica catchment (*Kraška polja Istočne Hercegovine, Vodoprivredna osnova, izvod, Trebinje 1967*)
- Hydrological study (*Knjiga 1. Hidrološka obrada podataka*) for the Project – Study on the possibilities of the utilisation of the unused and diverted water by increasing the installed capacity of PHE Čapljina or by building HE Dubrovnik II (*Studija mogućnosti iskorištenja neiskorištenih i prevedenih voda povećanjem instalacija PHE Čapljina ili izgradnjom HE Dubrovnik II*, *Sveska 1. Kraška polja: Nevesinjsko, Dabarskio i Fatničko*) Energoinvest, Energonženjering, Sarajevo, 1992
- Multipurpose use of the Upper Horizons waters of the river Trebišnjica (*Višenamjensko korišćenje voda Gornjih Horizonata r. Trebišnjice*) clients: SOUR Elektroprivreda BiH, RSIZ Vodoprivreda BiH, SOUR APRO Mostar), Study performed in accordance with the request of the Executive Council of the Parliament of SR BiH (*Izvršno vijeće Skupštine SR BiH*), Trebinje, 1984
- Effect of the Energy system Trebišnjica on the development of the adjacent region (*Uticaj izgradnje energetskog sistema Trebišnjica na razvoj gravitirajućeg područja*) , Institute of Economy, Faculty of Economy, Sarajevo 1973
- Study on the effects of diversion of Dabarsko polje water on the regime of Bregava river. (*Uticaj prevodjenaj voda Dabarskog polja na režim voda r. Bregave)* Institute for use and protection of water resources in karst Trebinje 1985
- Study on the effects of the Diversion of river Zalomka waters on water regime of Buna and Bunica, (Uticaj prevodjenja voda r Zalomke na *režim voda r. Bregave)* Institute for use and protection of water resources in karst Trebinje 1985
- River Bregava – Possibilities for low flow augmentation (*Rijeka Bregava Mogućnosti povećanja malih voda*), Institute for use and protection of water resources in karst Trebinje 1986
- Tunnel Dabar – Fatnica, Hydraulic Analyses, (*Tunel Dabar – Fatnica – Hidrauličke analize*), Energoinvest, OOUR Higrainženjering, Sarajevo 1985

- Excerpts from the project Tunnel Fatničko polje and Beleća reservoir, Energoinvest, Sarajevo
- Proceedings of USA-Yugoslav Symposium Karst Hydrology and Water Resources, held in June 2-7 1975. in Dubrovnik, Published by WRP – Water Resources Publication, Fort Collins, Colorado, Edited by V. Yevjevich -1976, Library of Congress Catalogue card Number 76-012972

Since the present study was conceived to be independent and unbiased, no direct comparison has been made with the results of the previous studies. However, the comparison can be made simply by comparing the synthesis results (for example the duration curve) with the equivalent functions obtained from earlier work. Such a legacy diagram is enclosed in the Appendix.

1.6. Water Management issues relevant to this project

In this section we shall concentrate only on the part of water resources management which are relevant to this project. The basis for establishing the tunnel operation rules were following two documents:

- BUILDING PERMIT (Vodoprivredna saglasnost) No.UP-I-06-337-180/86 of 27.05.1986, for building the tunnel Fatnica – Bileća issued by the Committee for Agriculture, Forestry and Water Resources of the Republic Bosnia and Herzegovina. (*Republički Komitet za Poljoprivredu, Šumarstvo i Vodoprivredu) uprava za vodopriverdu*) BiH, Sarajevo, Deputy Chairman of the Committee Božo Knežević.
- BUILDING PERMIT (Vodoprivredna saglasnost) No.UP-I-03-78-1/69 of 29.7.1969, for water transfer from Dabarsko polje to Fatničko polje issued by the Water Resources Administration of the Republic (Republička uprava za vodopriverdu) BiH, Sarajevo, Director Abdulah Huzbašić.

Provisions of the latter permit require the holder of the permit to build manage – operate the tunnel pursuant to the following rules (Figure 10):

- Whenever the water level in Dabarsko polje is lower than 472 m asl. low flow to Ponikve ponor should not be changed and water is allowed to flow to Hrgud spring (tunnel DP->FP closed)
- When the water level is between 472 and 490 m asl, access to Ponikve ponor is closed and water is transferred to Fatničko polje (tunnel open). When water level in Fatničko polje is higher than in Dabarsko polje, the tunnel closes and remains closed until the level in Fatničko polje becomes lower.
- When the water level in Dabarsko polje is higher than 490 m asl both the Ponikve ponor access and the tunnel are open.

In addition to the above rules, which deal with water levels and flow regulation, the Building permit, has several other provisions dealing with compensation to the farmers should the duration of he flood be longer than prescribed. These aspects have not been dealt with in this study in detail, because they do no affect the water regime in the Bregava catchment.

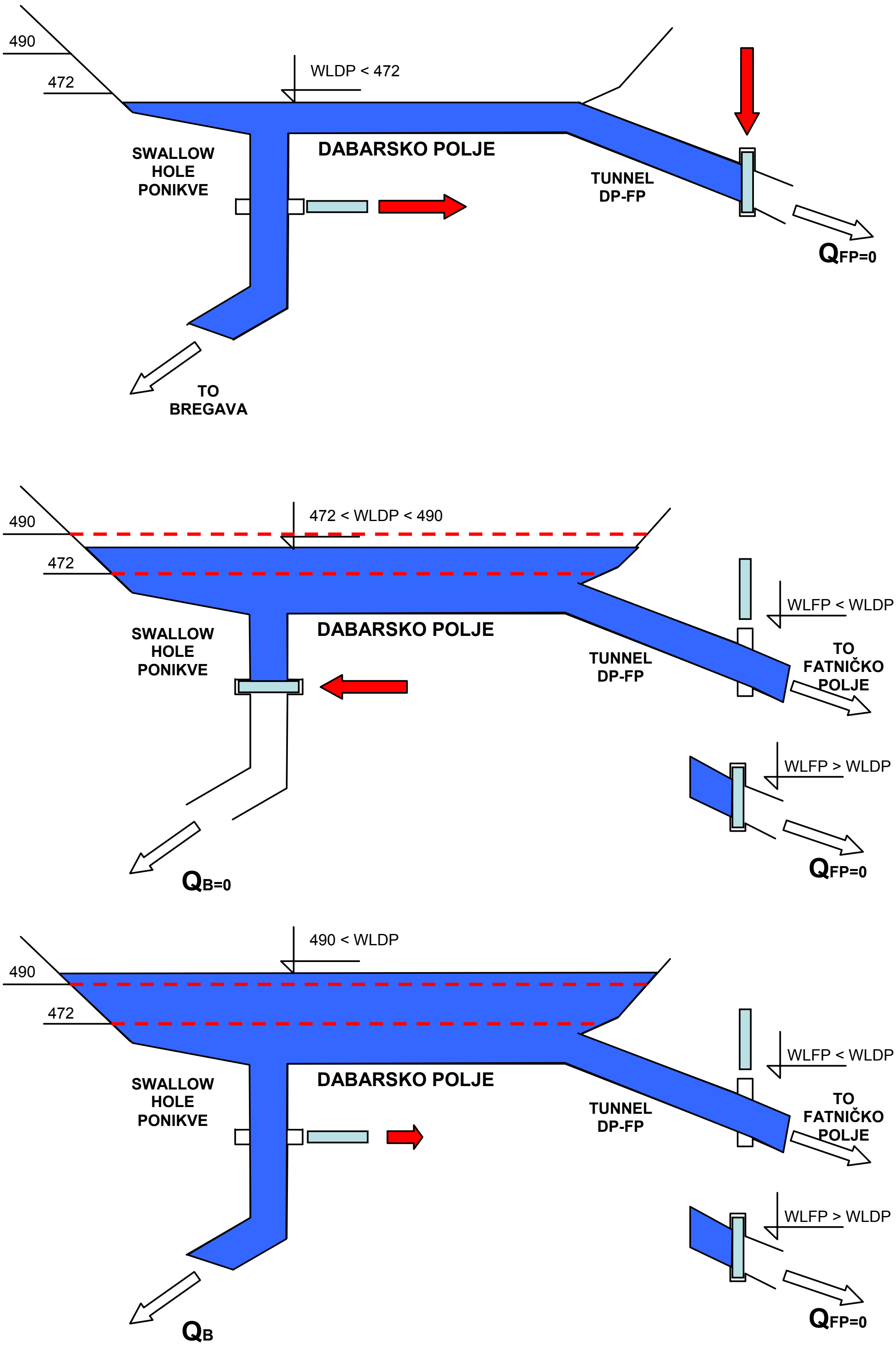


Figure 10. Conditions for flow regulation - operation of the tunnel

1.7. Interactions with the Inter-Entity Committee

Before this study was contracted it had been agreed between the relevant ministries of both entities in BiH (Republic Srpska and Federation of BiH) to create an expert team (herein called Inter-Entity Committee) consisting of 5 water experts from each entity. The Committee was tasked with re-examining the results of the previous studies and giving recommendation to the relevant governments on the viability and robustness of the findings and results obtained in the previous projects. By the time of production of this report the authors had not seen the recommendation of the above Committee. However, the authors remain open for consultation and exchange of views with the Committee on both the results of the present study and on recommendations of future activities which would be beneficial to establishing a positive atmosphere in which the local communities from both entities would be assisted by unbiased professional expertise and would benefit from being involved in the decision process for future developments which could improve living conditions while creating new business opportunities for the local population in both Entities.

1.8. Structure of the Report

The Report begins with an overview of the project's background, scope, and main assumptions (**Chapter 1**) and then presents the case study area in detail in terms of (a) Hydrogeology (**Chapter 2**) and Climate (**Chapter 3**). In both chapters attempts were made for an in-depth analysis of the issues relevant to the broader geographical area to provide the context in which the details of the case study area are presented. Long-term predictions of the evolution of the hydrogeology and climatic conditions, although not directly relevant to this study, are also discussed to provide a context for the interpretation of the results in the long-term and a basis for further water resources and environmental management studies in the broader area.

Chapter 4 presents the work performed in locating and processing spatial datasets using GIS, remote sensing and spatial analysis techniques for the case study area in order to produce reliable input of an adequate resolution for the modelling teams.

Chapter 5 is the modelling chapter and is divided into three parts, equal to the modelling approaches adopted in this work. Parts 1 and 2 focus on the first type of modelling approach applied: hydrologic calibrated parameter modelling and presents the models, analysis and results of the two hydrology modelling teams which worked independently for quality assurance and uncertainty control purposes (Institute J. Černi and NTUA). The modelling results, their interpretation and an assessment and quantification of the uncertainty resulting from the available datasets are also presented and discussed. Part 3 presents the results of the physically-based modelling approach, which is conceptually different from the other two and computationally more intensive. To reduce the uncertainty in the results, the modelling team developed two physically based models, in two different levels of detail to act as an internal quality assurance mechanism. The results of the models are presented and discussed in a format directly comparable to the other two result sets.

Chapter 6 draws upon the results and discussions of Chapter 5, presenting an overview of the main findings and provides a critical comparison of their differences and similarities. The Report's main conclusions are presented in **Chapter 7** and the main references used in the Report's development and are quoted in the text are presented in **Chapter 8**.

The main background reference for this study, which explains previous attempts to quantify the effects of the diversion on Bregava, i.e. the Study on the effects of diversion of Dabarsko polje water on the regime of the Bregava River. (*Uticaj prevodjenja voda Dabarskog polja na režim voda r. Bregave)* developed by the Institute for use and protection of water resources in the karst, Trebinje 1985 has been included in the Appendix (**Chapter 9**), together with the original duration curve to be used for comparison purposes by the reader.

2. Hydrogeology

2.1. Overall assessment of the hydrogeological conditions

The area of interest for the project is situated in Eastern Herzegovina (Figure 11). Geologically, it is the part of Dinaric Karst region.

The Dinaric Karst is a typical example of holokarst, comprised entirely of soluble carbonate rocks. It is characterized by the existence of surface and underground karst phenomena, with little arable land and vegetation.

There are several bigger and a few smaller poljes in this region. Poljes are usually elongated in the shape. Their longer axes follow geological structures, particularly the main overthrust direction from NW to SE. Almost all poljes are flooded in the period of high precipitation, when the inflow capacity of the ponors is lower than the quantities of water discharges in the polje.

Figure 11. Layout of the catchment areas of Bregava and Trebišnjica springs

There are two big rivers in the broader area, Neretva and Trebišnjica and a number of smaller surface water courses, most of them existing only in periods of high precipitation. While surface water flows are relatively rare and torrent, underground water flows are intensive. Generally, water infiltrates in upper parts of the catchment area and discharges at the springs in the lower erosion base levels. The ponors are situated at the southern edge of the poljes, while the springs are situated at the northern edge.

To analyse the Bregava river regime, the area of interest extends beyond its catchment area, to include the catchment area of the Trebišnjica springs, since part of the water from Fatničko polje discharges at the Bregava springs.

2.1.1. Basic lithostratigraphic and geostructural characteristics

This whole region consists of Mesozoic carbonate sediments with a thickness of over 2000 m. The rock mass consists mostly of karstified, stratified and thick-bedded limestone of Cretaceous and Jurassic age, interbedded with dolomite. The core of the hidrogeologically important "Lastva anticline" constitutes the most important Triassic dolomite. This structure, as a watertight screen, seals the right flank of the storage reservoir. It crosses the Canyon of the Trebišnjica River downstream from the dam site.

The Eocene Flysch, shaped like narrow zones, follows faults along the boundary of the Gatačko, Černica and Fatničko poljes. The thickness and depth of these flysch zones are highly variable with frequent interruptions and thinning of layers. Because clayey and marly components dominate in the flysch assemblage, these sediments, although insignificantly represented in the structure, have a very important role in forming the hydrogeological characteristics of this karst aquifer.

Numerous folds, reverse faults, striking parallel to the main structural direction, and a dense net of cross-ruptures have completely destroyed the homogeneity of the carbonate rock masses.

Analysis of the aerial photos shows that neotectonic activity has formed a few well-expressed zones, which have been greatly deformed. Thus, a dense rupture net was formed. This has been the basic condition governing the process of intensive karstification and formation of advantageous concentrated directions of underground circulation. A great rupture trending north-south is marked at the surface by a series of sinkholes, whose depth, in some cases, is more than 100 m. Numerous caves and deep shafts show that the rock mass in the investigated region is highly karstified.

2.1.2. The base of karstification and porosity

The investigations (geoelectrical sounding, exploratory drilling, gamma-gamma logging) and the collected data allow us, within the limits of the data, to estimate the depth of karstification and porosity in the karst aquifer.

In the zone of Trebišnjica springs karstification has affected the entire rock mass around the springs and a few kilometres northward up to an altitude of about 300 m (Figure 11 Figure 12 and Figure 13). Near the L-1 borehole, located just up gradient of the spring zone, a location of 16 zones whose porosity exceeds 10% has been determined. The rock mass in thes middle of the aquifer (zone of borehole PB-1) has been karstified up to an altitude of about 430 m. The base of karstification in the carbonate aquifer is generally inclined towards the discharge area. Its position is a result of the evolutionary process of the complex karst aquifer between Gatačko Polje and the spring zone.

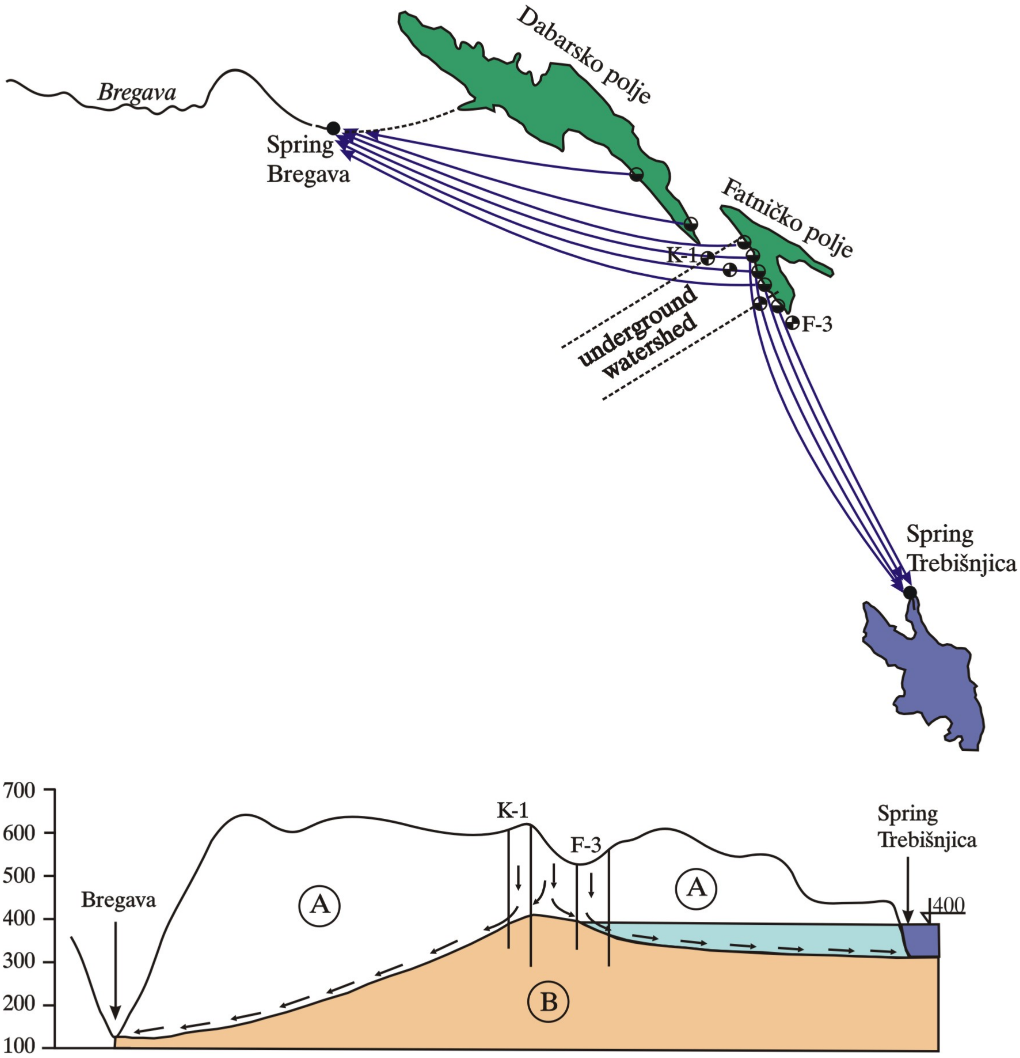


Figure 12. Base of karstification as underground watershed (Milanović, 1986)

(A) Karstified rock mass, (B) dense rock mass below base of karstification

The zones of the greatest underground circulation are mainly immediately above the base of karstification and converge towards the Trebišnjica spring zone. The existence of water movement paths below the base level of karstification cannot be excluded, but they are rare and represent limited transport capacity. Below the lowest position of the water table the porosity decreases abruptly. *The base of karstification and the lowest water table level approximately coincide*.

The relative downward displacement of the tectonic block in which the spring zone of Bregava River is located results in a zone of broad influence of the Bregava erosion base level towards Fatničko Polje. The result of this process is the enlargement of the underground catchment area.

The Bregava erosion base level, with altitudes lower than 130 m, is about 200 m lower than the Trebišnjica spring zone. Thus it is anticipated that in the next phase of the evolutionary process, the Trebišnjica karst aquifer will be captured by the Bregava River system.

The position of the watershed between the Trebišnjica and Bregava catchments has been determined by the position of the base of karstification in the region of Fatničko Polje. It is shallowest between the F-3 and K-1 boreholes (Figure 12) and plays a role of a hydrogeological barrier for underground water movement up to the elevation of high water level of the storage reservoir (altitude 400 m). The hydrogeological quality of this zone has been confirmed by 15 years of observations of the water tightness of the storage reservoir.

2.2. Trebišnjica River Catchment

2.2.1. Basic feature of the natural conditions

The spring zone of the Trebišnjica River is one of the biggest in the Dinaric karst. The broad karst aquifer, fed by a catchment area of 1100 km^2, discharges through this spring zone (Figure 13). The annual average flow of the Trebišnjica River, in the region of the Grančarevo Dam, is **80 m^3/s**, and at maximum flow it reaches **864 m^3/s.**

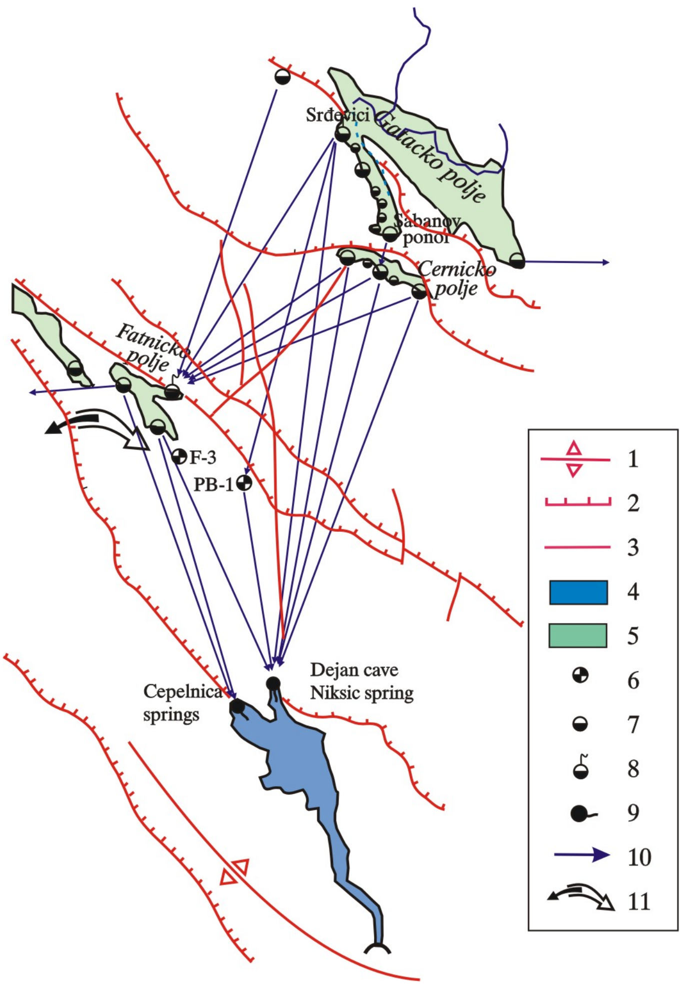


Figure 13. Area of broad background of Trebišnjica spring (Milanović, 1986)

1. Anticlinal axis, 2. Overthrust front, 3. Fault, 4. Bileća reservoir, 5. Karst polje, 6. Borehole, 7. Large ponor (swallow hole), 8. Large estavelle, 9. Spring, 10. Established underground link, 11. Watershed area

The Trebišnjica spring zone consists of big cave outlets including: Dejan's Cave, Nikšić spring and the spring of Čepelnica River. The Čepelnica spring zone is, in natural conditions, separated and contribute to the Trebišnjica River 3.5 km downstream from the Dejan's Cave.

Dejan's Cave is the most important site of concentrated outflow of the underground water. At an altitude of 325.5 m, the cave opening is 4 m wide and 6.5 m high. Under natural conditions this cave outlet dries up in summer, and usually flows of about 2 m^3/s are formed from a "blue hole" in the riverbed about 100 m downstream of the cave opening.

With the construction of the Grančarevo Dam, 18 km downstream, the spring zone was submerged in 1968 by the large Bileća storage reservoir, with a volume of 1300 million m^3. The normal peak water level of the storage reservoir is at an altitude of 400 m, which means that the spring zone is covered by a water column of as much as 75 m.

2.2.2. Basic characteristics of the aquifer regime

Besides the fact that the entire catchment area is characterized by high infiltration capacities, three zones are noted which have a very concentrated infiltration (Figure 14). These are the Gatačko Polje (with maximal intake capacity of 160 m^3/s), Černičko Polje (with maximal spring zone capacity of 50 m^3/s and maximal intake capacity of 40 m^3/s) and Fatničko polje (with maximal intake capacity of 120 m^3/s).

During periods of heavy precipitation, which can exceed 200 mm within 24 h, the inflow to the aquifer is extremely large. The result of such abrupt infiltration is the rapid saturation of the aquifer and rapid response of groundwater levels. In the region of boreholes PB-1 and F-3 these fluctuations occur quickly, with amplitudes of 123 m in PB-1 and 129 m in F-3. One of the characteristics of the groundwater level is the existence of the temporary steady water level at the altitude of 434 m, immediately above the base of karstification in the PB-1 area. Temporary stoppage of the water table shifting occurs in both cases, in the period of rising water table and in the period of water table decreasing.

The velocity of the underground circulation ranges between 0.9-14 cm/s depending on the groundwater level. In more than 50% of the cases observed it exceeded 5 cm/s. By comparing these velocities with average circulation in the Dinaric karst it is possible to conclude that a very fast circulation is occurring in this particular aquifer (Milanović, 1981).

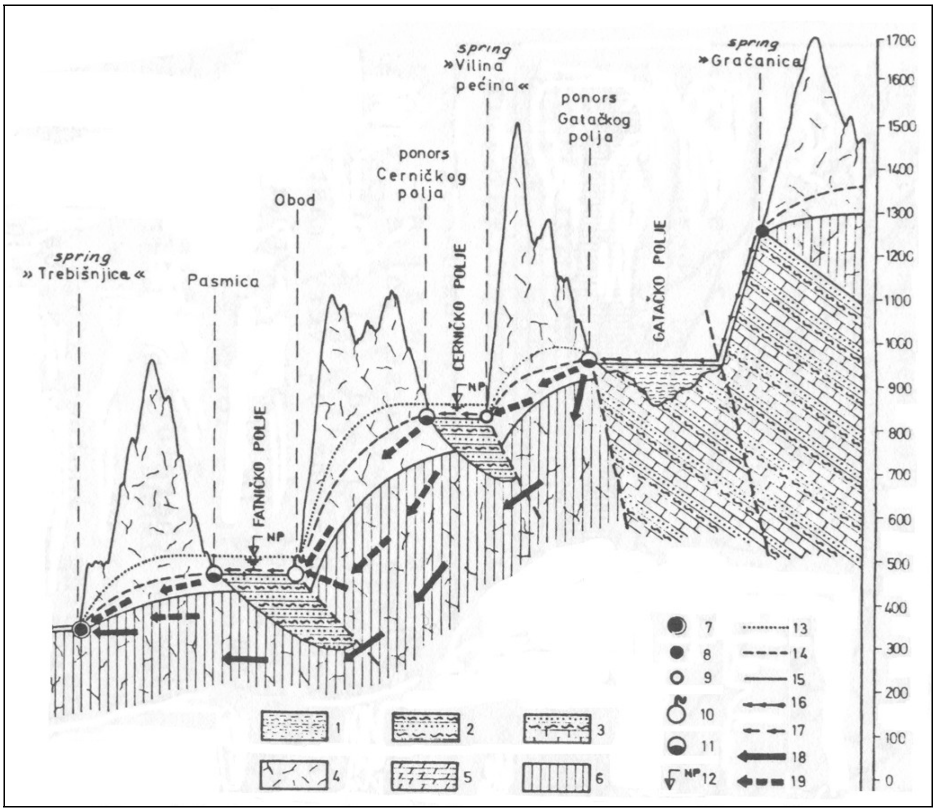


Figure 14. Simplified hydrogeological profile of Gatačko Polje - Trebišnjica spring (Milanović, 1972/1973)

1. Neogene sediments, 2. Eocene flush, 3. Creatoceous flush, 4. Karstified limestone, 5. Dolomite, 6. The zone beneath the lowest piezometric level, 7. Large and permanent karst spring with average capacity Q_{av} > 30 m^3/s, 8. Smaller, permanent karst spring, 9. Intermittent karst spring, 10. Estavelle, 11. Swalow hole (ponor), 12. Floodwater level in karst polje, 13. Piezometric water level during extremely high precipitation, 14. Piezometric water level during the wet season, 15. Piezometric water level during the dry season, 16. Permanent surface flow, 17. Temporary (intermittent) surface floe, 18. Direction of circulation during the dry period, 19. Direction of circulation during the wet period

The results of investigation of a great number of underground flows in the aquifer show high velocity variations, depending on instantaneous saturation of the aquifer. Thus, for example, to cover the distance (34 km) from Gatačko Polje to Trebišnjica spring, the underground flow takes 35 days when the water table is low and inflow is small. During the high water levels and large inflow, the pronounced water flow takes only 5 days to cover the same distance.

If an analysis of piezometers in the area is performed (Maitre 2003) one can notice an apparent hysteresis in ground water level. It can be observed that it takes considerable time for the underground storage both to fill and to empty (Figure 15)

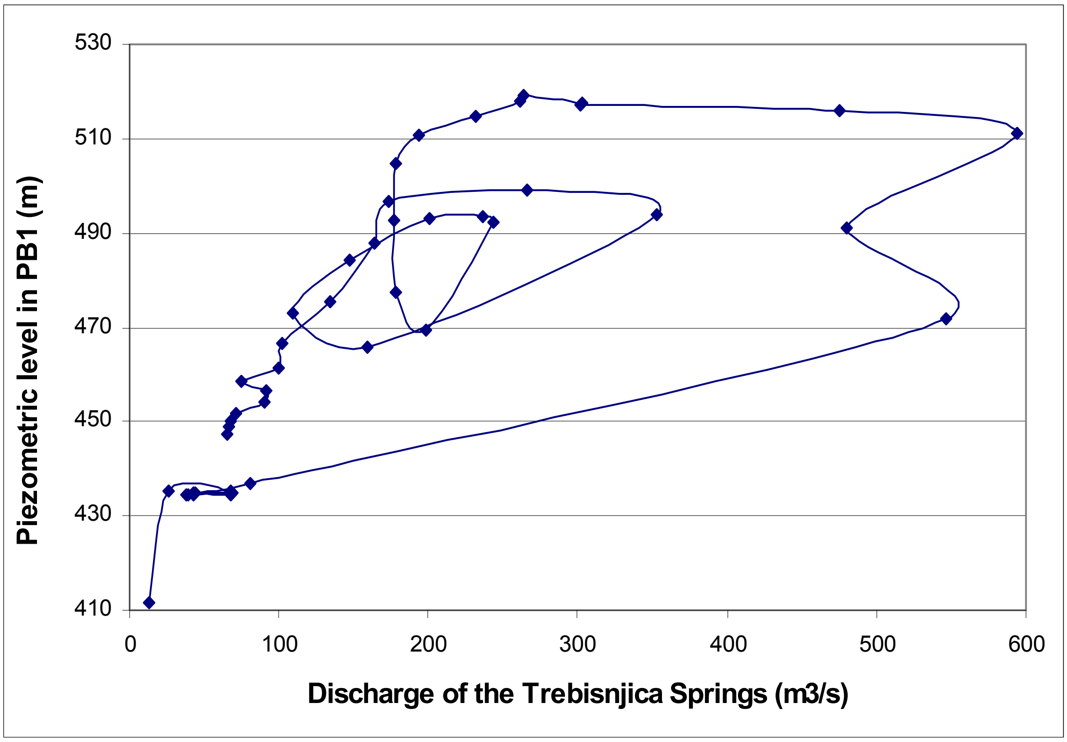


Figure 15. Hysteresis effect: Study of the period 14/11/87—28/12/87

It can be furthermore observed (Figure 15) that, as discussed, the karstic aquifer does not behave in the same way during the rise of the water table and during the decrease.

2.2.3. Water regime of Fatničko polje

The Fatničko Polje with an area of 5.6 km^2, is the natural elongation of the Dabarsko polje in the south-east direction. They are separated by thick limestone rock mass, which separated them into two, hydrologically distinct, areas.

The water regime of the Fatničko Polje is determined by the regime of the karstic springs Obod, Baba Jama and Pribabići, located at the south-east edge and swallow zones (ponor) zone Pasmica and Estavells in the zone of Velika Pećina at the south edge of the polje (Figure 16). Water from the Pasmica ponor zone discharges at the Trebišnjica springs. Water from the ponors in the zone of Velika Pećina discharges at the erosion base level, of both Trebišnjica and Bregava springs. The Bregava springs discharge minor water quantities, only when the water depth in Fatničko polje is over 10 m (water level approximately 472.6 m a.s.l.). The quantity of water discharged through the Bregava springs contributes about 10% (maximum 15%) to the peak flows of Bregava river (quantities over 50 m^3/s – Figure 17).

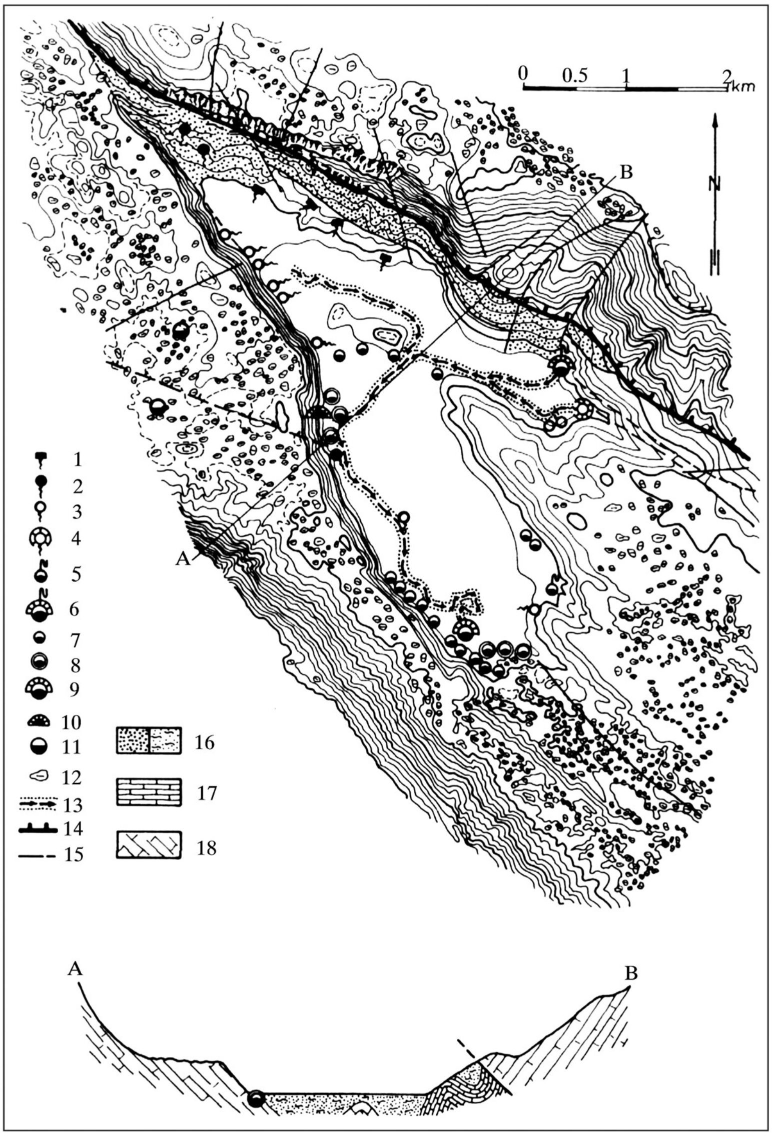


Figure 16. Fatničko Polje

1. Tapped spring, 2. Permanent spring, 3. Temporary spring, 4. Great temporary spring "Baba Jama", 5. Estavelle, 6. Estavelle "Obod", 7. Ponor, 8. Group of near ponors, 9. Great ponor, 10. Big Cave, 11. Jama, 12. Karren, 13. Temporary river, 14. Overthrust front, 15. Fault, 16. Eocene sediment flush, 17. Eocene limestone, 17. Karstified Cretaceous limestone.

The quantity of water discharged in Fatničko Polje is measured at two locations: Obod (1959) and Baba Jama (1959) (the position of these springs can be seen in Figure 16, point 6 and 4 respectively), while the springs are not flooded. After that, the discharge quantity of water in the polje cannot be measured, but calculated from the water balance equations. The swallowing capacity of the ponors in Fatničko polje is highly variable and under particular conditions it depends on the flood level in the polje (Figure 17).

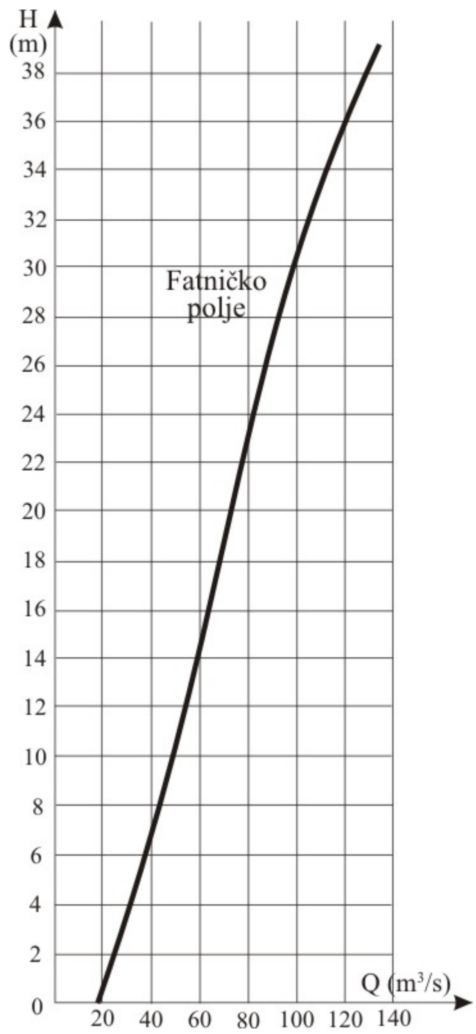


Figure 17. The estimated relationship of flood level (H) and the cumulative swallow capacity (Q) for Fatničko Polje

Results of floods analysed on the basis of data observed on the Pasmica gauge station, under natural conditions (before the filling of the Bileća storage reservoir), are:

- The minimum annual duration of flood is 67 days,
- The maximum annual duration of floods is 235 days,
- The average duration of floods is 137 days.

A diagram of flood duration, in an average year, is presented in Figure 18.

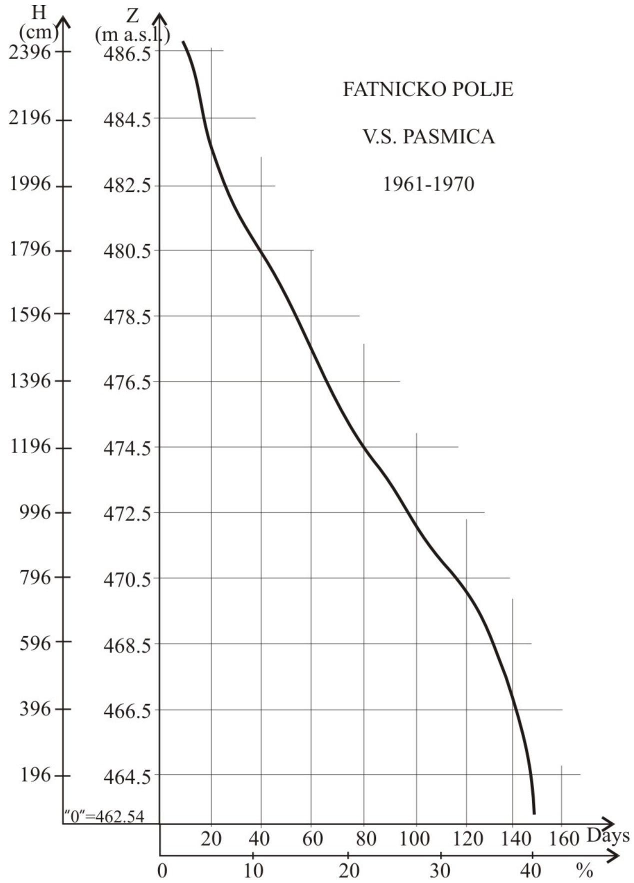


Figure 18. The annual flood duration curve of in Fatničko Polje under natural conditions in the zone of the Pasimca gauging station (Paviša, 1983)

2.2.4. The water regime under anthropogenic pressure

The hydrogeological characteristics of a part of the karstic aquifer have been changed after the Trebišnjica springs were submerged. However, there has been no influence on the water balance of the spring zone.

Part of the zone of aeration of the karstic aquifer has changed its function and become a zone with emphasized transport characteristics. This change has been prominent in the immediate vicinity of the spring, but at a distance of about 15 km it is minimal. Thousands of cubic meters of karstified rock through which, before the storage reservoir was formed, only vertical percolation had occurred, are now the transport zone of the aquifer with a predominant horizontal circulation. The reactivation of old karstic water circulation zones is reflected in the formation of new locations of water discharge. On the slope about 40 m above the submerged spring zone (Dejan's Cave) a new spring zone was formed, and many small water discharges have been noticed at surrounding locations.

In addition to inflow and precipitation, the other factor that affects water regime is the underground water table movement: it's effect depends on whether the aquifer is in a filling (raising limb) or emptying (recession) phase.

The highest level of the underground water table was recorded when the average daily inflow to the storage reservoir was 267 m^3/s, and was preceded by days with inflows of 555 and 646 m^3/s.

The submergence of the spring zone affects the dynamics of the emptying of the karst aquifer. The high water levels of the storage reservoir decrease the hydraulic gradient so that the flow velocities are smaller in relation to natural conditions. In the region of borehole PB-1 (12 km from Trebišnjica spring), during a high stage of the storage reservoir (390 - 400 m a.s.l.), lowering of the aquifer water table from 500 to 450 m, requires twice as much time as before submergence of the spring (Figure 19).

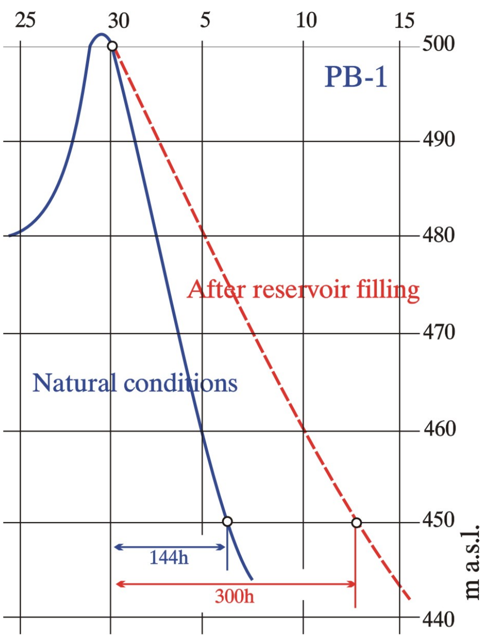


Figure 19. Water table recession curve in borehole PB-1

This change of discharge regime has affected the duration of flooding in Fatničko Polje, so that it is prolonged, but has not affected the actual flood heights or the total hydrogeological balance of the polje.

The influence of the submergence of the spring on the aquifer regime has been somewhat moderate because the aquifer transverse section, through which circulation occurs and the area of active outflow openings through which the aquifer discharges, have been increased.

It has been proven that the high position of the base of karstification south of Fatničko Polje defines the underground catchment of the Bregava system, so there is no loss of water to the Bregava from the Trebišnjica aquifer under the influence of backwater from the storage reservoir.

With the monitoring of hydrogeological conditions of the right flank of the Bileća storage reservoir in the period since it was first filled, it has been proven that there is good hydraulic connection between the storage reservoir and the nearest part of the Trebišnjica aquifer. This connection is maintained even under the most drastic changes of hydraulic conditions.

In parts of the aquifer, 4 - 6 km from the storage reservoir, the influence of the reservoir is variable because of the complex lithostratigraphic characteristics and tectonic structures. During wet periods the aquifer water table in this region mostly fluctuates independently as compared to the water level of storage reservoir, but it does not fall below the level of the storage reservoir during wet periods. The levels equalize after extended periods of low precipitation and in droughts. The influence of the storage reservoir in this part of the aquifer is negligible after its level falls below 360 m. Then the natural regime in that part of the aquifer is restored. In the other parts of the aquifer, on the right flank of reservoir, natural conditions are restored during variations of the water level in the reservoir (between 360 and 374 m asl.). In this period, the fluctuations of the underground water table and the reservoir level are completely independent.

2.3. Bregava River Catchment

2.3.1. Spring zone data

The catchment area of the Bregava spring zone encompasses about 396 km^2. The spring zone consists of Bitunja Spring at 130 m asl and Mali Suhavići and Veliki Suhavići at 190 m asl. Total measured discharge of spring zone is:

$Q_{min} = 0.45\ m^3/s$
$Q_{max} = 59\ m^3/s$
$Q_{mean} = 17.5\ m^3/s$

The catchment area is divided by a deep hydrogeological barrier (impervious Tertiary sediments) beneath the Dabarsko polje, in two hydrogeological units (Figure 20). One is the direct catchment area, which includes a huge mass of the Hrgud and Sitnica mountains located in the zone between Dabarsko Polje and the regional fault between Ljubomirsko Polje and Stolac. It covers about 60% of total catchment area. The other part of the Bregava spring catchment area, known as *indirect catchment area*, consists of the catchment area of Dabarsko Polje, which includes the catchment areas of Trusinsko Polje and Lukavačko Polje. The additional water quantity inflows to Dabarsko polje from the indirect catchment through the permanent Vrijeka spring and the Opačica torrent flow. All water from Dabasko Polje discharges through a few large ponors (swallow holes). The largest one is Ponikva ponor. Additionally, a small percentage of water from Fatničko Polje is discharged through the spring zone Bitunja - Suhavići.

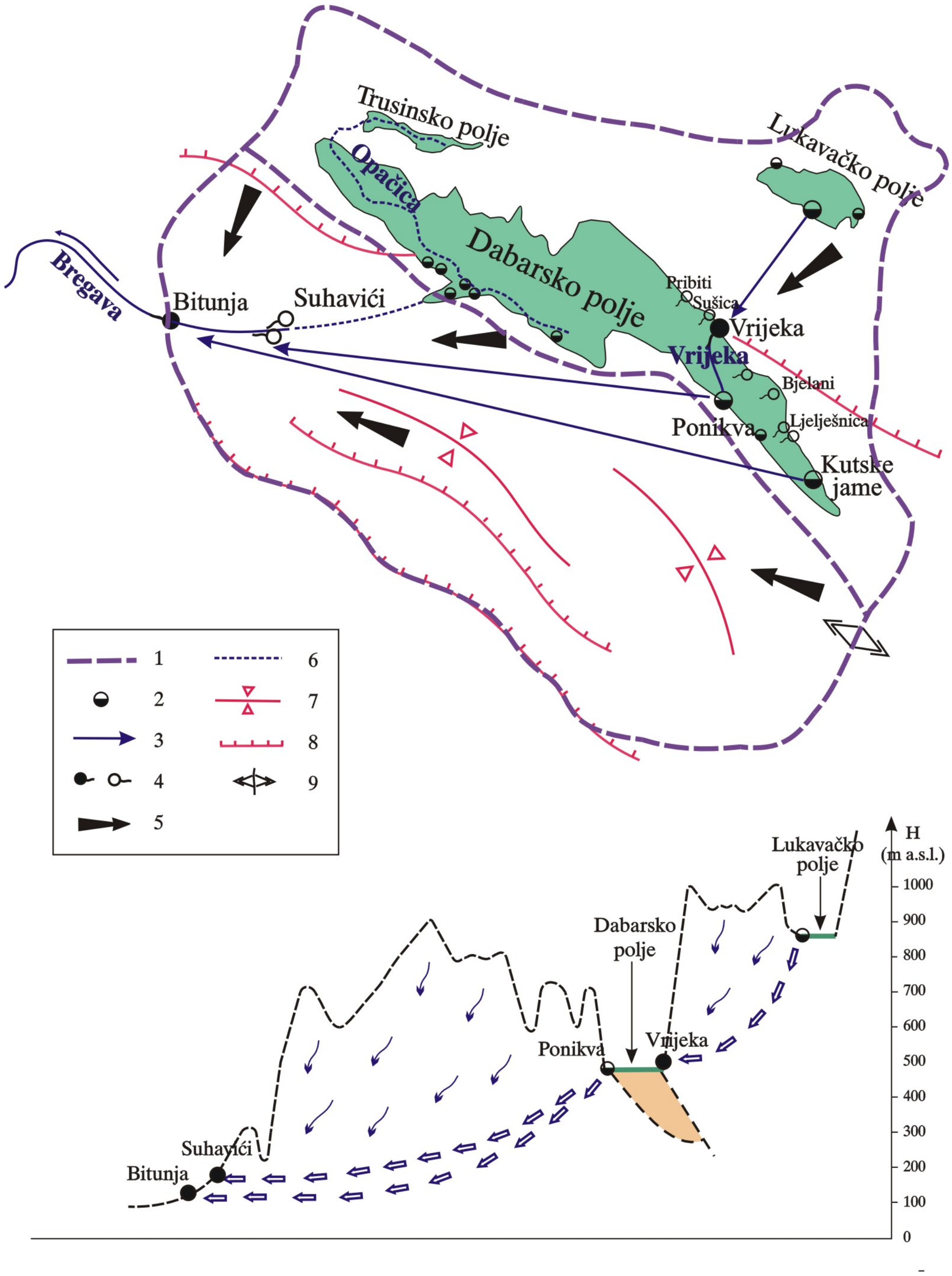


Figure 20. Simplified hydrogeological map of Bregava source spring drainage area

1. Catchment area, 2. Ponor, 3. Underground communication detected by a dry test, 4. Permanent or intermittent source spring, 5. General directions of underground water circulation, 6. Dry valley, 7. Synclinal axis, 8. Reverse fault, 9. Zone off bifurcation

The Bregava River valley is composed of the Cretaceous and Paleogene sediments, covered with debris and slope breccias in the canyon, and downstream of Stolac with the alluvial deposit (the Vidovo Polje). Faults of reverse type and the folded structures of the Dinaric direction give a tectonic character to this area. The most rugged tectonic element is the anticlinal form in which the canyon section of the watercourse is cut through. The anticline is broken by a fault, which imposed the forming of the canyon valley from the source close to the settlement of Stolac.

The thickness of alluvial deposits in the riverbed ranges between 4 and 23 m. Alluvial deposits accumulated faster after the construction of a small dam upstream from Stolac. The limestone below the alluvium is highly karstified and water permeable. At certain locations the limestone is so porous that its structure looks like a sponge. The ground water level is deep under the riverbed.

Discharge of the Bregava springs exists owing to well-deposited alluvium (clogging layer) through which a relatively small quantity of water percolates so that the permanent course disappears only downstream of Stolac. When this layer is penetrated by a borehole, the much karstified limestone is encountered which has almost infinite permeability.

2.3.2. Basic characteristics of the aquifer regime: evolution of karstification

In its early stages the Bregava River contained more water, as it drained the tributary areas of Nevesinjsko Polje and Dabarsko Polje. The surface water from Nevesinjsko, Lukavačko and Slato poljes drained to the Bregava River along the Zalomka riverbed, and water from Dabarsko Polje was directly conveyed by the Bregava to the Neretva River. Intensive evolution of the karst process has resulted in fast development of an underground hydrogeological network and formation of a series of ponors in karst poljes.

The direction of the most intensive karstification as well as the direction of the most important karst drains result from an interaction between geological composition and the position of the erosion basis. From the scheme shown in Figure 21, it can be concluded that between Slato Polje and the Zalomka River, the dry valley was formed after the ponor in Slato Polje was developed. The Zalomka River now receives this water indirectly. With the opening of the ponor in Lukavačko Polje, the Zalomka River lost one of its tributaries. Dabarsko Polje has a much lower erosion base. It received these waters forming another dry valley from Lukavačko Polje towards Zalomka River.

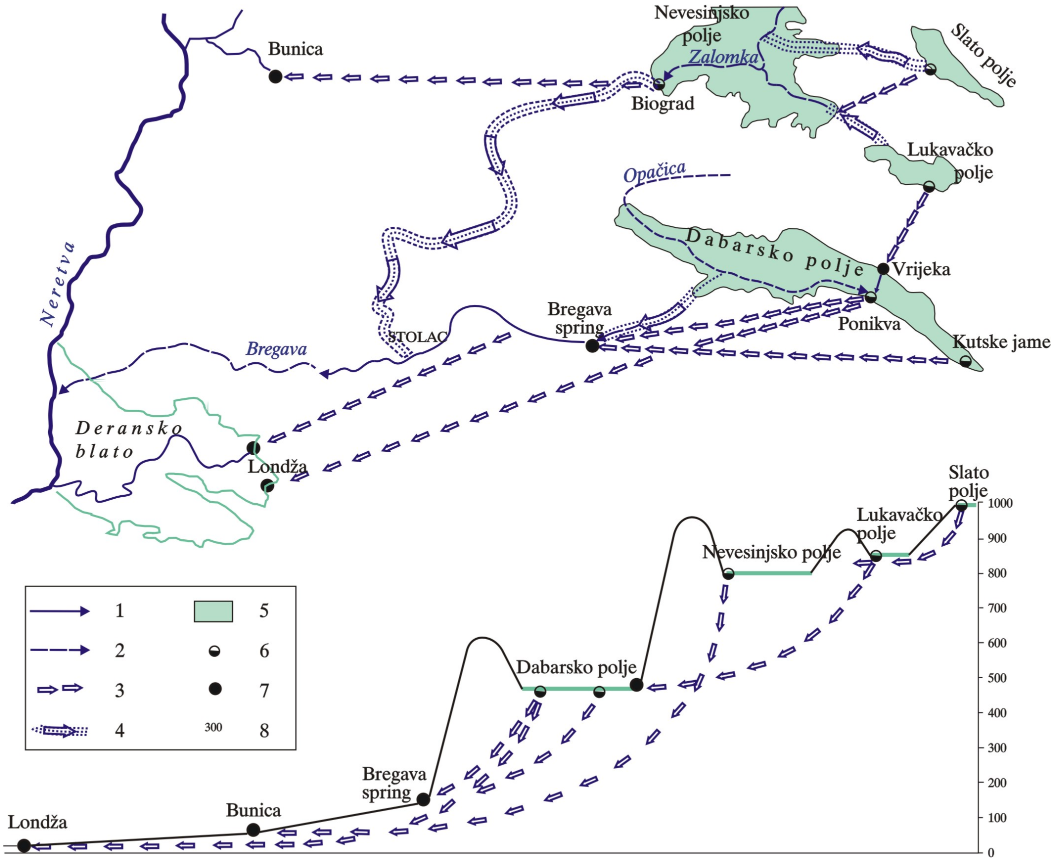


Figure 21. Break-up of surface river network of the Bregava River basin as a result of the evolution of processes (Milanović, 1981)

1. Permanent surface basin, 2. Temporary surface basin, 3. Dry river valley, 4. Underground connections established by dye tracing method, 5. Karst polje, 6. Ponor, 7. Permanent spring, 8. Elevation above the mean sea level

Water flows intermittently in the downstream parts of this valley from Slato Polje. The greatest loss in flow of the Bregava River occurred after the creation of the Biograd Ponor. The river valley was blocked by tectonic activity until the capacity of the ponor drainage system reached its necessary size. At present, water from the Zalomka River flows underground to Buna and Bunica Springs and the stretch between Biograd ponor and Bregava River is now a dry karst valley.

Regardless of the fact that the Bregava River has lost one of its important tributaries, *the river is in a dying phase due to natural conditions*. This dying process started at the head of the river basin, when Ponikva Ponor and Kuti Ponor (swallow hole) were formed in Dabarsko Polje. The dry valley between Dabarsko Polje and Bregava Spring was formed by this process and by local tectonic uplift. A similar process started in the downstream part of the river basin. The water of the Bregava River and its karstic aquifer accommodates to the new lowest erosion base level at Hutovo depression (Londža Spring, + 4 m asl). As time passes, Londža Spring and its underground karst system will completely overtake the surface drainage of this region and the Bregava River canyon will become a dry karst valley.

2.3.3. The water regime of Dabarsko Polje and Bregava Springs

The Dabarsko Polje with an area of 31.7 km^2, is a common example of a closed karst polje. The direction of the longer axis of the polje follows geological structures, particularly the main owerthrust direction from northwest to southeast.

The water regime of Dabarsko Polje is determined by the regime of karst springs and ponors. The only permanent spring in the polje is Vrijeka, with maximal capacity of about 25 m^3/s, and the periodic springs, that form torrent flows Ljelješnica, Sušica, Opačica and Pribit (Figure 20). The swallow hole (ponor) zones Ponikva and Kutske Jame are located at the southern edge of the polje. Vrijeka has a permanent (but very short) stream, with a length of about 2.5 km, and minimum flow of 100 l/s. It ends at Ponikva ponor. All water sinking in the ponor zone discharges at Bregava springs (Veliki Suhavići, Mali Suhavići, Bitunja and Hrgud). The total (maximum) swallowing capacity of the ponor zone of the Dabarko Polje is 43 m^3/s. The swallowing capacity is a highly variable value, which only under particular conditions depends on the flood water level at the field. Under these conditions, the relation is given in Figure 22.

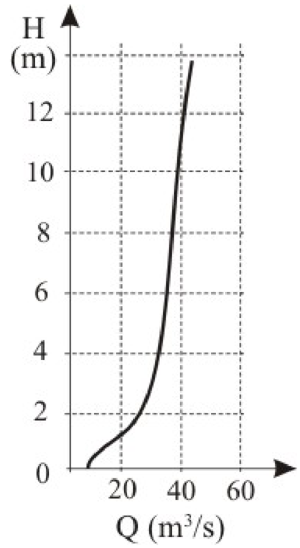


Figure 22. The relationship of flood level (H) and the cumulative swallow capacity (Q) for Dabarsko Polje

The most significant ponor in Dabarsko Polje is Ponikva ponor. This ponor consists of two cave inlets. The inlet channels are nearly horizontal. The maximum swallowing capacity amounts to 15 - 20 m^3/s. In the period of high underground water level the swallowing capacity of ponor is totally blocked.

Floods analysed on the basis of data observed with gauge stations Kuti and Ponikva give the following results:

- The minimum annual duration of flood is 42 days,
- The maximum annual duration of floods is 216 days,
- The average duration of floods is 110 days.

A diagram of flood duration, in an average year, is presented in Figure 23.

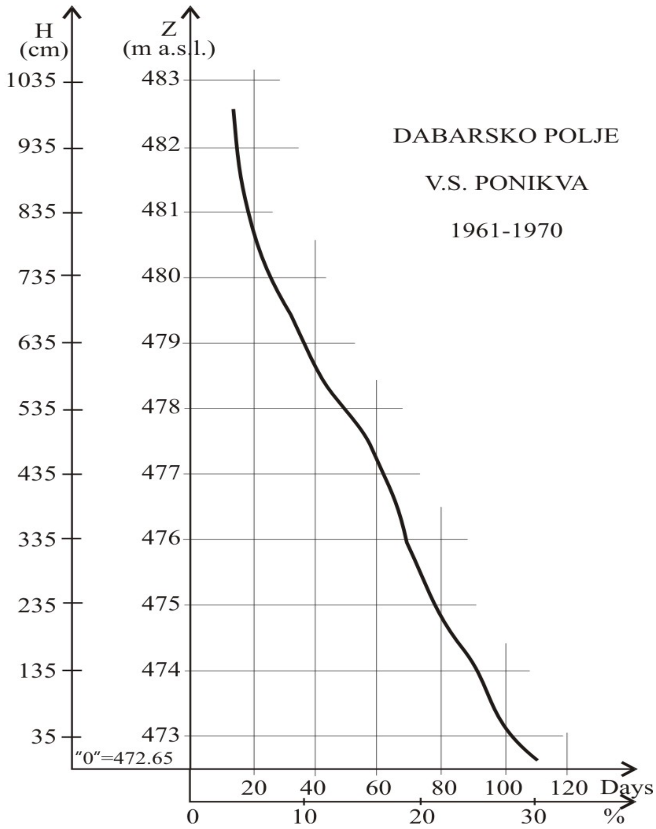


Figure 23. Duration diagram of annual flood in Dabar Polje in the zone of gauge station Ponikva, under natural conditions (Paviša, 1983)

3. Meteorology and Climatology

3.1. Climate database construction

The first step in a pluviometric regime study is to obtain long data series. The climate database for Trebišnjica catchment was constructed from the following data sources:

- Historical daily and monthly climate data published by the Federal Hydrometeorological Institute of FR Yugoslavia (Meteorological Yearbook I and II, for the period 1925-1986);
- The database of the Institute for Urbanism of the Republic Srpska a. d. Banja Luka which was constructed under the LIFE INFRA RED project: Institutional FRAmework for Regional Environmental Development [LIFE TCY/BIH/042]-pilot project for the Trebišnjica catchment;
- The Hydro Electric Power Plants (HEPP) Trebišnjica, meteorological database for period 1985- 2003;
- The Climate Atlas of the former SFR Yugoslavia, for the period 1931-1960;
- Observed gridded climate data sets (monthly mean values for air temperature and precipitation) for Bosnia and Herzegovina for the period 1901-2000, which have been compiled from the internet site www.tyndall.ac.uk;
- A number of different gridded data sets of monthly mean values (that represent large scale climatic features for the northern hemisphere) have been compiled for use as predictors in the construction of empirical models. The data sets were compiled from Climate Data Assimilation System internet sites (NOAA/NCAR Reanalysis-CDAS):http://wesley.wwb.noaa.gov/cdas_data.html, and http://wesley.ncep.noaa.gov/ncep_data/index_wesley.html (monthly, rotating archive)
- The results of experimental numerical predictions of the global climate for 100 years with a coupled atmosphere-ocean general circulation model (CGCM) developed by the Meteorological Research Institute (MRI) of the Japan Meteorological Agency (JMA), in order to assess the effect of global warming on the climate (1998, CD-ROM);
- Data sets of air temperature and carbon dioxide concentration trends from the database of the World Meteorological Organization and Intergovernmental panel on Climate Change;
- Recent regional climate change projections for Europe and Mediterranean region produced by the Meteorological Office (Hadley Centre) of the United Kingdom (HadRM3: www.metoffice.com/research/hadleycentre; Results from the MEDALUS international project related to climate change effects on desertification in the Mediterranean region: www.medalus.demon.co.uk; and Results from the project Europe Climate Assessment.

From the above mentioned sources all available historical climate data have been compiled for the period 1925-2003, for 51 meteorological stations located on the area: 17.45E-18.82E; 42.41N-43.52N. Simple graphical analysis has been applied for heterogeneity identification. In most of the data series related to the area of interest a large amount of missing data was identified, especially for the period of civil war in Bosnia and Herzegovina. An interpolation of missing values was performed for the annual and monthly temperature and precipitation time series displaying gaps. The interpolation considered a linear regression between the monthly time series with gaps and the reference series. In addition, Gstat software, using a co-criging methodology for interpolation of missing annual data was used. Monthly temperature and precipitation