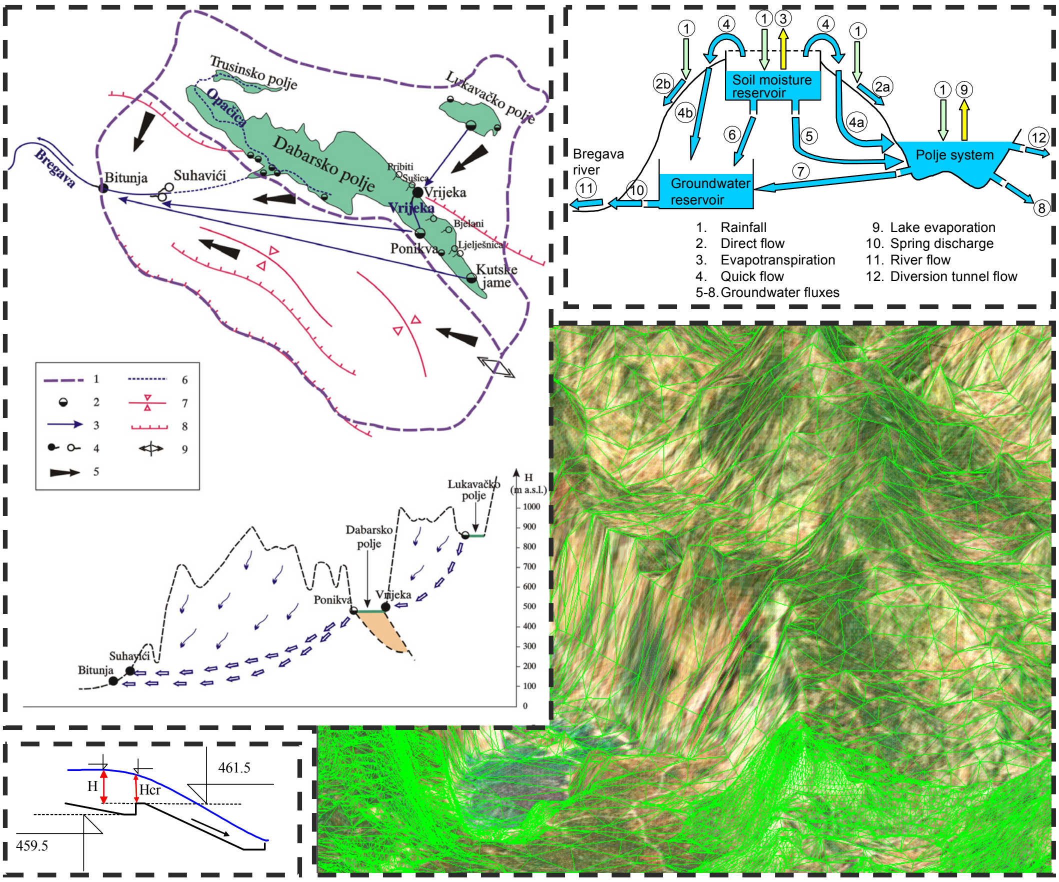
Analysis of the effects of water transfer through the tunnel Fatničko Polje – Bileća reservoir

on the hydrologic regime of Bregava River in Bosnia and Herzegovina



Project Title:	Analysis of the effects of water transfer through the tunnel Fatničko Polje – Bileća reservoir on the hydrologic regime of Bregava River in Bosnia and Herzegovina
Client:	Energy Financing Team (Switzerland) GmbH, Pestalozzistrase 2, CH-9000 St. Gallen, Switzerland (EFT-CH)
Main Contractor:	CUW-UK
Sub-Contractor:	ICCI Limited
Coordination & Editing:	Prof. Čedo Maksimović (Imperial College London) Dr Christos Makropoulos (Imperial College London)
Authors:	Prof. Čedo Maksimović (Imperial College London) Prof. Howard Wheater (Imperial College London) Prof. Demetris Koutsogiannis (NTU Athens) Prof. Stevan Prohaska (University of Belgrade) Dr Denis Peach (British Geological Survey) Dr Slobodan Djordević (University of Exeter) Dr Dušan Prodanović (University of Belgrade) Dr Christos Makropoulos (Imperial College London) Mr Paul Docx (Imperial College Consultants) Dr Tina Dašić (University of Belgrade) Dr Miloš Stanić (University of Belgrade) Mrs Danica Spasova (IURS Banja Luka) Mr Dragan Brnjoš (HET Trebinje)
Quality Assurance:	Prof. Howard Wheater (Imperial College London) Dr Denis Peach (British Geological Survey)
Report Type:	**Final**
Publishing Date	24 June 2004
Circulation	Restricted

Executive Summary

Objectives

The objective of this study was the analysis of the possible effects of water transfer through the tunnel Fatničko Polje – Bileća reservoir on the hydrologic regime of the Bregava River under current and future hydrological and operational management conditions. The study describes in detail the hydrologic situation in the area of interest, discusses possible effects under a range of operational scenarios, identifies the sources of the associated uncertainties and critically presents the results obtained.

Conclusions

In this report a state-of-the-art hydrological analysis of the effect of water transfer through the tunnel Fatničko Polje – Bileća reservoir on the hydrologic regime of Bregava River have been carried out by three independent institution and different methodologies. The study is based on the best available data sets and builds on information extracted from the technical documentation elaborated by the leading consulting companies and research institutions and experts in Former Yugoslavia (Bosnia and Herzegovina, Croatia and Serbia) in the periods related to planning, design, post construction evaluation and operational management of various elements of the Trebišnjica catchment multipurpose system.

A significant source of information was a set of proceedings of the USA-Yugoslav Symposium **Karst Hydrology and Water Resources[1]**, held in Dubrovnik in which the results of research carried out under partial NSF funding within a USA-YU project was presented. Most of the research was based on extensive field monitoring in Trebišnjica catchment.
Additionally, in order to set-up the rules for the future operational management of the system, use was made of the conditions set in the building permit (*Vodoprivredna saglasnost*) for water transfer form Dabarsko polje to Fatničko polje issued by Water Resources Authority of the Republic Bosnia and Herzegovina, (*Republička uprava za Vodoprivredu, Sarajevo, 1996 Director Abdulah Huzbašić*), No UP-I-03-78-1/69) and the building permit (*Vodoprivredna saglasnost*) for tunnel Fatničko polje – Bileċa reservoir, issued by the Committee of Agriculture, Forestry and Water Resources (*Republički Komitet za Poljoprivredu, Šumarstvo i Vodoprivredu, Pomoćik predsjednika Božo Knežević*), Sarajevo, No. UP-I-06-337-180/86

Internal control and quality assurance (QA) of the study has been performed by leading British experts in Hydrology (Imperial College London) and Hydrogeology (BGS British Geological Survey).

The following conclusions can be drawn from the present study:

a. The Trebišnjica catchment has already undergone partial development in accordance with projects and concepts subject to regular planning and approval procedures in force at their planning stage.
b. In general the methodology applied in the assessment and planning of the multipurpose use of water resources in the area was sound and in accordance to the standards of the period and suitable data bases were created to support the planning process. These databases were at the time of a high standard.

[1] Published by WRP – Water Resources Publication, 1976, Fort Collins, Colorado (LCCCN, 76-012972)

c. In its planning stage the whole system of the Trebišnjica catchment, of which the "Upper Horizons" are an integral part, was conceived as a multipurpose one, based on optimal water resources management principles for flood protection, irrigation, hydro-energy production, water supply and environmental mitigation under unfavourable karst conditions.
d. During the past twelve years, due to conflict in the area, a lot of monitoring and data acquisition practice has deteriorated thus both quantity and quality of data for the most recent period has significantly degraded.
e. Despite unfavourable conditions most of the vital physical assets have been preserved in good working condition and this is especially true for the hydro-energy sub-system.
f. In the meantime several attempts have been made in order to assess the status of the environment and infrastructure and to revitalise other parts of the system and provide better conditions for revival of the economical activities in the area.
g. One of the projects that preceded this study is the EU co-funded LIFE-INFRARED project in which assessment of the environmental pressures and impacts of various alternative activities was performed and innovative informatics techniques have been developed and have been used in the present study.
h. The present study focused on the Bregava river catchment which shares resources with the Trebišnjica catchment depending on hydrological and meteorological conditions, **under the assumption that the whole system will be completed and that the provisions of the design conditions and permits will be strictly observed**.
i. The results of the study supports the claim that the system of tunnels from Dabarsko polje to Fatničko polje and from Fatničko polje to Bileća reservoir has a favourable effect in reducing flood hazard (especially depth and duration) in these two poljes and thus liberating scarce land resources for agriculture.
j. The study has taken into account the assumption that the outflow from Dabarsko polje to Bregava river will be regulated (a flow regulation gate-valve) to be built on to entrance to Ponikve ponor. The rules for operation of the flow regulation are taken form the above mentioned building permits.
k. The study has quantified the effect of the diversion of a part of the flood water from Dabarsko polje to Fatničko polje and to Bileća reservoir on the hydrological regime of the Bregava River in the cross section of the hydrometric station Do, by performing three independent analyses. The results obtained by all three methods are similar: there seems to be little effect on extremely high flows (over $50m^3/s$), the most pronounced effect (reduction of flow) occurs in the range between 5 – 50 m^3/s, and the effect is almost negligible for flows lower than 5 m^3/s. **The study cannot therefore support the claim that the tunnel Fatničko Polje – Bileća reservoir will contribute to the drying up of the Bregava River basin, or to the 'desertification' of the area, under the assumptions of proper operation discussed above. In fact, our study suggests the reverse in the event that the "Upper Horizons" project is completed and flow regulation provisions are observed by the operators**, allowing for augmentation of flows in the Bregava during dry periods (see also item m).
l. It should be noted that **this result is obtained without taking into account the ponor Kutske jame as well as several smaller ones on the southern rim of Dabarsko polje which leads us to believe that the effect on low flows could be even smaller than assessed.**
m. This study has not discussed the conditions that will be in place after the construction of the reservoirs in Nevesinjsko polje on Zalomka River. According to the conditions imposed, after that construction, the low flows to the Bregava River will be additionally enriched for at least 1 m^3/s. To quantify the effects of

the works planned in Nevesinjsko polje (Zalomka River) on both Bregava and on Buna and Bunica rivers, a separate study is recommended.

n. **It is also strongly recommended that the crucial hydrometric stations be rehabilitated and equipped with modern and reliable sensors and to closely monitor the post construction performance of the system. Post project monitoring would decrease the uncertainty in the modelling results and predictions identified and discussed in the report and provide a means for tailoring the operational rules of the system to the actual conditions and needs of the area.**
o. Since this study did not include water quality aspects it is suggested that this should be done in a next phase as a part of an overall environmental impact assessment in Trebišnjica and Neretva catchments which is planned to be performed in the near future. The methodology and informatics support developed in this project can be easily incorporated into a broader modelling framework.
p. The authors hope that this study will be used for a broad awareness raising on the interdependencies of catchment processes and for building capacity for regional co-operation similar to the UNESCO endorsed **PCCP** (from **P**otential **C**onflict to **C**o-operating **P**artnership) principles.

TABLE OF CONTENTS

List of Figures

List of Tables

Glossary of Key Terms

Calibrated Parameter Models (Hydrological Models)	A calibrated parameter model is one which has one or more parameters that can be evaluated only by fitting computed hydrographs to the observed hydrographs. Calibrated parameters are usually necessary if the watershed component has any conceptual component models, which is true for most presently used watershed models. Thus, with a calibrated parameter model, a period of recorded flow is needed, usually several years, for determining the parameter values for a particular watershed.
Karst	Karst is a geological phenomenon, first described in Slovenia. The basic aspects of karst areas are soluble bedrock, cracks and water. Rain and groundwater dissolves the rock and forms caves and caverns. Common rocks for karst areas are: Limestone (calcium carbonate $CaCO3$) Dolomite (magnesium calcium carbonate $CaMg2CO6$) Gypsum ($CaSO4 + H2O$)
Measured Parameter Models (Physical Models)	A measured parameter model is one for which all the parameters can be determined satisfactorily from known watershed characteristics, either by measurement or by estimation. For example, watershed area and channel length can be determined from existing maps, channel cross sections can be measured in the field. Soil characteristics can be determined in a lab but not at the scale of model application. Characteristics like channel roughness are often estimated. A measured parameter model can, in principle, be applied to totally ungaged watersheds and is therefore highly desirable. However, the development of such a model that is continuous, acceptably accurate, and generally applicable is a goal that has not yet been fully attained, mainly due to the problems of characterising soil and groundwater properties.
Polje	Large closed depression draining underground, with a flat floor across which there may be an intermittent or perennial stream and which may be liable to flood and become a lake. The floor makes a sharp break with parts of surrounding slopes
Ponor	Swallow hole of karstic origin
Aquitard	A layer of rock having low permeability that stores groundwater but delays its flow.

Abbreviations

ASL	Above sea level
DEM	Digital Elevation Model
GIS	Geographic Information System
SLP	Sea level pressure

1. Introduction

1.1. Background

This report is the final deliverable of the project: Analysis of the effects of the water transfer through the tunnel Fatničko Polje – Bileća reservoir on the hydrologic regime of the Bregava River in Bosnia and Herzegovina. This was undertaken by a multidisciplinary team composed of experts from:

- ICCI LTD
- CUW-UK (Centre for Urban Water), London, UK
- BGS (British Geological Survey)
- Imperial College Consultants, London, UK
- University of Exeter, UK
- National Technical University of Athens (NTUA), Greece
- Institute of Hydraulic and Environmental Engineering, University of Belgrade, Serbia and Montenegro
- Institute for Water Resources Jaroslav Černi, Belgrade, Serbia and Montenegro
- Urban Planning Institute of Banjaluka, RS – Bosnia and Herzegovina.

Data needed for the study has been provided by the client (EFT GmbH) mostly based on the HIS-HET data base originating from HET Trebinje.

The principal activity in the study was hydrologic – hydrodynamic modelling performed independently by three teams using three different methodologies. Although the experts from all three teams involved in the modelling exercise had some models developed beforehand, all three groups had to make significant updates and additional model development in order to be able to cope with the unique karstic features of the Trebišnjica and Bregava catchments.

The key results, demonstrating the effects of water diversion through the tunnel Fatničko polje – Bileća reservoir, **are presented in the form of duration curves for flows (discharges) at the hydrometric station "Do".**

An important work, by the same authors, that acts as background to this study is the EU funded LIFE-Third Countries INFRARED project, which places emphasis on the identification and assessment of environmental pressures and management options on a catchment level and deals specifically with the Trebišnjica catchment. The EU study's background together with the tools developed within this work can serve as a springboard for comprehensive environmental impact studies not only for the whole of the Trebišnjica and Neretva catchments, but also for other catchments of a karstic nature.

1.2. Purpose of the Study

According to the ToR (Terms of Reference) the Study had to perform the following tasks:

1. Analysis of rainfall and runoff (flow) data and selection of the relevant time series for further processing
2. Analysis and critical evaluation of the previous studies and methods of analysis which are pertinent to the analysis of the effect of water transfer through the tunnel

3. Selection (or development) of the appropriate data processing model, of its structure and parameters
4. Definition of the model application and verification
5. Analysis of the results obtained by modelling
6. Numerical and graphical presentation of the results
7. Assessment of the effects of water transfer with regards to the balance and
8. Recommendations and conclusions.

The analysis had to be performed by making use of the data of the previous studies that were made available to CUW-UK. Additionally, use was made of any data that were obtained in the recent years, although due to recent conflict in the region most of the monitoring equipment has been damaged and measurements discontinued.

The study includes (as suggested in the ToR) several innovative methodologies compliant with current international practice, including:

1. Updated analysis of the pluviometric regime including data obtained in the past decade and assessment of the potential effect of the climate changes based on the internationally accepted criteria and models.
2. Development, to the extent data and time availability permit, of a physically based model of the system consisting of Dabarsko Polje, Fatničko Polje, the underground karstic aquifer, Bregava river springs and the upstream part of Bregava river – between the springs and the hydrometric station Do.
3. GIS based representation of the physical features of the catchment and of the results of the analysis where appropriate.

It should be clearly stated that this is a karstic catchment and aquifer with a limited amount of monitoring sites and data series, the quality of which is to a large extent uncertain, thus the result of analysis will always involve certain degree of uncertainty. Efforts have been made to identify the sources and to quantify the uncertainty whenever possible.

1.3. Description of the area and hydro-system

The area which is subject of this study is located in the broader region of East Herzegovina characterised by a predominantly karstic terrain. Fertile soil is found only in polje (karstic fields) while the rest is bare rock (Figure 1).

Figure 1. Karstic landscape

The Bregava River is a tributary of Neretva River, which has passed through several phases of development in its hydrogeological history as will be described in Chapter 2. In addition its direct catchment is mainly fed through the Hrgud spring which originates from the Dabarsko polje. In its most upstream part it shares water resources with a part of the Trebišnjica catchment: Fatničko polje. It benefits from the existence of a "bottleneck" in the karstic barrier downstream from Dabarsko polje which acts as "low pass filter" limiting the peak flows to the capacity of an underground system of fissures and larger karstic conduits (fed by Ponikve and Kutske jame ponors).

The present study dealt with the part of Bregava catchment upstream from the hydrometric station Do. In its reach downstream from Stolac, low discharges percolate (flow) though the alluvial sediment and the river flows mostly underground.

In its upstream part the catchment underwent water resources development in view of the broader concept of management of the Trebišnjica and Zalomka catchments. The following phases can be identified in this system's development:

a. Natural conditions

Before the development of the first phase of the Trebišnjica multipurpose system in its natural conditions (Figure 2) the system was characterised by the following features:

- Trebišnjica, as the biggest sinking river in Europe, flooded regularly the Popovo polje rendering it unsuitable for human settlements
- A high level of vulnerability to natural disasters was observed.
- The "flood free" period lasted about 100 days thus limiting agricultural production (Film *Vode Trebišnjice*, directed by Hajrudin Krvavec, available from HET, Trebinje)
- There was a low level of water use although it was the most precious resource in the region
- There was low level of economical activity thus encouraging the local population to immigrate to the other parts of the world.

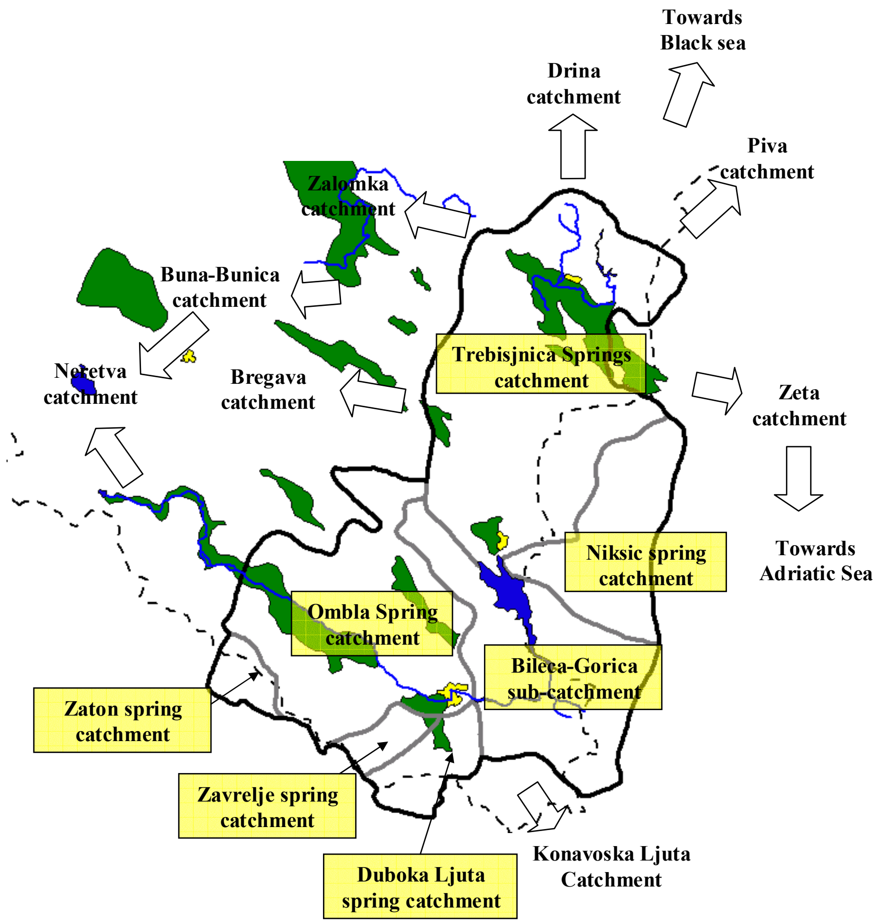


Figure 2. Trebišnjica and Bregava catchments and their interactions under natural conditions (Position of Bileća reservoir indicated)

b. Planning of water resources development (late 50-s)

Planning of water resources development in this period was based on the following principles for the karstic environment:

- Capture and store water on the surface in wet periods and use it in dry periods
- While using its hydro potential for energy production enable spatial diversification of the resources so that all parts of the catchment can benefit from the scheme
- Multipurpose water use: drinking, flood protection, irrigation, hydro-energy production, low flow augmentation (special conditions for Bregava), amenity, water sports and recreation,
- Some (simple) forms of protection of natural resources and environmental values.

The longitudinal section though the major elements of the system is shown in Figure 3. These principles were applied in the implementation phase that followed.

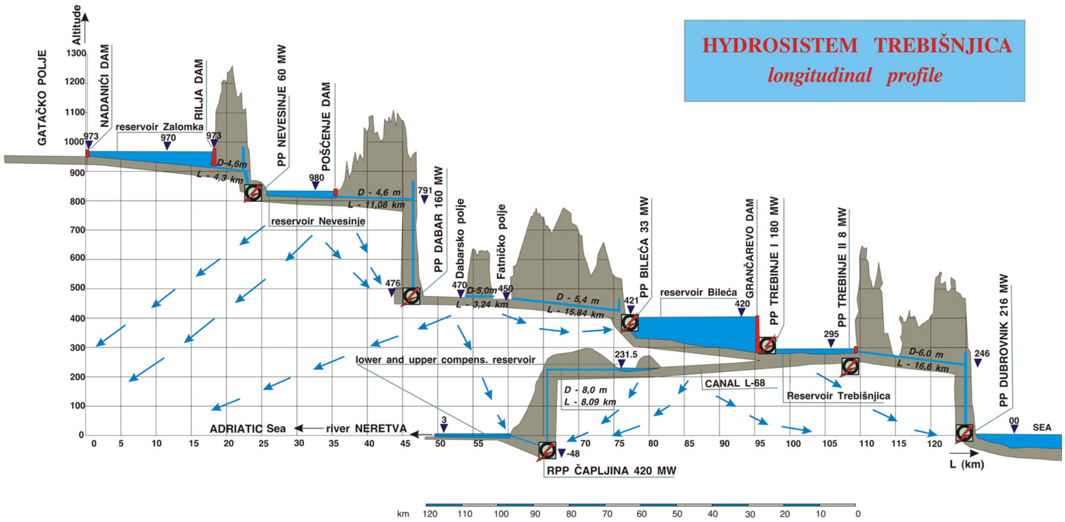


Figure 3. Longitudinal section though the key elements of the Trebišnjica system as planned

c. The first phase of the system's development

In the first phase of the system's development the following subsystems have been developed:

- The Grančarevo arch dam (height 123 m) with the Bileća reservoir (total volume 1.28 x 10^9 m^3) and the Trebinje I hydroelectric power plant (180 MW installed capacity)
- The Gorica gravity dam (height 33.5m) with upstream reservoir (total volume 15,9 10^6 m^3) Trebinje II hydropower plant (8 MW)
- Tunnel (16.5 km long) and hydropower plant of Dubrovnik (210 MW, head 270 m).
- A flood alleviation scheme and a channel through Popovo polje (68 km) and the pump storage hydropower station Čapljina (429 MW)
- Water supply systems for Herceg Novi and Konavli and an irrigation scheme for Konavsko polje
- Improvement of the water supply for Bileća and Trebinje and wastewater treatment plants for Bileća and Trebinje

d. The "Upper horizons" upgrade scheme

The scheme is named "Upper" because it is aimed at development of water resources schemes in the karstic poljes which are at elevations higher than Bileća reservoir (upper elevations between 400 and 1100 m a.s.l.). In this next phase it was planned to build (develop) the following:

- Three dams (Nadanići, Rilja and Pošćenje and the adjacent reservoirs on the Zalomka river (reservoir Zalomka and "compensation" reservoir in Nevesinjsko polje)
- Two tunnels from Nevesinjsko polje (for the Dubrave plateau – for irrigation and tunnel to Dabar Hydropower plant) with a diversion of additional water quantity for augmentation of Bregava river low flows
- Flood alleviation schemes for Dabarsko polje (Tunnel Dabrsko polje – Fatničko polje – built in 1986) and assurance – management of low flows for Bregava river) (see Figure 10)
- An irrigation scheme in Nevesinjsko polje (Zlatac) Dabarsko polje and Fatničko polje

- Flood alleviation scheme for Fatničko polje (Tunnel Fatničko polje - Bileća reservoir) which had been planned to be also used for energy production (HE Bileća). Construction of the tunnel started in 1986, discontinued during the war and resumed in 2002. The construction of HE Bileća has been postponed for a later stage.
- Agricultural improvement in the Fatničko polje
- Low flow augmentation for Buna, Bunica and Bregava rivers.

During the planning phase the effect of the flood water transfer to Bileća reservoir has been analysed by Milićević and Zotović. A brief description of this model is given in the Appendix.
The development planned in the Upper Horizons scheme can be seen in Figure 4.

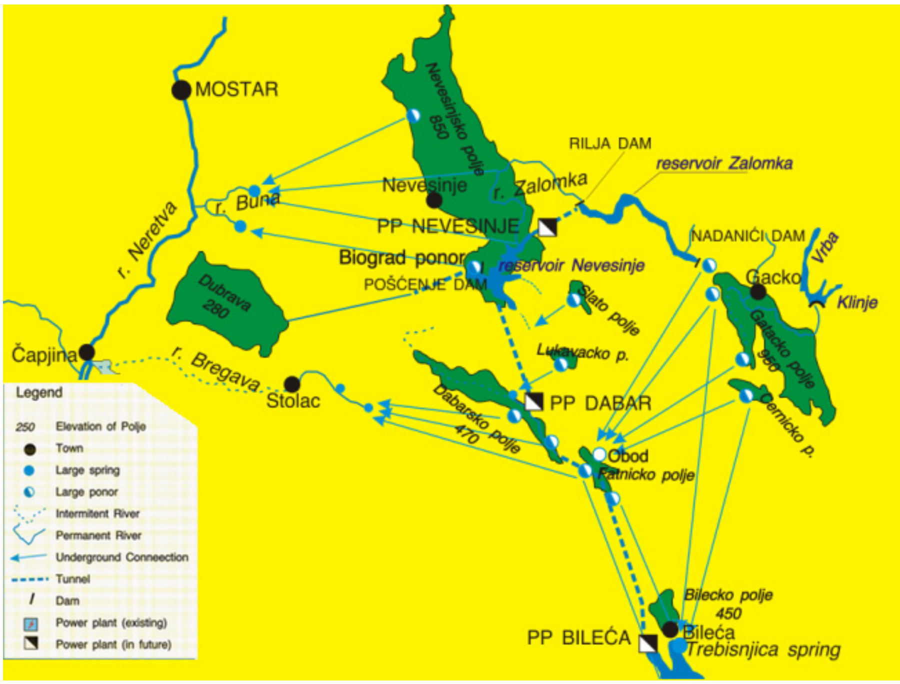


Figure 4. The "Upper Horizons" system includes three new dams, two reservoirs, flood alleviation schemes for Nevesinjsko, Dabarsko and Fatničko Polje, irrigation scheme for Dubrave, Nevesinjsko, Dabarsko and Fatničko Polje, low flow augmentation for Buna Bunica and Bregava rivers and three hydroelectric power plants.

The current status of the development of the whole Trebišnjica system is presented in Figure 5. From that figure it can be seen that while the part of the system downstream from Bileća reservoir is in an advanced stage of development, in the Upper horizons part of the system, besides the Zlatac irrigation system (Nevesinjsko polje), only the tunnel DP-> FP has been constructed while the FP->BR tunnel is about to be constructed within the coming months. This leaves the area vulnerable to natural disasters (floods and droughts) and the natural resources (water, solar energy, and fertile soil) in the karstic poljes remain to a large extent unused. This is the case, for example, in agricultural production, where BiH struggles to reduce its dependence on import of food.

Figure 5. Current level of development of the whole Trebišnjica system

e. Future

The plan of the Trebišnjica Multipurpose System was conceptualised in the 1950-s and 60-s and the system was developed following the general concept with timely modifications. In the mean time following disintegration of the Former Yugoslavia, former republics act as independent states which are preparing for integration into the EU, thus embracing the principles of the EU Water Framework Directive (WFD). The Directive puts emphasis on environmental issues within the context of water resources management. The karstic region under investigation has its unique features to which the appropriate tools will have to be developed in order to implement WFD principles. The *implementability* of WFD under karstic conditions has been examined in an ongoing EU LIFE Third Countries project: INFRARED. A number of relevant reports have been produced so far by *Imperial College London*. Based on the results of the above studies and of other analyses performed in this project, some general conclusions about the future trends can be deducted:

- The general concept of the multipurpose system development in the Trebišnjica, Zalomka and Bregava catchments is viable and can serve as a basis for the further upgrade providing that all current environmental concerns and environmental management principles are taken into account
- The system is attractive because it can provide conditions for sustainable economical development (agriculture based on additional land vacated with reduced flood risk, tourism, flood protection) and at the same time it can generate additional amount of renewable energy without increasing atmospheric pollution (no greenhouse gases emission)

- Some elements of the system can be upgraded with relatively low investment costs
- In the future planning of the system's upgrade, environmental pressures and impacts have to be analysed in a way similar to Vukadinović (2003).
- *The existing system of monitoring is degraded and needs a significant overhaul.* This includes selection of a smaller number of representative sites for monitoring of flows, surface and groundwater level, water quality indicators and replacement of the mechanical sensors and data acquisition systems with more robust ones preferably based on wireless communications.
- In all schemes the sustainability of the proposed solutions has to be analysed and built in the concept.
- The system even provides space for some new lucrative initiatives to be implemented, for example transfer of high quality water to the arid regions in the Southern Italy.
- Advanced schemes for day-to-day management of all components of the system have to be implemented.
- There is a need for more activities in awareness raising and involvement of key stakeholders in consultation process
- There is a possibility to facilitate the, sometimes, "overheated" disputes by promoting discussions based on sound arguments. However, a prerequisite for forming such arguments is professional analyses similar to this study. The UNESCO's PCCP (From Potential Conflicts to Co-operation Partnership) concept can serve as an attractive template.
- **It is strongly recommended to perform an analysis similar to the analysis performed here, for two different cases**: (i) The Nevesinjsko polje and the interaction between Buna, Bunica and Bregava with Trebišnjica and (ii) the integration both models and additional features thus producing the model for the whole catchment.
- A reactivation of the Institute for Karst Research in Trebinje would be useful, in order to safeguard the longevity of the results achieved so far and to act as a catalyst for future research.

The above conclusions and recommendations are seen as added value results from the study which became apparent during our work.

1.4. Engineering work in Dabarsko and Fatničko poljes

In this section we shall present only those works which are directly relevant to the results of this study i.e. work in Dabarsko and Fatničko polje.

1.4.1. Tunnel Dabrsko Polje and Fatničko polje (DP->FP)

The tunnel was constructed in 1986 according to a detailed design (*Glavni projekat*) performed by Energoinvest, Sarajevo (February, 1985). A plan view and cross section of the tunnel are shown in Figure 6. The flow through the tunnel is regulated at the downstream end of the tunnel by vertical sluice gate, which is operational. At the moment (before the construction of the tunnel between Fatničko polje and Bileća reservoir (FP->BR) is commissioned) the operational rule requests only that the gate should be closed when the water level in Fatničko polje is higher than in Dabarsko polje. In the future (after the FP->BR tunnel becomes operational) the new phase in the project development requires specific conditions set-up in the building permit (see section 1.6).

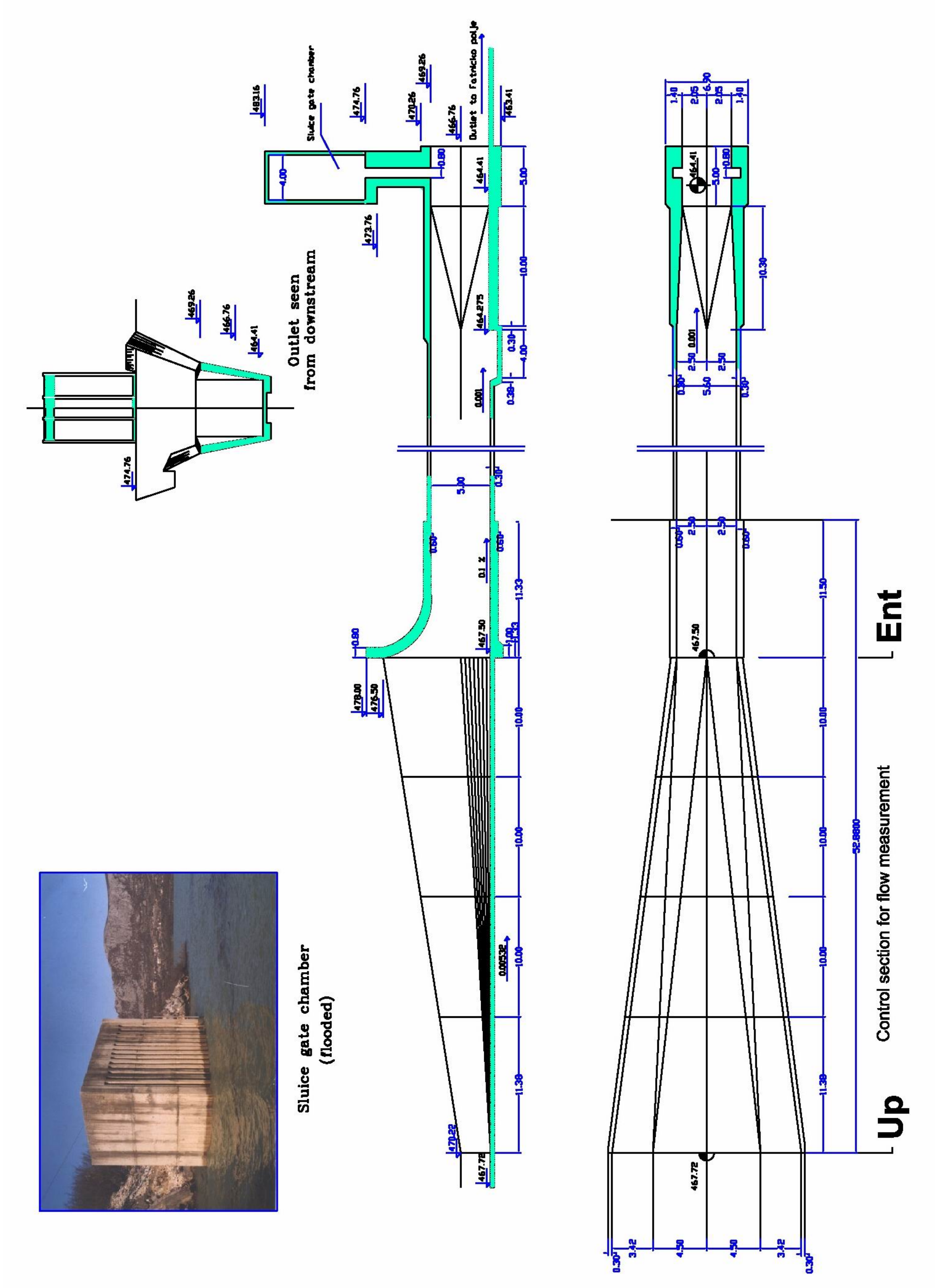


Figure 6. Longitudinal section and plan view of the tunnel Dabrsko polje - Fatničko polje

For operational purposes and to assist the correct calibration of models run in this study it was necessary to know the discharge capacity of the tunnel. The capacity function is determined by hydraulic conditions under two distinct regimes:

1. **Free surface flow in the tunnel:** When the flow in the tunnel is free surface, the flow regime in the tunnel is sub-critical (FROUDE Number smaller than 1) and the slope of the approaching channel is low, at the entrance to the tunnel the normal depth in the tunnel interacts with the water level in the approaching channel (transition from the trapezoidal to rectangular cross section - Figure 6). The lower portion of the flow – discharge curve is calculated 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 are taken).
2. **Tunnel surcharged:** When the tunnel is surcharged its capacity is determined by is friction losses and it depends on the water level in Dabarsko polje. As far as the authors of this chapter are aware there were attempts to measure the friction of the tunnel (by compressed air flow), but this report was not available to the team. Therefore the analysis has been done with two hypothetical Manning roughness factors (n= 1/60 m-1/3s and n= 1/80 m-1/3s, whereas K=1/n). The results are shown in Figure 7. These results have been used by all modelling groups.

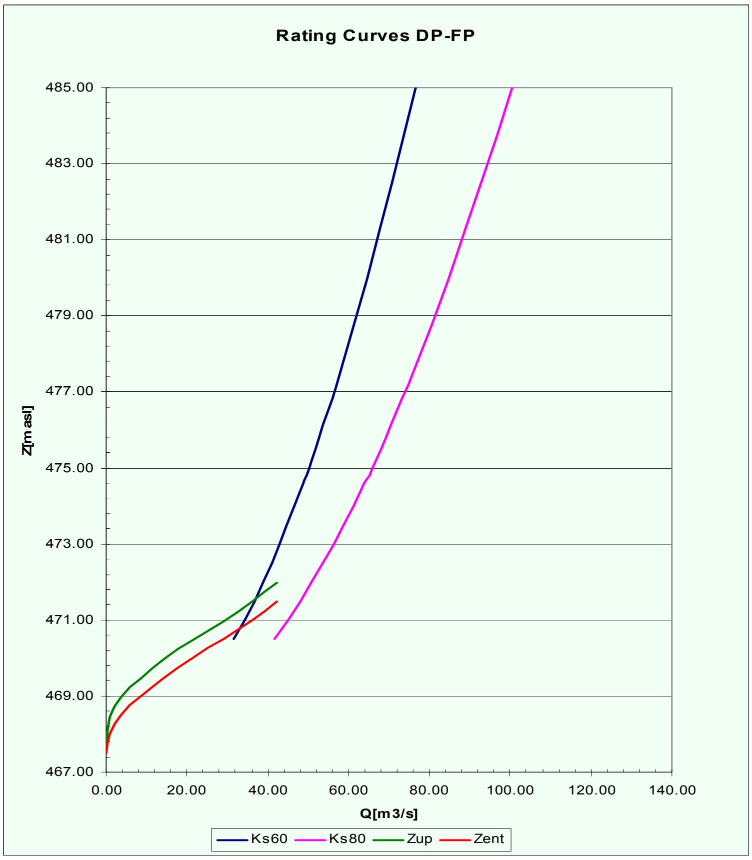


Figure 7. Capacity of the tunnel between Dabrsko Polje and Fatničko polje