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Protection and Sustainable Use of the Dinaric Karst Transboundary Aquifer System

CLASSICAL DINARIC KARST AQUIFER – AN OVERVIEW OF ITS PAST AND FUTURE

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and Zoran Stevanovic, Regional Consultant *University of Belgrade - Faculty of Mining & Geology, Department of Hydrogeology, Belgrade, Serbia*

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Task of Working group G 1

1. Defined at project document and specified in details in 2011.

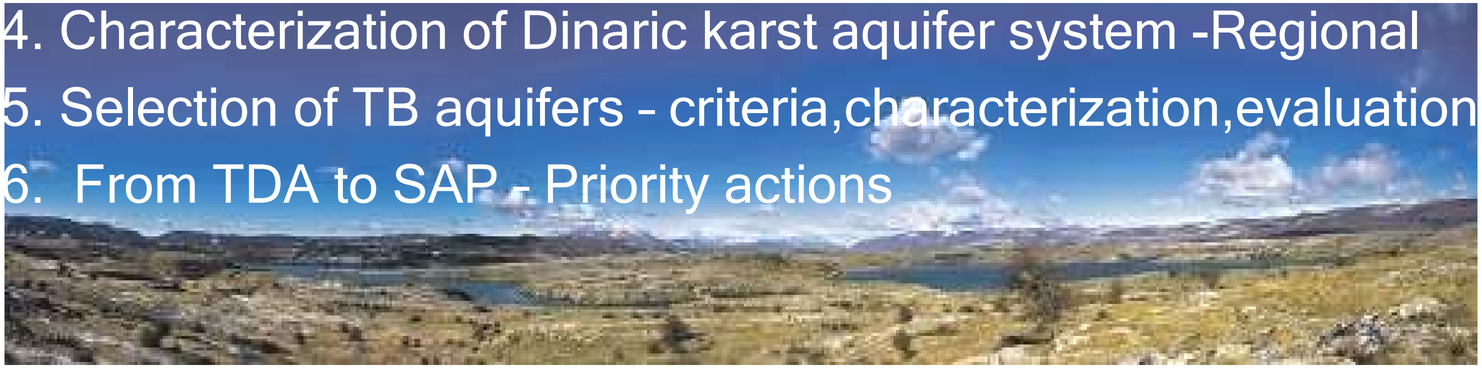
2. GIS produced Hydrogeology map in print scale 1:500.000. Source: data from maps1:100.000-500.000 of former YU and Albania

3. Delineation of study area, link with neighbour countries, problem to synchronizing coordinate systems, content and legend, GIS expert support

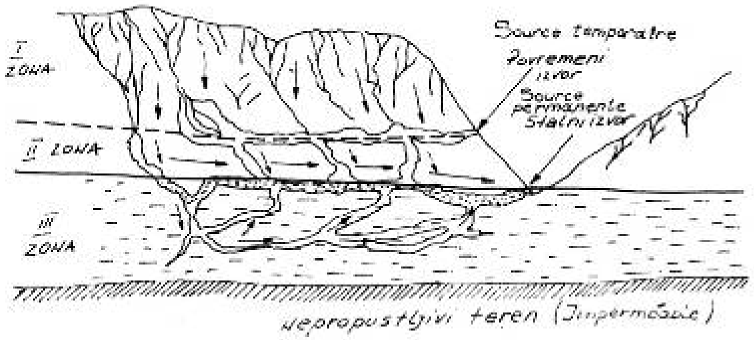
4. Characterization of Dinaric karst aquifer system -Regional

5. Selection of TB aquifers – criteria,characterization,evaluation

6. From TDA to SAP - Priority actions



Jovan Cvijic - founder of karstology and karst hydrogeology



Gold medal of American geographical Society, New York, 1924

COPIA

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SUMMIS AUSPICIIS AUGUSTISSIMI IMPERATORIS AC REGIS

FRANCISCI IOSEPHI I

DOCTORIS PHILOSOPHIAE NOMEN ET HONORES IURA ET PRIVILEGIA

Doctoral Degree Certificate, Vienna, **1893**

Professors and graduates, Vienna University, **1893**

"I was not aware of great importance that this work would have. I got only several printed copies, while the others were sent by Mr.Penck to those whom he usually sends "Geographische Abhandlungen". I first realized the considerable impression made by "Karstphänomen" by letters that I started to receive from abroad...

... So young as I was at that time, I was pleased and additionally motivated when I realized that I was considered a recognized scientist. This was even more emphasized by my new works"

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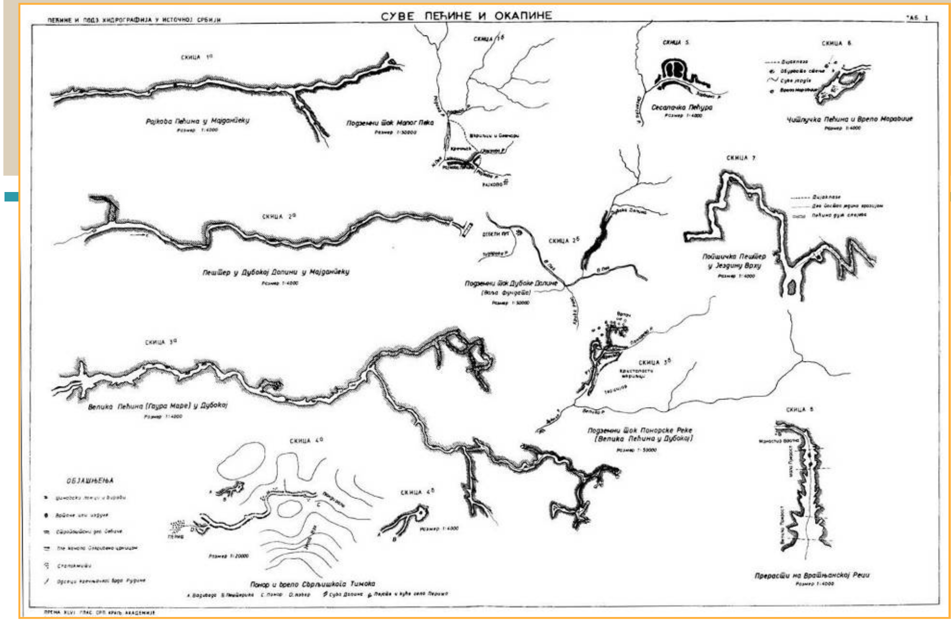
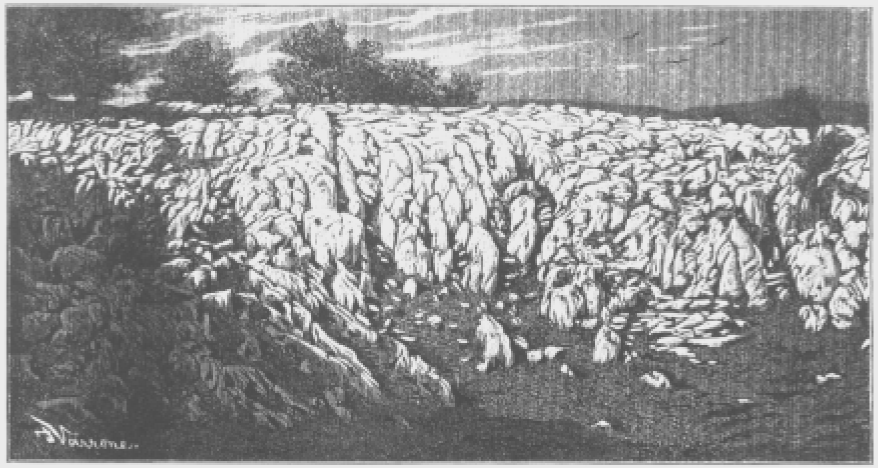


Велика Прерасти наВрајњанској Реци.



Ерозиони облици у ђрпачи коњари у Коришту

КОМАРИЧКИ ВИР

Cvijić exploration, Rila Mt., Bulgaria, **1894**

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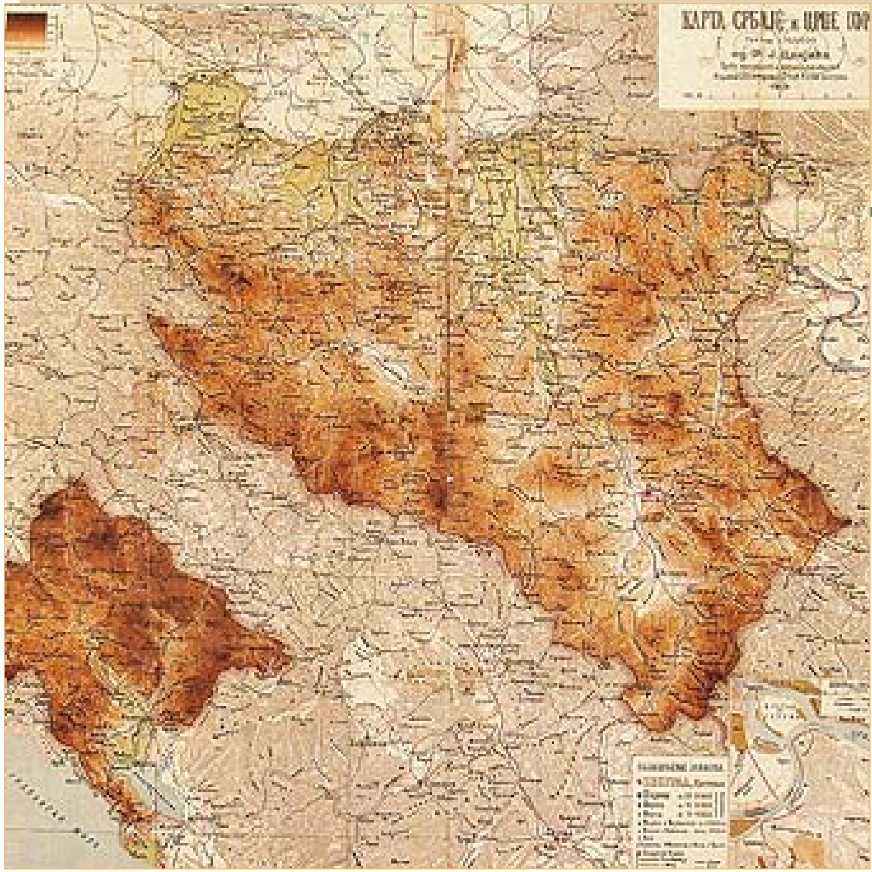
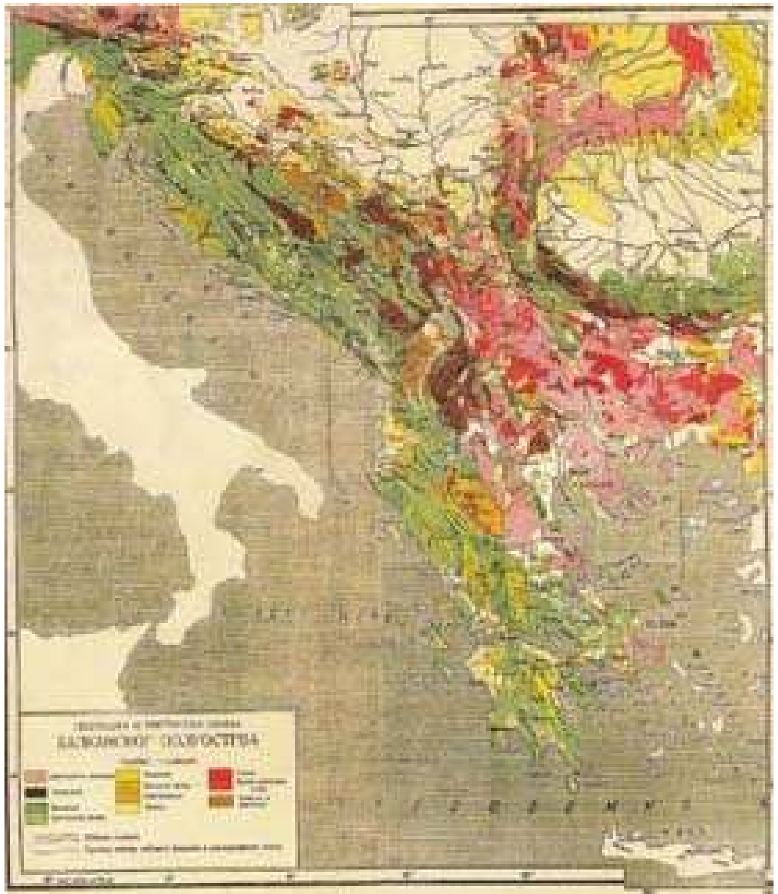


Map of Serbia and Montenegro designed by Cvijić, Belgrade, ***1911***

Geological and tectonic sketch of Balkan peninsula designed by Cvijić



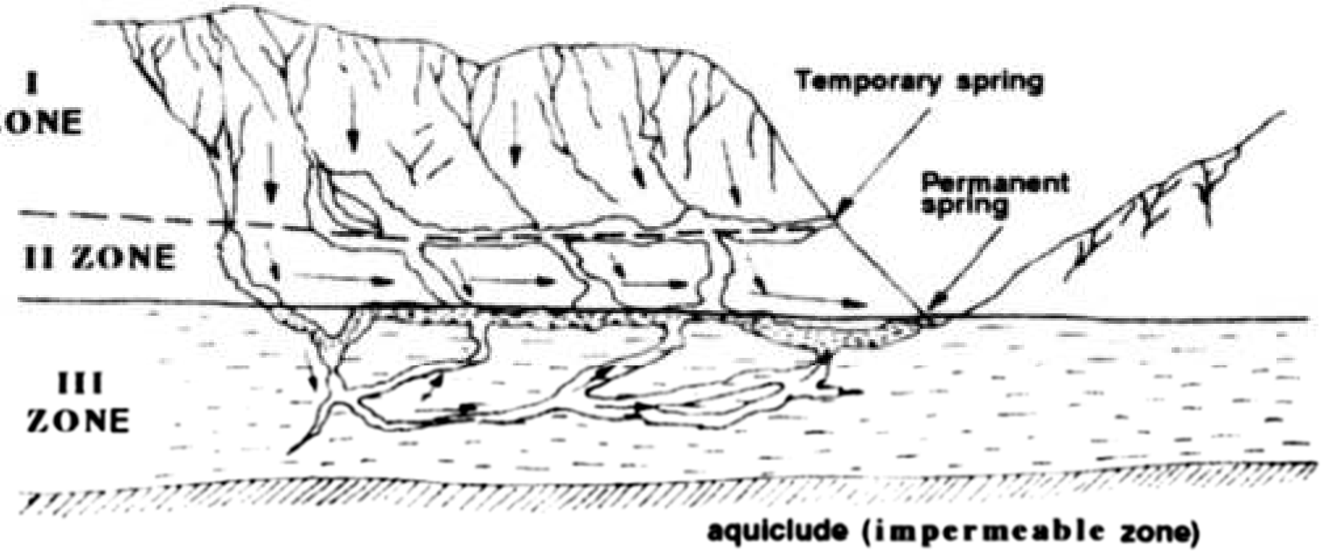


Figure 3. - Schematic hydrogeological cross-section of the karstic aquifer which lies on the aquilude substratum; the superposition hidrogeologic zones (after Cvijic hypothesis)

1. Dry zone - The karstic surface characterized by total absence of water, the cave and karstic chanels are also dry. During rain periode only vertical water percolation exists.

2. Transition zone - This zone has two characteristics: first permanent, second - periodical. In this caves and chanels exists transit of water flows to lower zone - karst aquifer

3. Karst aquifer zone - This zone represent the fully water reservoir like "Grundwaser" after A.Grund; the permanent grounwater flow with the ascendent flows along the bottom of of karstic poljes are posible.

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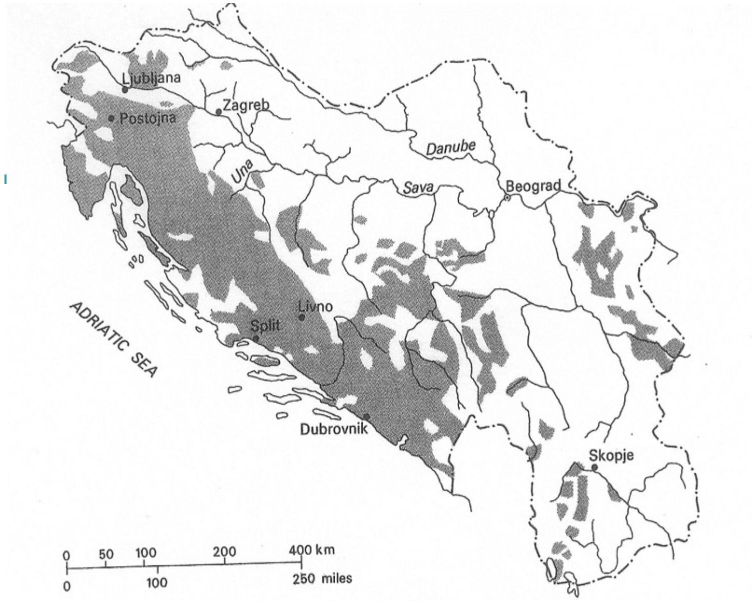

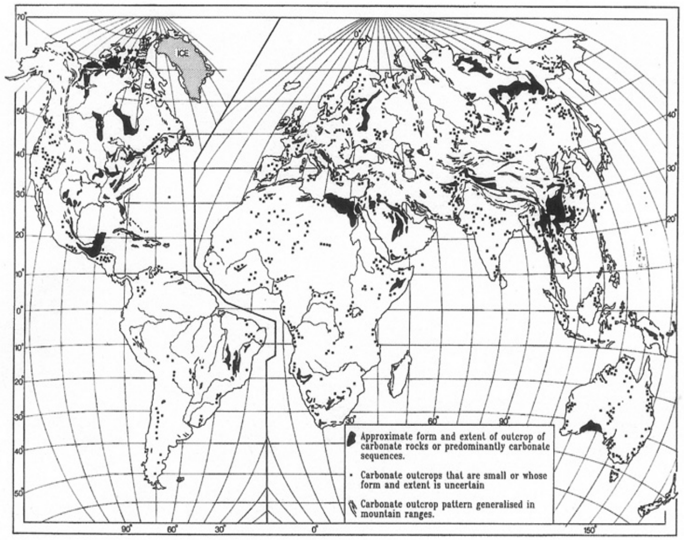

- Cvijić established the regional name ‘karst’ as the generic name for solutional landforms and caves.
- Edouard Martel wanted to name it ‘causse’.
- It is now adopted worldwide but…

From Derek Ford presentation on IAH conf. KARST 2005

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Cvijić' Medals
Gold medal of American geographical Society, New York,
1924

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"All of us climb on each others' shoulders"

Geographical and geological boundaries of Dinaric karst

The Dinaric system (Dinarides) is a long, NW-SE oriented orogenic belt, parallel to the Adriatic Sea, with numerous intermountain depressions, large karst poljes, and valleys created by perennial and sinking streams.

Its NW fringe is the Carso area around Trieste in Italy while the SW part continues deep into Albania. In between, it extends over the territories of six countries of former Yugoslavia: Slovenia, Croatia, Bosnia and Herzegovina, Montenegro, Serbia, and FYR of Macedonia.

Boundaries has been extended in Albania to the southern direction.

Transboundary concerns

Abundant but variable water resources

Taken from
Elsevier's book
Groundwater Hydrology of Springs
(eds. Kresic & Stevanovic)

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Tapping karstic springs - Traditional way of water supply since Roman time

- An ancient art in the area. We all learn from Roman time experiences
- 11 long aqueducts delivered more than 13 m^3/s of water to Rome from distances ranging from 16-91 km.
- Several water supply systems from that time are completely reconstructed but still use the same springs and pipeline routes.

- Along with alluvial groundwater and surface water from the reservoirs, the water from the karstic springs is the main source of water supply in the region.

- Tapping large springs is the traditional method of water supply in the region but the main concern is their unstable discharge regime.

- There are several large cities with populations of over a half of million that depend on karst aquifers and their discharge regimes. Among them are the five capitals of SEE: Vienna, Tirana, Skopje, Sarajevo, and Podgorica.

- Some areas, such as southern Montenegro characterized by a very intensive water balance: average specific yield is over 40 l/s/km^2.

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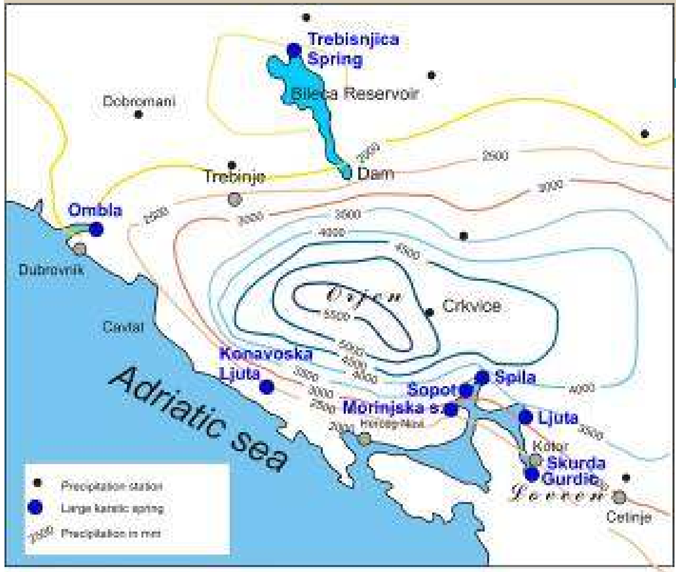
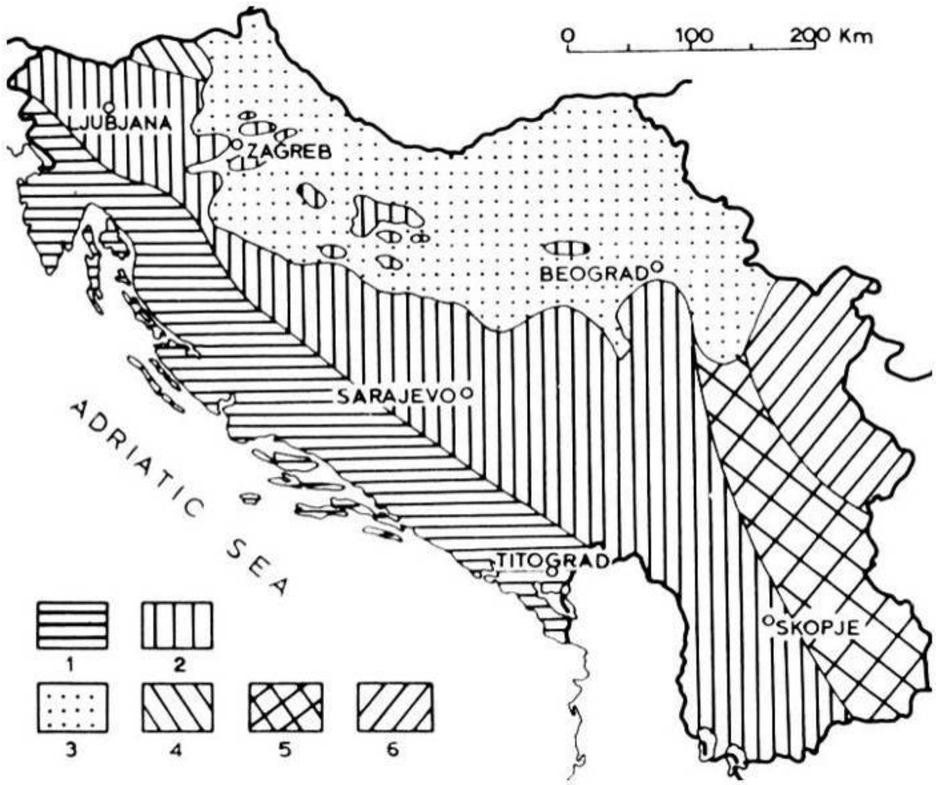
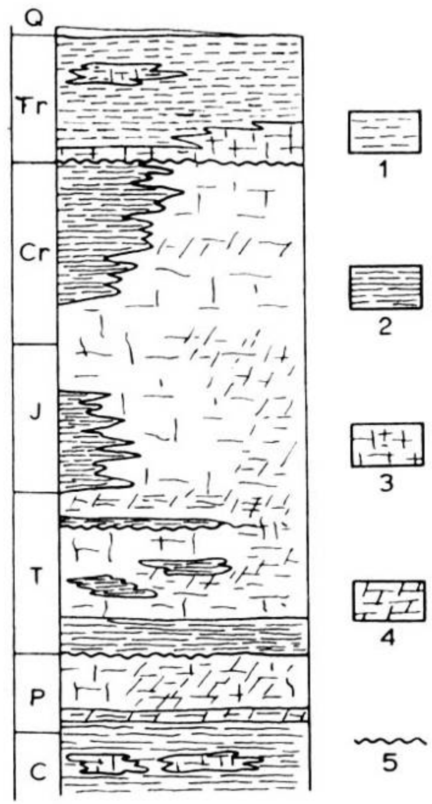
Climate, hydrography, hydrology



Geology and tectonics classification



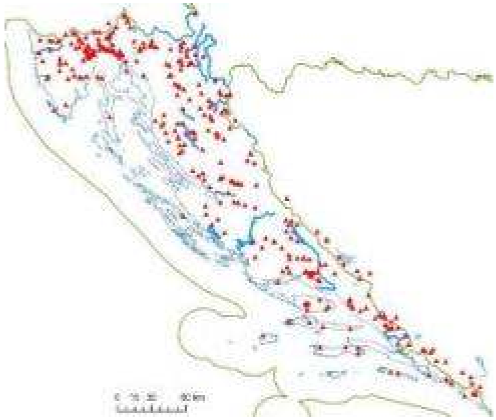


Major tectonic areas of Yugoslavia (Herak, 1972).
1 = Outer Dinaric units (Adriatic and high karst); 2 = inner Dinaric and south Alpine units;
3 = Pannonian Basin; 4 = eastern Alps; 5 = Serbo-Macedonian Belt; 6 = Carpatho-Balkanian Belt.

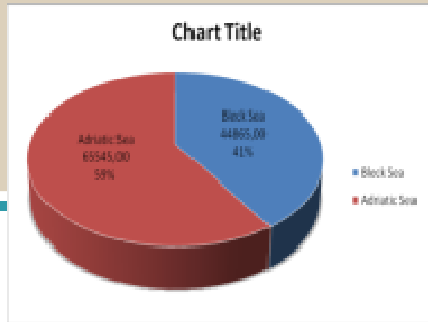
Karstification and morphological features

- Cimmerian, Laramian, Pyrenean phases...
- Recent glaciaton (Pleistocene)
- Karstification intensity and depth
- Features: karren (lapies), dolines, ponors
- dry valleys, pits (jamas), caves and caverns

uvalas, poljes and karst plains as large forms



Groundwater flow directions

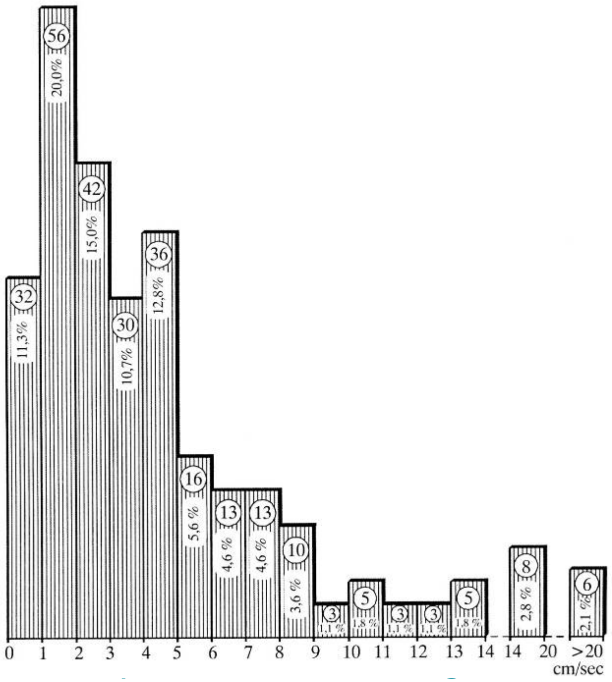


- Two main catchments: The first, of the External (Outer) Dinarides, is the Adriatic / Ionian Sea catchment, while the Internal (Inner) Dinarides drains into the Danube (Sava) i.e. the Black Sea catchment.
- The main river basins in the Adriatic/Ionian catchment area are the Vjosa, Seman, Drini, Buna (Bojana), Zeta, Neretva, Cetina, Krka, Zrmanja and Soča.
- Karstic groundwater from the river basins of the Tara, Piva, Vrbas, Pliva, Sana, Una, the upper course of the Kupa River and the Krka (in Slovenia) gravitates to the Black Sea catchment area.
- In eastern Herzegovina alone, 281 localities were surveyed by tracer experiments; in the catchment area of the Cetina River, 99 localities; and in the Skadarsko Lake catchment area, 77 localities.

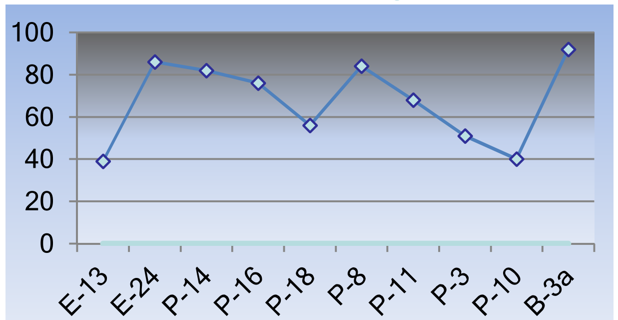
Groundwater flow directions

- Milanović P. (1976) and A. Magdalenić (1971) found that based on 380 conducted experiments, the frequency of fictive groundwater velocities in Dinaric karst is as follows: in 70% of cases from 0 to 5 cm/s; in 20% of cases 5 to 10 cm/s; and in 10% of cases more than 10 cm/s.

Vf: In Eastern Herzegovina 0.002 to 55.2 cm/s. (Milanovic, 2000); in Prespa Lake connected with Ohrid Lake the maximal values in the test in 2002 were 19 and 80 cm/s (Amataj 2005).



Difference in velocities: High / Low waters



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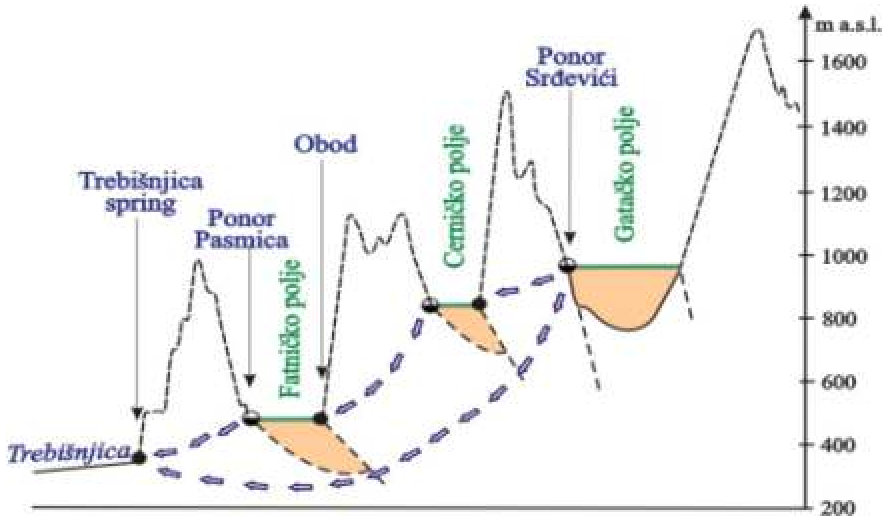
Groundwater flow directions

Connections between ponors and springs in
South Dinaric region confirmed by dye tests (Milanović P. 2005)



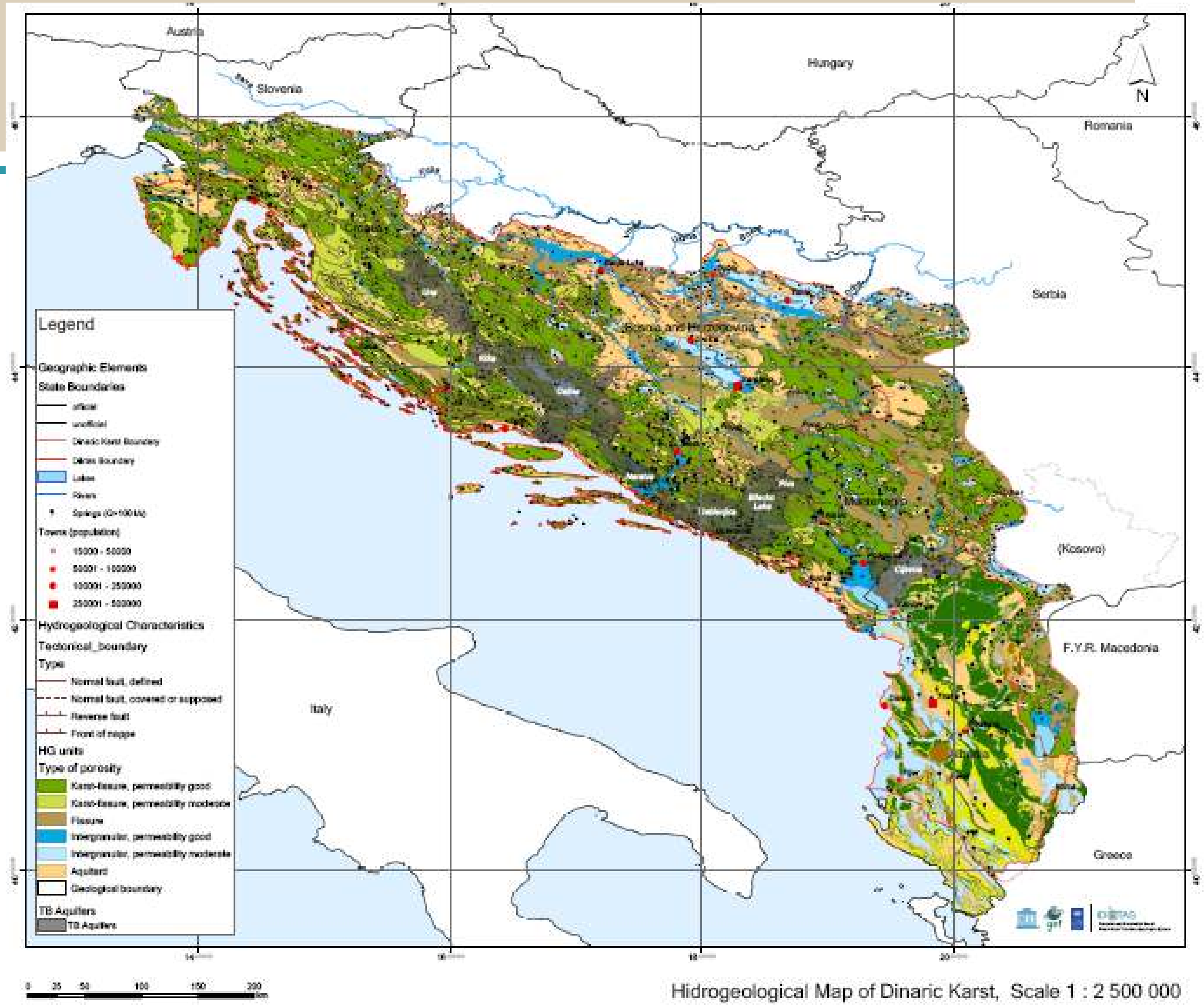
Recharge/Discharge of karst aquifer

- Roughly, it can be assessed that the average infiltration rate is 60% of precipitation.
- Some authors stated that in the Dinaric region of ex-Yugoslavia there are 230 springs with a minimal discharge over 100 l/s, while about 100 springs have minimal discharge over 500 l/s
- In Albanian karst there are roughly about 110 springs with average discharge exceeding 100 l/s. Of these, 17 have discharges exceeding 1000 l/s (Eftimi, 2010).

TDA

The TDA is a fact-finding activity, meant to improve the knowledge of the project area and provide a basis for the so-called Strategic Action Plan (SAP). The main TDA activities are 1. Regional hydrogeological characterization, 2. Regional environmental and socio-economical assessment, 3. Regional assessment of legal and institutional frameworks and policies, 4. Synthesis and finalization of the Transboundary Diagnostic Analysis, 5. Local Scale activities/Case Studies

One of the main results of the regional hydrogeological characterization is the GIS based digital **Hydrogeological map of the Dinaric Karst region**. Its creation involved harmonization of data, classifications methodologies, reference systems, projections, semantics.



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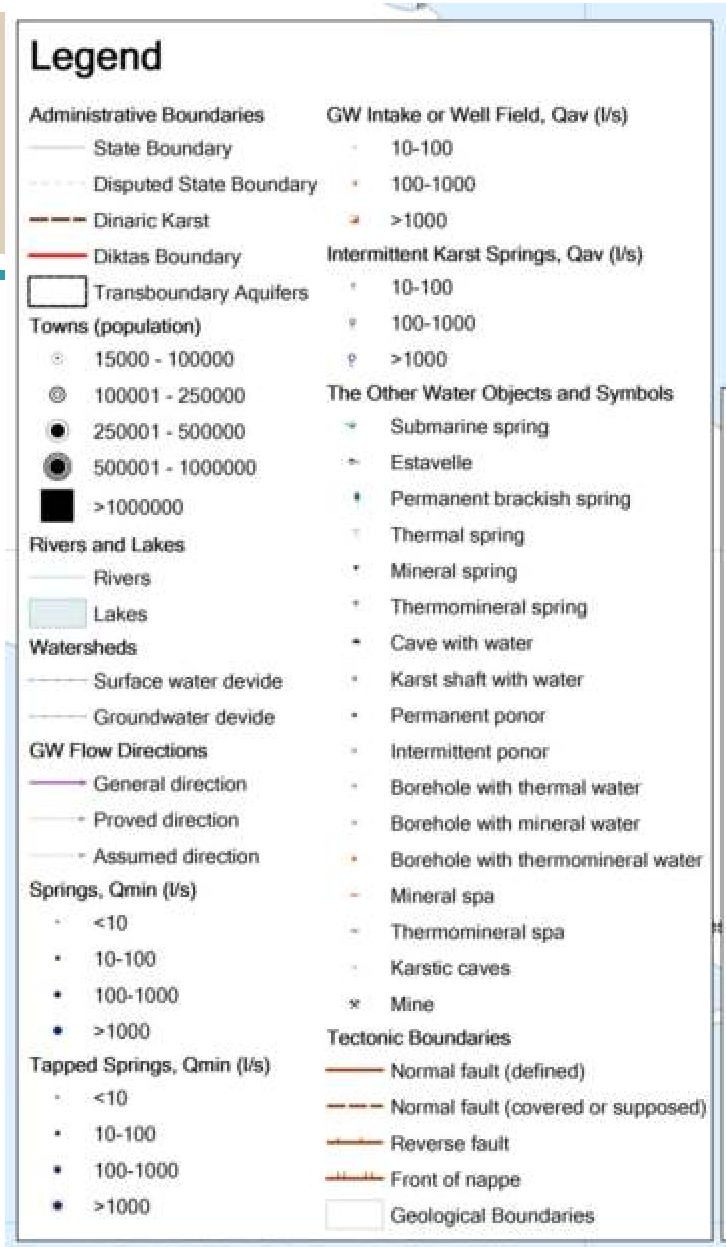
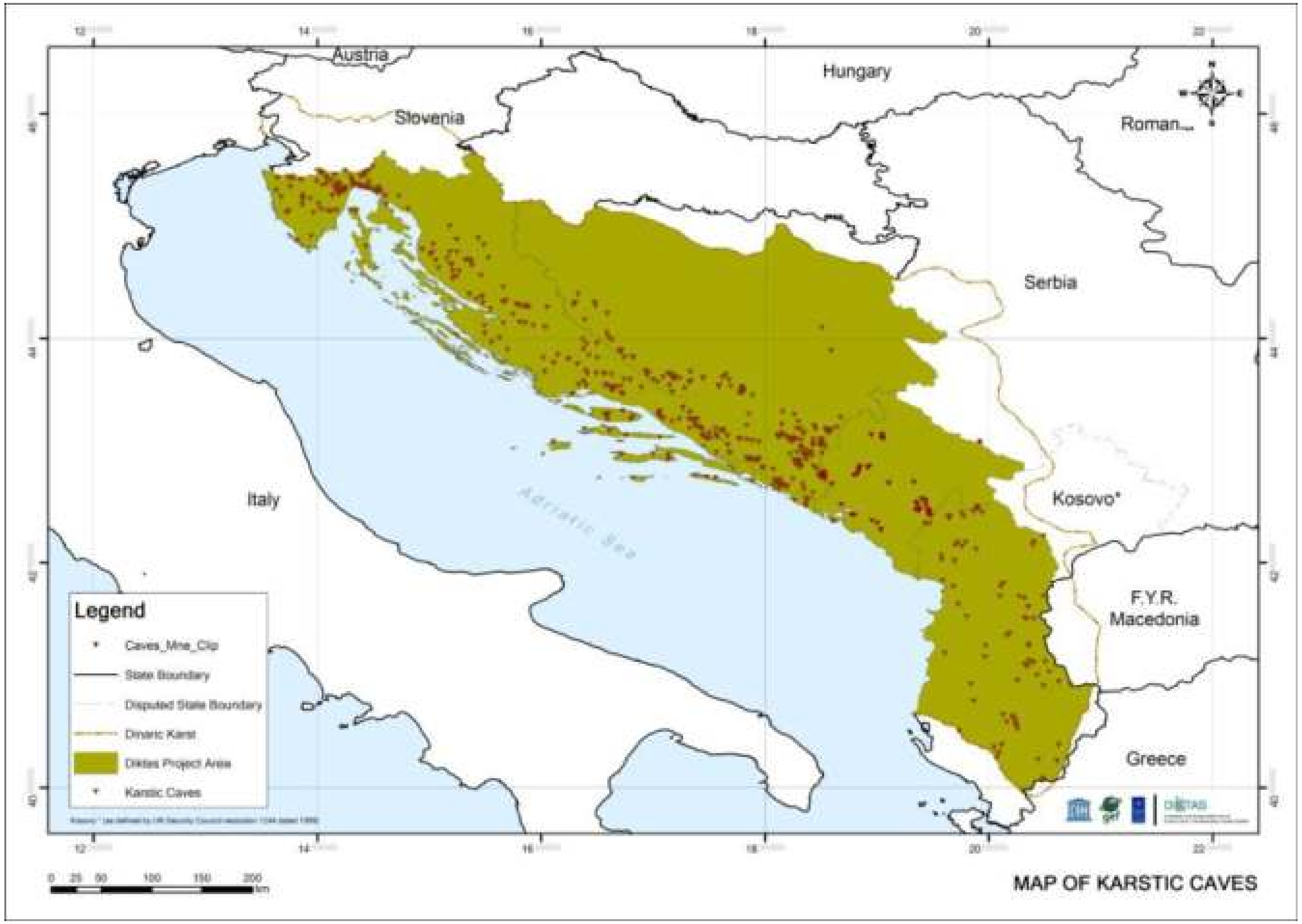
Austria
Slovenia
Hungary
Romania
Serbia
Kosovo*
F.Y.R.
Macedonia
Greece
Adriatic Sea
Legend
Hydrogeological Units
14
16
18
20
22
40
42
44
46
0 25 50 100 150 200 km
HYDROGEOLOGICAL MAP OF DINARIC KARST


Legend
Administrative Boundaries
State Boundary
Disputed State Boundary
Dinaric Karst
Diktas Boundary
Transboundary Aquifers
Towns (population)
15000 - 100000
100001 - 250000
250001 - 500000
500001 - 1000000
>1000000
Rivers and Lakes
Rivers
Lakes
Watersheds
Surface water devide
Groundwater devide
GW Flow Directions
General direction
Proved direction
Assumed direction
Springs, Qmin (l/s)
<10
10-100
100-1000
>1000
Tapped Springs, Qmin (l/s)
<10
10-100
100-1000
>1000
GW Intake or Well Field, Qav (l/s)
10-100
100-1000
>1000
Intermittent Karst Springs, Qav (l/s)
10-100
100-1000
>1000
The Other Water Objects and Symbols
Submarine spring
Estavelle
Permanent brackish spring
Thermal spring
Mineral spring
Thermomineral spring
Cave with water
Karst shaft with water
Permanent ponor
Intermittent ponor
Borehole with thermal water
Borehole with mineral water
Borehole with thermomineral water
Mineral spa
Thermomineral spa
Karstic caves
Mine
Tectonic Boundaries
Normal fault (defined)
Normal fault (covered or supposed)
Reverse fault
Front of nappe
Geological Boundaries

Hydrogeological Units

Symbol	Hydrogeological Description	Age	Prevalent Lithology
KA1	Karst aquifers of high permeability. Intensively karstified terrains with karstic type of porosity, high transmissivity and turbulent water regime of groundwater flow.	$E_{1,2}$; Pg; K_2,Pg; K_2; $K_{1,2}$; K; J,K; J_3; $J_{2,3}$; J_2; J_1; J; T,J; $T_{2,3}$; T_2; T	Limestones, massive and bedded, occasionally with dolomites
KA2	Karst aquifers of moderate permeability, karst-fissure type of porosity and medium level of transmissivity.	M_2; M; E_3; $E_{2,3}$; Pg; K_2; $K_{1,2}$; K_1; J,K; J_3; $J_{2,3}$; J_1; J; J,T; T_3; $T_{2,3}$; T_2; T; Pz	Marly limestones, thin bedded; Marbles; Alternating limstones and dolomites; Dolomites and dolomitic limstones; Calcirudites and breccias; Limestones interbedded with sandstones
FA	Fissured aquifers, fissure type of porosity and mainly low permeability and yielding .	Ng; E; Pg; K_2; J,K; J; B; Pz	Sandstones, marly limestones and limestones; Thinly bedded limestones, marls, marly limestones, conglomerates, gabbroides
IA1	Porous aquifers, intergranular type of porosity and good permeability.	a; al; gl	Gravel and sands, alluvial deposits (a-covered by loess or loess-like deposits); Gravel and sands, alluvial deposits, occasionally clayey; Alluvial sands occasionally clayey
IA2	Porous aquifers, intergranular type of porosity and moderate permeability.	a; al; d; p; t; gl; Pl; M,Pl; M_3; $M_{2,3}$; M_2; $M_{1,2}$; M_1; M; Ng; Ol,M;	Sands, mainly fine-grained, occasionally clayey; Fine-grained sands; Eolian sands; Loess and sandy loess; Loess-like deposits; Deluvial deposits; Glaciofluviatile deposits; Sands interbedded with clays, marls and coal; Alternating marls, sand and gravels; Clays, sands, gravels,sandstones, conglomerates, marls and limestones
AT	Terrains mainly without aquifers; practically impermeable rocks.	a; B; ts; Pl; M,Pl; M_3; $M_{2,3}$; M_2; $M_{1,2}$; M_1; M; Ng; Ol; $E_{2,3}$; E_2; E; Pg; Γ; K,Pg; K_2,Pg; $K_{2,3}$; K_2; K_1; J,K; J_3; J; Se; T,J; T_3; $T_{2,3}$; T_2; T_1; T; Mz,Pg; P; Pz	Terra rossa with calcareous fragments, eluvium; Clays, marly clays, sandy and gravelly clays, some sands; Marls, shales, marly limestones; Conglomerates, sandstones, breccias, shales, marls and marly limestones in alternation; Massive dolomites; Dacites, andesites, porphyrites, basalts and diabases; Granites and granodiorites; Green-schists and amphibolites; Serpentinites and peridotites; Andesite-cherty and porphyrite-cherty formation; Diabase-cherty formation; Gabbros, diabases, basalts; Sandstones and conglomerates; Slates, phyllites, sandstones and conglomerates

Database – Attribute: Caves



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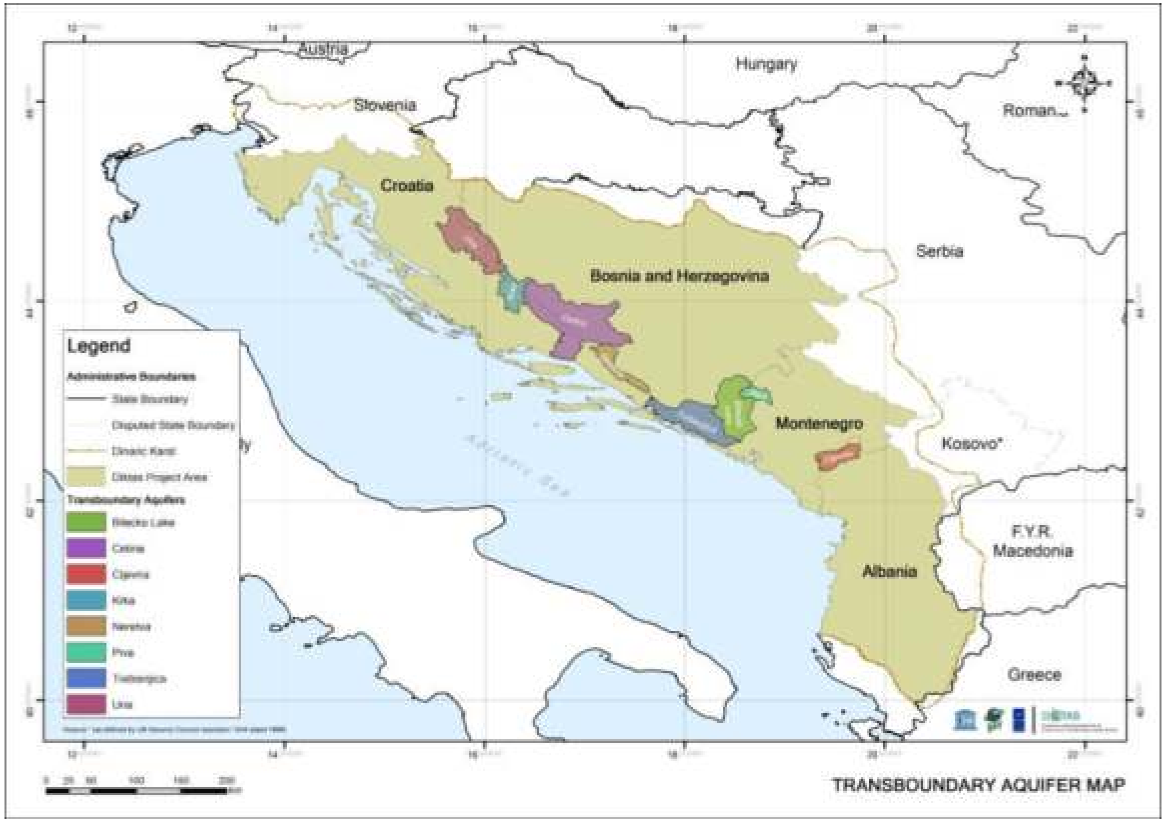
Selected TBAs

In total, eight TBA are selected for detailed analyses: Una, Krka, Cetina, Neretva, Trebisnjica (all shared by CRO and B&H), Bilecko Lake and Piva (B&H and MNE) and Cijevna/Cemi (MNE and ALB). Six of these TBAs belong to the Adriatic Sea catchment area and only two (Una,Piva) are part of the Black Sea basin. The TBAs comprise of in total a surface area of 12,000 km^2, which is around 10% of the entire study area. The surface area of individual TBA varies from 668 km^2 (Krka) to 3,455 km^2 (Cetina).



Selected TBAs - CRO/B&H

TRANSBOUNDARY AQUIFER B&H -CROATIA

No	Transboundary aquifer name	Shared between	General direction of groundwater flow
1	Una	B&H, Croatia	From Croatia to B&H
2	Krka	B&H, Croatia	From B&H to Croatia
3	Cetina	B&H, Croatia	From B&H to Croatia
4	Neretva	B&H, Croatia	From B&H to Croatia
5	Trebišnjica	B&H, Croatia	From B&H to Croatia

-All relevant documents are used in process of delineation of TBA: geological and hydrogeological maps, studies, national water management strategies, RBC Reports-e.g. Cetina, RBMP e.g.Trebišnjica-Neretva and Sava etc.

-Results : -delineateded TBA between B&H and Croatia

-base for characterisation of TBA

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Table for Evaluating Impact of Transboundary Aquifer (WG 1, April 2012, Podgorica)

Test area:	
Sharing between the countries:	1. 2.
GEOGRAPHY AND HYDROGEOLOGY	
Total surface area (km²)	
Surface area in Country 1 (km²)	
Surface area of karst in Country 1 (km²)	
Surface area of non-karst in Country 1 (km²)	
The main catchment (1) and sub-catchments (2,3...)in Country 1 (km²) (River and main tributaries)	1. (km²) (..., ..., ...) 2. (km²) (..., ..., ...) 3. (km²)
Main springs (T, NT) and their max/av/min discharges in Country 1	1. (T) (0.8/0.25/0.055) 2. (NT) (0.45/0.15/0.03)
Main rainfall gauging station in Country 1 (av. annual sum in mm) and total average sum	1. (822 mm) 2. (750 mm) Σ: (810mm) equivalent to ... x 10⁶ m³ / an.
Surface area in Country 2 (km²)	
Surface area of karst in Country 2 (km²)	
Surface area of non-karst in Country 2 (km²)	
The main catchment (1) and sub-catchments (2,3...)in Country 2 (km²) (River and main tributaries)	1 (km²) (..., ..., ...) 2 (km²) (..., ..., ...) 3 (km²)
Main springs (T, NT) and their max/av/min discharges in Country 2	1 (T) (0.8/0.25/0.055) 2 (NT) (0.45/0.15/0.03)
Main rainfall gauging station in Country 2 (av. annual sum in mm) and total average sum	1 (822 mm) 2 (750 mm) Σ: (810mm) equivalent to ... x 10⁶ m³ / an.
General assessment of groundwater reserves in karst in country 1 (in 10⁶ m³ / an)	

PRESSURES	
Main cities in study area and population (in 000) in Country 1	1. 2. 3.
Main cities in adjacent area and population (in 000), (dependent on water resources) in Country 1	1. 2. 3.
Main activities in study area of Country 1	
Main registered water pollutants in Country 1	
Water demands per sectors in Country 1 (in m³/s):	Drinking: Small industry: Agri: Others (specify):
Water demands of dependent eco-systems in country 1 (in 10⁶ m³ / an):	
Main cities in study area and population (in 000) in Country 2	1. 2. 3.
Main cities in adjacent area and population (in 000), (dependent on water resources) in Country 2	1. 2. 3.
Main activities in study area of Country 2	
Main registered water pollutants in Country 2	
Water demands per sectors in Country 2(in m³/s):	Drinking: Small industry: Agri: Others (specify):
Water demands of dependent eco-systems in country 2 (in 10⁶ m³ / an):	

WATER RESOURCES AVAILABILITY	
General assessment of total groundwater reserves in karst in country 1 (in 10⁶ m³ / an)	
General assessment of available groundwater reserves in karst in country 1 (in 10⁶ m³ / an) (total-dep.eco-systems)	
General assessment of total groundwater reserves in karst in country 2 (in 10⁶ m³ / an)	
General assessment of available groundwater reserves in karst in country 2 (in 10⁶ m³ / an) (total-dep.eco-systems)	
Main concerns (list)	

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TRANSBOUNDARY AQUIFERS – TABLE FOR EVALUATING IMPACT OF TRANSBOUNDARY AQUIFERS – TBA UNA (CROATIA-B&H) GEOGRAPHY AND HYDROGEOLOGY

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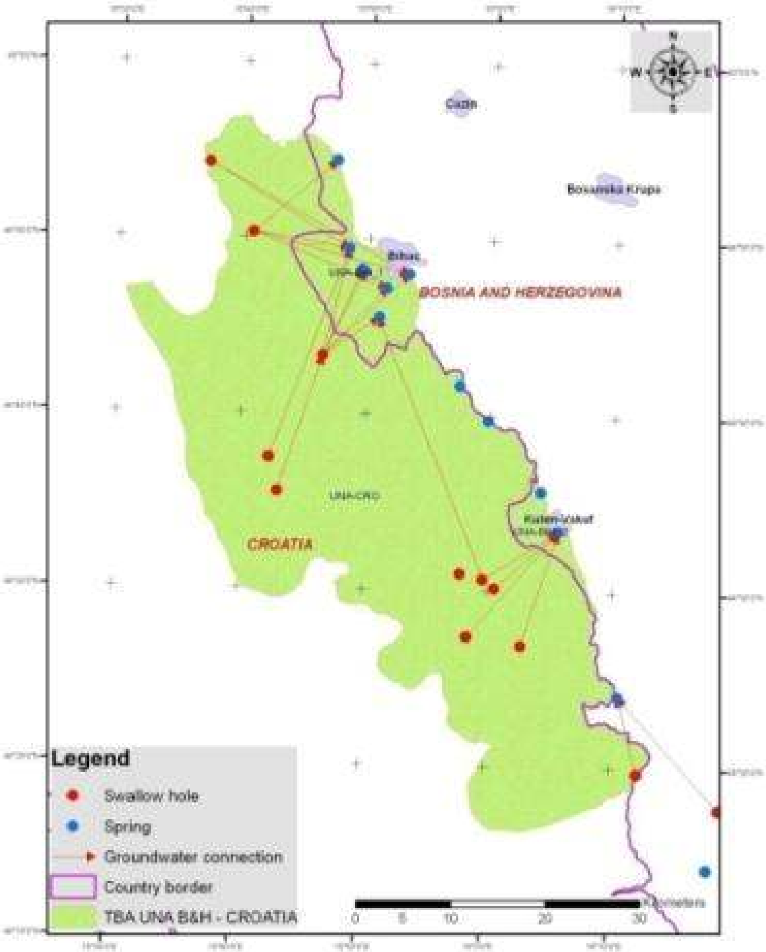

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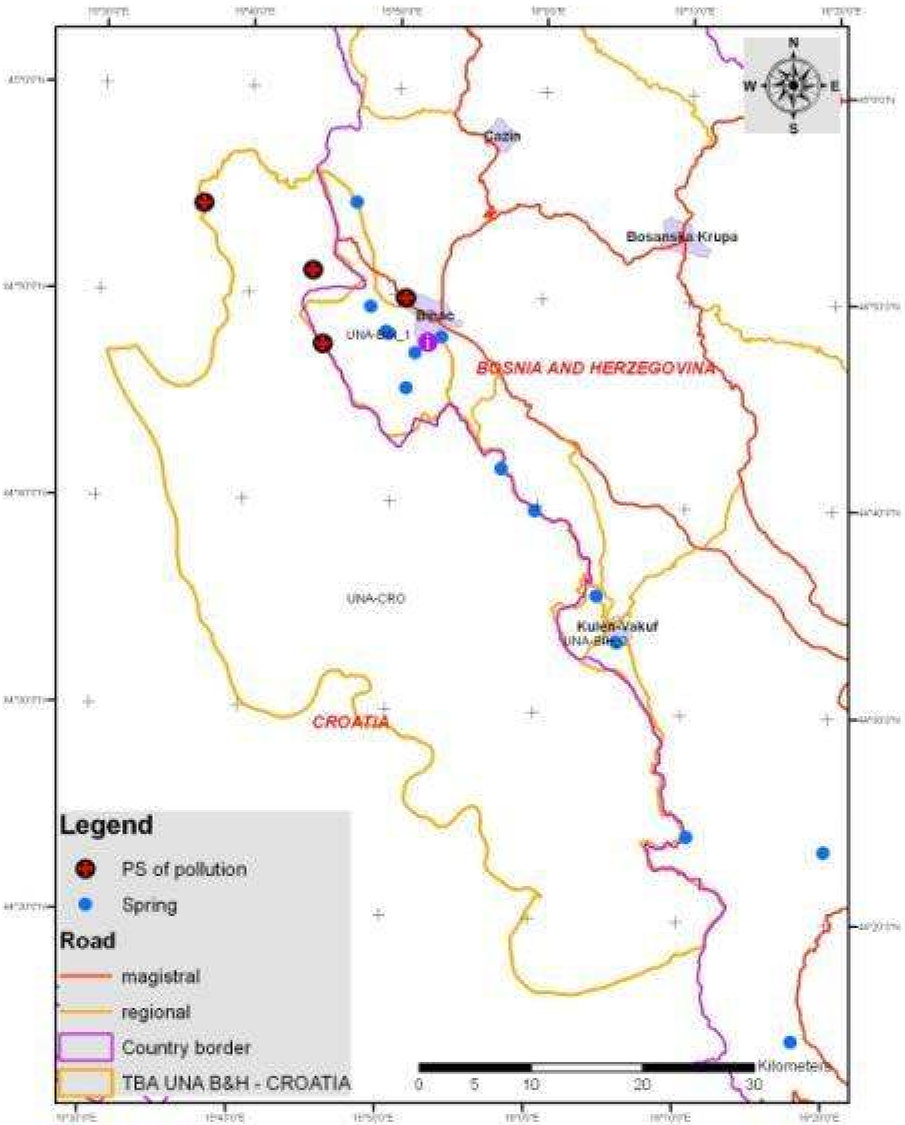
Table for Evaluating Impact of Transboundary Aquifer

Test area:	**UNA**
Sharing between the countries:	1.Bosnia and Herzegovina 2.Croatia
GEOGRAPHY AND HYDROGEOLOGY	
Total surface area (km^2)	1750
Surface area in Country 1. (km^2)	168
Surface area of karst in Country 1. (km^2)	136
Surface area of non-karst in Country 1. (km^2)	32
The main catchment (1) and sub-catchments (2,3...) in Country 1. (km^2) (River and main tributaries)	1. Una 2. Ostrovica 3. Klokot
Main springs (T, NT) and their max/av/min discharges in Country 1 (m^3/s)	1. (T) Klokot (4.4/14/70) 2. (T) Ostrovica (0.789/3.71/12) 3. (T) Privilica (0.03/-/2) 4. (T) Toplica-Klisa (0.06/-/1) 5. (NT) Dobrenica (0.23/0.61/5) 6. (NT) Ilijića vrelo (0.1/-/-) 7. (NT) Panjak (0.005/-/0.4) 8. (NT) Bistrica (0.015/-/0.1) 9. (T) Žegar (0.006/-/1) 10. (NT) Đakulin-Loskun (0.18/-/4.8) 11. (NT) Crnoć-Nebljusi (1.2/-/-) 12. (NT) Draga (0.03/-/0.5)
Main rainfall gauging station in Country 1 (av. annual sum in mm) and total average sum	1. Bihać (1308 mm) Σ: 1308 mm equivalent to 220 x 10^6 m^3 / an.

TRANSBOUNDARY AQUIFERS – TABLE FOR EVALUATING IMPACT OF TRANSBOUNDARY AQUIFERS – TBA UNA (CROATIA-B&H) PRESSURES AND WATER RESOURCE AVAILABILITY



PRESSURES	
Main cities in study area and population (in 000) in Country 1.	1. Bihać (70)
Main cities in adjacent area and population (in 000) (dependent on water resources) in Country 1.	-
Main activities in study area of Country 1	1. Industry 2. Forestry
Main registered water pollutants in Country 1	1. Destroyed military installations 2. Wastewaters 3. Unregulated waste disposals 4. Traffics
Water demands per sectors in Country 1 (in m^3/s):	Drinking: 0.5 Small industry: 0.01 Agri:- Others (specify):-
Water demands of dependent eco –systems in country 1 (in 10^6 m^3/ an):	230

WATER RESOURCES AVAILABILITY	
General assessment of total groundwater reserves in karst in country 1 (in 10^6 m^3/ an)	770
General assessment of available groundwater reserves in karst in country 1 (in 10^6 m^3/ an) (total-dep.eco-systems)	540
General assessment of total groundwater reserves in karst in country 2 (in 10^6 m^3/ an)	
General assessment of available groundwater reserves in karst in country 2 (in 10^6 m^3/ an) (total-dep.eco-systems)	
Main concerns (list)	-sanitary protection zones for drinking water sources -undefined problem of possible presence of PCBs in springs use for water supply of Bihać region -

TRANSBOUNDARY AQUIFERS – TABLE FOR EVALUATING IMPACT OF TRANSBOUNDARY AQUIFERS – TBA CETINA (CROATIA-B&H) GEOGRAPHY AND HYDROGEOLOGY

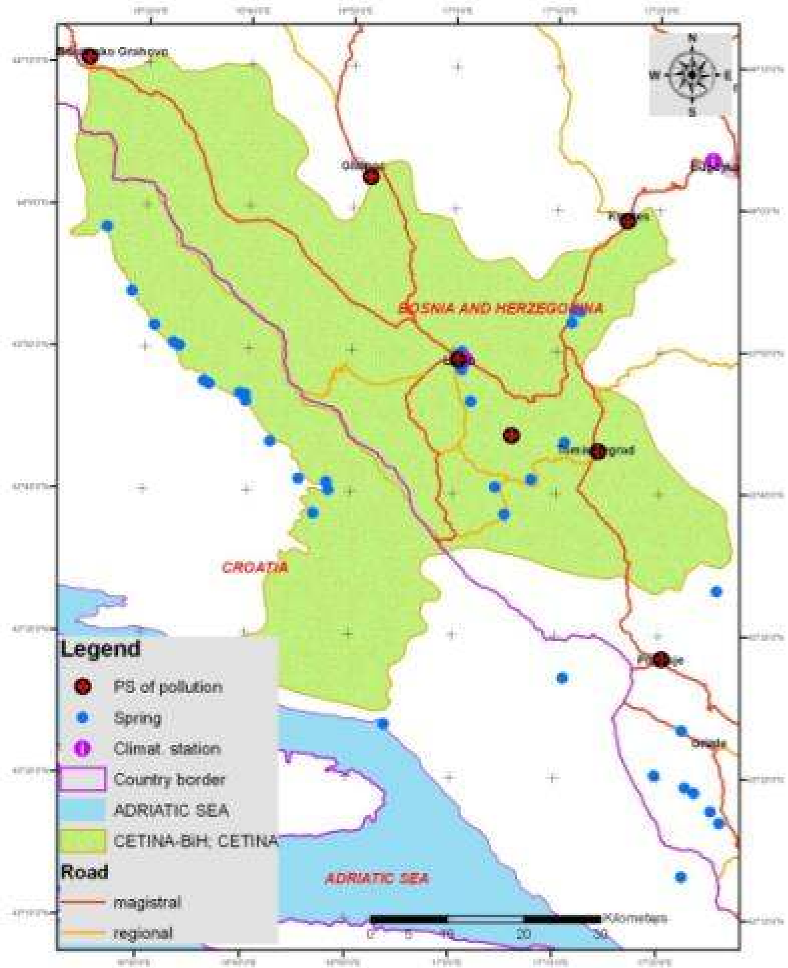


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Table for Evaluating Impact of Transboundary Aquifer

Test area:	**CETINA**
Sharing between the countries:	1.Bosnia and Herzegovina 2.Croatia
GEOGRAPHY AND HYDROGEOLOGY	
Total surface area (km^2)	3442
Surface area in Country 1. (km^2)	2450
Surface area of karst in Country 1. (km^2)	1741
Surface area of non-karst in Country 1. (km^2)	709
The main catchment (1) and sub-catchments (2,3...) in Country 1. (km^2) (River and main tributaries)	1. Cetina (2340 km^2) 2. Šuica (730 km^2) 3. Bistrica 4. Sturba 5. Žabljak 6. Ričina 7. Milač 8. Jaruga
Main springs (T, NT) and their max/av/min discharges in Country 1 (m^3/s)	1. (T) Duman (0.600/3.60/24.13) 2. (T) Žabljak (0.140/2.06/4.96) 3. (NT) Sturba (0.9/4.48/9.50) 4. (NT) V. Stržanj (0/-/-) 5. (NT) M. Stržanj (0/-/-) 6. (NT) Volarica (0.11/-/-) Q_{min} 4+5+6=0.11 Q_{av} 4+5+6=2.29 7. (T) Ostrožac (0.04/0.21/-) 8. (NT) Ričina (0/9/>60)
Main rainfall gauging station in Country 1 (av. annual sum in mm) and total average sum	1. Glamoč (1420 mm) 2. Livno (1140) 3. Tomislavgrad (1295) 4. Kupres (1204) Σ: (1265 mm) equivalent to 3100 x 10^6 m^3 / an.

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TRANSBOUNDARY AQUIFER CETINA
GROUNDWATER BODIES IN B&H

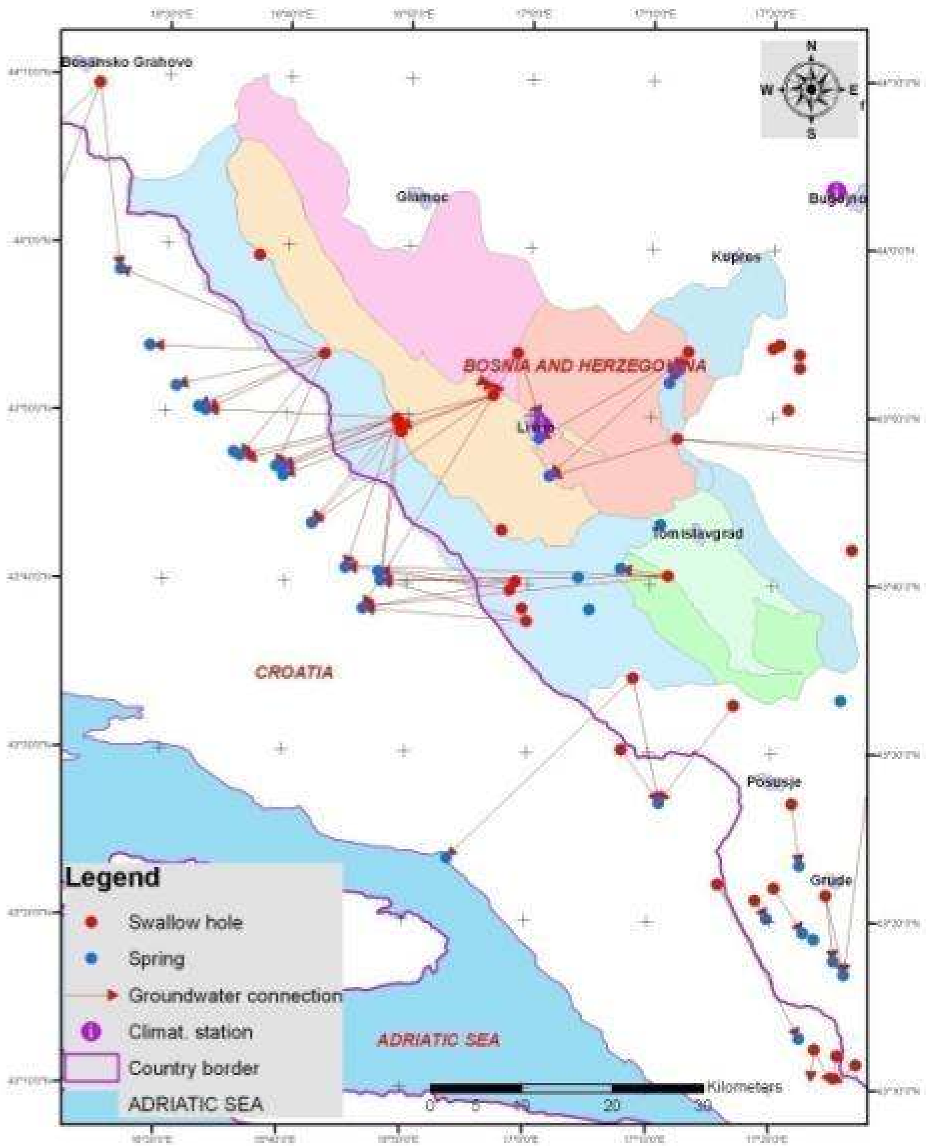

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Table for Evaluating Impact of Transboundary Aquifer

Test area:	**CETINA**
Sharing between the countries:	1.Bosnia and Herzegovina 2.Croatia
GEOGRAPHY AND HYDROGEOLOGY	
Total surface area (km²)	3442
Surface area in Country 1. (km²)	2450
Surface area of karst in Country 1. (km²)	1741
Surface area of non-karst in Country 1. (km²)	709
The main catchment (1) and sub-catchments (2,3...) in Country 1. (km²) (River and main tributaries)	1. Cetina (2340 km²) 2. Šuica (730 km²) 3. Bistrica 4. Sturba 5. Žabljak 6. Ričina 7. Milać 8. Jaruga
Main springs (T, NT) and their max/av/min discharges in Country 1 (m³/s)	1. (T) Duman (0.600/3.60/24.13) 2. (T) Žabljak (0.140/2.06/4.96) 3. (NT) Sturba (0.9/4.48/9.50) 4. (NT) V. Stržanj (0/-/-) 5. (NT) M. Stržanj (0/-/-) 6. (NT) Volarica (0.11/-/-) Q_{min} 4+5+6=0.11 Q_{av} 4+5+6=2.29 7. (T) Ostrožac (0.04/0.21/-) 8. (NT) Ričina (0/9/>60)
Main rainfall gauging station in Country 1 (av. annual sum in mm) and total average sum	1. Glamoč (1420 mm) 2. Livno (1140) 3. Tomislavgrad (1295) 4. Kupres (1204) Σ: (1265 mm) equivalent to 3100×10^6 m³ / an.

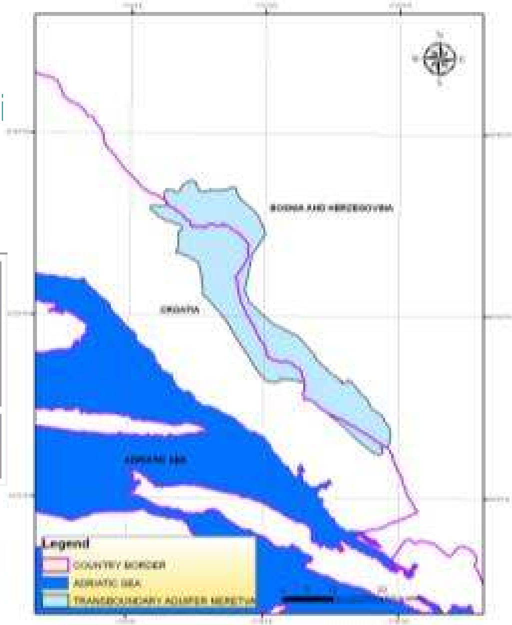
Cetina case example

- The majority of data on spring yields is from the period before 1990. These data generally consist of minimum and maximum spring yield data based on investigators' estimates during different investigation works and of a relatively small number of occasional measurements in springs.
- There is no monitoring of groundwater level fluctuations in the area of this transboundary aquifer.
- Only three springs on the territory of Croatia are included in the national groundwater quality monitoring network.
- The estimated surface of the TBA Cetina is 3454 km^2, of which 2462 km^2 (71.3 %) located in Bosnia-Herzegovina and, and 992 km^2 in Croatia.
- Tapped amount of groundwater for water supply in B&H is 0.2 m^3/sec and about 0.27 m^3/sec (without tapped surface water from Cetina) in Croatia.
- In general, it can be stated that the available groundwater reserves within the TBA Cetina are very large in relation to the current needs.

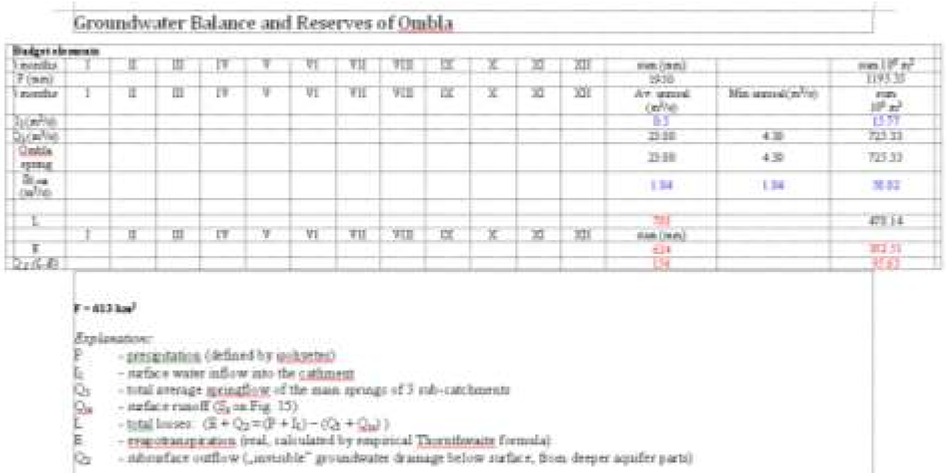
Neretva TB aquifer

- The estimated surface of the TBA Neretva is 638 km^2, of which 354 km^2 (55.5%) is located in Bosnia-Herzegovina and 284 km^2 in Croatia.
- The available groundwater reserves are approximately 11 m^3/s. The ecologically minimum acceptable flow is taken as the minimum spring discharge. Its values for the springs are the total of 3.82 m^3/s.
- The tapped amount of groundwater for water supply in Bosnia-Herzegovina is 0 m^3/s and about 0.43 m^3/s in Croatia (maximum allowed amount of tapped water under the concession contracts is 0.63 m^3/s).
- The total amount of tapped groundwater within the TBA Neretva is about 2% of the groundwater reserves considering the average spri in comparison with the minimum spring discharges.

Q_{aver} (m^3/s)	Tapped groundwater (m^3/s)	Ratio Q_{avail}/Q_{tapped} (%)	Q_{min} (m^3/s)	Tapped groundwater (m^3/s)	Ratio Q_{min}/Q_{tapped} (%)
11	0.43	3.9	3.82	0.43	11.25



TRANSBOUNDARY AQUIFER TREBIŠNJICA
GROUNDWATER BODIES AND ESTIMATED AVERAGE TRANSBOUNDARY GROUNDWATER FLOW FROM B&H TO CROATIA

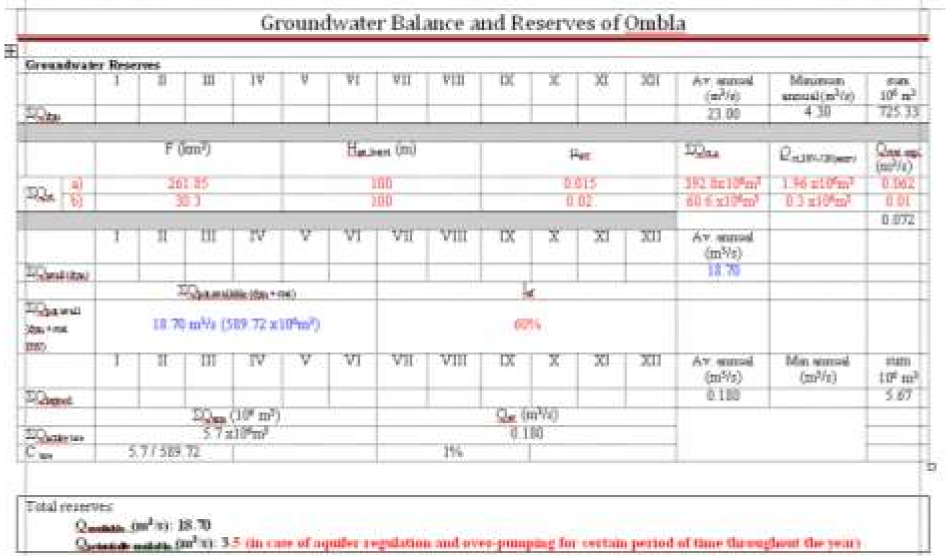


Groundwater Balance and Reserves of Ombla

Budget elements	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII			
months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	sum (mm)		sum 10^6 m^3
P (mm)													1930		1193.35
months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Av. annual (m^3/s)	Min annual (m^3/s)	sum 10^6 m^3
I_1 (m^3/s)													0.5		15.77
Q_1 (m^3/s)													23.00	4.30	725.33
Ombla spring													23.00	4.30	725.33
Q_{sur} (m^3/s)													1.04	1.04	[illegible]
L													[illegible]		473.14
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	sum (mm)		
E													[illegible]		[illegible]
Q_2 (L-E)													[illegible]		[illegible]

F = 613 km²

Explanation:
P - precipitation (defined by isohyetes)
I_1 - surface water inflow into the catchment
Q_1 - total average springflow of the main springs of 3 sub-catchments
Q_{sur} - surface runoff (Q_s on Fig. 15)
L - total losses: $(E + Q_2 = (P + I_1) - (Q_1 + Q_{sur}))$
E - evapotranspiration (real, calculated by empirical Thornthwaite formula)
Q_2 - subsurface outflow („invisible" groundwater drainage below surface, from deeper aquifer parts)



Groundwater Balance and Reserves of Ombla

Groundwater Reserves		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Av. annual (m^3/s)	Minimum annual (m^3/s)	sum 10^6 m^3
ΣQ_{dyn}														23.00	4.30	725.33
		F (km²)				$H_{av.lev}$ (m)				μ_{ef}				ΣQ_{sta}	Q_{st}	Q_{sta} (m^3/s)
ΣQ_{st}	a)	261.85				100				0.015				392.8 x$10^6$$m^3$	1.96 x$10^6$$m^3$	0.062
	b)	30.3				100				0.02				60.6 x$10^6$$m^3$	0.3 x$10^6$$m^3$	0.01
																0.072
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Av. annual (m^3/s)		
$\Sigma Q_{avail.(dyn)}$														18.70		
		$\Sigma Q_{gw.available (dyn+sta)}$								k_{ef}						
$\Sigma Q_{gw.avail. (dyn+sta)}$		18.70 m^3/s (589.72 x$10^6$$m^3$)								60%						
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Av. annual (m^3/s)	Min annual (m^3/s)	sum 10^6 m^3
$\Sigma Q_{exploit.}$														0.180		5.67
		ΣQ_{exp} (10^6 m^3)								Q_{ef} (m^3/s)						
$\Sigma Q_{exploit.}$		5.7 x$10^6$$m^3$								0.180						
C_{use}		5.7 / 589.72						1%								

Total reserves:
$Q_{available}$ (m^3/s): 18.70
$Q_{potentially\ available}$ (m^3/s): 3-5 (in case of aquifer regulation and over-pumping for certain period of time throughout the year)

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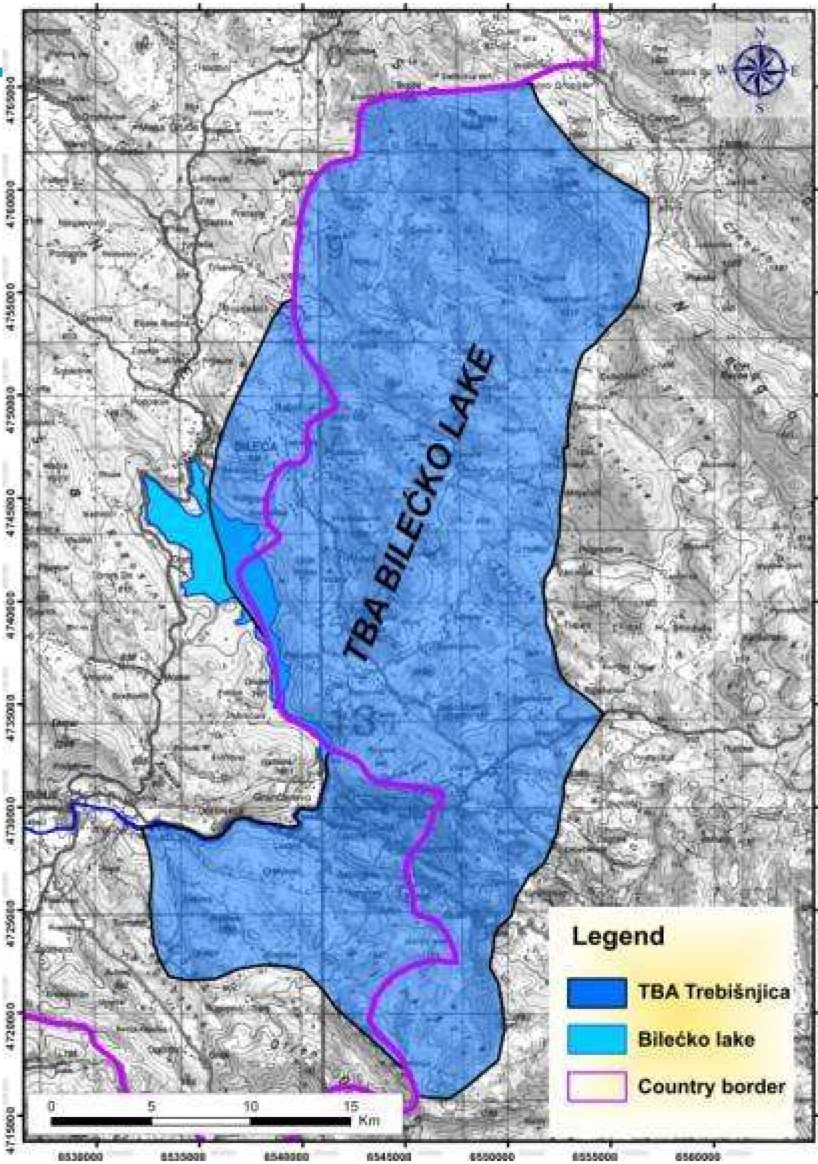
II TRANSBOUNDARY AQUIFER B&H - MONTENEGRO



DIKTAS

Table for Evaluating Impact of Transboundary Aquifer

Test area:	BILEĆKO LAKE
Sharing between the countries:	1. Montenegro 2. Bosnia and Herzegovina
GEOGRAPHY AND HYDROGEOLOGY	
Total surface area (km^2)	696
Surface area in Country 1. (km^2)	540
Surface area of karst in Country 1. (km^2)	506
Surface area of non-karst in Country 1. (km^2)	34
The main catchment (1) and sub-catchments (2,3,...) in Country 1. (km^2) (River and main tributaries)	1. Trebišnjica (540) 2. Sušica (25)
Main springs (T, NT) and their max/av/min discharges in Country 1 (m^3/s)	1.
Main rainfall gauging station in Country 1 (av. annual sum in mm) and total average sum	1. (??? mm) 2. (??? mm) Σ: (??? mm) equivalent to ??? x 10^6 m^3 / an.
Surface area in Country 2. (km^2)	156
Surface area of karst in Country 2. (km^2)	124
Surface area of non-karst in Country 2. (km^2)	32
The main catchment (1) and sub-catchments (2,3,...) in Country 2. (km^2) (River and main tributaries)	1. Trebišnjica (129 km^2) 2. Sušica (27 km^2)
Main springs (T, NT) and their max/av/min discharges in Country 2	1. Dejanova pećina (T) - submerged 2. Nikšićka vrela (NT) – submerged 3. Čepelica (NT) – submerged Q_{min} 1+2=2.0; Qav 1+2+3=41; Q_{max} > 800 4. Oko (T) – submerged (0.5/4/40)
Main rainfall gauging station in Country 2 (av. annual sum in mm) and total average sum	1. Bileća (1550 mm) 2. Trebinje (1780 mm) Σ: (1665 mm) equivalent to 260 x 10^6 m^3 / an.
General assessment of groundwater reserves in karst in country 1 (in 10^6 m^3 / an)	1419

OUTPUT 7

A Strategic Action Program (SAP) for the DIKTAS, and National Implementation Plans, elaborated and adopted by the country at high ministerial level

ACTIVITIES

The Strategic Action Program is a regional, non binding document crystallizing the commitment of the four countries to undertake a series of agreed actions. The SAP will be translated into SAP National Implementation Plans (NIPs).

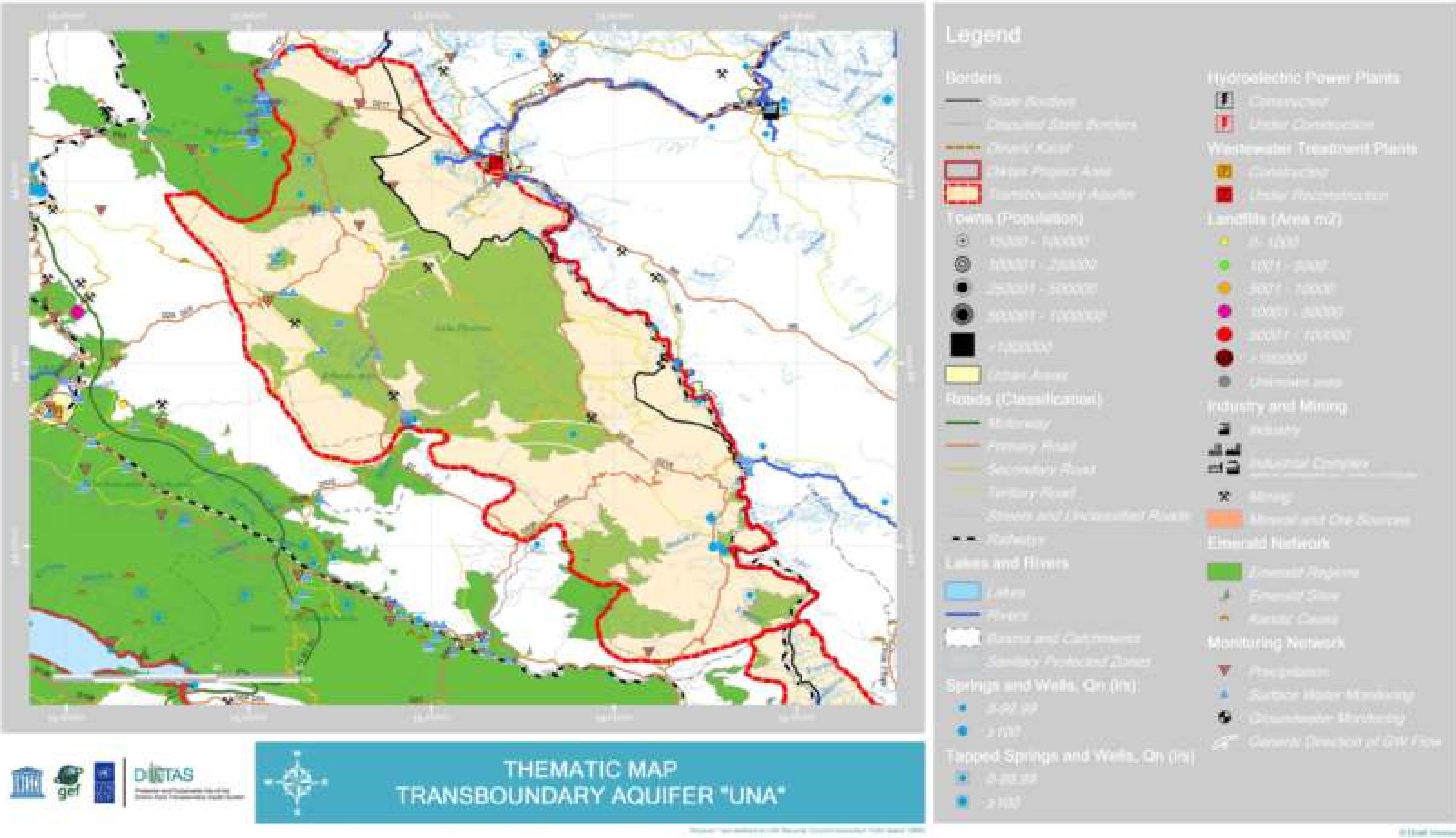
PRIORITY ACTION - Harmonisation of sanitary protection zones

ZONE		CROATIA[3]			B&H			MONTENEGRO	ALBANIA[1]
					Rep. of Srpska[1]	Federation[4]			
I	IA	min 10 m			7 days (min 50 m)	min 25 m (extremely 10 m)		min 10 m	immediate protection area[2]
	IB	flooding zone							
II		1 day	>3 cm/s	inner part of the catchment area (hydrological)[2]	90 days (min 250 m)	1 day	extremely > 2.5 km/day	area from which pollution can reach the source[2]	close protection area2
III		1 - 10 days	1 - 3 cm/s	main part of the catchment area[2]	180 days (min 200 m out of zone	1 - 10 days	extremely 1 - 2.5 km/day	complete catchment area	remote protection area[2]
IV		10-20 days (< 20 l/s) 20-40 days (20-100 l/s) 40-50 days (>100 l/s)	extremely: < 1 cm/s	complete catchment area[2]	no	complete catchment area		no	no
RESERVATION		zone of accumulation and retention			no	no		no	no criteria

PRIORITY ACTION - Remediation - example TBA Una

- During the war period numerous civil and military facilities, with polychlorinated biphenyls (PCB), had been destroyed. One of these facilities is the former military airport Željava, located at the border between Croatia and Bosnia and Herzegovina (north-western part of Bosnia and Herzegovina). The destroyed former military airport Željava is built on and within (underground facilities) very karstified limestones of the Cretaceous age. Connections between numerous swallow holes located in wider area of the airport and springs in Bihać area (the most important spring is Klokot) are certainly proved by numerous dye tests in the past.

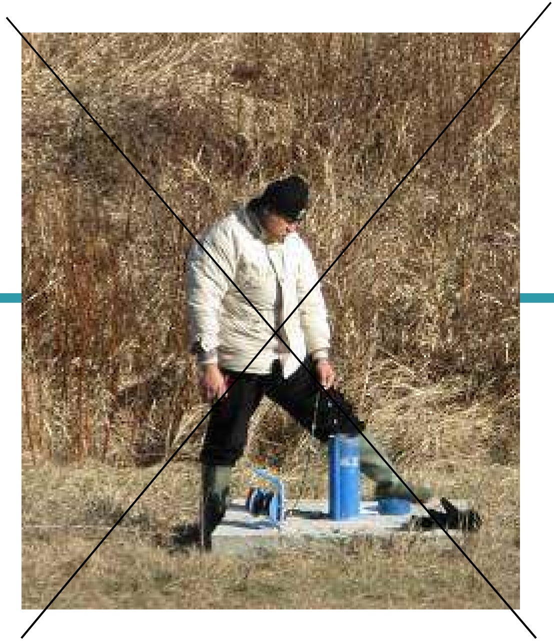
PRIORITY ACTION - WWTP implementation example - TBA Una

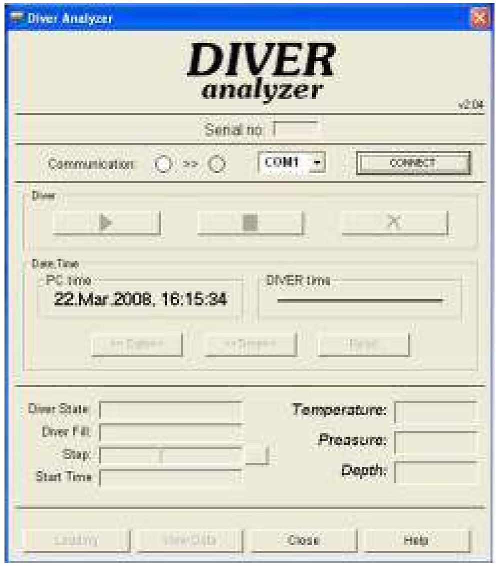


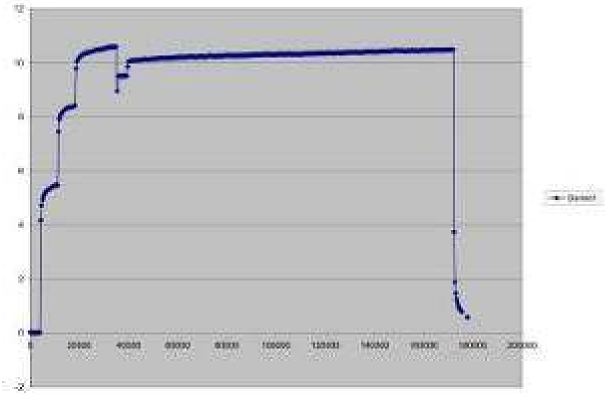
PRIORITY ACTION -- GW Monitoring (Weak point)

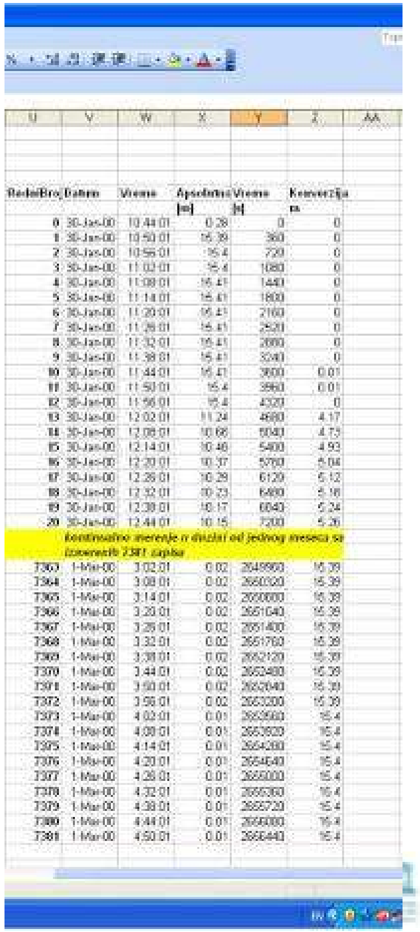
- **Croatia:** Characterization of GW bodies completed; Monitoring is taking place in accordance with EU WFD (Hrvatske Vode responsible).
- **B&H:** Characterization of GW bodies is on-going; no defined methodology for GW status/risk assessment.
- **Albania:** Preliminary characterization of GW bodies performed within CEMSA project. Currently, characterization undertaken by Albanian geological Survey (scale 1:200 000).
- **Montenegro:** Characterization of GW bodies firstly made in 2005 (ICPDR), a new one is taking place; Not yet established methodology for GW status/risk assessment.

Monitoring is crucial for GW sustainable use and management

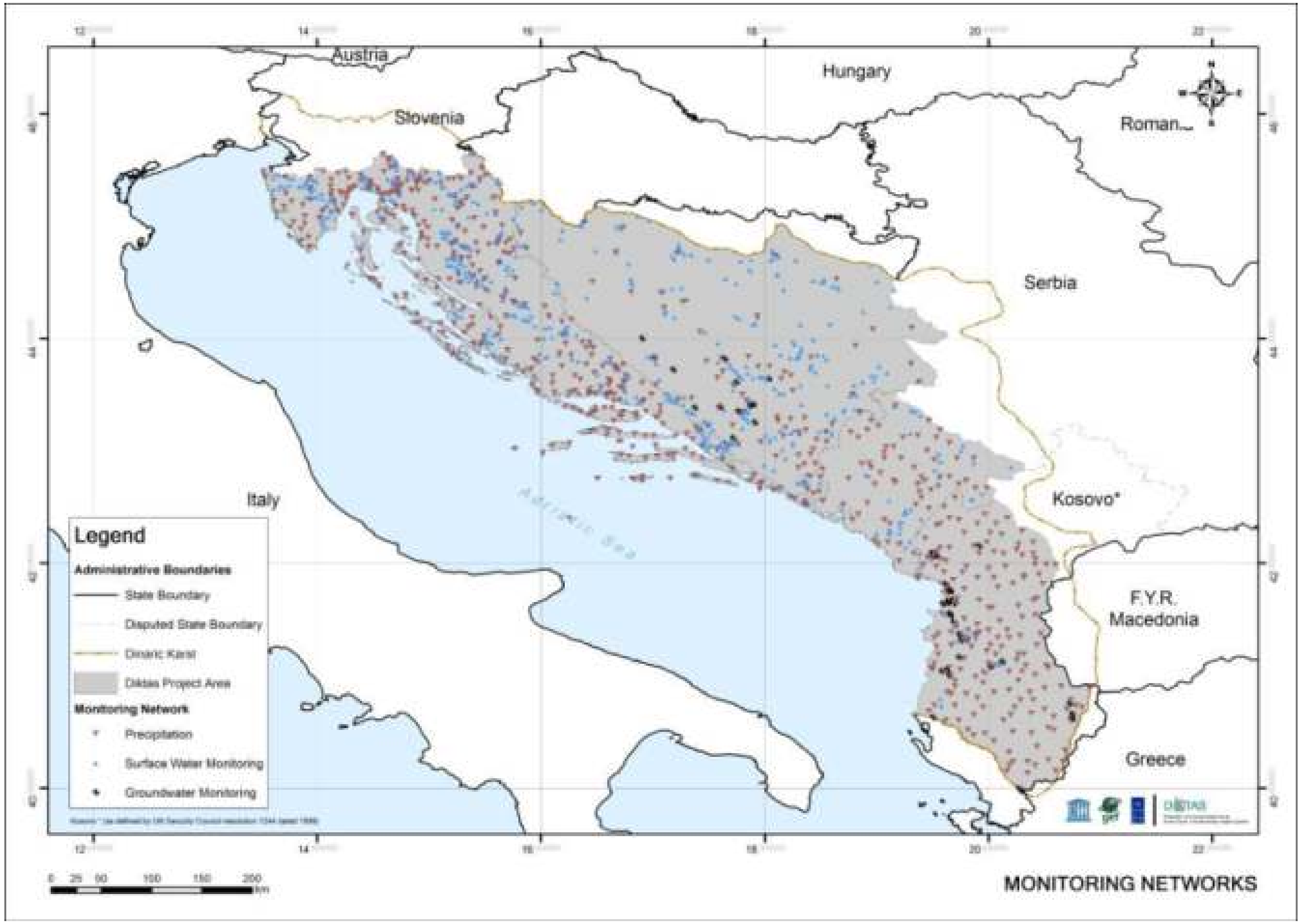








Database - Monitoring groundwater sites
(permanently and sporadically observed)

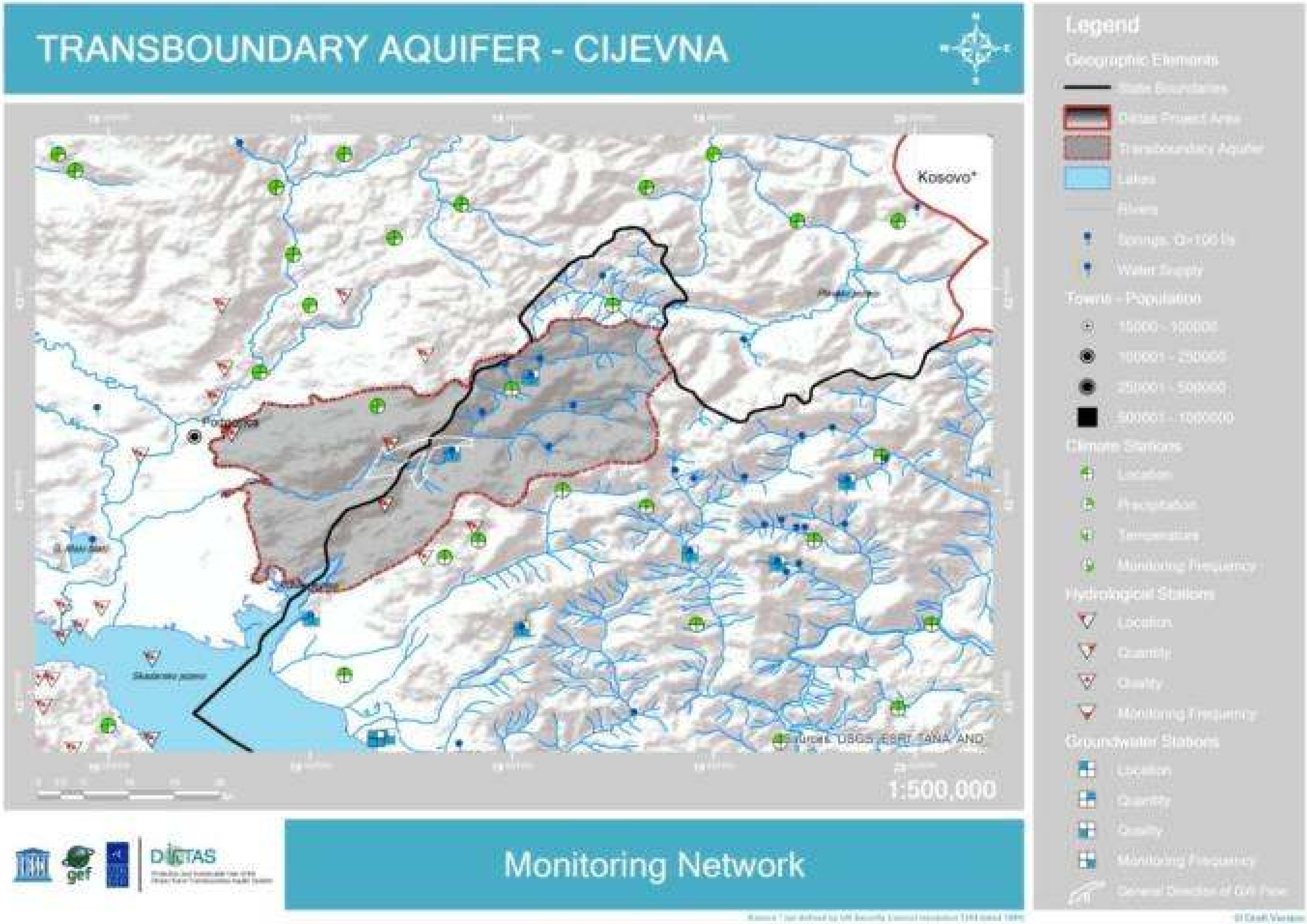


http://diktas.iwlearn.org

Recommendations for GW monitoring

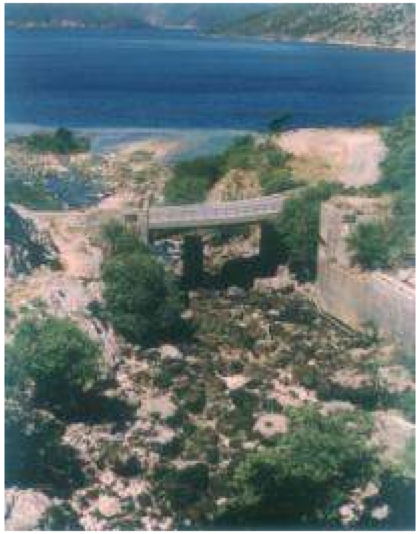
- The WFD does not specify the minimum duration or frequency of surveillance monitoring. Operational monitoring, however, must be conducted at least once a year, during the interval between surveillance monitoring cycles.
- WFD the following core set of determinants must be monitored on all GW bodies: dissolved oxygen, pH-value, electrical conductivity, nitrate, ammonium,
- As for the transboundary groundwater bodies, beside the core set of parameters they shall also be monitored for those parameters which are relevant for the protection of all of the uses supported by the groundwater flow.
- ICPDR recommends that temperature and a set of major (trace) ions should also be monitored.

Thematic maps of TBAs – Cijevna/Cemi



- PRIORITY ACTION -- Managing Aquifer Recharge and Discharge

Montenegro coastal springs
Q min:max 1:100.000 ?!



Main Objective of MAR: *Managing aquifer recharge (MAR) of certain selected sources will arise awareness of local water managers and communities of advantages of aquifer control and sustainable utilization of tapped groundwater.*

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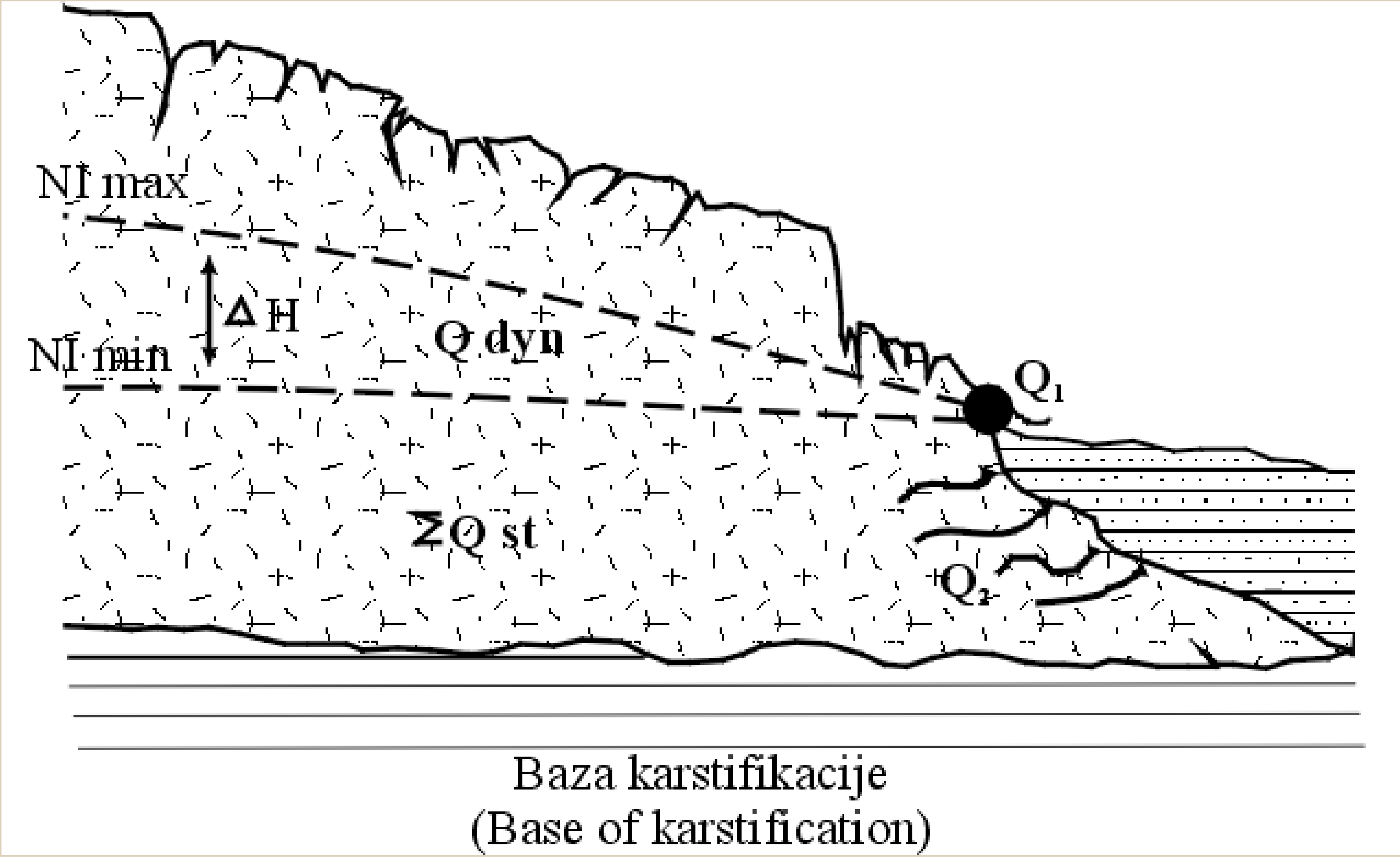


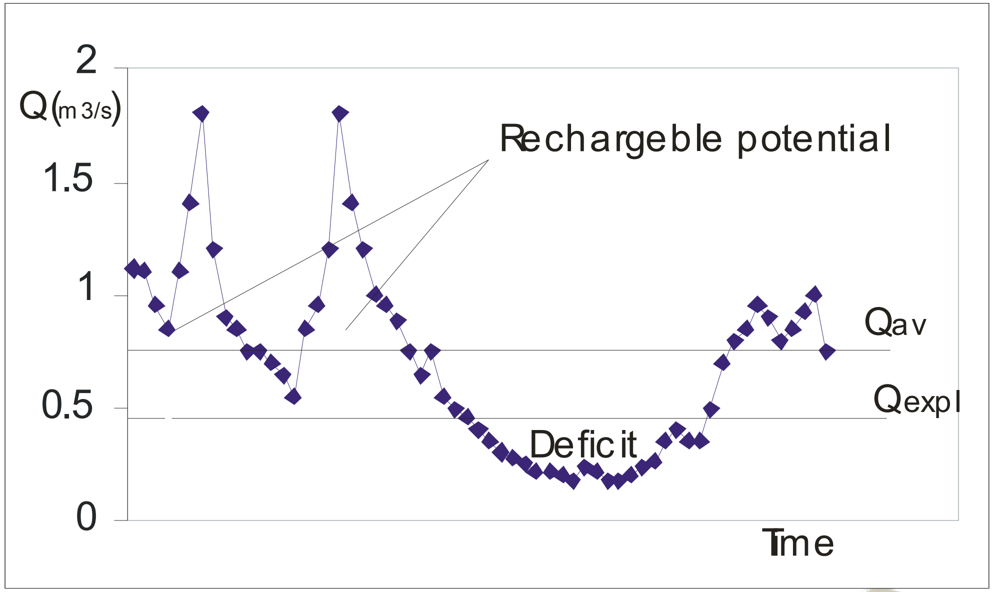
- ***Natural groundwater reserves of karst aquifer – dynamic & static (case with ascending spring Q1 and underground discharge Q2)***

Exploitable reserves as total dynamic and part of static reserves but with controlled and limited usage:

Rare, but logical case

$$Qexp = Qdyn + n \times Qst / T - WL$$

Temporary use of static waters is justifiable if replenishment potential is sufficient !



Contrary to arid areas where such approach often lead to aquifer over-exploitation, in SEE region the climatic and hydrogeological preconditions provide an adequate replenishment potential

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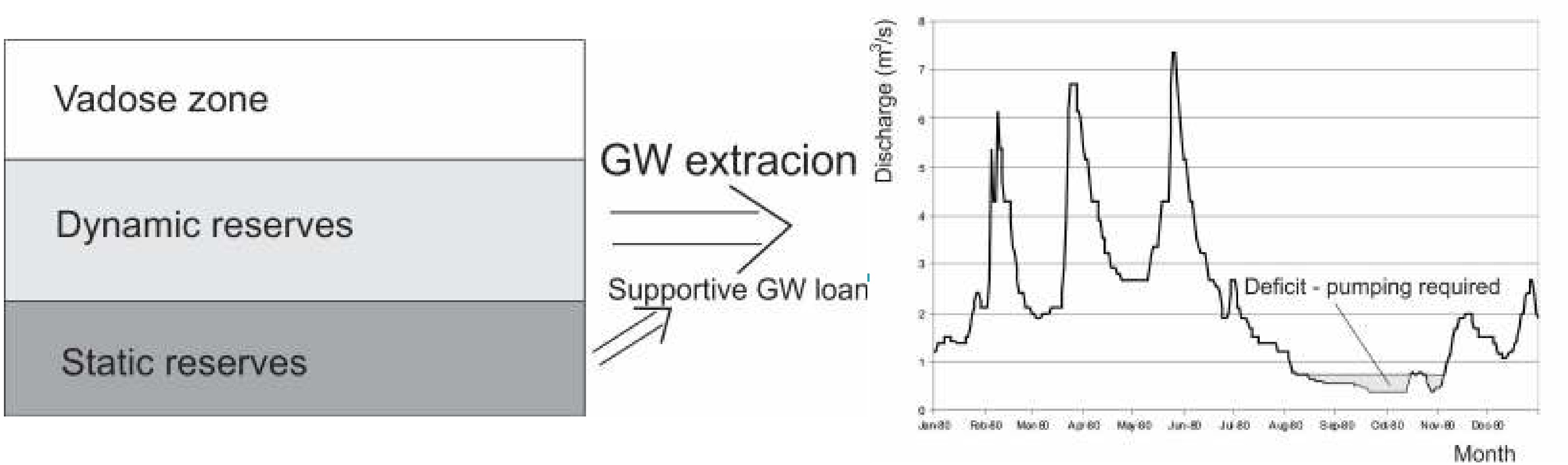

The temporal loan of stored water when water demands are higher than natural discharge does not lead to over-extraction if sufficient replenishment potential exists. The issue of safe yield has been discussed in similar way in articles of Custodio (1992) or Burke & Moench (2000).

$$\text{If} \quad Q_{expl} > Q_{dyn}, \text{ and}$$

$$Q_{expl} = Q_{dyn} + Q_{st\text{"}loan\text{"}} \text{ , then}$$

$$Q_{st\text{"}loan\text{"}} = Q_{expl} - Q_{dyn}$$

where,

Q_{expl} – Exploitation request, water demands; Q_{dyn} – Dynamic groundwater reserves; $Q_{st\text{"}loan\text{"}}$ – Static groundwater reserves for periodic loan (equal to difference between demands and natural flow).

A successful project - New intake for Montenegro coast

- Sub lacustrian spring Bolje sestre in Skadar basin
- $Q_{min} = 2.3\ m^3/s$
- The total pipeline length is 140 km.
- The system is planned for a maximum capacity of 1.5 m^3/s in two stages.
- The water discharges through several registered points near the shore.
- Order: Avoid mixture of water (fresh groundwater and lake)

DIKTAS

- Complex investigation programme included: hydrology, geophysical survey (geoelectric tomography and electromagnetic VLF method),drilling, tracing tests, hydrogeological mapping, diving, permanent sampling and analyses of the water quality (biological, chemical, radiological).

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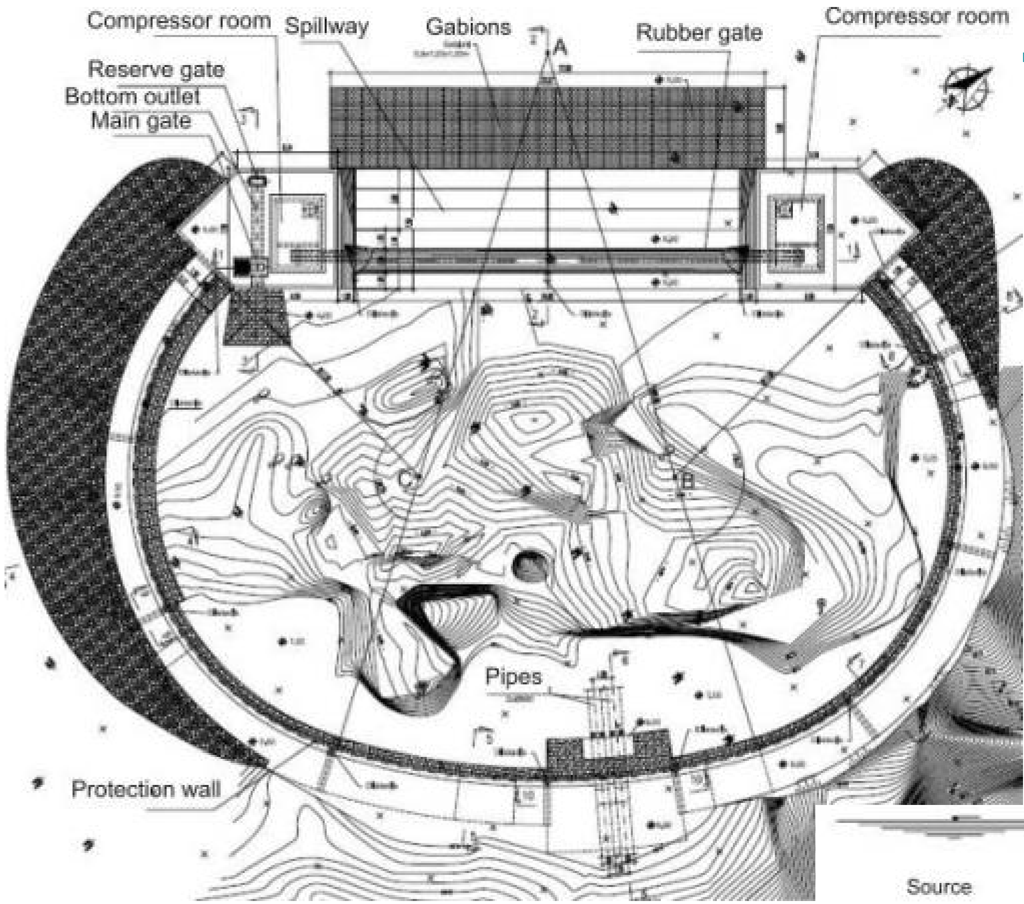
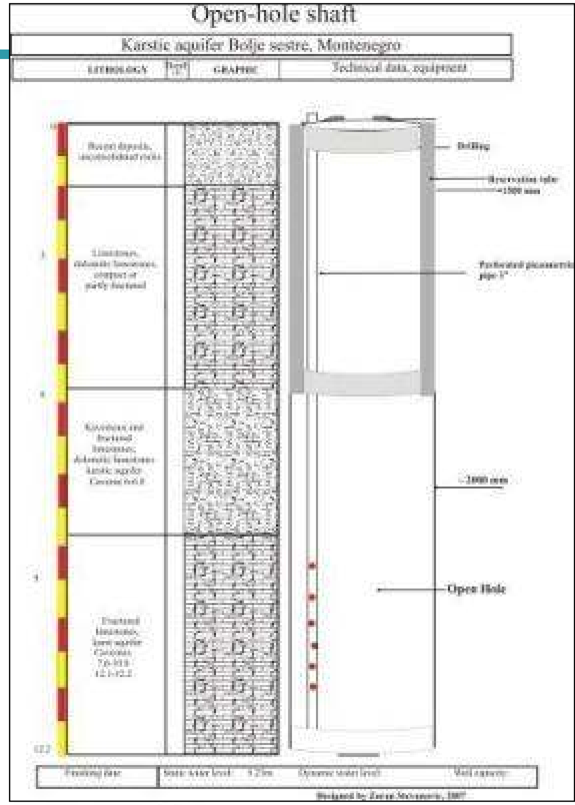
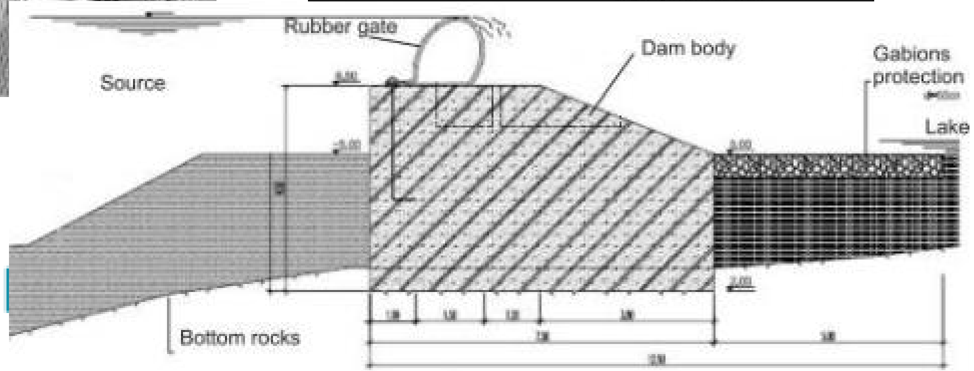
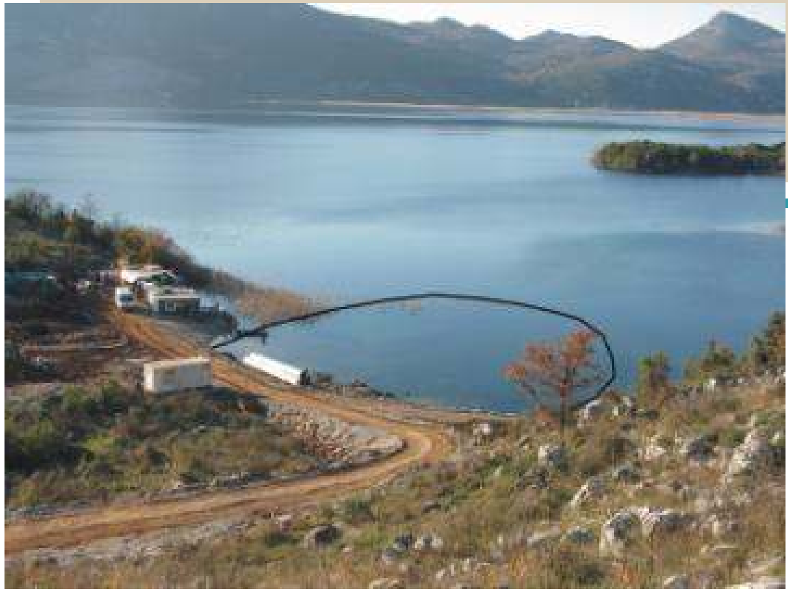
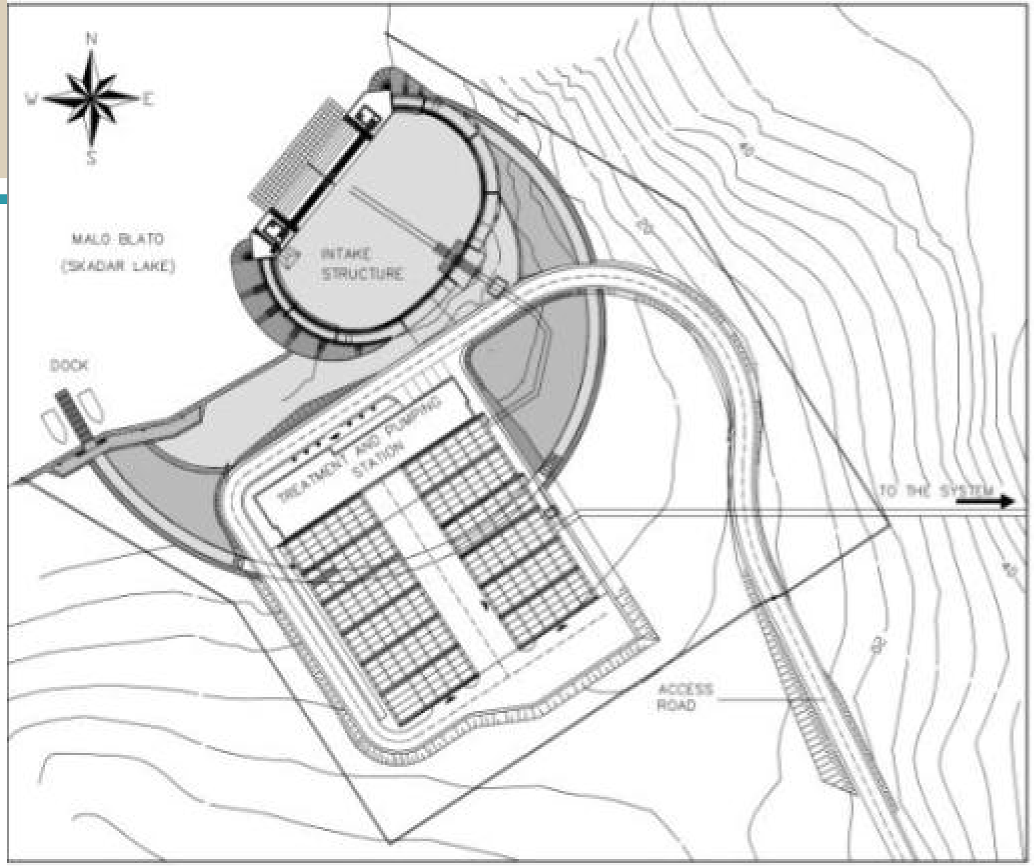
Specific intake - The concrete elliptical coffer dam covers an area of some 300 m² and has a rubber gate spillway











It confirmed a very small influence resulting in a maximum decrease in the level of the lake of less than 1cm under the extraction of 1.5 m^3/s (Stevanovic et al. 2008)

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SAP - Priority action 5 MAR

- To achieve the main objective the following activities should be undertaken:
- *A. 1. **Preliminary selection**.* The list of potentially suitable sites in Dinaric karst and in selected studied TB aquifers is provided by experts of WG1. The proposals come out after consultation with national authorities and other DIKTAS experts.
- *A. 2. **Research**.* Geological and hydrogeological surveys are carried out aiming at define catchment areas, thickness of the saturated zone of proposed sources, assess aquifer properties and above all aquifer's regime and storativity.
- *A. 3. **Feasibility and initial design**.* Out of all proposed sources, selection of two or three the most promising sources for engineering intervention is made and feasibility study and initial design of intake are prepared.
- *A. 4. **Implementation**.* Construction work, test and establishment of groundwater monitoring station (quantity and quality) including installation of an Early Warning System for prevention from pollution and guarantee of eco-flow.
- *A. 5. **Publicity.*** To minimize any negative effects of the proposed interventions along with undertaken survey and optimization of technical solutions, very careful explanation of the tasks and of the benefits to the local water managers and consumers is provided.

Local and international capacity building

International Course
Characterization and Engineering of Karst Aquifers
Trebinje, Bosnia & Herzegovina,
3-10 June, 2014

This course is supported by:

Organizers:

- Department of Hydrogeology and Centre for Karst Hydrogeology of the University of Belgrade - The Faculty of Mining & Geology (http://www.karstedu.rs)
- The Geological Survey of the Republic of Srpska, Zvornik (Bosnia & Herzegovina) (http://www.geozavodrs.com)

other supporters:

- Department of Geological Sciences, The University of Texas at Austin, USA (http://www.geotexas.edu)
- Karst Commission of the IAH (International Association of Hydrogeologists (http://www.iah.org/karst)
- The Jaroslav Černi Institute for the Development of Water Resources (JCI) and its UNESCO's Category 2 Centre, Serbia (http://www.jcerni.org)
- IGRAC (International Groundwater Resources Assessment Centre), Delft, The Netherlands (http://www.un-igrac.org)
- Edwards Aquifer Authority, San Antonio, Texas, USA (www.edwardsaquifer.org)
- Speleological club "Zelena brda" (Green Fields), Trebinje, Bosnia & Herzegovina (http://www.24casa.com/zelenabrda/contact.php)

Curricilum

UNIVERSITY OF BELGRADE-
FACULTY OF MINING AND GEOLOGY (FMG)
Republic of Serbia, Belgrade 11000, Djusina 7

Department : HYDROGEOLOGY

Level of Certified Studies: Master Study (MS in Hydrogeology)

Course: Characterization and Engineering of Karst Aquifers

Responsible Teacher / Assistant: Dr Zoran Stevanovic, Prof. / Dr Sasa Milanovic, Res. Ass.

Other lecturers: Other staff members of FMG, visiting professors and experts from country and abroad

Course status: Optional

Usually offered: Spring Semester

Typical structure: 2 hours lecture, 2 hours practical exercise, discussion and work in the field

ESTC (credits as per European system): 6 (out of 30 per semester)

Prerequisite(s): Courses on undergraduate level

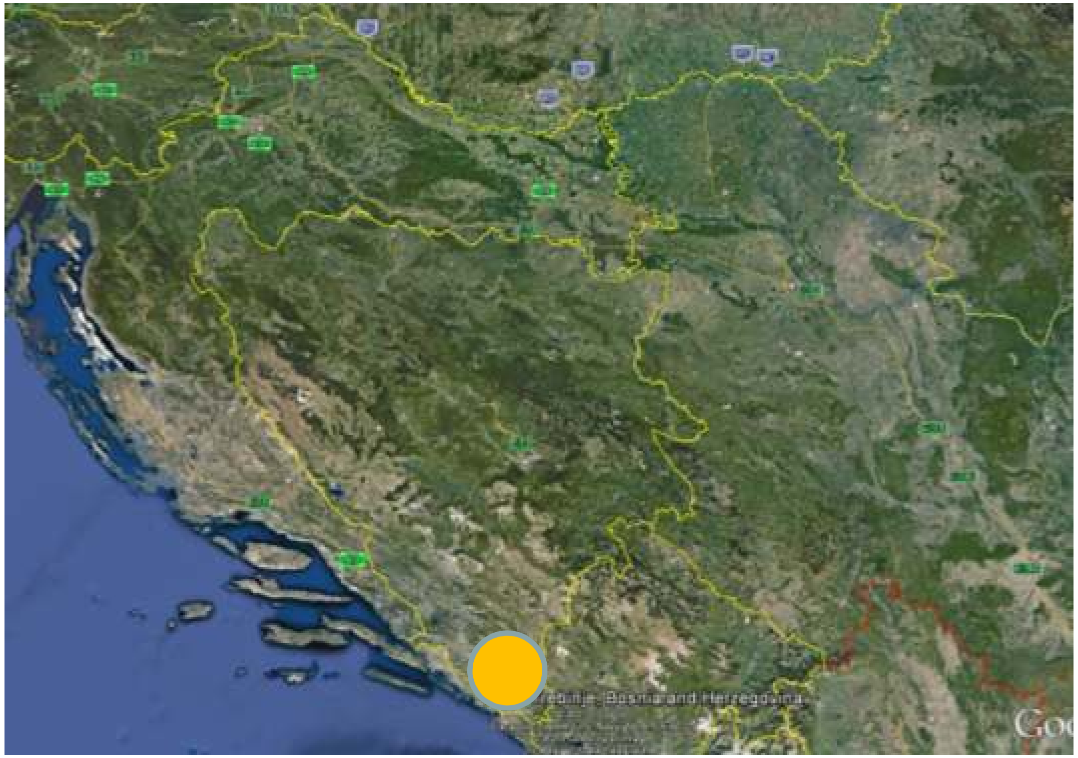
Grading: Regular : 6 (51-60 points),7 (61-70), 8 (71-80), 9 (81-90), 10 (91-100)

(Maximal points 100)

Pre-exam activities	Max. Points	**Final Exam**	поена
Lectures/Discussion	**10**	Test / Oral	**50**
Practical work	**10**		
Colloquium / Seminars	**30**		

DIKTAS

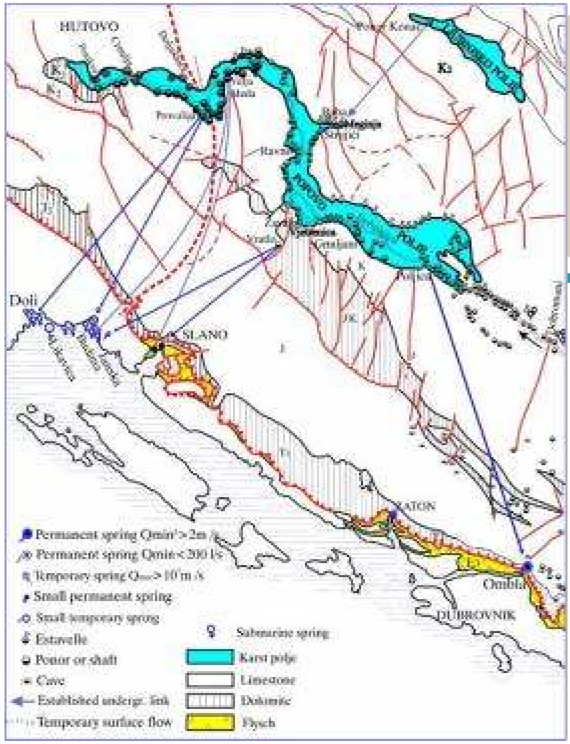
Why Trebinje ?



DIKTAS

Lecturers for the year 2014.

- Dr Zoran Stevanović, prof. FMG, University of Belgrade, Serbia
- Dr Neven Krešić, ex-prof. AMEC, USA
- Dr Petar Milanović, prof. ret., University of Mostar, Enregoproject, HET, Serbia
- Dr Ognjen Bonacci, prof. emeritus, University of Split, Croatia
- Dr Bartolome Navarro, prof. University of Malaga, Spain
- Dr Francesco Fiorillo, prof. University Sannio, Benevento, Italy
- Dr Neno Kukurić, UN-IGRAC, the Netherlands
- Dr Dragan Milovanović, prof. FMG, University of Belgrade, Serbia
- Dr Vesna Ristić Vakanjac, assoc. prof. FMG, University of Belgrade, Serbia
- Dr Saša Milanović, res. assoc. FMG, University of Belgrade, Serbia



Legend:

- Route
- A Trebinje
- B Vjetrenica Cave
- C Buna spring
- D Bregava River
- E Dabarsko polje
- F Fatničko polje
- G Spring Trebišnjica and reservoir „Bileća"

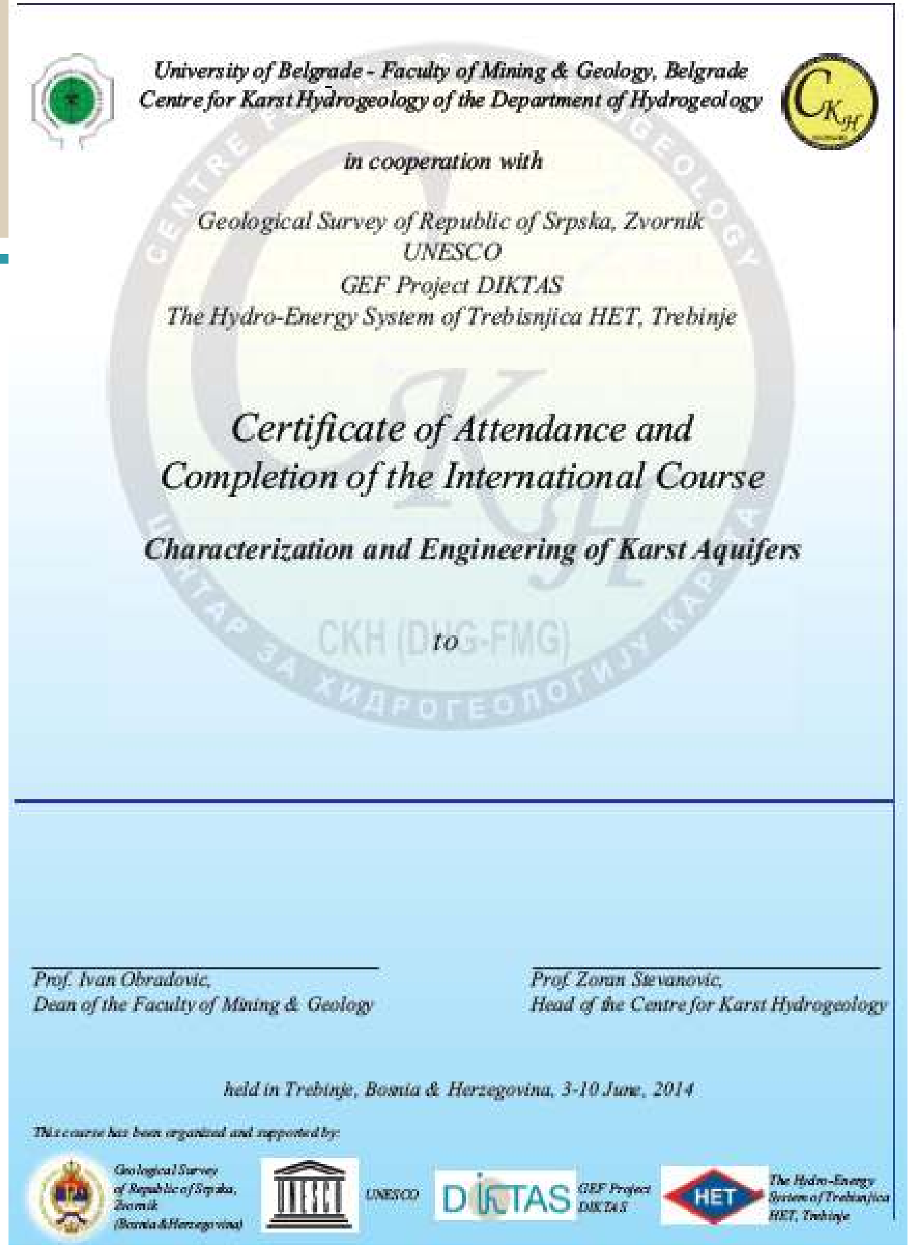
DIKTAS

21 participants from 11 countries

7 days of teaching and field works

13 students examined

10 teachers from 6 countries


University of Belgrade - Faculty of Mining & Geology, Belgrade
Centre for Karst Hydrogeology of the Department of Hydrogeology

in cooperation with

Geological Survey of Republic of Srpska, Zvornik
UNESCO
GEF Project DIKTAS
The Hydro-Energy System of Trebisnjica HET, Trebinje

Certificate of Attendance and
Completion of the International Course

Characterization and Engineering of Karst Aquifers

to

Prof. Ivan Obradovic,
Dean of the Faculty of Mining & Geology

Prof. Zoran Stevanovic,
Head of the Centre for Karst Hydrogeology

held in Trebinje, Bosnia & Herzegovina, 3-10 June, 2014

This course has been organized and supported by:

Geological Survey of Republic of Srpska, Zvornik (Bosnia&Herzegovina)
UNESCO
GEF Project DIKTAS
The Hydro-Energy System of Trebisnjica HET, Trebinje


Vjetrenica

DIKTAS

gef

Conclusions

- Although the Dinaric region has the most intensive water budget in all of Europe, there are numerous problems for sustainable utilization of GW. The main problem is the great annual variation of natural flows and the vulnerability of aquifers to pollution which comes mostly from still unregulated waste water discharges and solid wastes improper deposition.
- **Tasks:**
- to quantify the water reserves of transboundary aquifers,
- to apply engineering solutions to regulate aquifer discharges,
- to ensure ecological flows,
- to eliminate sources of pollution,
- to improve the quality of water, and
- to establish proper water monitoring systems,
- **to learn more on karst and raise awareness of its resource importance!**

Thank you!

http://diktas.iwlearn.org

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