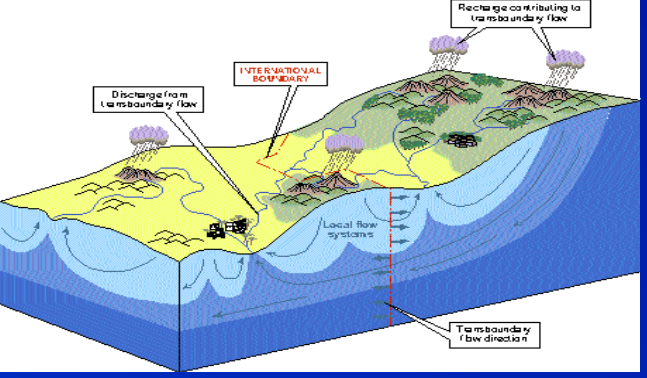


Workshop on the protection of groundwater as a source of drinking water in karst areas

April 14-15, 2008, Malinska - CROATIA

HYDROGEOLOGICAL RESEARCH OF THE CROATIAN PART OF THE TRANSBOUNDARY AQUIFERS (HR-SI) BETWEEN KVARNER BAY AND TRIESTE BAY

Assist.prof.dr. Ranko Biondić [1]
Prof.dr. Božidar Biondić [1]
Assist.prof.dr. Sanja Kapelj [1]
Josip Rubinić, M.Sc. [2]

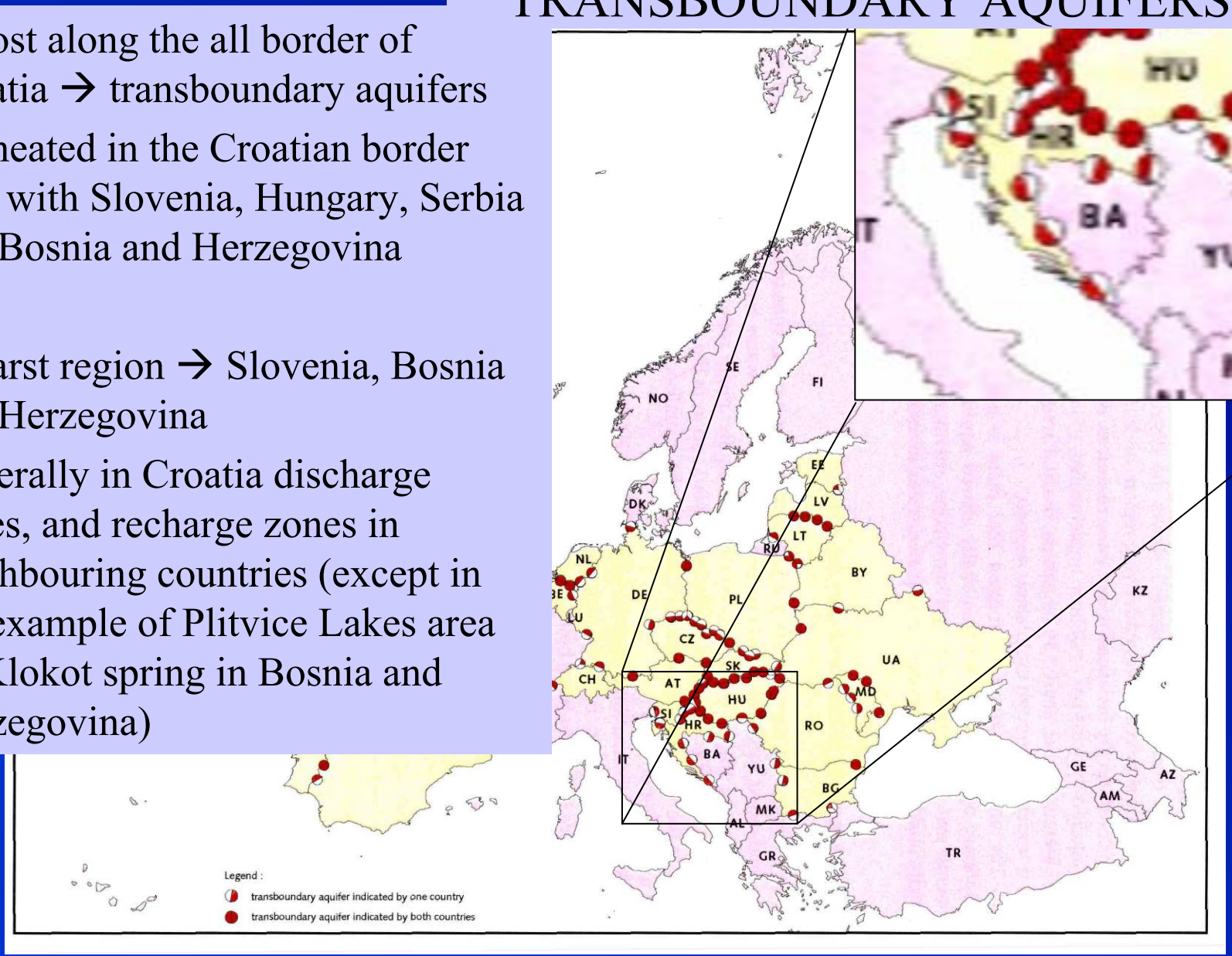
1 University of Zagreb
Faculty of Geotechnical Engineering
Hallerova aleja 7, HR-42000
Varaždin, Croatia

2 University of Rijeka
Faculty of Civil Engineering
V.C. Emina 5, HR-51000 Rijeka,
Croatia

SKETCH OF EUROPEAN TRANSBOUNDARY AQUIFERS

- almost along the all border of Croatia → transboundary aquifers
- delineated in the Croatian border area with Slovenia, Hungary, Serbia and Bosnia and Herzegovina

- in karst region → Slovenia, Bosnia and Herzegovina
- Generally in Croatia discharge zones, and recharge zones in neighbouring countries (except in the example of Plitvice Lakes area → Klokot spring in Bosnia and Herzegovina)



• Internationally Shared (Transboundary) Aquifer Resources Management – A Framework Document (IHP-VI, Non Serial Documents in Hydrology, 2001)

TRANSBOUNDARY KARST AQUIFERS IN CROATIA
(Slovenia, Bosnia and Herzegovina)

HOW THE PROJECT STARTED ?

- Before nineties of last Century in former country there were not common researches of that border parts of former republics in such way

- Beginning of thinking about common researches of transboundary aquifers between Croatia and Slovenia was in 1998
- Common interests in protection and management of transboundary aquifers → the base for water-supply of very wide area

- In the late 90-ties the most important transboundary aquifers between Croatia and Slovenia that could be investigated were emphasized :
  - Carbonate area between Trieste and Kvarner Bays
  - Catchments area of Čabranka and Kupa Rivers
  - Žumberak-Gorjanci area
  - Intergrannular aquifer of Sava River
  - River Sutla catchment area
  - Intergrannular aquifers of Drava and Mura Rivers

►**firstly we started with carbonate area between Trieste and Kvarner Bays**

►Initiative for the project through the Slovenian-Croatian scientific-research project "Protection of karst aquifers in the border area"

►Common karst aquifers, in use on both sides of the state border

►For good management of water resources and objective political decisions in that area necessary is very good level of knowledge of natural conditions → needs for complex hydrogeological researches

►On transboundary aquifers is connected water-supply systems of Koper, Piran and Ilirska Bistrica in Slovenia and the biggest part of Istrian peninsula, Rijeka and Opatija in Croatia → about 400.000 inhabitants

Main objectives of the project

Hydrogeological level of knowledge in the function of usage and protection of karst aquifers in border area of Croatia and Slovenia

Improvement and using of hydrogeological research methods (geological- morphostructural analyze, groundwater tracing tests, hydrogeochemical researches, hydrological research, continual monitoring of physical-chemical parameters on main springs etc.)

Presentation of all data in GIS – common GIS

Equalizing of criteria for groundwater protection for the border area according to WFD

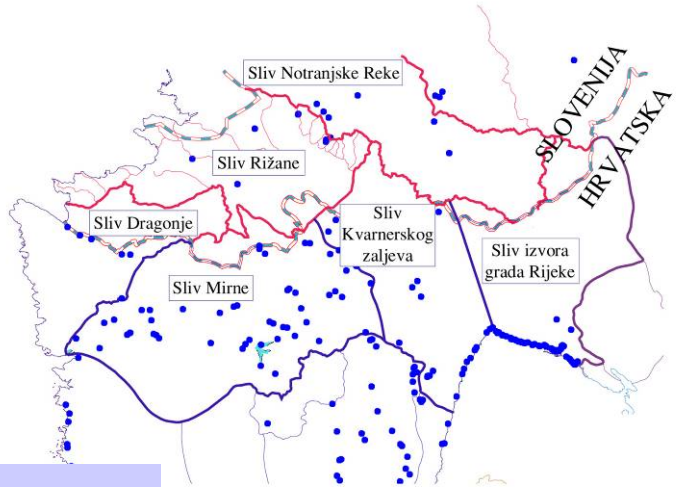
Common assessment of qualitative and quantitative status of groundwater in aquifers in the border area

Monitoring of qualitative and quantitative status of groundwater in aquifers in the border area

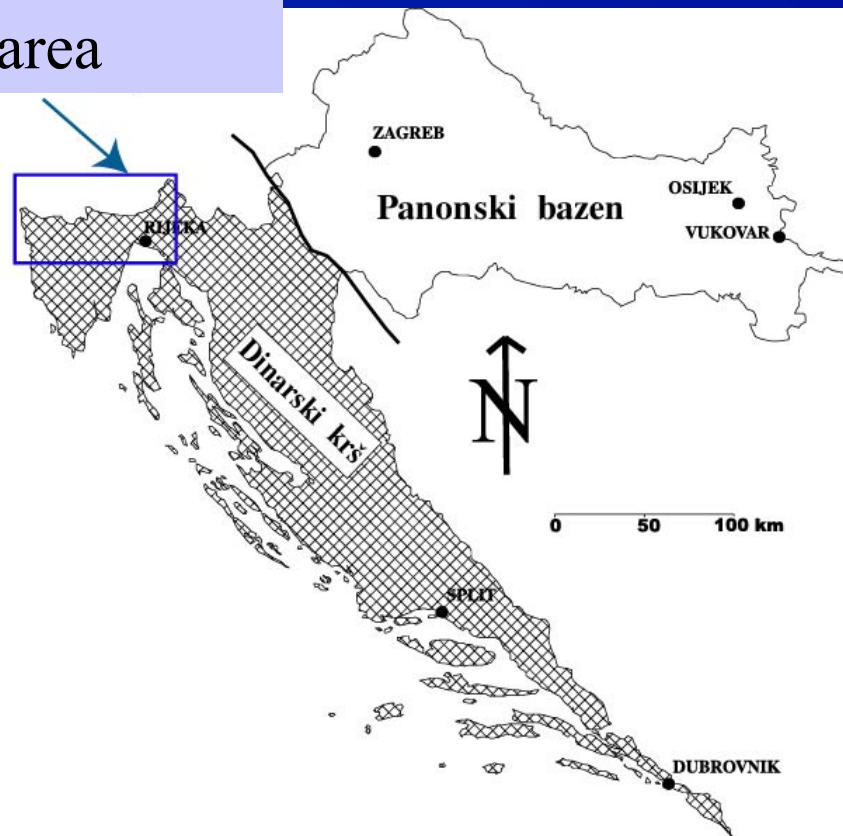
Physical and regional planning in the function of aquifer protection

Optimal usage of existing water-supply springs and plans for capturing of new ones, especially in the recharge zones of catchments

- **Karstic area between Trieste and Kvarner Bays**
- This area consists of 7 catchment areas:
  - Dragonja River catchment area
  - Mirna River catchment area
  - Kvarner Bay catchment area
  - Catchment area of the springs in western part of Rijeka
  - Catchment area of the springs in the town of Rijeka
  - Rižana spring catchment area
  - Ilirska Bistrica spring catchment area
- Whole researches were divided into three phases
  - two of them were finished



Research area



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RESEARCH PROGRAM

I. RESEARCH PHASE

1. Preparation of hydrogeological map M 1:50.000

2. Hydrogeological analyses of all catchment areas
- Measurements on springs (CND, T)

3. Hydrological analyze (beginning)
-Collecting of available data from existing gage stations
-Proposal of new gage stations

4. Hydrogeochemical researches
- Preparation of monitoring net, analyses and data processing

5. Tracing test → Buje area

6. Preparation of annual report

II. RESEARCH PHASE

1. Hydrogeological measurement of CND and T (monthly) on springs

2. Hydrological analyze

3. Tracing tests → Novokračine, Snežnik

4. Hydrogeochemical research (radioactive and stabile isotopes, microelements, chemical composition) on 9 measuring locations

5. Analyze of existing water protection zones and measures of protection

6. Data processing, preparation of data for final GIS in the 3rd phase

7. Preparation of annual report

III. RESEARCH PHASE

1. Hydrogeological measurement of CND and T (monthly) on springs

2. Two tracing tests

4. Hydrogeochemical research

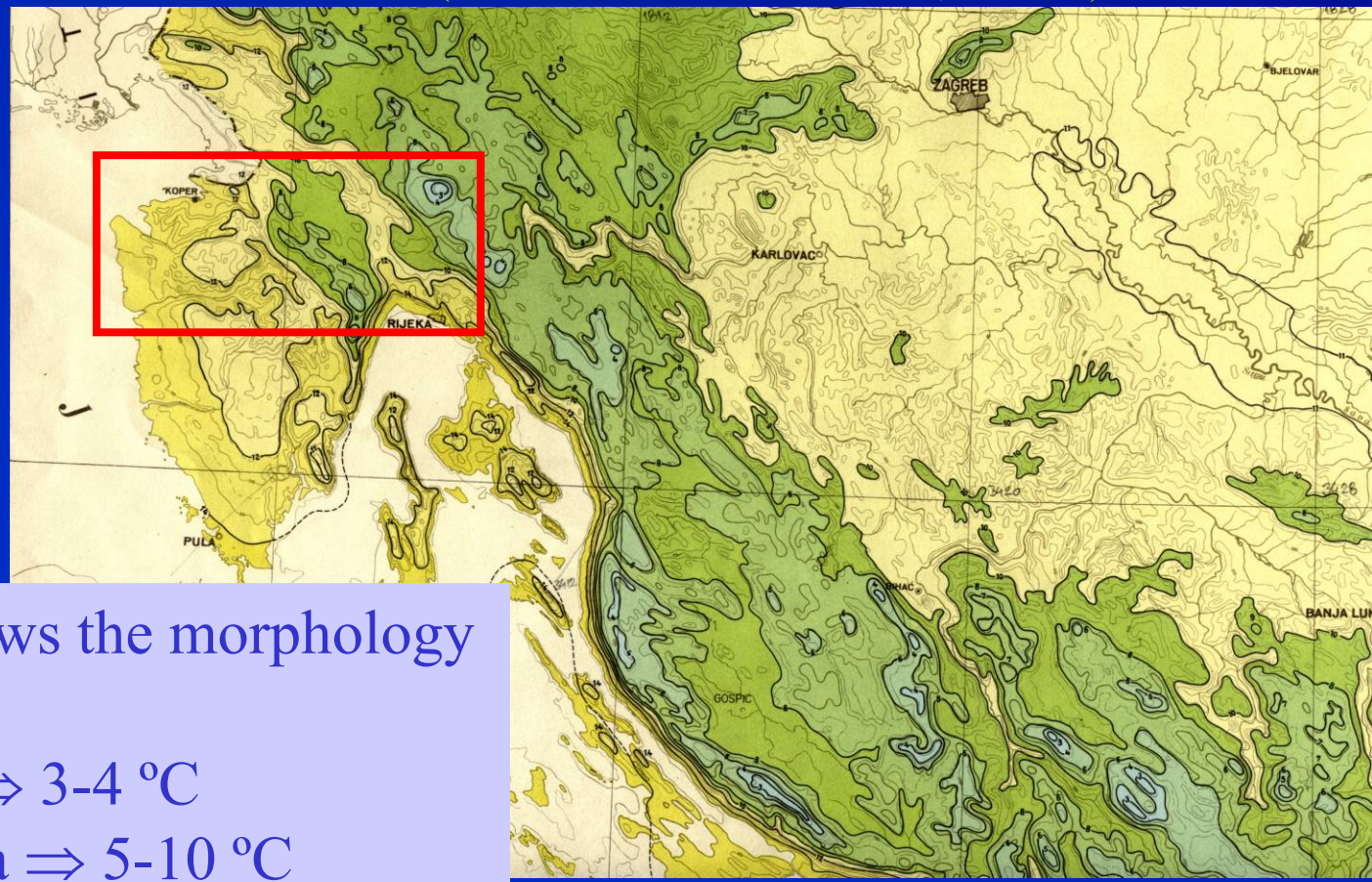
5. Vulnerability, hazard and risk maps of all catchment areas

6. Preparation of final GIS

7. Data processing and preparation of final report

Climatic characteristics - temperature

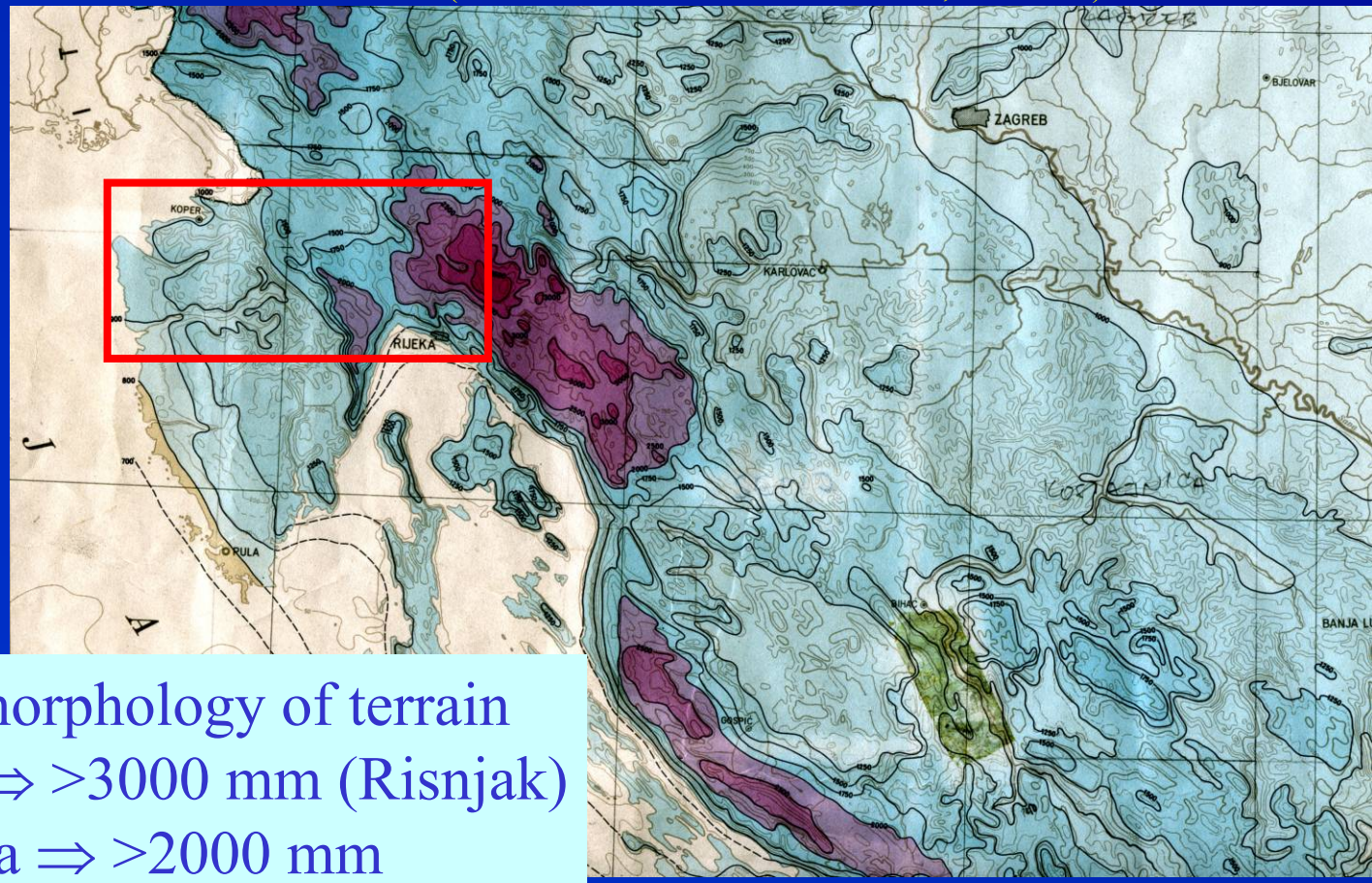
Average annual temperature for period 1931-1960
(after: SAVEZNI GEOLOŠKI ZAVOD, 1969-1976)



- Temperature follows the morphology of terrain
  - Gorski kotar ⇒ 3-4 ºC
  - Učka , Ćićarija ⇒ 5-10 ºC
  - Istra ⇒ 12-16 ºC

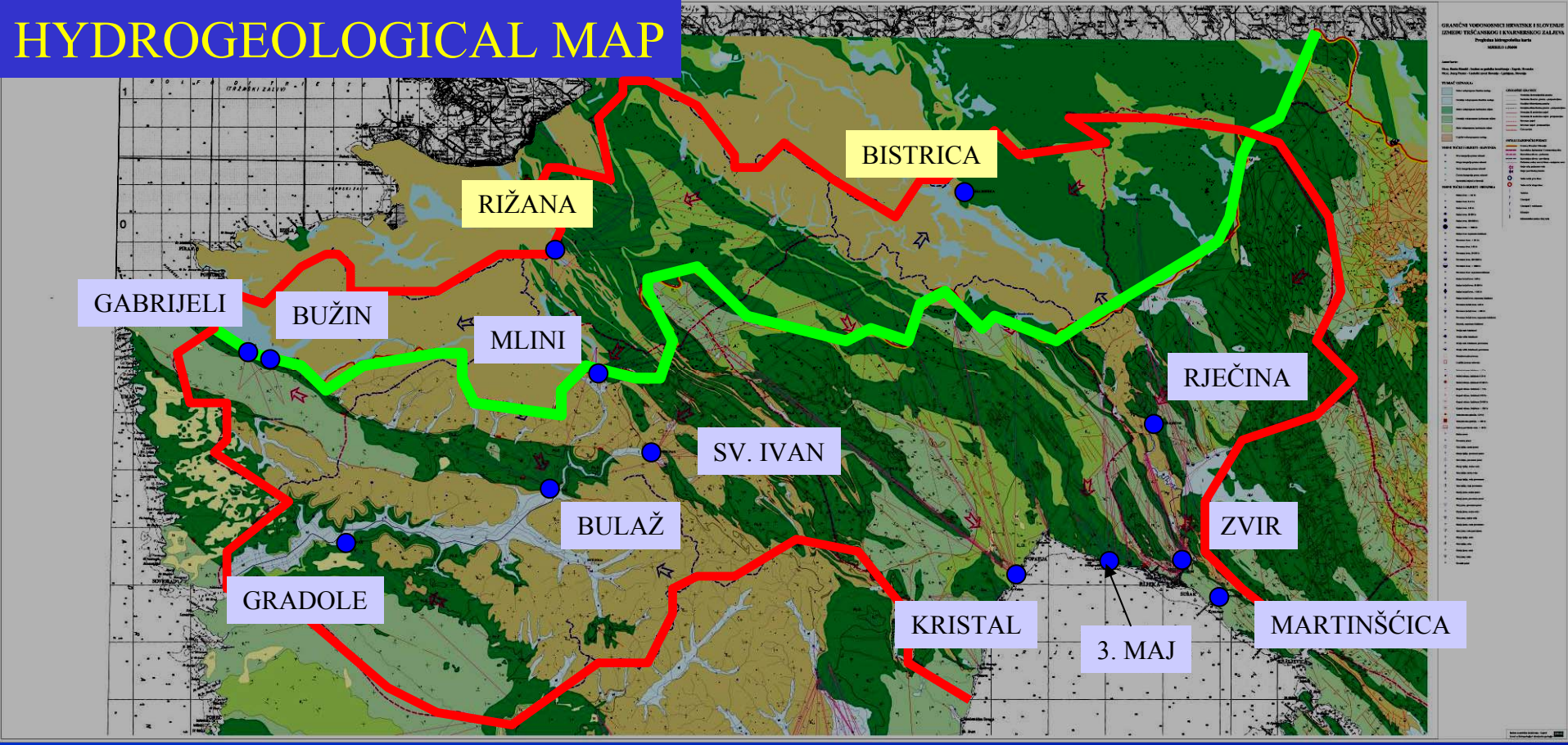
Climatic characteristics - precipitation

Average annual precipitation rate for period 1931-1960
(after: SAVEZNI GEOLOŠKI ZAVOD, 1969-1976)



- precipitation ⇔ morphology of terrain
  - Gorski kotar ⇒ >3000 mm (Risnjak)
  - Učka , Ćićarija ⇒ >2000 mm
  - Istra ⇒ 700 – 1000 mm

HYDROGEOLOGICAL MAP

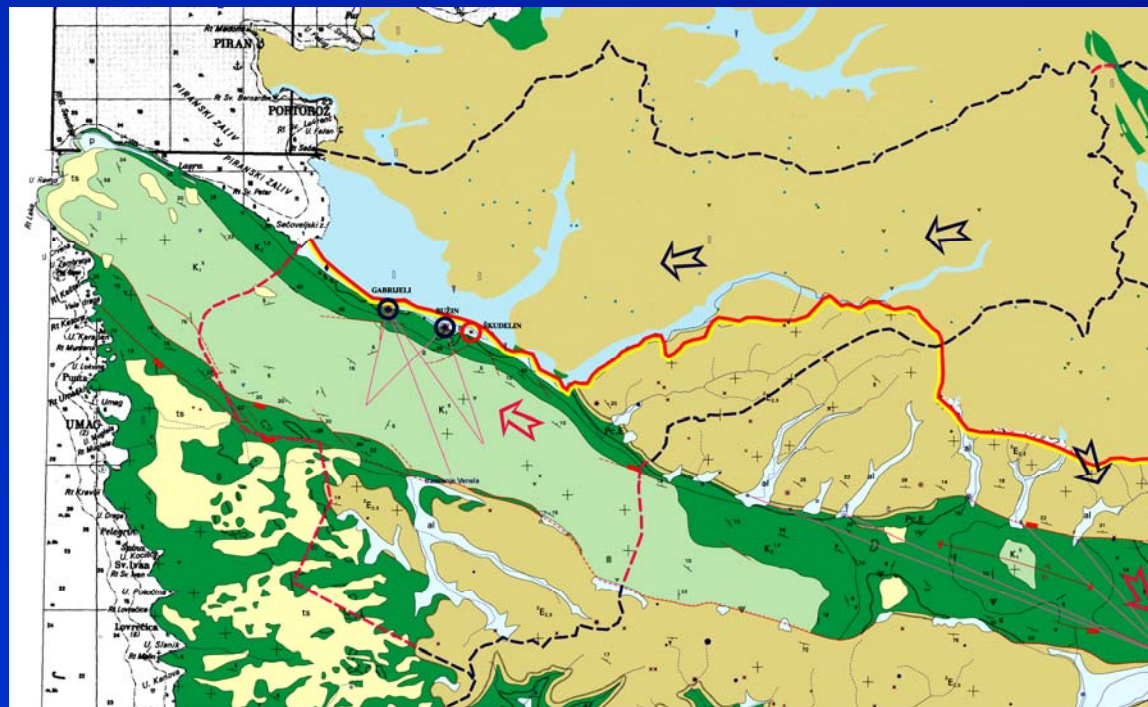


- According to structural-tectonic analyze there are 3 main regional overthrusted structures
  - overthrusted structure of Ćićarija
  - overthrusted structure of Snežnik
  - overthrusted structure on the south edge of Buje anticline structure
- Besides tectonics, for the groundwater flow forming inside the carbonate mass very important is relation of lithological units
  - very important is relation of permeable and impermeable rocks and deposits – on the contact of carbonate rocks and flysch → springs
- 3 basic groups of deposits and rocks ← according to the hydrogeological characteristics
  - Carbonate rocks → with 3 levels of permeability depending on dolomite content
  - Clastic deposits of basic structures (flysch)
  - Clastic deposits of Quaternary ages

Hydrogeological description of catchment areas

Dragonja River catchment area

- on the Croatian side catchment area of 228 km^2
- Located in the western part of Istrian peninsula
  - Transboundary catchment area (in Slovenia → flysch deposits – mostly surface flow)
- Carbonate part of catchment area in Croatia → anticline form between Istarske Toplice, Buje to the most western part of peninsula
  - The most important recharge area for the springs in the valley of Dragonja
  - Springs:
    - Gabrijeli 60 l/s
    - Bužin 50 l/s
    - Škudelin 1-10 l/s



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Dragonja River catchment area

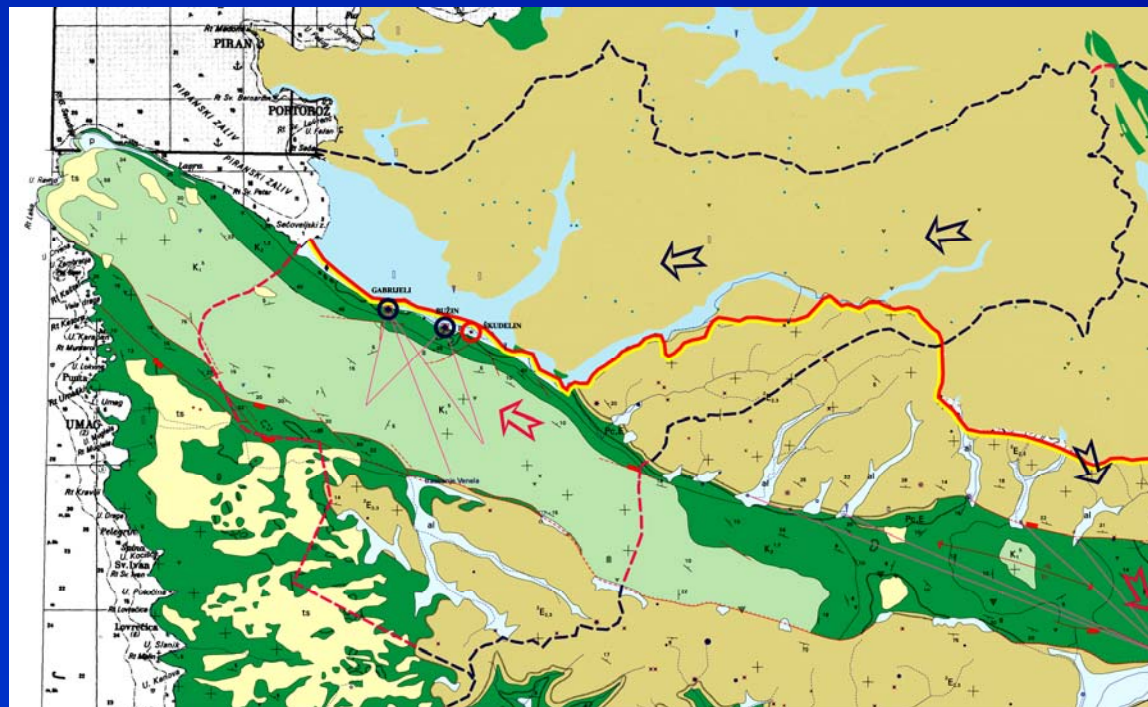
Škudelin

Gabrijeli

Bužini

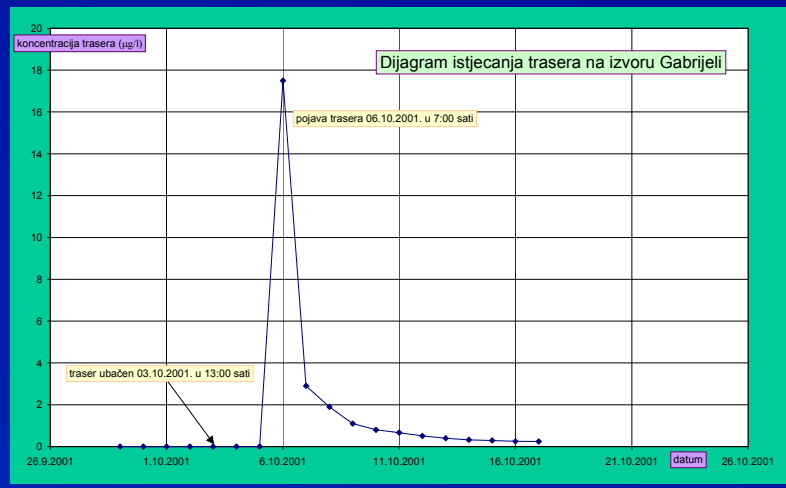
Gabrijeli and Bužini springs used for the water-supply system of Koper before 2003

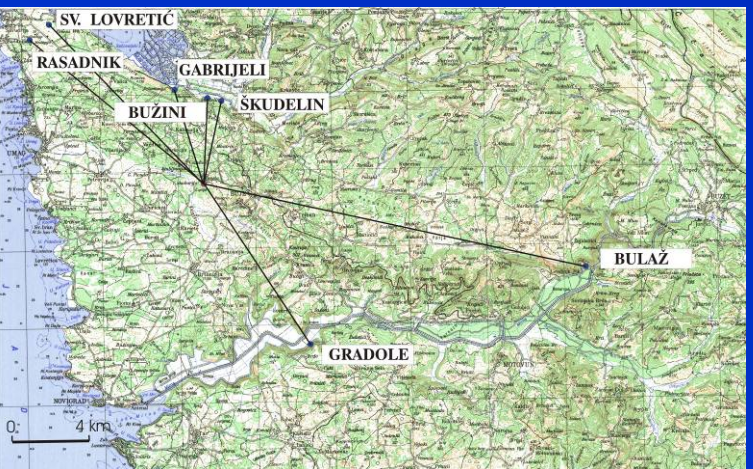
after 2003 not in use

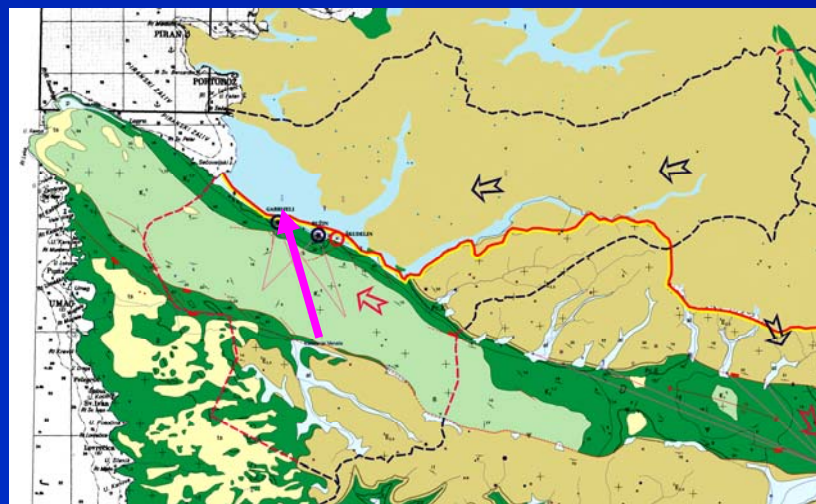


Dragonja River catchment area

- tracing test → Venela near Buje (3.10.2001.)
  - 16 kg uranine
  - monitoring objects:
    - Gabrijeli
    - Bužin
    - Škudelin
    - dig-well in Savudrija
    - spring near St. Lovretić church in Savudrija
    - Gradole spring
    - Bulaž spring
  - apparent velocity → 2,07 cm/s
  - according to Regulations for water protection zones must be in III. zone (now in II. zone → limitation of development of Buje region)







Mirna River catchment area

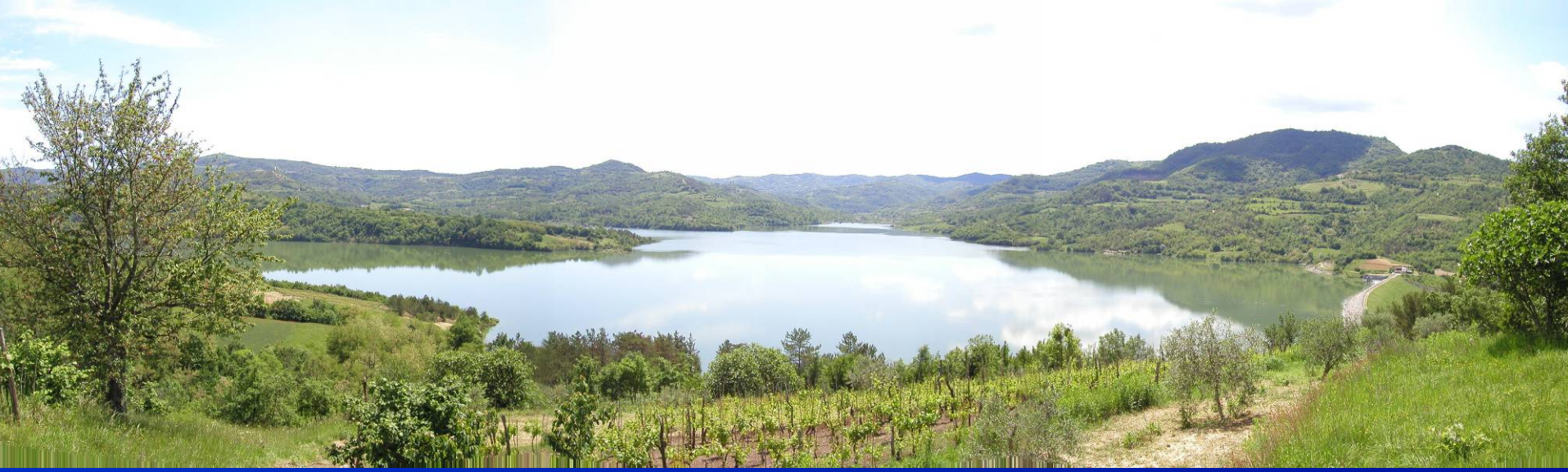
This springs and Butoniga reservoir are the base for the water-supply of Istria

- Almost whole in Croatia, except minor part which surface drain to the Bulaž spring and carbonate part of the catchment in the hinterland of Mlini spring

Bulaž

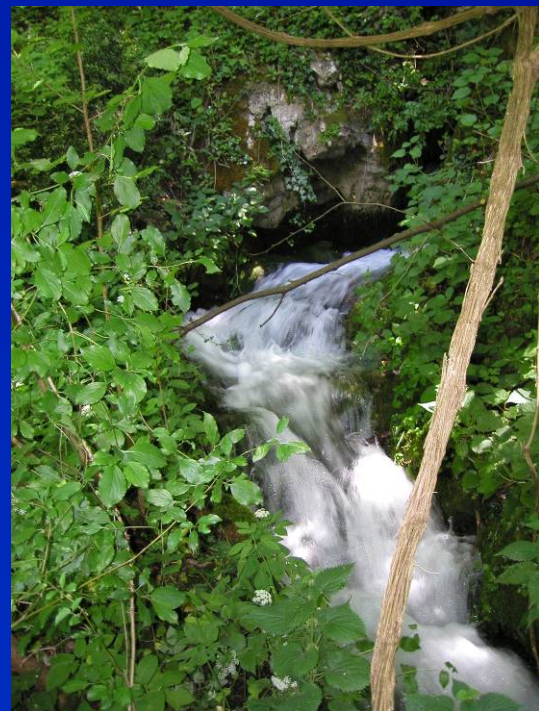
Sveti Ivan

Gradole



Butoniga

Mlini



Kvarner Bay and western part of Rijeka catchment area

- Important springing zone in coastal area
  - In Opatija springs are not captured
    - problems with salt water intrusion
    - Kristal
    - Admiral

    } 0,5 – 1 m^3/s
  - In western part of Rijeka
    - springs are mostly captured for industrial water
    - Preluka (coastal)
    - Kantrida (coastal)
    - 3. Maj (50 l/s in min.; > 1 m^3/s in max.)
    - Pod Jelšun (Torpedo) (80 l/s in min.; > 2 m^3/s in max.)
    - INA Mlaka (350 l/s)
    - Rikard Benčić (200 – 600 l/s)

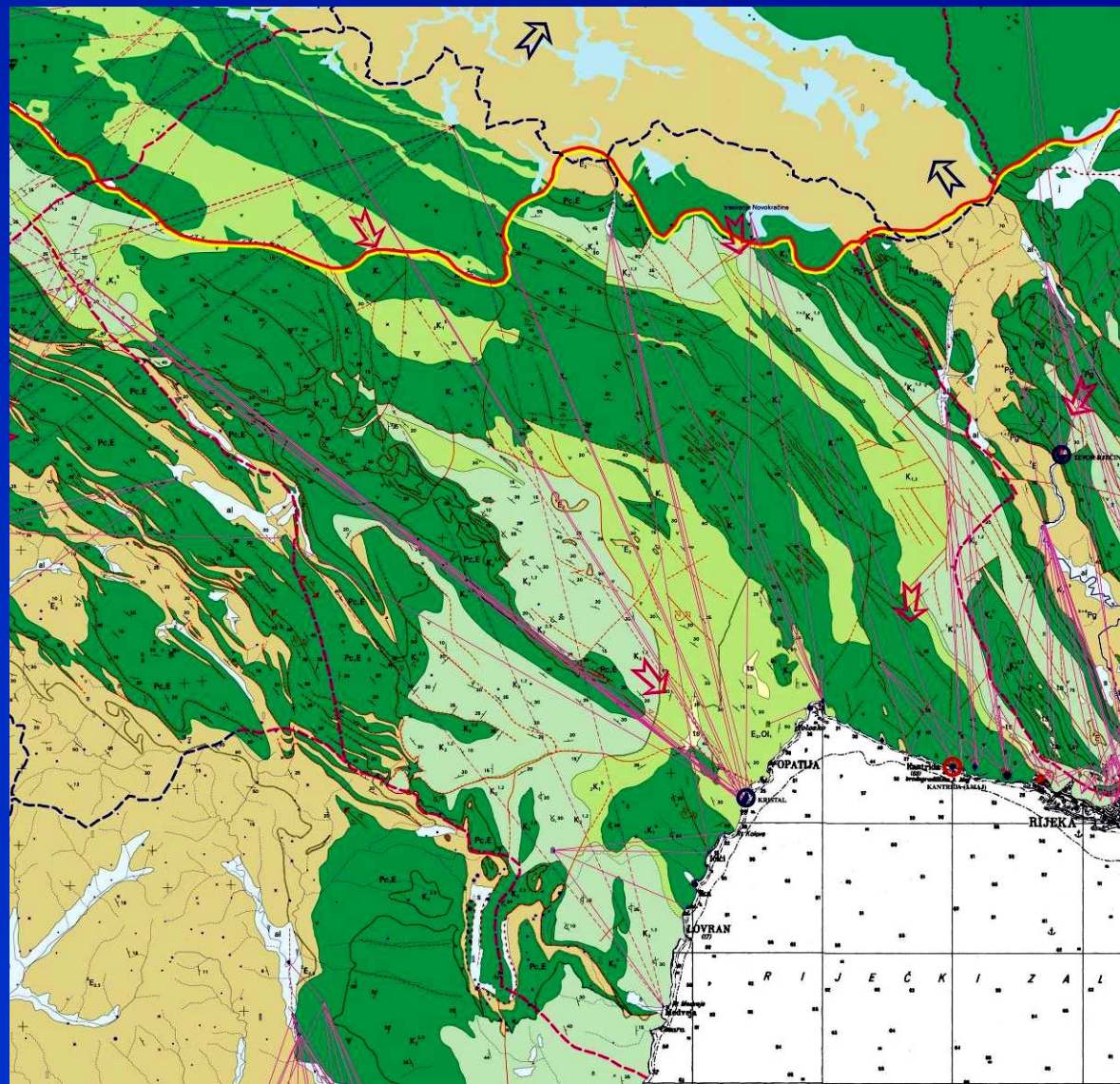
3. Maj (Rijeka)

Kristal (Opatija)

Admiral (Opatija)

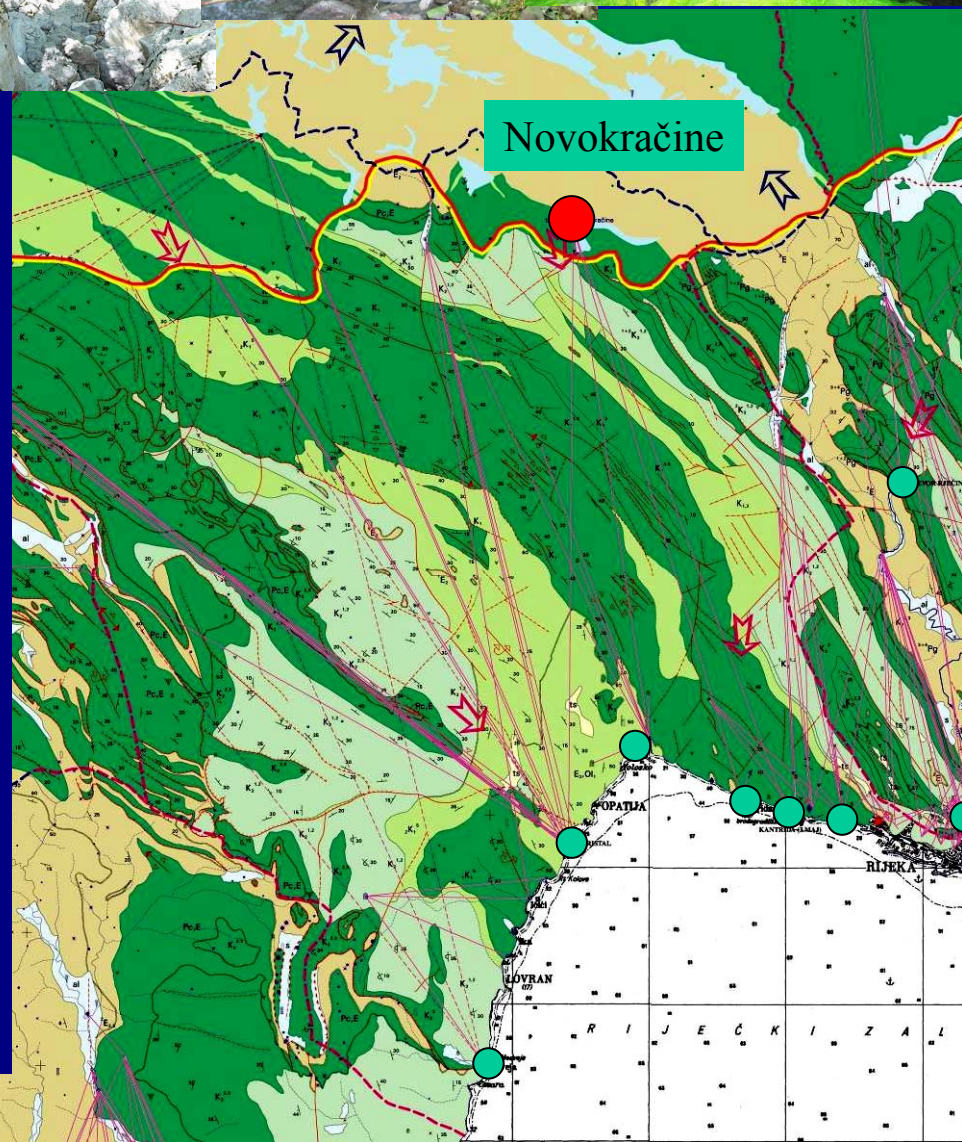
Kvarner Bay and western part of Rijeka catchment area

- very big catchment area
- no one spring captured for the water-supply
- part of the catchment is in Slovenia (Podgrad area and Novokračine area)
- tracing test in Novokračine (29.11.2003.)
- tracing test in Podgrad region is in the programme for the 3rd phase of the project



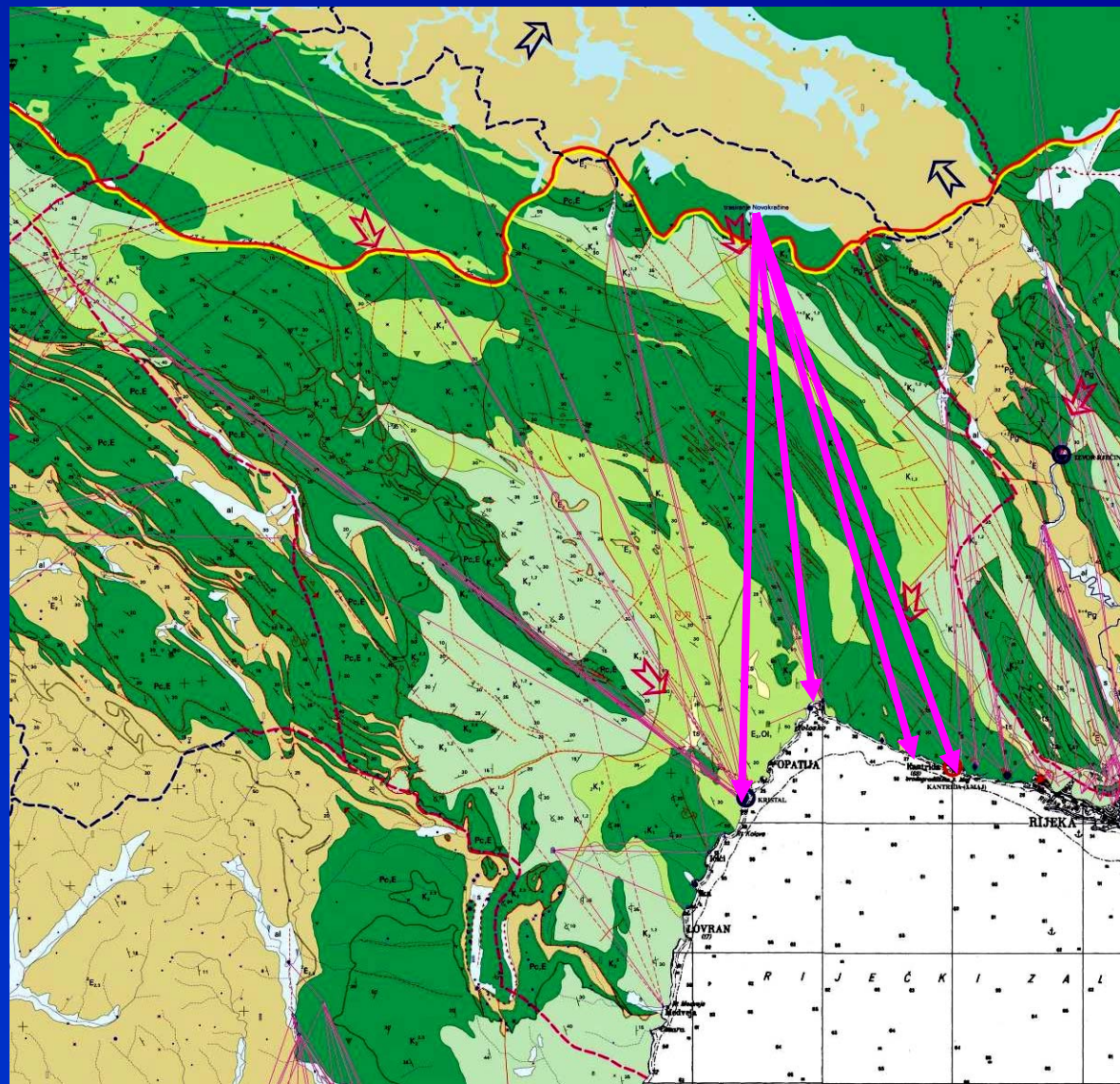
- temporary swallow-hole in Novokračine of Sušački stream which occurring on impermeable flysch deposits and swallow-hole is on the contact with Cretaceous limestones
- flow rate is from 0 l/s to 10 m^3/s
- best time for tracing is when the flow rate is about 350 l/s

- injected 30 kg of uranine
- monitoring objects:
  - spring in the camp in Medveja
  - Kristal (Opatija)
  - Preluka coastal spring
  - Kantrida coastal spring
  - spring in shipyard 3. Maj
  - Pod Jelšun spring (Torpedo factory)
  - well in INA Mlaka
  - spring R. Benčić
  - Zvir
  - Rječina River spring



Kvarner Bay and western part of Rijeka catchment area

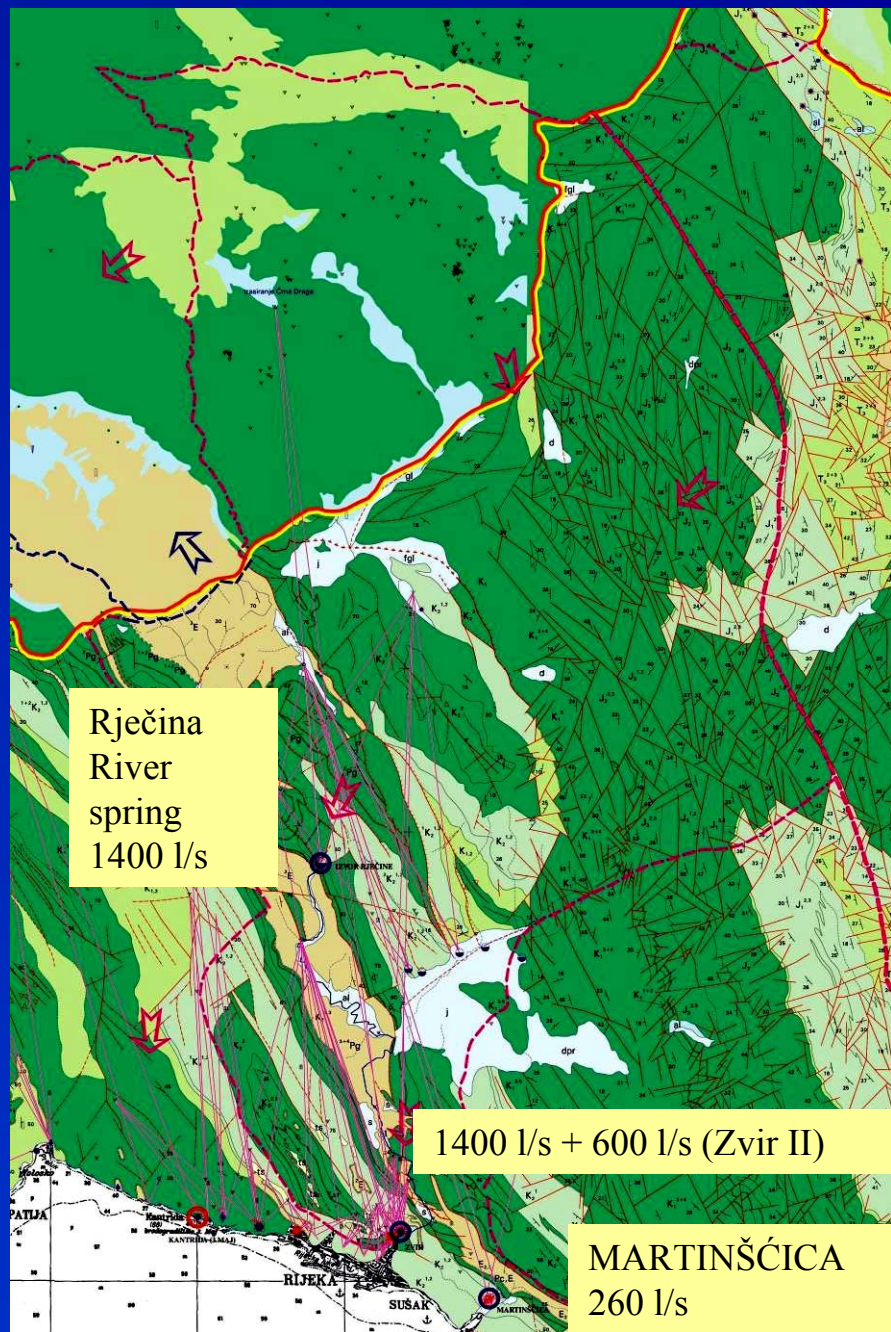
- tracing test in Novokračine (29.11.2003.)
  - proved connection with coastal springs in Opatija and western part of Rijeka
  - apparent velocities from 0,57 to 0,77 cm/s



Rijeka springs catchment area

- The most valuable drainage unit in research area
- main concentration of discharge in canyon of Rječina River and in the Martinšćica valley

- Complex geological condition are reflected on hydrogeological situation
  - Snježnik, Obruč – recharge area
  - Rječina River spring and NW edge of Grobničko polje – zone of temporary discharge
  - Springs in Rijeka – zone of permanent discharge
- Snežnik mountain in Slovenia in the catchment area of Ilirska Bistrica spring (SI) and in the catchment areas of Rječina and Zvir (HR) → in protection zones of both group of springs (overlapping)
  - proposed tracing test



Rječina River spring - dry

Rječina River spring (1400 l/s)

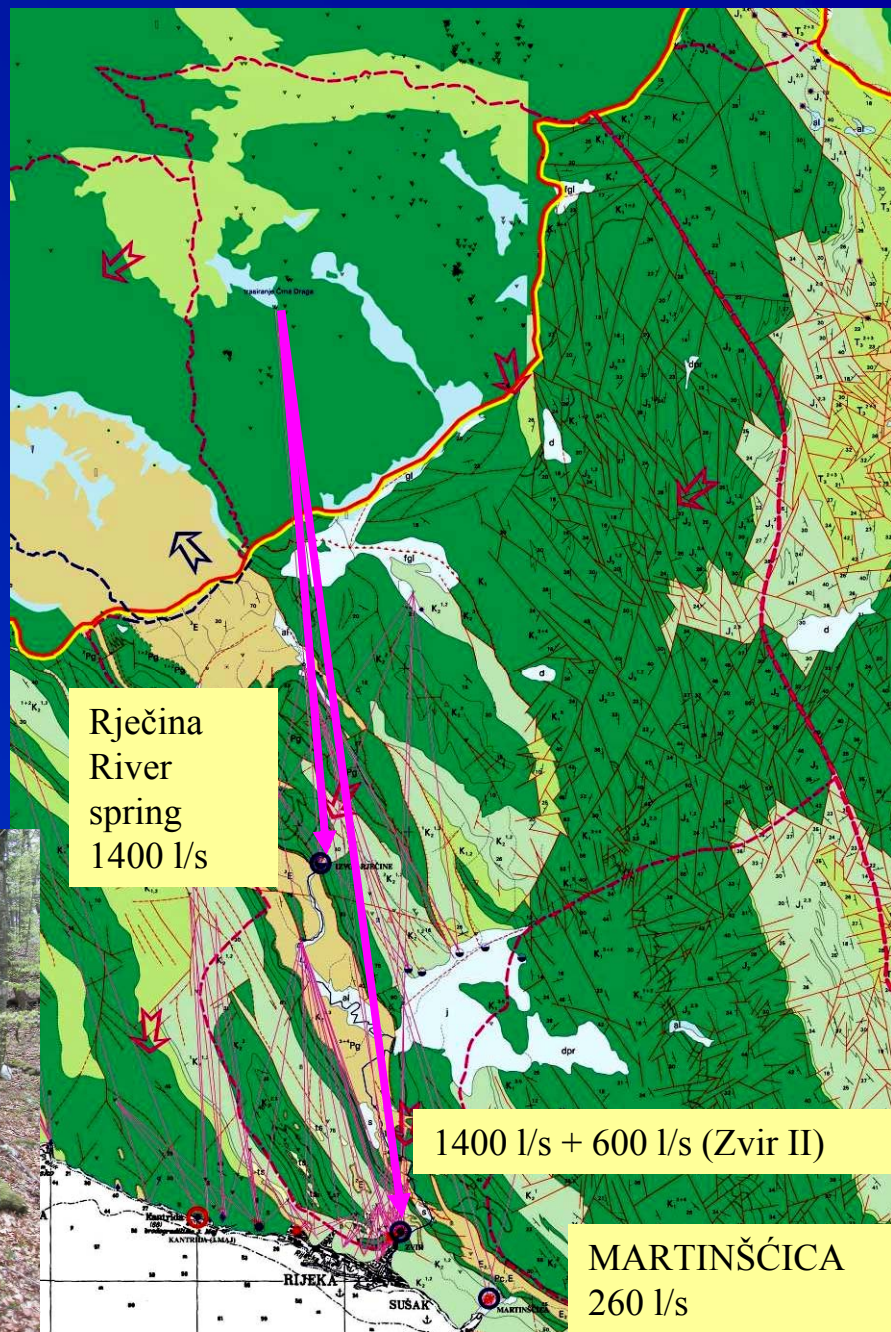
Zvir (1400 l/s)

Zvir II (600 l/s)

Martinšćica valley (260 l/s)

Rijeka springs catchment area

- Tracing test → Črna Draga (Snežnik) 22.05.2004.
  - location of tracer injection is natural pit found by the help of Slovenian speleologists
  - pit is at 1400 m a.s.l.
  - monitoring objects:
    - Rječina River spring (HR)
    - Zvir (HR)
    - Rastinčica – Grobnik polje (HR)
    - Lužac – Grobnik polje (HR)
    - Čabranka River spring (HR)
    - Ilirska Bistrica (SI)
    - Knežak (SI)
    - Snežnik Grad (SI)
  - Rječina River spring 0,49 cm/s, but higher concentration of tracer
  - Zvir spring 0,68 cm/s → velocities appropriate to IV. protection zone



Measurement of temperature and CND on the springs (monthly)

- According to WFD (2000/60/EC) CND value is one of the main parameters for determining of chemical status of groundwater
  - Good status - without big changes of CND
  - Bad status - impact of the salt water intrusion
- Monitoring net of CND and T in Croatia:

– Rječina River spring	325 m a.s.l.	Rijeka
– Zvir	2 m a.s.l.	
– Kristal	coastal	Opatija
– Admiral	coastal	
– Sveti Ivan	35 m a.s.l.	Mirna
– Bulaž	17 m a.s.l.	
– Gradole	2 m a.s.l.	

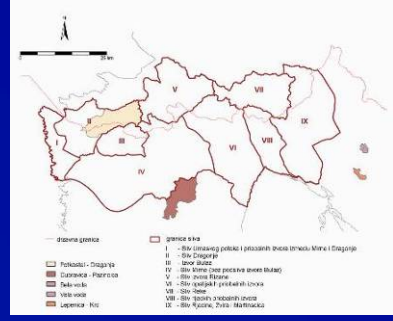
SPRING	ELEVATION (m a.s.l.)	CND (μS/cm)	TEMPERATURE (° C)
RječinaRiver spring	325	238	7,3
Zvir	2	257	8,6
Kristal	0	13850	11,5
Admiral	0	20310	12,7
Sveti Ivan	35	444	12,1
Bulaž	17	549	12,4
Gradole	2	517	13,7

Three basic groups:

- springs in Rijeka – the lowest CND and T
- springs in Opatija – very high CND – impact of the sea water
- springs in Istria – higher T (because of average annual air temperature in catchment) and CND (big part of catchments built of flysch deposits)

Hydrological analyses

- analyze based on existing hydrological stations
- huge number of hydrologic stations, but only three has 30-year data series:
  - Buzet (Mirna)
  - Ponte Porton (Mirna)
  - Grohovo (Rječina)
- in analyze included discharge data from springs Gradole, Sv.Ivan, Bulaž, Zvir, and partly Rječina River spring
- objectives of hydrological analyses:
  - analyze of discharge on the springs (minimum, maximum, average discharge)
  - analyze of surface flow rate
  - estimation of water balance in different catchment areas



CATCHMENT	NAME OF CATCHMENT	area (km^2)	precipitation (mm)	temperature (0^C)	Specific flow q_{SR} ($l/s*km^2$)	Q_{SR} (m^3/s)	Annual outflow coefficient K	METHOD
I	Umaški potok and coastal springs between Mirna and Dragonja	100,14	950	13,4	7,03	0,70	0,23	Langbein
II	Dragonja	218,81	1049	12,4	10,81	2,37	0,33	Langbein
III	Bulaž spring	104,38	1251	10,9	17,24	1,80	0,43	Langbein
IV	Mirna catchment (except Bulaž)	602,55	1235	11,4	16,79	10,12	0,43	Langbein
III+IV	Mirna River catchment	706,93	1238	11,3	16,85	11,92	0,43	Langbein
V	Rižana spring catchment	244,39	1522	9,5	26,10	8,10	0,54	Langbein
	USING OF LANGBEIN METHOD ON THE WHOLE ANALYZED CATHMENT AREAS							
VI	Kvarner Bay catchment	365,80	1937	9,3	39,24	14,35	0,64	Langbein
VII	Reka catchment	188,97	1891	7,5	40,11	7,58	0,67	Langbein
VIII	Western part of Rijeka	141,88	2026	10,5	40,57	5,76	0,63	Langbein
IX	Rijeka catchment (Rječina, Zvir and Martinšćica)	395,42	2669	6,9	65,31	25,82	0,77	Langbein
	USING OF COMBINED METHODS OF LANGBEIN AND TURC							
VI	Kvarner Bay catchment	365,80	1937	9,3	41,57	15,21	0,68	Langbein &Turc
VII	Reka catchment	188,97	1891	7,5	42,20	7,97	0,70	Langbein & Turc
VIII	Western part of Rijeka	141,88	2026	10,5	43,08	6,11	0,67	Langbein & Turc
IX	Rijeka catchment (Rječina, Zvir and Martinšćica)	395,42	2669	6,9	69,20	27,36	0,82	Turc

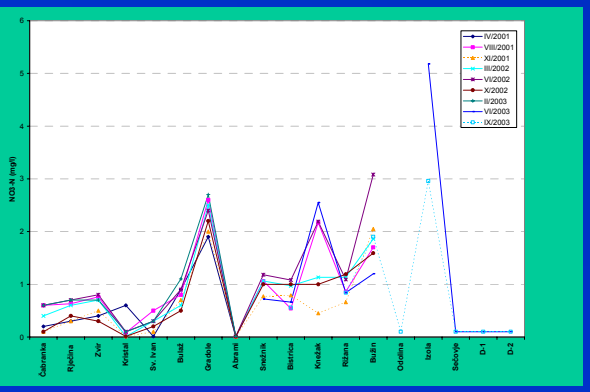
Hydrogeochemical research

- very important to establish simultaneous and standardized monitoring and sampling, analytical working and common interpretation of Slovenian and Croatian researchers

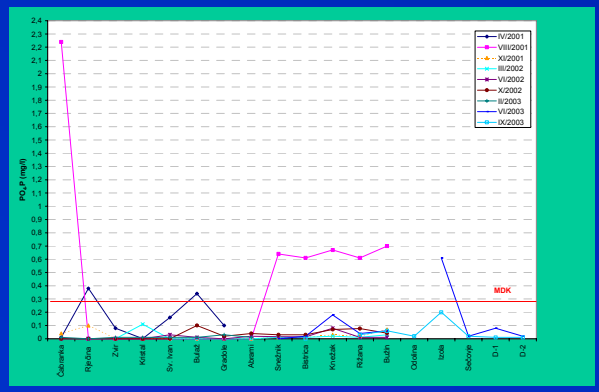
Groundwater quality

- almost all springs in research area in Croatia are below maximum allowed concentration for drinking waters → but on some springs there were indications of anthropogenic impact (higher concentrations of nitrates on Gradole and Bužin spring)

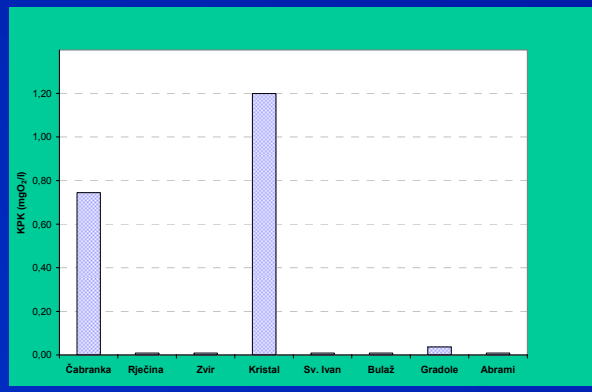
- Gabrijeli and Bužini →increasing bacteriological composition and temporary higher values than maximum allowed value for turbidity, microorganism, mineral oil and fecal streptococcus



concentration of nitrate



orthophosphate



chemical oxygen consumtion

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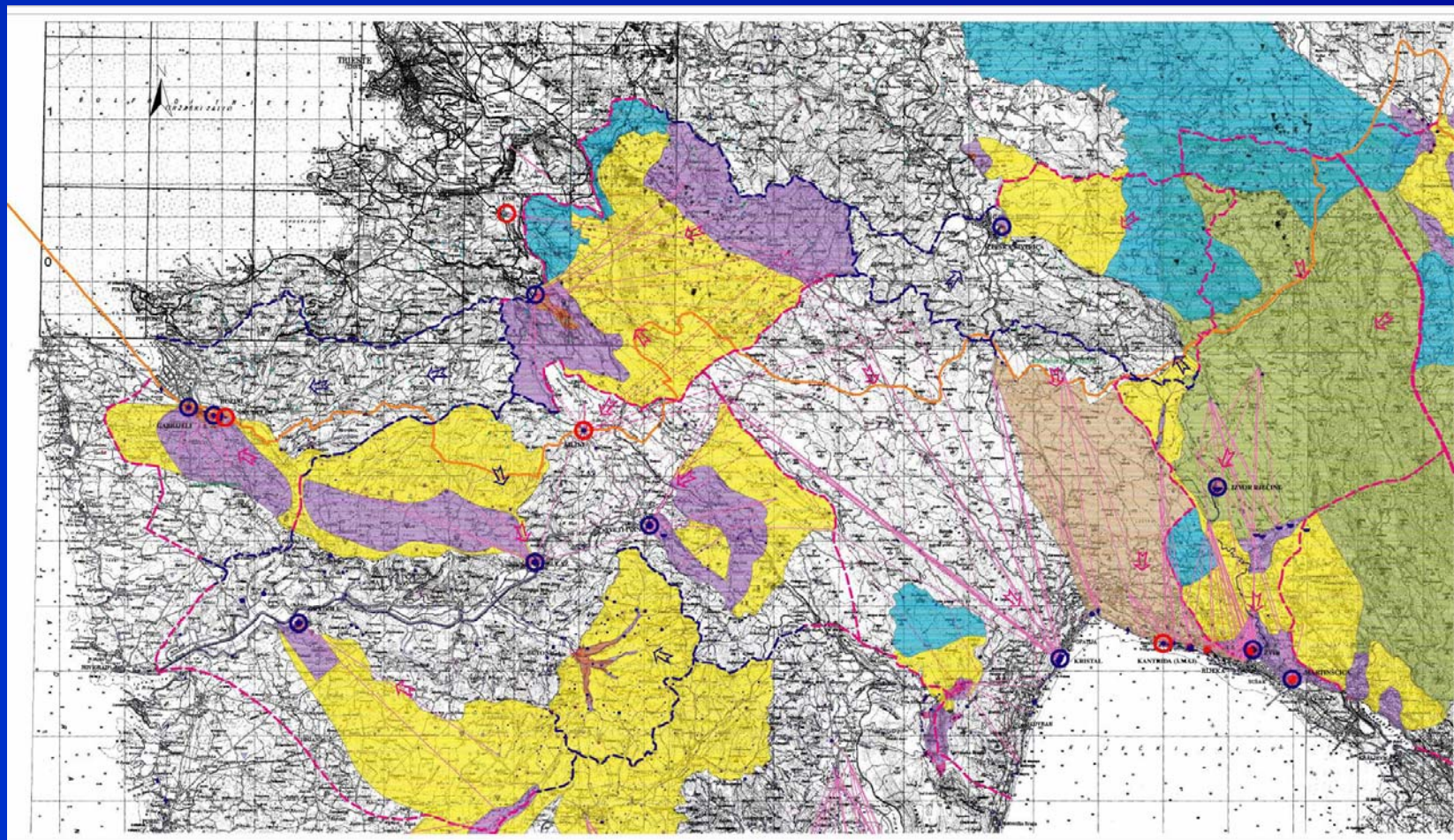
Protection zones analyses

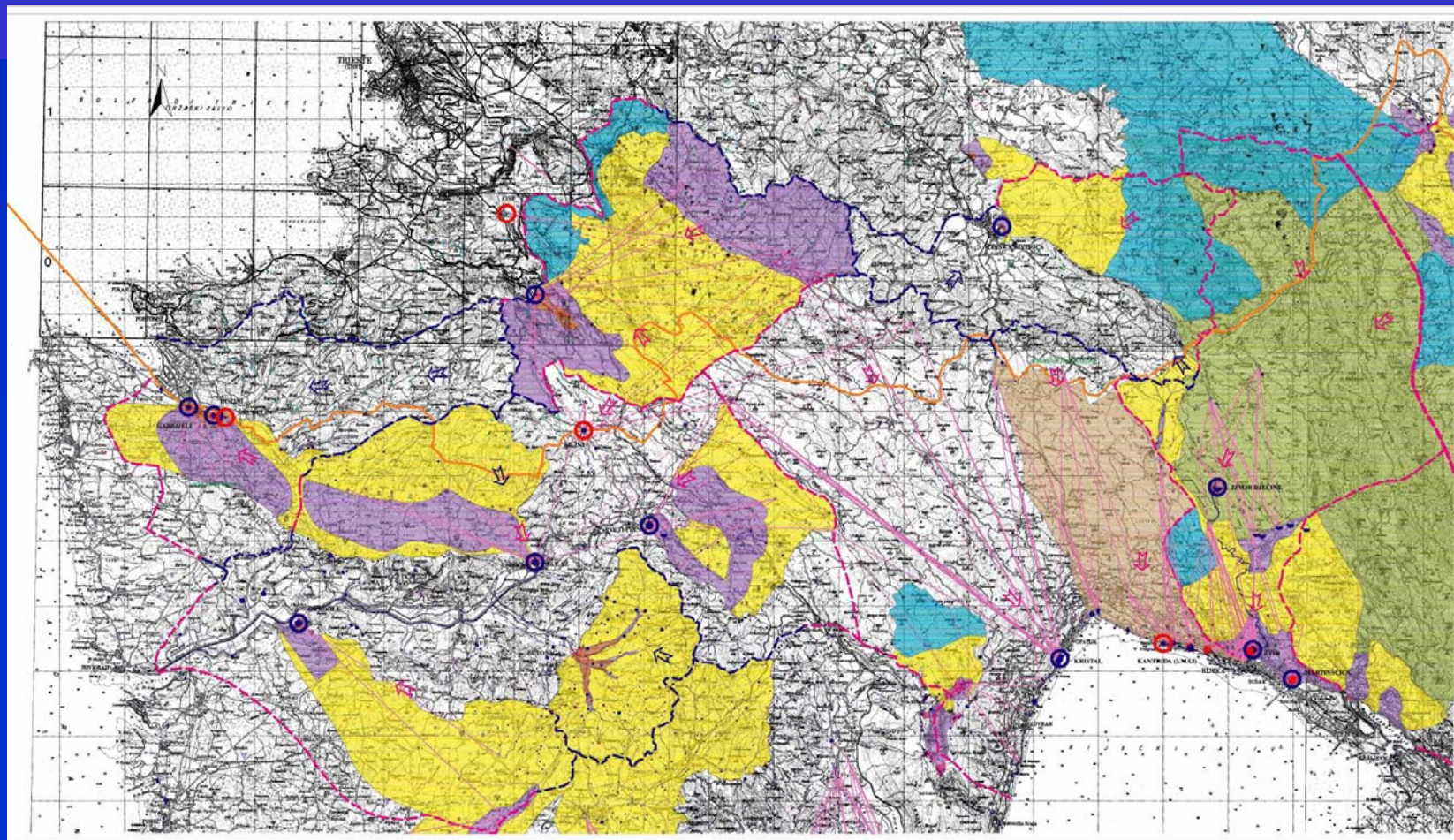
- analyzed in 2003 valid protection zones and their relation to proposal of novelation of protection zones (RGN, 2003; recent valid protection zones)
- some problems existed and overlapping of protection zones in Croatia and Slovenia existed
  - mostly is the problems of old protection zones (valid before independency of Croatia and Slovenia)
  - today zones are defined in each country until the state border → not good because the most vulnerable places has to be protected regardless in which country they are



NECESSARY:

→ third phase of the project is MISSING → vulnerability map, hazard map and risk map → will delineate most vulnerable parts of catchments and parts of the catchments where the some improvement programs are needed

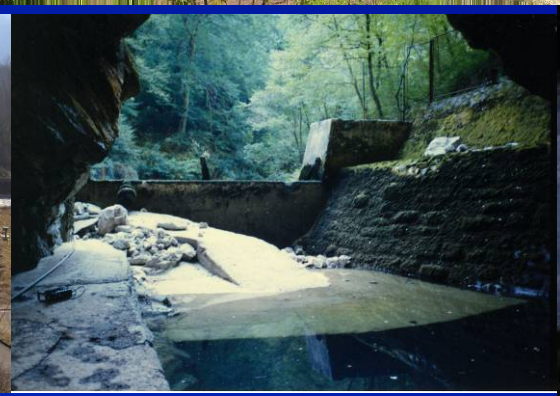
→ after preparation of new protection zones map in the area of northern Istria some overlapping has to be emphasized and due to the protection measures level the protection has to be established also in neighbouring country → DECISION HAS TO BE MADE ON THE COUNTY LEVEL FOR THE ZONES TO BECOME LEGAL !!!



What has to be done in the third phase to finish the project for the area between Kvarner and Trieste Bay ??

- continuation of hydrogeological measurements on springs (T, CND)
  - Bulaž, Sveti Ivan, Rječina, Zvir, Čabranka, Kristal, Gradole, Mlini
- tracing test in the border area of catchments Rižana, Sveti Ivan and Kvarner Bay
- processing of quality and quantity data and definition of trends
- final hydrological research on the Slovenian side
- Hydrogeochemical research
  - definition of residence time in aquifers
  - detachment of basic flow from overflow (separation of hydrograms by stabile isotopes)
  - hydrogeochemical and isotope-hydrological model
- vulnerability, risk and hazard map for all catchment areas in research area of Croatia
- proposal of permanent monitoring of quality and quantity of transboundary water bodies
- proposal of changing of protection zones according to the protection measures in Croatian and Slovenian regulations
- Common GIS of all data

University of Zagreb
Faculty of Geotechnical Engineering



Thanks for Your attention !!!

ranko.biondic@zg.t-com.hr