1. PREFACE (A. KRANJC)

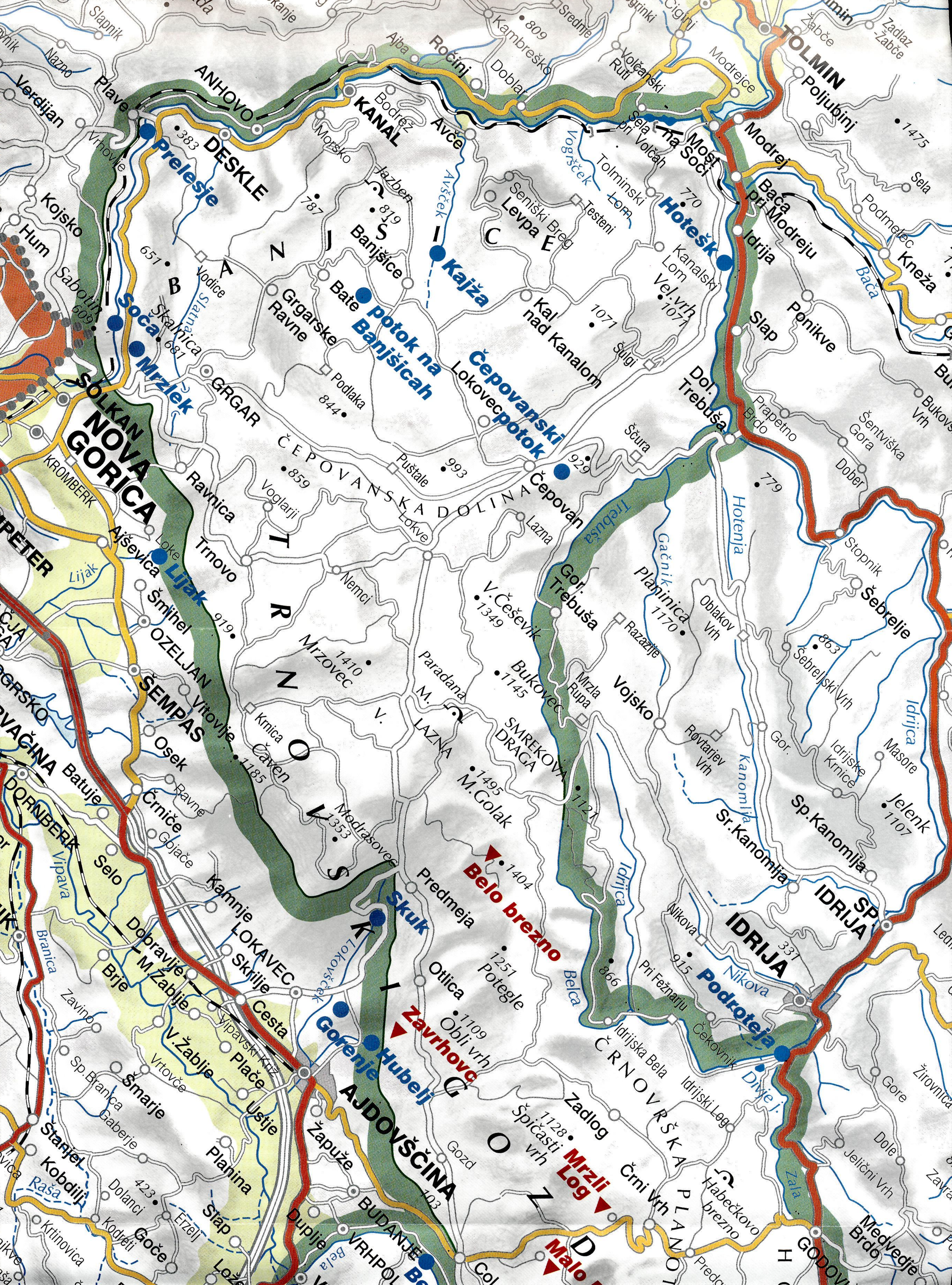
During the 6th SWT at Karlsruhe (1992) the proposal of the participants from Slovenia to organise the next, the 7th SWT in Slovenia, was generally approved. In the autumn of the same year was organised a meeting in Slovenia; a group of experts visited the karst plateau Trnovsko-Banjška Planota conducted by the Slovene specialists who provided appropriate explanations. The final decision to accept the Slovenian proposal passed in Ljubljana.

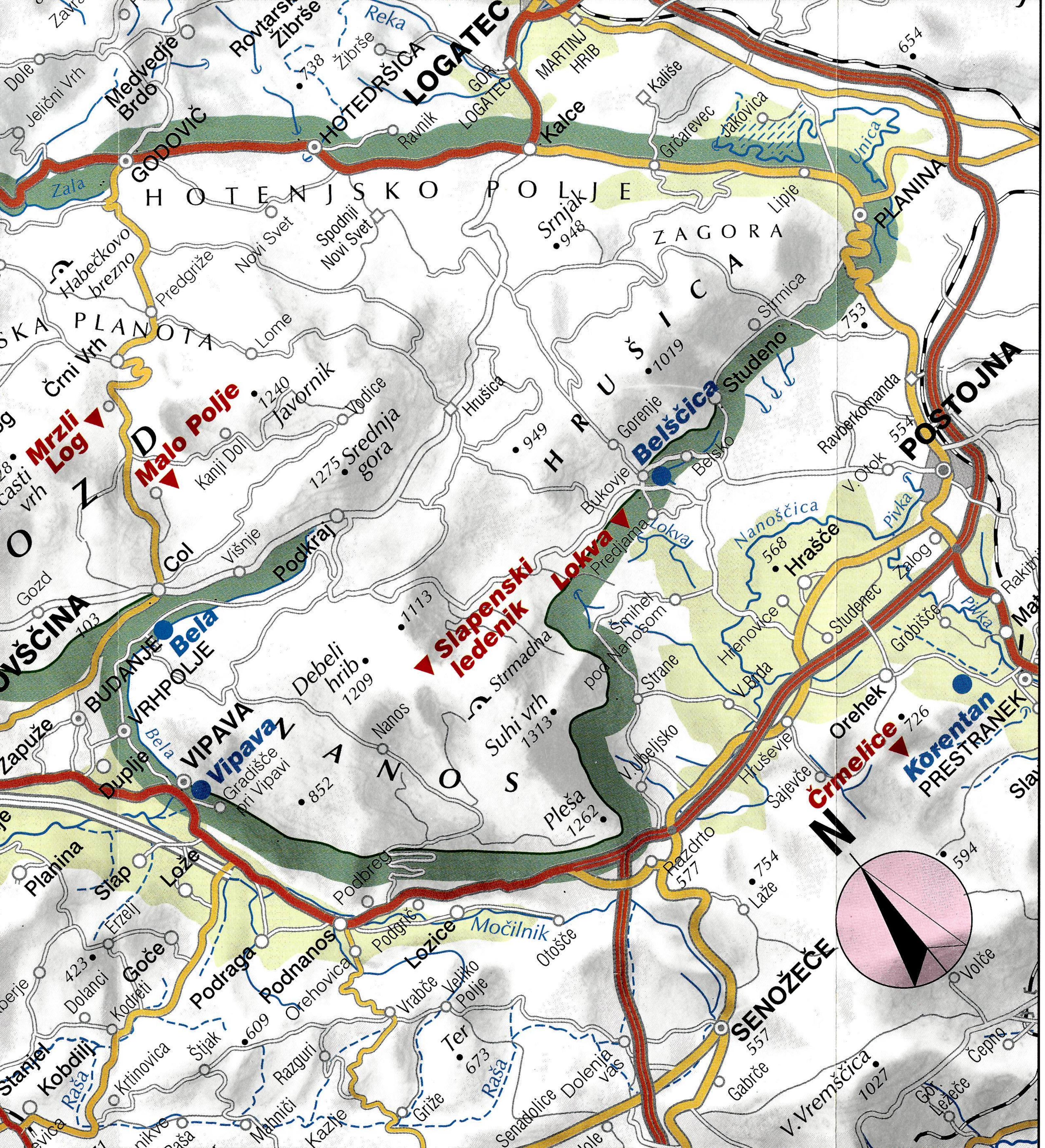
Immediately three committees were designed: the preparatory one (consisting of the members of ATH), the research council (for the research project at Trnovsko-Banjška Planota), and the organising committee. Research activities required for the symposium were carried out in the frame of the international project "Transport of pollutants in karst: tracers and models in different aquifers - field research on Trnovsko-Banjška Planota 1992-1995". Project was mainly financed by the Slovene Ministry of Science and Technology and Ministry of Environment and Physical Planning and, occasionally, by communes and water organisations in the surroundings of Trnovsko-Banjška Planota. The research work including both the field and the laboratory work of the research associates not living in Slovenia, was financed by their organisations or by themselves. More than 50 researchers of various professional profiles from 16 organisations from Austria, Germany and Slovenia co-operated at the research work of the mentioned project. Due to finances, to large number of participants, to their fluctuations, and to questions, opened during the investigations, the course of the research as well as some aims and targets had to be changed, but the essential of the initial plan was kept all the same. To minimise co-ordination questions regular "Preparatory Meetings" were held twice a year in different countries and places, where about 30 researchers gathered every time.

As the editor of Acta carsologica and as the Organising Secretary of the 7th SWT I am very glad that both the Classis IV of the Slovene Academy of Sciences and Arts with Editorial Board and the ATH decided that the results of Trnovsko-Banjška Planota investigations will be published in Acta carsologica, with special title "Karst Hydrogeological Investigations in south-western Slovenia". Due to vast number of very different researches, of large amount of data gathered, of great number of authors and of various ways and methods of data interpretation, the preparation of the material for this volume was hard and complicated. But the results prove that it was worth the work and troubles. The editor is deeply grateful, and owes a great debt of thanks to the 7th SWT Editorial Board and to the colleagues from the Karst Research Institute.

Map. 1: Visoki Kras (The High Karst) plateaux in western Slovenia (p. 12).
Map 2: Trnovsko-Banjška Planota, an overview map (Inštitut za geodezijo in fotogrametrijo FGG, Ljubljana) (p. 13).

BANJŠICE
TRNOVSKI GOZD
HRUŠICA
NANOS
KRAS
Soča
Idrijca
Vipava
Bela
Unica
Nanoščica
Pivka
Reka
Selška Sora
Poljanska Sora
Merilo 1 : 450.000
© Geografski inštitut ZRC SAZU


TOLMIN
Poljubinj
Modrej
Most na Soči
Bača pri Modreju
Idrija
Hotešk
Slap
Ponikve
Kneža
Dol. Trebuša
Šentviška Gora
Dober
Stopnik
Šebrelje
Sebreljski Vrh
Gor. Trebuša
Trebuša
Hotenja
Gačnik
Plaminica
Oblakov Vrh
Razazje
Vojsko
Rovtarjev Vrh
Kanomlja
Idrijske Krnice
Masore
Jelenk
Sp.Kanomlja
Sr.Kanomlja
SP. IDRIJA
IDRIJA
Nikova
Podroteja
Pri Fežnarju
Čekovnik
Idrijska Bela
Idrijski Log
ČRNOVRŠKA PLANOTA
Črni Vrh
Habečkovo brezno
Zala
Medvedje Brdo
GODOVIČ
Žirovnica
Gore
Dole
Jelični Vrh
Belca
Idrijca
Mrzla Rupa
SMREKOVA DRAGA
Bukovec
V.Češevik
Paradana
M. LAZNA
M.Golak
Belo brezno
Predmeja
Otlica
Potegle
Obli vrh
Zavrhovc
Mrzli Log
Špičasti vrh
Zadlog
Gozd
AJDOVŠČINA
Gorenje
Hubelj
Skuk
Lokovšček
Modrasovec
Čaven
Krnica
Mrzovec
Nemci
TRNOVSKI GOZD
Trnovo
Ravnica
Voglarji
ČEPOVANSKA DOLINA
Lokve
Lazna
Puštale
Čepovan
Šcura
Čepovanski potok
Lokovec
Kal nad Kanalom
Vel.vrh
Kanalski Lom
Šulgi
Tolminski Lom
Testeni
Seniški Breg
Levpa
BANJŠICE
Banjšice
Bate
potok na Banjšicah
Kajža
Avšček
Vogršček
Sela pri Volčah
Volčanski Ruti
Modrejce
Avče
Bodrež
Morsko
Jazben
KANAL
Ročinj
Ajba
Doblar
Kambreško
Srednje
ANHOVO
DESKLE
Prelesje
Plave
Vrhovlje
Verdijan
Kojsko
Hum
Sabotin
Vodice
Slatna
Škalnica
Soča
Mrzlek
GRGAR
Grgarske Ravne
Podlaka
SOLKAN
NOVA GORICA
KROMBERK
ŠEMPETER
Lijak
Loke
Ajševica
Šmihel
OZELJAN
Vitovlje
ŠEMPAS
Osek
Ravne
Črniče
Gojače
Batuje
DORNBERK
Vipava
Selo
Kamnje
LOKAVEC
Skrilje
Cesta
Dobravlje
M.Žablje
V.Žablje
Vipavski Križ
Plače
Ustje
Brje
Zavino
Branica
Sp.Branica
Vrtovče
Šmarje
Gaberje
Štanjel
Kobdilj
Raša
Dolanci
Kodreti
Krtinovica
Goče
Erzelj
Slap
Planina
Žapuže
Budanje
Duplje
Vrhpolje
Col
Bela
Nazno
Slapnik
Malo
1475
Sela
Podmelec
770
1071
1071
779
863
1170
1107
331
915
866
1121
1145
1349
1410
1495
1404
1251
1109
1128
103
1185
1353
919
859
993
929
844
681
651
609
787
819
383
423
809

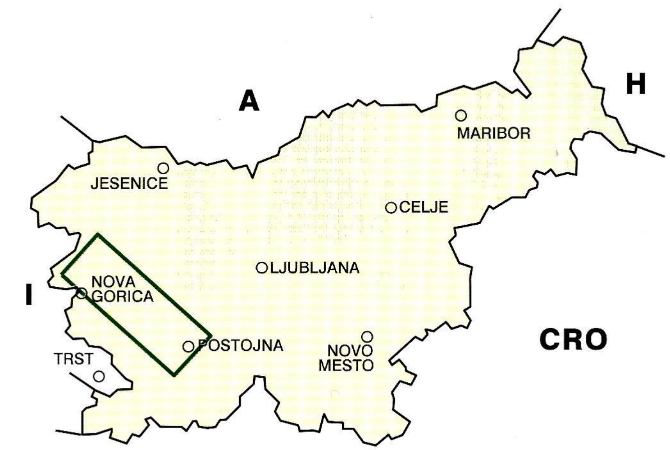


PREGLEDNA KARTA TRNOVSKO-BANJŠKE PLANOTE

GENERAL MAP OF TRNOVSKO-BANJŠKA PLANOTA

MERILO 1 : 125 000 0 km 1 2 3 4 5

- ▼ INJICIRNO MESTO / INJECTION POINT
- ● MESTO VZORČENJA / SAMPLING POINT
- MEJA OBMOČJA RAZISKOVANJA / BORDER OF RESEARCH TERRITORY
- DRŽAVNA MEJA / NATIONAL BOUNDARY



Viri: Kartografska osnova: Karta Republike Slovenije - izrez v merilu 1 : 125 000. Ostali podatki: Inštitut za raziskovanje krasa ZRC SAZU, Postojna.

Kartografska in računalniška izvedba ter tisk: Inštitut za geodezijo in fotogrametrijo FGG, Ljubljana, Slovenija, 1997

2. NATURAL BACKGROUND

2.1. PHYSICAL GEOGRAPHY OF TRNOVSKO-BANJŠKA PLANOTA (P. HABIČ)

The test area of the 7th Symposium on Water Tracing includes a part of High Dinaric Karst in the western Slovenia; it is bounded by the valleys of the rivers Soča, Idrijca, Vipava and Pivka. From the Soča river in the north-west up to the sinking karst rivers Pivka and Ljubljanica in the south-east, there are, within otherwise uninterrupted landscape of the High Karst, morphologically slightly different areas as for example Banjšice, Trnovski Gozd, Črnovrška Planota, Hrušica and Nanos. This area of the High Karst is usually referred to as Trnovsko-Banjška Planota (TBP).

The belt of the High Karst between the northern border of the Adriatic Sea and eastern foot-hills of the Southern Limestone Alps narrows the most in the western Slovenia. A block of carbonate rocks belonging structurally to the Dinaric Mountains, is from 10 to 15 kilometres wide and about 50 km long, covering roughly 700 km^2 of the surface. Deeply karstified Cretaceous and Jurassic limestones and Triassic dolomites prevail; towards the north-west they underlie younger, mostly Eocene flysch rocks. Flysch encompasses karstified limestones of Trnovski Gozd and neighbouring plateaux in the southern and eastern side thus acting as a partial, hanging hydrogeological barrier. In the north the High Karst is surrounded by mostly impermeable Middle and Lower Triassic, partly also Permian and Carboniferous rocks. The valleys of the Belca, Idrijca, Trebuša, Hotenka, Kanomlja and Zala rivers are cut into these rocks. In their river basins, specially on the Vojsko Plateau, there are some sinking streams, caves and karst springs.

For several reasons this final edge of the High Dinaric Karst between the Vipava valley and the foot-hills of the Julian Alps dissected by the valleys of the Idrijca and Soča rivers was chosen as a test area of Association of Tracer Hydrology for the preparation of the 7th International Symposium on Water Tracing.

From a physiographic and hydrogeological point of view this is a relatively well-confined mountainous karst area bounded by lower, non-karstic margin regions from almost all the parts. The rainfall from this entire area sinks into deep karst aquifer feeding abundant karst springs located at its foot along the tributaries of the Idrijca, Vipava, Soča and Ljubljanica rivers. Smaller sinking streams may only be found in the western and eastern side of Trnovski Gozd. In the valleys on its border major karst springs are distributed, such as Mrzlek, Avšček, Kajža and Vogršček along the Soča; Lijak, Hubelj and Vipava along the Vipava; and Divje Jezero, Podroteja and Hotešk along the Idrijca. The rivers Idrijca, Soča and Vipava belong to the Adriatic water system, and Ljubljanica to the Black Sea basin. Thus the underground watershed between the Adriatic and Black Sea is found within the High Karst.

Karst springs in the border of the High Karst are captured for water supply of villages in Vipava valley, on Goriško and along the Soča and Idrijca. As these are the only abundant sources of drinking water in western Slovenia their karst background must be protected against pollution. Due to hydrographical complexity within this karst aquifer, it has not yet been possible to define the extent, size and capacity as well as threat to each karst spring separately. For the same reason, protection measures were not introduced separately but for the area as a whole.

Previous hydrological and geological researches indicated the main drainage directions of karst waters, but a series of unsolved hydrological questions remained. To solve these would provide better exploitation and better protection of water resources.

Intensive karstification is evidenced by solution channels, runnels and karren on bare rocky surfaces. There are numerous, karst dolines and ouvalas, more than 100 m deep, and many caves and shafts, some more than 300 m deep. In the ice-cave Velika Ledena Jama v Paradani cavers have reached a depth of almost 700 m. This external image of intensive karstification is complemented by hydrological indicators. After rainfall the discharge in springs increases rapidly and also decreases relatively fast.

Deep karstification is shown also by the location of karst springs in the bottom of the valleys and by their deep siphon outflow passages; at Mrzlek they are below the Soča riverbed, in Divje Jezero cave divers reached more than 100 m below the Idrijca valley without getting to the end of this typical Vauclusian spring.

Karst relief dominates over the entire area. Among the elevations typical cone-shaped features prevail; isolated peaks are distributed in levels over the central ridge but they appear also on lower, more flattened borders. Between the elevations there are deep dry valleys with dolines. Such a relief neutralises the superficial watershed. Deep fluvial valleys are cut on the border of the High Karst plateau only. The bottoms of river valleys are from 50 to 300 a.s.l. and this is also the altitude where are the lowest probable free surface springs.

Central karst plateaux reach altitudes from 600 to 1500 m a.s.l.; the slopes of the valleys are steep and high. The south-western edge of the High Karst from Razdrto past Vipava and Ajdovščina up to Gorica is nearly vertical and at the foot of limestone walls there are recent and fossil scree slopes above the Vipava valley.

Carbonate rubble and breccia on the flysch base represent smaller porous aquifers. Calcarenite, breccia and conglomerate inliers of carbonates in Eocene flysch along the Soča to the western border of Banjška Planota represent aquifers of karst and fissure porosity of local importance. In the eastern and western side of Trnovski Gozd, specially on Banjšice, along northern border of Nanos, near Črni Vrh and on Pivka they contribute a part of waters to the central karst aquifer which is seen also in the hydrochemical properties of related springs.

Orographic properties of the surface are controlled by geological structure and by younger tectonic movements and by geomorphologic development from the Middle Pliocene onwards. The main ridge of the High Karst trends from north-west to south-east, but it is slightly displaced towards the north-east border. The highest elevations in the central part of Trnovski Gozd are the peaks named Veliki Golak (1495 m) and Mali Golak (1480 m). On the southern and western border of the main ridge of Trnovski Gozd there are some marginal shelves preserved as remains of former, broader planations. There were found the remains of fluvial gravel deposited by waters from neighbouring Pre-alpine valleys when the rivers flowed over the actual High Karst towards the Adriatic Sea.

Transverse and also longitudinal dry valleys are downcut into an old, levelled surface. The most expressive is the valley of Čepovan, 20 km long and more than 300 m deep. It widens in its southern part and passes into a smaller karst margin polje near Grgar (280 m). The lowest exit of Grgar lies in the continuation of a dry valley on Preval, 336 m a.s.l. between Sveta Gora (681 m) and Škabrijel (546 m) which is almost 300 m above the present riverbed of the Soča near Gorica. The bottom of the dry valley reaches the highest point in the north of Čepovan, at 620 m and it lowers to 540 m in its northern border near Vrata to remain hanging in a steep edge, 270 m above the Idrijca riverbed. The valley of Čepovan is a natural border between Banjšice to the west and Trnovski Gozd to the east.

The highest main ridge of Trnovski Gozd between Paradana, Mala and Velika Lazna and Krnica is cut by a transverse dry valley. Similar are transverse valleys in the south-eastern side of Trnovski Gozd between Mala Gora and Kovk and between Črni Vrh and Col. Transverse dry valleys are important for traffic and they are used for local and forest roads. However, main traffic roads lead along the High Karst by the valleys of the Idrijca and Vipava. An important cross traffic road passes along the western border of the High Karst by the Soča valley between Gorica and Tolmin.

There is little soil on the karstified limestones of Trnovski Gozd (The Wood of Trnovo) and wood prevails there as its name indicates. The rather humid mountainous climate is favourable for fir and beech trees. These two species comprise Vast fir-beech forests. On the highest ridge of Trnovski Gozd the trees are exposed to strong wind, the bora, and therefore the trees are lower with typically shaped branches bent and blasted by the wind. The highest Golaki displays the features of upper tree limit. Instead of beech, dwarf pines appear there. This species may also be found at the bottom of deep karst dolines where cooler air accumulates. In these frost-places the vegetation belts are inversely distributed. A belt of beech is followed downwards by a belt of spruce and at the bottom of doline there is a belt of dwarf pines; in the deepest karst dolines, in particular at the entrance to ice-caves, a belt of mountainous meadows without trees may even appear. These vegetation specialities of Trnovski Gozd very early aroused the attention of experts. Forest management, that is regulation and protection of karst woods accompanied by a suitable exploitation, has a several hundred years long tradition.

From a climatic point of view the High Karst is a typical transitional area between the Mediterranean climatic influences of the Adriatic and the continental and Alpine climatic region of inner Slovenia. The high karst ridge is a sort of barrier against the frequent south-western wind that brings the humidity from Mediterranean. As humid air lifts over the first mountainous barrier it releases heavy precipitation. Thus the central part of Trnovski Gozd receives annually more than 3000 mm, and the maximal daily rainfall may even surpass 300 mm. The mean annual temperature varies from 7 to 9° C. The mean air temperature in January is about -2° C, and in July about 16° C. On Golaki where the upper tree limit is at 1440 m a.s.l. the mean air temperature in July is about 12° C. In the cold half of the year cool air from the south-eastern side frequently passes from the High Karst towards the Mediterranean; this occurs as a strong wind in gusts, called the bora, which may reach more than 200 km/h in the Vipava valley and in dry transverse valleys. Relatively early in autumn snow falls on the peaks of Trnovski Gozd and in spite of some thawing during the winter it may be found in deep dolines up to May, and in caves with large entrances throughout the summer. In many ice caves the local people used to cut out the ice and transport it to the valley and to Triest and Gorica to chill food and drink in times when electric refrigerators did not yet exist.

On the border of Trnovsko-Banjška Planota and on Nanos the trees were cut down. At first the land was used for pastures, and later permanent settlements grew. The most dense population is found on Banjšice as far as Grgar to the south and Čepovan and Lokovec to the north. On flysch rock there is more soil which favours agriculture. On Lokovec north from Čepovan and around Trnovo, Voglarji and Lokev south from the Čepovan valley there are less cultivated surfaces. Slightly more soil is provided by disintegrated cherts that occur as lens-shaped inliers in Cretaceous and Jurassic limestones. The same may be said for the inhabited south-eastern part of Trnovski Gozd where modest farms are scattered on the border of the plateau from Predmeja, over Otlica, Kovk, Gozd and Križna Gora to Col, Podkraj and Vodice.

Some scattered farms may also be found to the north of the main ridge of the High Karst near Zadlog, Črni Vrh and Lomi. In the western border of Nanos the former Vast pastures are more and more overgrown by vegetation and only two farms remain there. Sparse population and low agricultural activity are relatively favourable to protecting the karst aquifer. But, together with endeavours to protect karst waters, there exists a wish to increase the economic development of these villages. In the past they mostly survived by cattle breeding and forestry. Later local people travelled to work in the valleys, and in factories in Gorica, Ajdovščina, Vipava and Idrija; in recent years they try to get work at home in craft and smaller industries. Former rainwater reservoirs are replaced by piped water supply; water is pumped from lower lying springs and increased quantities of waste water flow mostly untreated, underground. The economic development on Trnovsko-Banjška Planota must as soon as possible be co-ordinated with protection of this important karst aquifer which is capable of supplying the larger and more inhabited valley area of the High Karst around Vipava, Gorica and Idrija with drinking water.

2.2. HYDROLOGY (N. TRIŠIČ)

2.2.1. Basic description of the area

The area of the Trnovski Gozd, the Banjšice, the Nanos, and a part of the Hrušice plateaux hydrologically belongs to the Soča river basin extending over approx. 2000 km^2 in Slovenia, which is almost one tenth of Slovenian territory (Fig. 2.1). The river basin stretches from the central part of the Julian Alps over the pre-Alpine mountains, the territories of Cerkljansko and Idrijsko, the high karst area of the Nanos and the Trnovsko-Banjška Planota, the flysch area of the Vipavska Dolina, to the level gravel-sand accumulation of the Soča and its tributaries on Italian side. In Slovenia, the Soča river basin borders on the Upper Sava river basin, and the Ljubljanica and the Timava river basins, and on Italian side, on the Tagliamento river basin (Fig. 2.1).

The strongest tributaries of the Soča are two left tributaries, the Idrijca and the Vipava, which drain the area of Idrijsko and Cerkljansko, the high karst area of the Trnovsko-Banjška Planota, the Nanos, a part of the Hrušica, and the flysch area of the Vipavska Dolina valley. The entire area can be studied as two separate hydrological units, one of which as the catchment area of the karstic springs of the Vipava, and the other one as the catchment area of the karstic springs at the rims of the Trnovsko-Banjška Planota.

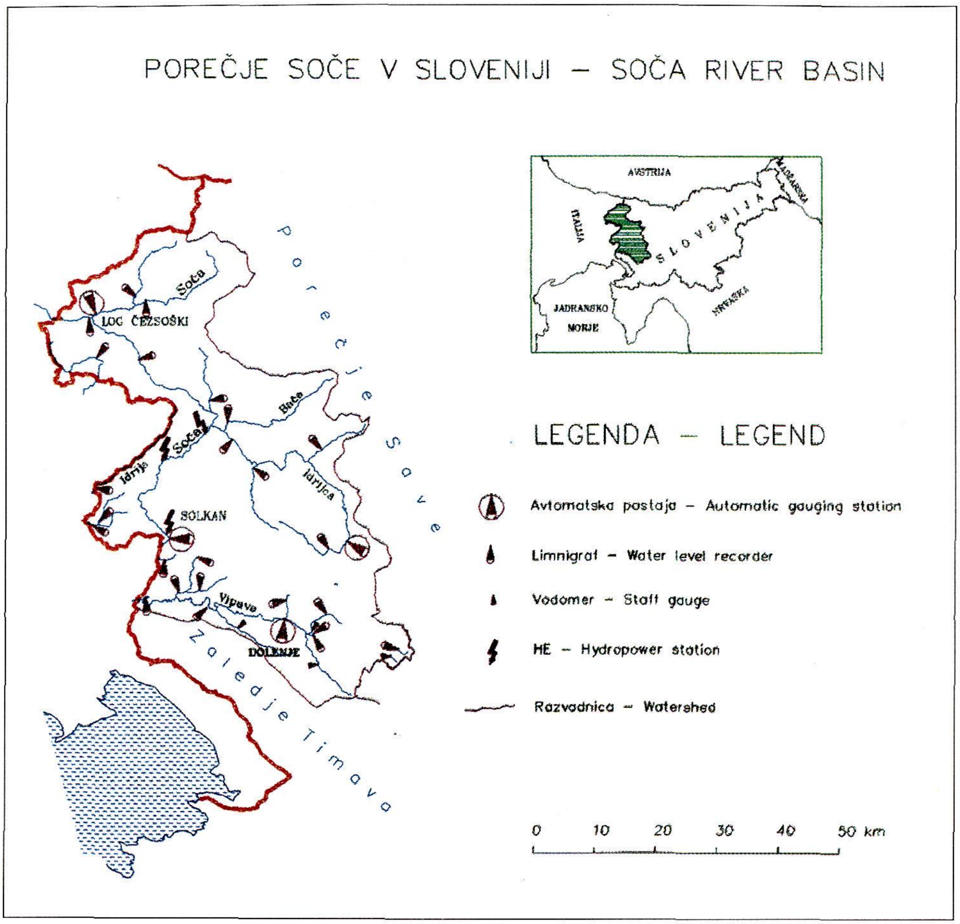


Fig. 2.1: The Soča river basin.

2.2.2. The springs of the Vipava

The karstic part of the catchment area of the Vipava springs stretches over the entire area of the Nanos and a part of the Hrušica, while the part with surface drainage stretches over the flysch river basins of the ponor streams in the basin of Postojnska Kotlina which gravitates towards the Vipava springs.

The size of the catchment area is not exactly determined due to the watershed between the Vipava and the Ljubljanica on the area of the Hrušica where it assumes the karstic features. For the river basin of the Pivka, a partial discharge of its waters to the Vipava springs has been established, which represents the bifurcation between the Adriatic and the Black sea basins

(P. HABIČ 1989). At high waters, the bifurcation was also noticed in the area of the Osojščica ponor stream (HABE 1976). A partial discharge of the Osojščica waters ends in the Belščica which runs towards the Vipava springs, and the other part of its waters drain to the Pivka, i.e. towards the Black sea. The watershed against the Trnovski Gozd is represented by the flysch part of the Bela riverbed, and also the watershed against the Močilnik is surface running and reliable. The catchment area of the Bela stretches over approx. 2 km^2. The low and medium waters of the Bela already sink in the area of Sanabor; only the high water waves run on the surface to the Vipava. The Vipava-0VP Vipava gauging station is located about 500 m downstream of the Vipava springs. This profile includes the discharges of all the permanent springs of the Vipava, and probably, also the medium and low waters of the Bela which sinks under the village Sanabor (Tab. 2.1). Only the high waters of the Bela and the discharges of periodical springs between Vipava (town) and Vrhpolje which are only active at high waters and join the Vipava river downstream from the town, are not included in the gauging profile.

Tab. 2.1: The Vipava-LP Vipava: the 1961-90 characteristic discharges and their ratio (m^3/sec).

Q_{min}	Q_{mean}	Q_{max}	Q_{min} : Q_{mean} : Q_{max}
0.727	6.78	70.0	1 : 9 : 96

Tab. 2.2: The average annual precipitation heights in the catchment area of the Vipava springs (mm).

Nanos-Ravnik	Podkraj	Hrušica	Razdrto	Slap p. Vipavi
1834	2179	2088	1678	1513

The total size of 125.25 km^2 of the catchment area of the Vipava springs also includes about 2 km^2 large catchment area of the Bela. Yet, the data on discharges at the gauging station do not comprise the discharges of the Bela. Since also the springs between Vipava (town) and Vrhpolje are active during the high water situation, the datum on the maximum discharge of the Vipava must be slightly higher than the quoted 70 m^3/sec. Besides, the quoted datum on the size of the catchment area of the Vipava springs is - considering the data on precipitation heights (Tab. 2.2) and runoff - also too small (Tab. 2.3).

Tab. 2.3: The 1961-90 data for the Vipava-LP Vipava profile.

F km²	Precipitation Q (m³/sec)	Evaporation (m³/sec)	Precip. Runoff (m³/sec)	Q_s (m³/sec)	difference (m³/sec)
125.25	7.98	2.51	5.47	6.78	+1.3

Three sides of the catchment area of the Vipava springs border on flysch layers (i.e. the areas of the Močilnik, the Pivka and the Bela), therefore, the only possible way of the catchment area expansion is the area of the Hrušica, at the cost of the catchment area of the Ljubljanica. Mathematically, the catchment area of approx. 150 km² would correspond with the data on precipitation (2024 mm) and discharge (6.78 m³/sec).

A time distribution of the mean monthly discharges shows that two annual maximums occur, the first in April and the second in November, while the lowest mean discharges occur in July and August (Fig. 2.2 and Fig. 2.3). The first maximum of the monthly mean discharges occurs in April and it is higher than that of November, in spite of the fact that precipitation are more abundant in autumn; this is the result of snow melting in the spring months.

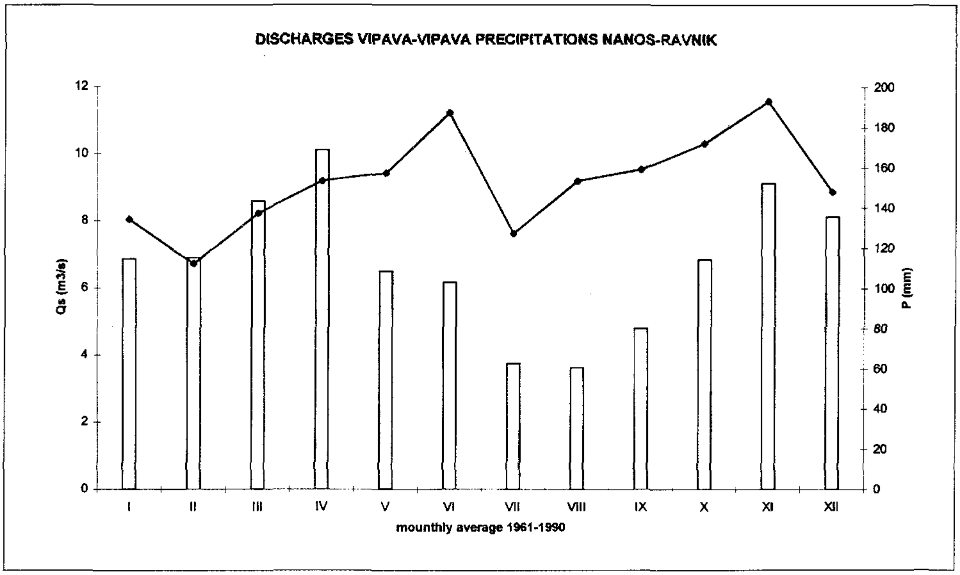


Fig. 2.2: The Vipava monthly mean discharges and monthly mean precipitation in the recharge area (1961-1990).

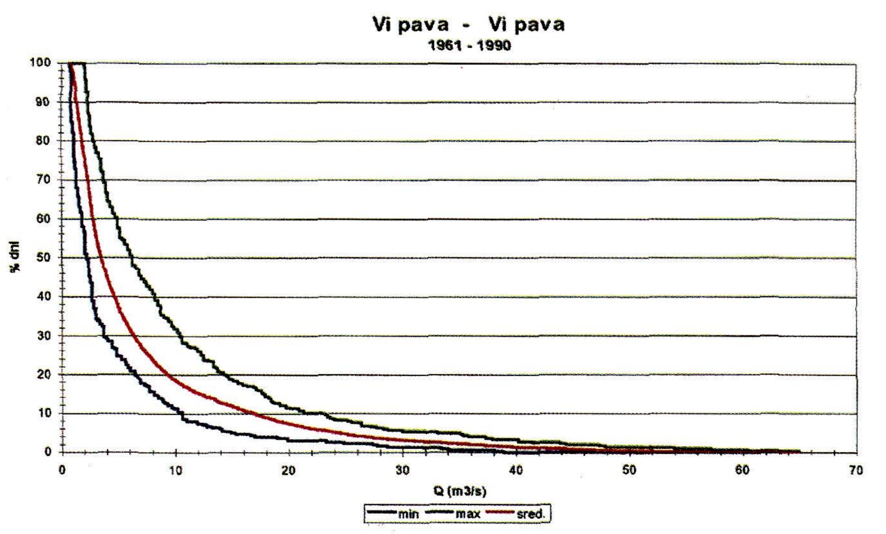


Fig. 2.3: The lines of the 1961-90 discharge duration of the Vipava at the gauging station Vipava.

2.2.3. The area of the Trnovsko-Banjška Planota

The area of the Trnovsko-Banjška Planota which can roughly be limited with the Hrušica area in the east, the Soča river in the west, the Vipavska Dolina in the south, and the valley of the rivers Trebuša, Belca and the Upper Idrijca in the north, stretches over approx. 490 km^2 of the territory. The area is bordered, except for the Hrušica area, with the steep and precipitous slopes. A permanent surface hydrographical network is only developed in the western part of the Banjšice which drains towards the Soča. This area of the so-called hanging barrier stretches over approx. 90 km^2 (see Chapter 2.6) The remaining central part consists of the high karst plateau where the precipitation immediately enter the unsaturated part of the karstic system where the vertical component of percolation prevails. Without the surface part of the catchment area of the Idrijca and the Trebuša, the area of the high karst plateau of the Trnovski Gozd, the Banjšice, the Črnovrška Planota, and a part of the territory towards Hotedrščica, stretches over approx. 350 km^2. The foregoing karstic areas drain entirely into the karstic springs which are arranged at the rims of these plateaux. The largest water quantities are drained by the springs Divje Jezero, Podroteja, Mrzlek, Lijak and Hubelj, and a minor share by the spring Hotešk ob Idrijci and the springs in the Soča valley (Vogrščck) and the Avščck valley (Bolterjev Zdenc and Kajža).

The gauging profiles for the registration of discharges from the karstic part of the plateau are fixed at the following locations:

Idrijca - Podroteja
Lijak - Šmihel
Hubelj - Ajdovščina

Idrijca - LP Podroteja

The Idrijca - Podroteja gauging profile comprises the discharges as from the springs Divje Jezero and Podroteja, as from the surface part of the catchment area of the Idrijca and the Belca (Fig. 2.4 and 2.5). The surface part of the catchment area stretches over approx. 50 km^2 and exerts impact on the water regime at the gauging profile to such an extent that the karstic regime of drainage is obliterated. The size of the catchment area of 112.84 km^2 taken into account for the gauging profile, is also mathematically too small (Tab. 2.4, 2.5 and 2.6). The karstic part of the catchment area spreads towards the area of Hotedrščica where bifurcation with the Ljubljanica was established (3.SUWT), and also in the Trnovski Gozd massif, the watershed cannot be determined since the bifurcations were established in the areas of Vodice and also of Črni Vrh (HABIČ 1987).

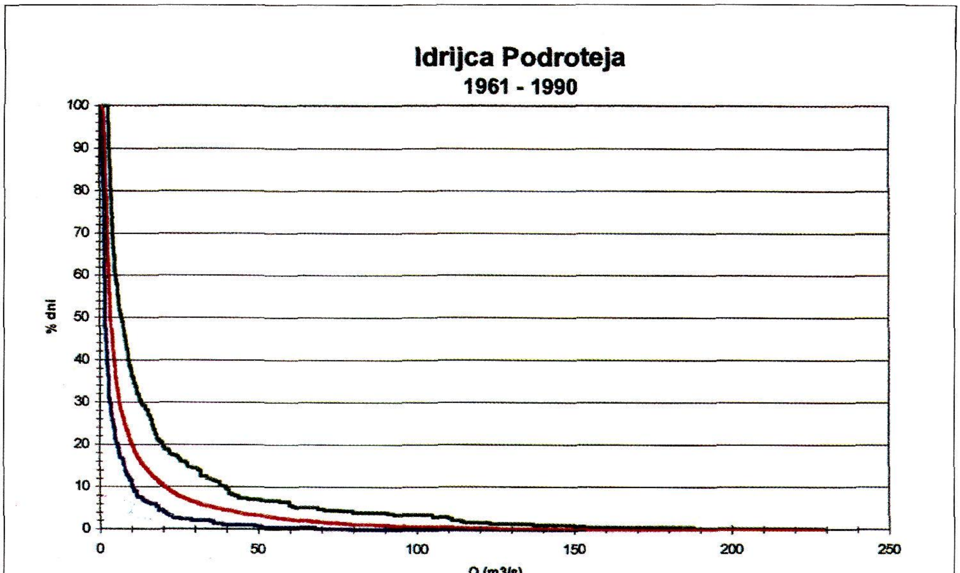


Fig. 2.4: The lines of the 1961-90 discharge duration of the Idrijca at the LP Podroteja gauging profile.

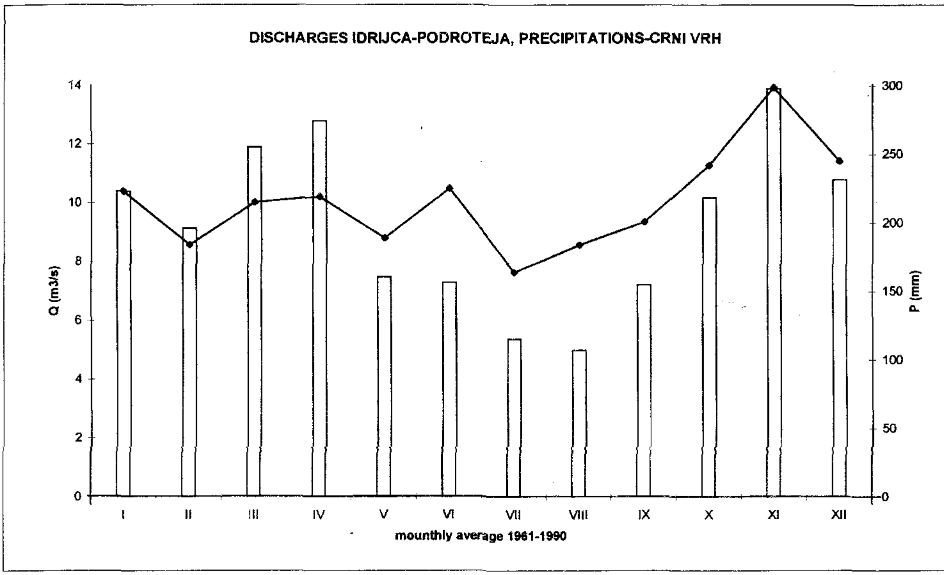


Fig. 2.5: The average monthly precipitation in the catchment area of the Idrijca and the mean monthly discharges (1961-1990).

Tab. 2.4: The 1961-90 data for the Idrijca - LP Podroteja profile.

F km^2	Precipitation Q (m^3/sec)	Evaporation (m^3/sec)	Precipit. runoff (m^3/sec)	Q_s (m^3/sec)	difference (m^3/sec)
112.84	9.20	2.21	6.99	9.75	+2.3

Tab. 2.5: The characteristic discharges of the 1961-90 period at the Idrijca-Podroteja, and their ratio (m^3/sec).

Q_{min}	Q_{mean}	Q_{max}	Q_{min} : Q_{mean} : Q_{max}
0.84	9.29	306	1 : 11 : 364

The ratio between the maximum and the minimum discharges of the Idrijca at the LP Podroteja gauging profile is so high exactly due to the surface part of the catchment area (Tab. 2.5).

Tab. 2.6: The average annual precipitation in the catchment area of the Idrijca (mm).

Črni Vrh	Idrijska Bela	Mrzla Rupa	Vojsko
2589	2623	2784	2450

Lijak - Šmihel

In the gauging profile at the Lijak - Šmihel station discharges are registered of the periodically active springs, which are only an overflow of high waters from the catchment area of the Mrzlek spring. The hydraulic link between these two springs has been confirmed. At low waters, the water level of the Lijak oscillates parallel to the oscillation of the water level in the Solkan hydropower-plant reservoir, and the gradient towards the Soča is minimal. When the spring Lijak is active, the water table in its karstic catchment area rises even more than by 40 m. There were no continuous observations of the spring in the 1961-90 period, therefore, the characteristic data for that period are missing. The highest registered discharge is 32.6 m^3/sec, but a greater part of a year the spring is dry.

The catchment area of the Lijak can also be considered as a bifurcation area since the high waters of the spring also gravitate towards the Vipava, and when the spring is not active, all the waters from the catchment area gravitate towards the spring Mrzlek, i.e., to the Soča. The regime of the Lijak spring demands a special interpretation of water balance, since the high water waves exert impacts on the discharge regime of the lower section of the Vipava, but the size of its belonging catchment area cannot be defined. The correlation with the Hubelj spring was studied for the Lijak spring; it shows a strong dependence between the regimes of both springs (MUŽIČ 1986).

Hubelj - Ajdovščina

The gauging station is located less than 2 km downstream of the Hubelj spring. At the spring itself, water is tapped for the water supply, which reduces the volume by 50 to 150 l/sec.

The orographically determined size of the catchment area (F = 85.25 km^2) for the gauging station on the Hubelj is too big, therefore the calculation of water balance gives so great a difference between the calculated and the gauged runoffs (Tab. 2.7). The theoretically calculated size of the belonging catchment area measures approx. 50 km^2 (STAHL 1994).

Tab. 2.7: The 1961-90 data for the Hubelj - VP Ajdovščina profile.

F km^2	Precipitation Q (m^3/sec)	Evaporation (m^3/sec)	Precip. runoff (m^3/sec)	Q_s (m^3/sec)	difference (m^3/sec)
85.25	6.64	1.76	4.89	3.03	-1.9

Tab. 2.8: The characteristic discharges of the 1961-90 period at the Hubelj - VP Ajdovščina, and their ratio (m^3/sec).

Q_{min}	Q_{mean}	Q_{max}	Q_{min} : Q_{mean} : Q_{max}
0.185	3.03	59.5	1 : 16 : 322

The Q_{max}/Q_{min} coefficient is high and speaks in favour of the fact that in the case of the Hubelj spring its maximum discharge is not suppressed (Tab. 2.8).

Tab. 2.9: The average annual precipitation heights in the catchment area of the Hubelj (mm).

Ajdovščina	Lokve	Otlica	Podkraj
1553	2381	2409	2179

The largest quantity of precipitation in the catchment area of the Hubelj spring falls in November, on average, while the mean monthly discharges of the Hubelj are the highest in April when snow begins to melt (Fig. 2.6 and 2.7, and Tab. 2.9).

The distribution of the maximum discharges in all three discussed gauging profiles do not offer any law; but from the distribution of the minimum discharges, the influence is clearly visible of the water reserves from the snow cover, even on the minimum discharges in the summer months. The minimum discharges of the Hubelj and the Vipava occur in February, and in September or October, and they are practically equal, while the autumn minimum discharges of the Idrijca are essentially lower than those in February (Fig. 2.8).

The quoted basic hydrological conditions of the discussed area and the springs already represent the hydrological problems which are typical of the karstic hydrological systems (Fig. 2.9). Besides the inaccurately determined sizes of the catchment areas and the directions of water streams in the system, an additional uncertainty occurs in the area of the Trnovski Gozd and the

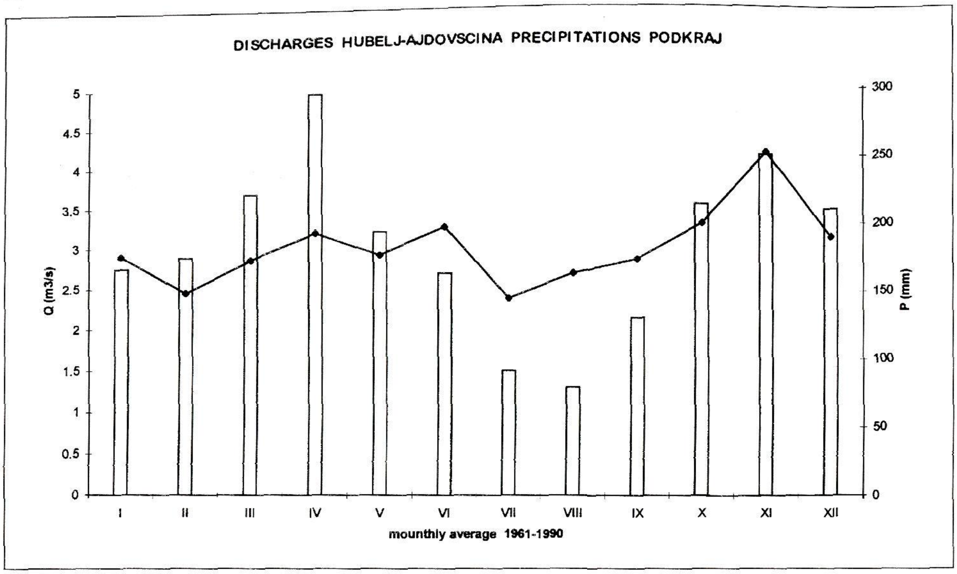


Fig. 2.6: Mean monthly discharges of the Hubelj and mean monthly precipitation in the 1961-90 period.

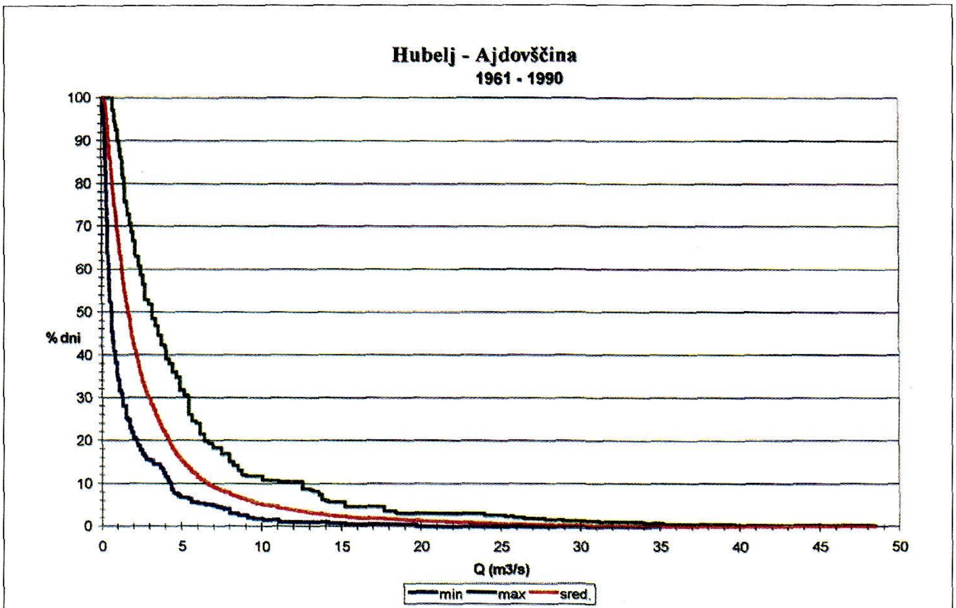


Fig. 2.7: The lines of the 1961-90 discharge duration of the Hubelj at the VP Ajdovščina gauging station.

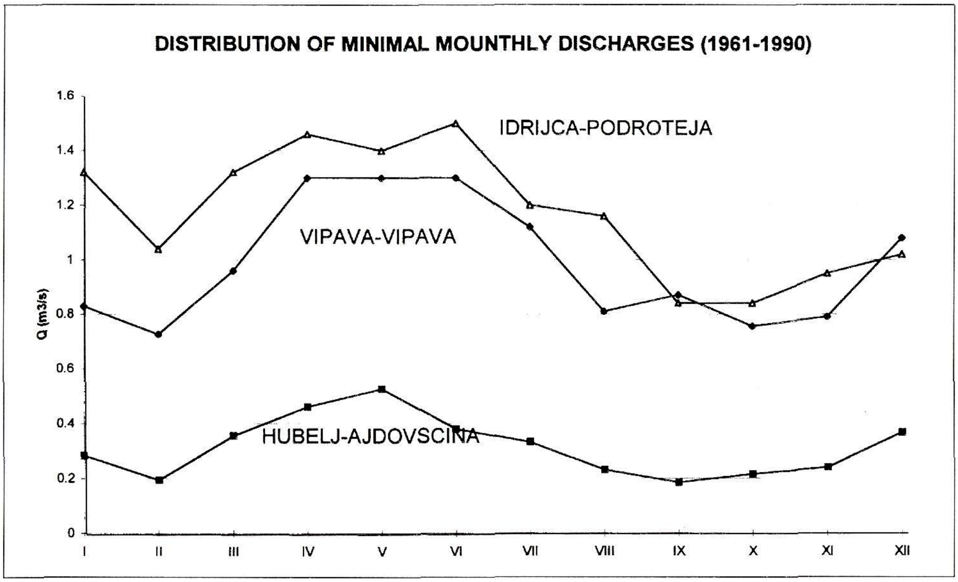


Fig. 2.8: The distribution of the minimum monthly discharges in the 1961-90 period.

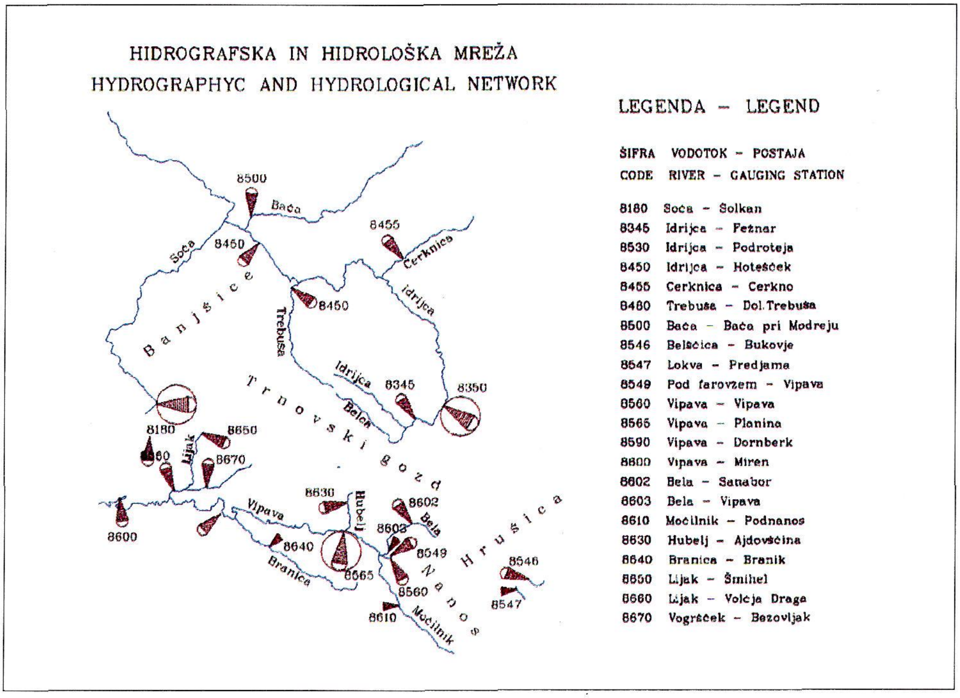


Fig. 2.9: Hydrographic and hydrological network.

Banjšice, which further aggravates the comprehension of hydrological conditions. These are the unspecified discharges of the Mrzlek spring which flows into the Soča in the area of the Solkan HPP reservoir and, thus, cannot be directly gauged.

2.3. THE CLIMATE OF THE TRNOVSKO-BANJŠKA PLANOTA (J. PRISTOV)

2.3.1. Meteorological conditions

The Trnovski Gozd, the Banjšice and the Nanos are the first mountain barrier (the altitudes of peaks between 1000 and 1500 m above sea level) on the way from the Mediterranean, or the Northern Adriatic, towards the north and the north-east. Naturally, there is the Kras plateau before it, yet, it mainly does not exceed the altitude of 600 m. Therefore, the orographic precipitation are modest on the Kras, but they already become rather abundant at the barrier running from the Banjšice to the Nanos, and they are the most abundant at the southern part of the Julian Alps. There, the altitudes of the peaks already reach approximately 2000 m, and the average annual precipitation already amounts to 4000 mm, which is the highest value in the Alps. This barrier represents a divide between the Mediterranean and the Alpine climates. The Vipavska Dolina and Goriško region, both located at the southern rims of the Trnovski Gozd, are under the intense influence of the Mediterranean climate. Yet, the Trnovski Gozd, the Banjšice and the Nanos already have the real Alpine climate with the abundant snow during the rather cold winters.

The precipitation are abundant all year round, with the explicit maximum in October and November. In the heart of the Trnovski Gozd, i.e. the area of Golaki, they exceed the precipitation average over the period of 30-years, which is 3000 mm, and also the entire area of the Banjšice, the Trnovski Gozd and the Nanos, annually receives over 2000 mm of precipitation, on the average.

The most intense precipitation very often occur in October, up to 900 mm (Vojsko 888 mm; Mrzla Rupa 855 mm; Otlica 702 mm), but on the average, October is not the wettest month. Namely, oscillations of precipitation quantity are extremely sharp in this month: on the one hand, the monthly precipitation extremes occur with heavy precipitation, and on the other, this month often receives the minimum precipitation and sometimes - although it happens rarely - they do not fall at all (in 1965). November is the month with the largest average quantity of precipitation, yet the oscillations are not as sharp as in October, and therefore, the annual extremes do not occur in this month. Although rarely, but very heavy precipitation also occur in the month of September.

It is typical of autumn precipitation that they are very intense in shorter periods, and they are often unevenly distributed over the discussed area. It happens that the intensity of precipitation in individual areas differs a lot (the ratio of 1:5), which is not the case with the convective precipitation, but with the orographic precipitation related to the front system. For determining the quantities of precipitation by individual precipitation situations, a rather dense network of precipitation gauging stations would be necessary, or, great errors could occur due to the intensely agitated precipitation area.

The Trnovski Gozd receives the majority of precipitation in autumn, when the sea is still rather warm, and the very warm and humid air, driven by the SW winds, flows in from above the Mediterranean. When on its way during the precipitation situation this air reaches the first higher mountain barrier, it must ascend to pass it, which results in the orographic precipitation. Such situations often occur during the generation of secondary cyclones in the Genoa bay or above the Northern Adriatic. It is in autumn and spring when the secondary cyclones are most frequent, only that the warm air in autumn contains quite a lot of humidity. The humidity of air is considerably lower in spring due to the cooler northern Mediterranean, and therefore, the orographic precipitation are not so abundant.

The monthly quantity of precipitation considerably exceeds the evaporation. July is the least wet month, and even then, more than 160 mm of precipitation fall; concurrently, it is also the month with the most intense evaporation, when the potential evapotranspiration (ETP) on the Nanos amounts to 130 mm, and at Čepovan, to 122 mm (Fig. 2.10 and 2.11). Since the monthly precipitation, on the average, always exceed the ETP, it is assumed that the actual evapo-

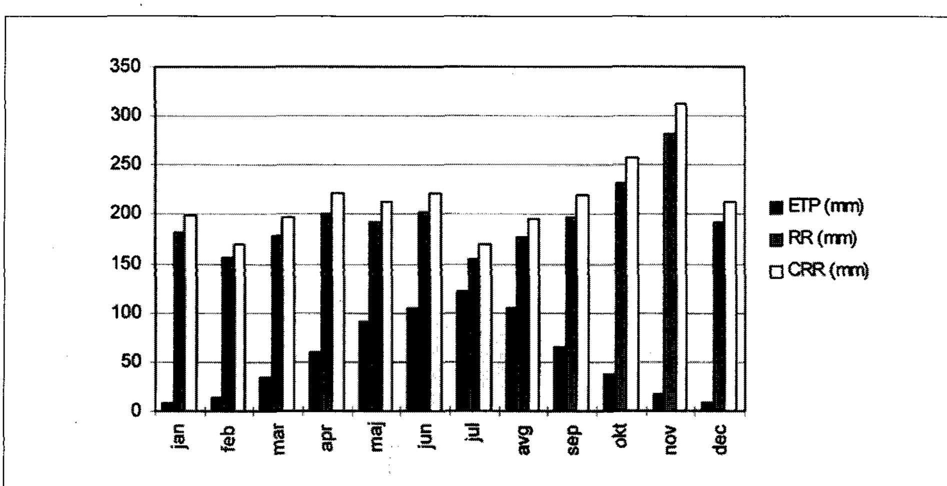


Fig. 2.10: Mean monthly values of potential evapotranspiration (ETP), precipitation (RR) and corrected precipitation (CRR) on the station Čepovan.

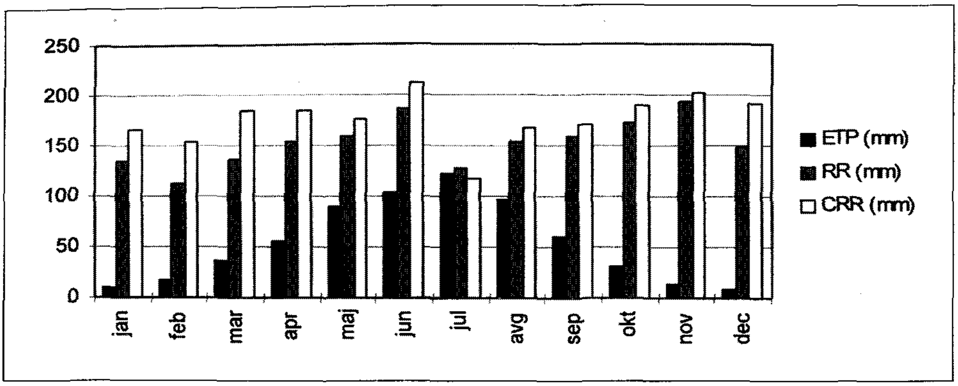


Fig. 2.11: Mean monthly values of potential evapotranspiration (ETP), precipitation(RR) and corrected precipitation (CRR) on the station Nanos-Ravnik.

transpiration (ET) equals to the potential evapotranspiration (ETP); therefore, in the continuation of this paper, only the term evaporation is used and is equalised with the ETP. On the average, more than 300 mm of precipitation fall in November at Vojsko and Mrzla Rupa, but only 15 mm evaporate. In October, the same area receives more than 250 mm of precipitation, but only about 35 mm evaporate.

On the average, the greatest discharges occur in October, although the greatest quantity of precipitation fall in November. The air in the inland of Slovenia is already so cold in this month that the higher altitudes of the Trnovski Gozd are already covered with snow, which is immediately manifested in the reduced discharges. The secondary maximum of discharges occurs in the spring months when the snow cover is melting.

As it has already been mentioned, the Trnovski Gozd and Nanos represent the divide between the Mediterranean and the Alpine climates. When the inland of Slovenia is filled with the cold air from the north or the Northeast, great temperature differences originate at the foregoing barrier, as well as great pressure gradients. When the air descends from above the Trnovski Gozd and the Nanos towards the Vipavska Dolina and the Kras, it is adiabatically warmed, yet, it is still cooler than the air above the northern Adriatic. The result of this temperature difference is that the cold air cascades down the slopes, and reaches great velocities, while due to the agitated landforms, violent turbulences are generated. This strong wind is known under the name of bora, and reaches the velocities of up to 200 km/h with individual gusts. Relatively frequent occurrence of the bora, of smaller velocity of course, is also the cause that the air above the Kras and the Vipavska Dolina is dryer than the air above the other regions of Slovenia. Such relatively dry atmosphere provides for the natural drying of ham which is famous as a speciality under the name *kraški pršut* (i.e. the karstic crude ham).

2.3.2. The water balance

The equation of water balance

$$P = Q + E + N^* + R \quad (1)$$

expresses that in a specified area the precipitation, P, equal the sum of water discharges, Q, evaporation, E, the changes in water reserve, N*, and the water captured for the biological and industrial consumption, which is pumped from the studied area, R. In our case, the amount of the pumped water is small in comparison to the possible errors at precipitation gauging and making the precipitation maps, and therefore, it is not directly taken into consideration.

For the longer periods it can be assumed that the changes in water reserves in an average year are negligible, and the equation is reduced to the following items only:

$$P = Q + E \quad (2)$$

which means that the precipitation in a specified area equal the sum of discharges and evaporation.

For the needs of evaluating tracing experiments we wished to obtain water balance for the short periods, i.e., for the individual precipitation situations, or, at least for the periods of several months during which the individual tracing experiments were performed.

The results of water balance for the shorter periods were not encouraging although we tried to do our best when making the basic maps.

For the precipitation map of wider area of the Nanos and the Trnovsko-Banjška Planota, the data were made use of from 40 precipitation stations where daily precipitation were gauged at 7 hrs (Archives of the Hydrometeorological Institute, Slovenia).

In individual precipitation situations, very explicit minor precipitation cells occurred, which were impossible to be correctly presented through such low density of precipitation gauging station network.

During the relatively stationary precipitation situations, the differences of precipitation between individual areas (from the north towards the south, or, from the west towards the east), even reached the ratio of 10:1. At such sharp precipitation changes, errors occur in the making of precipitation maps, especially at the determining of precipitation for the relatively small contributing areas, particularly if the watersheds are not strictly defined.

The equation of water balance in which the precipitation are equal to the sum of water runoff and evaporation, apply only in case when the changes in the water reserve N* are negligible, which is almost impossible to expect at precipitation situations. With heavy precipitation the water reserve in the ground considerably increases. In the late autumn months, the higher altitudes of the Trnovski Gozd are already under the snow cover which can contain quite large water quantities.

To avoid all these troubles, the 30-year water balance was taken as a basis. Let it be assumed in this case, that the water reserve at the end of the period equals to that at the beginning, since the difference in an average year is minimal in so long a period, thus, it means N* = 0.

Also at the gauging of precipitation, the casual errors are eliminated by averaging; however, the systematic errors remain, which can be considerably reduced by applying supplementary procedures (precipitation correction due to wind, etc.).

Due to the considerable oscillation of annual precipitation in the 30-year period, the water balances were determined also for the 5-year and the 2-year periods, and it was also assumed that N* was negligible. Although this is a rough premise, yet, it is acceptable were the accuracy taken into consideration, of the precipitation gauging, which is particularly problematic at the higher altitudes due to wind, while the terrain configuration does not allow that the vertical precipitation gradients be directly applied.

Precipitation determining

Precipitation are gauged with a gauge of Hellmann type which collects too little precipitation in windy weather. The experiments proved that, at wind speed of more than 5 m/sec, only 22 % of the actual snow precipitation are gauged, and 87 % of the actual rain precipitation (YANG et al. 1994). Experiments on precipitation gauging in wind conditions were not carried out in Slovenia; therefore, we assumed the WMO intercomparison results.

For the stations registering wind observations, force of wind was reduced for each precipitation day, to the altitude of Hellmann's gauge, and then, the adequate coefficient or the anticipated precipitation quantity was calculated. On the basis of gauge locations and direct obstacles, the precipitation stations were ranked into classes. For each class, the monthly and annual coefficients for the correction of precipitation were specified, on the basis of data from the stations with wind observations. By means of these coefficients, the quantities of precipitation were also corrected for the stations without wind observations.

Because the precipitation in Slovenia are heavier than in the places where the experiments were performed, it is assumed that also the rain drops and the snow flakes, on average, are slightly greater and heavier, respectively. Therefore, we reduced the corrective coefficients by 20 % for the places at the altitudes between 1000 m and 1500 m, and by 35 % for the places lying higher than 1500 m. Thus, the corrective coefficients amount to between 1.01 and 1.05; for the very exposed locations only, between 1.05 and 1.08; for the exposed locations above 1000 m in the area of the Nanos and the Trnovsko-Banjška Planota, up to 1.14.

Besides the increase of precipitation due to wind, we also took into account the increase of precipitation due to the gauge moistening. Whenever the gauge is emptied, a slight amount of water remains on the bottom and the sides of container. Following the results of laboratory testing, we took for the precipitation days with more than 1 mm of precipitation, the correction of 0.3 mm for a rainy day, and the correction of 0.15 mm for a day with snow precipitation. For all the precipitation maps, the corrected precipitation data were made use of.

In the making of precipitation maps (Fig. 2.12), the vertical precipitation gradients were not taken into account (a rather even increase of precipitation with the altitude), but the distribution was assessed subjectively, depending on the terrain configuration and precipitation data. Namely, it turned out that certain lower-lying places had received more precipitation than the higher-lying ones (Mrzla Rupa, 930 m above sea level - 2940 mm; Vojsko, 1070 m above sea level - 2800 mm; similar situation occurs in some other stations).

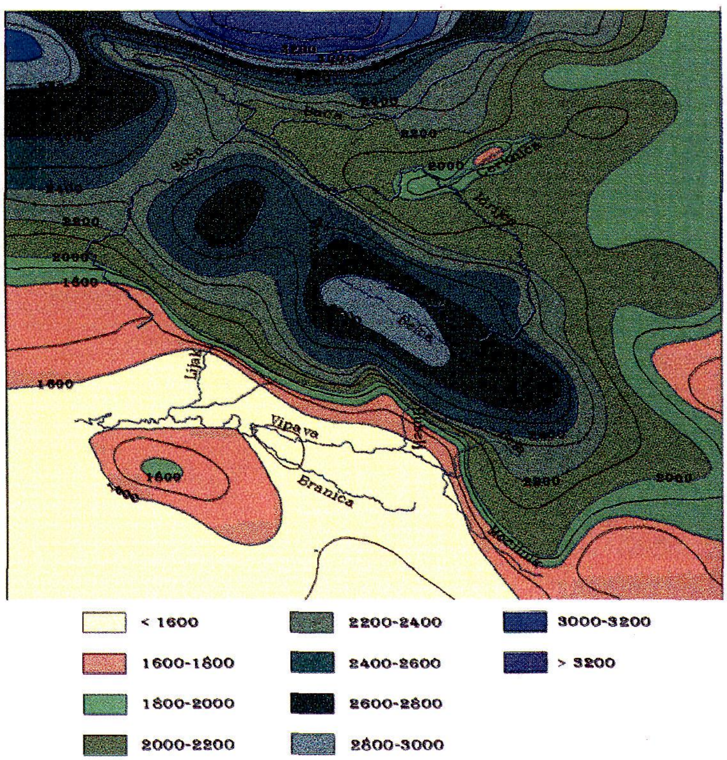


Fig. 2.12: The 1961-90 period precipitation map (mm).