4.2. Common methodology for determination of water availability in Adriatic area

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DRINK ADRIA

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TABLE OF CONTENTS

1. INTRODUCTION 5

2. TEST AREAS 10

  2.1. ITALY..10

    2.1.1. ISONZO/SOČA PLAIN 10

    2.1.2. ATO3...16

    2.1.3. OSTUNI..20

  2.2. SLOVENIA - KOBARIŠKI STOL, MIA AND MATAJUR AQUIFER 22

  2.3. CROATIA...24

    2.3.1. NORTHERN ISTRIA - SPRINGS SV. IVAN, GRADOLE AND BULAŽ.............24

    2.3.2. SOUTHERN DALMATIA - SPRING PRUD AND BLATSKO POLJE 31

  2.4. BOSNIA AND HERZEGOVINA – TREBIŽAT RIVER 34

  2.5. MONTENEGRO – NIKŠIĆ...36

  2.6. ALBANIA – DRINI BASIN 42

  2.7. GREECE – CORFU ISLAND 44

3. ANALYSIS OF CC IMPACT ON RENEWABLE WATER RESOURCES 50

  3.1. COMMON METHODOLOGY...50

  3.2. ITALY..51

    3.2.1. ISONZO/SOČA PLAIN 51

    3.2.2. ATO3...59

    3.2.3. OSTUNI..62

  3.3. SLOVENIA - KOBARIŠKI STOL, MIA AND MATAJUR AQUIFER 68

  3.4. CROATIA...72

    3.4.1. NORTHERN ISTRIA - SPRINGS SV. IVAN, GRADOLE AND BULAŽ.............75

    3.4.2. SOUTHERN DALMATIA - SPRING PRUD AND BLATSKO POLJE 98

  3.5. BOSNIA AND HERZEGOVINA – TREBIŽAT RIVER 114

  3.6. MONTENEGRO – NIKŠIĆ...127

  3.7. ALBANIA – DRINI BASIN 134

  3.8. GREECE – CORFU ISLAND 146

  3.9. RESULTS 150

4. EVALUATION OF WATER DEMAND AND CALCULATION OF WATER EXPLOITATION INDEX 162
4.1. COMMON METHODOLOGY 162
4.2. ITALY 163
4.2.1. ISONZO/SOČA PLAIN 163
4.2.2. ATO3 172
4.2.3. OSTUNI 176
4.3. CROATIA 181
4.3.1. NORTHERN ISTRIA - SPRINGS SV. IVAN, GRADOLE AND BULAŽ 181
4.3.2. SOUTHERN DALMATIA – SPRING PRUD AND BLATSKO POLJE 191
4.4. MONTENEGRO - NIKŠIĆ 200
4.5. ALBANIA – DRINI BASIN 202
4.6. GREECE – CORFU ISLAND 207
4.7. RESULTS 221
5. CONCLUSIONS ON WATER RESOURCES AVAILABILITY ON TEST AREAS 227
6. REFERENCES 229
7. ANNEXES 238

1. INTRODUCTION

There is growing evidence for changes in the global hydrological cycle over the past decades that may be linked to changes in climate (CC). In 4.2. Activity: Present and future risks on water resources availability with emphasis on drinking water supply common methodology for determining available water resources was agreed, taking into account different resources types and water intake for public water supply, different manifestations of climate impacts, different sizes of analyzed test areas, as well as different levels of data availability for describing current state of water resources and forecasting possible changes. On figure 1.1. the relation between activities within work package 4 (WP4) and also outputs are presented.

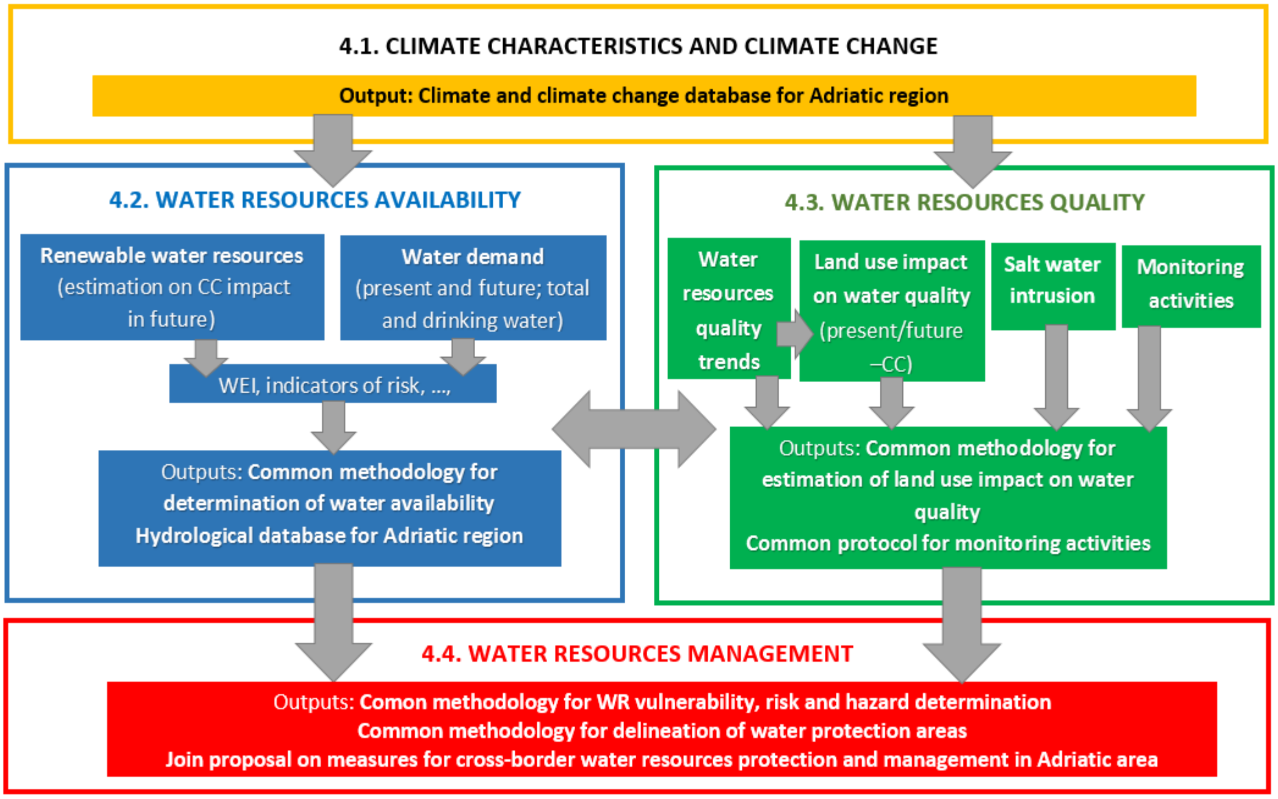


Figure 1.1: WP4 activities and outputs

In the Adriatic area 9 test areas were selected (figure 1.2) to analyse the risk on water resources availability in the future 2021-2050 period under the climate change impact, where as a criterion for consideration of climate change impact standard climatological 30-year period 1961-1990 was selected as reference.

The availability of water resources was analysed from the aspect of total use and use for drinking purpose.

Water resources in test areas have cross-border or cross-regional character and their availability can affect the water supply in more than one country or region within the country.

On figure 1.3, test area locations are shown with marked meteorological stations whose data are included on figures 1.4 and 1.5.

Figure 1.2: Test area locations

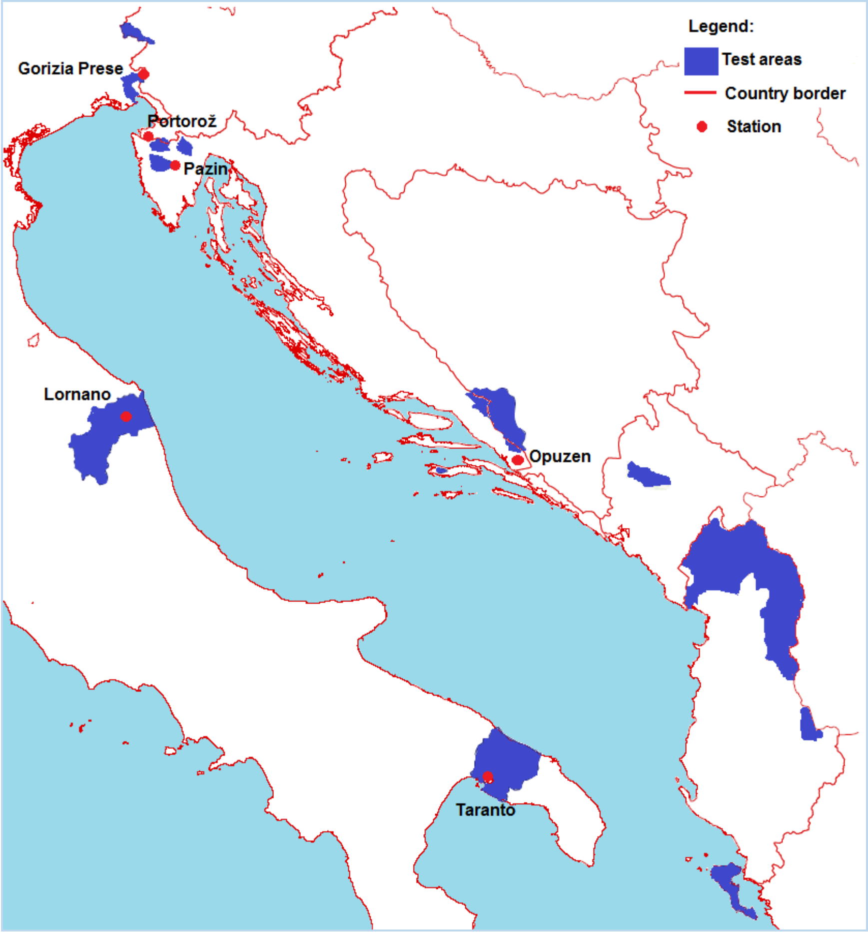


Figure 1.3: Test area locations with marked meteorological stations whose data are included on figures 1.4 and 1.5

Given that some FBs have been partners in CCWaterS project (http://www.ccwaters.eu/) where water resources availability was also analysed in relation to CC it was decided to apply part of that methodology for assessment of water availability on selected test areas in DRINKADRIA project.

For analyses of present and future risks on water resources availability with emphasis on drinking water supply it is important to have the possibility to compare results so FBs had to prepare a REPORT ON WATER RESOURCES AVAILABILITY ON TEST AREAS that consisted of three parts: analysis of CC impact on renewable water resources, evaluation of water demand and calculation of water exploitation index. With all the diversity of analyzed test areas, DRINKADRIA project also had a common methodological approach for assessing the climate change impact - the mentioned selected reference periods that were common on all analyzed test areas, and the project also had a common methodological approach to assess climate change based on three basic climatological models (RegCM3, Aladin and Promes). Conducted analyses and climatological assessments are shown in detail in the report 4.1. Climate and climate change database for Adriatic area. On the basis of such common approach as well as available basis and knowledge, all further analysis for certain test areas were conducted.

Due to the large spatial distribution of analyzed test basins, the range of analyzed climate impacts on the processes of runoff and water resources state in critical periods of drought is also large, during the previous period, and for the period until 2050 until when forecasted climate changes are dated. On figure 1.3 mean annual air temperatures (in modular values) are shown for data generated with model Promes for several selected stations from analyzed test areas for the period until 2050, and on the figure 1.4 annual precipitation amounts are shown. It can be seen that associated trends are very different, which also implies a very different impact of those climatological changes on hydrological states of analyzed water resources. It can also be seen that the smallest generated trend of increase in air temperature is 4%/100yr for Gorizia Prese and the biggest one is 24%/100yr for Pazin in Northern Istria test area. For annual precipitation amount, even the signs of trends vary - for the southernmost located station Taranto the biggest trend of precipitation decrease is predicted (8%/100yr), and for the northernmost analyzed station Gorizia Prese even the trend of increase in annual precipitation amount (14%/100yr) is predicted. The previously mentioned percentages refer to the total change in relation to the mean value in 100 years.

Due to the different character of those resources, as well as the basis availability, different forecasting hydrological models were also used on certain test areas. In doing so, knowledge and methodological approaches elaborated in the framework of the mentioned EU project CCWaterS are largely respected.

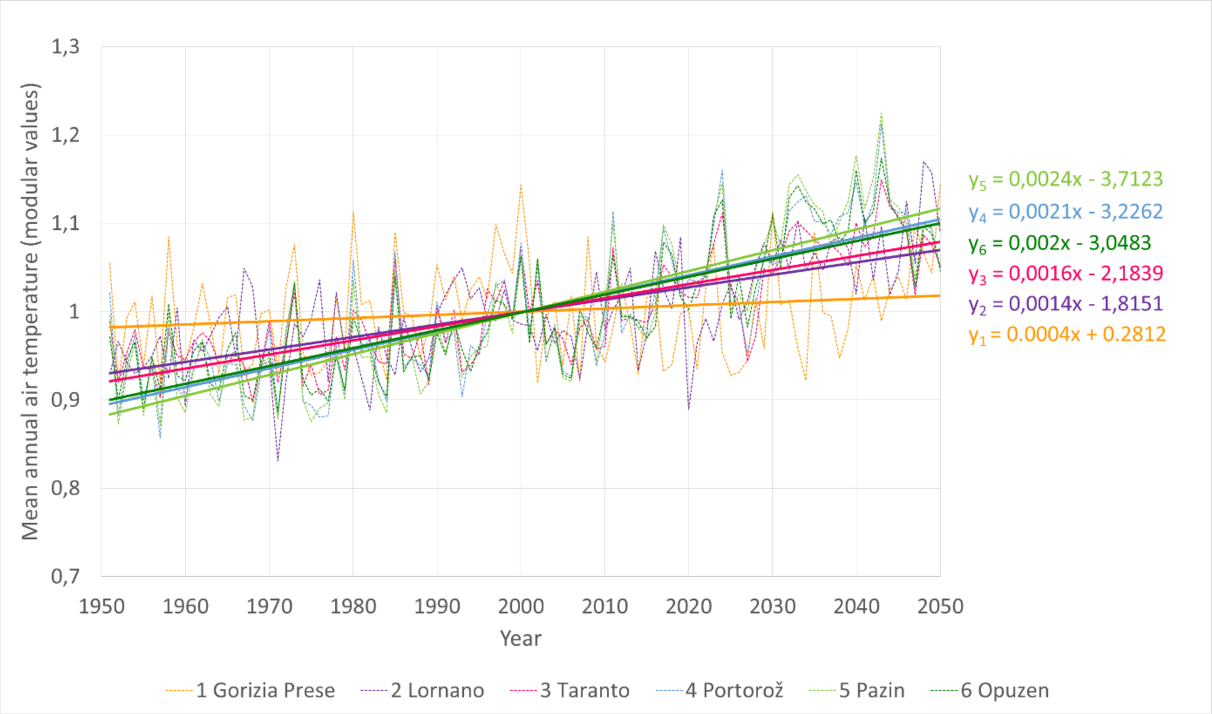


Figure 1.4: Mean annual air temperature (modular values) for model Promes for several selected stations

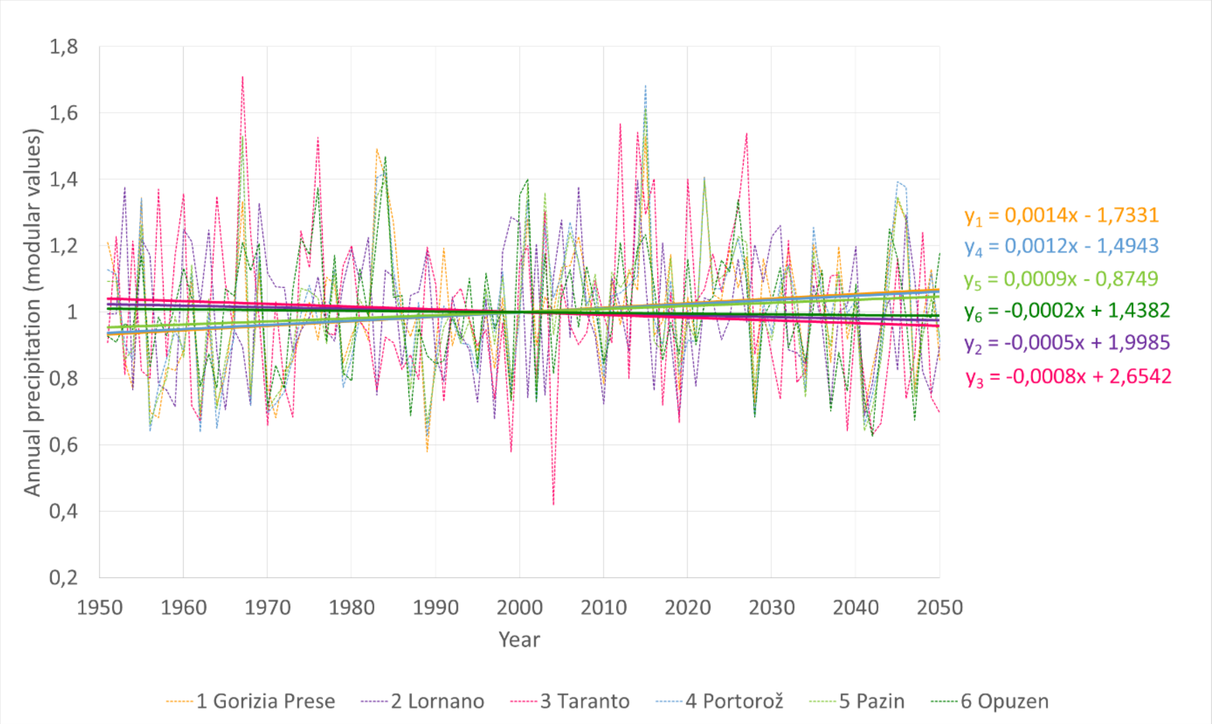


Figure 1.5: Annual precipitation amount (modular values) for model Promes for several selected stations

In this document first test areas are shortly presented in Chapter 2. In Italy three test areas were selected: Isonzo/Soča Plain (in Friuli Venezia Giulia, reports prepared by LP), ATO3 (in Marche, reports prepared by FB2) and Ostuni (in Apulia, reports prepared by FB3). In Slovenia test area is Kobariški Stol, Mia and Matajur aquifer. In Croatia analyses were done for two test areas Northern Istria – springs Sv. Ivan, Gradole and Bulaž (reports prepared by FB8) and Southern Dalmatia - spring Prud and Blatsko polje (reports prepared by FB8 and FB9). FB12 prepared a report about Trebižat River that has been used for reports regarding spring Prud in Croatia. In Montenegro the analysed test area is Nikšić (report is prepared by FB14 for FB10). Test area selected in Albania is Drini Basin (report prepared by FB11) and in Greece the Corfu Island (report prepared by FB16). Test areas are very different with area range between 28,4 km^2 (eg. Blatsko polje on the island of Korčula, Croatia) and 14173 km^2 (Drini Basin which is dominantly, 5973 km^2, in Albania, but also covers parts of the former Yugoslav Republic of Macedonia and Montenegro).

In Chapter 3 results of analyses of CC impact on renewable water resources on test areas and in Chapter 4 results for water demand and water exploitation index (WEI) on test areas are presented. All material regarding test areas analyses are extracted from FBs' reports given in Annexes to this Report.

In Chapter 5 conclusions are given based on results from reports prepared by FBs.

2. TEST AREAS

2.1. ITALY

2.1.1. ISONZO/SOČA PLAIN

From Annex 1:

The studied area, located in the north eastern side of Italy, belongs to the hydrogeological basin of the Friuli Plain and includes part of Slovenia. The Friuli Venezia Giulia Region extends from the Alps to N, to the Adriatic coastline to S, bounded by the Livenza River to the W and the Isonzo River watershed to the E. From N to S it is possible to find the Mountain Basins, the High Plain and the Low Plain up to the Adriatic Sea and the Classical Karst (Figure 2.1). The surface and groundwater flow directions mainly are from N to S. The High Plain is characterized by a phreatic aquifer, while the Low Plain consists of eleven confined aquifer systems. The two plain physiographic zones are divided by the resurgence belt that represents a kind of “overflow” for the High Plain into the Low Plain.

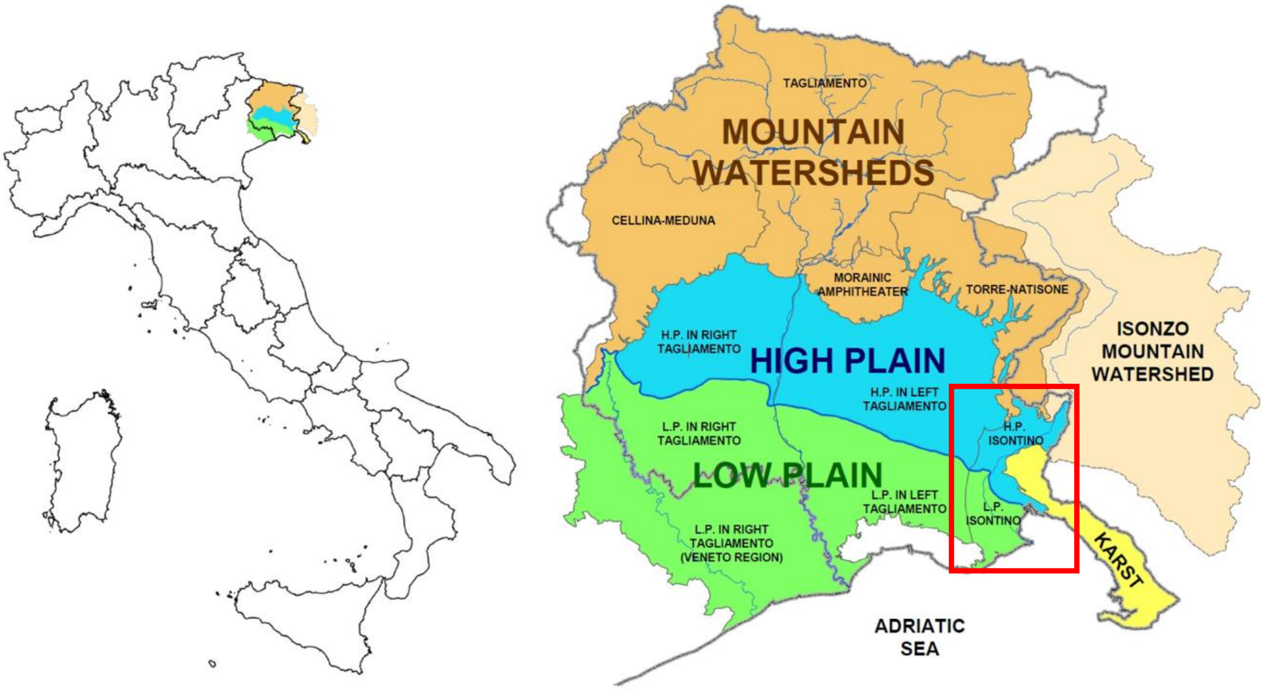


Figure 2.1: Study area location (in the red rectangle), Zini et al., 2013.

The mountain part presents very complex characteristics from the lithological and structural point of view (Carulli et al., 1980; Carulli, 2006). To North, along the border with Austria, mainly outcrops the more ancient Palaeozoic units where clastic lithotipes (claystones, marls, sandstones often in facies of Flysch) are prevailing on the platform carbonate lithotipes weakly metamorphosed.

The central part is characterized by Mesozoic sediments as calcareous and dolomitic rocks. In the piedmont belt considered as the connector between mountains and plains, are mainly present the Flysch silico-clastic lithotipes, the Cenozoic Molasses and the moraine amphitheatre of the Tagliamento River.

The Friuli Plain extends south Carnic and Julian Prealps between Livenza and Isonzo/Soča rivers and the Classical Karst. It represents the eastern edge of the Po Valley Plain, although its characteristics must be considered marginal compared to the evolution of the latter being characterized by greater steepness and coarser sediments. Its highest elevation is about 250 m a.s.l., on a north-south length of about 90 km (Antonelli et al., 1981).

Quaternary sediments are widely present in the Plain reaching thickness, near Latisana, of more than 600 m gradually decreasing towards East until 250 m near Grado (Cimolino et al., 2010; Della Vedova et al., 2008; Nicolich et al., 2004).

In the High Plain, characterized by a high permeability of the loose coarse deposits, a phreatic continuous aquifer is recognized gradually reaching the surface while approaching the resurgence belt.

During the year, the water table excursions are very different from place to place: from the lowest values reached along the southern side of the resurgence belt with few centimetres of oscillation, it switches to more than 50 meters close to the pre-Alpine mountains arc (Cucchi et al., 1999).

Moving towards the Low Plain, the phreatic aquifer joins in a complex layered aquifer systems characterized by gravel-sand deposits variously interspersed with clay and silt increasingly frequent and powerful. In almost all the Low Plain wherever outcrop discontinuously gravelly-sandy horizons, at shallow depth, is present a discontinuous phreatic aquifer that has some relevance for the issues related to land (use, pollution, etc.). Here, enclosed in aquitard or aquiclude layers have been recognized eleven confined aquifer systems of which the deeper have geothermal character (Stefanini et al., 1976; Stefanini et al., 1977a, 1977b; Stefanini, 1978). To describe the subsoil of the Low Friuli Plain, has been adopted a scheme which provides the presence of seven “cold” confined aquifer systems (designated as A, B, C, D, E, F, G in the direction of increasing depth) between 10 and 400 m of depth, and, four “hot” aquifer systems, characterized by geothermal waters (called H, I, L and M) (Cucchi et al., 2008a, 2008b; Della Vedova et al., 1994; Martelli et al., 2007a, 2007b; Martelli et al., 2010; Nicolich et al., 2008; Stefanini et al., 1976; Stefanini et al., 1977a, 1977b; Stefanini, 1978; Stefanini et al., 1978) (Figure 2.2).

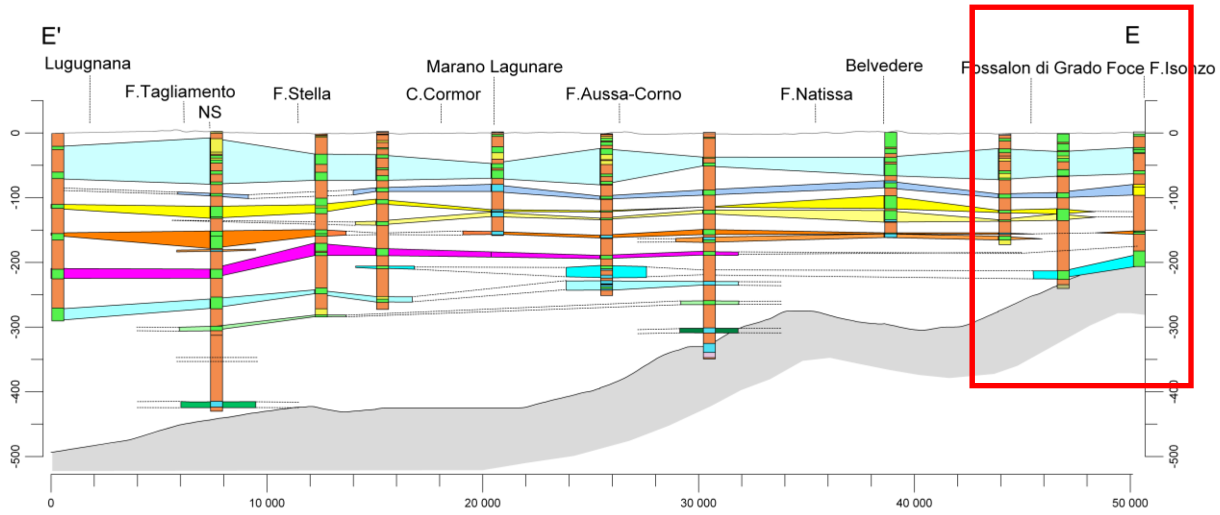


Figure 2.2: E-W correlations among different systems of aquifers (Zini et al., 2011). The vertical lines represent the drilled wells, while each coloured horizontal or sub-horizontal area correspond to a different aquifer system. In the red box the Isonzo/Soča area.

In this framework is present the test area that corresponds to the Isonzo/Soča Plain located in the north-eastern side of the Friuli Venezia Giulia Region at the border with Slovenia (Figure 2.1 and Figure 2.4). Its extend approximately between latitude 45° 58’ 00” and 45° 49’ 00” and longitude 13° 20’ 00” and 13° 40’ 00”, WGS1984, UTM ZONE 33N. The Isonzo/Soča Plain has genetic and hydrogeological characteristics typical of lowland areas, facing the sea and sited at the foot of hills. It is an area arched as the course of the Isonzo River, which extends from the outlet at the Italian-Slovenian border into the plain to the sea and the lagoon of Grado (about 35 km long, 10 wide). The plain is the result of the combined actions among the alluvial deposits from East transported by Vipacco and Soča rivers and those from the North brought by the Judrio and Versa streams and Torre and Natisone rivers. The fluvial deposits, interacting with the ones from the Adriatic Sea, took to the construction of the plain, often giving rise to furniture lagoons. Deposits fill what we might call the paleovalleys of Vipacco, Isonzo/Soča, Torre and Natisone rivers. Bedrock is partially formed by cretaceous limestones, partially by terrigenous deposits in facies of Flysch (Tertiary) deepening hundred meters from East to West and from North to South (Figure 3). The corrugations related to the main tectonic lines approximately E-W oriented (sometimes partially broken by transcurrent N-S) complicate the bedrock morphology.

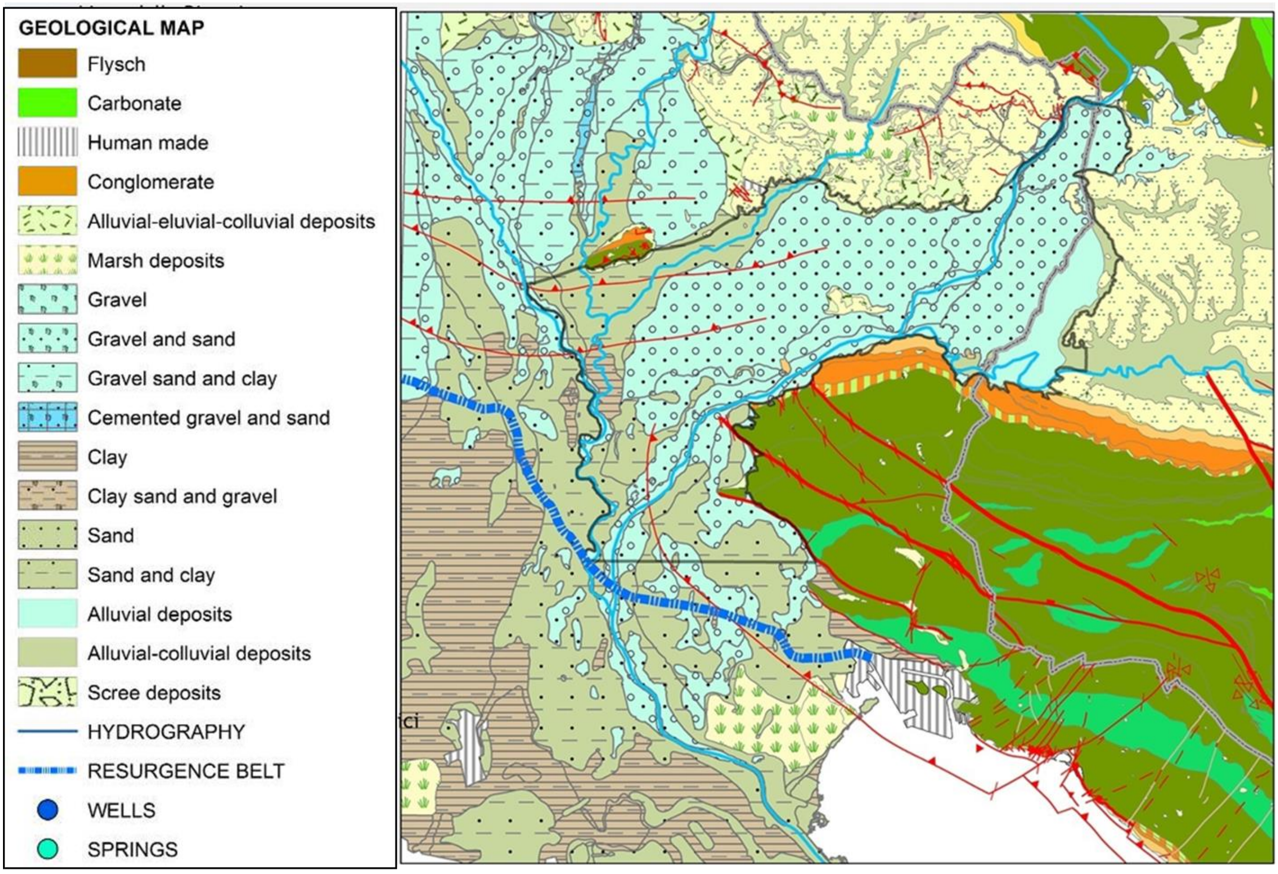


Figure 2.3: Sketch of the geological Map (from 1:10.000 scale data) of the test area.

According to the characteristics of the deposits, the Isonzo-Soča Plain (Figure 2.1) is divided in two areas: the High Plain to the North and the Low Plain to the South. The High Plain at its North edge has the Collio Hills, made up by marlstones and sandstones of the Eocene Flysch. To the South are present instead the cretaceous limestone reliefs of the Karst Plateau (Figure 2.3). Coarse and very permeable deposits that hold a well-developed phreatic aquifer mainly constitute the High Plain. The rivers have an influent character with respect to the High Plain; for this reason, Torre and Judrio rivers remain dry most of the year. Isonzo/Soča River loses about 25% of its discharge (Zini et al., 2011). The river losses, together with effective infiltration and run-off waters flowing from the hills, actively recharge the phreatic aquifer of the High Plain.

Proceeding towards the Low Plain from North to South, the phreatic aquifer joins into a multi-layered aquifer system characterized by alternating gravel-sand and clay-silt deposits. Due to the southward permeability decrease, as for the whole FVG Region, the High Plain phreatic waters outflow in correspondence to a NW-SE wide area displayed as a resurgence belt. Here waters are rising creating an outflow that can be identified as a water quantity and quality indicator. The significant phreatic aquifer and many rich artesian aquifers represent an important natural wealth, in terms of quantity, quality and ease of supply. The aquifers available in the plain are used for different purposes: drinking, household, industrial, agricultural and farming. They serve more than 350.000 inhabitants considering the ones living in the alluvial plain but also the ones of Trieste city and the province.

Figure 2.4: Test site area (in red) and the surroundings.

Main characteristics of test area Isonzo/Soča Plain are presented in table 2.1.

Table 2.1: Characteristics of test area Isonzo/Soča Plain (Calligaris et al., 2015)

Name of the area	Isonzo/Soča Plain
WR	Phreatic in the northern side and confined multilayered aquifer in the southern side.
Related City	Gorizia, Trieste, Monfalcone (All the Province of Gorizia and a wide part of the Trieste Province)
Geographical coordinates	45.9413046 N 13.6215457 E (of Gorizia town)
Altitudinal range	0-80 m a.s.l. for the plain area
Size	168 km^2 (the whole study area)
Morphology	Mainly plain area having in the NW and in the E the hills
Aquifer type	Porous aquifer. Mainly phreatic in the northern part and confined in the southern, downstream the resurgence belt
Surface water interaction	Isonzo/Soča river has an influent character
Geology	Limestone, Flysch, alluvial deposits
Mean annual precipitation	1397,5 mm (1103min – 1955 max)
Mean annual temperature	13,1°C (-11min 39max°C)
Soil types	Skeletic cambisol 37,30%; Calcaric cambisol 18,59%; Skeletic regosol 15,50%; Eutric cambisol 12,09%; calcaric fluvisol 11,51%; covered 2,47%; other 2,54% (the whole study area)
Land uses	Agriculture 58,81%; Natural environment 10,50%; Urbanized area 22,48%; Water surface 3,56%; Industrial area 3,14%; Sport and leisure facility 0,94%; Quarry and landfill 0,57% (the whole study area)
Protection areas	According to the Italian low D.L. 152/2006
Water abstraction	4 m^3/s from wells withdrawals; 16 m^3/s from the spring belt

2.1.2. ATO3

From Annex 2:

ATO 3 Test Area territorial extent is around 2.520 km^2. It is located in the central part of Marche Region, Italy, stretching from the Apennines to the Adriatic coast (Figure 2.5).

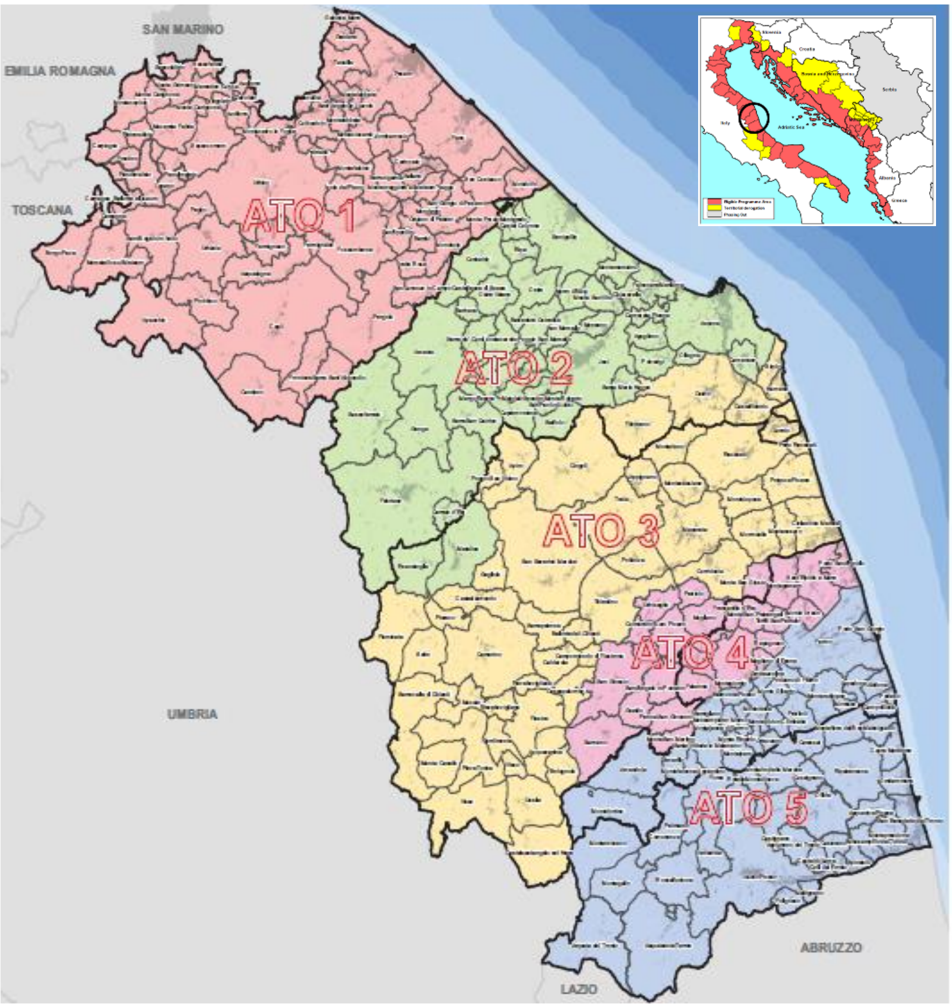


Figure 2.5: Individuation of ATO 3 Test Area, Marche Region, Italy

The most important Water Resources are located within two different physiographic "Macro-Regions" corresponding to as many hydrogeological domains (Figure 2.6):

1) WR1 – Calcareous ridges
2) WP2 – Alluvial plains.

Several geological-structural units can be identified within these regions, determining the formation of important aquifer complexes with different storage capacity and groundwater circulation velocity.

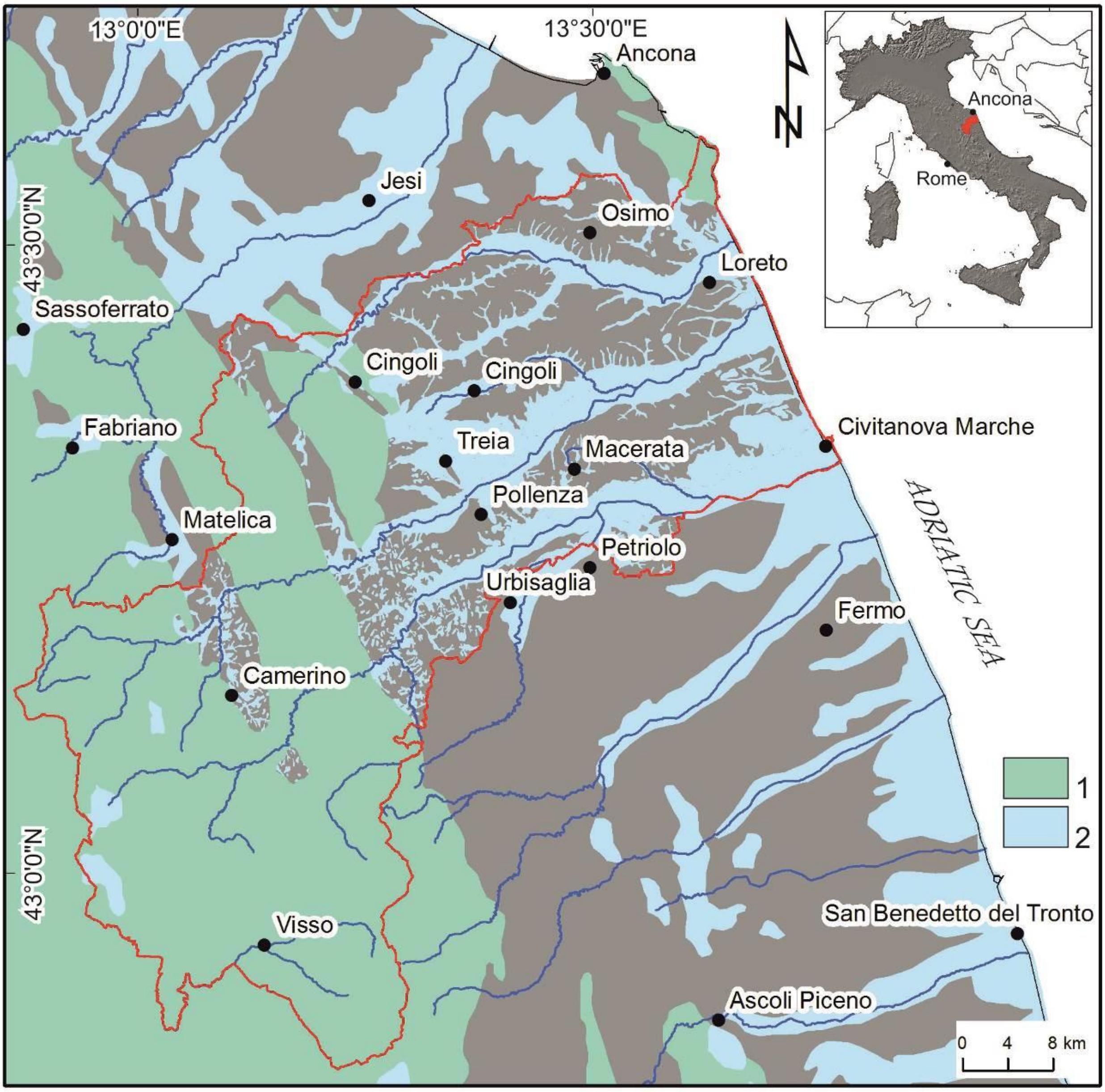


Figure 2.6: ATO3 Test Area (marked with the red line): 1) "Calcareous ridges" hydrogeological domain; 2) "Alluvial plains" hydrogeological domain.

From a climatic point of view, previous studies (Amici and Spina, 2002), carried out on the whole territory of Marche Region using a discrete number of pluviometers, have led to a generalized division into three longitudinal sectors, homogeneous in the range of altitudes and especially for mean annual precipitation and overall climatic conditions. The same subdivision can be associated to the Test Area (Figure 2.7a):

i) a coastal zone, with mean annual precipitation between 600mm and 850 mm;

ii) an intermediate medium-low hilly sector, with values between 850mm and 1100 mm;

iii) an inland high-hilly and mountain area, with mean values greater than 1100 mm, and maximum around 1700 mm.

Such rainfall pattern ensures a fair recharge in mountain areas where the largest number of water supply facilities is concentrated (Figure 2.7a); on the other hand a more limited recharge, often at risk during summer periods, characterizes the alluvial plains mainly located in the low-hilly and coastal sectors, where the number of Water Resources is lower, almost entirely made up of well fields and pumping stations. Figure 2.7b shows the subdivision of the test area in four of the five main land use classes according to the Corine Land Cover, 2006. Two classes are dominant: agricultural areas characterize the low-hilly and flat areas while natural areas and forest dominate the mountain areas

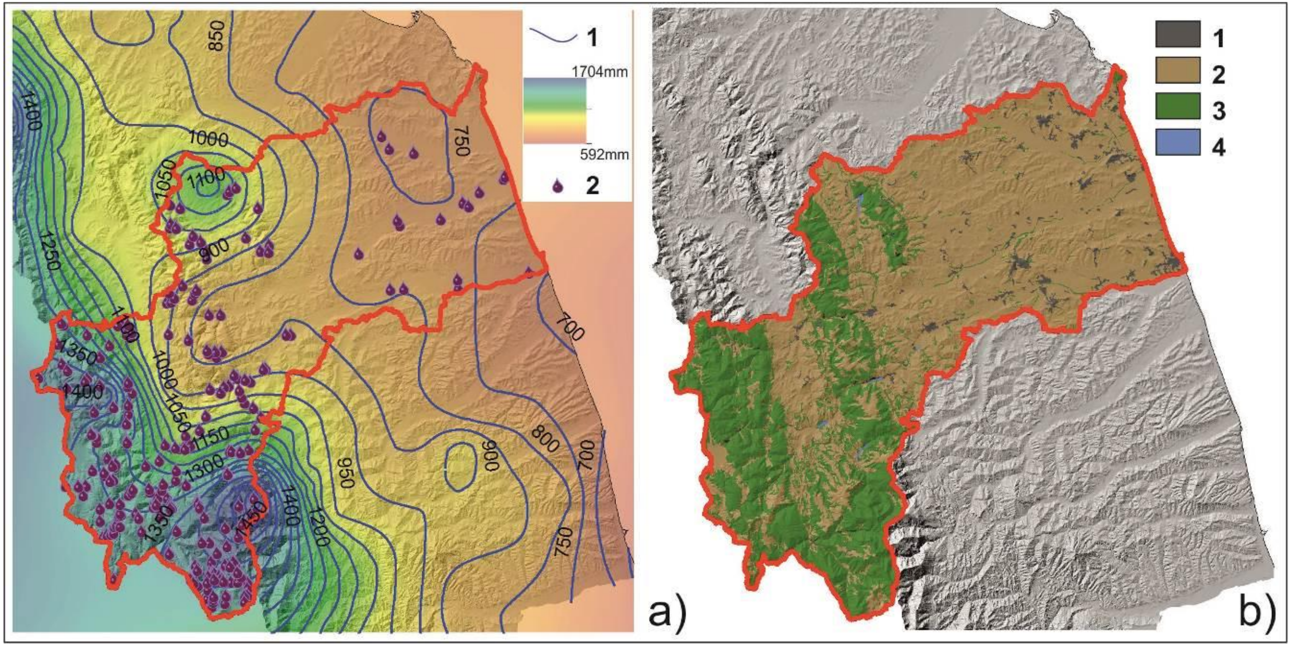


Figure 2.7: a) Pluviometric characteristics of the test area: 1. isohietal line; 2. water supply facilities. b) Land use classes (based on the Corine Land Cover, 2006): 1. artificial surfaces; 2. agricultural areas; 3. forest and semi-natural areas; 4. water bodies.

Main characteristics of the test area ATO3 are presented in table 2.2.

Table 2.2: Characteristics of test area ATO3 (Nardi et al., 2015)

Name	**ATO3**	
WR	**WR-1 (Calcareous Ridges)**	**WR-2 (Alluvial Plains)**
Related Cities	Acquacanina, Apiro, Belforte del Chienti, Bolognola, Caldarola, Camerino, Camporotondo di Fiastrone, Castelraimondo, Castelsantangelo sul Nera, Cessapalombo, Cingoli, Fiastra, Fiordimonte, Fiuminata, Gagliole, Monte Cavallo, Muccia, Pievebovigliana, Pieve Torina, Pioraco, Poggio San Vicino, San Severino Marche, Sefro, Serrapetrona, Serravalle di Chienti, Ussita, Visso	Appignano, Civitanova Marche, Corridonia, Macerata, Montecassiano, Montecosaro, Montefano, Montelupone, Morrovalle, Pollenza, Porto Recanati, Potenza Picena, Recanati, Tolentino, Treia, Castelfidardo, Filottrano, Loreto, Numana, Osimo, Sirolo
Geographic coordinates	[12°50' – 13°15'] E [42°52' – 43°26'] N	[13°16' – 13°45'] E [43°06' – 43°33'] N
Altitudinal range	300m-2210m a.s.l.	0m – 350m a.s.l.
Size	~ 963 km^2	~ 834 km^2
Morphology	Calcareous ridges and high-hilly reliefs. Presence of tectonic-karstic depressions	Gently sloping or flat alluvial plains with presence of several order of fluvial terraces
Aquifer type	Presence of at least three overlapped aquifers, sometimes hydraulically connected: groundwater circulation mainly due to a secondary porosity connected to several joint and fracture networks	Mainly unconfined sandy-gravelly aquifers: local presence of perched or leaky confined aquifers near the coast
Surface water interaction	Interaction between the basal (regional) aquifer hosted in the "Calcare massiccio" complex and the main rivers cutting the calcareous ridges: presence of so called "linear springs"	Interaction between the water table aquifer and the main river beds: the riverbeds are usually fed by the aquifer, but groundwater flow can be locally reversed in presence of meanders or during high stream stages or flood episodes
Geology	Limestones, marly limestones and marls	Gravelly-sandy-silty alluvial deposits
Mean annual precipitation	1200-1300mm	600-1100mm
Mean annual temperature	11°-13°C	15°C
Soil types	Reptosols, Regosols, Phaeozems, Cambisols, Luvisol	Fluvisols, Leptosols, Cambisols, Luvisols
Land uses *(Based on the CORINE Land Cover 2006)*	Agriculture: 35% Forestry: 63% Artificial surfaces: ~ 1% Water bodies: ~ 1%	Agriculture: 77% Forestry: 16% Artificial surfaces: 6% Water bodies: <1%
Protection areas	Protection areas have been defined only in few sites using mainly an "hydrogeological" or mixed "temporal-hydrogeological" methodology, on the basis of methods known in the literature	Well-head protection areas have been only locally defined using a temporal methodology
Water abstraction (Mm^3/year)	Drinking: 19,1 Industrial: 2,2 Agricultural: 10,3 **Total: 31,4**	Drinking: 26,2 Industrial: 6,5 Agricultural: 19,7 **Total: 52,4**

2.1.3. OSTUNI

From Annex 3:

The Ostuni test area includes the territories belonging to the Municipality of Ostuni and the surrounding 23 municipalities which span from the Adriatic to the Ionian coast of the Apulia region. This extended area has been selected for the WP4 as an interesting hydrogeological domain for the whole Puglia region, due to the high natural recharge rate in the inland plateau and high degree of groundwater exploitation in the lowland coastal areas. The test area is shown in the following Figure 2.8.

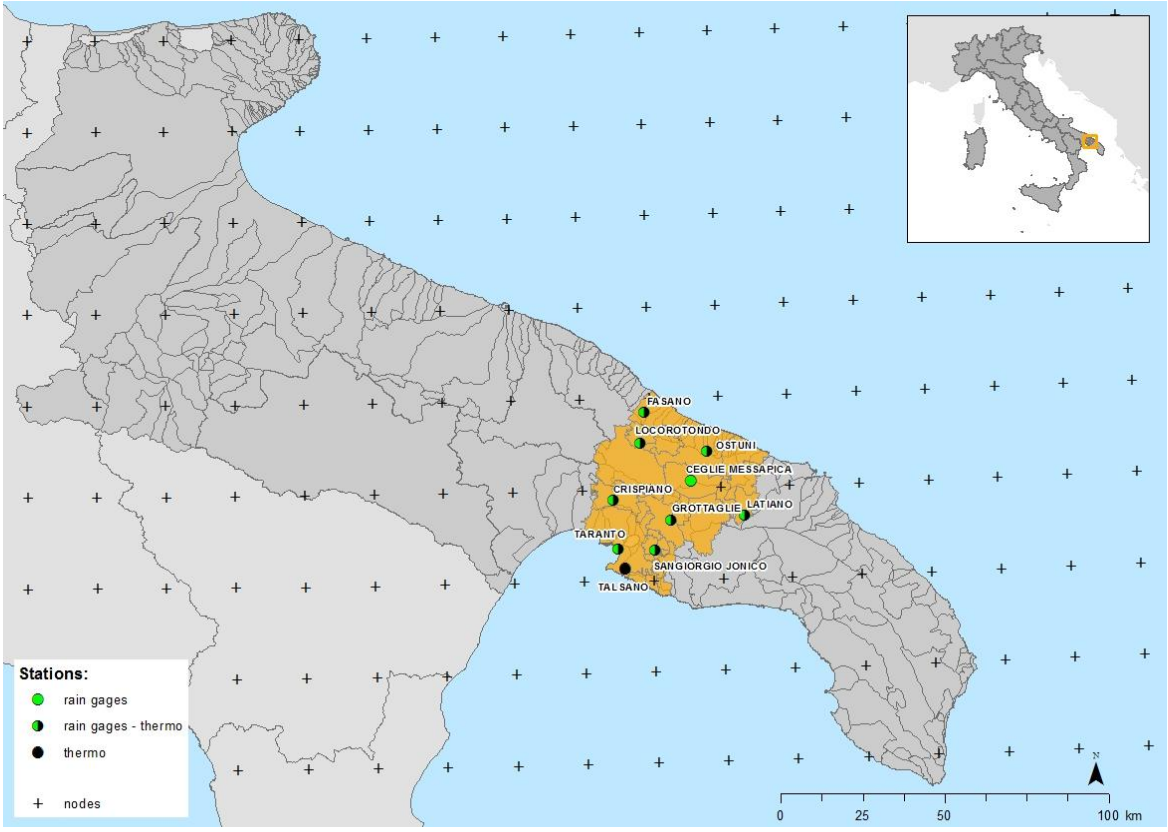


Figure 2.8: Position of the Ostuni test area in Southern Italy with representation of climate stations.

A fast growing trend in the irrigation demand was observed in the last decades leading to a massive exploitation of groundwater resources. As a result, the groundwater level has dramatically decreased and sea water intrusion was observed in most of the coastal zones. An increasing trend was also observed in the touristic sector in the last two decades along the coastal areas with consequent increase of water demand for drinking and gardening (e.g. golf courses).

In several coastal areas, groundwater salinity became incompatible with irrigation practice and most wells were abandoned having TDS values above 6 g/L. The observed trend in seawater intrusion is quite insensitive to the occasional very wet years (rainfall above normal values) and asks for innovative groundwater management measures as investigated in WP6.

Remediation actions to improve groundwater quantity and quality are necessary. A mathematical model will be applied in the WP6 to simulate the sea water intrusion and pollutant migration in groundwater under different scenarios by considering both global warming and anthropogenic impacts on groundwater. FB3 will investigate the best groundwater management options in order to improve water quality by reversing the sea water intrusion. The estimation of the groundwater volumes potentially recovered will be used as water supply for touristic areas.

Main characteristics of the test area Ostuni are presented in table 2.3.

Table 2.3: Characteristics of test area Ostuni (Water Research Institute - National Research Council, 2015)

Name	**OSTUNI WP4 TEST AREA**
Related city	Ostuni
Geographical coordinates	40.630° N 17.740° E
Altitudinal range	0 m- 510 m
Size	1992 km^2
Morphology	Hills and carbonate plateau sloping seaward to flat coastal plains. Presence of endoreic catchment related to tectonic and karst phenomena.
Aquifer type	Karst limestone aquifer
Surface water interaction	None. With ephemeral streams perching to groundwater.
Geology	Carbonate rock with terrarossa and silicate sedimentary rocks.
Mean annual precipitation	594 mm
Mean annual temperature	15.65°C
Soil type (WRB-UTS1)	Epileptic Luvisol, Calcic Kastanodem, Rhodic Luvisol, Chromic Luvisol, Endoskeletic Phaeozem
Land uses	Agriculture 80% Forestry 13% Artificial surfaces 7% Water bodies 0%
Protection areas	Groundwater protection zones for natural recharge areas; Banned groundwater exploitation areas for salinity excess.
Water abstraction (*) from extra-regional water resources	Drinking*: 66.0 Mm^3/yr Touristic*: 1.4 Mm^3/yr Industrial: 4.2 Mm^3/yr Agricultural: 73.9 Mm^3/yr Total groundwater abstraction rate: 2480 l/s

2.2. SLOVENIA - KOBARIŠKI STOL, MIA AND MATAJUR AQUIFER

From Annex 4:
Slovenia test area covers three potential aquifers; Kobariški Stol, Mia and Matajur aquifer, which are located in NW Slovenia. Due to mostly mountainous area and low human pressure, this area is one of the less polluted areas in Slovenia. At four locations within the test area the water flow and/or lever of surface water is measured for the national monitoring and these are the only measured data for water resources availability assessment.

Water availability analysis for the test area Kobariški Stol aquifer was performed in the frame of the research of the drinking water resources in the Posočje area (Brenčič et al., 2001). Report done by FB5 summarizes the results of that research, which are essential for determining water availability in the Kobariški Stol area as a part of test area within DRINKADRIA project.

The test area (Figure 2.9) in Slovenian-Italian border covers the areas of Kobariški Stol, Mia and Matajur aquifers. Geological and hydrogeological characteristics of these aquifers are potential to capture high-quality drinking water (Žvab Rožič et al., 2015). Detailed investigations of water availability were carried out within the area of Kobariški Stol (Brenčič et al., 2001) that cover the northern part of test area (red circle on Figure 2.9).

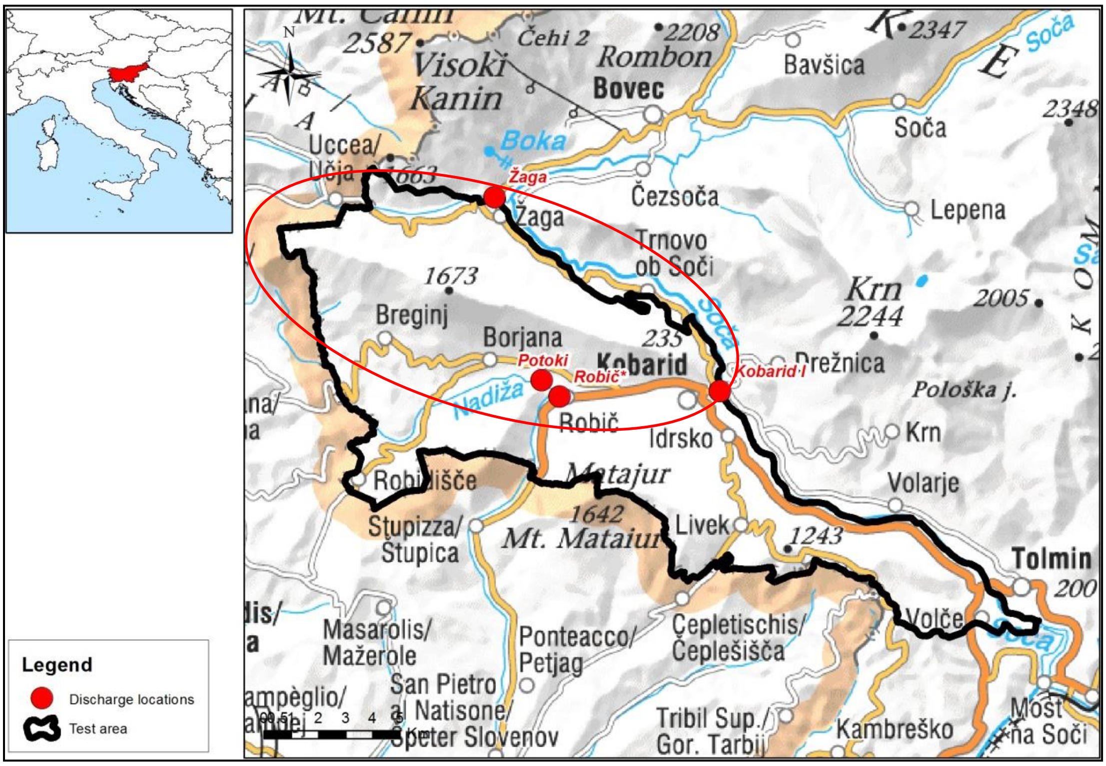


Figure 2.9: Locations of monitoring stations for hydrological measurements on surface waters within the test area Kobariški Stol

Main characteristics of the test area Kobariški Stol, Mia and Matajur aquifers are presented in table 2.4.

Table 2.4: Characteristics of test area Kobariški Stol, Mia and Matajur aquifers (Žvab Rožič et al., 2015)

Name of test area	Kobariški stol, Mija and Matajur aquifers
WR	1 aquifer system, 3 aquifers
Related City*	Kobarid (46.248 °N, 13.579 °E)
Geographical coordinates	46.319 °N – 46.167 °N, 13.375 °E – 13.740 °E
Altitudinal range	152 – 1648.4 m (687.2 m)
Size	163 km^2
Morphology	Mostly mountains, alluvial plane of Učja and Nadiža river
Aquifer type	Karstic
Surface water interaction	Unknown
Geology	Triassic to Upper Cretaceous Limestone, Upper Flyschoid Formation (*Figure 2*)
Mean annual precipitation	Meteorological station Kobarid 2681.1 mm (1596.0 – 4354.2 mm), Livek 2543.8mm (1496.8 – 3679.8 mm) and Žaga 2964.6 mm (1828.0 – 4041.5 mm)
Mean annual temperature	Meteorological station Vogel: 4.89 °C (3.60 - 6.12°C)
Soil types	Predominant soils on carbonate rocks; leptisols (redzic, mollic, lithic), cambisols (dystric, eutric), calcaric regosols, calcaric fluvisol, eutric gleysol
Land uses	Artificial areas (0.28 %), Agricultural areas (14.56 %), Forest and semi natural areas (85.27 %) (*Figure 4*)
Protection areas	Water protection zones: WPA I, WPA II, WPA III (*Figure 3*)
Water abstraction	No data

2.3. CROATIA

2.3.1. NORTHERN ISTRIA - SPRINGS SV. IVAN, GRADOLE AND BULAŽ

From Annex 5:

The analysed test area of northern Istria (Figure 2.10) lies in the westernmost part of Croatia and includes part of the basin of the Mirna River, the most important watercourse of the Istrian Peninsula. The largest part of the Mirna basin, whose total surface area is app. 700 km^2, lies on the territory of Istria County, i.e. Croatia, while its peripheral regions (surface area of app. 40 km^2) lie on the territory of Slovenia, from where certain karst springs are recharged. Practically one half of the Mirna water balance, estimated at its mouth at a total of 11.3 m^{3}s^{-1}, is accounted for by its permanent springs Bulaž, Mlini, Sv. Ivan and Gradole, intermittent springs Tombazin and Pivka, and several minor springs in the Mirna valley (Rubinić et al., 2006).

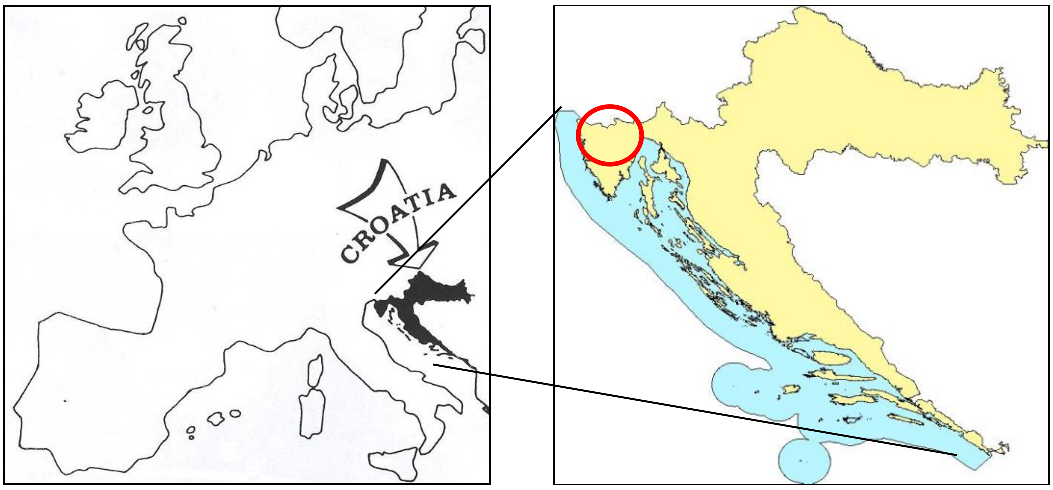


Figure 2.10: Position of the northern Istria test area in Croatia

In terms of its geological structure (Figure 2.11), this area belongs to the peripheral part of the Adriatic Carbonate platform (Herak, 1991). The geological structure includes carbonate and clastic deposits with stratigraphic range from the Upper Jurassic to the Eocene. In tectonic terms, the basic structure in Istria is the western Istrian anticline with Upper Jurassic limestones in the core. The central part of the Istrian Peninsula is composed mostly of flysch deposits and is relatively undisturbed. The northern, i.e. north-eastern part of Istria is characterized by significant structural disturbance which had caused the formation of complex flake structures with specific hydro-geological relations (Vlahović, 2001). The highest-lying parts of the basin lie in this area and belong to the thrust structures of the high carbonate massif of Mt Učka and Mt Ćićarija. The central and south-eastern parts belong to the Pazin flysch basin, while the north-western edge of the analysed area belongs to the Trieste flysch basin. The Buje carbonate anticline rises between these basins, while the western and south-western parts belong to the western

Istrian carbonate anticline. The Mirna River had formed its course between the above-mentioned structures, partly also through a valley area composed of an alluvial deposit reaching also deep below the sea level, thus retarding groundwater flow. Groundwater occurs in the form of several significant karst springs in the Mirna basin at a point of contact between the karst hinterland and the above-mentioned alluvial deposits. In the Buzet area, the discharge of springs is determined by the existence of a Buzet flysch depression. In Slovenia, the rising Brkini Mountains, also composed of flysch deposits of a widely distributed belt of Eocene flysch syncline Klana – Ilirska Bistrica – Trieste, border on the flattened Ćićarija massif from the north.

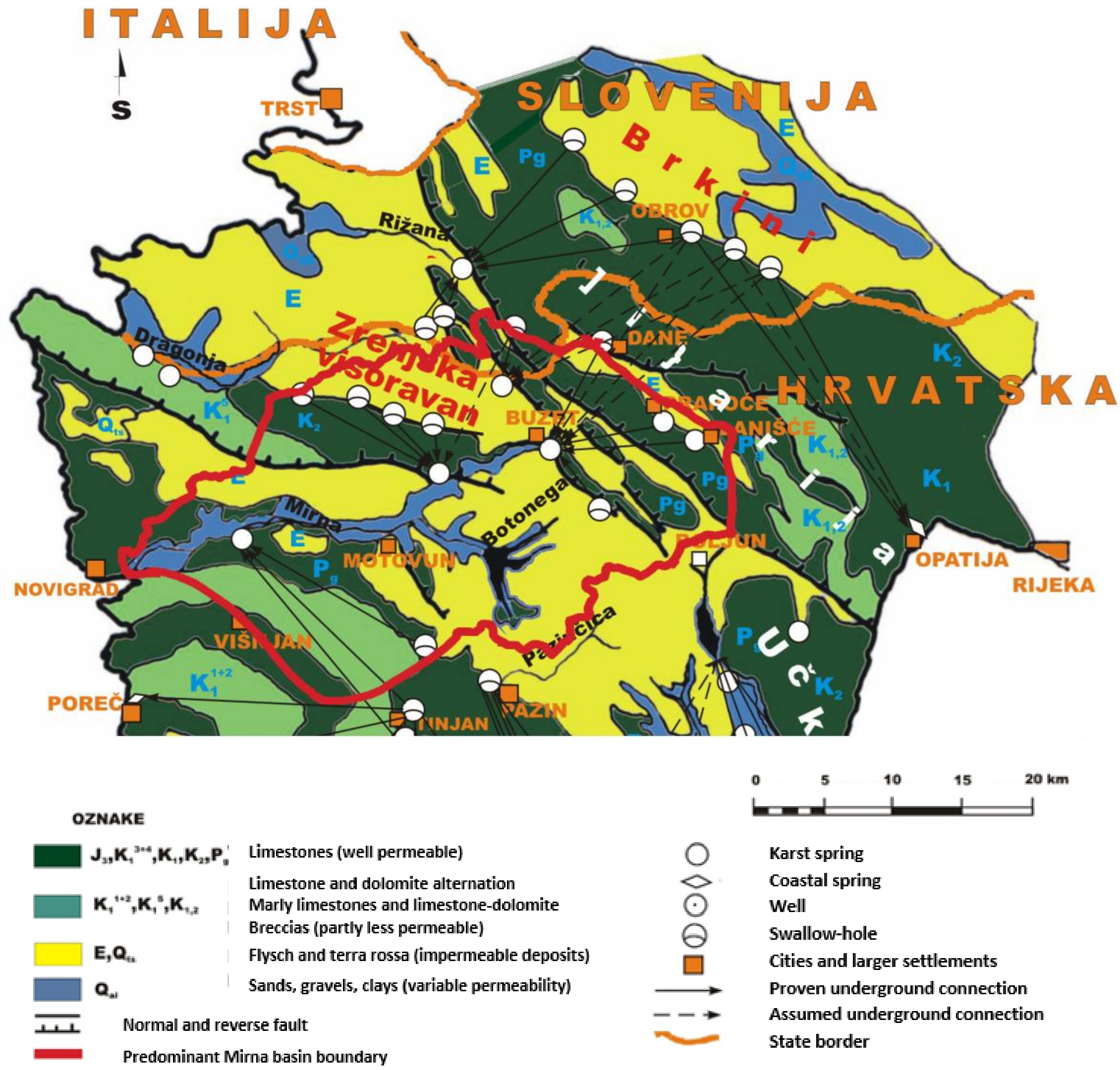


Figure 2.11: Geological structure of northern Istria

Due to the importance of the springs in the Mirna basin in Istria's water supply system (they meet app. 60% of all water supply needs), a relatively large number of dye tracing tests (Figure 2.11) had been done in the analysed area as part of water research works.

Their results, interpreted in detail by Urumović (Hidroprojekt-ing, 2000), indicate that it was exactly this complex system of recharge and discharge of springs in the analysed area of the Mirna basin that led to their high sensitivity both to the input and transport of pollution even to larger distances, including from transboundary regions.

For example, practically the entire drainage basin of Mlini spring and around 16% of the entire drainage basin of Bulaž spring (some 104 km^2) lie in Slovenia. The impacts of deep regional flows from the Slovenian karst are also recorded at Sv. Ivan spring, and according to some assumptions (Faculty of Mining, Geology and Petroleum Engineering, 1996; 1999), they are possible even at Gradole spring.

The results of the above mentioned dye tracing tests, balance analyses of the water quantities discharged at individual springs, and hydro-geological interpretation of the geological structure were used as the basis for defining the sanitary water source protection zones in Istria County, of which as much as three are karst springs in the Mirna basin, i.e. in the northern Istria test area. These springs are called Sv. Ivan, Gradole and Bulaž which is used as a back-up water abstraction site (Figure 2.12). One should also note the Butoniga reservoir with a volume of app. 20 million m^3. It also lies in the Mirna basin and has a dominant role in water supply, but the issues associated with it were not the scope of the present analyses.

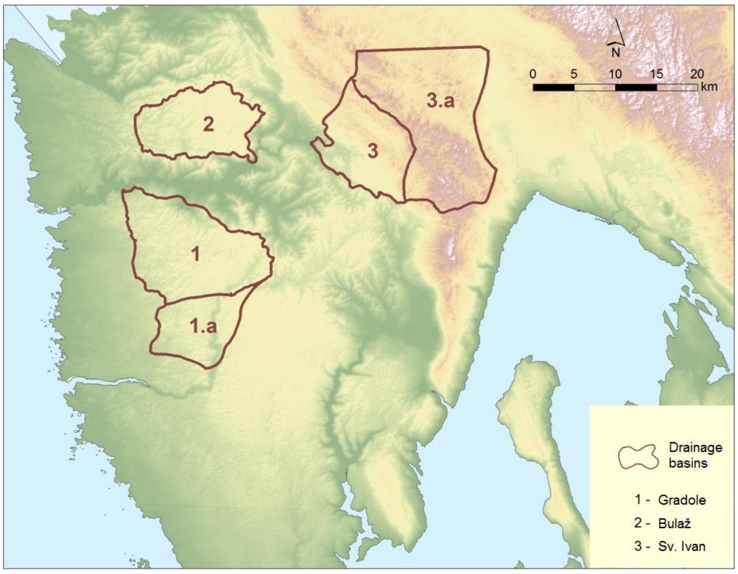


Figure 2.12 Drainage basins of the analysed karst springs in northern Istria

(Note: The letter "a" denotes those parts of the drainage basins of the analysed karst springs which represent a wider – potential recharge area but do not represent a zone of dominant water recharge as the drainage units denoted only with numbers)

Gradole spring is the most significant groundwater spring of the Istrian water supply system. Its yield varies between several hundred litres per second and more than 18 m^{3}s^{-1}. During approximately two months in the year all the available water quantities discharging at this spring are abstracted so it doesn't overflow. When the spring doesn't overflow, the yield and the water level at the spring are determined both by natural inflows and by the abstraction regime, which is why the minimum yield of this spring cannot be unambiguously specified – the lowest such recorded average monthly abstractions without overflow amounted to mere 0.280 m^3s^{-1}. Approximately 0.469 m^3s^{-1} is abstracted on average for water supply. The highest average abstractions are associated with the periods of the strongest water demand, in July and August, when the spring has sufficient yield, mostly in the range between 0.7 and 0.8 m^3s^{-1}, not rarely even up to 0.9 m^3s^{-1}. The maximum daily abstractions under favourable hydrological conditions even exceed 1.1 m^3s^{-1}. Some water from this source is also delivered to neighbouring Slovenia to improve water supply to its coastal region.

Sv. Ivan spring has a different recharge character compared to Gradole – it reacts much faster to rainfall in its drainage basin. Since the area of its recharge extends to Mt Ćićarija as well, the rainfall is generally more frequent and significantly heavier than in the Gradole drainage basin. This spring functions as a system of springs to which the main spring Sv. Ivan in Buzet belongs, but also several minor springs within sanitary protection zone I of Sv. Ivan spring, one of which is in certain years also used as a secondary spring that is seasonally put into exploitation. Tombazin spring, a very intermittent spring in terms of yield, also belongs to this system of springs. It lies upstream on the edge of the valley (where the Mirna branches, Rečina and Draga, join) and functions as an intermittent overflow due to the limited capacity of high water discharge at Sv. Ivan spring (app. 2.2 m^3s^{-1}). The average annual yield of the main spring Sv. Ivan has a relatively close range of between 0.657 m^3s^{-1} (registered in 2011) and 1.09 m^3s^{-1}. Even though this is an overflow karst spring, its minimum yields partly still depend on the water level at the spring and on the abstraction regime. As such, its yield ranges around 0.10-0.12 m^3s^{-1} on the level of average monthly discharges. Approximately 0.167 m^3s^{-1} on average is abstracted for water supply.

The highest abstractions are associated with the periods of the strongest water demand, in July and August, when the spring has sufficient yield, and they mostly exceed 0.2 m^3s^{-1}. The maximum daily abstractions under favourable hydrological conditions reach as much as 0.3 m^3s^{-1}.

Bulaž spring also has a different recharge character compared to Gradole – it reacts much faster to rainfall in its drainage basin since its drainage basin has a binary structure and is for the most part recharged from a number of surface watercourses in the Zrenjska plateau whose courses end in sinkholes at a point of contact between the water impermeable flysch and the carbonate anticline. The spring itself lies on the edge of the Mirna valley, near the Istrian thermal resort, and the bottom of the pond formed at its discharge point lies below the level of the sea from which it is more than 25 km away and separated by the Mirna valley which had been formed by sedimentation processes and which lies at app. 20 m. This spring is a back-up water abstraction site of the Istrian water supply system and is put into exploitation by conveying the abstracted quantities to Gradole spring. Since the second half of 2012, water has been also been conveyed through a newly built branch pipeline to the plant treating water from the Butoniga reservoir. Bulaž spring has an average annual yield of 1.3 m^3s^{-1}. Since its minimum yields partly also depend on the water level at the spring and on the abstraction regime, its average monthly overflow discharges amount to around 0.08 m^3s^{-1} at the level of natural discharges, and as much as app. 50% more when the quantities abstracted exceed the natural inflows. Since 1989, only app. 0.01 m^3s^{-1} has been abstracted for water supply. However, during extremely dry 2012, the average monthly abstraction amounted to 0.17 m^3s^{-1} in July and August, when such significant quantities were ensured by seasonal abstraction of its static water reserves.

The springs mentioned above are not affected by salinization even though they discharge at very low elevations (Gradole and Bulaž) since the active parts of their karst aquifers are separated from the impact of the sea with sedimentation processes (the Mirna valley). However, despite that, these springs are highly sensitive to climate change and to droughts which significantly reduce the available water balance of these springs in certain years.

The year 2012 was particularly critical as it had a character of a low water event with a return period between 100 and 200 years (Faculty of Civil Engineering Rijeka, 2013). Another problem is an unresolved issue of ensuring the environmental flow (EF), i.e. biological minimum, due to which certain parts of the Mirna course run completely dry in such exceptionally dry periods.

Namely, despite several prepared documents concerning EF assessment in the basin of the Mirna and its tributaries (Faculty of Civil Engineering Rijeka, 2008 & 2013; Oikon, 2013; IGH PC Rijeka, 2010), there is still no defined EF nor solutions on how to ensure it. One of the possible reasons for this is the present orientation to restrictive measures, i.e. “ensuring sustainable abstraction from Sv. Ivan and Bulaž springs which will not compromise the EF in the Mirna watercourse” (Oikon, 2013). A simplified look at this problem with a strict restriction of water abstraction from the springs for the needs of water supply would for now represent an irreparable loss of water intended for that purpose in the order of magnitude of several hundred l/s in extremely dry hydrological conditions. Due to an inability to ensure back-up water supply sources, this would imply imposing water use restrictions and even water-saving measures to the population and tourists in critically dry hydrological conditions. Hence, a more appropriate method is to define the EF and look for solutions which will enable optimization of use of all available surface water and groundwater resources, compensating for the low Mirna waters from the said springs used for water supply to the maximum extent by ensuring back-up water quantities from the surface reservoirs intended for flood protection and irrigation.

Main characteristics of the test area Northern Istria – springs Sv.Ivan, Bulaž and Gradole are presented in table 2.5.

Table 2.5: Characteristics of test area Northern Istria (Rubinić et al., 2015)

Name of test area	**Northern Istria - karst springs in Mirna river basin**		
WR	**Sv. Ivan**	**Gradole**	**Bulaž**
Related City*	*Priority*: towns/municipalities Buje, Buzet, Pazin, Brtonigla, Cerovlje, Gračišće, Grožnjan, Karojba, Kaštelir-Labinci, Lanišće, Lupoglav, Motovun, Oprtalj, Sv.Lovreč, Sv.Petar u Šumi, Tinjan, Višnjan, Vižinada, Vrsar, Žminj, Pićan above the level 330. *Possibility or occasionally*: towns/municipalities Poreč, Rovinj, Bale, Kanfanar. Water is also delivered to Rižanski vodovod Koper.	*Priority*: towns/municipalities Novigrad, Poreč, Rovinj, Umag, Vrsar. Water is also delivered to Rižanski vodovod Koper. If necessary, water is also delivered to Vodovod Pula.	Bulaž is used to recharge spring Gradole and reservoir Butoniga. Exceptionally water can be directly inserted into the pipeline Sv.Ivan. **Butoniga**: *Priority*: towns/municipalities Pazin, Rovinj, Bale, Cerovlje, Gračišće, Kanfanar, Sv.Petar u Šumi, Žminj. *Possibility or occasionally*: towns/municipalities Poreč, Sv.Lovreč, Vrsar, Pićan above the level 330. Water is also delivered to Vodovod Pula.
Geographical coordinates	Lat. 45.401 Long. 13.977	Lat. 45.343 Long. 13.704	Lat. 45.380 Long. 13.891
Altitudinal range	Min.: 47 m a.s.l. Max.: app. 1106 m a.s.l.	Min.: 3,5 m a.s.l. Max.: app. 480 m a.s.l.	Min.: 15 m a.s.l. Max.: app. 492 m a.s.l.
Size	About 102,97 km^2 (predominant inflow area of the spring is adopted)	About 162,79 km^2 (predominant spring catchment)	About 108,02 km^2
Morphology	Mountain coastal areas with altitudes up to about 1000 m a.s.l. Spring Sv.Ivan is located in valley area.	The upper parts of sub-basins have the character of highlands (500 m a.s.l.). Spring Gradole is located in valley area.	The upper parts of sub-basins have the character of highlands (500 m a.s.l.). Spring Bulaž is located in valley area.
Aquifer type	Karstic aquifer: spring	Karstic aquifer: spring	Karstic aquifer: spring
Surface water interaction	River Mirna.	River Mirna.	River Mirna.

	Sinking rivers on the Ćićarija area.	Basin/watercourse Marganica.	7-8 surface watercourses from Zrenjska plateau.
Geology	In the basin of spring Sv.Ivan generally prevails karst which alternates with flysch area.	The basin of spring Gradole is made of carbonate rocks and partly of flysch deposits.	On the basin of the spring karst and flysch alternate.
Mean annual precipitation	1559,8 mm	1066,7 mm	1195,6 mm
Mean annual temperature	10,1 °C	11,3 °C	11,0 °C
Soil types	Rendzic Leptosols and Chromic Cambisols	Chromic Luvisols, Rendzic Leptosols and Chromic Cambisols and Eutric, Calcic Gleysols	Rendzic Leptosols and Chromic Cambisols
Land uses	Discontinuous urban fabric 0.50 %, Pastures 2.61 %, Coniferous forest 4.07 %, Land principally occupied by agriculture 5.18 %, Complex cultivation patterns 6.53 %, Natural grasslands 7.45 %, Transitional woodland 9.74 %, Mixed forest 10.62 %, Broad-leaved forest 53.31 %. (by CLC in 2012)	Non-irrigated arable land 0.21 %, Coniferous forest 0.40 %, Discontinuous urban fabric 0.98 %, Vineyards 2.46 %, Pastures 5.73 %, Complex cultivation patterns 7.73 %, Mixed forest 7.92 %, Transitional woodland 12.69 %, Broad-leaved forest 26.41 %, Land principally occupied by agriculture 35.48 %. (by CLC in 2012)	Mineral extraction sites 0.21 %, Coniferous forest 1.10 %, Complex cultivation patterns 2.91 %, Pastures 10.99 %, Mixed forest 12.02 %, Transitional woodland 14.70 %, Land principally occupied by agriculture 22.53 %, Broad-leaved forest 35.55 %. (by CLC in 2012)
Protection areas	Water protection zones.	Water protection zones.	Water protection zones. Protected site - a forest vegetation reserve Motovun forest.
Water abstraction	Sv.Ivan: Monitoring period: 1986.-2012. Mean annual abstraction: 0,167 m^3s^{-1}	Gradole: Monitoring period: 1987.-2012. Mean annual abstraction: 0,469 m^3s^{-1}	Bulaž: Monitoring period: 1989.-2011.(2012.*) Mean annual abstraction: 0,010 m^3s^{-1} *incomplete due to construction interventions during extremely dry 2012

*Cities and rural settlements receive their drinking water supply from the test area.

2.3.2. SOUTHERN DALMATIA - SPRING PRUD AND BLATSKO POLJE

From Annex 6:

Investigated test area of Southern Dalmatia (Figure 2.13) is associated with two systems which are hydrologically independent (the island of Korčula and Prud spring in the Neretva River valley) but which are in hydro-engineering terms connected with the Neretva – Pelješac – Korčula – Lastovo (NPKL) water supply system for which water is abstracted exactly at Prud spring. It is a regional water supply system which supplies parts of the area in the Neretva valley (Metković, Opuzen and the surrounding settlements), the Pelješac Peninsula, the island of Korčula, with submarine pipelines built towards the islands of Lastovo and Mljet. Part of the island of Korčula is supplied with water from the island's local aquifer – wells in Blatsko polje.

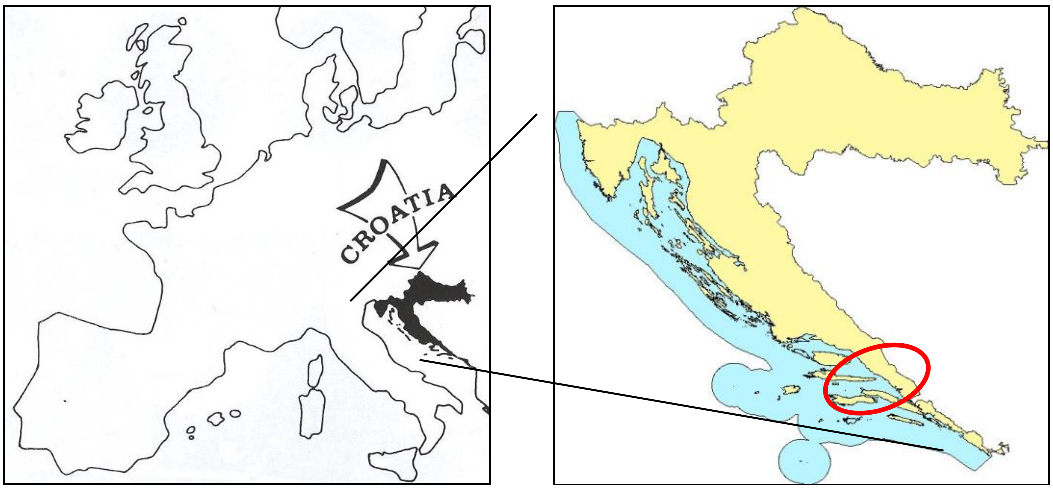


Figure 2.13: Position of the Southern Dalmatia pilot area

Prud is a spring with a very high average discharge (app. 6 m^3s^{-1}), as well as a very high minimum discharge (app. 2 m^3s^{-1}). For the purpose of supplying water to the above-mentioned areas, it is equipped with a spring-water intake with a capacity of 0.38 m^3s^{-1}, from which app. 4 million m^3 of water is abstracted annually. What makes it specific is the fact that its drainage basin lies almost in its entirety on the territory of neighbouring Bosnia and Herzegovina. Prud spring itself is the origin of the Norinska River, the right tributary of the Neretva River. With underground hydrographic connections, Prud spring is connected with waters from the Trebižat river basin with a total catchment area of app. 1,450 km^2 (Slišković and Ivičić, 2000), which is also the right tributary of the Neretva. This is a hydro-geologically and hydrologically complex system of a sinking river which bears as much as six names in different parts of its course. In the highest horizon (app. 900 m above sea level), it starts its flow as the Ričina, flows through Pošučko polje as the Suvaja, enters the Vrljika in Imotsko polje, sinking into the Sajinovac sinkhole near Drinovci in Herzegovina under the name of Matica. After 2 km of underground flow, it resurfaces as Tihaljina, after which it has a continuous surface flow, but nevertheless changes its name three more times, at first into Sita, then into Mlade, and eventually into Trebižat, its best-known name, as which it enters the Neretva. In its course it has losses which appear as inflows in the neighbouring drainage basins, including in the drainage basin of Prud spring. Due to the transboundary character of the aquifer of Prud spring which surfaces only 300 m from the border between Croatia and Bosnia and Herzegovina, with practically its entire drainage basin lying in neighbouring Bosnia and Herzegovina, Prud was selected as of the test areas within the DRINKADRIA Project. Several partners have been involved in research in this area. Croatian meteorological and hydrological service has made climatological analysis, Faculty of Civil Engineering – University of Rijeka has made hydrological analysis, Croatian Geological Survey (CGS) taking part of analysis in the field of hydrogeological considerations from both sides of the border. Also, document “Trebižat River – Water Balance” (HEIS, 2015) done by Hydro-Engineering Institute of the Faculty of Civil Engineering in Sarajevo (HEIS) which is prepared within the Drink-Adria Project was taken into account when preparing this report (see chapters 2.4 and 3.5) . The other part of the analysed Southern Dalmatia pilot area is Blatsko polje on the island of Korčula, with a very small drainage basin (28.4 km^2) and an island aquifer, with the characteristics of its water balance and estimations of climate change impacts on the availability of water analysed under an earlier EU-financed project, CCWaterS (CCWaterS, 2012) from which the summary results have been taken over, as well as the methodology used for the analyses made for Prud spring.

Main characteristics of the test area Southern Dalmatia – spring Prud and Blatsko polje are presented in table 2.6.

Table 2.6: Characteristics of test area Southern Dalmatia (Lukač Reberski et al., 2015)

Name of test area	Prud catchment area	Blatsko polje catchment area
WR	Springs	Wells and spring
Related City*	Metković	Blato
Geographical coordinates	N43,095; E17,619	N42,950; E16,760
Altitudinal range	10 – 1660 m a.s.l.	5,2 – 15 m a.s.l.
Size	2296 km^2	28,4 km^2
Morphology	Hills and karst polje	Hills surrounding karst polje
Aquifer type	Karst aquifer	Karst aquifer
Surface water interaction	Rivers - groundwater interaction through swallow holes	None
Geology	Limestone, dolomite, lake sediments	Limestone, dolomite, lake sediments
Mean annual precipitation	1200 mm	860 mm
Mean annual temperature	12˚C	15,4 ˚C
Soil types	Terra rossa, fluvisol, semigley, eugley, chernozem, brown soils, antropogenic soil, rendzina	Chromic cambisol, rendzic leptosols
Land uses	Forest and semi natural areas: 68,88 % Agricultural areas: 29,14 % Artificial surfaces: 1,77 % Water bodies: 0,18 % Wetlands: 0,04 %	Agriculture: 56,8 % Forestry: 38,7 % Artificial surfaces: 4,5 %
Protection areas	Water protection zones	Water protection zones
Water abstraction	100 L/s	50 L/s

*Cities and rural settlements receive their drinking water supply from the test area.

2.4. BOSNIA AND HERZEGOVINA – TREBIŽAT RIVER

From Annex 7:

Prud is a water source located in Croatia, while majority of its catchment area is located on the territory of BiH.

Water balance of the Trebižat River and hydro-geological map were prepared in order to assess water availability in the pilot area Prud due its significance for the water resources management process as one of the main objectives of the DRINKADRIA project and the main objective of WP4. During the project implementation, hydrological measurements were carried out in the period of 12 months between March 2014 and March 2015. These measurements were carried simultaneously by both FB09 from Croatia and FB12 from BiH. Collected data were used as inputs for this report in order to determine common indicators of risk and present and future water demand. Combination of data collected from different sources was jointly analysed and used for an ultimate objective of determining water availability in this area. In particular, it was used as a basis for determining an impact of water phenomena on the territory of BiH on the recharge of the Prud spring.

First a brief description of the test area hydro-geology and summary of the significant springs and sinkholes in the catchment area considered belonging to both the Trebižat River and the Prud spring is given. In this sense, it is necessary to identify approximate borders of the afore-mentioned catchment area on the territory of BiH. North-western border of the Prud spring on the territory of BiH starts with the location of Cera Pusića (border with the Republic of Croatia) stretching in the direction of northeast and the location of Lučina. In this location, the catchment area border runs in the direction of Zavelim, trigonometric point Kolokovac (elevation: 1,347), Grad (elevation: 1,012), and the settlement of Nevistići (elevation: 937). From this location, it continues further into the area of Raško Polje, surrounds the settlement of Radoši and the area of Rudine including the mount Mala Takošnica (elevation: 1,032), and reaches Ravno Brdo, Bojin Dolac (the mount Midena), Studena Vrila, Provaljenica and the mount Gvozdac (elevation: 1,153). With this elevation, line of the Prud catchment area enters the area of the mount Oštrc and reaches the elevation point (1,080) in the direction of Veliki Oštrc and Malo Oštrc via Koprivnjak. This position presents a basis for leading the catchment area borders across the ridge Jaram towards trigonometric point Krajnja Glavica (elevation: 1,087) and trigonometric point Kolobarića K (elevation: 1,362). Position of this trigonometric point has a contraflexure, i.e. modified direction of the Prud catchment area border (northeast – south). In the area of the mounts of Štitar Planina and Debelo Brdo, including the valley Donje Konjsko as well, the catchment area borders the Ugrovača River sinkhole. In this location, the joint cuts through the valley Rakitno, surrounds trigonometric point Kozja Glavica (elevation: 1,007) via Sutina and Korito and enters into the plain between Privatina and Ravna. By following this direction, the catchment area border surrounds the village of Galići and reaches the areas of Rupa and Zvirići across the Trebižat River, via the line Čerkezi – Baraći – Skoki – Čerkezi (Kosmaj) – Šarovanja – Soldatuša (elevation: 250) along the location Gradska, i.e. Mostarska vrata. After this, it reaches the area of Ajderova Greda and completely surrounds this spring via the line Garišta.

According to hydro-geological features (covering large area on the territory of Bosnia and Herzegovina), the Prud catchment area includes the area comprising sediments of large water permeability (cavernous-fractured porosity), sediments of medium water permeability (fractured porosity), as well as sediments of low or no water permeability at all (generally without noticeable porosity features).

In the hydro-geological sense, the Prud spring is located in the limestone-dolomite area of the cavernous-fractured type of porosity, primarily dominated by the Upper Cretaceous sediment (K2). In this sense, the entire Upper Cretaceous of the analysed area presents a powerful hydro-geological collector of the cavernous-fractured porosity. It is an aquifer of exceptionally karst features into which atmosphere and surface water migrates through chasms and fractures, as well as complex groundwater flows and relatively fast circulation in the ground, which enables water to reappear on the surface in the form of strong springs.

Lower cretaceous sediments (K1) have dominantly the feature of low water impermeability. Better collecting features are present only in the area of higher horizons. Result of these features is conditioned by strong lateral tectonics. Their karstification is related to the younger carbonate sediments. They have changeable porosity, including low fractured and cavernous porosity, and have a role in forming direction and intensity of the karstification of the younger cretaceous sediments.

In the lower levels of this chronostratigraphic member, massive and banked dolomites dominate and form a massif with the function of hydro-geological isolator in the hydro-geological sense. As a result, low effective porosity was identified, which includes low water impermeability, while there are also rear barriers. They are inclined to disintegration into fiddling dolomite sand, and they appear within anticlinal nucleuses and local hydro-geological joints (such as the case of pilot area).

In addition to depository area of the Upper cretaceous, Promina sediments (E, Ol) also belong to the same group of water impermeable sediments according to hydro-geological features. Lithologically, they are formed by conglomerates, marl limestone and marls. Therefore, this is a medium hydro-geological collector of fractured porosity. Locally, more significant porosity can be noticed, as well as features of cavernousity, related to the zones of intensive tectonic disruptions. The drilling proved that more intensive porosity in these sediments occurred in smaller depths of 100 metres.

The category of water impermeable rock includes the sediments of Eocene (E1,2), (E2,3), and Miocene (1M) and (2M). They are very rare within the pilot area and, according to their low collecting features, they have only local significance. In contact with water impermeable area, the occurrence of spring with a limited capacity may be noticed. In general, they are characterized by the weak fractured porosity and thus have a function of hydro-geological isolator. In the area they dominate, they are recognized as relatively limited lateral hydro-geological barriers.

The area covered by the Prud catchment area also includes Quaternary (Q), sedimentation area of various features of the groundwater filtration flow. Due to its surface dominance, as well as super position relations towards described sediments of large and medium porosity, it has an important role in determining hydro-geological relations that have an impact (potential or registered) on this spring.

Regarding the above description of hydro-geological features of the presented lithographic entities, the occurrence of more important water phenomena in the Prud spring catchment area will be presented in Chapter 3.5.

2.5. MONTENEGRO – NIKŠIĆ

From Annex 8:

The test area of Nikšić is located in Central - Western part of Montenegro as depicted in Figure 2.14. More precisely, drinking water sources (karst springs) are located in Nikšićko Polje, karst field with significant water yield and partly within the Upper Zeta river basin.

Figure 2.14: Position of Upper Zeta catchment

Drainage area of Upper Zeta catchments is 327 km^2 while area that covers Drinking Water Protection Zones (*inner -I, middle - II and outer -III*) for 3 sources used for water supply is approximately 310 km^2 based on Report on Drinking Water Protection Zones (DWPZ) for Poklonci source.

Two other springs Gornji and Donji Vidrovan are located within this area as well. Different geological groups of rocks create study area.

Terrains are predominantly comprised of rocks from a group of hydrogeological collectors with fracture and cavernous porosity that are Mesozoic carbonate sediments characterized by limestone. Besides to this there are Mesozoic dolomites and hydrogeological isolators represented by Younger Paleozoic, clay-marl layers, volcanic rock of volcanic rocks of

Triassic age, Jurassic layers of marl, and clay-marl-sandy and calcareous layers of Upper Cretaceous and Cretaceous-Paleogene flysch.

Given the hydrogeological properties of study area groundwater water divide at test area is not precisely delineated and very likely drainage area that contributes to recharge extends outer DWPZ, i.e., 310 km^2. The same applies to Nikšićko polje and Upper Zeta. Location of Upper Zeta and outer DWPZ for test area water sources are presented on Nikšićko polje hydrogeological map in Figure 2.15.

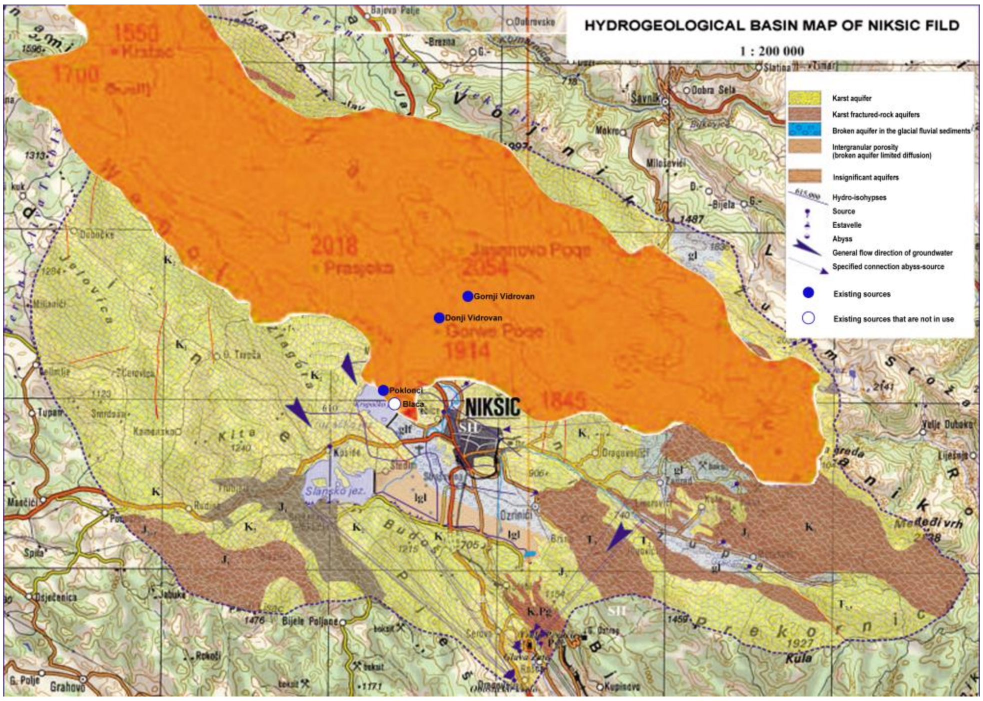


Figure 2.15: Location of Upper Zeta and DWPZs on the Nikšićko Polje hydrogeological map

Data presented in this section refer to meteorological station Nikšić. Based on the literature review, yearly precipitation average varies from 1986 up to 2200 mm per year, very likely due to different time frame analyzed.

Rainfall distribution during the year is characterized by maximum at the end of fall and beginning of winter and minimum quantity during the summer season in July. Data and information for monitored evapotranspiration (ETP) are reported in Montenegro Water Management Master Plan (2001) as summary values for Bar, Podgorica and Nikšić. Average ETP is approximately 1200 mm/year, with highest values observed during the summer season that are 5 to 6 time higher in comparison with spring, fall and winter for all stations.

Data for temperature are more uniformly reported in different reports and studies with annual average value of 10.7 °C, and minimum and maximum - 4.3 °C and 24.2 °C in January and July, respectively.

Given the scope of this report high percolation rate should be underlined with respect to groundwater recharge drainage area hydrogeological characteristics.

The water supply system of the city of Nikšić consists of springs, wells and pumping facilities, chlorine stations, reservoirs, booster units and primary and secondary network. The town and its suburban areas are water supplied from the sources Gornji Vidrovan, Donji Vidrovan and Poklonci.

Approximately 66,000 users are water supplied from these sources. The water supply system serves about 22,000 households and approximately 1,500 business entities. On average approximately 400 l/s of treated - chlorinated water is supplied by pumping stations. During the period of increased consumption, as a result of higher temperatures and agricultural needs, supplied water quantity ranges from 500 to 600 l/s for the period June - September.

Gornji Vidrovan is the main source which was tapped and put into operation in 1983. Its maximum capacity is over 1,000 l/s, which is more than enough for normal water supply of the city and its suburban area for period (November - June). The source is located in extremely karsts area and therefore due to increased consumption within the period of the year (July - September) with increased temperatures the water source rapidly loses its yield and comes to a minimum of about 150 l/s. The source is of a closed type; it is physically and technically protected and it has defined and marked water protection zones.

Donji Vidrovan is the source which was tapped in 1929 and 1954 and it was the only source for drinking water supply system. It is used all year round for the water supply of the northern part of Nikšić field (Vidrovan, Gornje Polje, Rastovac, and Miločani) as well as during dry summer months July - September. The spring has a maximum yield of 300 - 400 l/s in the period November - June, but it also loses its yield in the dry season (as well as the main source Gornji Vidrovan), which in some years reaches a minimum of 50 to 100 l/s. The source is also closed, physically and technically protected and has identified and marked water protection zones.

Poklonci karst spring was put into operation at the end of September 2008. This source is of a well type with a maximum capacity of about 190 l/s. It is only used in the dry season (July - September) due to reduced inflow of the previously mentioned springs in summer season. This water source has significantly reduced the problems of water supply in the city. Well pumps that are located at a depth of 28-30 m are physically and technically protected.

Wells B1 and B2, which are located within Donji Vidrovan, were put into operation in 1999; they have small capacities, in minimum 20 l/s & 10 l/s, but they are also used in the dry season. It is interesting that the water quality parameters from all three sources have approximately the same characteristics. The total water quantity from all sources is about 400 l/s in the minimum, which is on the limit of water demand in urban and suburban areas. As a result, two additional wells, with a capacity of 30-35 l/s each, have been examined and piped in Blace and in the vicinity of Poklonci. There is a plan to utilize these wells in the coming period.

Water is distributed by pump stations Duklo and Donji Vidrovan, well facility Poklonci and wells B1 and B2. A pumping station Duklo is the main facility used for water supply of the town and its suburban areas. In 2013, pump units and control system were replaced and therefore the operational safety is at a high level and with proper maintenance it is expected to run safely for the long period of time. It consists of three pump units with the power of 315 kW with centrifugal pumps, frequency controlled operation with the capacity of 200-400 l/s. A pumping station Donji Vidrovan has been rehabilitated several times and it consists of two power units of 45 kW, with a capacity of 40 l/s each**.**

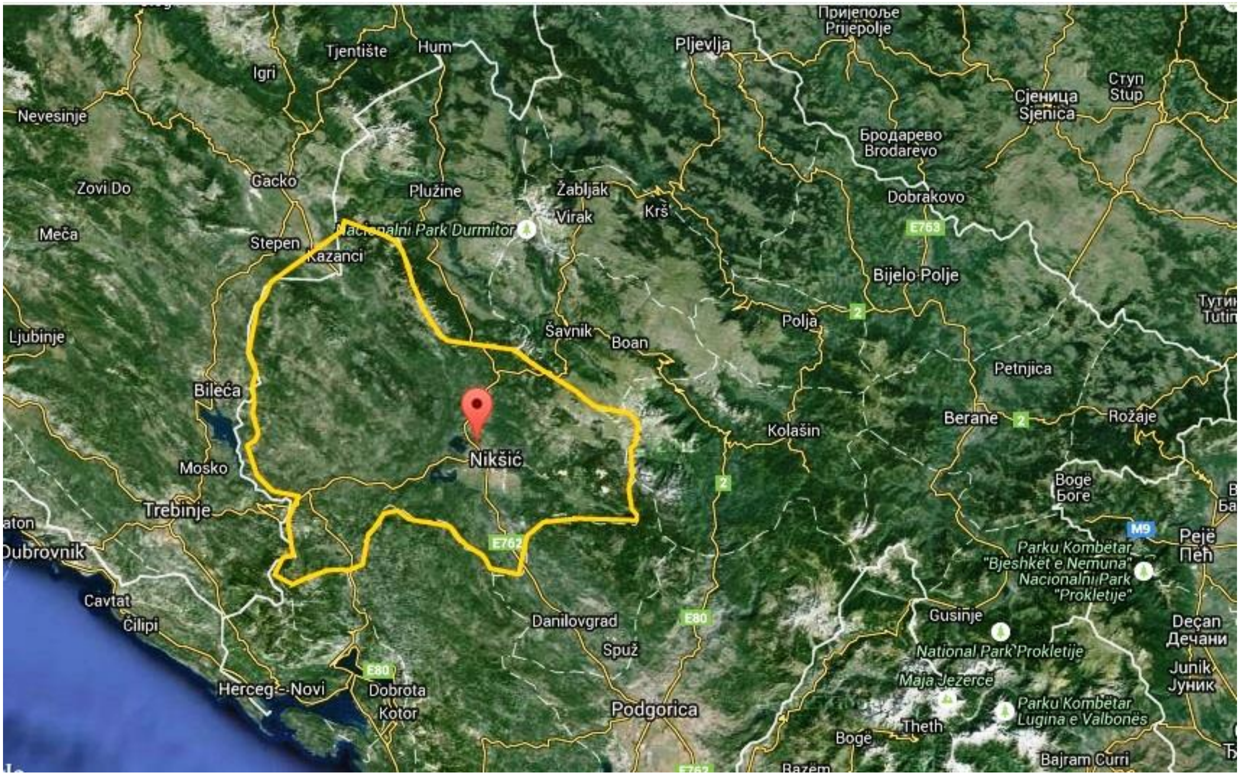


Figure 2.16: Nikšić municipality

The pumps are of a new generation with a variable frequency drive. Well pumping station Poklonci consists of five well pumps with the capacity of 30-40 l/s, accompanying well equipment, a control board with complete regulation and automatic control. A pumping station for Šipačno was put into operation in September last year; it is modern and it has automation and frequency regulation. Water is distributed to the village Šipačno by this pumping station, and in the future this pumping station will distribute water to the village Orah as well. A pumping station for Šume was put into operation in September this year; it is modern and it has automation and frequency regulation. Water is distributed to the village Šume by this pumping station.

A chlorination station is located on Donji Vidrovan and it consists of three up-to-date chlorinators. Chlorine gas is used for water treatment. At the pumping station Poklonci, there is a modern gas chlorinator for the treatment of water from that source. A reservoir area has a capacity of 7,500 m^3, and it consists of three reservoirs of 2,500 m^3. They are located on Trebjesa, at the elevation which is 69 m higher than the one where the pumping station Duklo is.

Booster units are built for providing more regular water supply for the users who are at higher elevations: Dragova Luka - 2 pieces, Rubeža - 2 pieces and Vitalac -1 piece. The water treatment plant and pumping station in Grahovo, along with about 4,500 meters of primary pipeline, is used for drinking water supply of the population in that settlement.

Primary and secondary water supply networks are made of different materials (cast iron, steel, asbestos-cement, polyethylene, PVC and galvanized pipeline) and they are of different age from 1931 until today.

The network is very jagged, and its length is about 450 km; approximately 365,027.59 m have been recorded and processed in GIS, which is 80%. Due to the age, different materials, and the decline in the quality of materials, there are a significant number of failures that ranges up to 2,000 annually.

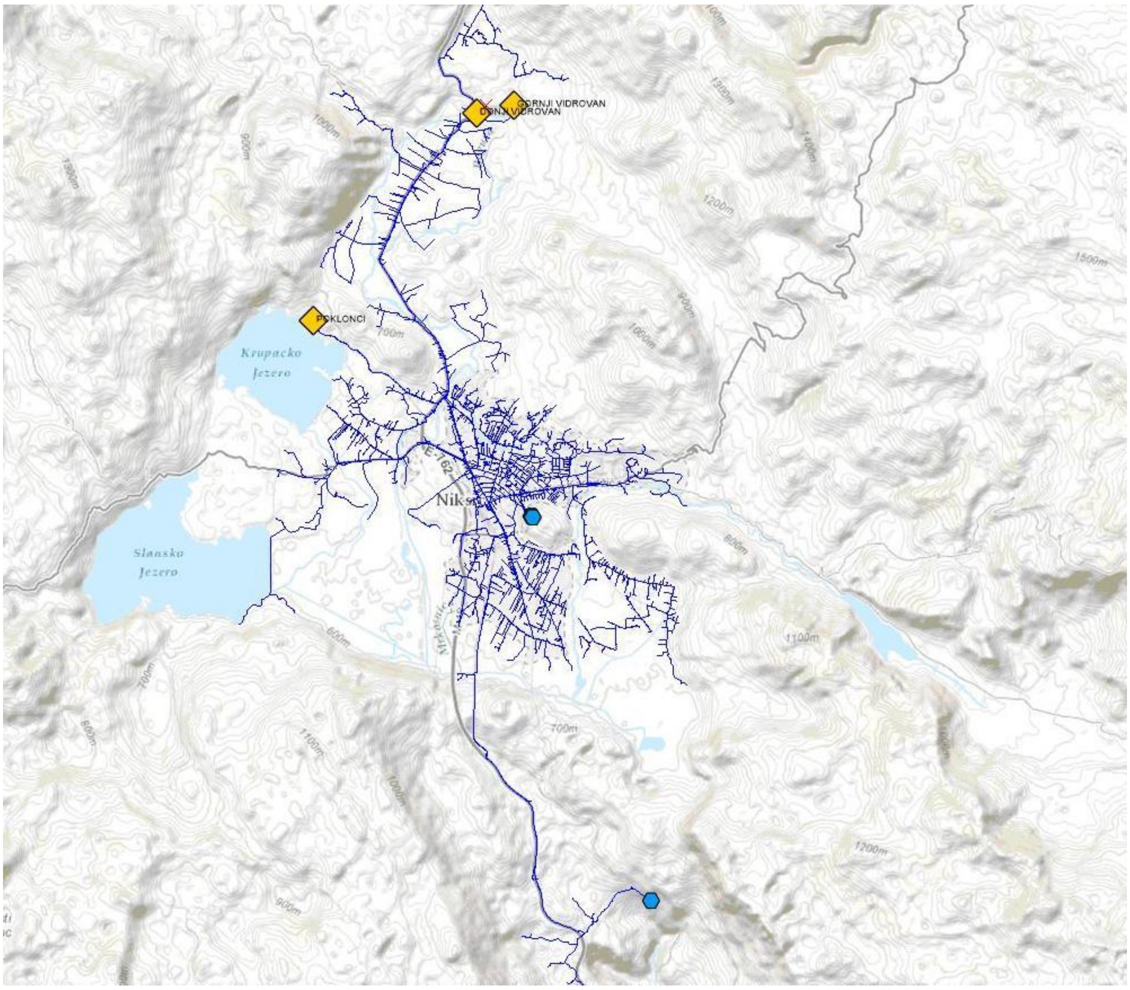


Figure 2.17: The water supply system with the main water sources

Main characteristics of the test area Nikšić are presented in table 2.7.

Table 2.7: Characteristics of test area test Area Nikšić (Kovač and Perović, 2015)

Name of test area	Test Area Nikšić
WR	Groundwater : Donji and Gornji Vidrovdan, Poklonci
Related City*	Nikšić
Geographical coordinates	18o 57’ 28’’ east longitude & 42o 46’ 29’’ north latitude
Altitudinal range	610 m.a.s.l.-762 m.a.s.l.
Size of drainage area	310 km2
Morphology	The hills surrounding karsts field
Aquifer type	Karsts aquifer groundwater
Surface water interaction	Yes, in Poklonci
Geology	In geological composition and structure limestone of Cretaceous age prevails
Mean annual precipitation	1995mm
Mean annual temperature	10.7 °C
Soil types	Calciferous-dolomite dark soil (Kalkomelansol) over 95%
Land uses	Agriculture 28.73% Forestry: 65.13% Artificial surfaces: 4.94% Water bodies: 1.20%
Protection areas	Sanitary protection zones
Water abstraction	Average 400l/s Maximum 600l/s

2.6. ALBANIA – DRINI BASIN

From Annex 9:

Water resources of Albania are abundant, almost in all the regions of the country, with an uneven seasonal distribution. The available quantity of surface water, and to a less extent of groundwater also, strongly decreases during the months of summer. Thus, only about 6-9 % of the annual runoff is observed during the dry season (July-September).

The mean annual precipitation in Albania are 1485 mm and the mean annual volume of water, discharged by all the rivers in the sea, is 41 km³ of water. It corresponds to a mean discharge of 1300 m³/s, approx. Drini with those of the Po River in Italy.

These water resources are mainly used for energy production, irrigation, industry, drinking water etc.

The hydrographic basin of Albania has a total area of 43,305 km² from which only 28,748 km² are situated within the state territory of Albania. The rest, which belongs to the catchments of the rivers Drini and Vjosa, is situated in Greece, FYROM and Yugoslavia.

Albania is crossed by several rivers, in general East - West direction: Drini, Ishmi, Erzeni, Shkumbini, Semani, Vjosa are the most important ones.

The mean annual discharge of all rivers of Albania is about 1300 m³/s, which corresponds to a specific discharge of 29 l/s.km², one of the highest in Europe. Surface water include also the natural lakes of Ohrid, Prespa and Shkodra, a multitude of minor lakes, and reservoirs built along the main rivers: at Fierza, Komani and Vau Deja along Drini river, Ulza and Shkopeti on the Drini river, and Banja on the Devolli river. Several lagoons are situated along the sea coast, the main ones being the Karavasta, Narta and Butrinti.

Test area in Albania is Drini basin.

Main characteristics of the test area Drini basin are presented in table 2.8.

Table 2.8.: Characteristics of test area Drini Basin (Kuriqi et al., 2015)

Name of test area	Drini Basin
WR	
Related City*	Shkodra
Geographical coordinates	42.02^0 N 19.30^0 E
Altitudinal range	0 m to 2,500 m
Size	14,173 km² (5,973 km² are on Albanian territory)
Morphology	Hills, Mountainous, Wetland
Aquifer type	Limestone formation, accompanied by karst phenomena in some parts of the river
Surface water interaction	Yes
Geology	sedimentary rocks, classical Karst
Mean annual precipitation	Average annual rainfall Eastern part: 934 mm Valbona zone: 1,543 mm Western part: 2,239 mm Seasonal distribution Winter Spring Summer Autumn E: 360mm 240mm 120mm 214mm V:524mm 365mm 184mm 470mm W:734mm 530mm 240mm 735mm
Mean annual temperature	-11.5-37.5 15
Soil types	clastic and flysch deposits from the early and middle Triassic eras, eruptive rocks of the middle Triassic and in the north-eastern part, flysch deposits from the Late Cretaceous era
Land uses	Agriculture 30.26 % Forestry 21.76% Artificial Surface Na Water bodies 1
Protection areas	Water protection zone
Water abstraction	60l/s

*Cities and rural settlements receive their drinking water supply from the test area

2.7. GREECE – CORFU ISLAND

From Annex 10:
The test area examined is the island of Corfu situated in the North western part of Greece in the Region of Ionian Islands (Figure 2.18). Corfu Island belongs to the Water District of Epirus (GR05) and the river basin of Corfu-Paxi (GR44). The river basin's area is 631 Km^2. The island's surface water bodies identified include three small rivers, three lagoons (transitional water bodies) and six coastal water bodies (Table 2.9) (Strategic Environmental Impact Assessment for Epirus Water District). Groundwater bodies identified include three aquifers: GR0500010, GR0500020 and GR0500030 (Table 2.10) (RBMP of Epirus, Del.5).
The main aquifers are developed in the carbonate formations of the Ionian zone containing high sulphates concentrations due of evaporates existing there (Figures 2.19 and 2.20). The initial characterization of the aquifers showed that the natural background (gypsum presence) causes high concentrations of sulphates and that point and diffuse sources of pollution are responsible for increased nitrates and ammonium concentrations of local importance. Additionally high concentrations of chlorides are locally met in the coastal zones due to sea intrusion caused by excessive pumping and due to natural causes (mainly the karstic ones).

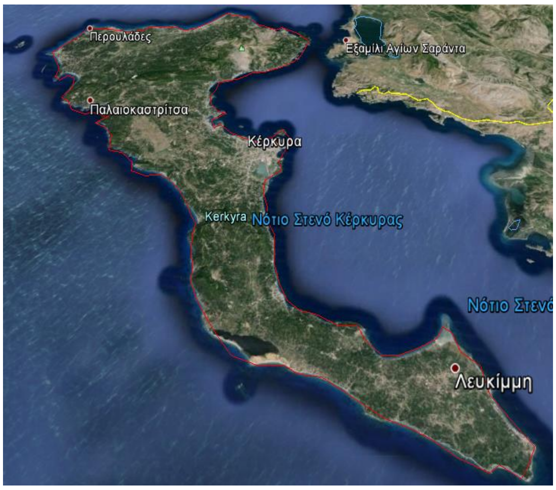
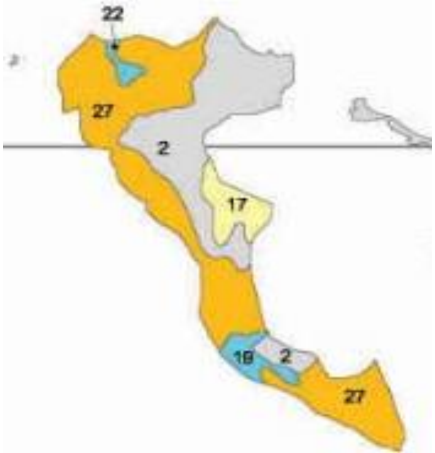


Figure 2.18: The Test area "Corfu Island" (in red) (from Google Earth).

Table 2.9: Surface Water Bodies in the River Basin District of Corfu – Paxi (Strategic Environmental Impact Assessment for Epirus Water District)

Rivers			**Transitional Water Bodies**			**Coastal Water Bodies**		
Name		Potami	Number		3	Number (total)		6
Code		GR0534R000101074N	Surface (Km^2)	Min	0.61	Heavily Modified		1
Name		Messagis		Average	2.34	Surface (Km^2)	Min	20.48
Code		GR0534R000301075N		Max	4.16		Average	101.16
Name		Fonissa		Total	7.01		Max	406.14
Code		GR0534R000501076N					Total	606.95
Length (Km)	Min	2.16						
	Average	5.52						

	Max	7.54
	Total	16.57



2. Calcaric Leptosol (LPca);

17. Calcaric Regosol (RGca);

19. Calcaric Fluvisol (FLca);

22. Calcaric Fluvisol (FLca);

27. Calcaric Cambisol (CMca);

Figure 2.19: Soil formations in Corfu (Strategic Environmental Impact Assessment for Epirus Water District)

Table 2.10: Main characteristics of the aquifers in Corfu island (initial characterization) (RBMP of Epirus, Del.5)

Aquifer's ID number	**GR0500010**	**GR0500020**	**GR0500030**
Name	Limestone system of Corfu island	Ternary breccia system of Corfu island	Granular aquifers system of Corfu island
Geology	Ionian zone. Jurassic and cretaceous limestones.	Ionian zone. Ternary breccia.	Alluvial and Neogene deposits
Aquifer type	Karstic	Karstic	Granular
Area	139	94	290
Average annual natural inflow* (hm^3)	75	40	40
Average annual abstraction* (hm^3)	6.8	7	15
Pollution	Locally increased NO_3 concentration values due to agricultural activities	Natural charge of SO_4 due to gypsum. Locally increased NO_3 concentration values due to agricultural activities	Locally increased NO_3 concentration values due to agricultural activities. Natural charge of SO_4 due to gypsum.
Sea Water intrusion	Yes. Local water salination mainly in the northern part	No	Yes. In coastal areas the chlorides concentration gets bigger due to seawater intrusion.
Qualitative status	Point & diffuse pollution sources additionally to the local minor agricultural activities. No pollution trend is noted.	No point or diffuse pollution sources except of local minor agricultural activities and urbanization. No pollution trend is noted.	Point & diffuse pollution sources additionally to the local minor agricultural activities. No pollution trend is noted. Good chemical

	Good chemical status.	Good chemical status.	status.
Quantitative status	There is no indication of over-exploitation	There is no indication of over-exploitation	There is no indication of over-exploitation

* The average values refer to the period of 1990-2010

Figure 2.20: The groundwater bodies (aquifers) identified in the test area (RBMP of Epirus, Del.5)

The hydrogeological map of the island of Corfu is presented in Figure 2.21 based on the River Basin Management Plan (RBMP of Epirus, Del.8) providing the infiltration and surface runoff (%) of each geological formation.

Figure 2.21: Hydrogeological map of the test area (RBMP of Epirus, Del.8)

Table 2.11: Classification from Figure 2.21

Classification	**Code**	**% Infiltration**	**% surface runoff**
Practically impermeable formations of low to very low permeability (flysch)	A1	5	30
Practically impermeable formations of low to very low permeability (gneiss)	A2	8	24
Practically impermeable formations of low to very low permeability (volcanic-igneous)	A3	5	30
Limestones, dolomites, crystalline limestones, marbles of high to medium water permeability	K1	45	8
Limestones of medium to low water permeability	K2	35	12
Ternary breccia and gypsum	K3	30	13
Granular alluvial deposits	P1	15	18
Miocene, Pliocene and Pleistocene deposits of medium to low water permeability	P2	10	20
Granular non alluvial deposits of low to very low water permeability (marls)	P3	5	30
Granular non alluvial deposits of low to very low water permeability (marls)	P4	5	30

As the aquifers GR0500010 and GR0500030 are at risk to meet the targets set by article N.4 of the WFD2000/60/EC, they need to be further characterized (Figure 2.20). In detail, the aquifers’ characteristics are described below.

The Limestone system of the Corfu Island (GR0500010)

This system includes all the karstic volumes of the island. The karstic system includes the limestones of Jurassic and Cretaceous age of the Ionian zone. In the Western part the Miocene marls are met creating a natural barrier in the water flow and protecting from the sea intrusion (RBMP of Epirus, Del.5). The system's area is 138.8 Km^2. This hydro system is considered as the one with the greatest groundwater reserves. The land uses include areas under cultivation, natural vegetation and forests and urbanization (RBMP of Epirus, Del.5). In this system there are increased concentrations of sulphates locally, due to the proximity with the carbonate ternary breccia with gypsum situated in the central part of the island. There are also locally met zones of salinization due to tectonic and geological causes and also the over exploitation of the groundwater (in the northeastern borders of the system) (RBMP of Epirus, Del.5). There are locally found increased values of nitrates due to human activities. Because of the significance of the system to cover drinking water needs compared to the deprived in quality groundwater of the ternary breccia system (due to the existence of gypsum) it is necessary to take protection measures to confront the salinization according to the River Basin Management Plan (RBMP of Epirus, Del.5). The average annual natural inflow of the karstic system is 75 x 10^6 m^3 and the abstractions are estimated to be 6.8 x 10^6 m^3/year (RBMP of Epirus, Del.5).

The Granular aquifers system of the Corfu Island (GR0500030)

The system includes all the granular aquifers of the island covering an area of 290 Km^2 (RBMP of Epirus, Del.5). The system consists of small alluvial basins, dunes and sands and argilum marl deposits of the neogene period of great thickness. Locally in the southern part there are ternary breccia deposits (RBMP of Epirus, Del.5). The water permeability is low. The aquifer's potential is low and it is exploited with wells. High sulphates concentrations are met locally in the whole aquifer due to the gypsum existence. High concentrations of chlorides are also met connected to the local presence of evaporites and abstractions in the coastal zones. Locally there is also increased concentration of nitrates and ammonium connected to human activities (RBMP of Epirus, Del.5).

The river basin management plan states that there are no indications of over exploitation in the system based on groundwater level measurements in drillings. The system accepts an annual natural inflow of 40 x 10^6 m^3 while the abstractions are 15 x 10^6 m^3/year (RBMP of Epirus, Del.5).

Main characteristics of the test area Corfu Island are presented in table 2.6.

Table 2.12: Characteristics of test area Corfu Island (Civil Engineering Department, University of Thessaly, 2015)

Name of test area	**CORFU ISLAND**		
WR	**GR0500010 groundwater**	**GR0500020 groundwater**	**GR0500030 groundwater**
Related City*	Corfu		
Geographical coordinates	latitude 39° 21’ 00” and 39° 49’ 00” longitude 19° 37’ 00” and 20° 06’ 00”		
Altitudinal range	0-906m (for the island)		
Size	138.8km^2	94km^2	290km^2
Morphology	Limestone	Ternary breccia	Granular aquifers
Aquifer type	karstic; groundwater	karstic; groundwater	granular; groundwater
Surface water interaction	None	None	Korission lake; Messagis river
Geology	Jurassic and cretaceous limestones. Ionian zone	Ternary breccia. Ionian zone	Alluvial and neogene deposits
Mean annual precipitation	94mm	94mm	94mm
Mean annual temperature	22.4°C	22.4 °C	22.4 °C
Soil types	Calcaric Leptosol; Calcaric Cambisol	Calcaric Leptosol; Calcaric Regosol; Calcaric Fluvisol	Calcaric Cambisol
Land uses	Crops; Natural vegetation – forests; urbanization	Crops; Natural vegetation – forests; urbanization	Crops; Natural vegetation – forests; urbanization
Land uses (for the island)	Area under cultivation and fallow land 73.0% Forests 10.2% Areas occupied by settlements 4.9% Pastures 4.7% Areas under water 1.1% Other areas 6.1%		
Protection areas	Water protection zone	No	No
Water abstraction	6.8x10^6m^3/year (215.6lt/sec)	7x10^6m^3/year (221.97lt/sec)	15x10^6m^3/year (475.6lt/sec)

3. ANALYSIS OF CC IMPACT ON RENEWABLE WATER RESOURCES

3.1. COMMON METHODOLOGY

Surface runoff and recharge constitute basic hydrological information for determining the characteristic renewable water resources. In order to understand the impact of CC on renewable water resources it is worth analysing the changes together with alterations in the hydrological basis (long-term averages of the total runoff, spring rate or the recharge).
Results about climate change (temperature and precipitation) from activity 4.1. were input data for calculation of change in water availability in test areas in the future period 2021-2050.

The common methodology (agreed in Belgrade on 4th project partners meeting 25-28 November 2014) to quantify CC impact on water availability was focusing mainly on the harmonised results, so uniform modelling tool was not proposed. The partners could use existing well known models or their own models to quantify CC impact on water availability. It was important to calibrate and validate the models.

In order to be able to compare CC impact on water resources in test areas it was agreed to calculate:

- long-term average water resources conditions (m^3/s) for the period 1961-1990 and
- characteristic renewable water resources (m^3/s) for the period 1961-1990 (if data were available).

Based on results from climate models and change in precipitation and temperature for the period 2021-2050 using available models it was agreed to calculate:

- long-term average water resources conditions (m^3/s) for the future period 2021-2050
- characteristic renewable water resources (m^3/s) for the period 2021-2050 (if data were available).

Both for long-term average conditions and characteristic renewable water resources the change (in %) between results for the period 2021-2050 and the baseline 1961-1990 had to be calculated.

Following the classification defined in the previous project CCwaterS, resources are characterized according to estimated changes (CCWaterS):

- low changes ≤ 10% (green),
- medium changes 11-25% (yellow),
- high changes 26-50% (orange) and
- extreme changes >50% (red).

3.2. ITALY

3.2.1. ISONZO/SOČA PLAIN

From Annex 1:
The quantification of the renewable water resources passes through the definition of the hydrogeological water budget. For the whole FVG Region, in the years 2010-11, a deep investigation was realized (Zini et al., 2011). The study focused on the identification of the single components of the water cycle allowing the definition of the water resources potentialities and sustainability.
The cycle is described by the following equation:

$$P = Et + R + I$$

where P are the precipitations, Et is the evapotranspiration, R is the run-off and I is the effective infiltration (Figure 3.1).

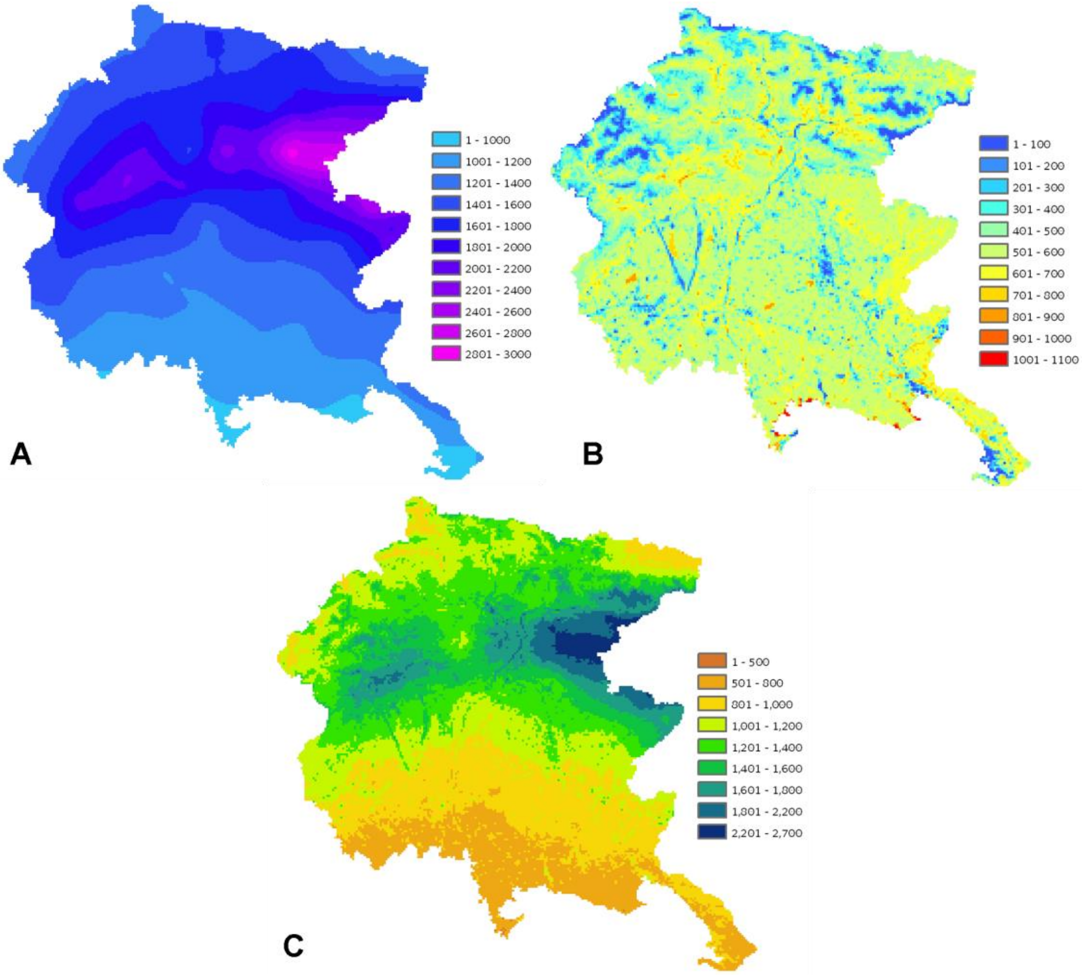


Figure 3.1: Thematic maps concerning P - Precipitation (A) in mm/y, ET - Evapotranspiration (B) in mm/y and R+I map realized for the surface Runoff and Infiltration (C) in mm/y (Zini et al., 2011).

Precipitation, evapotranspiration, runoff and infiltration were calculated to evaluate the inflow and outflow groundwater budget terms, using data recorded by 109 rainfall and 46 thermometric stations during 1979-2008. For the precipitations, any missing data were reconstructed using linear regression techniques (stepwise or multiregression) (Cicogna, 2008; Zini et al, 2011). The daily rainfall and temperature data spatialized on a 50 m grid were overlapped to the DEM. For the Precipitations (P) were used interpolating algorithms as Natural Neighbour, while for the temperatures were used experimental elevation gradients obtained correlating the thermometric daily data with the elevation of the stations (Cicogna, 2008; Castrignanò et al., 2005).

The Evapotranspiration (ET) was quantified as "crop evapotranspiration" calculated with the two-step approach as the product between the reference evapotranspiration and the crop coefficient K_c that incorporates and synthesizes all the effects on evapotranspiration due to the morfophysiologic characteristics of the different cultural species from phenological stage to the soil cover degree (Zini et al., 2011). K_c, depending from the type of vegetation and from the stage of plant development, was evaluated for each land use Moland class and for each decade of the year and associated to each cell of the grid. The reference evapotranspiration is a typical climate parameter expressing the tendency to perspire of a given plant. To calculate it, it was used the Hargreaves formula (Allen et al., 1998), described in the notebook 56 of the FAO (Food and Agriculture Organization). The average crop evapotranspiration for the Friuli Venezia Giulia Region is equal to 489 mm/y.

Surface Runoff (R) and effective Infiltration (I) components were used for the Plain, while for the whole mountain basins was considered the sum R+I. The surface runoff has been defined using the Curve Number (CN) methodology modified by Williams (1995) to fit the long-term analysis. CN was obtained for the whole regional territory combining on a 50x50 m grid the map of the hydrological groups, the land use map and the slope map extracted by DEM. From CN the retention parameter was calculated varying from a minimum, corresponding to a saturated soil, to a maximum, coincident with a dry soil depending from potential evapotranspiration of the computed day, from the precipitation and run off of the previous day (Zini et al., 2011). The mean annual runoff over the Plain is equal to 216 mm/y.

The effective infiltration component was calculated as difference between precipitation, evapotranspiration and runoff. The annual mean effective infiltration over the Plain is equal to 718 mm/y.

The mountain basins discharge (R+I) analysis allows quantifying the mean annual active recharge of the High Plain. If we consider the average R+I values, purged from the quantity of water outflowing to sea, they represent the average quantity that normally recharge the aquifers of the High Plain.

The analysis was conducted dividing the area into several main hydrological basins. Among these, are present also the High and Low Isonzo/Soča Plain. Based on a series of measurement surveys carried out in recent years (Consorzio di Bonifica Ledra Tagliamento, 1982; Cimolino et al., 2011) and on river discharge data surveyed by the "Servizio gestione risorse idriche della Direzione centrale ambiente, energia e politiche per la montagna of the FVG Region" were evaluated the percentages of river loses of each single water course. These values in conjunction with the shallow capture of waters for irrigation and industrial purposes and with the groundwater withdrawals permitted to compute the mean outflows at sea and, as difference, the effluences in the High Plain (Table 3.1).

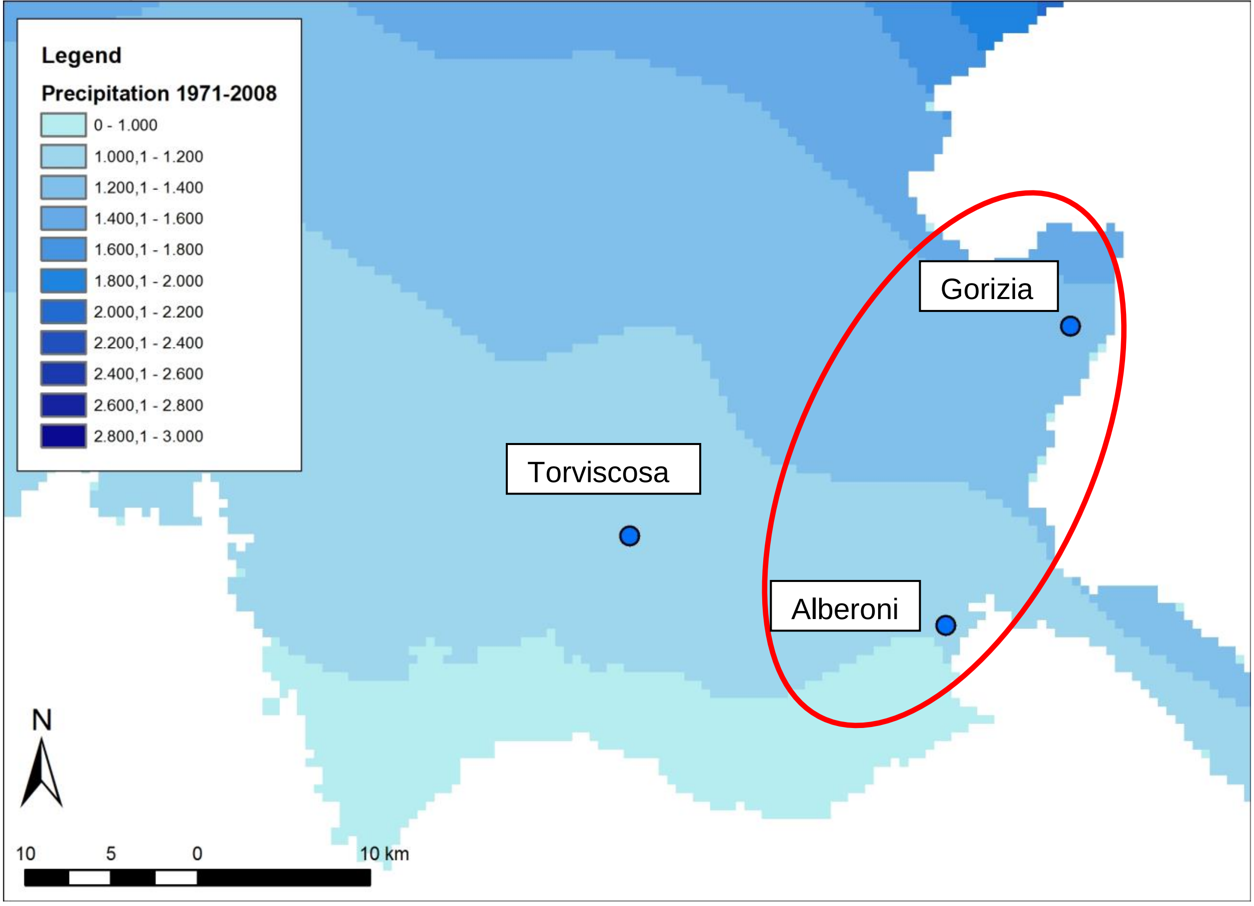


Figure 3.2: Areal distribution of the mean annual precipitation (P) expressed as mm/y.

Table 3.1: Mountain watersheds contribution to the High Plain aquifer recharge [m^3/s].

MOUNTAIN WATERSHED	OUTFLOW R+I	WITHDRAWALS IN THE MOUNTAIN WATERSHED	DIFFERENCE OUTFLOW - WITHDRAWALS	% RIVER LOSING IN THE HIGH PLAIN ACQUIFERS	CONTRIBUTION TO THE HIGH PLAIN AQUIFERS RECHARGE R_M
Cellina-Meduna	**28.5**	**25.1**	**3.4**	**100%**	**3.4**
Tagliamento	**100.7**	**25.4**	**75.3**	**72%**	**54.1**
Torre-Natisone	**32.8**	**2.5**	**30.3**	**90%**	**27.3**
Moraine amphitheater	**8.5**	**0.2**	**8.3**	**100%**	**8.3**
Isonzo/Soča	**170.8**	**26.3**	**144.5**	**26%**	**37.4**
TOTAL	**341.3**	**79.5**	**261.8**		**130.5**

For the Isonzo River basin, it has been decided to use the river discharge measured at the border (Gorizia - Ponte Piuma station). The discharge has an average value of 170.8 m^3/s of which 26.3 m^3/s are captured for irrigation and hydropower purposes, 107.1 m^3/s directly flow out to the sea and 37.4 m^3/s are the recharge to the aquifers of the Isonzo/Soča High Plain.

From the difference between the inputs of the High Plain and the resurgence rivers discharges, was estimated the input of the Low Plain as 43.7 m^3/s (Zini et al., 2011; Zini et al., 2013) – Figure 3.3.

On this input data, a discussion has to be done with respect to the Climate Change occurrences and outcomes from the Report WP4.1. In the Report were used three regional climate models (RCMs): Aladin (Bubnova et al. 1995), Promes (Castro et al. 1993) and RegCM3 models (Pal et al. 2007). The initial and boundary data for each RCM were provided from different global climate models (GCMs): the ECHAM5 GCM data were used to force RegCM3, Aladin was forced by the Arpege GCM and Promes was forced by the HadCM3Q GCM. Models have been compared with local observations (Observations - obs) and later corrected. The used reference period was 1961-1990, but unfortunately, not all the meteorological stations present in the study area have a complete data series.

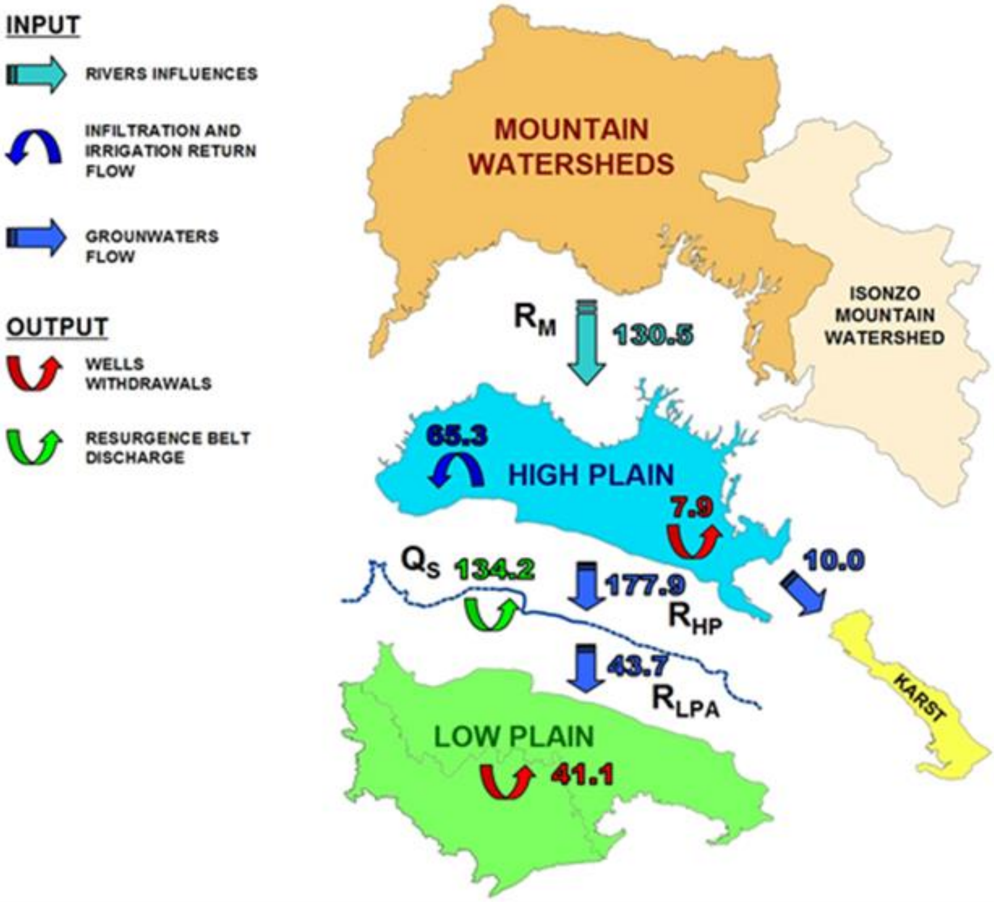


Figure 3.3: Water-budget scheme for the entire Friuli Venezia Giulia Region. Mountain Watersheds (light brown) and Isonzo/Soča River mountain watershed (in sandy colour) to the North, the High Plain (HP) area (light blue) separated from the Low Plain (LP) (light green) by the resurgence belt (blue dashed line). In yellow the Karst area. Blue arrows are related to the influences and water flows, while red and green arrows represents the well withdrawals and the resurgence belt discharges.

What emerges from the comparison between the observed data and the models is a general little overestimation in the yearly precipitation amount as in the mean temperature definition. This is more evident in the longer time series analysis (2001-2050).

Table 3.2: Comparison between the results obtained by the observed data and the proposed models within different periods. For the precipitations, the models applied to Alberoni station underestimates the observed values.

GORIZIA Prese (CBPI)				
% difference between the OBS data and models				
T		ECHAM5	Aladin	Promes
	1951-2000	0,7	0	0,7
	2001-2050	6,1	9,9	0,7
P		ECHAM5	Aladin	Promes
	1951-2000	3,1	3,3	3,1
	2001-2050	5,2	8,1	13,7

ALBERONI				
% difference between the OBS data and models				
T		ECHAM5	Aladin	Promes
	1951-2000	0	0	0
	2001-2050	4,7	9,1	11,1
P		ECHAM5	Aladin	Promes
	1951-2000	-4,1	-3,8	-4,2
	2001-2050	-2,3	0,5	5

TORVISCOSA				
% difference between the OBS data and models				
T		ECHAM5	Aladin	Promes
	1951-2000	2,3	2,3	2,3
	2001-2050	8,5	13,2	14,6
P		ECHAM5	Aladin	Promes
	1951-2000	1,05	1,2	1
	2001-2050	3,7	7,5	13,7

The selected 50-year period within which the impacts of potential climate change on water resources are analyzed shows characteristics of the rainfall regime that differ to the reference 30-year period 1961-1990. The behavior of the three studied stations is different. Gorizia observed data are indicating a decrease in the precipitations of the 7,4%, Alberoni instead is showing a very small increase, only 0,7%. A higher increase is instead shown by the Torviscosa station that has a 15,7% of increase in the precipitations in the period 1961-1990. If we look at the models for the Gorizia Prese station, for the period 2021-2050, their behavior is different, Promes is indicating a decrease, while the other two models are in agreement with an increase in the precipitation amount, ECHAM5 of less than 10%, while Aladin of approximately 20%. The situation is completely different if we analyze the trends proposed by the models for the period between 2001-2100. All the three models in fact indicate a decrease in the precipitations (Table 3.4).

For the temperature, the situation appear more in agreement among the models and the observed data. All the analyses done are indicating a future increase in the temperatures of a minimum of 5% till a maximum of 34,6% (PROMES model at Torviscosa station). Most part of the models are anyway indicating a possible temperature increase in the range 5-10% of the actual values (Table 3.4). For Torviscosa station, the obtained analyses on the observed data can not be considered enough reliable due to the shorter time-series available and used for the elaborations.

Table 3.3: Data summary for the three analysed climatological stations. Temperatures and precipitations were defined for different periods: 1951-2000 and 2001-2050 and compared with the recorded data.

GORIZIA Prese (CBPI)						
	Temperatures [°C]			Rainfall [mm]		
1961-1990 - Registerd						
mean	13,1			1397,5		
stdev	0,62			175,7		
Cv	0,046			0,13		
max	39			1955		
min	-11			1103		
1951-2000 - Model based						
	ECHAM5	Aladin	Promes	ECHAM5	Aladin	Promes
mean	13,2	13,1	13,2	1440,9	1443,3	1441,0
stdev	0,60	0,58	0,68	228,52	312,96	303,43
Cv	0,05	0,04	0,05	0,16	0,22	0,21
max	14,3	14,1	15	2026,7	2030,3	2238,6
min	11,3	11,4	12,2	1015,1	740,2	885,7
2001-2050 - Model based						
	ECHAM5	Aladin	Promes	ECHAM5	Aladin	Promes
mean	13,9	14,4	13,2	1471,0	1510,4	1588,9
stdev	0,74	0,73	0,68	199,44	359,09	279,68
Cv	0,05	0,05	0,05	0,14	0,24	0,18
max	15,7	16,1	14,9	1852,4	2345,4	2342,8
min	12,1	12,9	12,2	1037,7	869,0	990,9

ALBERONI						
	Temperatures [°C]			Rainfall [mm]		
1972-1990 - Registerd						
mean	14,4			1108,2		
stdev	0,50			128,2		
Cv	0,034			0,12		
max	36			1679,8		
min	-10,6			205,5		
1951-2000 - Model based						
	ECHAM5	Aladin	Promes	ECHAM5	Aladin	Promes
mean	14,4	14,4	14,4	1062,3	1064,6	1062,0
stdev	0,60	0,58	0,68	168,35	230,94	233,34
Cv	0,04	0,04	0,05	0,16	0,22	0,22
max	15,5	15,3	16,1	1512,3	1543,9	1724,7
min	12,5	12,8	13,4	785,9	554,1	647,3
2001-2050 - Model based						
	ECHAM5	Aladin	Promes	ECHAM5	Aladin	Promes
mean	15,1	15,7	16,0	1085,5	1114,3	1164,9
stdev	0,74	0,73	0,94	155,46	261,92	203,43
Cv	0,05	0,05	0,06	0,14	0,24	0,17
max	16,9	17,4	18,0	1380,4	1653,3	1680,3
min	13,3	14,2	14,1	754,3	603,8	716,2

TORVISCOSA						
	Temperatures [°C]			Rainfall [mm]		
1971-1990 - Registerd						
mean	12,9			1184,1		
stdev	1,28			199,2		
Cv	0,98			0,17		
max	37			1755,2		
min	-12,8			532,6		
1951-2000 - Model based						
	ECHAM5	Aladin	Promes	ECHAM5	Aladin	Promes
mean	13,2	13,2	13,2	1196,6	1198,0	1196,0
stdev	0,60	0,57	0,67	192,62	264,60	253,16
Cv	0,05	0,04	0,05	0,16	0,22	0,21
max	14,3	14,2	14,9	1623,1	1812,4	1934,5
min	11,4	11,7	12,1	840,4	604,4	795,3
2001-2050 - Model based						
	ECHAM5	Aladin	Promes	ECHAM5	Aladin	Promes
mean	14,0	14,6	14,8	1229,3	1274,3	1348,1
stdev	0,73	0,74	0,94	172,14	314,86	256,96
Cv	0,05	0,05	0,06	0,14	0,25	0,19
max	15,7	16,3	16,9	1605,7	2002,9	2132,6
min	12,2	13,1	12,9	844,9	735,5	792,6

Table 3.4: Temperature and precipitation trends expressed as % calculated over the period 2021-2050 and for the recorded data.

	P			T		
	GORIZIA Prese (CBPI)	ALBERONI	TORVISCOSA	GORIZIA Prese (CBPI)	ALBERONI	TORVISCOSA
2021-2050						
Aladin	18,7	17,5	19,2	6,1	5,6	6,1
PROMES	-9,1	-7,3	-11,9	9,1	5	5,5
ECHAM5	3,2	9,6	6,1	9,4	8,6	9,7
1961-1990						
obs	-7,4	0,7	15,7	9,4	5,1	22,3

According to what emerged from the previous report (Report WP4.1), Table 3.5 presents the water budget obtained for the pilot area and consequently the renewable water resources - WR (m^3/s) for the reference period 1961-2003 and for the modelled one 2021-2050 according to the three different Climate Change models applied (Arpege, Promes and ECHAMS5).

Table 3.5: Water budget information for the evaluation of the climate change on water resources related to the periods 1961-2003 and 2021-2050.

	WR (m^3/s) 1961- 2003	WR (m^3/s) 2021-2050
Q Isonzo/Soča river	37,4	37,4
Effective infiltration in the Isonzo/Soča High Plain	4,2	3,57
Q toward Karst	10	10
Withdrawals in High Plain	1,55	1,55
Resurgence belt discharge	16	15,37
Aquifers recharge of the Isonzo/Soča Low Plain	13,7	13,7
Withdrawals in Low Plain	2,27	2,27

To obtain the number presented in Table 3.5, assumptions and simplifications were taken. One of this is to consider almost constant the Isonzo/Soča river discharges controlled by the Salcano dam in Slovenia. What is changing in the water budget computation between the reference period and the 2021-2050 period is the amount of the effective infiltration. According to the climate change models, two of the three models show a rainfall increase of approximately 10%, as in the temperatures. The third model instead is highlighting a decrease in the rainfalls (PROMES -11,9%) associated to an increase in the temperature values (+5,5%). In this framework, a reasonable decreased in the effective infiltrations up to -15% was adopted in the provisional water budget computation (2021-2050). The implications of this decrease are in general an increase in the depth to water values in the High Plain and a pressure lowering in the artesian aquifers of the Low Plain. Moreover, the discharges at the resurgence belt will suffer a decrease (Table 3.5). The discharge value measured at the resurgence belt is moreover an indirect indicator of the sustainability of the actual use of the water resources. In this framework, the withdrawals reduction in the Low Plain, could help in the pressure increase of the artesian aquifers.

3.2.2. ATO3

From Annex 2:
In ATO 3 Test Area, as in many other Italian regions, groundwater represents the major source of “water intended for human consumption”. Deep groundwater resources, well protected by natural filters, can guarantee wholesome and good quality water and a safe supply. Safeguard measure are anyhow very important as the extensive and, often, unplanned land use could represent a serious danger.
Surface water is also used as source of “water intended for human consumption”: an artificial reservoir, called Castreccioni Lake is used for drinking water production and supply to a population of about 100.000 people. Another problem, also connected with human pressure on natural resources, is the eutrophic phenomenon, with the presence of toxic *Planktothrix rubescens* cells in the lake water, detected starting from January 2011, with increasing concentration of algae, up to 4 Million cells per liter.

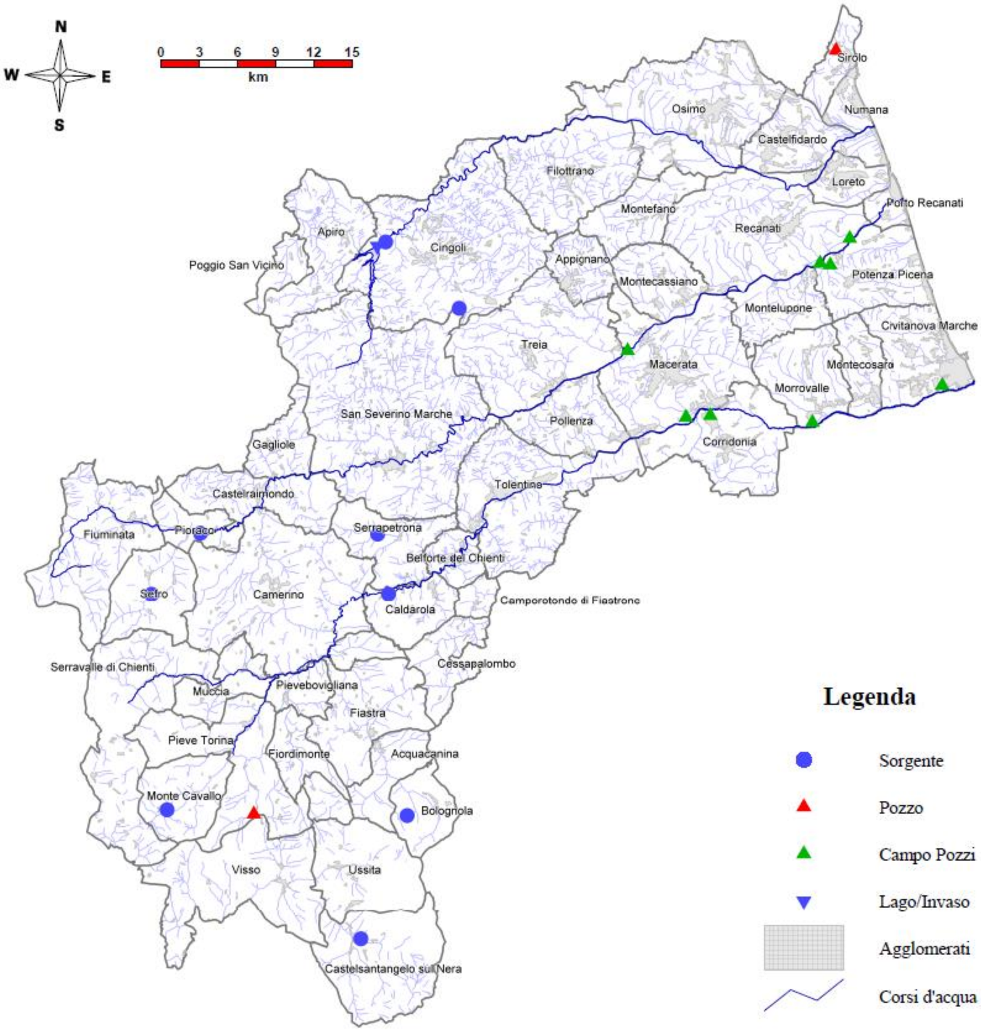


Figure 3.4: The most important Water Resources in use in ATO 3

The critical aspects associated with the qualitative and quantitative maintenance of water resources in the test area are essentially linked to the need to satisfy the growing demand in the various fields of use (drinking water, agriculture, industry) consequent to the increase in population and the apparent increase in the frequency of the "drought" seasons, especially observed in the last decade.

More uncertain are the information about the ongoing climate change and the increase of periods with prolonged absence of precipitation. Partial data (to be validated) indicate a shortening in the recurrence of dry seasons: if during the period 1950-2000 a dry season occurred every 10-15 years (Amici and Spina, 2002), after 2000 it seems to occur with a frequency of 5-10 years. More specifically, in the last fifteen years, there has been a peremptory alternating of dry periods especially in early autumn and late winter, followed by periods of intense and prolonged rainfall (even of 48-72 hours), with a total of 250-300 mm (equal to 20-30% of the annual value). The meteoric characteristics described above tend to favour and/or reinforce gravitational and flood phenomena already widespread in the test area and, consequently, to limit infiltration and groundwater recharge (Fazzini, 2002).

A moderate state of alert is instead associated with the feared deterioration of the drinking waters quality standard: a pollution increase by nitrates of agricultural origin has been observed in some pumping wells of the area while no significant phenomenon was found in the water resources fed by carbonate aquifers which still account for 42% of the resource used.

Concerning the available resources, the mountain aquifers of the test area currently seem to count on an effective recharge between 400mm and 1000mm per year, variously distributed based on the different permeability of bedrock and especially on the areal distribution of precipitation. The resulting volumes, recently estimated in some strategic sectors of the Apennines and partially within the study area, seem to be able to meet the current demand (Boni and Petitta, 2007; Petitta, 2011); nevertheless, the complex hydrogeological setting of the territory cannot exhaustively enable an assessment of the quantities involved, unless a continuous and effective monitoring of the spring discharges which currently concerns (sometimes partially) only some of the main water supply works.

A similar consideration can be done for the aquifers located in floodplain areas that constitute usually additional or alternatives resources to those taken in the carbonate mountain aquifers. The studies carried out so far, only partially fill the gap related to a proper characterization of the hydrogeological parameters of these aquifers and the volume of water actually available for the exploitation.

Typical of the aquifers located near the coast is the problem related to a possible saline water intrusion, resulting from freshwater overexploitation, sea level rise or human intervention. Also in this case, more detailed studies and targeted monitoring are therefore to be considered fundamental for a correct assessment of the qualitative and quantitative state of the water resources stored.

Aquifers sometimes significant, although, in most cases, very small, are then diffusely present throughout the whole ATO 3 territory. These aquifers are predominantly located within the terrigenous deposits present in mountain areas or in the monoclinal peri-adriatic structure, at the watershed of the major rivers (Musone, Potenza, Chienti) where crop formations consist of alternations prevailing composed by sandy-sandstone or conglomerate. Bibliographical data referring to these areas reveal the presence, in the period around the early ‘70s of last century, of numerous springs exploited especially at local level. In the hilly peri-adriatic area, widespread springs, matching the needs of small settlements, until the construction of the first main waterworks, are now disappearing or are left abandoned, even because of modern agriculture techniques and the social changes. These changes have significantly altered the hydrology and hydrogeological features of the local slopes, also favouring the activation and/or reactivation of mass movements (landslides). Although these water resources probably have not particularly high quality requirements, their recovery could be useful in case of needs of emergency water supply or for a possible rebalancing of the slope-valley system.

3.2.3. OSTUNI

From Annex 3:

The team from CNR-IRSA (FB3) has been working on developing a methodology for groundwater (GW) balance evaluation at the test area of Ostuni (Annex 3). The present water GW availability, i.e. the characteristic water resource availability CWR, has been evaluated by running a mathematical model able to simulate water balance components adopting the climate input for the period 1961-1990 considered as a representative time window of present conditions. Present water demand (PWD) was also evaluated including Environmental Flows and irrigation, industrial, household uses.

The development of a hydrological model G-MAT (Portoghese et al 2005) to evaluate both the natural recharge rate feeding the carbonate aquifers and the water demand resulting from agricultural, human consumption including touristic uses was therefore a fundamental step to evaluate the present degree of groundwater exploitation in the test area.

The basic hypothesis of the G-MAT model is that in almost flat landscapes (typical of carbonate plateaus) water fluxes through the soil surface and the unsaturated zone are mostly vertical and deep water table has negligible interaction with the surface drainage network. Under such conditions, regional groundwater flow is driven by the hydraulic gradient between the aquifer and the final receptor which in our case corresponds to the coast line. Moreover, rainfall infiltration below the vegetation root zone may be considered as recharge in the aquifer water balance, i.e. the downward output from the soil water balance model, provided that time delays of infiltration processes may be neglected only for aquifer water balance calculations at an yearly basis.

The G-MAT (Portoghese et al., 2005) model is adopted to estimate natural GW recharge and its space-time variability in the domain of test area. G-MAT is a semi-distributed GIS-based hydrological model and was originally developed for the sustainability assessment of water resources with particular emphasis on GW-dependent regions and irrigation requirements. It considers the major landscape features that determine the soil water balance, such as vegetation and soil moisture storage and water flux processes. G-MAT yields natural GW recharge on a monthly basis, through the distributed application of the soil water balance equation, evaluated as the difference between the inflows (rainfall, irrigation) and outflows (evapotranspiration, surface runoff), assuming the monthly irrigation supplies equal to the soil moisture deficit. The spatial resolution of the implemented model is 1 km^2, thus assuring a feasible representation of the spatial heterogeneity of soil and sub-soil, as well as a realistic description of catchment morphology. Accordingly, vegetation patterns are spatially-averaged thus assuming that field scale heterogeneities are compensated by the time-variation of crops. This coarse representation of vegetation was proved adequate to investigate regional scale patterns of water use for irrigation.

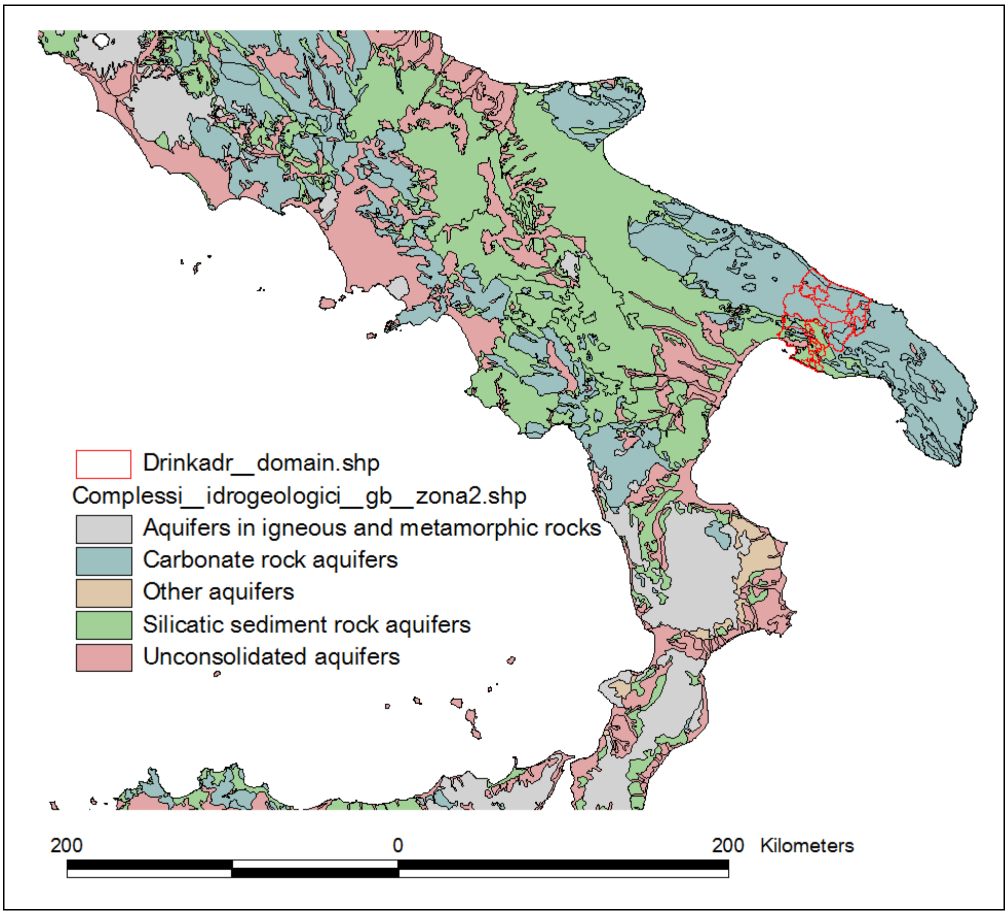
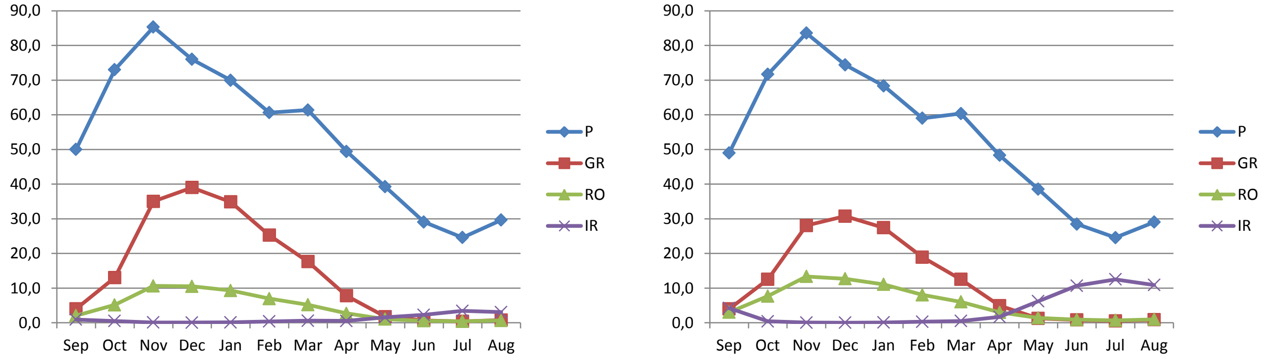


Figure 3.5: Main aquifers in Southern Italy. The location of the Ostuni test site domain is shown by the red line.

The G-MAT model was therefore developed for the Ostuni test area to evaluate the CWR under present conditions as well as the present degree of GW exploitation by adopting the WEI formulation. Time series of precipitation and temperature observations were elaborated to obtain multitemporal maps of precipitation (P) and potential evapotranspiration (ETo) which are input to the G-MAT model. Model parameters characterizing soil and subsoil hydrological features (Figure 3.5) as well as geomorphology, land cover and vegetation (including crop parameters) were also defined using available information. Through its soil water balance module the G-MAT also allows for the estimation of monthly crop water requirement which was proved to be well correlated to the GW withdrawals for irrigation in those areas where farm irrigation is not supplied by surface water resources (Portoghese et al. 2013).

By running the model, GW recharge was therefore estimated for the two sub-domains (Adriatic, ADR and Ionic, ION) with a monthly resolution and then summarized annually for the period 1961-1990. Similarly, GW irrigation withdrawals were also estimated at both monthly and annual scale. The annual average of GW recharge was then assumed as long-term average CWR for the Ostuni test area in the following sections. Model results are summarized in Figure 3.6 as mean monthly values for the reference period (1961-1990).



Adriatic sub-domain

Ionic sub-domain

Figure 3.6: Mean monthly water balance components simulated with G-MAT where P is precipitation, GR is GW recharge, RO is runoff, IR is irrigation. All quantities are expressed in mm.

One of the critical issues in the evaluation of climate change impact on water resources is the use of multiple climate model simulations (ensembles) as input to complex water resources models which often involves time-consuming pre-processing of climate model output to meet the data requirements of the adopted water resources models. To overcome the pre-processing and computational burden needed to run the G-MAT model under multiple climate scenarios (i.e. the available CC model simulations), a simplified regression model was adopted which is able to directly relate the basin-scale hydrological response (GW recharge in this case study) to the sole climate forcing.

The adopted approach involves a simple statistical method previously developed to simulate the inflow to a surface reservoir based on well-known Standardized Precipitation Indices (McKee et al 1993). This method called SPI-Q method (Romano et al. 2015) is based on some assumptions needed to establish some robust relationship between precipitation and the inflow regimes:

a) monthly time scale evaluation of inflows to the reservoir and the connected water demand is suitable for water management applications;

b) monthly inflows are determined using spatially averaged climatic forcing;

c) inflows are mainly dependent on precipitation summarized at different time scales and with different “weights”;

d) the parameters linking the precipitation regime to the inflow are considered constant over time.

Based on the previous assumptions, a modified multilinear regression model was calibrated and validated at monthly scale using the least-square method and adopting the time series of GW recharge modelled with G-MAT as a virtual observational dataset. In practice, the SPI-Q model was modified to emphasize the influence of thermal anomalies highlighted in the adopted climate change scenarios and the SPI was substituted by the new Standardized Precipitation-Evapotranspiration Index (Vicente-Serrano et al. 2010) in which the monthly difference between precipitation and evapotranspiration is used as a sort of net-precipitation.

The equation representing the SPEI-Q method is the following:

$$R(m,i) = a_{SPEI1}(m)\cdot SPEI1(m,i) + a_{SPEI3}(m)\cdot SPEI3(m,i) + a_{SPEI6}(m)\cdot SPEI6(m,i) + a_0$$

where *R(m,i)* is the recharge for the month m, year *i* (GW recharge in the Ostuni case study); *SPEI1(m,i)*, *SPEI3(m,i)* and *SPEI6(m,i)* are the Standardized Precipitation-Evapotranspiration Indices computed for the month m, year i on the net precipitation cumulated over 1, 3 and 6 months; *a_SPEI1(m)*, *a_SPEI3(m)*, *a_SPEI6(m)* and *a0(m)* are the coefficients from the multilinear regression of *SPEI1*, *SPEI3*, *SPEI6* for the month *m*. It is worth to note that to calibrate the SPEI-Q model a statistically significant dataset (both for inflow and precipitation) is mandatory.

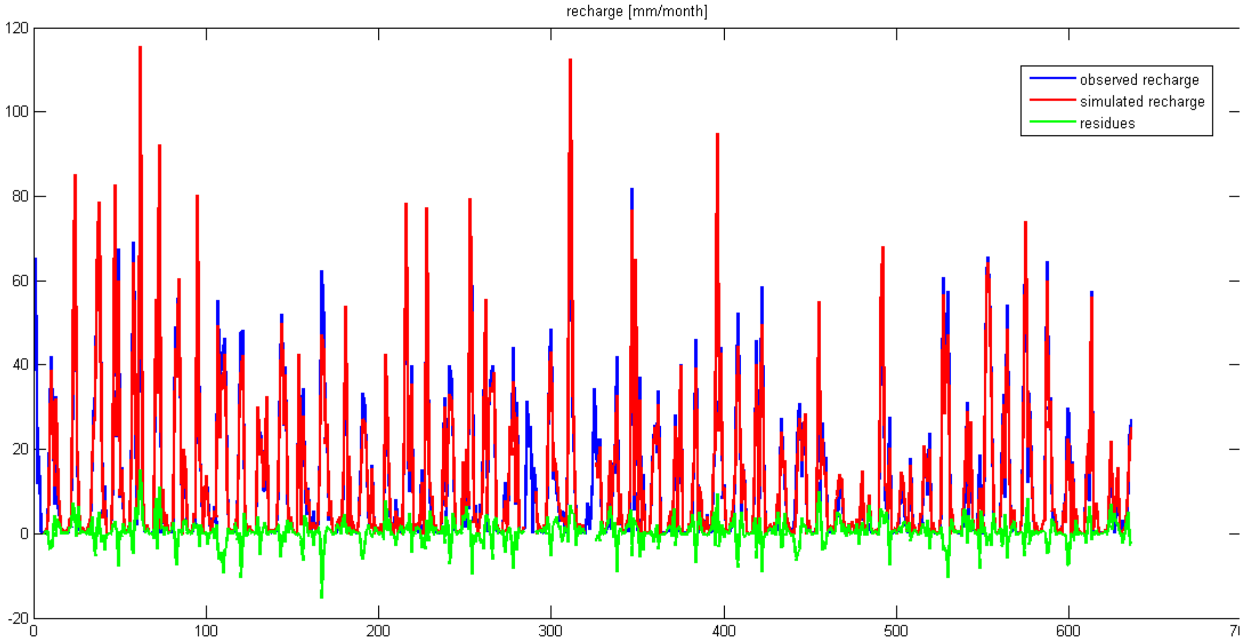


Figure 3.7: Monthly GW recharge estimations for the Ionic sub-domain simulated with SPEI-Q model.

The SPI-Q model has been already applied to three basins in Italy, quite different in terms of climate conditions and hydrological features: the Lake Maggiore basin (Switzerland and North Italy), the Ridracoli basin (Central Italy) and the Occhito Basin (South Italy). Inflow simulations resulted in good agreement with observations, mostly for low inflow regime; moreover, the values of the multilinear regression coefficients appeared to be representative of the different hydrological processes that affect the total monthly discharge to the reservoirs. As far as concerns the Ostuni case study, GW recharge simulations from G-MAT for the reference period were used to calibrate and validate the SPEI-Q model with reliable results in terms of mean error (Figure 3.7).

Based on the reliability of the SPEI-Q model calibrated for the case study, the same approach has been used for evaluating future water availability scenarios by adopting the CC-Waters scenarios for the 21st Century as shown in Figure 3.8.

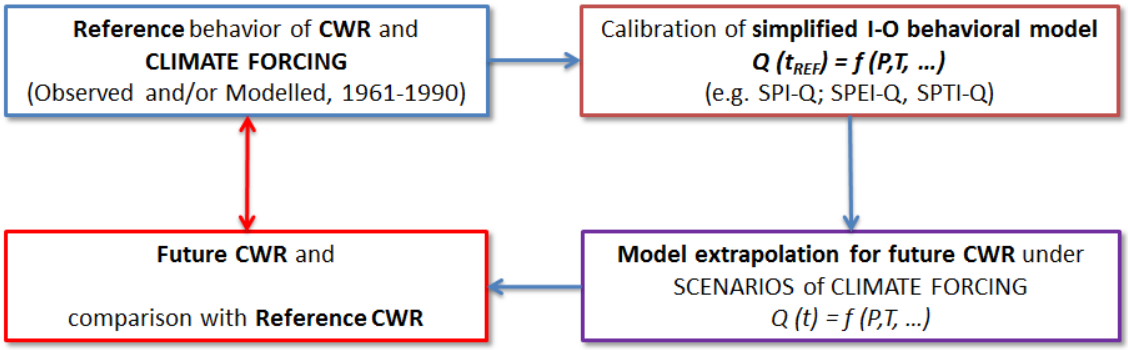


Figure 3.8: Scheme representing the adopted methodology to evaluate climate change impact on water resources.

The climate change analysis for the Ostuni test area was already presented in a previous report in which the expected change with regard to the reference period was discussed (Table 3.5). Broadly speaking, the three models are similar in terms of temperature scenarios but differ quite consistently for precipitation with PROMES showing a clear decrease in precipitation (from -7 to -9 %).

The methodology to evaluate climate change impacts on renewable water resources was presented in the previous section and may be summarized as follow:

- GW recharge was simulated at the monthly scale for the reference period 1961-1990 by implementing the distributed hydrological model G-MAT (m^3/month); GW recharge simulations were assimilated as observations of basin-scale hydrological response;
- Long-term average hydrological condition is given by averaging the annual GW recharge for the period 1961-1990 (mean annual recharge rate in m^3/s);
- Long-term average of GW recharge is considered as the characteristic water resources availability for the GW system under investigation (m^3/s); the underline assumption is that renewable GW resource can be assessed as long-term average of GW recharge;
- Using the simulated monthly time series of GW recharge the simplified SPEI-Q was calibrated and validated to establish a functional relationship between GW recharge and the climate observations for P and T;
- The SPEI-Q relationship calibrated for the reference period (1961-1990) was then used to evaluate GR recharge scenarios for the adopted climate change scenarios for the period 2021-2050; the climate input for the SPEI-Q model was determined using the delta-method estimated from climate change statistics between reference observations and scenarios (Table 3.6);
- Hydrological response under climate scenarios was estimated for the period 2021-2050 following the previous step; consequently % of change between reference and scenarios was evaluated (Table 3.7);
- Similarly, the CWR for the period 2021-2050 was estimated (m^3/s); the consequent percentage variation between reference and scenarios was evaluated (Table 3.7).

Table 3.6. Climate change statistics for temperature and precipitation obtained from the comparison with the reference period

Climate Model	RegCM3		ALADIN		PROMES	
Sub-domain	ADR	ION	ADR	ION	ADR	ION
TEMPERATURE	+ 7.7 %	+ 7.1 %	+ 11.9 %	+ 11.9 %	+ 11.8 %	+11.5 %
PRECIPITATION	+ 0.7 %	+ 1.2 %	- 4.9 %	+ 2.9 %	- 6.7 %	-9.4%

Table 3.7. Basic hydrological information for the evaluation of the climate change on water resources – AVERAGE CONDITIONS corresponding to CHARACTERISTIC RENEWABLE WATER RESOURCES, CWR

Country	Test area	Long-term average (m^3/s) Characteristic renewable water resources (m^3/s)				Changes compared to baseline (%)		
		1961-1990	2021-2050			2021-2050		
			RegCM3	Aladin	Promes	RegCM3	Aladin	Promes
Italy	Ostuni-Adriatic	6.23	5.81	4.84	4.61	-6.7%	-22.3%	-26.0%
Italy	Ostuni Ionic	5.24	4.86	4.80	3.46	-7.3%	-8.4%	-34.0%

3.3. SLOVENIA - KOBARIŠKI STOL, MIA AND MATAJUR AQUIFER

From Annex 4:

There are four national monitoring stations of hydrological measurements on surface water within the test area Kobariški Stol, Mia and Matajur aquifer: Kobarid I, Potoki, Žaga and Robič. The national monitoring is performed by the Slovenian Environment Agency. Geographical locations of the measuring stations and basic information are presented in Figure 2.9 and Table 3.8.

The monitoring frequency for water flow is once per day, but there are significant differences observed in sets of measurements between different locations. Therefore, where it was possible, for analyses we used the data from 1961.

Table 3.8: Basic information about the monitoring stations for hydrological measurements on surface waters for the test area Kobariški Stol.

Name of location	*Code*	*GKY*	*GKX*	*Level (m a.s.l.)*	*Stream name*	*Catchment area*
Kobarid I	8080	391414	123513	195.2	Soča	Adriatic
Potoki	8710	384865	123910	251.2	Nadiža	Adriatic
Žaga	8270	383125	130653	341.9	Učja	Adriatic
Robič	8730	385527	123315	264.5	Nadiža	Adriatic

The location Kobarid I is positioned in Soča river and has the longest and most complete set of data for water flow. Measurements started in 1941 and last up to now with some interruptions. The size of the river basin that is drained through the monitoring station is 434.70 km^2 (Brenčič et al., 2001). The average water flow from 1961 to 1985 is 34.41 m^3/s (min 5.5 m^3/s, max 552 m^3/s).

Potoki monitoring station is positioned in Nadiža River approximately in the centre of the test area. Measurements at this location started in 1956 but there are not continuous measurements and the series are interrupted several times. The size of the river basin that is drained through the monitoring station is 100.20 km^2 (Brenčič et al., 2001). The average water flow from 1961 to 1995 is 3.78 m^3/s (min 0.06 m^3/s, max 79 m^3/s).

The Žaga monitoring station is positioned in Učja River where measurements started in 1952. The size of the river basin that is drained through the monitoring station is 49.41 km^2 (Brenčič et al., 2001). The average water flow from 1954 to 1995 is 3.48 m^3/s (min 0.23 m^3/s, max 286 m^3/s).

In the period from 2001 to 2006 the water flow were measured at Robič sampling location that were positioned in Nadiža River. The average water flow is 2.80 m^3/s (min 0 m^3/s, max 78.1 m^3/s).

Hydrograph separation was performed in order to separate base or slow flow, which represents groundwater outflow, and the rapid flow, which represents surface runoff. The base flow index was used in order to determine the proportion of base flow in relation to the total runoff. The method is based on the assumption that the rapid flow reflects a component of high frequency, and base outflow represents an outflow of low frequency. For calculation of the base flow index the recursive digital filter method was used, where parameter α is introduced. From the literature there are various values for this parameter, therefore the base flow index was calculated for more values (0.875, 0.9, 0.925. 0.95).

The calculated base flow indexes for Soča River are between 0.60 and 0.49, for Nadiža between 0.31 and 0.23 and for Učja between 0.43 and 0.36. A direct comparison between different rivers is not entirely possible due to different time frame of the data series, while the base flow indices comparison shows that the base flow indices of the analysed rivers differ considerably. The highest base flow index was calculated for the Soča River, followed by Učja and Nadiža. Differences in the base flow indices are resulting from different types of hydrographs, which is due to differences in recharge areas of particular measuring station.

Hydrographs of particular events for the Soča River are much wider and longer, in spite of the presence of outstanding and very fast discharge increases. Hydrographs for Nadiža and Učja reflect shorter and outstanding hydrological events. This was also confirmed by autocorrelation diagrams that are more regular for Soča River regarding to Učja and Nadiža River that are quite irregular and erratic. Hydrograph shape is highly dependent on the characteristics of the particular river basin. The recharge area of the Soča River is in significantly higher elevations than for the other two rivers and is characterized mainly as carbonate aquifer type, which results in greater blurring of flow fluctuations. Hydrographs of Nadiža and Učja River are under higher influence of surface runoff.

A rough estimation of groundwater balance characteristics using the calculation of base flow was only possible for Nadiža and Učja river basin. For Soča river basin this is inappropriate because the greater part of the recharge area lies in a considerable distance from the measuring point and the hydrograph is statistically more flat. For Nadiža and Učja the average flow was estimated, which gives an average annual flow of the groundwater and the average volume of groundwater through particular measurement profile. Average annual specific base flow runoff can be estimated from the size of the basin. For the calculation base flow index for α = 0.925 was used. Rough estimations of balance parameters are given in Table 3.9. Specific runoff and thus groundwater volume through the measuring profile on the river Potoki is smaller than on the river Učja.

Table 3.9: Rough estimates of balance parameters for the river Nadiža and Učja

River	*Average annual groundwater flow (m^3/s)*	*Average specific groundwater flow ($m^3/s/km^2$)*	*Average annual groundwater runoff volume in the catchment ($m^3/year$)*
Nadiža (Potoki)	1.02	0.010	$3.21x10^7$
Učja (Žaga)	1.35	0.027	$4.25x10^7$

Within the survey of drinking water resources in the Posočje area analysis of the aquifer Kobariški Stol were carried out. Field research included geological mapping of the area, preparing of hydrogeological maps, hydrogeological mapping of the springs, discharge measurements as well as chemical and isotopic analyses of water samples to determine the recharge area of the springs and hydrodynamic conditions in the aquifer (Brenčič et al., 2001). This chapter summarizes the results of that research, which are essential for determining water availability in the area of Kobariški Stol aquifer.

Hydrogeological map was elaborated on the basis of geological mapping, field identification, and physical and chemical measurements. The area of Kobariški Stol is divided into the following units according to the common hydrogeological characteristics (Figure 3.9):

- high permeable porous aquifers (IAH classification: highly productive porous aquifers): gravel and sand alluvial deposits of the rivers Soča, Učja and Nadiža,
- high permeable porous aquifers on well permeable fissured aquifers (IAH: highly productive porous aquifers): slope rubbel, scree,
- high permeable fissured and karst aquifers (IAH: highly productive fissured and/or karst aquifers): Jurassic and Triassic limestone and dolomite,
- low permeable fissured aquifers (IAH: low and moderately productive fissured and/or karst aquifers): dolomite,
- very low permeable layers (IAH: insignificant aquifers): clay layers with silt and sand, clayey lake sediments, flysch rocks.

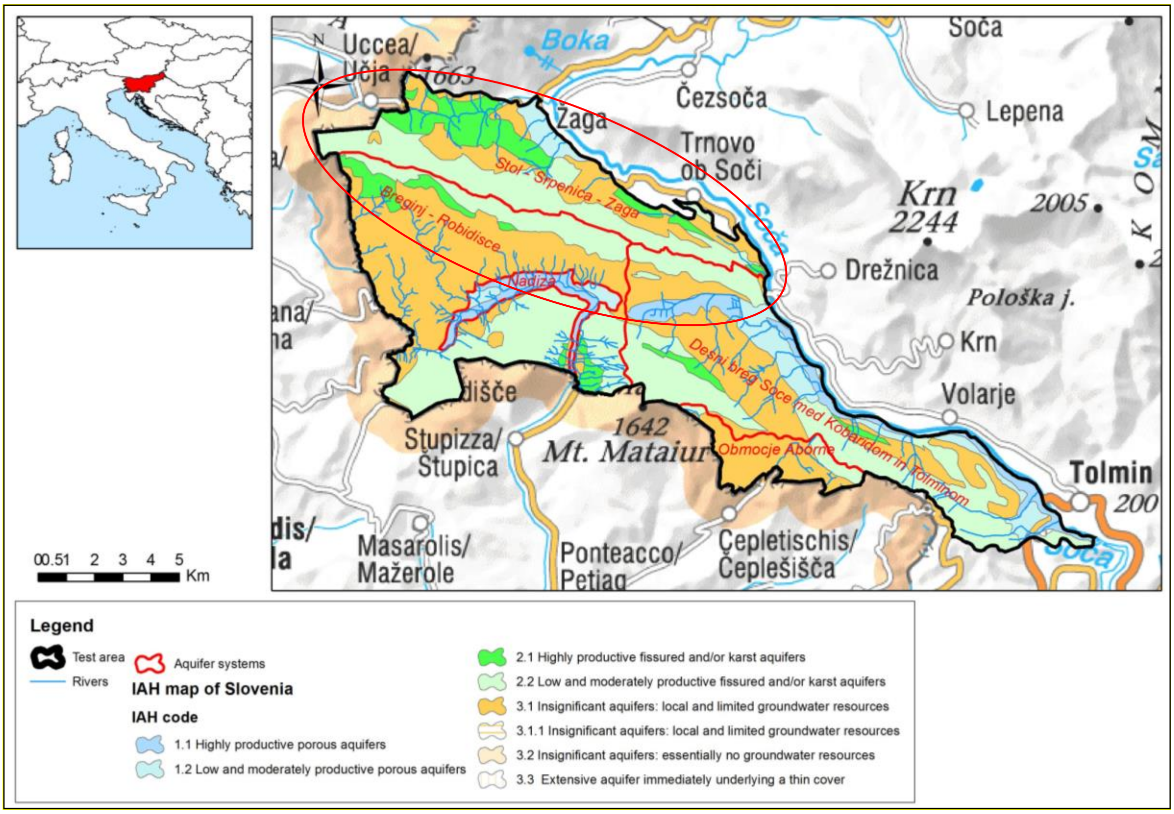


Figure 3.9: Hydrogeological map of the test area according to IAH (Slovene Environment Agency, 2015)

There are several springs in the test area. Discharge measurements on rivers around Kobariški Stol area were carried out within the investigations of drinking water resources in the Posočje area (Brenčič et al., 2001). For the assessment of the groundwater inflow into rivers, discharge measurements were performed on several points.

Discharge measurements were carried out with several methods, depending on discharge and flow characteristics:
- chemical integration method (injection of the NaCl or uranine),
- current meter (hydrometric wing).

The results of measurements and assessment of aquifer outflow at individual measuring points are shown in Table 3.10. Based on the presented results, it was estimated that the total groundwater flow from the Kobariški Stol area (aquifer) is around 2 m^3/s.

Table 3.10: Results of water flow at locations (streams and sources) for Kobariški Stol groundwater flow estimation

Location	*Inflow (l/s)*	*Assessment*
Učja above border	**>200**	<1/2 of discharge on the border
Učja between border and Žaga	**150**	>1/2 difference of measurements
Soča between Žaga and Kobarid	**<50**	assessment
Soča near Kobarid	**1000**	measurement
Sources near Kobarid	**100**	measurement
Idrija near Kobarid	**280**	measurement
Nadiža between Kred and Sužid	**<50**	assessment
Bela	**110**	measurement
Tributaries of Nadiža in Italy (Črni, Beli potok)	**>150**	>2/3 of measurement near Podbela
ALL	**App. 2000**	

It can be concluded that water availability analysis for the test area Kobariški Stol aquifer was performed in the frame of the research of the drinking water resources in the Posočje area (Brenčič et al., 2001). Based on the presented study, it was estimated that the total groundwater flow from the Kobariški Stol area (aquifer) is around 2 m^3/s. Kobariški Stol aquifer is therefore potential water resource for drinking water supply, which can be also considered for cross-border water supply between Slovenia and Italy.

Field measurements were basic and were performed in a short time period. Therefore further analyses are recommended, such as discharge measurements with duration in two hydrological years, isotopic analyses for the recharge area determination, etc.

3.4. CROATIA

From Annex 5:

The inflows from the selected drainage basins in the test area of northern Istria and test area of Southern Dalmatia under conditions of climate change were assessed using a simplified approach suitable for the available climatological and hydrological data. It is based on the comparison of the measured data on the balance of quantities discharged at the springs and data on the balance of the actual rainfall infiltrated into the basin, using in this process data on rainfall and temperatures in the basin.

The inflows from the selected drainage basins in the under conditions of climate change were assessed using a simplified approach suitable for the available climatological and hydrological data. It is based on the comparison of the measured data on the balance of quantities discharged at the springs and data on the balance of the actual rainfall infiltrated into the basin, using in this process data on rainfall and temperatures in the basin.

When assessing the balance of this actual rainfall in the Croatian karst, the most frequently used models are the empirical models by Turc (1954) and Langbein (1962) modified and developed for GIS application (Horvat and Rubinić, 2006). These are models with the help of which, based on spatial assessment of the annual rainfall and the average annual air temperatures in the analysed basin, with the surface area of the basin determined using hydro-geological methods, it is possible to define the spatial distribution of actual annual rainfall, i.e. the rainfall that had infiltrated into the karst aquifer basin. The relevant model is selected based on the comparison of the measured and estimated values of the average annual inflows. If the measured data on the spring discharge is missing, the selection is done on the basis of expert estimates and regional formulas giving estimated average annual run-off coefficients. In addition on the level of annual values, potential changes of hydrological conditions due to the expected climate change are expressed on a shorter time scale as well. In that process, the parameter of the lowest average monthly discharge was selected as the most relevant for the assessment of critical hydrological conditions for water supply, as a representative of the intra-annual distribution of dry hydrological events.

The estimated annual water balance is the basis for the presented balance model. The water balance elements were defined using two different approaches: the first one proposed by Turc (1954) and the second one by Langbein (1962). Turc's formula (1954) expresses runoff deficit (*D*) as a function of rainfall (*P*) and a temperature factor (*L*):

$$D = \frac{P}{\sqrt{0.9 + \frac{P^2}{L^2}}} \qquad (1)$$

The temperature factor (*L*) is calculated using the formula:

$$L = 300 + 25 \times T + 0.05 \times T^3 \qquad (2)$$

where *T* represents increasing air temperature.

As shown in Figure 3.10, the Langbein method (1962) is based on a unique relationship between rainfall–temperature factor ratio (P/K) and runoff–temperature factor ratio (Q/K), i.e. it uses rainfall and air temperature as the key attributes when estimating surface runoff. Air temperature (T) is incorporated through a temperature factor (K), which increases exponentially as air temperature increases:

$$K = 10^{0.0278T + 0.886} \quad (3)$$

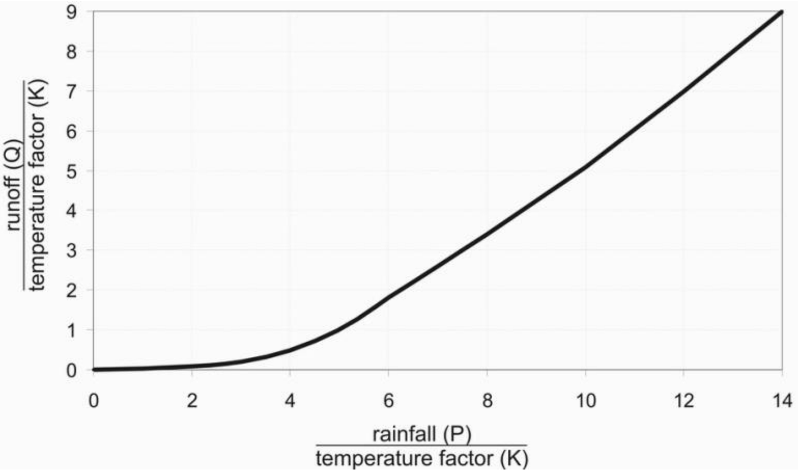


Figure 3.10: Langbein method: relationship between P/K and Q/K

Both approaches use the average annual rainfall and air temperatures (often the only available climatological data in hydrological analysis of the runoff) as spatially variable input parameters. Geographical information systems greatly facilitate the estimation of spatial distribution and spatial analysis of the input parameters and the results.

The first iteration (Figure 3.11) in estimating annual runoff starts with delineation of the drainage basins, based on hydro-geological estimations, followed by estimation of the spatial distribution of the meteorological parameters (rainfall and air temperatures). Then, estimation of the spatial distribution of the average annual runoff can be done, using both the Turc and Langbein methods.

Based on the results, comparisons with the measured data are made. If the differences are negligible, the selected method, i.e. its results can be accepted and the 3rd iteration, i.e. final estimation of the annual runoff can be carried out. Otherwise, a second iteration takes place, which includes alternation of one of the input parameters (e.g. drainage basin boundaries) or methodological modifications (such as the modification of the analytical expressions used for estimation of the hydrological parameters).

The model calibration and validation, i.e. the verification of the modelling results was made in two segments. One segment was the calibration of inputs into the hydrological model (data on the spatial distribution of average annual data on rainfall and average annual air temperature) for the referent 30-year period 1961-90 by identifying correction interrelations between the point data measured at the location of the selected climatological station and the values obtained on the basis of their spatial distribution. Another segment of the calibration done during the same 30-year period was the selection of the relevant model for estimating the average annual run-off/actual rainfall (according to the Turc or Langbein model). This was done based on the comparison of the modelling results and the measured data on run-off from the specified springs. In that process, the measured data on discharges from the springs in Northern Istria supplemented the reference 30-year period based on regression links with longer-series data from hydrological stations in the Mirna basin, showing a better match with balance estimations obtained using the Langbein model. The measured data on discharges from Prud spring supplemented the reference 30-year period based on regression links with data from the nearby hydrological stations.

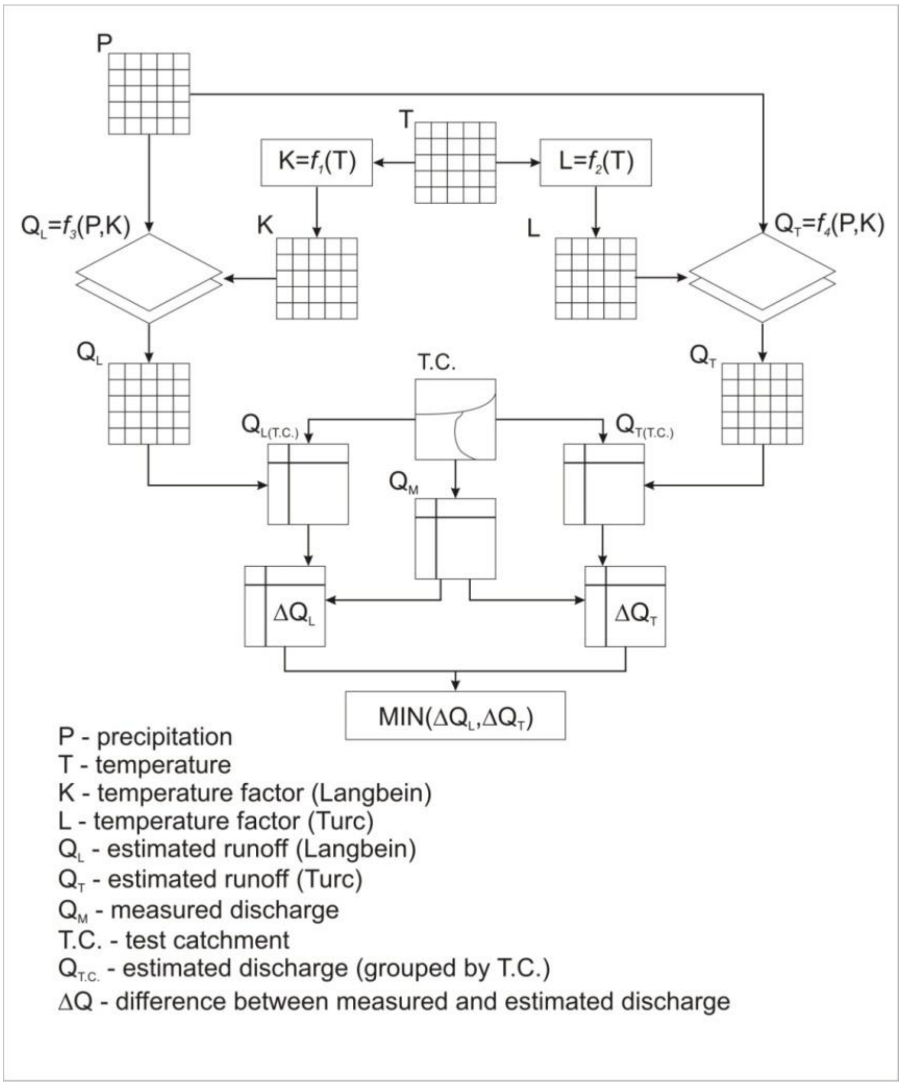


Figure 3.11: Scheme of the first iteration

Based on such verification of historical data, models were made for synthetic series of inflows – average annual yields of individual springs for the period 2021-2050 based on the values of average annual air temperatures and annual rainfall generated by the RegCM3, Aladin and Promes climate models and the estimated run-off – actual infiltration of rainfall from their basins into karst aquifers (Rubinić and Katalinić, 2014). In that process, the boundaries were defined based on available hydro-geological information, i.e. documents on the basis of which the boundaries of the sanitary protection zones were defined.

3.4.1. NORTHERN ISTRIA - SPRINGS SV. IVAN, GRADOLE AND BULAŽ

From Annex 5:

For Gradole and Sv. Ivan springs, the entire boundary of their sanitary protection zone III was taken as the dominant recharge area. For Bulaž spring, zone IV was also included since this is a drainage basin where the boundary of zone IV, which includes flysch sections of the drainage basins of watercourses in the Zrenjska plateau, is firmly defined, unlike the boundary of zone IV for Sv. Ivan and Gradole springs which is only roughly defined and also includes areas from which rainfall drains towards other water resources (Annex 5). The northern boundary of sanitary protection zone IV of Sv. Ivan spring, which lies on the territory of Slovenia, hasn't even been defined yet and is only provisionally delineated in the form of a straight line (Figure 2.12)
For that reason, the boundaries of zone IV for Gradole and Sv. Ivan springs (Figure 2.12, 3.13 and 3.14) are specifically delineated and denoted with an additional mark, "a", with a special analysis of their water balance in terms of estimating the actual rainfall in the total water balance of these springs (Horvat, 2014).
Even though climate change for a large number of stations from the wider drainage basin of the analysed springs in the Mirna basin was analysed and estimated as part of climatological analyses (DHMZ, 2014), one station – the Pazin climatological station – was selected as the reference station. This station has the longest and highest-quality continuous series of historical measurements and lies roughly in the middle of all the three drainage basins. Since the data on annual rainfall and air temperatures from this station (measured and generated) doesn't at the same time represent the average values for the given drainage basin, interrelations were defined in the form of reduction coefficients of such "point" data with the average value obtained on the basis of their spatial distribution throughout the drainage basin during the reference 30-year period 1961-90. A one-year period was selected as a period of discretization. The measured data on rainfall and temperatures for 1951-2012 and their generated values for the period until 2050 were used in the analyses.
A document prepared by the Croatian Meteorological and Hydrological Service (Državni hidrometeorološki zavod - DHMZ) and experts Cindrić, Gajić-Čapka, Güttler and Branković (4.1. report 2014) contains a detailed presentation of modelling results of the average annual air temperatures and annual rainfall based on the data registered at the Pazin station in the period 1951-2012. Table 3.11 gives only a summary overview of the characteristic results, i.e. characteristic values of the average annual air temperatures and annual rainfall for the selected 30-year periods. The table presents the results obtained using all the three models.
The presented data shows that the results of the climate modelling done during the reference 30-year period 1961-2012 are generally very similar to the observed data – the average annual values of both temperatures and average annual rainfall in each model fully match the corresponding values obtained from the observed data series. Compared to the observed values, slightly higher extremes of the average annual temperatures (maximums – in Aladin and Promes, minimums – in Aladin and RegCM3) and annual rainfall (maximums – in Promes, minimums in RegCM3) are expressed. However, at the level of individual annual values the differences are sometimes very significant, which is

the result of the 25-km spatial resolution of the regional climate models used and the success of their adjustment to the observed data.

Table 3.11: Registered and model-based results for average annual air temperatures and annual rainfall for the Pazin station

	Temperatures (^{0}C)			Rainfall (mm)		
1961- 1990 – Registered						
Mean	11.1			1167.8		
St.dev	0.38			207.8		
Cv	0.03			0.18		
MAX	11.7			1551.5		
MIN	10.3			803.9		
1961- 1990 – Model-based						
	RegCM3	Aladin	Promes	RegCM3	Aladin	Promes
Mean	11.1	11.1	11.1	1167.8	1167.8	1167.8
St.dev	0.51	0.57	0.63	244.6	144.3	249.8
Cv	0.04	0.05	0.05	0.15	0.09	0.14
MAX	11.9	12.1	12.5	1680.6	1523.9	1825.4
MIN	9.6	9.3	10.3	722.8	818.9	814.2
2012 - 2050 – Model-based						
Mean	12.7	12.2	13.2	1208.5	1215.0	1224.2
St.dev	0.63	0.60	0.69	273.5	193.5	218.8
Cv	0.05	0.05	0.05	0.23	0.16	0.18
MAX	14.0	13.7	14.9	1809.1	1607.2	1669.7
MIN	11.5	10.9	11.9	646.0	846.4	791.1

The selected 30-year period within which the impacts of potential climate change on water resources in 2021-2015 are analysed shows the characteristics of the rainfall regime very similar to the reference 30-year period 1961-1990 in terms of the average annual rainfall, even a slight increase by some 50 mm (3-4%), but with more marked variations and extreme rainfall values. According to all the models, the average annual air temperatures should rise significantly, with considerably different results of the models. For example, the Aladin model foresees a mean 30-year increase of the average annual air temperatures by 1.1 ^{0}C, RegCM3 by 1.6 ^{0}C, and Promes by as much as 2.1 mm (+19%), including increased both maximum and minimum air temperatures.

The availability of adequate data determines the application of particular run-off estimation methods. Climate data (rainfall and air temperatures) used in the analysis of basins in the Istria region is available in the form of spatial distribution of the average annual values for the 30-year period (1961-1990), in the form of a 1,000-meter spatial resolution raster prepared by Croatian Meteorological and Hydrological Service and experts Cindrić, Gajić-Čapka, Güttler and Branković (Figure 3.12a and 3.12b). This spatial resolution is identical to the spatial resolution of the digital elevation model (DEM) used.

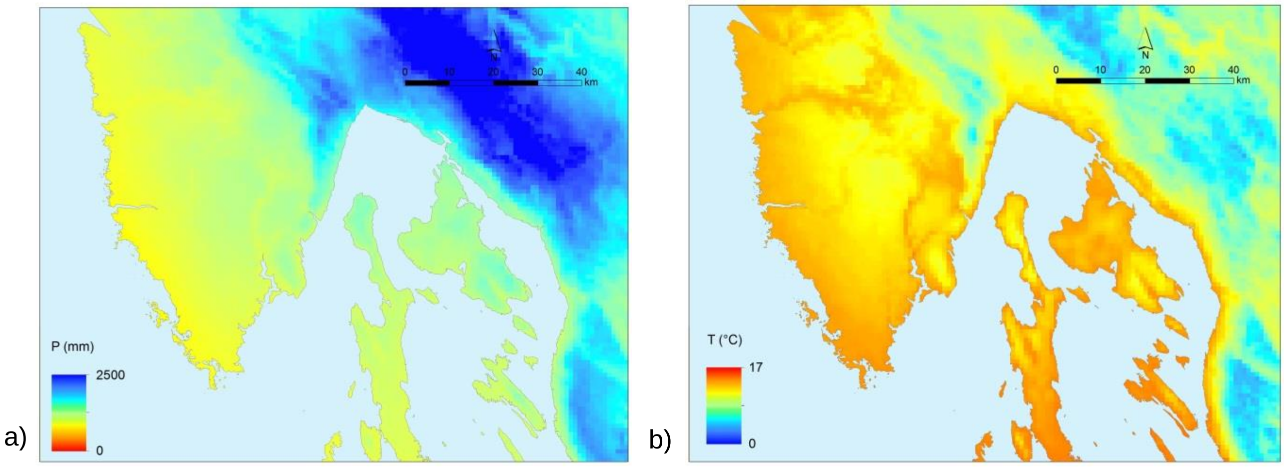


Figure 3.12: Spatial distribution of a) average annual rainfall, and b) average annual air temperature for Istria (1961-1990)

This climate data and the presented methodology were used for the definition of maps of the spatial distribution of specific run-off according to the Langbein (Figure 3.13a) and Turc methods (Figure 3.13b) and for the preparation of a map of spatial differences in results obtained by both methods (Figure 3.14) in the analysed areas.

The average annual specific run-off was estimated for the selected drainage basins presented in Figure 3.13. The main results (average temperatures and rainfall for individual basin units) are presented in Table 3.12, while Table 3.13 presents the values of specific and total average annual discharges from the analysed drainage basins of individual springs.

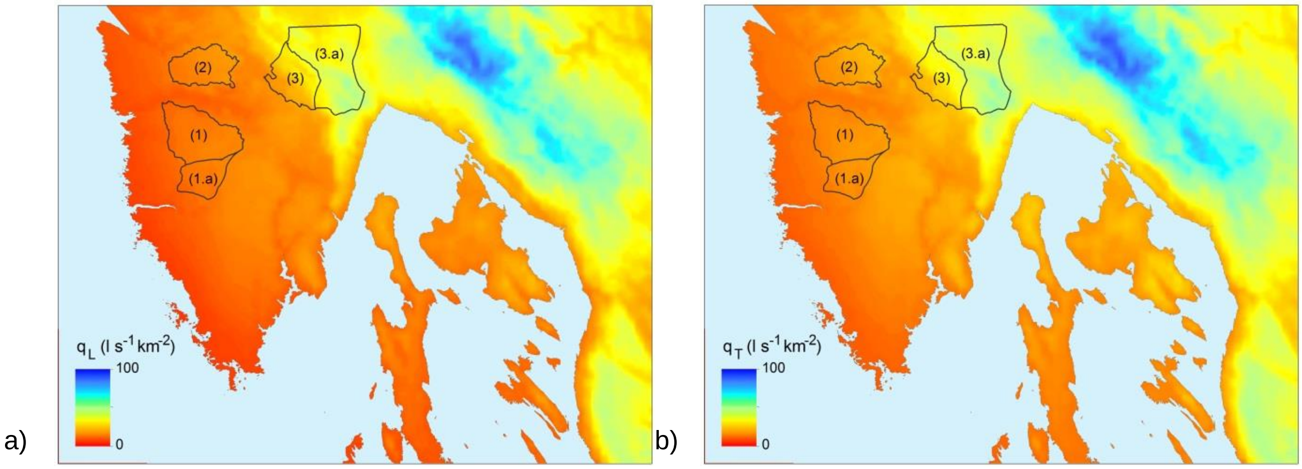


Figure 3.13: Spatial distribution of specific discharges in Istria for the period 1961-1990 defined by: a) Langbein method; b) Turc method

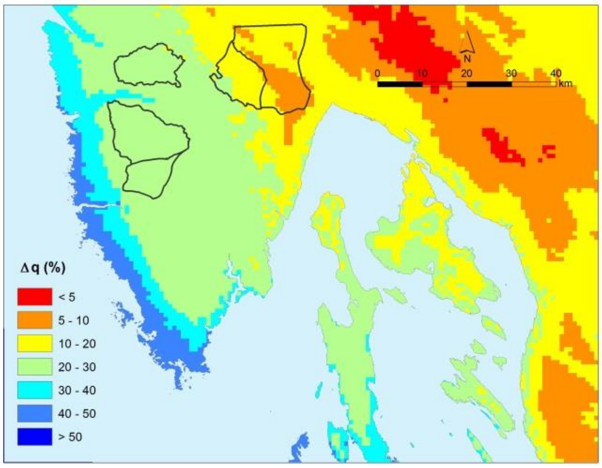


Figure 3.14: Difference in results obtained by the Turc and Langbein methods for the period 1961-1990

Table 3.12: Basic climate elements of the selected drainage basins in northern Istria (1961-1990)

DRAINAGE BASIN		Surface area (km^2)		Average annual air temperature (^{0}C)		Annual rainfall (mm)	
Gradole	1.	163.38	236.69	11.3	11.3	1066.7	1073.1
	1.a	73.31		11.4		1087.5	
Bulaž	2.	103.23	103.23	11.0	11.0	1195.6	1195.6
Sv. Ivan	3.	103.00	325.27	10.1	8.7	1559.8	1760.6
	3.a	222.27		8.1		1853.6	

Table 3.13: Average annual discharges in the analysed drainage basin units of individual springs based on water balance estimations

DRAINAGE BASIN UNIT		Specific discharges (l s^{-1} km^2)				Total discharges (m^3s^{-1})			
		q_{LANG}		q_{TURC}		Q_{LANG}		Q_{TURC}	
Gradole	1.	12.85	12.86	16.33	16.34	2.10	3.04	2.67	3.87
	1.1.	12.88		16.36		0.94		1.20	
Bulaž	2.	15.44	15.44	19.44	19.44	1.59	1.59	2.01	2.01
Sv. Ivan	3.	25.69	33.81	30.58	38.32	2.65	11.00	3.15	12.46
	3.1.	37.57		41.9		8.35		9.31	

In general, the values of specific discharges obtained using the Langbein method in all the analysed drainage basins are lower than the values obtained using the Turc method. It is evident that in Istria run-off is the heaviest in its north-eastern parts where the rainfall is also the heaviest, i.e. in the higher elevations (even exceeding 50 l s^{-1} km^2 in some places). This is also where the differences in results obtained from the two methods are the smallest (5-10 %). In the coastal regions of southern and western Istria surface run-off is lower than 10 l s^{-1} km^2, and the results of the Turc method exceed the run-off obtained using the Langbein method by 30-50 %. However, these regions lie beyond the boundaries of the analysed drainage basins. Consequently, the real differences in the estimation results obtained using the two above-mentioned estimation methods are considerably smaller and range between 5 and 30%.

Systematic hydrological observations at the analysed springs in the Mirna river basin started in the late 1980s. They include monitoring of water level fluctuations, overflow discharges, abstracted quantities and total yields (overflow discharges + abstracted quantities). They are implemented by the Croatian Meteorological and Hydrological Service in cooperation with the water supply company that is exploiting the springs, Water Utility of Istria from the town of Buzet. It needs to be noted that some earlier hydrological observations had been done at individual springs for a short period, but the analyses presented here use the data obtained from the above-mentioned integrated observations that started in 1986 at Sv. Ivan spring, in 1987 at Gradole spring, and in 1988 at Bulaž spring. In the present document, the available series of data collected in that way ending with the year 2013 are used.

On the basis of the regression analysis, this data supplemented the period 1961-2013 by correlating the average monthly values of discharges from individual springs and hydrological stations on the Mirna.

When supplementing the data from all the three stations (Sv. Ivan, Bulaž and Gradole), data from the station Portonski most – Mirna was used. The distribution of the average annual total discharges is presented below, as well as the lowest average monthly discharges for the analysed springs and the accompanying trends (Figure 3.15-3.17). The homogeneity of the supplemented and measured series of data on the average annual discharges was analysed using Wilcoxon's (1945) non-parametric test (rank-sum test), respecting in the process the level of confidence of $\alpha = \pm 0.05$, i.e. standard unit deviation of $U_0 \leq | 1.98$. Analysis was done of the original series which due to the downward discharge trends present at the time failed to display appropriate homogeneity, as well as series from which a trend was excluded (Table 3.14) but which turned out to be homogenous. With regard to the homogeneity present in the case of excluding the impact of that trend, the applied procedure of supplementing the series of the average annual discharges can be accepted.

Table 3.14: Homogeneity assessment of the registered and supplemented series of data on the average annual discharges of the analysed springs

	Original data series	Data series with excluded trend
Sv. Ivan		
Standard unit deviation U_O	3.67	0.94
Homogeneity assessment	Non-homogenous	Homogenous
Gradole		
Standard unit deviation U_O	2.34	0.88
Homogeneity assessment	Non-homogenous	Homogenous
Bulaž		
Standard unit deviation U_O	3.74	0.46
Homogeneity assessment	Non-homogenous	Homogenous

For the purpose of better comparison of the distributions, Figure 3.18 contains a collective presentation of the average annual discharges of the analysed springs with temporal discretization by hydrological years (October – September the following year) within which wet and dry periods are better distinguished.

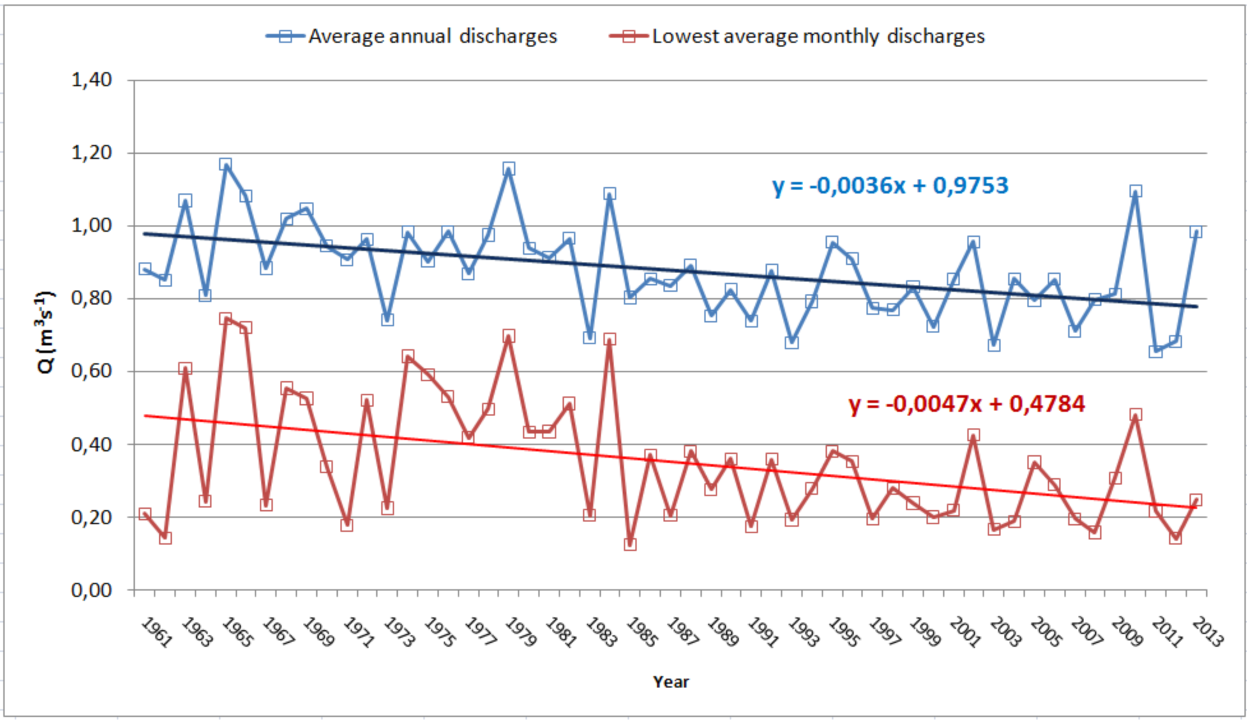


Figure 3.15: Distribution of the average annual discharges and the lowest average monthly discharges of Sv. Ivan spring (1961-2013)

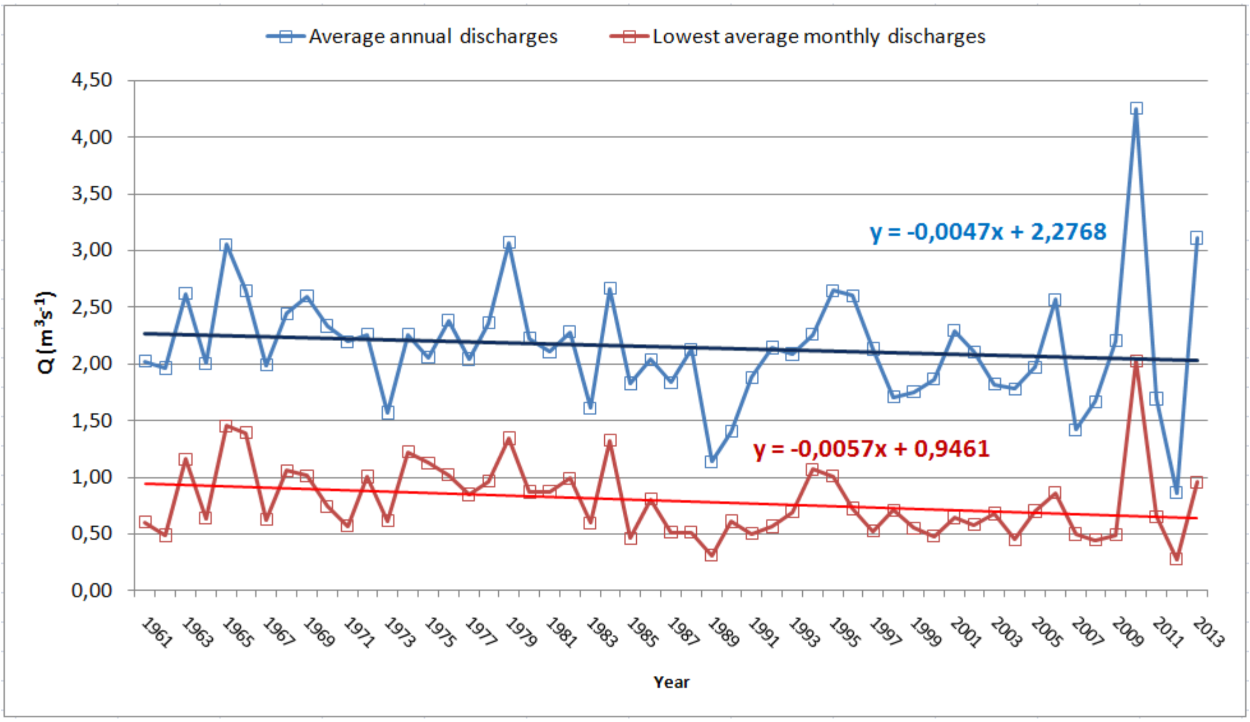


Figure 3.16: Distribution of the average annual discharges and the lowest average monthly discharges of Gradole spring (1961-2013)

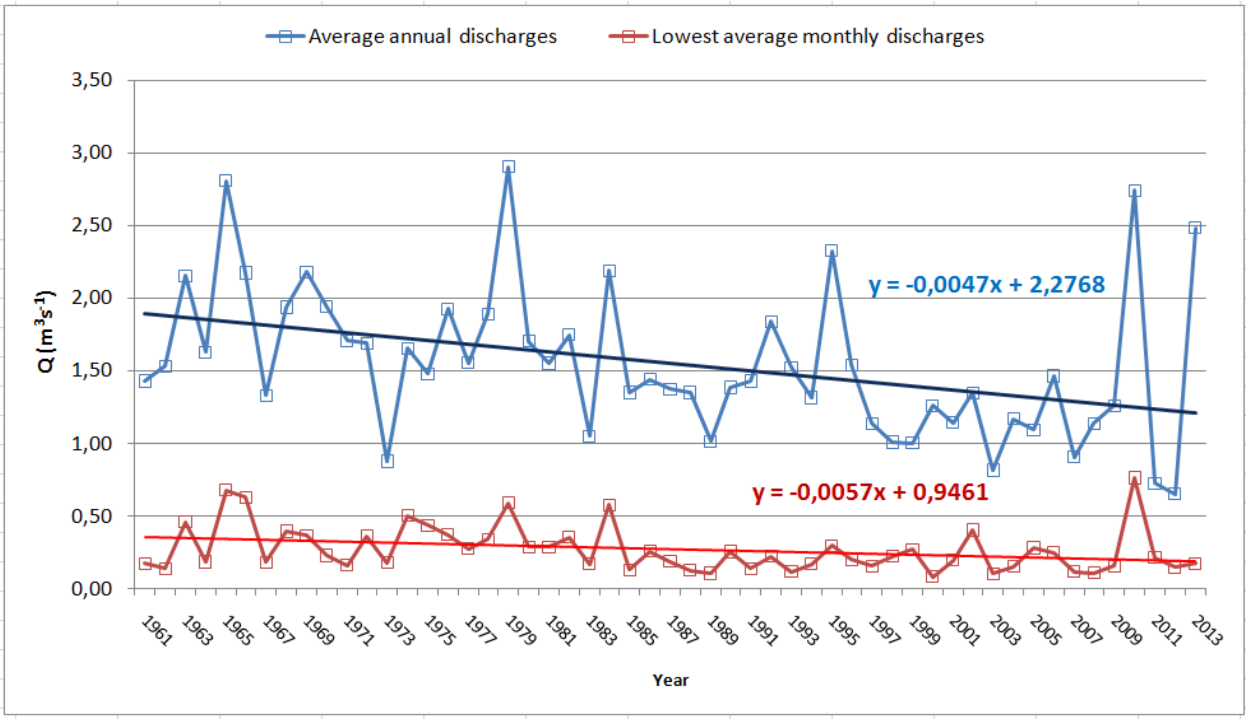


Figure 3.17: Distribution of the average annual discharges and the lowest average monthly discharges of Bulaž spring (1961-2013)

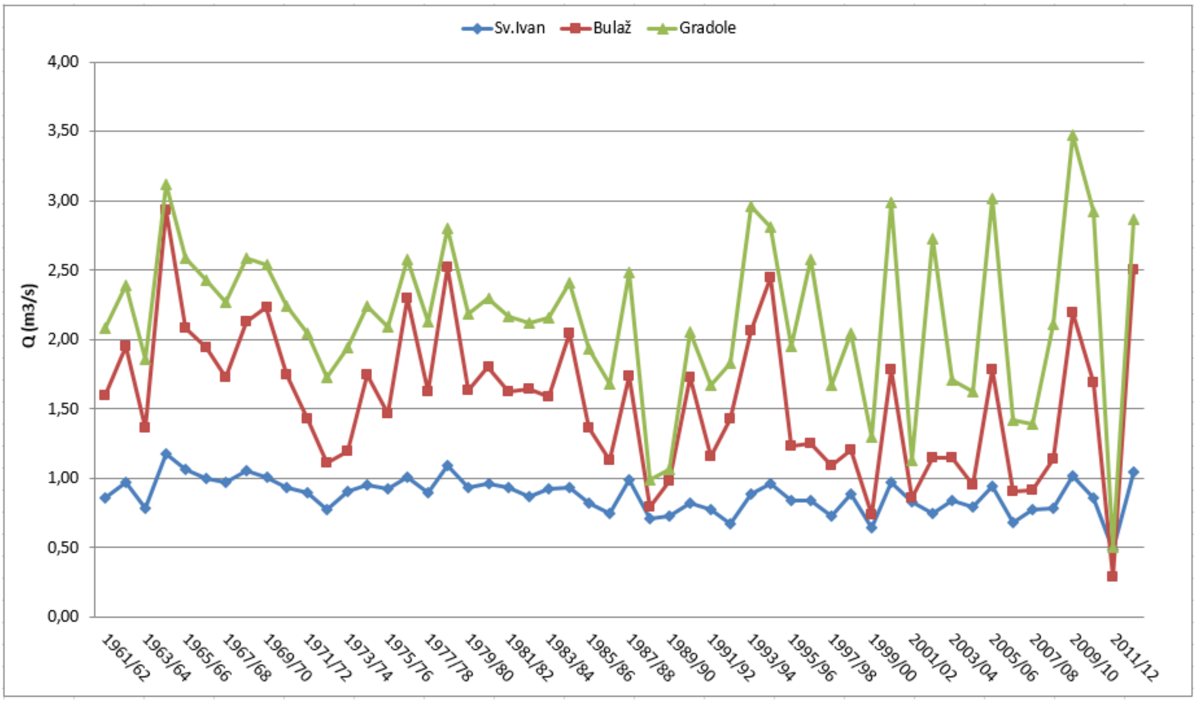


Figure 3.18: Comparative distribution of the average annual (by hydrological years) discharges of Sv. Ivan, Gradole and Bulaž springs (1961/62 – 2012/13)

A comparative presentation of the intra-annual distribution of the average monthly discharges of the analysed springs for the period 1961-2013 is presented in Figure 3.19. It shows that the average monthly discharges have a very similar intra-annual distribution, with Bulaž spring having more marked differences between the wet and dry periods.

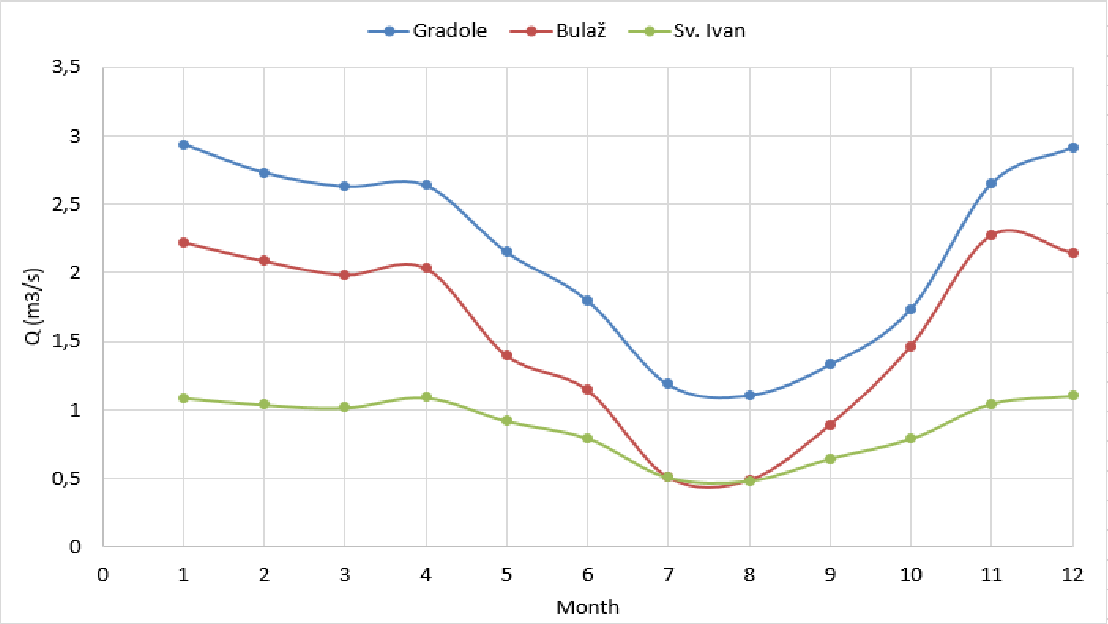


*Figure 3.19**:** Intra-annual distribution of the average monthly discharges of karst springs Gradole, Sv. Ivan and Bulaž (1961-2013)*

Based on the analysis of interrelations between the lowest average monthly discharges and the average annual spring discharges, the equations of such interrelations for each of the springs have been defined (Figure 3.20, Table 3.15). The correlation coefficients were used as the indicator of the strength of the relation. In this specific case, these correlation coefficients at springs which show lower variations in discharges and a much slower rate of emptying of water reserves (Gradole, Sv. Ivan) result in a slightly more significant value of the correlation coefficient (higher than 0.8) in relation to its value at Bulaž spring (0.75) which has the highest variations in discharges.

Table 3.15: Interdependence of the lowest average monthly discharges “y” and average annual discharges “x” of individual springs

Spring	Regression equation	Correlation coefficient
Sv. Ivan	$y= 0,025\ e^{3,1053\ x}$	0.81
Gradole	$y= 0.0594\ x^2 +0.2386\ x\ -0.0135$	0.85
Bulaž	$y= 0.0362\ x^2+0.112\ x$	0.75

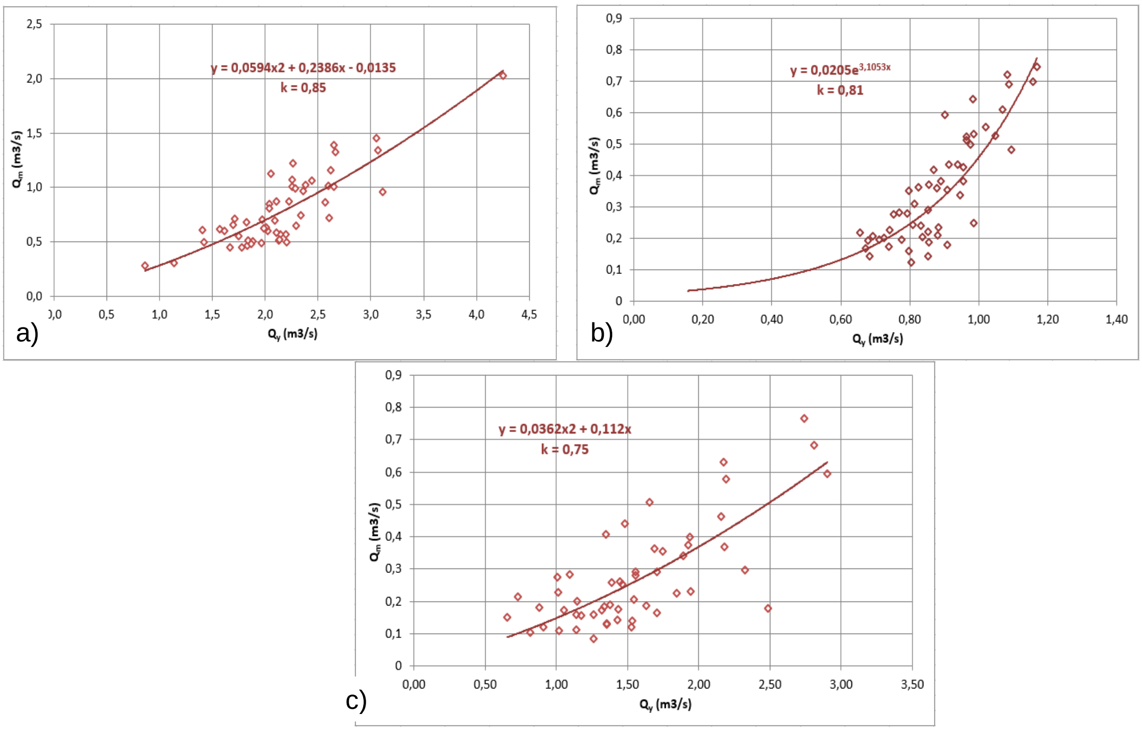


Figure 3.20: Interrelation between the average annual discharges and the lowest monthly annual discharges of springs in the Mirna River basin: a) Gradole, b) Sv. Ivan c) Bulaž

GRADOLE SPRING

Based on the comparison of the average annual discharge obtained from the measured data and the correspondingly supplemented data series (1961-1990), the value of which is 2.17 m^{3}s^{-1}, and the results of modelling done for the main drainage basin of Gradole spring (including the first three sanitary water source protection zones) which using the Langbein method give a discharge of 2.10 m^{3}s^{-1}, a very good match between these results can be identified (difference of app. 3%). It was precisely on this basis that such drainage basin was accepted for the estimation of the water balance under changed climate conditions, i.e. estimation of the average annual discharges of synthetic time series of discharges, obtained on the basis of the average annual temperatures and annual rainfall estimated on the basis of climate models. This is done using the methodology explained at the beginning of this chapter.

The results, values of historical time series and of time series of the average annual inflows generated based on the selected climate models are presented in Figure 3.21. Series of the lowest average monthly discharges (Figure 3.22) were formed based on the regression model presented in Table 3.15.Table 3.16 presents the characteristic values of historical and generated series of the average annual inflows and of the lowest average monthly inflows. Table 3.17 presents the differences in the results obtained.

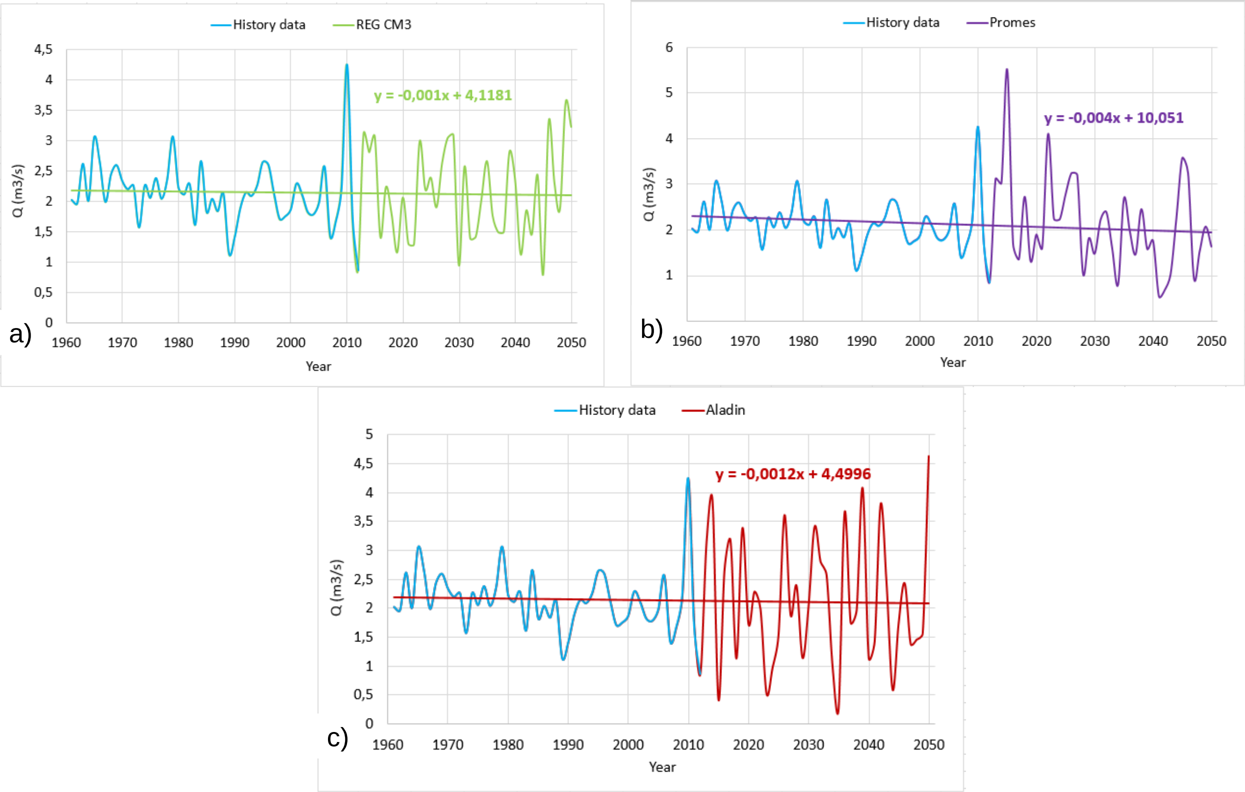


Figure 3.21: Historical time series and synthetic time series of the average annual discharges of Gradole spring generated using different climate models (1961-2050) with accompanying trends: a) REG CM3, b) Promes, and c) Aladin

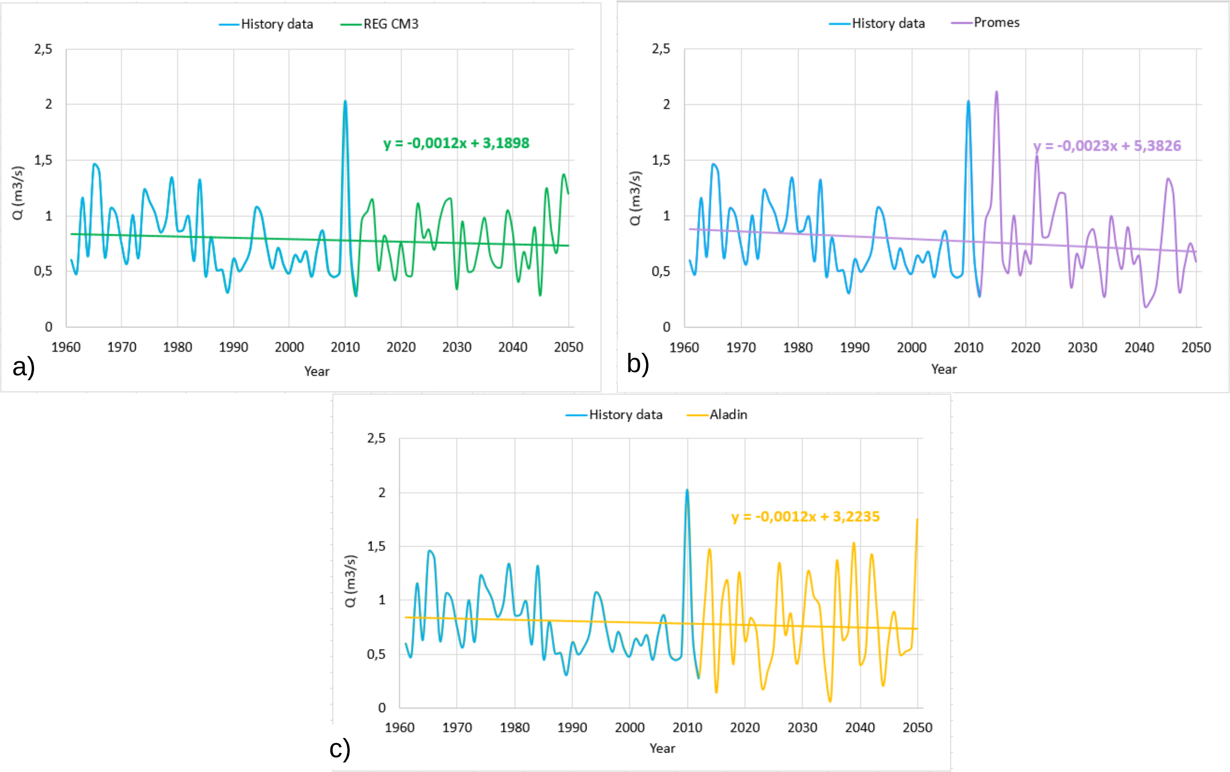


Figure 3.22: Historical time series and synthetic time series of the lowest average monthly discharges of Gradole spring generated using different climate models (1961-2050) with accompanying trends: a) REG CM3, b) Promes, and c) Aladin

It is evident that different models give different values quantifying water balance changes due to the projected climate change. For the period 2021-50, at the level of the average values of annual discharges, the expected changes, i.e. decrease in discharges compared to the average from the reference period 1961-90 range, depending on the model, between 1.9 and 7.8%. Changes are also expected in the lowest average monthly discharges to a slightly increased extent, where the discharge change/decrease for the analysed 30-year period 2021-2051 ranges, depending on the model, between 5.6 and 13.1%. On the average, the smallest changes are generated by the RegCM3 model, and the biggest ones by the Promes model. However, differences in terms of extreme values are even more significant – both for the average annual discharges and for the lowest average monthly discharges, with these differences reaching as much as 80% in certain models. Results of the Aladin-based estimation show bigger changes, while the results of the Promes model suggest slightly smaller changes. If scenarios of that kind would come true, even to a smaller extent, this would pose additional problems in the provision of water supply. This was actually to a considerable extent already felt in the year 2012, when category I water-saving measures were established in the Istrian region during the two months of a critically dry summer period.

The homogeneity of two data series was tested – for the period 1961-1990, obtained on the basis of measurements and the correspondingly supplemented series, and for the period 2021-2050, for which discharges were obtained by modelling the generated time series of data on rainfall and temperatures using the three climate models. Homogeneity was tested using Wilcoxon's non-parametric test.

The obtained results (Table 3.18) show that in all the three models the generated time series are homogenous with the recorded historical series, both for the generated series of data on the average annual discharges and for the generated series of the lowest average monthly discharges. The smallest deviations were recorded for the data series generated by the RegCM3 model, which also shows potential smallest changes in relation to the changes in the water regime of Gradole spring foreseen by the Promes and Aladin models. The obtained results point to the possibility of more frequent occurrence of years with very low average monthly discharges in the order of magnitude only slightly above 0.2 m^{3}s^{-1}. This in turn implies potential further deterioration of water supply conditions during dry summer periods when the water demand is the heaviest, and during exceptionally dry years the capacity of Gradole spring-water intake is as much as around five times lower than its nominal capacity, which is app. 1 m^{3}s^{-1}.

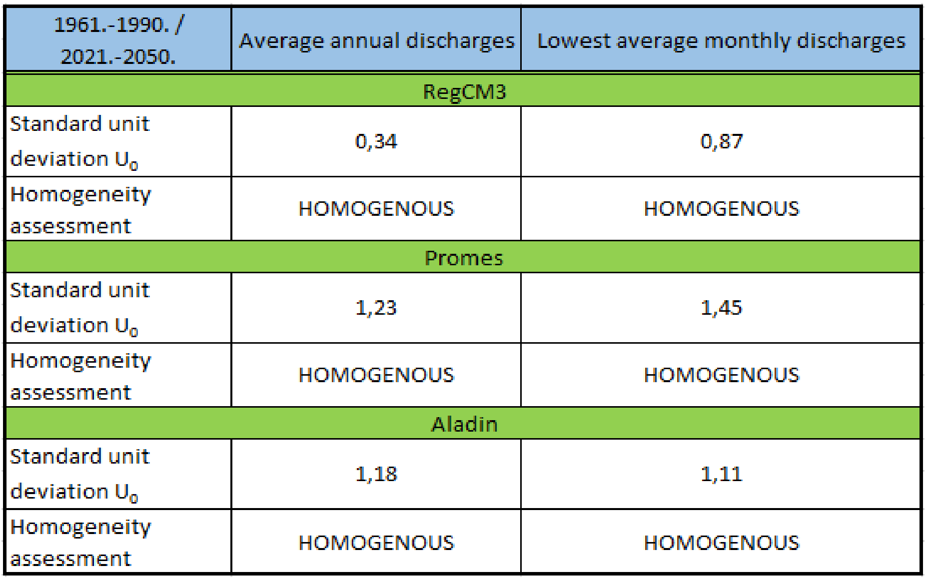
Table 3.16: Registered and model-based results for average annual and the lowest average monthly inflows of Gradole spring (1961-2050)

	Average annual inflows (m^{3}s^{-1})			Lowest average monthly inflows (m^{3}s^{-1})		
1961- 1990 – Registered						
Mean	2.17			0.86		
St.dev	0.43			0.31		
Cv	0.20			0.36		
MAX	3.07			1.45		
MIN	1.14			0.31		
2021- 2050 – Model-based						
	RegCM3	Aladin	Promes	RegCM3	Aladin	Promes
Mean	2.13	2.08	2.00	0.80	0.81	0.75
St.dev	0.77	1.11	0.89	0.38	0.58	0.45
Cv	0.36	0.53	0.44	0.48	0.72	0.60
MAX	3.62	4.64	4.10	1.63	2.37	1.96
MIN	0.80	0.26	0.54	0.21	0.05	0.13

Table 3.17: Identified changes (in %) in the main water balance indicators of the average values of average annual discharges and the lowest average monthly discharges of Gradole spring for the period 2021-2050 in relation to the period 1961-1990

	Changes in average annual discharges (%)			Changes in the lowest average monthly discharges (%)		
2021-2050						
	MEAN	MAX	MIN	MEAN	MAX	MIN
RegCM3	-1.9	18.1	-29.8	-7.2	12.2	-30.7
Aladin	-4.1	51.2	-77.0	-5.6	63.2	-82.9
Promes	-7.8	33.5	-52.5	-13.1	34.9	-57.1

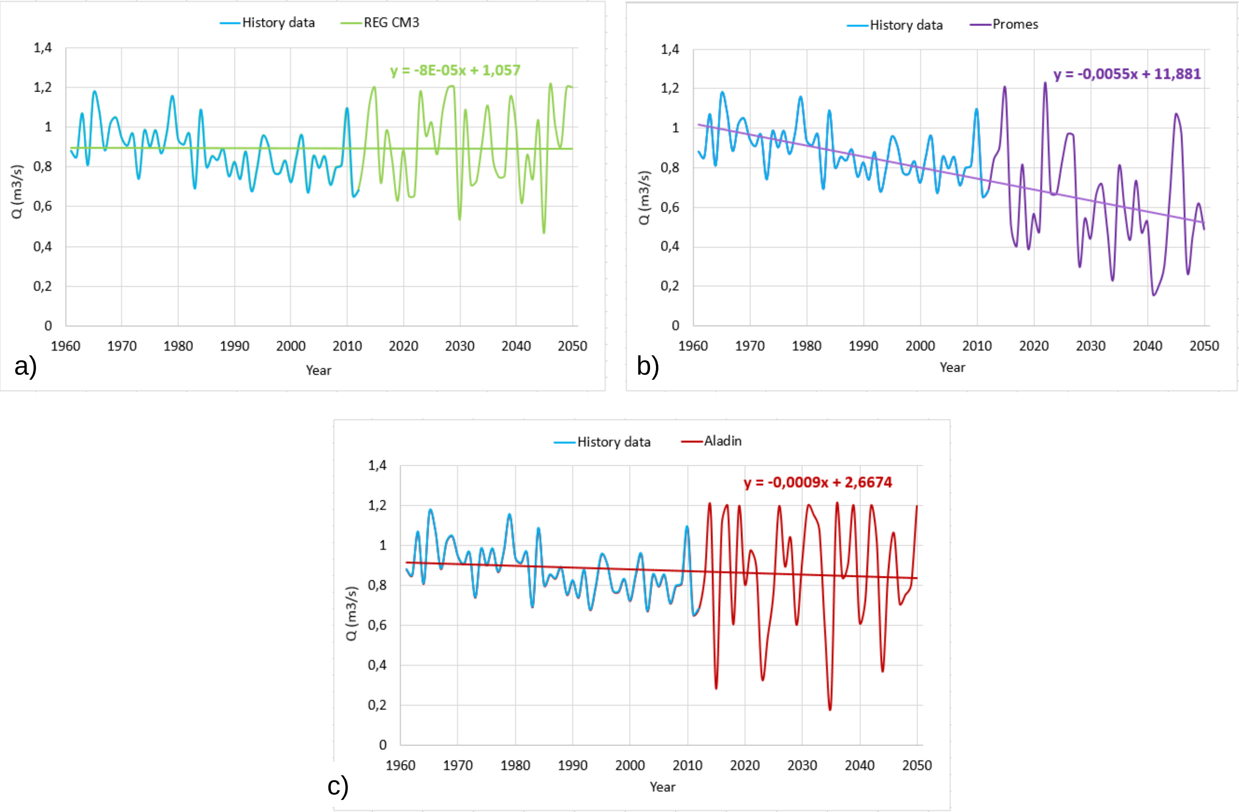
Table 3.18: Assessment of homogeneity of data on the average annual discharges and the lowest average monthly discharges of Gradole spring for the historical period 1961-1990 and the period 2021-2050 generated by the climate models



1961.-1990. / 2021.-2050.	Average annual discharges	Lowest average monthly discharges
RegCM3		
Standard unit deviation U_0	0,34	0,87
Homogeneity assessment	HOMOGENOUS	HOMOGENOUS
Promes		
Standard unit deviation U_0	1,23	1,45
Homogeneity assessment	HOMOGENOUS	HOMOGENOUS
Aladin		
Standard unit deviation U_0	1,18	1,11
Homogeneity assessment	HOMOGENOUS	HOMOGENOUS

SV. IVAN SPRING

What makes Sv. Ivan spring specific is the fact that the groundwater from its drainage basin discharges at springs, and even at several levels of discharge, some of which (Tombazin, Pivka) are very strong but intermittent karst springs. The comparison of the average annual discharge obtained from the measured data and the correspondingly supplemented data series (1961-1990), the value of which is 0.92 m^3s^{-1}, and the results of estimations of the contribution of the main drainage basin of Sv. Ivan spring (including the first three sanitary water source protection zones) to the water balance, which using the Langbein method give a discharge of 2.65 m^3s^{-1} (Table 3.13), shows a huge difference. This difference can be attributed to restrictions in terms of discharge quantities at the spring and to exploitation of the springs not covered by monitoring. However, when the contribution of water from the drainage basin discharging at main spring Sv. Ivan was reduced, all the data on external climate impacts was reduced to the total balance contribution at the level of a 30-year average during 1961-90 with a value of 0.92 m^3s^{-1}. On the basis of this, the given drainage basin and the above-mentioned balance reductions were accepted for water balance estimation, i.e. estimation of the average annual discharges of synthetic series of discharges formed using the climate models. This is done using the methodology explained at the beginning of this chapter.



a)

b)

c)

Figure 3.23: Historical time series and synthetic time series of the average annual discharges of Sv. Ivan spring generated using different climate models (1961-2050) with accompanying trends: a) REG CM3, b) Promes, and c) Aladin models

The results, values of historical time series and of time series of the average annual inflows generated based on the selected climate models are presented in Figure 3.23. Series of the lowest average monthly discharges (Figure 3.24) were formed based on the regression model presented in Table 3.15. Table 3.19 presents the characteristic values of historical and generated series of the average annual inflows and of the lowest average monthly inflows. Table 3.20 presents the differences in the results obtained.

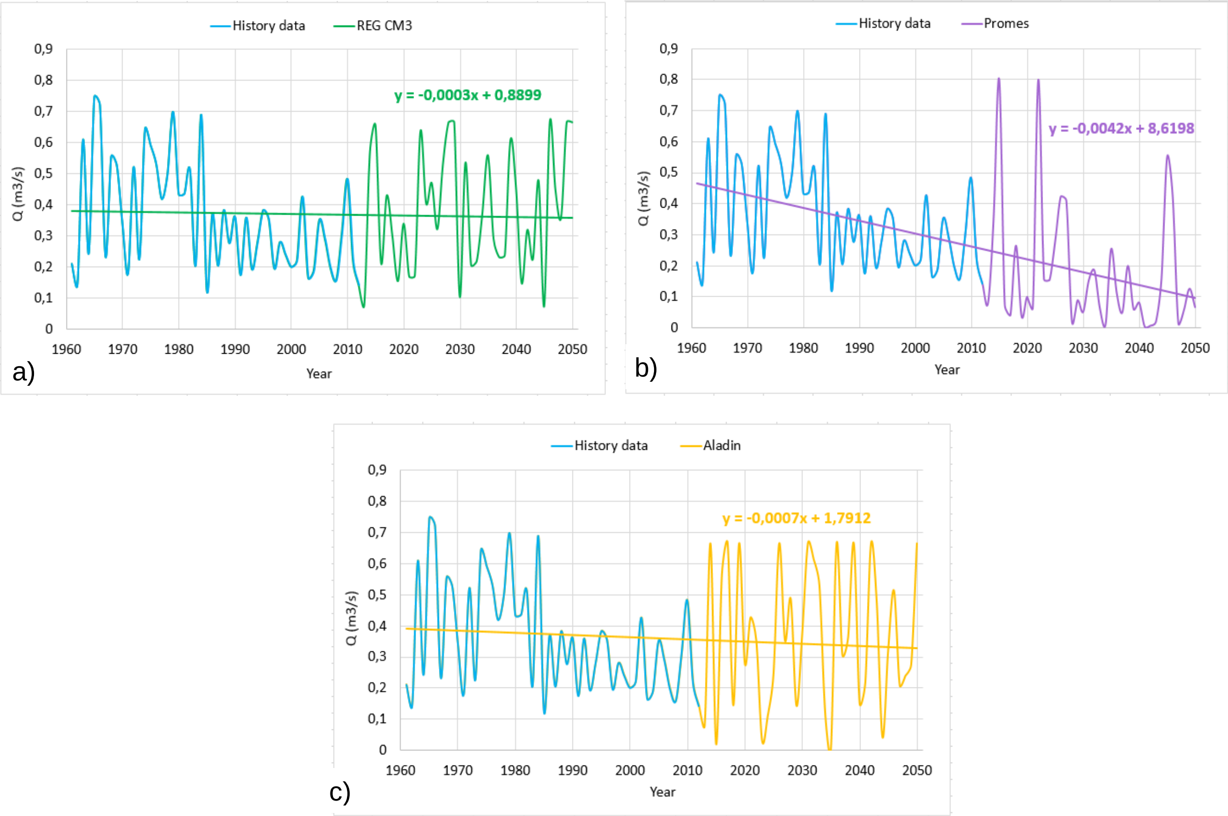


Figure 3.24: Historical time series and synthetic time series of the lowest average monthly discharges of Sv. Ivan spring generated using different climate models (1961-2050) with accompanying trends: a) REG CM3, b) Promes, and c) Aladin models

It is evident that for the reference period 2021-2050 different models give very different values quantifying water balance changes due to the projected climate change. For that period, at the level of the average values of average annual discharges, the expected changes, i.e. decrease in discharges compared to the average from the reference period 1961-90 range, depending on the model, between 0.3% (RegCM3 model) to as much as 34.9 % (Promes model). Changes are also expected in the lowest average monthly discharges to an even more marked extent, where the discharge change/decrease for the analysed 30-year period 2021-2051 ranges, depending on the model, between 0.5% and as much as 60.3% (also using the Promes model). However, differences in terms of extreme values are even more significant – both of the average annual discharges and of the lowest average monthly discharges, with these differences even reaching nearly 100% in certain models.

Table 3.19: Registered and model-based results for average annual and the lowest average monthly inflows of Sv. Ivan spring (1961-2050)

	Average annual inflows (m^3s^{-1})			Lowest average monthly inflows (m^3s^{-1})		
1961- 1990 – Registered						
Mean	0.92			0.42		
St.dev	0.12			0.19		
Cv	0.13			0.45		
MAX	1.17			0.75		
MIN	0.69			0.12		
2021- 2050 – Model-based						
	RegCM3	Aladin	Promes	RegCM3	Aladin	Promes
Mean	0.92	0.86	0.60	0.42	0.39	0.17
St.dev	0.22	0.28	0.27	0.24	0.27	0.19
Cv	0.24	0.32	0.44	0.58	0.69	1.11
MAX	1.20	1.20	1.23	0.81	0.80	0.80
MIN	0.47	0.20	0.16	0.06	0.01	0.00

Table 3.20: Identified changes (in %) in the main water balance indicators of the average values of average annual discharges and the lowest average monthly discharges of Sv. Ivan spring for the period 2021-2050 in relation to the period 1961-1990

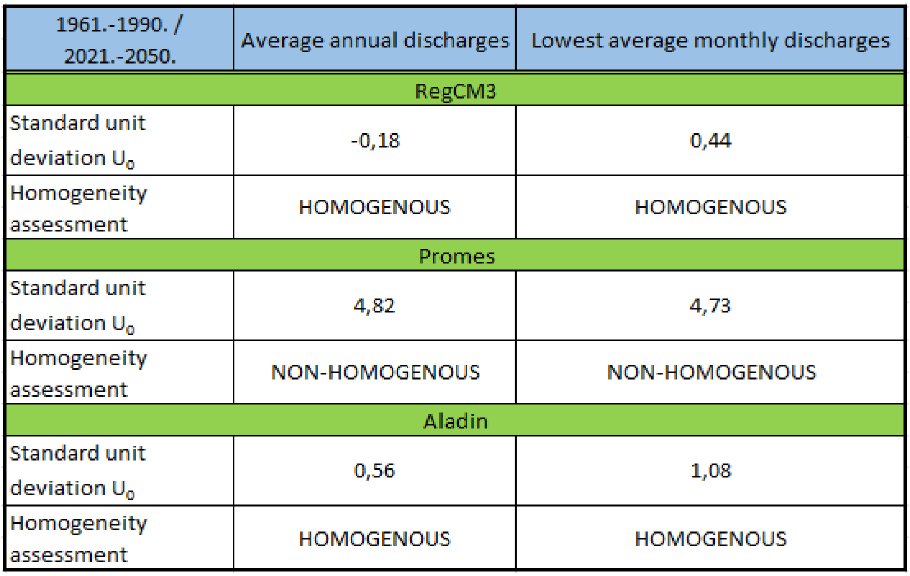
	Changes in average annual discharges (%)			Changes in the lowest average monthly discharges (%)		
	Mean	MAX	MIN	Mean	MAX	MIN
RegCM3	-0.3	2.6	-32.7	-0.5	8.2	-53.5
Aladin	-6.5	2.6	-71.3	-8.4	7.2	-95.4
Promes	-34.9	5.1	-76.6	-60.3	7.1	-97.3

Results of the Aladin-based estimation show the biggest changes, while the Promes model suggests slightly smaller changes. However, neither of the two cases can be deemed realistic since they imply Sv. Ivan spring running dry, which is, based on the available knowledge, not possible.

Therefore, in order to assess homogeneity and at the same time the credibility of the resulting data series from the reference historical period (1961-90) and the generated 30-year series (2021-2050), Wilcoxon's test was performed (Table 3.21).

The obtained results show that data on discharges, both average annual discharges and the lowest average monthly discharges, generated for the period 2021-2050 on the basis of climate projections compared to the data on discharges obtained on the basis of measurements and the correspondingly supplemented data series for the reference 30-year climate period 1961-1990 shows mutual non-homogeneity in the Promes model and that it cannot be accepted as information about the potential impacts of climate change on water resources. Discharge data generated by the RegCM3 climate model shows a higher degree of homogeneity compared to the Promes-generated data and it can be regarded as a statistically more acceptable estimation of potential future events. Based on such estimates, more frequent and more intensive dry years are to be expected but without excessive deviations compared to the already recorded extremely dry period 2011-2012. The lowest average monthly discharges show that in certain years very intensive decreases of Sv. Ivan spring yields are possible during prolonged periods of drought compared to the decreases recorded so far, by as much as 50%.

Table 3.21: Assessment of homogeneity of data on the average annual discharges and the lowest average monthly discharges of Sv. Ivan spring for the historical period 1961-1990 and the period 2021-2050 generated by the climate models



1961.-1990. / 2021.-2050.	Average annual discharges	Lowest average monthly discharges
RegCM3		
Standard unit deviation U_0	-0,18	0,44
Homogeneity assessment	HOMOGENOUS	HOMOGENOUS
Promes		
Standard unit deviation U_0	4,82	4,73
Homogeneity assessment	NON-HOMOGENOUS	NON-HOMOGENOUS
Aladin		
Standard unit deviation U_0	0,56	1,08
Homogeneity assessment	HOMOGENOUS	HOMOGENOUS

BULAŽ SPRING

Bulaž is a concentrated spring draining in one place the groundwater from the wider surrounding hinterland which includes practically the entire area of the Zrenjska plateau with a number of sinking rivers which after a short flow over the flysch sections of the drainage basin flow in to the carbonate plain and sink into the underground through marked sinking zones. The comparison of the average annual discharge obtained from the measured data series and the correspondingly supplemented data series (1961-1990), the value of which is 1.70 m^3s^{-1}, and the results of estimations of the contribution of the drainage basin of Bulaž spring (including all the four sanitary water source protection zones) to the water balance, which using the Langbein method give a discharge of 1.59 m^3s^{-1} (Table 3.13), shows acceptable similarity, i.e. a difference of only app. 7%.

It was precisely on this basis that such basin was accepted for water balance estimation, i.e. estimation of average annual discharges of synthetic time series of discharges, obtained on the basis of the average annual temperatures and annual rainfall estimated based on the climate models. This included reductions with which the contribution of this drainage basin to the water balance was balanced with the contribution to the water balance estimated on the basis of a historical series of measured data on the total discharges from this spring.

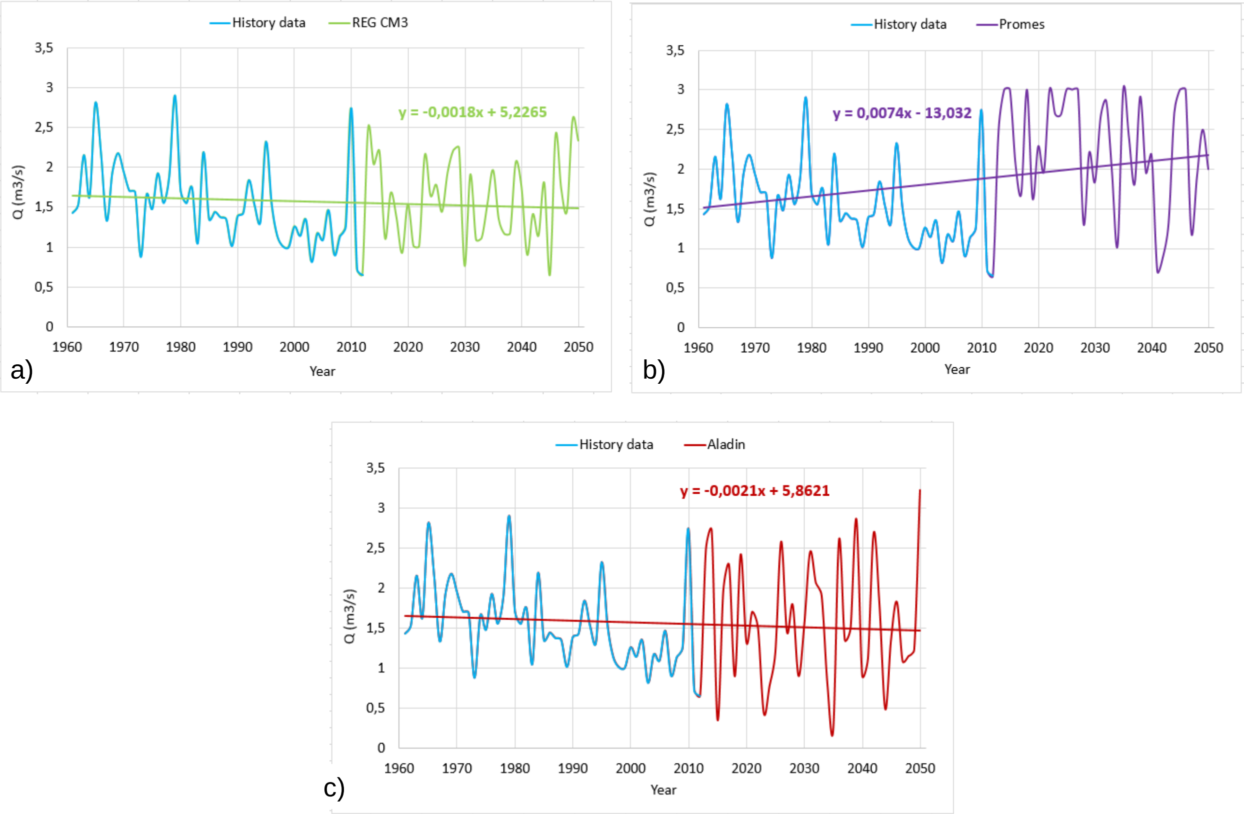


Figure 3.25: Historical time series and synthetic time series of the average annual discharges of Bulaž spring generated using different climate models (1961-2050) with accompanying trends: a) REG CM3, b) Promes, and c) Aladin models

This was done using the methodology presented at the beginning of this chapter. The results, values of historical time series and of time series of the average annual inflows generated based on the selected climate models are presented in Figure 3.25.
Series of the lowest average monthly discharges (Figure 3.26) were formed based on the regression model presented in Table 3.15. Table 3.22 presents the characteristic values of historical and generated series of the average annual inflows and of the lowest average monthly inflows. Table 3.23 presents the differences in the results obtained.

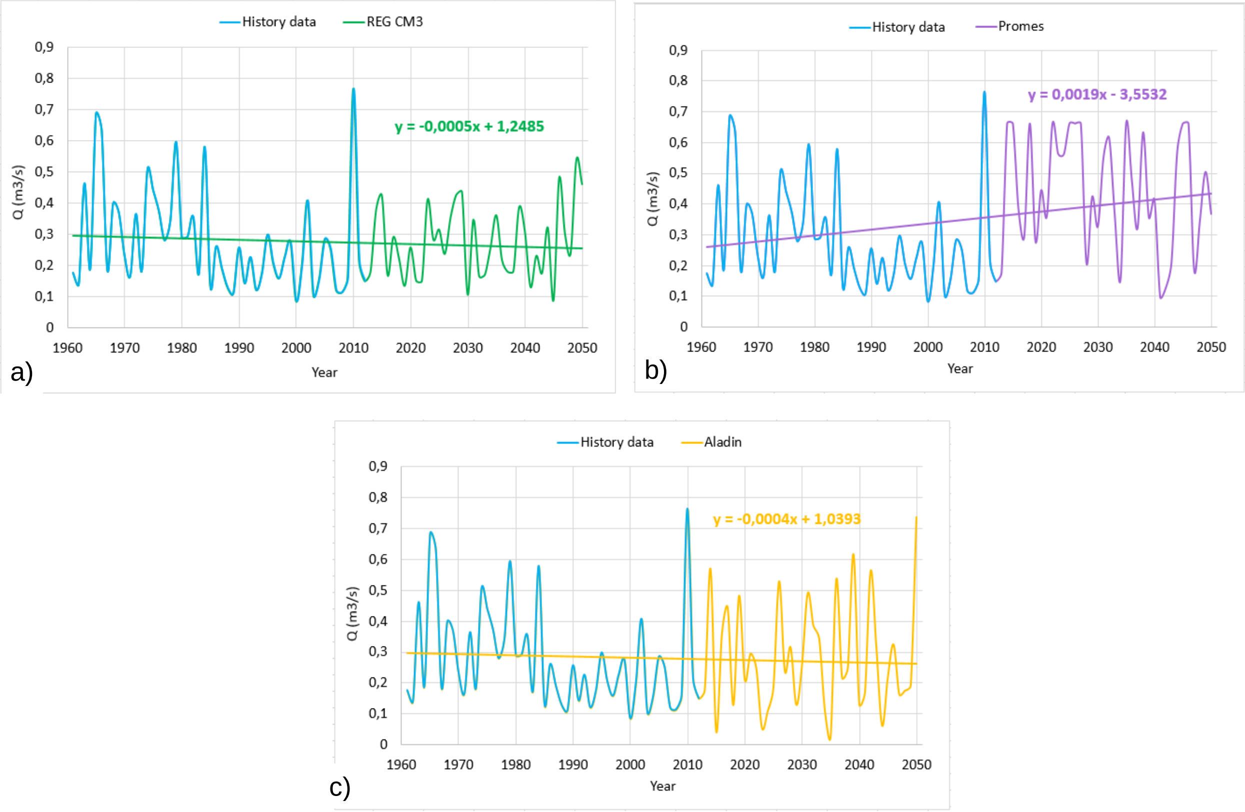


Figure 3.26: Historical time series and synthetic time series of the lowest average monthly discharges of Bulaž spring generated using different climate models (1961-2050) with accompanying trends: REG CM3, b) Promes, and c) Aladin models

It is evident also from the example of Bulaž spring that for the reference period 2021-2050 different models give very different values of the characteristic discharges quantifying water balance changes due to the projected climate change. For that period, at the level of the average values of average annual discharges, the expected changes, i.e. decrease in discharges compared to the average from the reference period 1961-90 range, depending on the model, between 6.3% (RegCM3 model) to even an increase of 30.8 % (Promes model). Changes are also expected in the lowest average monthly discharges to an even more marked extent, where the discharge change for the analysed 30-year period 2021-2051 ranges, depending on the model, between 11.2% (Aladin) and very close 11.4% (RegCM3). Differences in terms of extreme values are even more significant – both of the average annual discharges and of the lowest average monthly discharges, with these differences reaching nearly 75% in certain models. Results of the Aladin-based estimation show the biggest changes, while the Promes model suggests slightly smaller changes. Therefore, in order to assess homogeneity of the resulting data series from the reference historical period (1961-90) and the generated 30-year series in the mid-21st century (2021-2050), Wilcoxon's test was taken (Table 3.24).

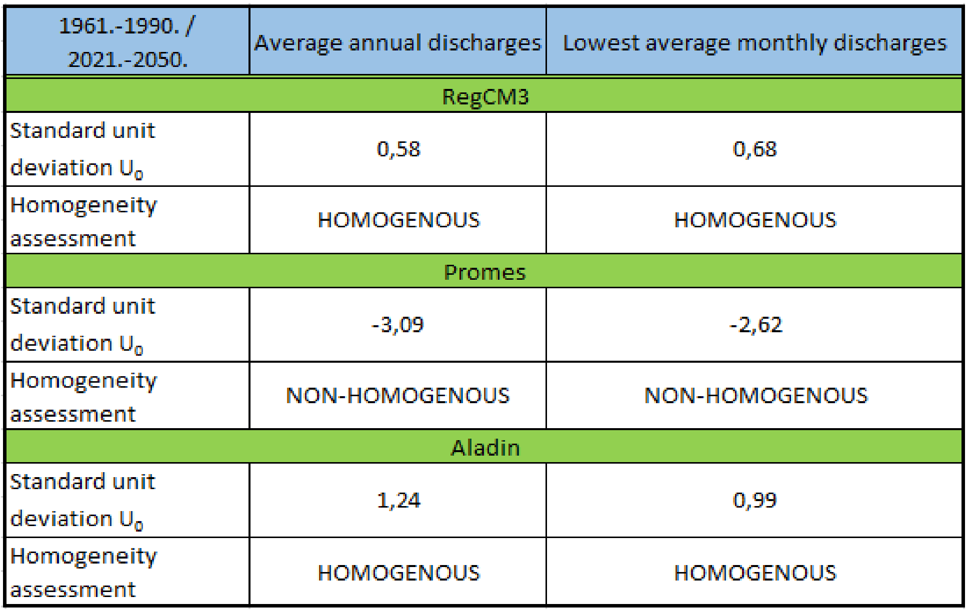
Table 3.22: Registered and model-based results for average annual and the lowest average monthly inflows of Bulaž spring (1961-2050)

	Average annual inflows (m^3s^{-1})			Lowest average monthly inflows (m^3s^{-1})		
1961- 1990 – Registered						
Mean	1.70			0.32		
St.dev	0.46			0.16		
Cv	0.27			0.51		
MAX	2.90			0.68		
MIN	0.88			0.11		
2021- 2050 – Model-based						
	RegCM3	Aladin	Promes	RegCM3	Aladin	Promes
Mean	1.59	1.55	2.22	0.28	0.28	0.45
St.dev	0.53	0.75	0.72	0.12	0.18	0.19
Cv	0.33	0.48	0.32	0.43	0.64	0.42
MAX	2.60	3.22	3.00	0.54	0.74	0.66
MIN	0.65	0.23	0.72	0.09	0.03	0.10

Table 3.23: Identified changes (in %) in the main water balance indicators of the average values of average annual discharges and the lowest average monthly discharges of Bulaž spring for the period 2021-2050 in relation to the period 1961-1990

	Changes in average annual discharges (%)			Changes in the lowest average monthly discharges (%)		
	Mean	MAX	MIN	Mean	MAX	MIN
RegCM3	-6.3	-10.4	-26.3	-11.4	-21.3	-19.4
Aladin	-8.8	11.0	-73.9	-11.2	8.1	-74.7
Promes	30.8	3.3	-18.2	41.2	-3.0	-8.9

Table 3.24: Assessment of homogeneity of data on the average annual discharges and the lowest average monthly discharges of Bulaž spring for the historical period 1961-1990 and the period 2021-2050 generated by the climate models



1961.-1990. / 2021.-2050.	Average annual discharges	Lowest average monthly discharges
RegCM3		
Standard unit deviation U_0	0,58	0,68
Homogeneity assessment	HOMOGENOUS	HOMOGENOUS
Promes		
Standard unit deviation U_0	-3,09	-2,62
Homogeneity assessment	NON-HOMOGENOUS	NON-HOMOGENOUS
Aladin		
Standard unit deviation U_0	1,24	0,99
Homogeneity assessment	HOMOGENOUS	HOMOGENOUS

The analyses of the potential impact of climate change on the water resources/karst springs used for water supply in the Mirna basin in Northern Istria: springs Gradole, Sv. Ivan and Bulaž showed that different models forecasting changes in climate indicators result in different scenarios of the intensity of the impact of such changes on the selected water balance indicators. The values of the average annual discharges and the lowest average monthly discharges were selected as indicators. The results of analyses based on climate estimations using the Aladin and Promes models gave more extreme projected values of the average annual discharges compared to the results obtained using the RegCM3 model. However, on the other hand, it was exactly the results of modelling of characteristic discharges (average annual discharges and the lowest average monthly discharges) where discharges were projected based on RegCM3-model climate predictions of rainfall and temperatures for 2021-2050 that gave the lowest deviations from homogeneity in the analysed area compared to the series from the reference period 1961-1990.

It is assessed that, should the projected climate scenarios come true, the average annual discharges at the analysed sources during 2021-2050 could, even if analysed using the most conservative model of changes based on RegCM3 climate projections, at the level of the total 30-year average amount to between 0.3% (Sv. Ivan) and 6.3% (Bulaž) with much more intensive variations and a potential for the years drier even than the extremely dry 2011/2012. There are even more significant estimations of changes in the lowest average monthly discharges which in the results obtained from the said model range between 0.5 % and 11.4 %, with certain years having extreme values of the lowest average monthly discharges even exceeding the 50-percent values of the ever recorded minimums. All the trends of characteristic distributions of discharges show a trend of decreasing discharges, hence also of water resources available for water supply.

So, depending on the location and the model used, a very wide spectrum of results was obtained. They unambiguously indicate potential notable deterioration of the water balance interrelations should the trends of the recently recorded climate change/variations continue. It is therefore already now essential to come up with potential answers (structural solutions and management decisions) to such critical situations. Indeed, the objective of the research done was not to precisely quantify some projections of the future changes, but rather to establish a framework for water resource management which will also take account of the potential changes in their hydrological characteristics. It is to be expected that an appropriate environmental flow (EF) will have to be ensured in the near future in the Mirna basin which could, coupled with potential further adverse climate change, lead to the water supply service faced with particularly difficult challenges during extremely dry periods.

3.4.2. SOUTHERN DALMATIA - SPRING PRUD AND BLATSKO POLJE

From Annex 6:

Even though climate change for a large number of stations from the wider drainage basin of the analysed springs in the Neretva basin and the surrounding coastal area was analysed and estimated as part of climatological analyses, one station – the Opuzen climatological station – was selected as the reference station (Annex 6). This station has a sufficiently long series of historical measurements, the continuity of which wasn't interrupted even by the war events in the first half of the 1990s, unlike climatological monitoring in the Trebižat basin in Bosnia and Herzegovina. Since the data on annual rainfall and air temperatures from this station (measured and generated) doesn't at the same time represent the average values for the given drainage basin, particularly since this station lies at a very low elevation (3 m above sea level) and laterally to the basin itself, interrelations between the data from this station and from the Prud spring drainage basin were defined. These interrelations were expressed in the form of reduction coefficients of such "point" data with the average value obtained on the basis of their spatial distribution throughout the drainage basin during the reference 30-year period 1961-90. A one-year period was selected as a period of discretization. The measured data on rainfall and temperatures for 1961-2012 and their generated values for the period until 2050 were used in the analyses.

A document prepared by the Croatian Meteorological and Hydrological Service (DHMZ, 2014) contains a detailed presentation of modelling results of the average annual air temperatures and annual rainfall based on the data registered at the Opuzen station in the period 1961-2012. Table 3.25 gives only a summary overview of the characteristic results, i.e. characteristic values of the average annual air temperatures and annual rainfall for the selected 30-year periods. The table presents the results obtained using all the three models.

The presented data shows that the results of the climate modelling done during the reference 30-year period 1961-1990 are generally very similar to the observed data – the average annual values of both temperatures and average annual rainfall in each model fully match the corresponding values obtained from the observed data series. Compared to the observed values, slightly higher extremes of the average annual temperatures are expressed – maximums in Promes and minimums in Aladin and RegCM3. When it comes to extreme annual rainfall, the recorded extremes are slightly more marked in all the models compared to the recorded values.

The selected 30-year period within which the impacts of potential climate change on water resources in 2021-2050 are analysed shows the characteristics of the rainfall regime very similar to the reference 30-year period 1961-1990 in terms of the average annual rainfall – practically the same average value during the forthcoming 30-year period compared to the reference 30-year historical period, but with slightly more marked variations according to the Aladin and RegCM3 models. According to all the models, the average annual air temperatures should rise significantly, with considerably different results of the models. For example, the RegCM3 model foresees a mean 30-year increase of the average annual air temperature by 1.22 ^{0}C, Aladin by 1.8 ^{0}C, and Promes by as much as 2.2 ^{0}C (+19%), including increased both maximum and minimum air temperatures.

Table 3.25: Registered and model-based results for average annual air temperatures and annual rainfall for the Opuzen station (DHMZ, 2014)

	Temperatures (^{0}C)			Rainfall (mm)		
1961- 1990 – Registered						
Sr	15.5			1308.5		
St.dev	0.4			227.3		
Cv	0.03			0.17		
MAX	16.2			1734.6		
MIN	14.6			710.3		
1961- 1990 – Model-based						
	RegCM3	Aladin	Promes	RegCM3	Aladin	Promes
Sr	15,5	15,5	15,5	1308,5	1308,5	1308,5
St.dev	0,6	0,5	0,6	146,6	157,4	146,8
Cv	0,04	0,03	0,04	0,11	0,12	0,11
MAX	16,4	16,4	17,0	1577,1	1686,2	1646,0
MIN	14,0	14,3	14,6	991,4	1008,5	1073,2
2021-2050 – Model-based						
Sr	16,7	17,2	17,7	1315,7	1310,4	1285,6
St.dev	0,6	0,6	0,7	152,1	180,7	131,9
Cv	0,04	0,03	0,04	0,12	0,14	0,10
MAX	18,3	18,9	19,0	1672,4	1669,4	1550,4
MIN	15,2	16,2	16,1	1066,6	922,2	1027,6

PRUD SPRING

The availability of adequate data determines the application of particular run-off estimation methods. Climate data (rainfall and air temperatures) used in the analysis of basins in Southern Dalmatia is available in the form of spatial distribution of the average annual values for the 30-year period (1961-1990), in the form of a 1,000-meter spatial resolution raster prepared by experts of the Croatian Meteorological and Hydrological Service (Figure 3.27a and 3.27b). This spatial resolution is identical to the spatial resolution of the digital elevation model (DEM) used. On the other hand, the Croatian Geological Survey has defined several basin units in the wider impact area of the Prud spring basin in order to be able to better assess the impact of their water balance on the yield of Prud spring (Figure 3.28).

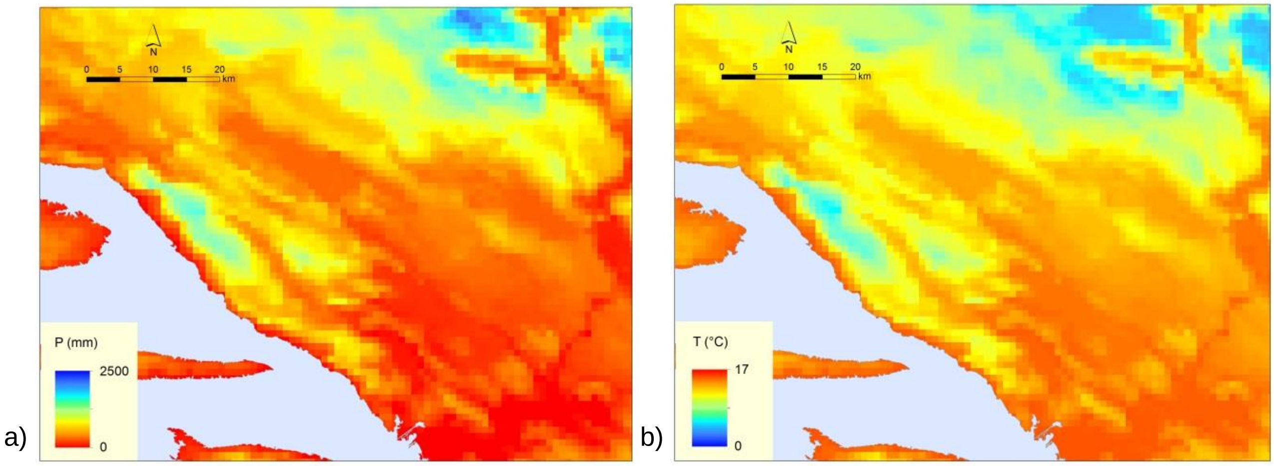


Figure 3.27: Spatial distribution of a) average annual rainfall, and b) average annual air temperature for Southern Dalmatia (1961-1990) (according to DHMZ)

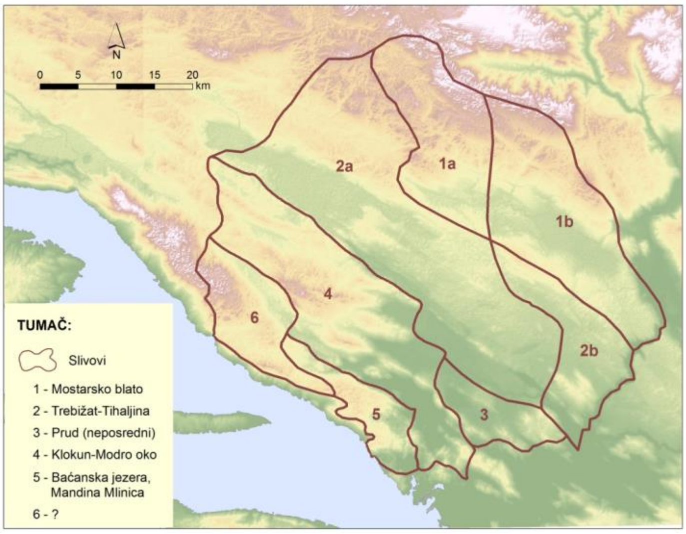
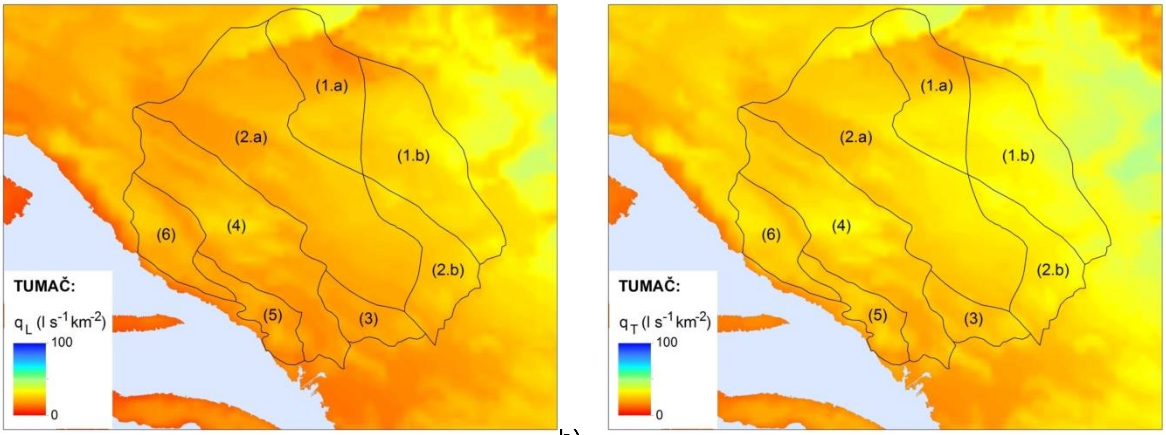


Figure 3.28: Defined basins with potential impact in the wider catchment area of Prud spring



a) b)

Figure 3.29: Spatial distribution of specific discharges in Southern Dalmatia for the period 1961-1990 defined by: a) Langbein method; b) Turc method

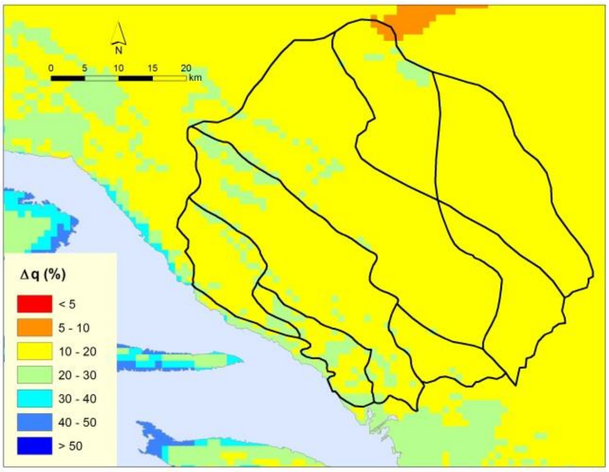


Figure 3.30: Difference in results obtained by the Turc and Langbein methods for the period 1961-1990

The average annual specific run-off was estimated for the selected drainage basins presented in Figure 3.28. The main results (average temperatures and rainfall for individual basin units) are presented in Table 3.26, while Table 3.27 presents the values of specific and total average annual discharges from the analysed drainage basins of individual springs. Based on additional hydro-geological considerations, the drainage basin of Opačac spring (surface area of app. 176 km^2) was subsequently associated with drainage basin 2b, with the potential drainage basin of Prud spring presented in Figure 3.31. Naturally, the balance shares of individual potential basin units in the overall Prud water balance differ with regard to the dominant direction of groundwater drainage through the Trebižat River.

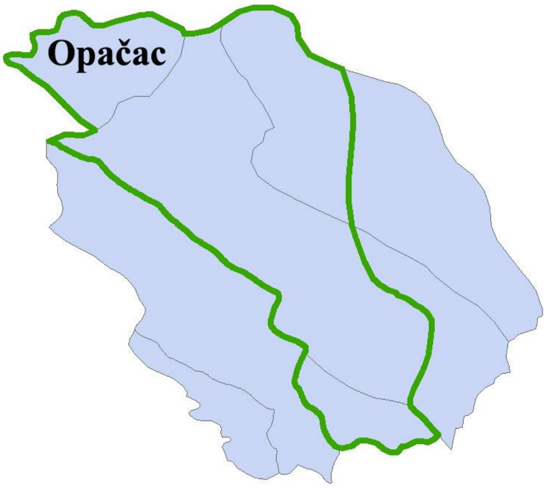


Figure 3.31: Defined basin of Opačac spring as part of potential total basin of Prud spring

Table 3.26: Basic climate elements of the selected drainage basins in Southern Dalmatia (1961-1990)

DRAINAGE BASIN		Surface area (km^2)	Average annual air temperature (^{0}C)	Annual rainfall (mm)
Mostarsko blato	1a	249.6	14.6	1496.0
	1b	358.8	12.9	1396.1
Tihaljina -Trebižat	2a	712.0	10.7	1665.9
	2b	179.1	12.7	1394.9
Prud – immediate	3	93.6	11.8	1479.6
Klokun-Modro oko	4	451.4	12.6	1699.6
Baćina Lakes - Mandina mlinica	5	98.4	9.3	1507.7
Mt Biokovo hinterland	6	146.8	14.6	1433.0

Table 3.27: Average annual discharges in the analysed basin units of Southern Dalmatia based on water balance estimations (1961-1990)

		Specific discharges (l/s/km²)		Total discharges (m³s⁻¹)	
DRAINAGE BASIN		Turc	Langbein	Turc	Langbein
Mostarsko blato	1a	28.03	23.12	7.00	5.77
	1b	33.42	27.7	11.99	9.94
Tihaljina - Trebižat	2a	27.08	21.91	19.28	15.60
	2b	30.71	24.95	5.50	4.47
Prud – immediate	3	24.2	19.49	2.26	1.82
Klokun-Modro oko	4	26.08	21.09	11.77	9.52
Baćina Lakes - Mandina mlinica	5	23.63	18.92	2.33	1.86
Mt Biokovo hinterland	6	26.12	21.24	3.83	3.12

In general, the values of specific discharges obtained using the Langbein method in all the analysed drainage basins are lower than the values obtained using the Turc method. It is evident that in Southern Dalmatia run-off is the heaviest in its north-eastern parts where the rainfall is also the heaviest, i.e. in the higher elevations (even exceeding 50 l s^{-1} km^2 in some places). This is also where the differences in results obtained from the two methods are the smallest (mostly 10-20 %). In the coastal regions surface run-off is lower than 10 l s^{-1} km^2, and the results of the Turc method exceed the run-off obtained using the Langbein method by 20-30 %. However, these regions lie beyond the boundaries of the analysed drainage basins. Consequently, the real differences in the estimation results obtained using the two above-mentioned estimation methods are considerably smaller and range between the above-mentioned 10 and 20%.

Systematic hydrological observations at Prud spring started in 1978 by monitoring water levels and measuring discharges, with 86 discharge measurements carried out so far. However, due to the low position of level "0" of the staff gauge and due to a significant impact of the growth-covered downstream course of the Norinska River, and even an indirect retarding impact of the Neretva into which the Norinska River enters, so far discharges haven't been calculated in organization of the DHMZ. Despite the lack of observation results based on which the Prud spring balance could be estimated, this document nevertheless estimates the inflows on the basis of the newly defined stage-discharge curves for the period best covered with discharge measurements (1995-2001). Namely, 61 discharge measurements were carried out in that period, i.e. approximately 10 per year, as opposed to the other years when their number was significantly lower or there were no discharge measurements at all for almost ten years (2003-2011). The seasonal annual stage-discharge curves have been defined (Table 3.28).

Table 3.28: Defined stage-discharge curves for Prud spring based on the results of discharge measurements by DHMZ with accompanying value of determination coefficient R^2 (1995-2001)

	WINTER MONTHS	SUMMER MONTHS
1995	$y = 0.0023x^2 - 0{,}3681x + 19.088$ $R^2 = 0.9978$	$y = 0.0001x^2 - 0.0282x + 5.6831$ $R^2 = 0.0618$
1996	$y = 0.0008x^2 - 0.0622x + 5.3728$ $R^2 = 0.7818$	
1997	$y = 2.6766e^{0{,}0116x}$ $R^2 = 0.9979$	$y = 0.9537\ln(x) + 0.7425$ $R^2 = 0.033$
1998	$y = 1.6883e^{0{,}0138x}$ $R^2 = 0.9039$	$y = 0.0005x^2 - 0.0244x + 2.9438$ $R^2 = 0.981$
1999	$y = 1.6883e^{0{,}0138x}$ $R^2 = 0.9039$	$y = 2.7806\ln(x) - 7.9936$ $R^2 = 0.1103$
2000	$y = 0.0014x^2 - 0.1611x + 9.0333$ $R^2 = 0.9779$	$y = 3.3497e^{0{,}0011x}$ $R^2 = 0.023$
2001	$y = 0.3459e^{0{,}03x}$ $R^2 = 1$	$y = -0.0028x^2 + 0.4064x - 11.5$ $R^2 = 1$

The missing data on the average monthly discharges for Prud spring for the 1961-2013 period was supplemented based on the data on daily discharges and on their basis derived monthly discharges for Prud spring for the above-mentioned 7-year period using regression links with the monthly discharges for “Modro oko” spring as well as “Kamen most na Vrljici” station. That process took no account of data on the quantities of water abstracted from Prud spring which are very low compared to the total yield, and there is in addition no available data about the quantities abstracted during a longer series of past years. During 2011-2013, app. 3.5-4.0 million m^3 of water was abstracted from Prud spring, i.e. between 0.110 and 0.125 m^3s^{-1}. It has to be noted that the highest average annual abstractions (during the summer months – July and August) are twice higher.

Table 3.29 presents the average monthly yields of Prud spring and their statistical indicators. They illustrate that the average annual discharge of this spring is around 6.2 m^3s^{-1}, or around 6.4 m^3s^{-1} if abstractions are also taken into account. The distribution of the average annual discharges is also presented (Figure 3.32), as well as the intra-annual distribution of characteristic monthly discharges (Figure 3.33). It is evident that the distribution of average annual discharges (the analysis includes the hydrological years and not the calendar years since the hydrological years give a more appropriate presentation of the status of water resources) are characterized by a slightly decreasing trend of their average values as well as of the minimum extremes, while the maximum extremes have a slightly increasing trend. The results of the presented intra-annual distribution of discharges show that Prud spring has a relatively low variability in its yields, with August and September being the driest months, while the period with the most abundant water quantities is December – April.

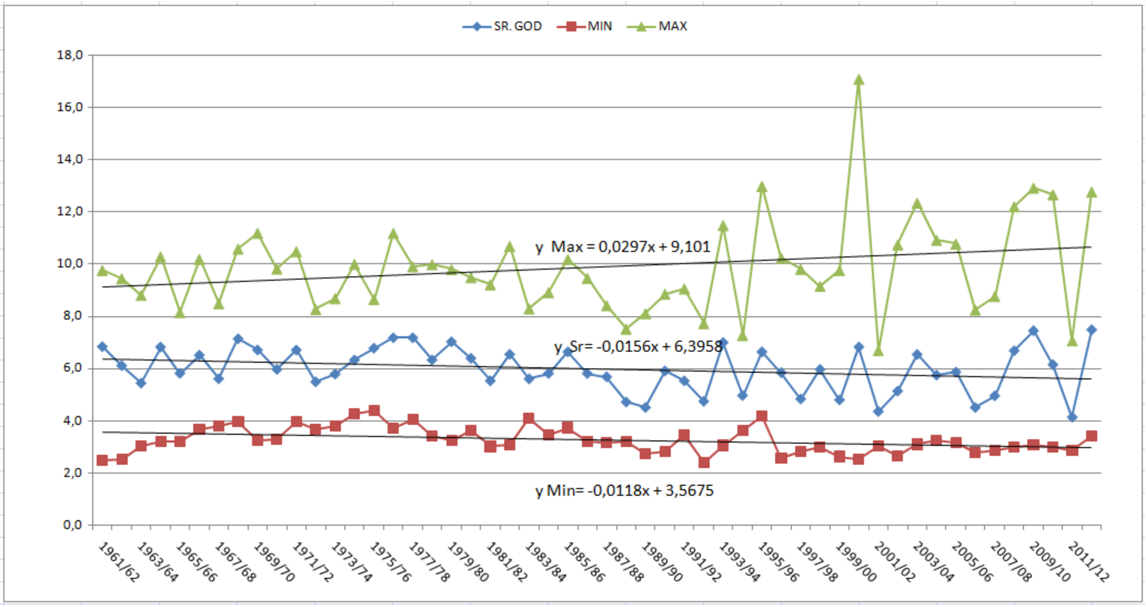


Figure 3.32: Distribution of the average annual discharges of Prud spring (1961/62 – 2011/12)

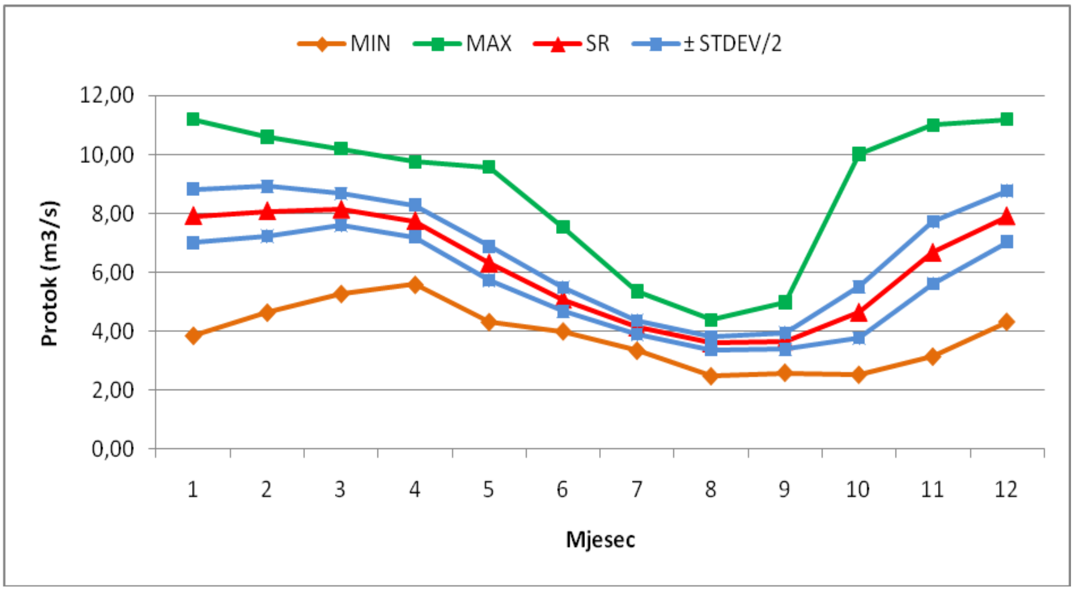


Figure 3.33: Intra-annual distribution of the average monthly discharges of Prud spring (1961-2013)

The water balance of Prud spring heavily depends on the underground recharge from the neighbouring Trebižat basin and its associated aquifers in the upper horizons. Based on the analyses made, the average annual discharge of Prud spring in the reference 30-year period 1961-90 is 6.16 m^3s^{-1}, within which the contribution of the defined basin unit 3 (the immediate Prud drainage basin) to the water balance is, depending on the assessment methodology for specific discharges (Langbein or Turc), estimated at 1.82 or 2.26 m^{3}s^{-1}, which means that Prud spring is recharged from the Trebižat basin with considerably higher inflows than the inflows in the immediate basin.

Table 3.29: Characteristic average monthly and annual yields of Prud spring during the reference 30-year period (1961-1990)

Month/Statistical parameter	Prud spring (1961 - 1990)												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	God
SR	7,91	8,08	8,13	7,75	6,31	5,08	4,13	3,59	3,67	4,64	6,67	7,91	6,16
STDEV	1,82	1,69	1,08	1,08	1,15	0,81	0,47	0,44	0,57	1,75	2,10	1,74	0,61
CV	0,23	0,21	0,13	0,14	0,18	0,16	0,11	0,12	0,15	0,38	0,32	0,22	0,10
MAX	11,20	10,60	10,20	9,75	9,57	7,54	5,35	4,38	4,98	10,01	11,00	11,20	7,39
MIN	3,85	4,64	5,28	5,59	4,32	4,00	3,34	2,47	2,59	2,52	3,14	4,33	4,72

This difference in inflows ranges between 3.9 and 4.34 m^{3}s^{-1}, which is very close to the estimations of losses in the Trebižat basin on a section between hydrological stations Humac and Stubica made by the project partners from BiH (HEIS, 2015), according to which the loss is 4.5 m^{3}s^{-1} on the level of the average annual discharges. The difference is also affected by the period of analyses. The colleagues from BiH used a considerably longer data series (1926-1978) in their report (Annex 7), i.e. the analyses also included the periods with higher discharges compared to the 30-year period, as the result of which the losses are slightly heavier compared to the average losses during the reference period with the adopted average inflows.

If the Turc's method, which is used most frequently in the Dinaric region (Bonacci, 1987) and gives slightly higher balance contributions, is adopted as the relevant distribution of specific discharges, it follows that the average balance of the Prud drainage basin consists of the inflow of 2.26 m^{3}s^{-1}, and 3.9 m^{3}s^{-1} flowing in from the indirect Trebižat basin, i.e. 20% of the estimated balance of the upper course of the Trebižat basin (2a). No further analysis is made for inflows into that basin from the upper parts of the drainage basin of Mostarsko blato (1a) and for the additionally defined drainage basin of Opačac spring. It is based on such shares that balance estimations of climate change impacts on the average annual yield of Prud spring were made and are presented below.

The average annual inflows of Prud spring for the period after the year 2012, i.e. after the historical period with the available discharges, were estimated on the basis of the average annual temperatures and annual rainfall estimated based on the climate models. This was done using the methodology presented at the beginning of this chapter. The results, values of historical time series and of time series of the average annual inflows generated based on the selected climate models are presented in Figure 3.34. Series of the lowest average monthly discharges (Figure 3.35) were formed based on the regression model presented in Table 3.29. Table 3.30 presents the characteristic values of historical and generated series of the average annual inflows and of the lowest average monthly inflows. Table 3.31 presents the differences in the results obtained.

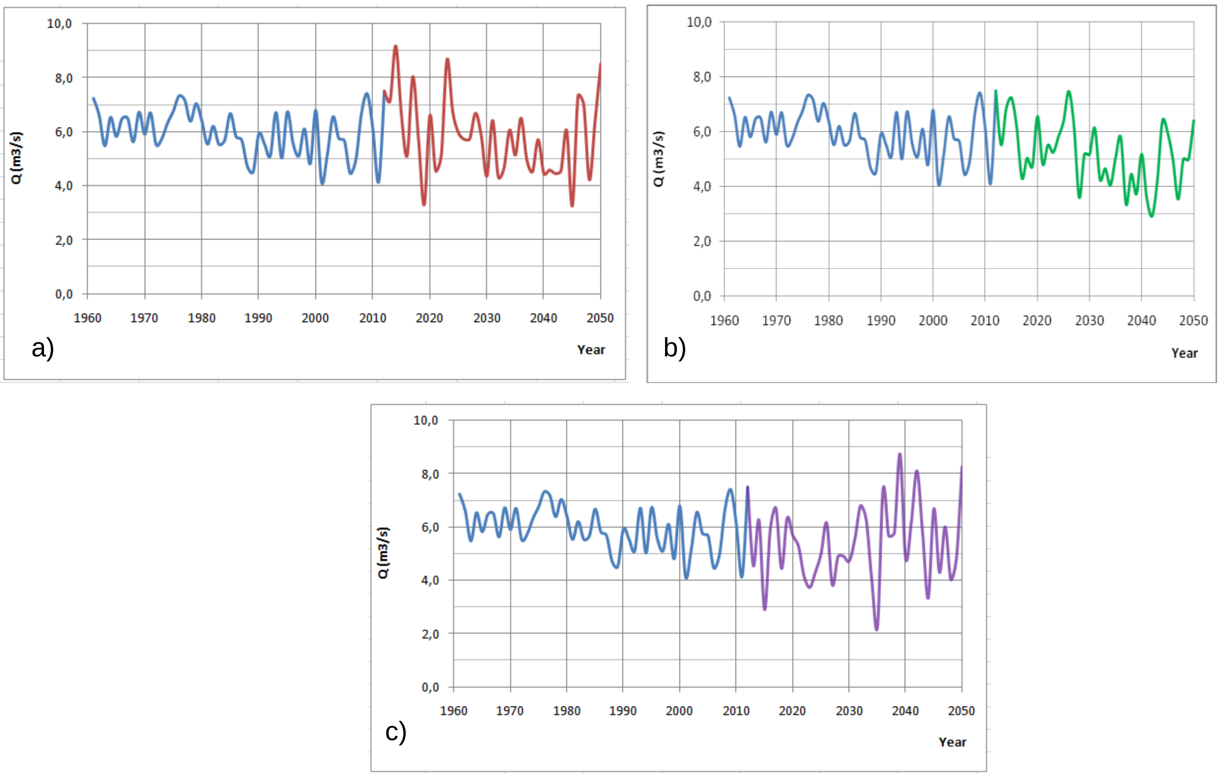


Figure 3.34: Historical time series and synthetic time series of the average annual discharges of Prud spring generated using different climate models (1961-2050): a) REG CM3, b) Promes, and c) Aladin

It is evident that different models give different values quantifying water balance changes due to the projected climate change. For the period 2021-50 on the level of the +mean annual average discharges, the expected changes, i.e. decrease in discharges compared to the average from the reference period 1961-90 range, depending on the model, between 9.1 and 18.7% in the Promes model. Changes in a similar extent are also expected in the minimum average monthly discharges, where the discharge change/decrease for the analysed 30-year period 2021-2051 ranges, depending on the model, between 6.8 and 13.1%. On the average the smallest changes in the mean values are generated by the RegCM3 model, and the biggest ones by the Promes model.

However, differences in terms of extreme values are even more significant – the maximum average annual discharges generally increase significantly, while the minimum average annual discharges in all the models decrease, in the range of 31.4 - 52.3%. Slightly less marked changes can be expected in the lowest average annual discharges, ranging between 6.9% and 21.1% depending on the model. Results of the Aladin-based estimation show bigger changes, while the results of the Promes model suggest slightly smaller changes. With the current water use regime, if scenarios of that kind would come true, even to a smaller extent, this wouldn't represent a big issue because the yields of the springs exceed the needs. Prud spring has a very balanced regime of groundwater discharge which affects its recharge from the remote parts of the neighbouring basins.

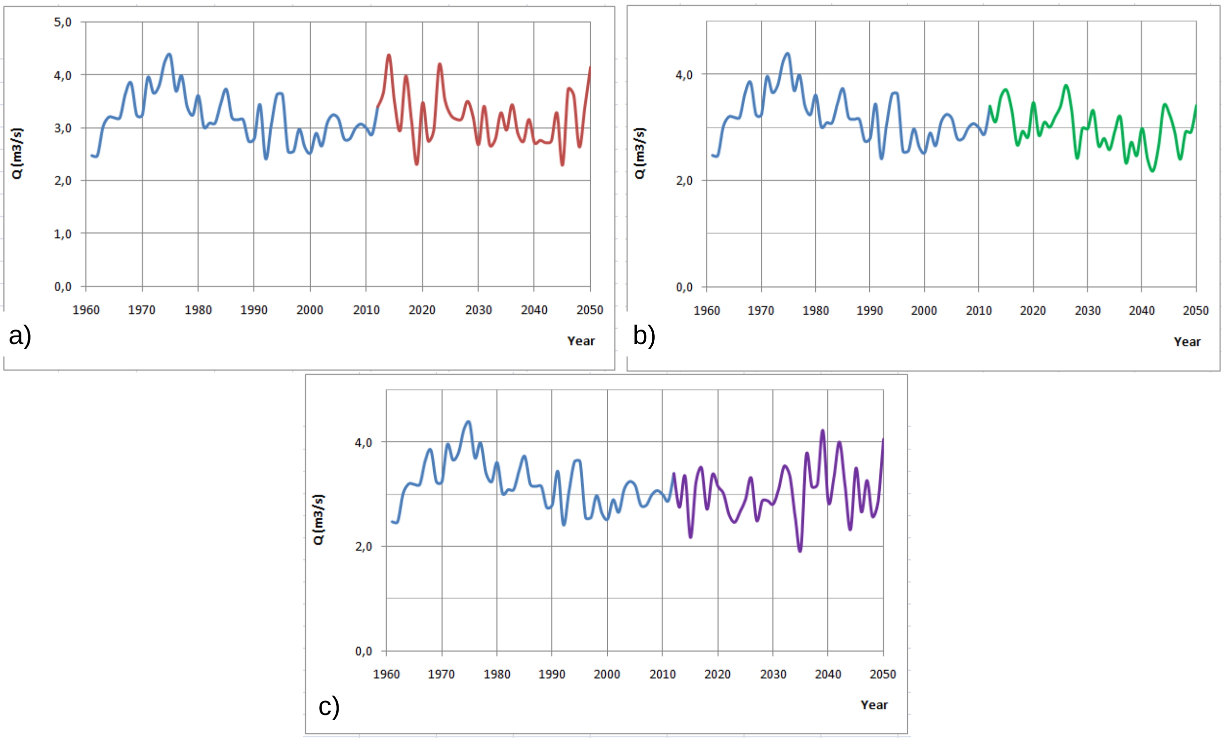


Figure 3.35: Historical time series and synthetic time series of the lowest average monthly discharges of Prud spring generated using different climate models (1961-2050): a) REG CM3, b) Promes, and c) Aladin

Table 3.30: Registered and model-based results for average annual inflows and the lowest average monthly inflows of Prud spring (1961-2050)

	Average annual inflows			Lowest average monthly		
1961 - 1990 – Registered						
Sr	6.16			3.36		
St.dev	0.61			0.47		
Cv	0.10			0.14		
MAX	7.39			4.38		
MIN	4.72			2.47		
2021- 2050 – Model-based						
	RegCM3	Aladin	Promes	RegCM3	Aladin	Promes
Sr	5.60	5.39	5.01	3.13	3.05	2.92
St.dev	1.28	1.51	1.09	0.45	0.53	0.38
Cv	0.23	0.28	0.22	0.14	0.17	0.13
MAX	8.66	8.73	7.49	4.20	4.23	3.79
MIN	3.24	2.25	2.93	2.30	1.95	2.19

Table 3.31: Identified changes (in %) in the main water balance indicators of the average values of average annual discharges and the lowest average monthly discharges of Prud spring for the period 2021-2050 in relation to the period 1961-1990

	Changes in average annual discharges (%)			Changes in the lowest average monthly discharges (%)		
	MEAN	MAX	MIN	MEAN	MAX	MIN
RegCM3	-9.1	17.2	-31.4	-6.8	-4.1	-6.9
Aladin	-12.5	18.1	-52.3	-9.2	-3.4	-21.1
Promes	-18.7	1.4	-37.9	-13.1	-13.5	-11.3

The homogeneity of two data series was tested – for the period 1961-1990, obtained on the basis of measurements and the correspondingly supplemented series, and for the period 2021-2050, for which discharges were obtained by modelling the generated time series of data on rainfall and temperatures using the three climate models. Homogeneity was tested using Wilcoxon's non-parametric test, both for the original data series (Table 3.32), and for the series modified in such a way to exclude their trends (Table 3.33). The obtained results show that the original data series, except in case of the lowest average monthly discharges in the RegCM3 model, from the historical (1961-1990) and generated periods (2021-2050) don't show any mutual homogeneity (Table3.32). However, if the present trends are excluded (Table 3.33), it is evident that there is homogeneity in all the analysed cases, which would suggest that the data from the generated period isn't statistically any different from the historical series. Since the results obtained from the Promes-based climatological estimations show the smallest deviations in homogeneity of the modified data series, the results obtained using that model can therefore roughly be deemed the most suitable.

Table 3.32: Assessment of homogeneity of data on the average annual discharges and the lowest average monthly discharges of Prud spring for the historical period 1961-1990 and the period 2021-2050 generated by the climate models – original series

1961.-1990. / 2021.-2050.	Average annual discharges	Lowest average monthly discharges
RegCM3		
Standard unit deviation U_0	2,08	1,88
Homogeneity assessment	NON-HOMOGENOUS	HOMOGENOUS
Promes		
Standard unit deviation U_0	4,1	3,5
Homogeneity assessment	NON-HOMOGENOUS	NON-HOMOGENOUS
Aladin		
Standard unit deviation U_0	2,62	2,31
Homogeneity assessment	NON-HOMOGENOUS	NON-HOMOGENOUS

Table 3.33: Assessment of homogeneity of data on the average annual discharges and the lowest average monthly discharges of Prud spring for the historical period 1961-1990 and the period 2021-2050 generated by the climate models – modified series with excluded trend

1961.-1990. / 2021.-2050.	Average annual discharges	Lowest average monthly discharges
RegCM3		
Standard unit deviation U_0	0,64	1,88
Homogeneity assessment	HOMOGENOUS	HOMOGENOUS
Promes		
Standard unit deviation U_0	0,37	0,74
Homogeneity assessment	HOMOGENOUS	HOMOGENOUS
Aladin		
Standard unit deviation U_0	1,27	1,39
Homogeneity assessment	HOMOGENOUS	HOMOGENOUS

BLATSKO POLJE

The assessment of climate change impacts in the Blatsko polje test area on the island of Korčula was carried out under the CCWaterS Project by the same team of researchers of the Croatian Geological Survey and the Faculty of Civil Engineering in Rijeka (Rubinić et al., 2011) using the same methodology. For that reason, the report – Annex 6 has not presented the entire content of these earlier research exercises, but rather only their summary results. The DRINKADRIA project has capitalized on the results of the CCWaterS Project, which were used for additional analyses and interpretations under the recent DRINK ADRIA Project

Figure 3.36 presents historical series and generated synthetic series of the mean annual discharges generated by the different climatological models, while Figure 3.36 presents such evaluations for the lowest mean monthly discharges. The results of evaluations made are presented in Table 3.34, and the results of the identified changes for the generated series against the historically recorded series are presented in Table 3.35.

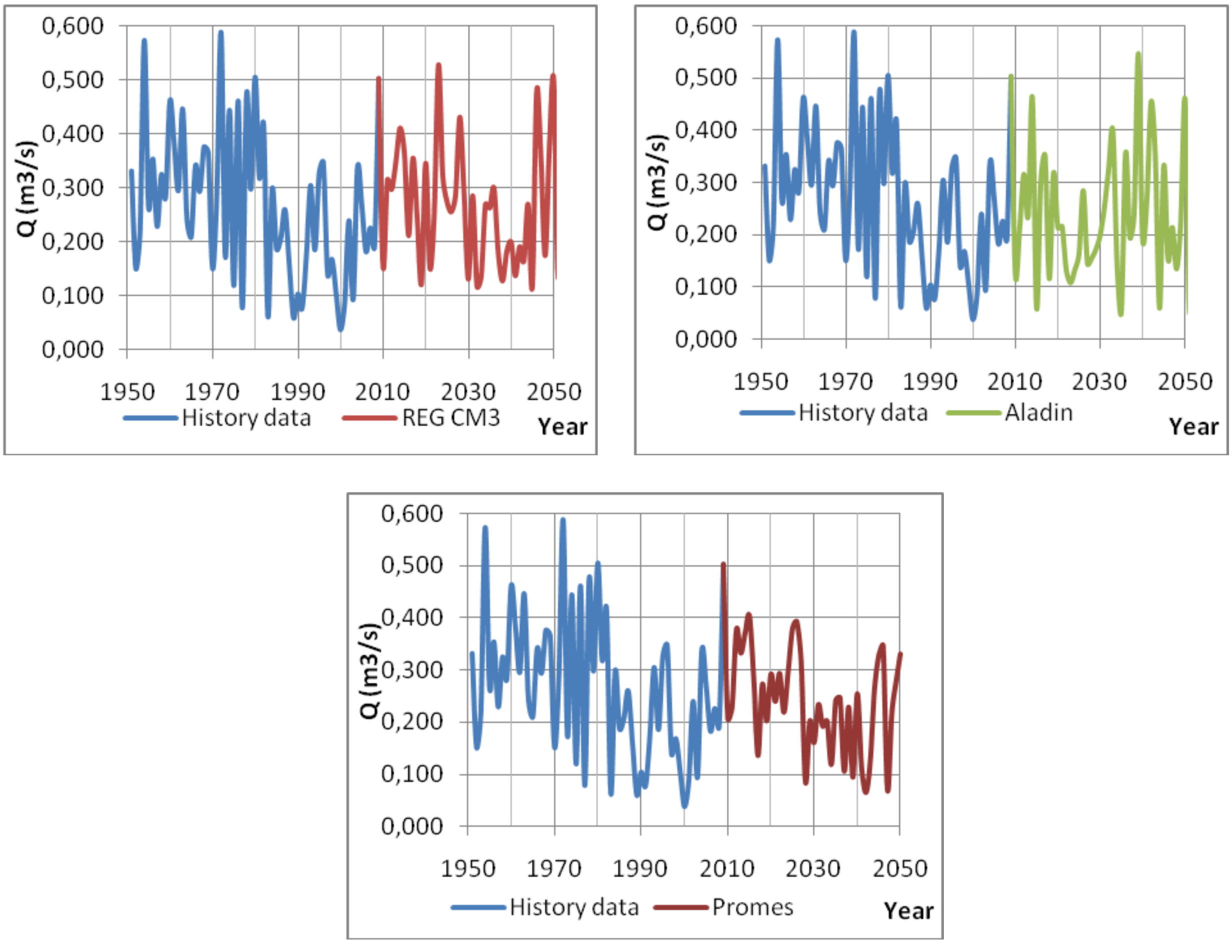


Figure 3.36: Presentation of time changes of mean annual recharge into Blatsko polje generated for the period 1950-2050 evaluated by all three climatological models (RegCM3, Aladin, Promes).

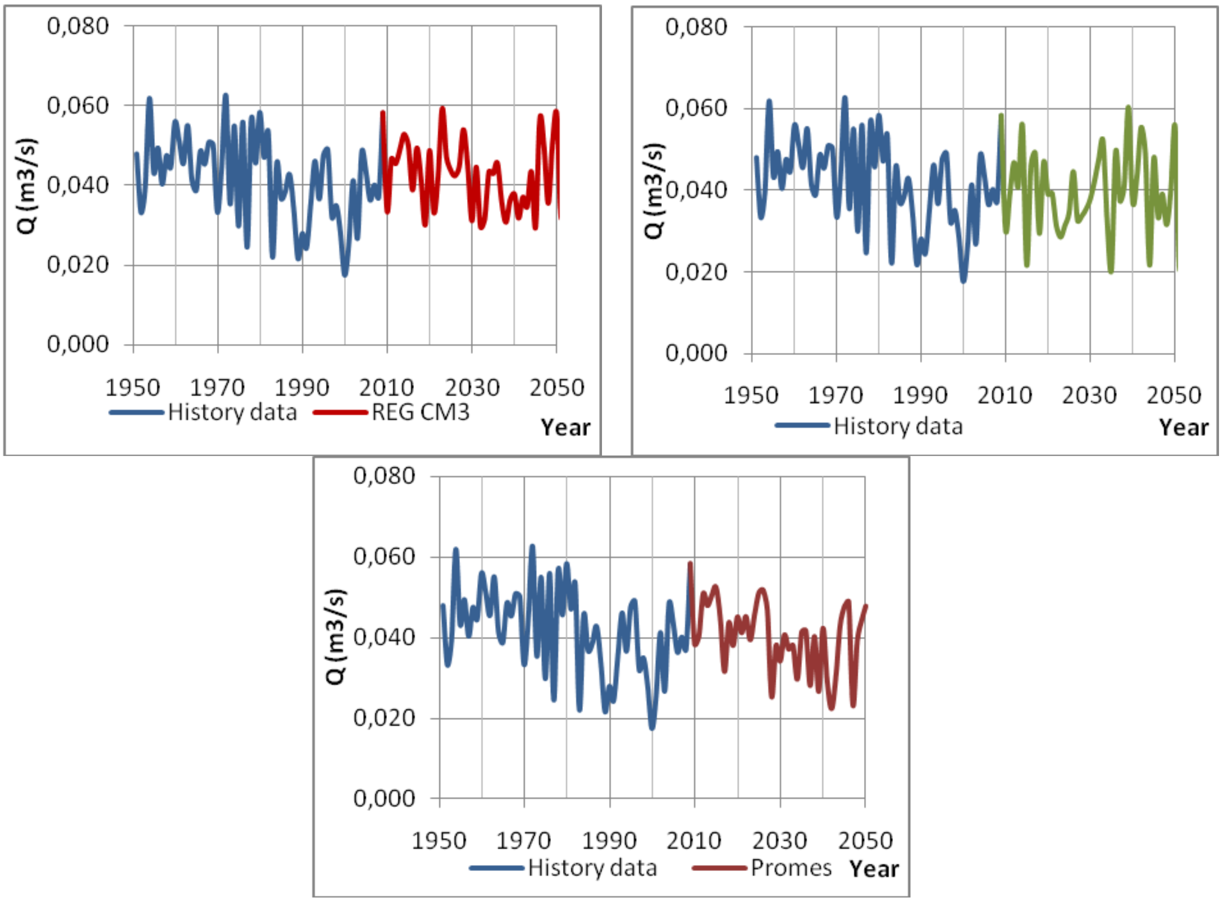


Figure 3.37: Presentation of time changes of minimum mean monthly recharge into the Blatsko polje generated for the period 1950-2050 evaluated by all three climatological models (RegCM3, Aladin, Promes)

Table 3.34: Basic water balance parameters: mean annual and minimum mean monthly discharges for the Blatsko polje test area and for selected time periods

	Mean annual discharges (m^3s^{-1})					**Minimum mean monthly discharges (m^3s^{-1})**				
1961-90										
	MEAN	St.dev.	Cv	MIN	MAX	MEAN	St.dev.	Cv	MIN	MAX
Historical data	0.287	0.141	0.49	0.061	0.588	0.043	0.011	0.26	0.022	0.063
2021-2050										
RegCM3	0.259	0.116	0.45	0.118	0.528	0.042	0.009	0.21	0.030	0.059
Aladin	0.235	0.121	0.52	0.054	0.546	0.040	0.010	0.24	0.021	0.060
Promes	0.222	0.093	0.42	0.066	0.393	0.039	0.008	0.22	0.023	0.052

Table 3.35: Changes in percentages of the main balance parameters: mean annual and minimum mean monthly discharges for the Blatsko polje test area and for selected time periods

	Mean annual discharges (%)					**Minimum mean monthly discharges (%)**				
2021-2050										
RegCM3	-9.8	-17.7	-8.2	93.4	-10.2	-2.3	-18.2	-19.2	36.4	-6.3
Aladin	-18.1	-14.2	6.1	-11.5	-7.1	-7.0	-9.1	-7.7	-4.5	-4.8
Promes	-22.6	-34.0	-14.3	8.2	-33.2	-9.3	-27.3	-15.4	4.5	-17.5

It is evident that different models result with different values which quantify balance changes according to the predicted climate changes. For the period 2021-2050, at the mean annual discharges level, expected changes from the state in the referent climatological period 1961-1990 are from 9.8 to 22.6%. Changes of minimum mean monthly discharges are of somewhat lower range: from 2.3 to 9.3%. The smallest changes were predicted by RegCM3 model and the highest by Promes. Since the status of water supply from the local island resources in the existing conditions is already critical, there is no doubt that every new deterioration of hydrological conditions will result in inability to ensure water supply during the critical hydrological conditions.

3.5. BOSNIA AND HERZEGOVINA – TREBIŽAT RIVER

From Annex 7:

In this Chapter the occurrence of more important water phenomena in the Prud spring catchment area is presented. From the hydrological aspect, this area is dominated by the Tihaljina River or the Trebižat River. Its features, the recharge method, seasonal variations, and particularly water balance and its impact on the recharge of the Prud spring are described in details in the following text.

Names and coordinates of the significant sinkholes and springs are presented in the tables 3.36 and 3.37.

For the sinkhole of the Ugrovača River, a groundwater connection with the potential springs Klokun and Vrioštica was identified. There is a possibility of connection between these 2 springs and the Prud spring, which requires further research. For this sinkhole, there is also a groundwater connection with the Lištice spring which covers the area beyond the catchment area Prud. Sinkhole in the location of Predgrađe was approximately identified on the 100 m a.s.l. and a groundwater connection with the Prud spring was identified. Location of Sobač presents an area with approximately defined elevation of 92 m a.s.l. and it also has a groundwater connection with the Prud spring. Sinkhole Musinac is located in the area of contact between alluvial and lake sediments nearby the settlement of Grude. According to the tectonics, there could be a hydrological connection with the Prud spring, although it was not proved by the measurements.

Table 3.36: Names and coordinates of the significant sinkholes in the Prud catchment area – territory of Bosnia and Herzegovina

No.	Phenomenon	Y	X	Connection
1	Sinkhole Ugrovače	6456160.79	4820196.33	Klokun and Vrioštica
2	Sinkhole Predgrađe	6465967.08	4782446.85	Spring Prud
3	Sinkhole Sobač	6460285.52	4780510.78	Spring Prud
4	Sinkhole Musinac	6452548.70	4802630.08	Valley Grudsko
5	Sinkhole 1 – no name	6450514.35	4804600.03	Valley Bekijsko
6	Sinkhole 2 – no name	6451945.57	4804257.17	Valley Bekijsko
7	Wetland Krenica	6446271.38	4803758.18	Kongora

Table 3.37: Coordinates of the significant springs in the Prud catchment area – territory of Bosnia and Herzegovina

No.	Phenomenon	Y	X	Connection
1	Spring Klokun	6455084.19	4793069.71	Trebižat
2	Spring Vrioštica	6459498.09	4787887.29	Trebižat
3	Grudsko Vrilo	6450374.74	4805595.37	Valleys of Bekijsko and Grudsko
4	Modro oko	6451193.92	4795724.47	Trebižat
5	Spring Grabovo	6456490.26	4791061.69	Trebižat

Table 3.37 presents only larger springs in the analysed Prud catchment area on the territory of BiH. Their features and the connection with the Prud spring will be discussed further in the text.

The Trebižat River is located in the southwest of Bosnia and Herzegovina and flows in the direction of northwest – southeast, in the nearby area of the border with the Republic of Croatia. This is a river with different names for different river sections as given by local people. At the spring, it is known as the Tihaljina River. In the area of Klobuk, it is known as the Sita River, while the Mlade River is its name after it passes the area of Klobuk. From the location of the gaging station (GS) Humac, it is simply known as the Trebižat River. Its water course is dominantly karstic and thus the surface hydrological network of tributaries is highly deficient.

The river is recharged via the karst spring Tihaljina and a number of temporary and permanent springs flowing into Trebižat from the left side, such as Jakešnica, Nezdravica, Zelengora, Modro oko and Klokun as the most significant spring regarding its capacity. There are also some other springs appearing in the very riverbed or its nearby area along the water course, such as temporary spring Grab, and Vrioštica and Studenčica as the only permanent surface tributaries of this short water course. Into this river, water is evacuated from the Imotsko-Bekijsko Valley via the tunnel and the chute built in the period of the Austrian-Hungarian Monarchy. Recently, the hydro power station (HPP) Peć-Mlini was constructed downstream from the Tihaljina source, which uses the water from the Imotsko-Bekijsko Valley and the Nuga Lake located in the valley's southeast. HPP operation disrupts natural regime of the river and may be a problem for the identification of losses on certain river sections, should the measurements be carried out during the HPP operation.

Water balance identification for this water course requires measurement data from all wells and along the riverbed of the affected area. However, detailed measurements and observations were made only for a few profiles, such as GS Tihaljina (downstream), GS Klobuk, GS Humac (data of perennial measurements and observations are available for this GS), and GS Stubica (located downstream from the Kravice Waterfalls and upstream from the confluence with the Studenčica River). For the aforementioned profiles, measurement data for the period of 1994 – 2002 were collected, whereas most of the measurements were carried out simultaneously on all mentioned profiles.

Basic objective is the identification of a capacity for some smaller catchment areas located within the catchment area of the interrelated Prud spring and Trebižat River.

Water balance for the Trebižat River includes determination of water surplus or deficit occurring in its riverbed per measurement sections. The focus is on the section Humac – Stubica, assuming the possibility of water loss in accordance with the geological and hydro-geological analysis. The measurements identified water loss. Disappearing streams on this location can have an impact on the capacity of the Prud spring, i.e. water lost in the Trebižat riverbed most likely appear in this spring as well. The following text presents water balance in order to identify the areas and the recharge directions, or identify the affected area of the Prud spring.

Position of the measurement profiles is presented in Figure 3.38.

Figure 3.38: Area of the Trebižat River flow, including measurement locations

For every measurement profile, baseline information is presented in the text below:

Profile Peć-Mlini (downstream) is a gauge station that enables control of the water coming from the Tihaljina spring and the water evacuated via the chute from the Imotsko-Bekijsko Valley.

Profile Klobuk is located approx. 10 km downstream from the previous measuring profile. At this location, it is possible to control all inflows into the Trebižat River, either via groundwater or the springs of Modro oko and Klokun. In addition to the above mentioned larger springs, there are also a few smaller springs at this section with the unknown capacity at this moment.

Profile Humac is located approx. 15 km downstream from the profile Klobuk. This profile has been used as a gauging station for continuous observations and measurements for a number of years (GS Humac on the Trebižat River was formed in 1883). On the section between Klobuk and Humac, there is a temporary Grab spring appearing nearby the riverbed, and the Vrioštica spring appearing in the Vitina settlement in the length of 1.5 km from the riverbed. However, due to the use of this spring for irrigation, Vrioštica flows into the Trebižat River at the following location – 10 km downstream from the spring and 2 km upstream from the profile Humac. It is important to mention the abstraction of certain (unknown) water quantity from Trebižat in the location of Otok and its transport to the area of Rastoke for the purpose of agricultural irrigation.

Profile Stubica is located approx. 10 km downstream from the profile Humac, i.e. upstream from the confluence with the Studenčica River and approx. 2.5 km downstream from the Kravice Waterfalls. In this section, there is no visible recharge and no water used for irrigation in the summer time. Therefore, this section is highly favourable for identification of potential water losses along the riverbed in all hydrological situations.

Within the DRINKDRIA project, simultaneous flow measurements were carried out on the Trebižat River, section of Humac – Stubica. However, during project planning, disappearing water quantities were assumed to occur within error thresholds during the measurements. However, due to the hydrological circumstances in 2014, it was assessed that such measurements would not result in adequate accuracy. Furthermore, it would be very difficult to determine potential water losses in the period of the HPP Peć-Mlini operation, commissioned in the second half of 2004.

For this reason, earlier measurement data from the period prior to the HPP Peć-Mlini operation were collected. Measurement data from the period prior to the HPP Peć-Mlini operation are presented in Table 3.36.

In addition to the data presented in Table 3.36, the complete statistical hydrological analysis of GS Humac was available. The period of 53 years, 1926 – 1978, was analysed.

By analysing data obtained from the Agency for Watershed of the Adriatic Sea Mostar, Table 3.36 (data selected per measurement dates on all profiles – originally obtained data are presented in Hydrological database), it was concluded that the measurements were mostly carried out simultaneously on the same day or in the time lag of 1 day. In order to review results of the simultaneous measurements as an input for defining water balances in Table 3.36, the measurements in Humac are fully presented, as obtained from the agency in Mostar. The measurements on other profiles are presented only for the dates of measurements carried out at the same day on both this profile and the profile of GS Humac. By sorting out data from Table 3.38, it can be noticed that the largest water quantity of low waters during the summer period in the Trebižat riverbed is contained on the profile Klobuk.

Downstream from Klobuk towards Humac, water is used for irrigation during the summer time and thus significant water deficit occurs on the section of Klobuk – Humac (although the springs of Grab and Vrioštica are located on this section). The identified deficit is caused artificially and occurs only in the period of vegetation, but it does not have significant impact on the Trebižat tributaries on this section.

During the period of high and medium waters or beyond the period of vegetation, water deficit does not occur. However, Table 3.36 indicates that there is a water deficit in the section of Humac – Stubica in all hydrological situations.

It was already mentioned that the Trebižar River had no significant surface tributaries. Instead, it is a recipient for the karst springs located along its riverbed or in the nearby area. Moreover, it is assumed that there might be overflown wells detected only by measurements. In order to determine water balance for these water courses, available simultaneous hydro-metrical measurements presented in Table 3.38 will be used.

Due to the above described recharge of the Trebižat River, water balance will be determined by defining characteristic flows on all measurement profiles through GS Humac, since statistical hydrological analysis exists for this GS.

Table 3.38. Summary of simultaneous measurements on the Trebižat River carried out in the period of 1994 – 2002

Measurement date	Flows (m³/s)				
	Peć-Mlini	Klobuk	Humac	Stubica	
19.11.1994.			4,23		
30.11.1994.			6,56		
29.11.1994.			10,9		
10.03.1995	21,6	53,9	69,9		
21.04.1995.		10,7	25,5		
25.08.1995.	1,48		5,74		
15.09.1995.			116		
25.10.1995.		10,7	12,3		
21.11.1995.	2,12	7,15	8,21		
10.12.1995.	70,7*	74,5	120		
12.12.1995.	70,9*		102		
02.01.1996.			120		
11.01.1996.		86,6	120		
16.04.1996.		35,8	45,6		
16.01.1997.	37,9	58,4	73,9		
13.02.1997.	10,0	19,2	24,7		
25.07.1997.		3,72	2,82		
04.08.1998.			2,73		
27.11.1998.			54,7		
03.12.1998.	19,3	46,5	67, 3		
27.08.1998.			2,68		
08.09.1999.	0,92		3,09	2,40	
24.11.1999.	24,5	53,5	88,9	79,0	
19.07.2000.	0,67	4,22	3,39		
16.08.2000.			1,84	1,18	
21.11.2000.			83	76,3	
28.11.2000.	68,2	104	132	120	
01.08.2001.	0,68	4,39	2,27	1,85	
30.08.2001.			1,4		
18.04.2002.			17,4	13,7	
21.11.2001.	4,81	13,2	13,8		
30.08.2002.		5,49	6,3	4,97	
14.10.2002.		61,5	106	88,1	
14.09.2011.	0,39	3,25	1,65		

*) Measured with floats

For every measurement profile, dependency with GS Humac will be determined by using simultaneous measurements from Table 3.38. Based on this determined correlation, medium and low waters will be identified for the perennial period, which will be further used for determination of perennial water balance.

Based on identified characteristic flows on the measurement profiles, water surplus and water deficit along the Trebižat River will be determined for all hydrological conditions on the sections between the profiles used during the measurements.

As already mentioned, positions of measuring profiles are presented on the Trebižat River map, Figure 3.38.

GS Humac

In order to define characteristic flows on the analysed profiles – to be determined via GS Gumac – characteristic flows of the Trebižat River are presented in the text below for different hydrological circumstances identified by the statistical hydrological analysis of GS Humac. Summary of characteristic low, medium and high waters obtained from HiSO is presented in Tables 3.39, 3.40 and 3.41, respectively.

Table 3.39: Summary of medium annual flows of the Trebižat River on GS Humac

Q_{Sred}. (m3/s) Period 1926 – 1978	Medium annual flows (m^3/s) of the range of occurrence T (years)				
	2	5	10	20	50
39,8	39,8	48,1	52,2	55,4	58,8

Table 3.40. Summary of minimum annual flows of the Trebižat River on GS Humac

Minimum annual flows (m^3/s) of the range of occurrence T (years)				
2	5	10	20	50
3,71	2,09	1,54	1,20	0,82

Table 3.41. Summary of maximum annual flows of the Trebižat River on GS Humac

Maximum annual flows (m^3/s) of the range of occurrence T (years)					
2	5	10	20	50	100
231	259	273	284	288	303

Profile Peć-Mlini

Characteristic flows of the Trebižat River on the profile Peć-Mlini were determined by establishing correlation with the flows on GS Humac. The correlation is determined by simultaneous measurements on these 2 profiles and presented in Figure 3.39 (the analysis did not include measurements with the floats).

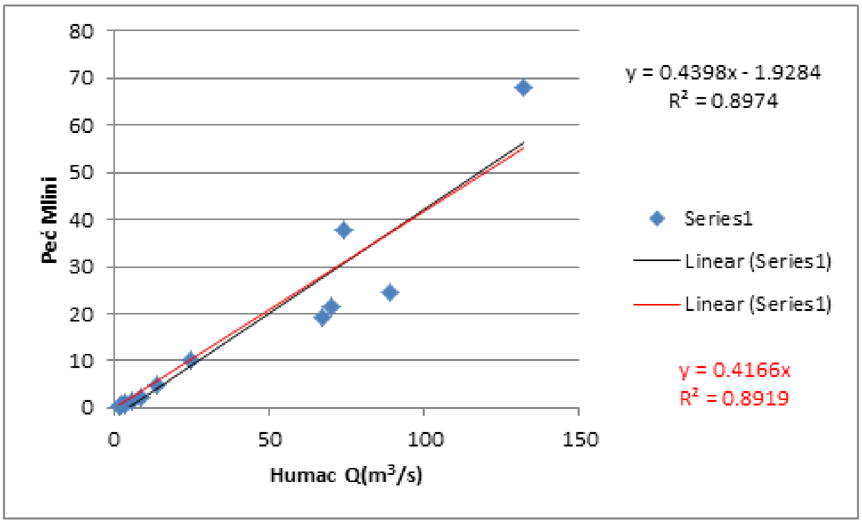


Figure 3.39: Correlation of flows between profile Peć-Mlini and GS Humac

Characteristic flows on the profile Peć-Mlini were calculated by using the following equation:

$$Q_{Peć\text{-}Mlini} = 0{,}4166\ Q_{Humac}$$

Tables 3.42, 3.43 and .3.44 present characteristic medium, minimum and maximum flows.

Table 3.42. Summary of medium annual flows of the Trebižat River on the profile Peć-Mlini

$Q_{avr.}$ (m3/s) period 1926 – 1978	Medium annual flows (m³/s) of the range of occurrence T (years)				
	2	5	10	20	50
16,5	16,5	20,0	21,7	23,1	24,5

Table 3.43: Summary of minimum annual flows of the Trebižat River on the profile Peć-Mlini

Minimum annual flows (m³/s) of the range of occurrence T (years)				
2	5	10	20	50
1,54	0,87	0,64	0,5	0,34

Table 3.44: Summary of maximum annual flows of the Trebižat River on the profile Peć-Mlini

Maximum annual flows (m³/s) of the range of occurrence T (years)					
2	5	10	20	50	100
96,2	107	113	118	120	126

It should be noted that maximum flows on the profile Peć-Mlini determined with this method are not validated and thus are not completely reliable, having in mind that they were determined through the correlation between the flows of Peć-Mlini and Humac, which is not an acceptable approach.

Profile Klobuk

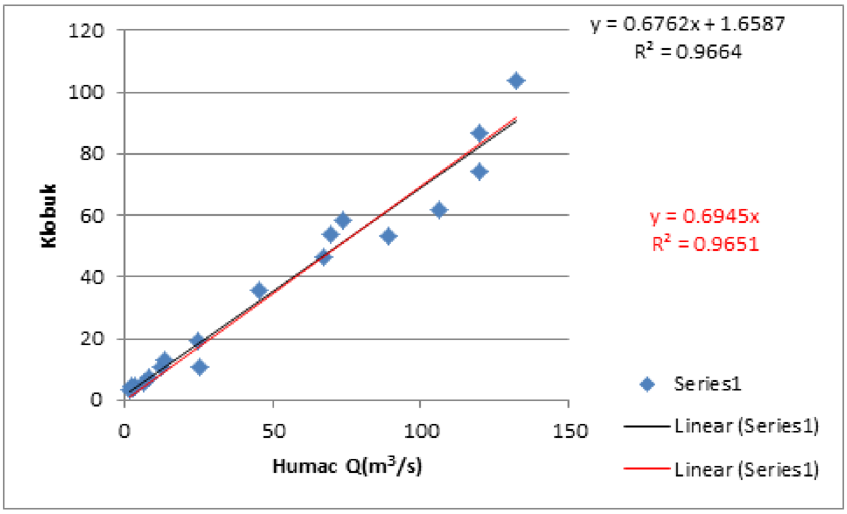


Figure 2.40: Correlation of flows on the Trebižat River between profile Klobuk and GS Humac

Similarly to the method discussed above, characteristic flows of the Trebižat River were also determined on the profile Klobuk by using the correlation with GS Humac, graphically presented in Figure 3.41.

Flows on the profile Klobuk were calculated by using the following equation:

$$Q_{klobuk} = 0{,}6945\ Q_{Humac}$$

Calculated values are presented in the Tables 3.45,3.46 and 3.47.

Table 3.45: Summary of medium annual flows of the Trebižat River on the profile Klobuk

$Q_{avr.}$ (m3/s) period 1926 – 1978	Medium annual flows (m³/s) of the range of occurrence T (years)				
	2	5	10	20	50
27,6	27,6	33,4	36,2	38,5	40,8

Table 3.46: Summary of minimum annual flows of the Trebižat River on the profile Klobuk

Minimum annual flows (m^3/s) of the range of occurrence T (years)				
2	5	10	20	50
2,6	1,45	1,07	0,83	0,57

Table 3.47: Summary of maximum annual flows of the Trebižat River on the profile Klobuk

Maximum annual flows (m^3/s) of the range of occurrence T (years)					
2	5	10	20	50	100
160	180	189	197	200	210

For these maximum flows, the same note is relevant as for determination of maximum flows for the profile Peć-Mlini.

Profile Stubica

In the same manner, characteristic flows were also determined for the profile Stubica in order to determine total water balance for the Trebižat River up to this profile, i.e. in order to define water quantities that might be disappearing in the Trebižat riverbed. In this case, the correlation with GS Humac was made and graphically presented in Figure 3.41.

The flows on the profile Stubica were calculated by using formula resulting from the derived established linear equation:

$$\mathbf{Q_{Stubica} = 0{,}886\ Q_{Humac}}$$

Calculated values are presented in Tables 3.48, 3.49 and 3.50.

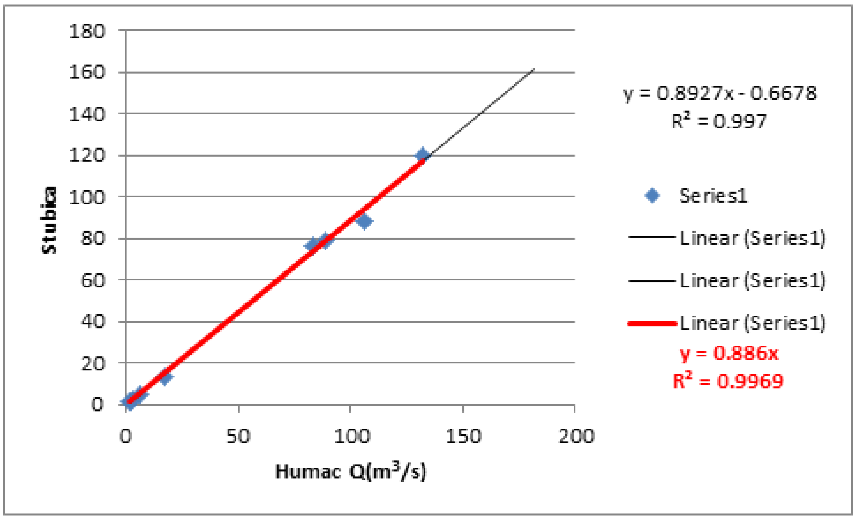


Figure 3.41: Correlation of flows on the Trebižat River between GS Humac and profile Stubica

Table 3.48: Summary of medium annual flows of the Trebižat River on the profile Stubica

$Q_{avr.}$ (m3/s) period 1926 – 1978	Medium annual flows (m^3/s) of the range of occurrence T (years)				
	2	5	10	20	50
35,3	35,3	42,6	46,2	49,1	52,1

Table 3.49: Summary of minimum annual flows of the Trebižat River on the profile Stubica

Minimum annual flows (m^3/s) of the range of occurrence T (years)				
2	5	10	20	50
3,3	1,85	1,36	1,06	0,73

Table 3.50: Summary of maximum annual flows of the Trebižat River on the profile Stubica

Maximum annual flows (m^3/s) of the range of occurrence T (years)					
2	5	10	20	50	100
205	229	242	252	255	268

In this case, the above described estimate of high waters was made for the purpose of illustration, while it can be definitely stated that this is a large error due to the aforementioned reasons.

After determination of all characteristic flows on the Trebižat River for all analysed profiles via GS Humac, it is possible to define waster balance per sections and in total – up to the profile Stubica which is actually the most downstream profile and data for this profile are known. Table 3.51 presents a summary of characteristic flows of the two-year range of occurrence for all analysed profiles.

Table 3.51: Summary of determined characteristic annual flows on all profiles

Measurement profile	**Medium perennial flow Q (m3/s)**	**Minimum annual flows Q (m3/s)**	**Maximum annual flows Q (m3/s)**
Peć-Mlini	16,5	1,54	96
Klobuk	27,6	2,6	160
Humac	39,8	3,7	231
Stubica	35,3	3.3	205

By using the flows presented in Table 3.51, water balance of the Trebižat River was prepared up to the profile Stubica. It was prepared by summing differences for every section ($\Delta Q = Qd_{ownstream} - Q_{upstream}$) and the results are presented in Table 3.52.

Table 3.52: Water balance of the Trebižat River for the analysed sections up to profile Stubica

River section	**Flow differences (∆Q difference) (- ∆Q loss) (m3/s)**		
	∆Q Medium annual	**∆Q Minimum annual**	**∆Q Maximum annual**
Spring Tihaljina – Peć-Mlini	**16,5**	**1,54**	**96,2**
Peć-Mlini – Klobuk	**11,1**	**1,06**	**63,8**
Klobuk – Humac	**12,2**	**1,11**	**71,0**
Humac – Stubica	**-4,5**	**-0,41**	**-26**
Trebižat to profile Stubica (∑∆Q)	**35,3**	**3,3**	**205**

According to Table 3.52, it is obvious that there is a water deficit on the Trebižat River section between Humac and Stubica for all 3 analysed hydrological situations, although results for high water should be taken with caution. However, the established correlation between simultaneous measurements on GS Humac and the profile Stubica does not show any signs of the change in the correlation even during the flows exceeding 100 m^3/s. This confirms the assumption that waters of the Trebižat River disappear on the section downstream from Humac and most likely flow into the Prud spring in the Republic of Croatia. Moreover, it can be also seen that the increase of the Trebižat flow linearly increases water loss in the riverbed. As a result, the increase of flow – water level in the river causes water losses to occur via cracks located in the rear of the riverbed. In accordance with the largest quantity measured on Humac – 132 m^3/s, the largest measured water loss of $\Delta Q = 12\ m^3/s$ was recorded.

Hydrological features of the Prud spring will be determined by measuring determined correlation between the flows on the Prud spring and the Trebižat River – GS Humac. The features will be determined in the same way hydrological features on all analysed profiles along the Trebižat River were determined, which were used for determination of the water

During 2014 and in the early 2015, there were 7 hydrometric measurements carried out on the Prud spring and the Trebižat River. Majority of the measurements were carried out on the same day. Summary of the measurements is presented in Table 3.53.

Characteristic flows of the Prud spring were determined as discussed in the text above by establishing correlation between simultaneously measured flows on the Prud spring and the Trebižat River – GS Humac. The established correlation for measurements during low and medium waters is graphically presented in Figure 3.42.

Table 3.53: Summary of the measurements carried out on the Prud spring and the Trebižat River

Date of measurement	Time of measurement		Trebižat River	GS Humac	Spring Prud Q (m3/s)
	GS Humac	Prud	H(cm)	Q (m3/s)	
25.03.2014.		14,30	183	28,8	7,62
14.07.2014.			127	6,43	
15.07.2014.		10,30			3,15
26.08.2014.		12,00	122	5,51	3,05
30.09.2014.	13,00	14,00	175	23,5	5,48
30.10.2014.	13,30	13,45			3,45
31.10.2014.			125	6,38	
10.12.2014.	14,00		297*	92,8*	
11.12.2o14.		12,30			8,10*
17.03.2015.		12,20	207	40,5	10,3

*) The measurements marked in red were carried out on 2 different days and during high flow instability on both GS Humac and the Prud spring most likely.

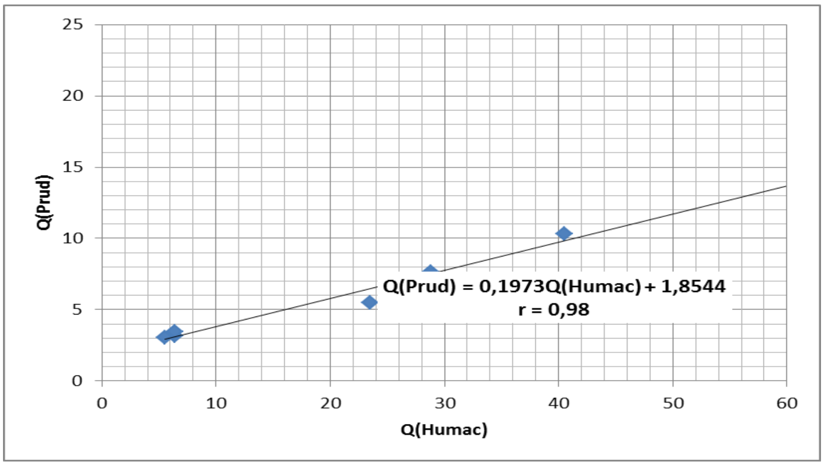


Figure 3.42: Correlation between the flows on the Prud spring and the Trebižat River

Determination of the aforementioned correlations did not include measurement carried out on 10 December 2014 on the Trebižat River and the measurement carried out on 11 December 2014 on the Prud spring. These were the only measurements carried out during high water on Trebižat when the flow of above 90 m^3/s was recorded. Simultaneously, the Prud spring was also measured and the flow of 8 m^3/s was recorded, which probably implies a significant error. Representatives of FB9 from Zagreb emphasised that this data was questionable. However, should the measurements be repeated during high water, the most likely conclusion would imply that the correlation between the flows of Trebižat and Prud is changed in such hydrological situation, i.e. the correlation line is 'broken'. It means that the Prud capacity is limited and the high water evacuation from the catchment area is carried out via some other discharge spot. Momentarily, there are no data for such conclusion, although the measurements carried out on 10 – 11 December 2014 point to that direction. As a karst spring, Prud appears from the karst conduit of smaller dimensions. This fact represents a basis for the aforementioned assumptions, which should be proved. Namely, if 100% error was made during the Prud flow measurements in December 2014, these new measurements would also diverge from the determined correlation presented in Figure 3.42. This correlation was determined based on the measurement data for low and medium waters. It would provide a basis for the aforementioned assumption.

Tables 3.54 and 3.55 present characteristic medium and minimum flows of the Prud spring determined by the correlation with the Trebižat River – GS Humac.

Table 3.54: Summary of medium annual flows of the Prud spring

$Q_{avr.}$ (m3/s) period 1926 – 1978	Medium annual flows (m^3/s) of the range of occurrence T (years)				
	2	5	10	20	50
9,7	9,7	11,3	12,1	12,8	13,4

Table 3.55: Summary of minimum annual flows of the Prud spring

Maximum annual flows (m^3/s) of the range of occurrence T (years)				
2	5	10	20	50
2,58	2,27	2,16	2,09	2,02

Based on the results, the above discussed analysis of the Trebižat River water balance up to the profile Stubica, and determined characteristic medium and low water of the Prud spring, it is possible that the recharge of the spring during medium water is carried out with approx. 46% of water lost in the Trebižat riverbed on the section of Humac – Stubica. During annual law water, this ratio is only 15.4%, while during minimum water of the 20-year range of occurrence, the Trebižat contribution amounts to only 6.7%.

This is very logical due to the Prud capacity during law water being larger than the Trebižat flow for the analysed section of Humac – Stubica. In addition, the Trebižat River has highly expressed gradient of the flow decrease on this section during law water. On other hand, based on the results, the Prud spring had quite stable capacity during law water.

It is possible that defined water deficit in the Trebižat riverbed during medium and high water occurred due to the recharge of some other springs appearing on the right-bank wetland area of the Neretva River in the wider area of Metković and Gabela. This could be clarified by additional simultaneous measurements on Prud and Trebižat during high water. Momentarily, there are no data about possible existence of the springs in the previously mentioned locations or it may have been no research.

By analysing all collected results, it is still too early to make final conclusions regarding the Prud spring catchment area. Therefore, we believe that the research of interaction between these two water phenomena should be continued, including additional measurements and analysis of catchment areas for waters of the Prud spring and the Trebižat River.

3.6. MONTENEGRO – NIKŠIĆ

From Annex 8:

Data for climate change assessment impact on available water resources

Data for climate change influence in Temperature and Precipitation time series are based on outputs from Report – Climate and Climate Change data for Pilot Area Nikšić (Institute for Development of Water Resources Jaroslav Černi, 2014). In summary, outputs from 3 climatological models (Aladin, Promes and RegCM3) for two periods and trend assessment in observed data are compared for temperature and precipitation at Nikšić and Lukovo station. For precipitation huge discrepancy is identified in models outputs for referent period (1961 - 1991). As a result, correlation is established based on measured data to decrease uncertainty. However, outputs are still unreliable. Based on trend assessment in observed data series, results for temperature are more uniform, and are in line with other studies at regional and global level. Observed temperature trends for Meteorological Station Niksic are in the range 0.5 – 1.0 °C / 100 years with seasonal increasing trends in winter, spring and particularly summer, while decreasing trend is observed for autumn. Seasonal increasing trends have been observed in winter, spring and particularly summer, while decreasing trend is observed for autumn. Despite that temperature modeled data for similar period they underestimated temperature by 3.0 °C on yearly average in comparison with measured data (Figure 3.43).

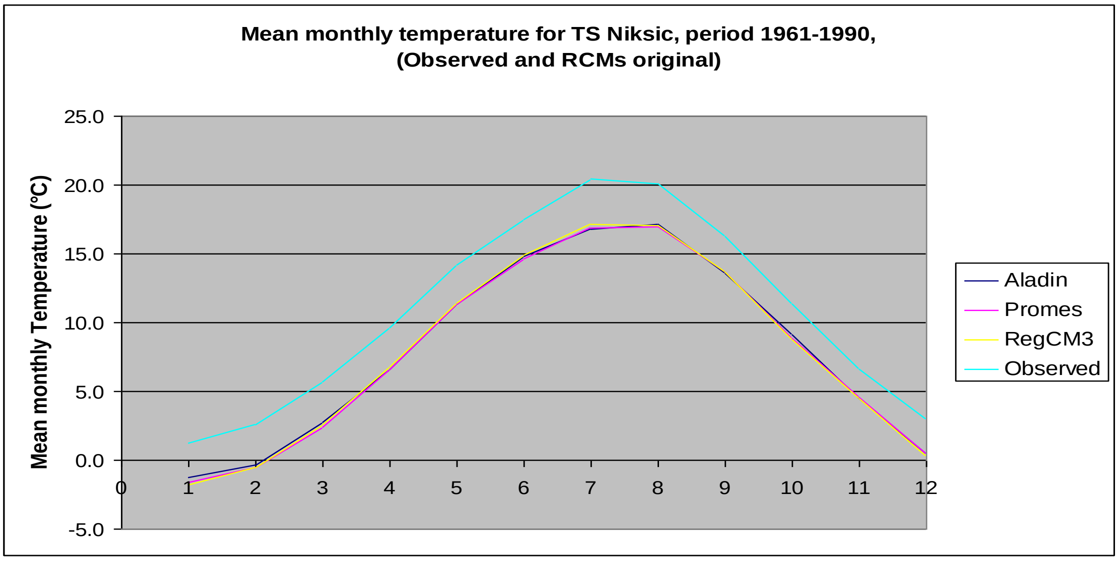


Figure 3.43: Summary of comparison of Temperature for observed and modeled data

As presented in Table 3.56, for modeled temperature data for referent period correction factor is developed based on observed data.

Table 3.56: Comparison of Temperature data for Nikšić station and correction factor values

	RCMs from CCWaterS				Corrected values for RCMs		
Month	Aladin	Promes	RegCM3	Observed	Aladin	Promes	RegCM3
JAN	**-1.3**	**-1.6**	**-1.8**	**1.3**	**2.5**	**2.8**	**3.0**
FEB	**-0.4**	**-0.6**	**-0.5**	**2.6**	**3.0**	**3.2**	**3.1**
MAR	**2.7**	**2.4**	**2.6**	**5.7**	**3.0**	**3.3**	**3.1**
APR	**6.6**	**6.6**	**6.8**	**9.6**	**3.1**	**3.0**	**2.8**
MAY	**11.3**	**11.4**	**11.4**	**14.2**	**2.9**	**2.8**	**2.8**
JUN	**14.8**	**14.6**	**14.9**	**17.5**	**2.7**	**2.9**	**2.6**
JUL	**16.8**	**16.9**	**17.2**	**20.5**	**3.7**	**3.6**	**3.3**
AUG	**17.1**	**16.9**	**17.1**	**20.1**	**2.9**	**3.1**	**3.0**
SEP	**13.6**	**13.7**	**13.6**	**16.3**	**2.7**	**2.6**	**2.6**
OCT	**9.1**	**8.9**	**8.8**	**11.4**	**2.2**	**2.5**	**2.6**
NOV	**4.4**	**4.5**	**4.5**	**6.6**	**2.2**	**2.1**	**2.1**
DEC	**0.4**	**0.5**	**0.3**	**2.9**	**2.5**	**2.5**	**2.7**
Year	7.9	7.8	7.9	10.7	2.78	2.87	2.82

Temperature trends in observed data are calculated for per decade (°C/10 yrs) for Nikšić station for periods 1949-2012 and 1949-2006 (Table 3). Similar trends are detected in Serbia for period 1949-2006 (JČI 2011; HMSS 2011).

Table 3.57: Trends in observed temperature

Month	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Year**
Season	**Winter**			**Spring**			**Summer**			**Autumn**			
Period	**Temperature station Nikšić**												
°C/10yrs 1949-2012	**-0.14**	**0.21**	**0.08**	**0.16**	**0.05**	**0.20**	**0.29**	**0.28**	**0.25**	**-0.04**	**0.08**	**-0.02**	0.12
	0.05 *			0.13 *			0.27 *			0.01 *			
°C/10yrs 1949-2006	**-0.16**	**0.21**	**0.07**	**0.11**	**-0.11**	**0.17**	**0.21**	**0.19**	**0.07**	**-0.17**	**0.11**	**-0.11**	0.05
	0.04 *			0.06 *			0.15 *			-0.06 *			

* Average trends in three months

Modeled values for precipitation appears to be significantly underestimated for referent period in comparison with observed data for Nikšić station, namely over 3 times lover than observed values on yearly average amounts. Table 3.58 summarizes outputs and correction factors for precipitation.

Table 3.58: Precipitation Nikšić summary data for period 1961 - 1991

	RCMs from CCWaterS				Corrected values for RCMs		
Month	Aladin	Promes	RegCM3	Observed	Aladin	Promes	RegCM3
JAN	**76**	68	**83**	208	**2.75**	**3.06**	**2.52**
FEB	71	**74**	**63**	194	**2.72**	**2.62**	**3.07**
MAR	**74**	**69**	73	186	**2.52**	**2.68**	**2.55**
APR	65	**67**	**74**	170	**2.61**	**2.55**	**2.29**
MAY	**69**	**69**	66	108	**1.56**	**1.56**	**1.64**
JUN	**61**	**58**	55	93	**1.53**	**1.59**	**1.70**
JUL	42	**43**	**43**	63	**1.51**	**1.48**	**1.48**
AUG	43	**47**	**53**	86	**2.02**	**1.84**	**1.64**
SEP	66	**83**	**70**	138	**2.10**	**1.66**	**1.96**
OCT	**92**	80	**88**	202	**2.19**	**2.51**	**2.29**
NOV	108	**111**	**112**	298	**2.76**	**2.69**	**2.67**
DEC	97	**99**	97	239	**2.46**	**2.42**	**2.46**
Year	863	869	877	1986			

The greatest discrepancies in monthly average data in comparison are observed for Aladin RCM, followed by RegCM3. Figures 3.44 and 3.45 present comparisons of precipitation data from models and observed data and corrected models outputs and observed data for period 1951 -2000. It is evident from graph with corrected values that future projection for selected variables should be assessed and evaluated given the contradiction with observed data.

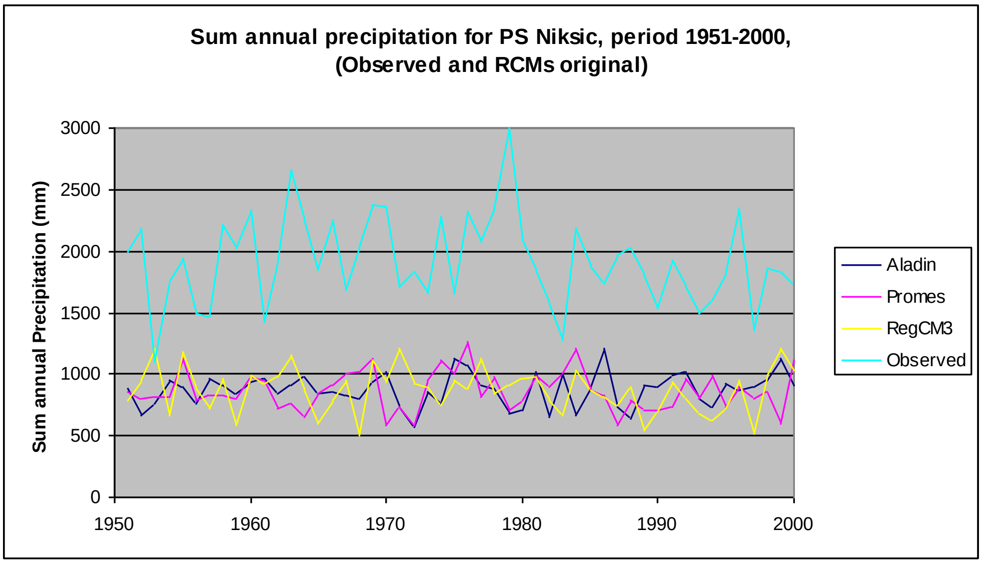


Figure 3.44: Comparison of modeled and observed data

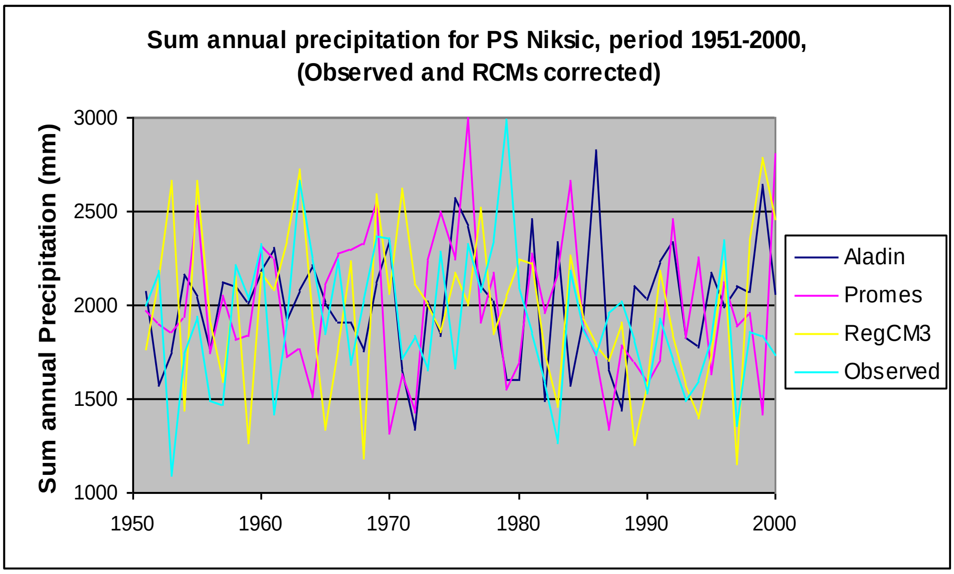


Figure 3.45: Comparison of corrected modeled and observed data

Given the disparity among results future water resources availability will be assessed based on 4 precipitation data for future period (2021 -2050), namely outputs from 3 RCMs and trend assessment in observed data series.

Methodology for climate change assessment impact on available water resources

The simplified water balance approach in drainage basin for drinking water source in the Nikšić pilot area is applied for the assessment of available water resources under conditions of climate change (Annex 8). Methodology is selected based on available data and information and includes some assumptions.

According to Study for Poklonci karst spring water protection zones delineation, outer protection zone is approximately 310 km^2 and includes other two springs (Donji and Gornji Vidrovdan) that are water sources for Nikšić Drinking Water Supply System.

For referent period (1961 -1991) observed average temperature is 10.7 °C, precipitation average yearly amount is 1986 mm, and evapotranspiration is assumed to be 1100 mm since period of observation was shorter than referent period and only average value for 3 locations is available.

Given the decrease in precipitation, increase in ETP and demand during the summer season water resources availability for all scenarios will be estimated on the yearly basis.

Based on literature review and natural features of water sources recharge area and surrounding drainage area value of 0.65 for effective infiltration coefficient (EIS) is assumed to be conservative enough since value from 0.4 to 0.8 for EIC (water retention) is used for fissured aquifers (IAH classification).

Water resources availability at present and in the future

For area of 310 km^2, water balance is calculated for present and future period changes in average annual precipitation based on outputs from 3 Regional Climate Models (Aladin, Promes, RegCM3) and Trends in Observed (TOB) data with respect to referent period, available data on ETP and assumed EIC. In this report water resources availability are not assessed separately for 3 drinking water sources since delineation of recharge areas do not exist. Thus, for the whole drainage area water balance is calculated as difference between precipitation volume and ETP to assess roughly available water resources. Evapotranspiration for the future scenarios is calculated for each season since it is 5 – 6 time higher in summer in comparison to winter (Master Water Management Plan for Montenegro, 2001). Approximation is based on available observed monthly data contribution in yearly summary. Available data refer to meteorological station in Nikšić. Following equations and assumptions are used in calculations for water resources availability based on methodology described in previous section for present and future scenarios.

$\mathbf{P} = ETP + Q\ (10^6\ m^3 / year)$

$\mathbf{Q} = Q_{srf} + Q_{gw}\ (10^6\ m^3 / year)$

$\mathbf{Q}_{\mathbf{srf}}$ is runoff volume

$\mathbf{Q}_{\mathbf{gw}}$ is quantity available for aquifer recharge= $\mathbf{Q * EIC}$

$\mathbf{EIC} = 0.65$

$\mathbf{A} = 310\ km^2$

Table 3.59 summarizes results for approximation of water balance for present and future scenarios based on modeled results and trend assessment based on observed data.

Table 3.59: Summary Water Balance for Nikšić Test Area

Time Frame	**1961 - 1991**	**2021 – 2050, EIC = 0.65**			
Variable		**TOB***	**Aladin**	**Promes**	**RegCM3**
P (10^6m^3)	**615.7**	**610.1**	**602.9**	**584.4**	**601.4**
ETP(10^6m^3)	**341.0**	**396.6**	**392**	**379.9**	**391**
Q (10^6m^3)	**274.7**	**213.5**	**211**	**204.5**	**211**
Q gw(10^6m^3)	**164.8**	**128**	**127**	**122**	**126.3**
Q srf (10^6m^3)	**109.9**	**87.5**	**84**	**82.5**	**84.7**

* - 7.2 mm/10yrs

Estimated water balance for study area for future scenario indicates decrease in water availability for aquifer recharge as the result of decrease in precipitation amounts and increase in temperature. It is noteworthy to mention that maximum water yield for all water sources used for drinking water supply in Nikšić water supply system is approximately 52.64 10^6m^3 while the minimum water yield is approximately 12.92 10^6m^3 . Given that the difference among maximum and minimum water yield is dynamic groundwater storage, i.e., groundwater reserves in aquifer water level fluctuation zone in hydrological cycle that are directly influenced by active recharge. Secondly, it is important to underline existence of any water quantity deficit for recharge given the aquifer type used as a source for drinking water supply. It is of particular Interest during the summer season since the highest abstraction rate is measured during that season (0.6 $m^3/$ s) while average abstraction is 0.4 $m^3/$ s. Scarcity of data sets with more detailed information and absence of hydrogeological model for Test area, results in approximation of ratio among water volume available for water recharge (Q_{gw}) and dynamic groundwater storage (D_{gws}) as one of indicators for water resources availability under the agreed scenarios for Climate Change effects on drinking water sources. In addition, available quantity for abstraction is approximated based on ratio of (D_{gws}) and abstracted water amount at the present and this ratio is applied for future scenarios. As presented in table 6 if the ratio among Q_{gw} and Dgws is same i.e., 0.22, or 22 % of available quantity for recharge there is evidence that dynamic groundwater storage decrease. For abstraction quantity this ratio is 31 %. Thus under the projected climate change and trends in observed data assessment for future period (2021 - 2050) decrease in renewable water resources quantity exist. As presented in table, the worst case scenario exists for summer, where deficit of quantity for ground water recharge is detected.

Table 3.60: Available Dynamic Ground Water Storage in the Future

	Q gw	Dgws
Scenarios	$10^6 m^3$	$(10^6 m^3)$
PRESENT	**164.8**	**39.71**
TOB (Y)	**128.12**	28.28
TOB MAM	24.28	5.36
TOB JJA	**- 68.30**	**-15.07**
TOB SON	70.71	15.61
TOBDJF	93.67	20.67
Aladin (Y)	**126.62**	27.95
MAM Aladin	31.04	6.85
JJA Aladin	**- 64.27**	**- 14.18**
SON Aladin	77.02	17.00
DJFAladin	82.84	18.28
Promes (Y)	**122.71**	27.08
MAM Promes	33.54	7.40
JJA Promes	**- 70.79**	**- 15.62**
SON Promes	88.95	19.63
DJF Promes	93.19	20.57
RegCM3	**126.29**	27.87
MAM RegCM3	26.53	5.86
JJA RegCM3	**- 61.46**	**- 13.57**
SON RegCM3	54.36	12.00
DJF RegCM3	106.92	23.60

As depicted in table above, deficit in summer season (JJA) exist in groundwater quantity available for recharge due to projected decrease in precipitation. The greatest decline for future water resources availability both in dynamic ground water storage and available quantity for summer season is noticed for scenario based on Promes model, followed by TOB and Aladin. Based on analyses the lowest decrease in water quantity availability is observed for RegCM3 scenario. On the other hand for annual data Promes scenario results in highest decline, followed by RegCM3 and Aladin. Results presented in table that lowest decries in water availability exist in TOB scenario. Accurate conclusion is not feasible due to significant discrepancy given the units of presented results, i.e., millions of cum. However, serious issues exist for the summer season since deficit is detected for all scenarios.

3.7. ALBANIA – DRINI BASIN

From Annex 9:

The mean annual flow of all rivers in Albania is 1300 m³/s, which corresponds to a module of 29 l/s.km², one of the largest in Europe. The mean values of annual runoff vary greatly across the country mainly following the distribution of precipitation. Thus, the flow takes values of 430 mm (module 13.8 l/s.km²) to Drini i Bardhe, 1490 mm (module 31.0 l/ s.km²) to Gjolja, 1293 mm (module 39.2 l/s.km²) Drini - Shoshaj and 1950 mm (module 61.7 l/s.km²) in Buna River.

The values of the flow coefficient range from 0.44 to 0.73 with an average value of 0.58 for the entire watershed. The high values of flow coefficient in the watersheds of northern country such as Buna (0.81), Drini (0.73) and Vjosa (0.60) can be explained by the low water loss through evapotranspiration (low temperatures and high humidity values of the air) but also from groundwater recharge from outside of the watershed. There are two characteristic periods in the year in terms of the water flow: the wet (October – May) and the dry period (June – September). 86% percent of the annual water flow is discharged during the wet period and 8% during the dry period. June is the transition period accounting for 6% of the annual water flow. In that context the rivers have mostly a pluvial regime.

The present chapter provides an overview of a study of climate impact on basic hydrological balance elements for all the rivers in Albania. The profiles selected are the downstream flow (Table 3.61) of these rivers. In this way the influence of upstream human influence cannot be neglected.

Table 2.61. Long-term runoff (Q – Discharge (m3/s); Vx106 - Volume (m3) per year)

River basin	Buna	Drini	Ishmi	Erzeni	Shkumbini	Semani	Vjosa	Bistrica	Pavla	Others	Total
Q (m^3/s)	680	104	19.8	16.9	60.2	85.4	184	32.1	6.69	72.1	1244
$Vx10^6$ (m^3)	21287	2756	624	533	1851	2712	5960	1012	211	2274	39220

The data used comprised both hydrological and climatologically data based on the mean values. Mean seasonal and annual runoff series are analyzed. The analysis shows the following distribution of long-term runoff, precipitation and evapotranspiration throughout the seasons for the period 1961– 2000. Runoff: 38.6% occurs in the winter, 35.6% in spring, 16.1% in autumn and 9.7% in summer. Precipitation: 35.3 % occurs in the winter, 29.3% in autumn, 24.2% in spring and 11.2% in summer and evapotranspiration: 5.7% occurs in the winter, 20.7% in spring, 27.1 % in autumn and 46.5% in summer.

The hydrographic catchment of the Drini has a total area of 19,582 km² from which 14,173 km² belong to the Drini itself and 5,187 km² to the Buna river. The Drini is formed by two main tributaries: the Drini i Zi, with a catchment area of 5,885 km², flowing from FYROM, and the Drini i Bardhe, flowing from Yugoslavia.

The Buna river drains Lake of Shkodra, which is fed by rivers originating from Montenegro and Albania; its larger tributary is the Moraça river.

In the past, the exits of Buna and Drini rivers have been separated. At present the old bed of the Drini, leading south to the city of Lezha, carries only a minor part of the discharge; the rest meets the Buna near Shkodra and follows its river bed along the border with Montenegro.

The Drini river for the period 1951-1985 has a mean annual discharge of 680 m³/s, of which 360 m³/s come from Drini itself and 320 m³/s from Buna. The resulting specific discharge is about 35 l/s.km² and the runoff coefficient 0.74. These high values are mainly due to the very high yield of the Buna, which cannot be much exploited - except for navigation. Keeping in mind the water use in Albania, the most important river is the Drini, with the following characteristics:

- annual discharge volume: 11,1 km³ (352 m^3 /s);
- specific discharge: 24.8 l/s.km²;
- ratio wettest month (December) to driest month (August): 5.7;
- one in 10 year high flow: about 13 times the river module;
- storage capacity of Fierza reservoir: 2,700 million m³ (about 25% of annual flow).

Chemical analyses of samples taken from the Drini showed good quality water, with stable mineral composition along the river course. Metallic ions are present in small amounts except for iron in some cases. It appears that no restriction for the present uses (hydropower, irrigation) could arise from the water quality in the Drini. A more difficult situation arises from the quality of the Kiri water, affected and possibly contaminating the local groundwater resources also. Its effects on the lake of Shkodra have not been clearly assessed.

Buna River is part of a water system of Shkodra Lake-Drini and Buna River. These three water body represent a unique hydrographic system collecting water from a watershed with a total area of 19,582 km2 (the lake Shkodra itself has a catchment area of 5,180 km2). From Shkodra Lake water flowed into the Adriatic Sea through river Buna and Drini River discharge its water just few km (1.5km) after Buna River comes out from the lake. Drini River used to flow directly in Adriatic Sea more in south in Lezha direction, but in 1846 due to big flood, Drini River inundated all the area around the Shkodra and after that it flows to the Buna River. Furthermore during the years 1950-1960 in the framework of irrigation engineering works in Zadrima plain, the Gjadri River was deviated discharging its water in Drini after the Vau Dejes dam.

Buna River is considered a plain river flowing in a plain territory, but it collects the waters from a mountainous watershed. It is the only discharge of Shkodra Lake. Through its river bed the waters of Shkodra Lake, Kiri and Drini are discharged into Adriatic Sea. The main altitude of its catchment's area is 909m above the sea level. The delta of the river is composed of some alluvial islands such as Ada, Franc Josef, Pa-Emer (No Name), etc. Since there are not maps or hydrographic surveys in different periods and in continuity, it is difficult to describe the dynamic of the development of these alluvial islands (Figure 3.46).

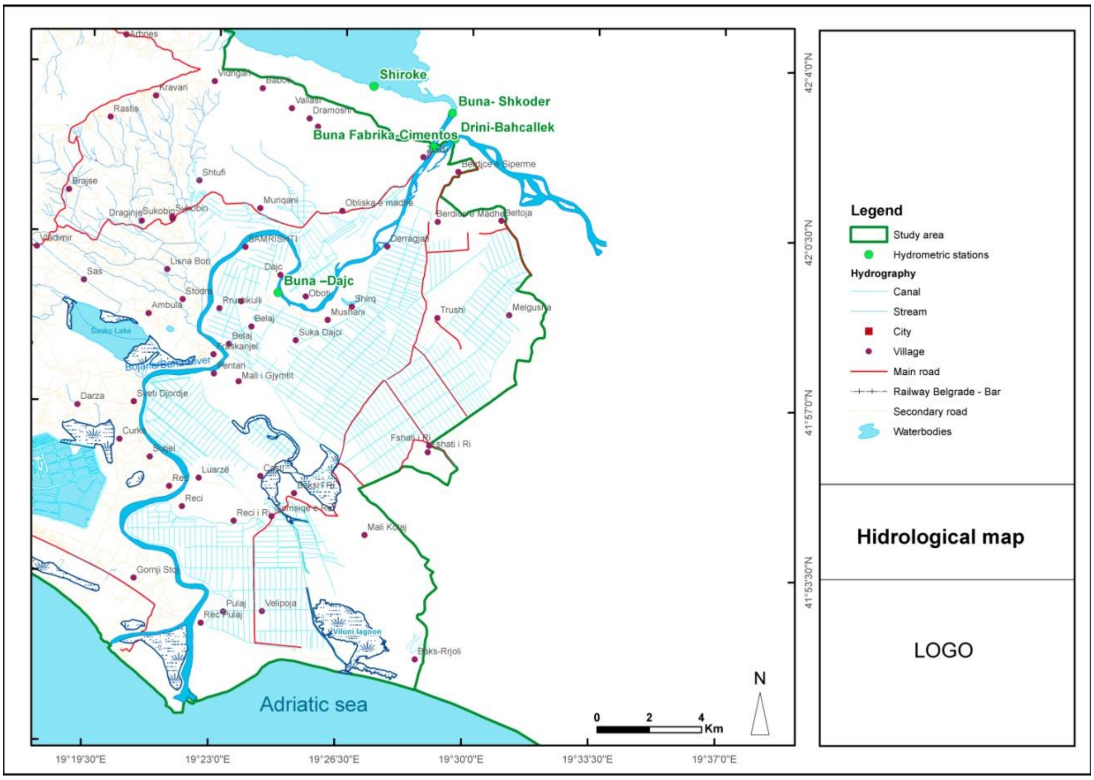


Figure 3.46: Buna River and hydrometric station installed (source Matt Mac Donald)

Buna River is the only discharge of the Shkodra Lake and its regime is strongly linked with this Lake. But in the same time in its river bed, Drini River discharges its water. The main parameter of the annual water flow is the annual mean discharge that represents the water availability of the watershed. To describe the main hydrological characteristics, the data from hydrometrics stations in the Buna and Drini rivers are used. Using these data from stations in Drini and Buna, the main hydrographic characteristics are determine and presented in the table 2.

The Buna River has a mean annual flow of 680 m³/s, with 360 m³/s from the Drini River and 320 m³/s for Buna (Table 3.61). The module corresponding to the total catchment area is 35 l/s.km². The Buna River has a very strong annual unit value: 61.7 l/s.km² that are two times the modulus of the whole country.

Table 3.62: The main hydrographic characteristics

River	Surface (km²)	Altitude (m)	Discharge (m³/s)	Precipitation (mm)	Runoff (mm)	Deficit (mm)	Runoff coefficient.
Drini	14,2	971	352	1220	781	439	0.64
Buna	5,2	770	320	2170	1950	220	0.9
Drini+ Buna	19,6	909	680	1461	1090	371	0.74

The flow coefficient also has great value: 0.68. It can be explained by the low values of evapotranspiration due to low temperatures, high humidity, and the abundant supply of groundwater from Alps karst area as well as the regulation of water regime by Lake Shkodra. After Vau-Deja Hydropower, the water discharge is totally controlled and there is no way to assess the natural water flow because in the river bad do not pass all the water volume of the Drini River (Table 3.62) but only part of it- the water discharged from the turbines. The values presented in this study belong to the period without the influence of the power station. After the gage station in Vau Deje two other rivers joint Drini, Gjadri and Kiri. Their characteristics are presented in the tables and graphs below. Another important characteristic is the distribution of the annual flow which represents the water regime of the river.

Table 3.63. Mean Monthly Discharge for Drini River

River	**Station**	**Discharge (m³/s)**												
		X	**XII**	**XII**	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**Mean**
Drini	**Vau Deja**	184	348	474	443	421	383	410	401	252	138	92.5	121	306
Drini	**Before conjunction**	228	396	501	493	459	446	507	490	293	155	104	141	351

The annual distribution of the water flow for the Drini River basin is closer to the snow and rainfall with two peaks: one in winter (December) and the other one at the end of the spring (April –May), only one minimum at the end of the summer time (August). From the month of March the upper parts of the watershed provide water from snow melting process, furnishing the Drini River flow (Figure 3.47).

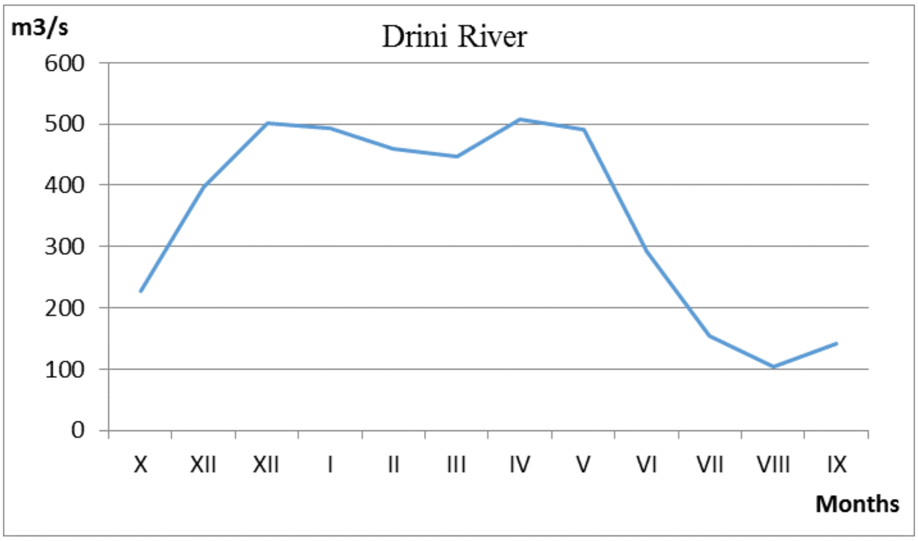


Figure 3.47. Annual distribution of Drini River

In the Buna River the maximum throughput is observed in winter (December-January) but even in the spring period March-April-May there are high value registered of discharge and this is the influence of Drini River with its nivo-pluvial regime. From this combination the regime of Buna River is a nivo – pluvial regime. In the (Table 3.63) and (Figure 3.48), the annual discharge is presented for Buna River when it flows out of lake and after its conjunction with Drini River.

Table 3.64. Mean Monthly Discharge for Buna River

River	**Station**	**Discharge (m^3/s)**												
		X	**XII**	**XII**	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**Mean**
Buna	**Shkoder**	154	374	529	574	440	404	372	371	295	167	91.4	68.8	320
Buna	**After Conjunction**	382	770	1030	1067	899	850	879	861	588	322	195	210	671

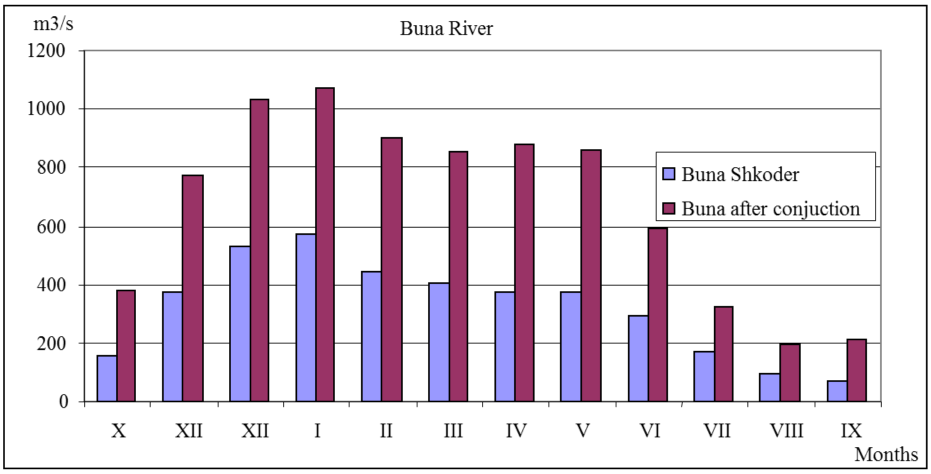


Figure 3.48. Annual distribution of the flow

The hydrograph network of this region consist of the main river Drini of Lezha, the biggest branch Gjader River, the canal of high waters-KUL and the Manatia stream. Drini of Lezha is the main river of the all water bodies in Lezha with a catchment's area of 314 km^2. The mean altitude of the basin is of 210 m and is long 50 km. (Stratoberdha P. et al, 2008)

In this river basin there was not any hydrometric gauging station. By utilizing the data registered for the observed rainfall, it was possible to determine discharge event probabilities and magnitudes for this basin. The water discharge is estimated by four different methods to convert the rainfall data in discharge: SCS TR – 55, Giandotti, Rational and Simplified Method of Water Balance (Ven Te Chow 1972) (Figure 3.49).

The results of the calculation are as follows:

- the mean annual discharge: 30 m^3/s;
- the maximum discharge: 215 m^3/s.

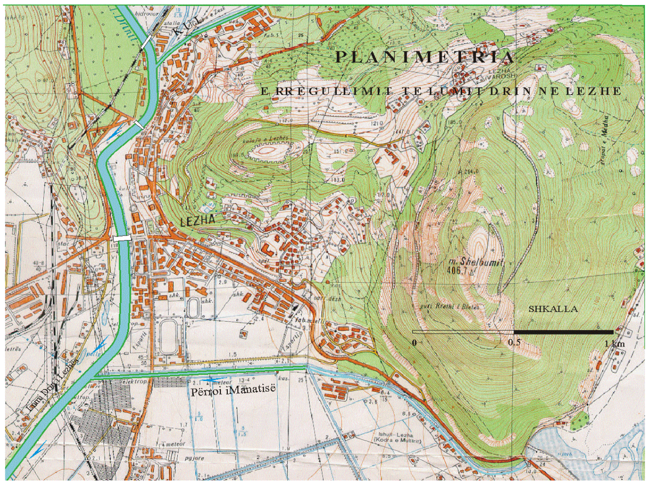


Figure 3.49. Part of Drini of Lezha water basin

Different studies show cycles with different continuity from 2-3 year to 100 year (Shehu.B.) The water flow differs from year to year under the influence of cliDrinic factors and mainly atmospheric precipitation and air temperature. Other factors, except human influence, have a slow influence, coming after the cliDrinic changes. So from all factors, the cliDrinic one is the most changeable. CliDrinic changes influence directly in water resources regime and step by step, the changes in flora, relief etc. in natural conditions the hydrologic regime needs century, and the soil and relief much more than this. But, under the human influence these rhythms change a lot in increasing direction.

Conditioned from the climate variability, the water flowing in the river, during the time, presents a certain variation. The water flow differs from year to year under the influence of cliDrinic factors and mainly atmospheric precipitation and air temperature. These values fluctuate around its *mean annual flow* that is a stable characteristic of the river and represents the average amount of the water that flows in that axes during the year. To characterize the water flow fluctuation, during the years, you must have a very long data series. To analyses the present situation trends, on must evaluate the fluctuation of the water flow during the years. For that from the data series of water discharge for every profile of the downstream station the yearly runoff anomalies for the long-term mean are calculated.

From the north, for the Buna River from the beginning of the observation period, it is observed a gradual growth of the discharge values for every year continuously. Indeed after the year 1953, all the annual values of the flow rate are above the multiannual mean and this is till 1978 (Figure 3.50). After that, only with some small fluctuation, almost all the mean annual values are below the multi-annual mean discharge. The curve is descending. So the period up to 1978, can be classified as a wet period, including years with values greater than the multiannual mean discharge. After 1980 it is evident that the trend is a negative one (Figure 3.50).

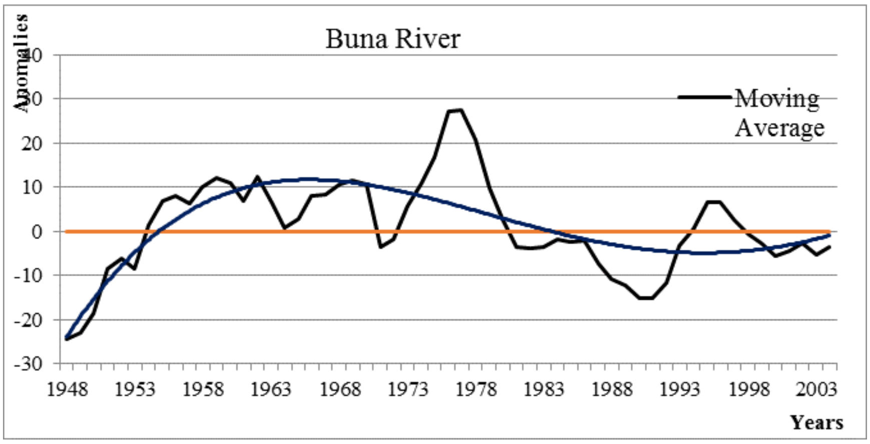


Figure 3.50: Yearly anomalies for Buna River flow

The main “furnisher” of the river is the precipitation coming down in forms of rain or even as snow. Falling in all the catchments area or in a part of it, they furnish directly the river channels or are deposited in its underground layers. Depending on the characteristics of the geological for Drini river, the water requires time to reach the watercourse. Time that is not the same for all the catchments and different within the same catchment in different periods of the year. The contribution of so many factors makes difficult to find out the direct relationship between precipitation and water flow. Therefore, it is correct to analyze this hydrological parameter too, on the frame of the precipitation regime and its influence in the water flow.

The water flow regime (flood and dry periods) is strongly related to the type of river inflow that is characterized by physical and geographical but mainly by conditions of the Drini basin. The main factors influencing, are especially the distribution of the precipitation and the temperatures of the air. However, a very important factor, in most of the cases not quantified, is the human influence that makes it very difficult to complete an impact analysis. The water flow of the Drini River has a seasonal and monthly variation. The flood and dry period are strongly related with type of river nourishment. The groundwater nourishing factor represents 30% of the annual discharge.

Although a period of 50 years may offer an extensive record of climate and stream variability, in fact it represents a very short period in terms of geologic history of the region. The gauged record represents only a small temporal window of the variability characteristics encompassing many centuries of River hydro-climate. The future River management decisions have to look forward and to rely heavily on forecasts. These forecasts typically assume that past properties of the river system, as revealed through observations, will be replicated in future conditions

To have a realistic view of this process different kind of relation between runoff and rainfall are performed. The period 1960-1990 is selected and from the graphical display it is evident that during the years, the runoff – rainfall relation has the same tendency (Figure 3.51).

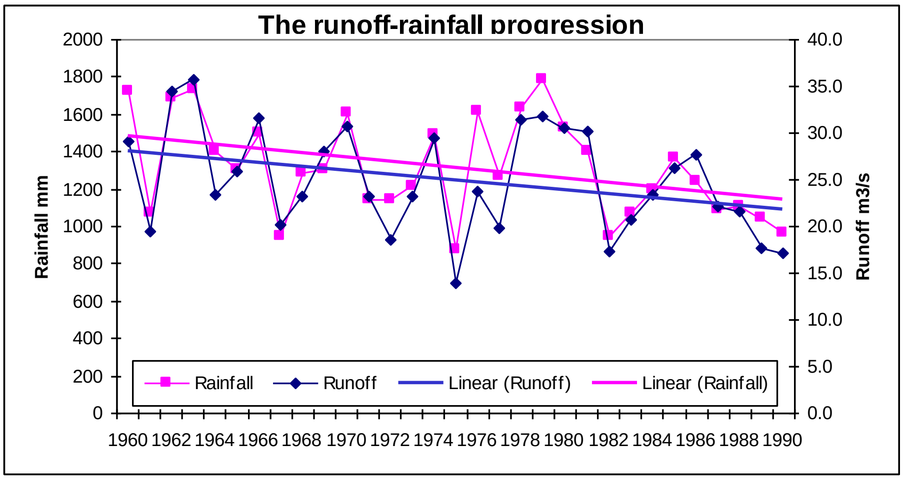


Figure 3.51: Runoff-rainfall progression

The water flow distribution in the river channel follows, in a smooth rate, the precipitation and air temperature distribution during the year. These are calculated, also flow as discharge/precipitation ratio (Figure 3.52) and moving average (5 years) of the mean discharge and precipitation.

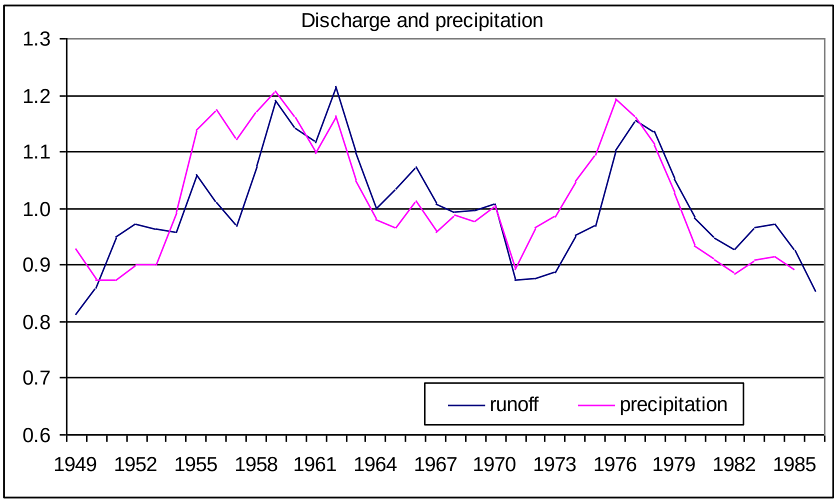


Figure 3.52: Years average ratio of discharges and precipitation

As per the distribution of the rainfall and runoff within there is a slight shift in months e.g., precipitation are higher in November and the flow is greater in December. This can be explained with the fact that a part of the precipitation during the fall (October –November) goes to fill the underground reservoir as the ground is dry from the summer time. Part of this amount comes out as runoff in the successor months. From February to May in the runoff it is evident the influence of the snowmelt in the basin. After the month of April to the fall, the amount of precipitation goes to furnish the “empty” underground reservoirs (Figure 3.53).

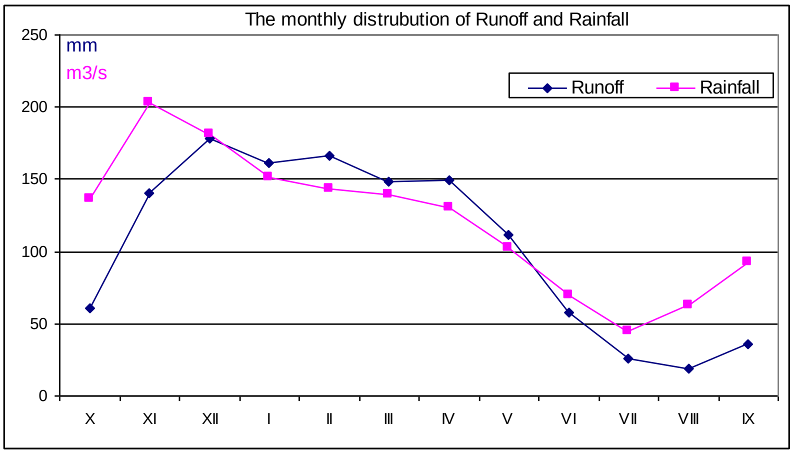


Figure 3.53: Long term annual distribution of precipitation and runoff

The main components of the hydrologic cycle are precipitation, evaporation, and transpiration. Changes in the climate parameters – solar radiation, wind, temperature, humidity, and cloudiness – will affect evaporation and transpiration. Changes in evapotranspiration and precipitation will affect the amount and the distribution, spatially and temporally, of surface runoff. Changes in runoff in combination with sea level rise will affect stream flow and groundwater flow. Stream flow and groundwater are considered natural water or hydrologic resources. One of the most significant impacts of a change in climates will be on hydrological processes and, consequently, water resources.

On the other hand water demand from all sectors can also be expected to change over the next decades. While there are many pressing problems regarding water supply, climate change is likely to add to them, making solutions more difficult. Global warming will also result in sea-level rise and models agree on the conclusion that the range of regional variation in sea level change is comparable to the global average sea level rise. In addition to submergence, seawater intrusion into freshwater aquifers in deltaic areas is an increasing problem associated with rising sea level.

Low flow is a seasonal phenomenon, and an integral component of the flow regime of any river. Drought, on the other hand, results from a less than normal precipitation over an extended period of time. Drought is a more general phenomenon, and may be characterized by factors other than just low stream flows. Knowledge of the magnitude and frequency of low flows for streams is important for water-supply planning and the design, waste-load allocation, reservoir storage design, and maintenance of quantity and quality of water for irrigation, recreation, and wildlife conservation. In many cases, the majority of natural gains to stream flow during low-flow periods are derived from releases from groundwater storage. Losses to stream flow during dry weather periods may be caused by direct evaporation. Natural gains and losses to low flows are both affected by anthropogenic impacts, which can include: Groundwater abstraction within the sub-surface drainage area; Changes to the vegetation regime in valley bottom areas through clearing or planting.

In the reports on the impact of climate change on water resources there are used different approaches: models or empirical relation between stream flow parameters and climate of Drini. There are a range of empirical approaches to estimate Drini climate impacts, based on the analysis of regional hydrological data. Empirical approaches do not require the local calibration of a model, and can provide very quick estimates of sensitivities to change in catchments. In the FNC for determining the impact of a changing climate on the mean annual runoff, two models that relate runoff–forming factors (annual sum of precipitation and mean annual evapotranspiration) to the long-term mean annual runoff are considered. These models are based on statistical relationships.

To the result of the empirical approaches are added more sophisticated analyses, based on hydrological models. Such models allow the investigation of the effect of different seasonal distributions of change and the importance of catchment's characteristics.

In the most general terms, the determination of the effects of climate change on flow regimes and water resources involves the following stages:

(i) Develop a hydrological model that converts climate inputs into hydrological response, and calibrate under the current climate conditions;

(ii) Create a climate time series, representing the climate under the scenario;

(iii) Run the model with the climate inputs, and compare indices of flow regime (such as mean monthly runoff) under the future climate with those under the current climate.

In previous text it was considered the application of a range of generalized procedures for the estimation of the impacts of climate change on some aspects of flow regime. Now the objective is to use a simple hydrological model applied in the basin to further explore the sensitivities of the flow, to changes. A monthly water-balance model is used. This model, referred as the Thornthwaite monthly water-balance program, is used to examine changes in monthly flow regimes, in average seasonal and annual runoff. In the following text the results from the application of the monthly model described above to estimate average annual runoff under a range of scenarios are presented. Results are compared with those obtained from the generalized procedures.

The WatBal model is an integrated water balance model developed for assessing the impact of climate change on river basin runoff. The water-balance model analyses the allocation of water among various components of the hydrologic system using a monthly accounting procedure based on the methodology originally presented by Thornthwaite (Thornthwaite, 1948; Mather, 1978, 1979; McCabe and Wolock, 1999; Wolock and McCabe, 1999). Inputs to the model are mean monthly temperature (*T*, in degrees Celsius), monthly total precipitation (*P*, in millimeters), runoff factor, direct runoff factor, soil-moisture storage capacity, latitude of location, rain temperature threshold, snow temperature threshold, and maximum snow-melt rate of the snow storage that are modified through the graphical user interface.

The output components are: effective precipitation, potential evapotranspiration, total modeled runoff (direct, surface, subsurface runoff and base flow). Monthly data series of 7 meteorological stations and 2 runoff gauging-stations covering the period from 1961 till 1990 have been used for calibration of the WatBal model in the local conditions of this area. The values of the modification of the air temperature and precipitation in the catchments, for the reference year of 2030, 2050, 2080 and 2100 were determined after the climate change scenarios prepared.

The sensitivity of average annual runoff to changes in average annual rainfall and potential evapotranspiration was assessed using data from the terminal gauging stations from all the rivers.

The first regression model is based and derived only on the relation rainfall-runoff from the data of the Drini catchment's area.

For all the river basins the sensitivity of average annual runoff to changes in average rainfall was expresses by the same regression:

$$\frac{R_1}{R_0} = \left(\frac{P_1}{P_0}\right)^{1.44}$$

Where the subscripts 0 and 1 refer to current and future conditions respectively. A 10% increase in average annual rainfall would increase average annual runoff by 17%.

According to the climate change scenarios the precipitation for the four time horizons will decrease as shown in the (Table 3.65) and in (Figure 3.54). The decrease in annual precipitation for the mean and minimal scenarios produces a decrease in annual runoff.

Table 3.65:.Scenarios of mean annual runoff change

	2030		**2050**		**2080**		**2100**	
	PRECIP	**RUNOFF**	**PRECIP**	**RUNOFF**	**PRECIP**	**RUNOFF**	**PRECIP**	**RUNOFF**
AVER	-3.84	**-5**	-8.46	**-12**	-14.37	**-20**	-18.13	**-25**
MAX	27.7	**42**	47.42	**75**	81.12	**135**	94.9	**161**
MIN	-35.39	**-47**	-56	**-69**	-78.64	**-89**	-89.69	**-96**

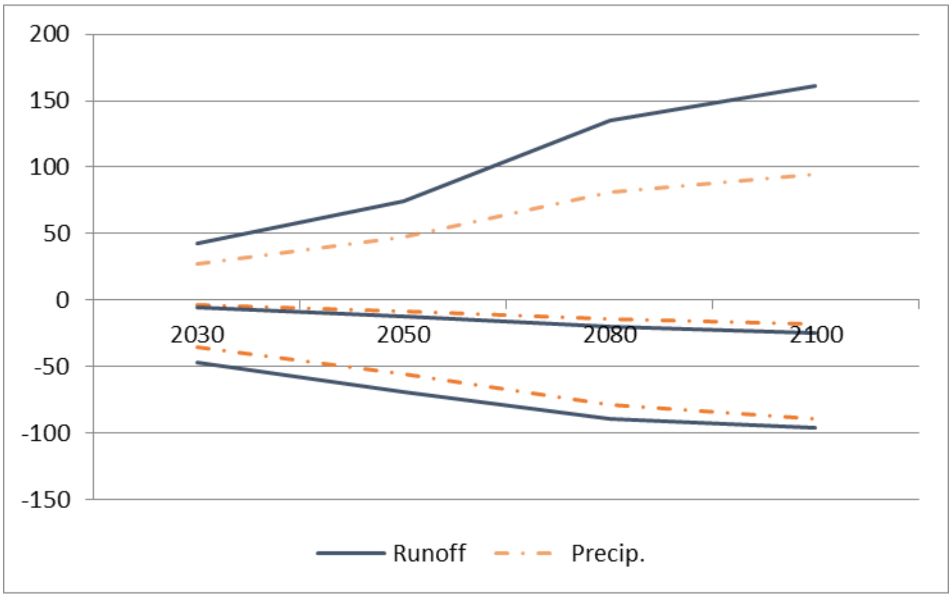


Figure 3.54: Graphical presentation of the precipitation and runoff changes

In the hypothesis of climate changes, the variation in air temperature and the precipitations on the river basins, estimated at the level of 2030, 2050, 2080 and 2100, the hydrographs of the mean monthly runoff were simulated. As it can be observed in (Table 3.66) the mean annual runoff decreases over time for each of the selected timeframes, for all climate models.

Table 3.66: Mean annual runoff simulated for the River Basins

Scenarios	**2030**	**2050**	**2080**	**2100**
Values in %				
Average	-8	-15	-25	-35
Low	-35	-48	-60	-89
High	30	54	89	100

Mean annual runoff simulated in the three hypotheses of climate changes (mean, maximal, and minimal) at the level of 2030, 2050, 2080 and 2100.

The analysis of the variation of the simulated mean monthly discharges based on climate models generally show that for the average and minimal scenarios, they decrease compared to the current regime for all the time horizons.

3.8. GREECE – CORFU ISLAND

From Annex 10:
Based on a report of 2003 from the competent ministry shows that the annual precipitation volume in Corfu is 1090 hm^3, the runoff volume is 388 hm^3 and the potential aquifers stocks are 266 hm^3 (www.ntua.gr). The River Basin Management Plan provide the average annual values of surface runoff of the three sub-basins of Corfu (Table 3.67) (RBMP of Epirus, Del.8).

Table 3.67: Average Annual Surface Runoff Values of the sub-basins in Corfu (RBMP of Epirus, Del.8)

Sub-basin	**Average Annual Value of Surface Runoff (hm^3)**
North Corfu	290.48
Central Corfu	125.37
South Corfu	53.75

The methodology followed in the River Basin Management Plan of Epirus (RBMP of Epirus, Del.8) to estimate the average annual runoff in the river basin of each river and lake water body was based on the analysis and treatment of all the necessary hydro meteorological data. Then the development of hydrological models in the spatial level was completed using the model of rain-runoff MikeSHE. The model's results are the water balances of the river basins. The basic equation for natural conditions not taking into consideration human interventions (e.g. abstractions from surface of groundwater) was the following (RBMP of Epirus, Del.8):

$$P + GIN = ET + RF + GOUT \pm \Delta S + \varepsilon$$

where: P is the precipitation, OL is the surface runoff, BF is the basic runoff, ET is the actual evapotranspiration, ΔS is the change in storage in aquifers, GOUT is the volume of the groundwater that came out of the basin, GIN is the groundwater volume that entered the basin, the coefficient of surface runoff CD=(OL+BF)/P and ε is the total error of simulation incorporated in the quantity ΔS (RBMP of Epirus, Del.8).
As stated in the River Basin Management Plan of Epirus (RBMP of Epirus, Del.8) the basic hypothesis of the model is that at the end of simulation all the water volume in the aquifers is presented as basic runoff. A significant hypothesis is that there are not inflows and outflows of groundwater from one basin to a neighbourhood basin of the same water district. Each basin is simulated as a closed system. The components of the water balance used in this methodology are the surface runoff in wet periods and the deep infiltration towards the aquifers for each basic basin. The results came out from the rain-runoff model in the form of time series of monthly time step for 20 hydrological years (1981-2000). The sum of the average time series annual values for each river basin is the estimated value of the average annual surface runoff (hm^3) in the exit of each catchment basin without including the runoff from the upstream basins. To convert the surface runoff values to the spatial level of the catchment basin of the surface water body, the values are multiplied

with the rate of the catchment basin area to the basic basin area. Finally, summing up the runoff values of the surface water bodies basins from upstream to downstream, the values of the average annual natural runoff came out for each surface water body basin. Except of the annual time base the methodology for estimating the average natural runoff is applied for the summer period of July-September using the average monthly value of the summer period. In the case of Corfu this value equals to 0.016. For this purpose the time distribution of the runoff based on flow measurements in reliable stations during the year was taken into consideration (RBMP of Epirus, Del.8).

Climatic characteristics for the test area of Corfu include the average temperature (^{o}C) and the precipitation (mm) per month for the period 1955-2014 and 1961-2013 respectively (Figures 5&6). The data are provided by the Hellenic National Meteorological Service (http://www.emy.gr/). Temperature and precipitation values trend to increase. Simulation models presented in Table 3.67 show the predicted temperature and precipitation values changes in the future (2021-2050).

Temperature values are projected to increase while precipitation is projected to decrease (Table 3.68).

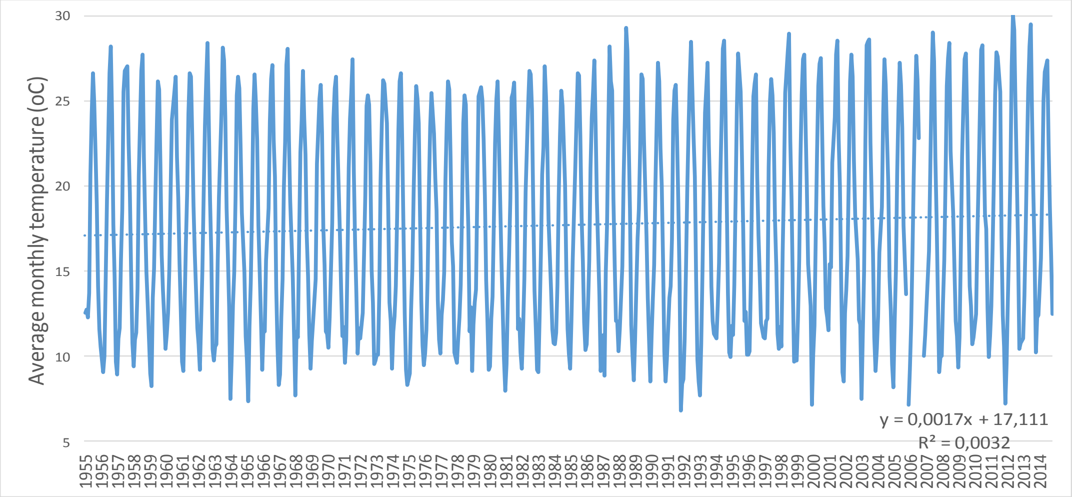


Figure 3.55: Monthly temperature values for Corfu, 1955-2014 (based on data from HNMS)

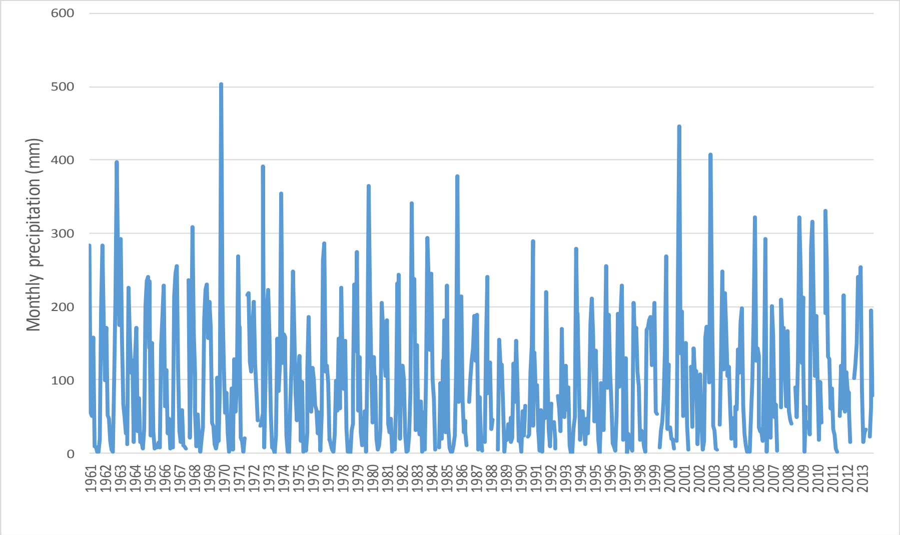


Figure 3.56: Monthly precipitation values for Corfu, 1961-2013 (based on data from HNMS)

Table 3.68: Changes in minimum, maximum, average temperature and total precipitation values predicted by climatic simulation models for Corfu area (period 2021-2015) (data obtained from the project Geoklima, http://geo-ellanikos.aegean.gr:88/geoclima/)

	Ensemble (A1B)					**Prudence (A2)**					**Prudence (B2)**					**REGCM (A1B)**				
Change in	Winter	Spring	Summer	Autumn	Year	Winter	Spring	Summer	Autumn	Year	Winter	Spring	Summer	Autumn	Year	Winter	Spring	Summer	Autumn	Year
minimum air temperature (ºC)	1,04	0,89	1,52	1,51	1,24	3,58	3,29	5,55	4,26	4,17	2,46	2,39	4,43	3,12	3,1	1,14	0,77	1,52	1,36	1,19
maximum air temperature (ºC)	0,98	0,93	1,5	1,51	1,23	3,81	3,77	6,19	4,68	4,61	2,43	2,48	4,78	3,4	3,27	1,15	0,9	1,53	1,47	1,26
average air temperature (ºC)	1,01	0,91	1,51	1,49	1,23	3,58	3,44	5,76	4,32	4,27	2,37	2,42	4,51	3,2	3,12	1,15	0,87	1,53	1,15	1,25
total precipitation (%)	2,29	-13,9	-11,13	-5,31	-3,9	-1,47	-15,1	-60,01	-24,88	-25,4	5,94	-1,19	-44,54	-3,15	-10,7	-16,56	-6,3	-44,01	-9,19	-7,9

Table 3.69: Basic hydrological information for the evaluation of the climate change on water resources – AVERAGE CONDITIONS

Country	**Test area**	**Long-term average (m^3/s)**		**Changes compared to baseline (%)**	**Remarks**
		1961-1990	**2021-2050**	**2021-2050**	
Greece	Corfu (GR0500010)	2.38	1.78 – 2.97	-25% to +25%	
Greece	Corfu (GR0500020)	1.27	0.95 – 1.59	-25% to +25%	
Greece	Corfu (GR0500030)	1.27	0.95 – 1.59	-25% to +25%	

As there are no available data on the evaluation of the climate change on water resources for the future, the long-term average water inflow values are given in Table 3.69. Regarding the prediction of the water inflow in the future (2021-2050), several scenarios are developed. They include the water inflow variations from -25% to +25% at a step of 5% (Table 3.69).

3.9. RESULTS

Isonzo plain (Italy) [Annex 1]

In the Isonzo/Soča pilot area (Italy, Region Friuli Venezia Giulia) the water resources on which the methodology have been applied are mainly phreatic waters in a porous aquifer. The spring belt remains southern than the study area. To calculate the water resources, as input data was defined the Isonzo/Soča river average discharge over a period of 50 years and the effective infiltration calculated for the area of interest. This last parameter was obtained using the Curve Number formula [Kannan N., Santhi C., Williams J.R., Arnold J.G. (2007) - Development of a continuous soil moisture accounting procedure for curve number methodology and its behaviour with different evapotranspiration method. Hydrological Processes (published online in www.interscience.wiley.com)]. The effective infiltration and the evapotranspiration were later calculated analyzing 46 (T) + 109 (P) climatic stations placed all over the Friuli Venezia Giulia Region for the period 1971-2008 (Zini et al. 2011 – ISBN 978-88-8303-314-8). The published P and T data were re-analyzed and the climate change models (RegCM3, Aladin and Promes) were later used to evaluate the difference in percentage between their results and the observed values of T and P within the period 1961-1990. Seen that the difference was always less than 20% (plus or less), this percentage was added or subtracted to the effective precipitation values.

As result the input renewable WR for the test area, in average conditions, were calculated to be of 37.4 m^3/s (Isonzo/Soča River average discharge). To this value is necessary to add the effective infiltration value that for the area, for the reference period 1961-2003 has been estimated to be 4.2 m^3/s.

According to the climate change models on test area Isonzo/Soča Plain two of the three models show a rainfall increase of approximately 10%, as in the temperatures. The third model instead is highlighting a decrease in the rainfalls (PROMES -11,9%) associated to an increase in the temperature values (+5,5%). In this framework, a reasonable decreased in the effective infiltrations up to -15% was adopted in the provisional water budget computation (2021-2050). The implications of this decrease are in general an increase in the depth to water values in the High Plain and a pressure lowering in the artesian aquifers of the Low Plain. Moreover, the discharges at the resurgence belt will suffer a decrease. The discharge value measured at the resurgence belt is moreover an indirect indicator of the sustainability of the actual use of the water resources. In this framework, the withdrawals reduction in the Low Plain, could help in the pressure increase of the artesian aquifers.

ATO3 (Italy) [Annex 2]

At the test area ATO 3 (Italy, Marche Region) the inland high-hilly and mountain area, with greater annual precipitation values, is very rich in terms of aquifers, potentially providing large volumes of good quality water. The information about the ongoing climate change and the increase of periods with prolonged absence of precipitation are uncertain. There has been a peremptory alternating of dry periods, especially in early autumn and late winter, followed by periods of intense and prolonged rainfall, in the last fifteen years. Such meteoric pattern tend to favour and/or reinforce gravitational and flood phenomena already widespread in the test area and, consequently, to limit infiltration and groundwater recharge. The uncertainties associated to the complex hydrogeological setting of the territory cannot exhaustively enable an assessment of the quantities involved, unless a continuous and effective monitoring of the spring discharges which currently concerns (sometimes partially) only some of the main water supply works. A similar consideration can be done for the aquifers located in floodplain areas. The studies carried out so far, only partially fill the gap related to a proper characterization of the hydrogeological parameters of these aquifers and the volume of water actually available for the exploitation. Typical of the aquifers located near the coast is the problem related to a possible saline water intrusion, resulting from freshwater overexploitation, sea level rise or human intervention. Also in this case, more detailed studies and targeted monitoring are therefore to be considered fundamental for a correct assessment of the qualitative and quantitative state of the water resources stored. The implementation of DRINKADRIA Pilot Action, concerning the installation of a real time monitoring and measurement system in the considered Test Area will contribute to fill the information gap and lead to a better knowledge of the hydrological model, so helping to determine the prospective availability of water resources, to be put in relation with future demand.

Ostuni (Italy) [Annex 3]

The analyses of the potential impact of climate change on the GW resources used for water supply in the Ostuni test site (Italy, Apulia region), showed that different models result in different scenarios of the intensity of the impacts on the selected water balance indicators. The results of the analyses based on climate simulations from the Aladin and Promes models gave more extreme projected values of the average annual GW recharge compared to the results obtained using the RegCM3 model. It is assessed that, in case the projected climate scenarios come true, the CWR for the Ionic subdomain (the most critical) during 2021-2050 could range between -7% (RegCM3) and -34% (Promes), thus all the considered projections forecast water scarcity conditions in the next decades. Concerning the Adriatic subdomain, all the three RCM scenarios show a tendency to decreasing aquifer recharge (-7% to -26%). However, while the WEI value is less than 1 adopting the RegCM3 scenario and the present WD, Aladin and Promes scenarios forecast an increase of the WEI values of 8% and 13% respectively. From the results briefly presented in the report, it clearly appears that depending on the location and the model used, a wide spectrum of climate change responses was obtained. However, they unambiguously indicate potential notable deterioration of the aquifer water balance whatever the adopted climate and WD scenarios. Such kind of results should be therefore adopted to come up with effective responses (structural solutions and management decisions) to contrast the potential impacts here detected.

Kobariški stol, Mia and Matajur aquifer (Slovenia) [Annex 4]

It can be concluded that water availability analysis for the test area Kobariški Stol aquifer in Slovenia was performed in the frame of the research of the drinking water resources in the Posočje area (Brenčič et al., 2001). Based on the presented study, it was estimated that the total groundwater flow from the Kobariški Stol area (aquifer) is around 2 m^3/s.

Kobariški Stol aquifer is therefore potential water resource for drinking water supply, which can be also considered for cross-border water supply between Slovenia and Italy. Field measurements were basic and were performed in a short time period. Therefore further analyses are recommended, such as discharge measurements with duration in two hydrological years, isotopic analyses for the recharge area determination, etc.

Northern Istria - springs Gradole, Sv. Ivan and Bulaž (Croatia) [Annex 5]

The analyses of the potential impact of climate change on the water resources/karst springs used for water supply in the Mirna basin in test area Northern Istria (Croatia): springs Gradole, Sv. Ivan and Bulaž showed that different models forecasting changes in climate indicators result in different scenarios of the intensity of the impact of such changes on the selected water balance indicators. The values of the average annual discharges and the lowest average monthly discharges were selected as indicators. The results of analyses based on climate estimations using the Aladin and Promes models gave more extreme projected values of the average annual discharges compared to the results obtained using the RegCM3 model. However, on the other hand, it was exactly the results of modelling of characteristic discharges (average annual discharges and the lowest average monthly discharges) where discharges were projected based on RegCM3-model climate predictions of rainfall and temperatures for 2021-2050 that gave the lowest deviations from homogeneity in the analysed area compared to the series from the reference period 1961-1990. It is assessed that, should the projected climate scenarios come true, the average annual discharges at the analysed sources during 2021-2050 could, even if analysed using the most conservative model of changes based on RegCM3 climate projections, at the level of the total 30-year average amount to between 0.3% (Sv. Ivan) and 6.3% (Bulaž) with much more intensive variations and a potential for the years drier even than the extremely dry 2011/2012. There are even more significant estimations of changes in the lowest average monthly discharges which in the results obtained from the said model range between 0.5 % and 11.4 %, with certain years having extreme values of the lowest average monthly discharges even exceeding the 50-percent values of the ever recorded minimums. All the trends of characteristic distributions of discharges show a trend of decreasing discharges, hence also of water resources available for water supply. So, depending on the location and the model used, a very wide spectrum of results was obtained. They unambiguously indicate potential notable deterioration of the water balance interrelations should the trends of the recently recorded climate change/variations continue. It is therefore already now essential to come up with potential answers (structural solutions and management decisions) to such critical situations. Indeed, the objective of the research done was not to precisely quantify some projections of the future changes, but rather to establish a framework for water resource management which will also take account of the potential changes in their hydrological characteristics. It is to be expected that an appropriate environmental flow (EF) will have to be ensured in the near future in the Mirna basin which could, coupled with potential further adverse climate change, lead to the water supply service faced with particularly difficult challenges during extremely dry periods.

Southern Dalmatia – Spring Prud and Blatsko polje (Croatia) [Annex 6]

It is evident that different models give different values quantifying water balance changes due to the projected climate change for test area Prud in Southern Dalmatia (Croatia). For the period 2021-50 on the level of the mean annual average discharges, the expected changes, i.e. decrease in discharges compared to the average from the reference period 1961-90 range, depending on the model, between 9.1 and 18.7% in the Promes model. Changes in a similar extent are also expected in the minimum average monthly discharges, where the discharge change/decrease for the analysed 30-year period 2021-2051 ranges, depending on the model, between 6.8 and 13.1%. On the average the smallest changes in the mean values are generated by the RegCM3 model, and the biggest ones by the Promes model. However, differences in terms of extreme values are even more significant – the maximum average annual discharges generally increase significantly, while the minimum average annual discharges in all the models decrease, in the range of 31.4 - 52.3%. Slightly less marked changes can be expected in the lowest average annual discharges, ranging between 6.9% and 21.1% depending on the model. Results of the Aladin-based estimation show bigger changes, while the results of the Promes model suggest slightly smaller changes. With the current water use regime, if scenarios of that kind would come true, even to a smaller extent, this wouldn't represent a big issue because the yields of the springs exceed the needs. Prud spring has a very balanced regime of groundwater discharge which affects its recharge from the remote parts of the neighbouring basins. Since the results obtained from the Promes-based climatological estimations show the smallest deviations in homogeneity of the modified data series, the results obtained using that model can therefore roughly be deemed the most suitable.

It is evident that different models result with different values which quantify balance changes according to the predicted climate changes for test area Blatsko polje in Southern Dalmatia (Croatia). For the period 2021-2050, at the mean annual discharges level, expected changes from the state in the referent climatological period 1961-1990 are from 9.8 to 22.6%. Changes of minimum mean monthly discharges are of somewhat lower range: from 2.3 to 9.3%. The smallest changes were predicted by RegCM3 model and the highest by Promes. Since the status of water supply from the local island resources in the existing conditions is already critical, there is no doubt that every new deterioration of hydrological conditions will result in inability to ensure water supply during the critical hydrological conditions.

Nikšić (Montenegro) [Annex 8]

Methodology for future water resources availability assessment in future for test area Niksic was applied on karst springs that are drinking water source. In addition to Aladin, Promes and RegCM3 modelled outputs from CCWaterS project, for pilot area Niksic trend evaluation in temperature and precipitation time series for observed data at Niksic meteorological station are used for climate change data evaluation. Discrepancy among the modeled data and observed data for referent period (1961 - 1991) resulted in correlation coefficient development. Thus, modeled data (from RCMs) corrected by this coefficient are used for future water (re)sources availability approximation and water exploitation index calculations. In generally, analyses are done within the proposed time frame. Based on available data and objectives of WR assessment, simplified water balance for Pilot area Niksic is developed to provide rough approximation of future water availability for water sources used as drinking water source. WR availability is approximated for average and summer season conditions. In spite of some shortcoming it might be useful for first approximation for areas with limited data availability or for first step in more detailed evaluation since water balance approach is extensive used by practitioners and scientific community.

Estimated water balance for study area for future scenario indicates decrease in water availability for aquifer recharge as the result of decrease in precipitation amounts and increase in temperature. It is noteworthy to mention that maximum water yield for all water sources used for drinking water supply in Nikšić water supply system is approximately 52.64 10^6 m^3 while the minimum water yield is approximately 12.92 $10^6 m^3$. Given that the difference among maximum and minimum water yield is dynamic groundwater storage, i.e., groundwater reserves in aquifer water level fluctuation zone in hydrological cycle that are directly influenced by active recharge. Secondly, it is important to underline existence of any water quantity deficit for recharge given the aquifer type used as a source for drinking water supply. It is of particular Interest during the summer season since the highest abstraction rate is measured during that season (0.6 m^3/ s) while average abstraction is 0.4 m^3/ s. Scarcity of data sets with more detailed information and absence of hydrogeological model for Test area, results in approximation of ratio among water volume available for water recharge (Q_{gw}) and dynamic groundwater storage (D_{gws}) as one of indicators for water resources availability under the agreed scenarios for Climate Change effects on drinking water sources. In addition, available quantity for abstraction is approximated based on ratio of (D_{gws}) and abstracted water amount at the present and this ratio is applied for future scenarios. As presented in table 6 if the ratio among Q_{gw} and Dgws is same i.e., 0.22, or 22 % of available quantity for recharge there is evidence that dynamic groundwater storage decrease. For abstraction quantity this ratio is 31 %. Thus under the projected climate change and trends in observed data assessment for future period (2021 - 2050) decrease in renewable water resources quantity exist. As presented in table, the worst case scenario exists for summer, where deficit of quantity for ground water recharge is detected.

Deficit in summer season (JJA) exist in groundwater quantity available for recharge due to projected decrease in precipitation. The greatest decline for future water resources availability both in dynamic ground water storage and available quantity for summer season is noticed for scenario based on Promes model, followed by TOB and Aladin. Based on analyses the lowest decrease in water quantity availability is observed for RegCM3 scenario. On the other hand for annual data Promes scenario results in highest decline, followed by RegCM3 and Aladin. Results presented in table that lowest decries in water availability exist in TOB scenario. Accurate conclusion is not feasible due to significant discrepancy given the units of presented results, i.e., millions of cum. However, serious issues exist for the summer season since deficit is detected for all scenarios.

Drini Basin (Albania) [Annex 9]

In the hypothesis of climate changes on test area Drini Basin in Albania, the variation in air temperature and the precipitations on the river basins, estimated at the level of 2050, the hydrographs of the mean monthly runoff were simulated. It can be concluded that the mean annual runoff decreases over time for each of the selected timeframe, for all climate models. The analysis of the variation of the simulated mean monthly discharges based on climate models generally show that for the average and minimal scenarios, they decrease compared to the current regime for all the time horizons.

Corfu island (Greece) [Annex 10]

The WRs analyzed are the three aquifers identified in the test area (Corfu island), namely GR0500010, GR0500020 and GR0500030. Two of them are karstic and the third is granular.

The data used for the long term average conditions for the present state (1961-1990) are obtained from the River Basin Management Plan of Epirus which used the model of rain-runoff MikeSHE. To estimate the average conditions for the future state (2021-2050) we used the range of -25% to +25% at a step of 5%. Regarding water demand, the River Basin Management Plan of Epirus provides water demand data for irrigation purposes for Corfu Island using a methodology to estimate the water needs for crops following the method Blaney-Griddle for the organized collective irrigation networks. Drinking water demand is based either in actual data of consumption from the water utilities or in a theoretical estimation based on population and the assumption for personal water consumption. The water demand data are average values from 1990-2010. The scenarios examine the water demand variations from -25% to +25% with a step of 5% for the three aquifers. The same percentage variations (from -25% to + 25%) are also examined for water natural recharge.

The results show that in all three aquifers the water inflow is greater than water demand in all cases. In aquifer GR0500010 water inflow values range from 56.25 (-25% variation) to 93.75 (+25% variation) hm3/year while water demand values range from 5.175 (-25% variation) to 8.625 (+25% variation) hm3/year. In aquifer GR0500020 water inflow values range from 30 (-25% variation) to 50 (+25% variation) hm3/year while water demand values range from 5.25 (-25% variation) to 8.75 (+25% variation) hm3/year. In aquifer GR0500030 water inflow values range from 30 (-25% variation) to 50 (+25% variation) hm3/year while water demand values range from 10.8 (-25% variation) to 17.28 (+25% variation) hm3/year.

(References: River Basin Management Plan of Epirus – Deliverable 3 and River Basin Management Plan of Epirus – Deliverable 8)

In the following Table 3.70 the methodology and models that were used by FBs for obtaining the change in water resources availability due to CC are extracted from FBs' reports.

Table 3.70: Methodology/models used for modeling CC impact on water resources availability in period 2021-2050 on test areas

Test area	Water resource type	Methodology/models
Isonzo/Soča plain	Water resources on which the methodology has been applied are mainly phreatic waters in a porous aquifer.	The water cycle: $P = Et + R + I$ (P - precipitations, Et - evapotranspiration, R - runoff, I - effective infiltration). The Evapotranspiration (ET) was quantified as "crop evapotranspiration" calculated with the two-step approach as the product between the reference evapotranspiration and the crop coefficient Kc. To calculate the reference evapotranspiration, the Hargreaves formula was used. The surface runoff (R) has been defined using the Curve Number (CN) methodology modified by Williams (1995) to fit the long-term analysis. The effective infiltration (I) component was calculated as difference between precipitation, evapotranspiration and runoff.
ATO 3	springs, wells, lakes	Qualitative assessment of CC impact on WR.
Ostuni	groundwater	The methodology to evaluate climate change impacts on renewable water resources may be summarized as follow: - GW recharge was simulated for the reference period 1961-1990 by implementing the distributed hydrological model G-MAT; - Long-term average of GW recharge is considered as the characteristic water resources availability; - Using the simulated monthly time series of GW recharge the simplified SPEI-Q model was calibrated and validated to establish a functional relationship between GW recharge and the climate observations for P and T; - The SPEI-Q relationship calibrated for the reference period (1961-1990) was then used to evaluate GR recharge scenarios for the adopted climate change scenarios for the period 2021-2050; the climate input for the SPEI-Q model was determined using the delta-method estimated from climate change statistics between reference observations and scenarios.

Northern Istria - springs Sv.Ivan, Gradole and Bulaž	springs	The water balance elements were defined using two different approaches: the first one proposed by Turc (1954) and the second one by Langbein (1962). Empirical models by Turc and Langbein modified and developed for GIS application. Estimation of the spatial distribution of the average annual runoff can be done, using both the Turc and Langbein methods. Specific run-off was calculated according to the Langbein and Turc methods.
Southern Dalmatia - spring Prud and Blatsko polje	spring and wells	Same as for test area Northern Istria - springs Sv.Ivan, Gradole and Bulaž.
Drini basin	rivers (river basin)	A monthly water-balance model is used. This model, referred as the Thornthwaite monthly water-balance program, is used to examine changes in monthly flow regimes, in average seasonal and annual runoff. The WatBal model is an integrated water balance model developed for assessing the impact of climate change on river basin runoff. The water-balance model analyses the allocation of water among various components of the hydrologic system using a monthly accounting procedure based on the methodology originally presented by Thornthwaite. Inputs to the model are mean monthly temperature, monthly total precipitation, runoff factor, direct runoff factor, soil-moisture storage capacity, latitude of location, rain temperature threshold, snow temperature threshold, and maximum snow-melt rate of the snow storage. The output components are: effective precipitation, potential evapotranspiration, total modeled runoff (direct, surface, subsurface runoff and base flow). The first regression model is based only on the relation rainfall-runoff from the data of the Drini catchment’s area. For all the river basins the sensitivity of average annual runoff to changes in average rainfall was expressed by the same regression: $$\frac{R_1}{R_0} = \left(\frac{P_1}{P_0}\right)^{1.44}$$ Where the subscripts 0 and 1 refer to current and future conditions respectively.
Nikšić	Water balance is calculated for the whole drainage area, and not separately for 3 drinking water sources (karst springs Gornji Vidrovan, Donji Vidrovan, Poklonci)	The simplified water balance approach in drainage basin for drinking water source is applied for the assessment of available water resources under conditions of climate change. For the whole drainage area water balance is calculated as difference between precipitation volume and ETP to assess roughly available water resources. Following equations are used in calculations for water resources availability for present and future scenarios: $P = ETP + Q\ (10^6\ m^3 / year)$

	since delineation of recharge areas do not exist.	$Q = Q_{srf} + Q_{gw}$ *(10^6 m^3 / year)* Q_{srf} *is runoff volume* Q_{gw} *is quantity available for aquifer recharge= Q *EIC* *EIC = 0.65 (effective infiltration coefficient)* *A= 310 km^2*
Corfu island	Three aquifers (GR0500010, GR0500020 and GR0500030) - two of them are karstic and the third is granular.	The methodology to estimate the average annual runoff in the river basin of each river and lake water body was based on the analysis of all the necessary hydro meteorological data. Then the model of rain-runoff MikeSHE was used. The model's results are the water balances of the river basins. The basic equation for natural conditions: $P + GIN = ET + RF + GOUT \pm \Delta S + \varepsilon$ Where: P is the precipitation, OL is the surface runoff, BF is the basic runoff, ET is the actual evapotranspiration, ΔS is the change in storage in aquifers, GOUT is the volume of the groundwater that came out of the basin, GIN is the groundwater volume that entered the basin, the coefficient of surface runoff CD=(OL+BF)/P and ε is the total error of simulation incorporated in the quantity ΔS. The basic hypothesis of the model is that at the end of simulation all the water volume in the aquifers is presented as basic runoff. The values of the average annual natural runoff come out for each surface water body basin. The data used for the long term average conditions for the present state (1961-1990) are obtained from the River Basin Management Plan of Epirus which used the model of rain-runoff MikeSHE. To estimate the average conditions for the future state (2021-2050), the range of -25% to +25% at a step of 5% was used.

According to the common methodological approach explained in chapter 3.1. the basic hydrological information for the evaluation of the climate change on water resources for average conditions for all test areas were calculated and the results are presented in Table 3.71. For all test areas average conditions are defined as characteristic renewable water resources except for test areas in Croatia. Analyses carried in Croatian test areas covered mean annual discharge and lowest mean monthly discharge, so extreme conditions were also analysed (Table 3.72).

For test area Isonzo plan as input parameter for the WR has been used the Isonzo/Soča average discharge. The +/- 20% has been calculated only for the effective infiltration on the study area.

For test area Corfu island to estimate the average conditions for the future state (2021-2050), the range of -25% to +25% was used.

Table 3.71: Basic hydrological information for the evaluation of the climate change on water resources for AVERAGE CONDITIONS

Country	Test area	WR (m³/s)				Changes in future (2021-2015) compared to baseline (1961-1990) in %		
		1961-1990	2021-2050					
			RegCM3	Aladin	Promes	**RegCM3**	**Aladin**	**Promes**
Italy	Isonzo plain	41.6	44.2	49.3	37.7	**6.3**	**18.5**	**-9.4**
	Ostuni- Adriatic	6.23	5.81	4.84	4.61	**-6.7**	**-22.3**	**-26.0**
	Ostuni - Ionic	5.24	4.86	4.80	3.46	**-7.3**	**-8.4**	**-34.0**
Croatia	N. Istria – Gradole	2.17	2.13	2.08	2.00	**-1.9**	**-4.1**	**-7.8**
	N. Istria –Sv. Ivan	0.92	0.92	0.86	0.60	**-0.3**	**-6.5**	**-34.9**
	N. Istria – Bulaž	1.70	1.56	1.55	2.22	**-6.3**	**-8.8**	**30.8**
	S. Dalmatia - Prud	6.16	5.60	5.39	5.01	**-9.1**	**-12.5**	**-18.7**
	S. Dalmatia - Blatsko polje	0.287	0.259	0.235	0.222	**-9.8**	**-18.1**	**-22.6**
Montenegro	Nikšić	1.26	0.88	0.89	0.86	**-30.2**	**-29.4**	**-31.75**
Albania	Drini basin – Drini river	(1951-1985) 360	340	310	290	**-5.6**	**-13.9**	**-19.4**
	Drini basin – Buna	(1951-1985) 320	305	290	275	**-4.7**	**-9.4**	**-14.1**
	Drini basin – Drini+Buna	(1951-1985) 680	645	600	565	**-5.1**	**-11.7**	**-16.8**
	Drini basin – Drini of Lezha	(1951-1985) 30	27	25	22	**-10**	**-16.7**	**-26.7**
Greece	Corfu - GR0500010	2.38	1.78-2-97			-25 to +25		
	Corfu -GR0500020	1.27	0.95-1.59			-25 to +25		
	Corfu -GR0500030	1.27	0.95-1.59			-25 to +25		

Table 3.72: Basic hydrological information for the evaluation of the climate change on water resources for CHARACTERISTIC RENEWABLE WATER RESOURCES

Country	Test area	WR (m³/s)				Changes in future (2021-2015) compared to baseline (1961-1990) in %		
		1961-1990	2021-2050					
			RegCM3	Aladin	Promes	**RegCM3**	**Aladin**	**Promes**
Croatia	N. Istria – Gradole	0.86	0.80	0.81	0.75	**-7.2**	**-5.6**	**-13.1**
	N. Istria –Sv. Ivan	0.42	0.42	0.39	0.17	**-0.5**	**-8.4**	**-60.3**
	N. Istria – Bulaž	0.32	0.28	0.28	0.45	**-11.4**	**-11.2**	**41.2**
	S. Dalmatia - Prud	3.36	3.13	3.05	2.92	**-6.8**	**-9.2**	**-13.1**
	S. Dalmatia - Blatsko polje	0.043	0.042	0.040	0.039	**-2.3**	**-7.0**	**-9.3**

Table 3.73: Qualitative assessment of CC impact on water resources availability

Country	Test area	Qualitative assessment CC impact on WR	
Italy	Marche	Climate change tend to favour and/or reinforce gravitational and flood phenomena already widespread in the test area and, consequently, to limit infiltration and groundwater recharge.	Mountain aquifers: effective recharge 400 – 1000 mm/year

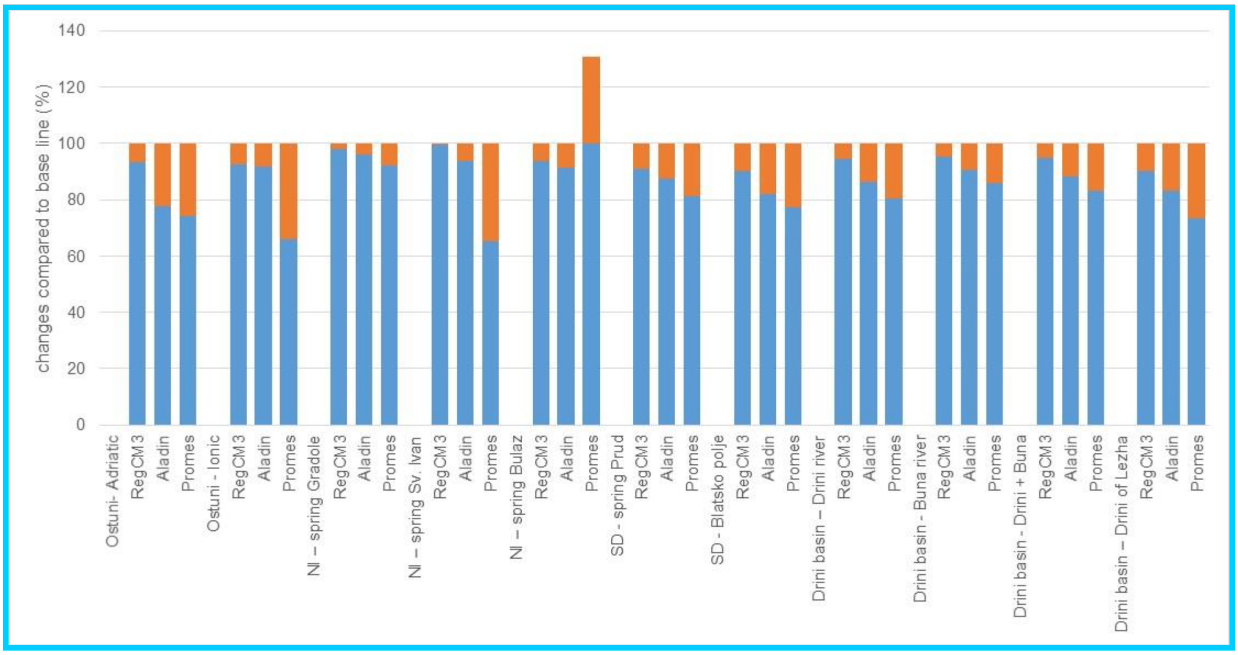


Figure 3.57: Changes in average flow and recharge for the future period 2021-2050 (orange) compared to the 1961-1990 baseline period (blue+orange)

From Tables 3.71 and 3.72 and Figures 3.57 and 3.58 it can be concluded that the test areas in the North (e.g. Northern Istria) show lower changes than those in the Southern part of the Adriatic Region (Southern Dalmatia, Ostuni, Drini Basin). The highest changes in water availability can be noticed in use of the Promes model, after that Aladin, and the lowest changes by the RegCM3 climate model.

On Figure 3.59 climate change impact on water resources in Adriatic region on selected test areas are presented for average conditions and for characteristic renewable water resources (the second column for test areas in Croatia).

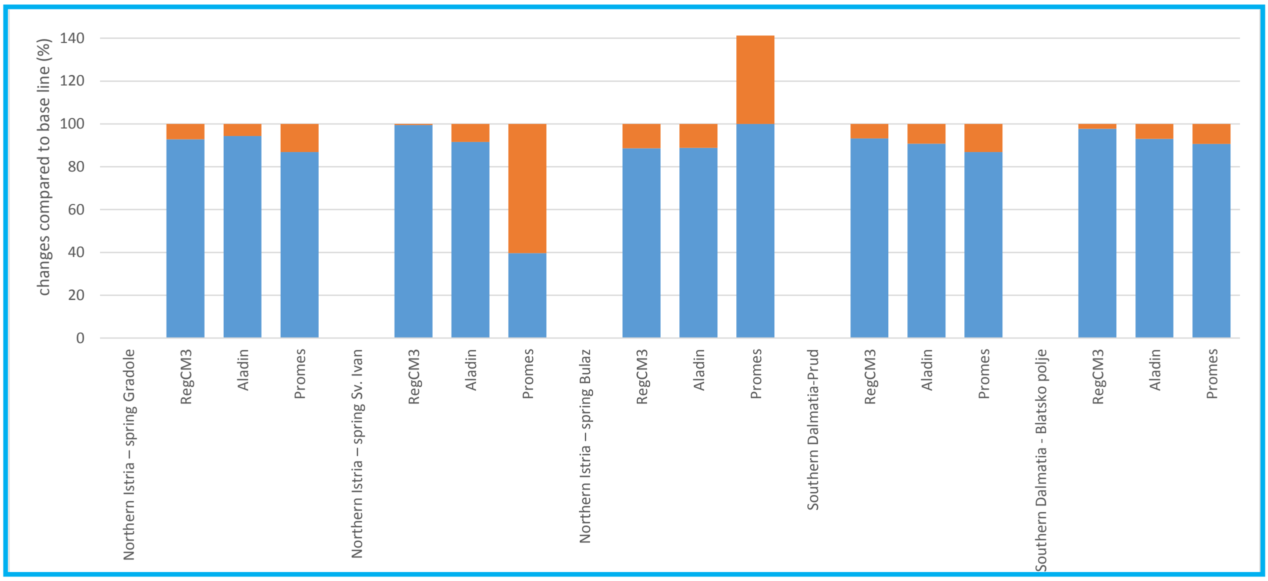
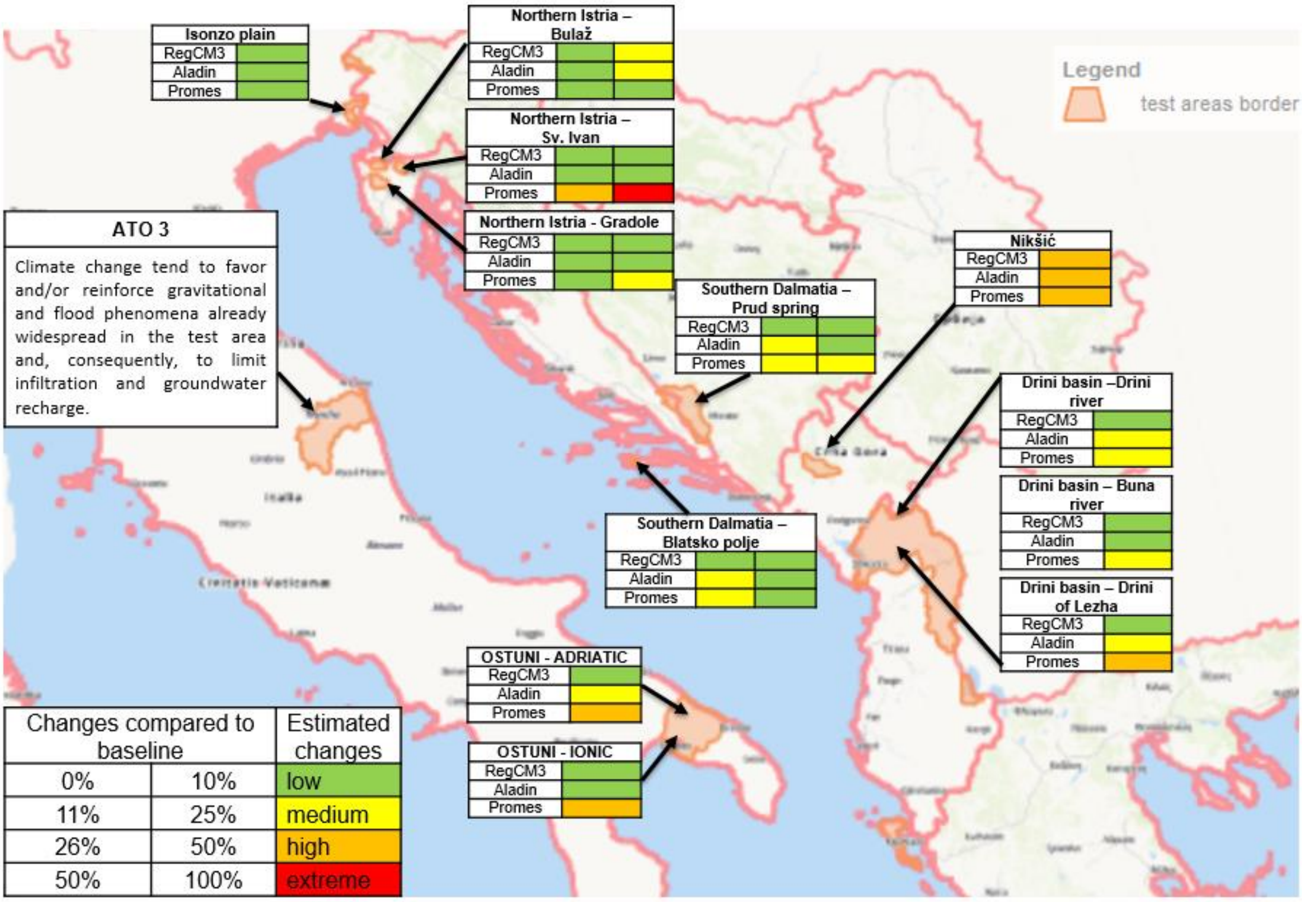


Figure 3.58: Changes in characteristic renewable water resources availability for the future period 2021-2050 (orange) compared to the 1961-1990 baseline period (blue+orange)



ATO 3

Climate change tend to favor and/or reinforce gravitational and flood phenomena already widespread in the test area and, consequently, to limit infiltration and groundwater recharge.

Changes compared to baseline		Estimated changes
0%	10%	🟩 low
11%	25%	🟨 medium
26%	50%	🟧 high
50%	100%	🟥 extreme

Figure 3.59: Climate change impact on WR for average conditions and characteristic renewable water resources (the second column for test areas in Croatia)

4. EVALUATION OF WATER DEMAND AND CALCULATION OF WATER EXPLOITATION INDEX

4.1. COMMON METHODOLOGY

Sensitivity and vulnerability of water supply depends on the water exploitation level and available water resources. To analyze the risk in test areas WEI was selected. WEI is the ratio of the water demand (WD) and renewable water resources (WR):

$$WEI = WD / WR$$

Total water demand consists of drinking water, water for irrigation, industry and ecological water demand. Although, the common practice is to determine water exploitation index using the total water use, in this case, WEI for drinking water was also calculated on some test areas.

FBs had to calculate the total demand and if possible drinking water demand in test areas. It was agreed that water demand should be calculated for three scenarios:

- scenario 0 (WD_0): present water demand
- scenario 1 (WD_1): future water demand 1 (present water demand increased by 25%)
- scenario 2 (WD_2): future water demand 2 (present water demand decreased by 25%)

Four different combinations of water demand scenarios and renewable water resources (average conditions - AC and characteristic renewable water resource – CRWR from table 3) were considered:

- $WEI_1 = WD_0 / WR_{1961-1990}$
- $WEI_2 = WD_0 / WR_{2021-2050}$
- $WEI_3 = WD_1 / WR_{2021-2050}$
- $WEI_4 = WD_2 / WR_{2021-2050}$

This assessment should have some threshold values to define different stages of vulnerability or risk. Following the classification defined in the previous project CCWaterS (www.ccwaters.eu), 70% exploitation rate has been selected for indicating strong risk (instead of the usual 90% a lower threshold is applied, considering a 20% decrease because of the uncertainty related to water dependent ecosystems) and 50% for indicating possible difficulties, so thresholds for defining risk based on the WEI that are applied are:

- Low risk ≤0.50 (green),
- Possible difficulties 0.51-0.70 (yellow),
- Strong risk 0.71-1.00 (orange),
- Not sustainable >1.00 (red).

4.2. ITALY

4.2.1. ISONZO/SOČA PLAIN

From Annex 1:

For the preparation of the report, were developed procedures that permitted to reach an adequate estimation of the wells withdrawals and their quotes divided among the different aquifer systems and for each different type of use and then compared to the available literature (Granati et al., 2000). In particular on the available datasets two different protocols were adopted: one for the wells subjected to licence (drinking, agricultural, fish breeding, industrial, hygienic, geothermal and other minor uses) and another for the estimated domestic wells (Treu, 2011).

For these purposes has been necessary to identify and evaluate the following characteristics: number of captures and their distribution on the territory, tapped aquifers, main uses and the effective consumptions. In order to define for each well the tapped aquifer systems were used the intersection between the depth of the screens, or the total depth, and the 3D model of the aquifers. The well withdrawals amount were evaluated on annual base for recent periods and are expressed as m^3/s.

Regard the wells subjected to license, useful information has been derived from a census done in Friuli Venezia Giulia Region starting from 2004 (ISTAT, 2001). It allowed to have good quality data on location, total depth, screen depth and licensed discharges. Using the screen depth, when available, or the total depth, it has been possible to assign the tapped aquifer. Additional information from water-meter consumption has been collected. All the data collected, even if of good quality, were anyway subjected to a validation protocol. The known wells are almost all the existing ones and therefore the analyzed number can be considered representative of the real situation.

Only for the wells without water-meter attributes, a reducing coefficient was assigned to the licensed discharge in order to estimate the real consumption. For each use, the coefficient value was evaluated according to the available water-meter data.

For the agricultural use, a value of 10% of the licensed discharge was assigned. This corresponds to 37 day of use per year and represents the irrigation period concentrated in summertime. For the drinking use, a value of 56% was assigned corresponding to an effective use of 13,5 hours per day. The fish breeding are active during all the year to maintain the correct water recharge and freshness, for this reason a value of 100% was assigned. For the industrial use, a value of 26% was assigned corresponding to 6.5 hours/day at full discharge.

Concerning the hygienic use, several uses are converging into this item (e.g. anti-fire). The estimation assigned a value of 7%.

Geothermal wells are active all over the year and so was considered a value of 100 % of the licensed discharge.

Concerning the other minor uses, the estimation assigned a value of 100 %.

Knowing the licensed discharges, the percentage of effective use of each well and the corresponding tapped aquifer it has been possible to estimate the withdrawals amount divided by type of use and aquifer systems (Figure 4.1 and Figure 4.2).

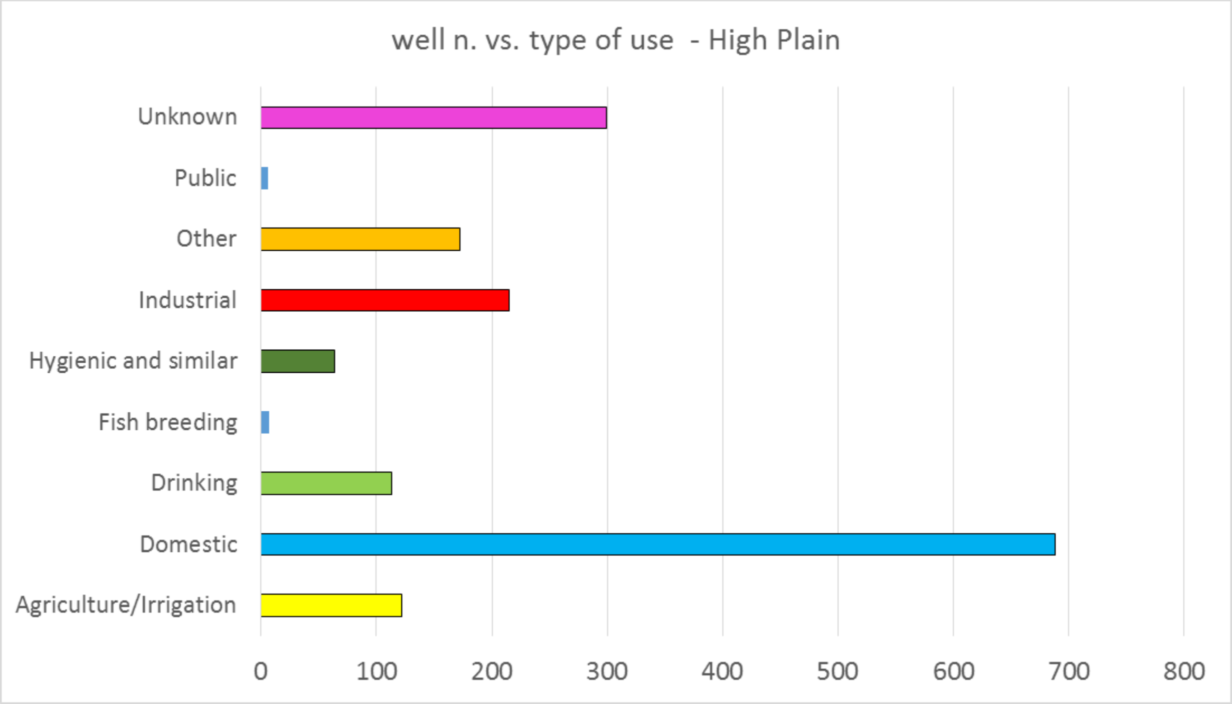


Figure 4.1: Number of well divided by type of use and computed on the Drinkadria test area – High Plain.

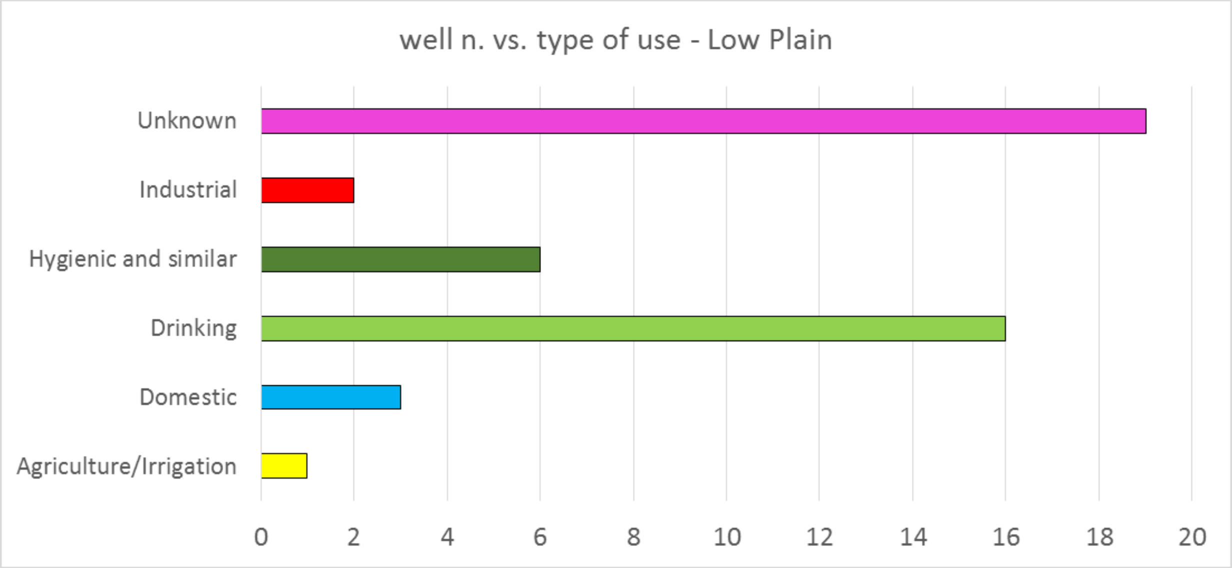


Figure 4.2: Number of well divided by type of use and computed on the Drinkadria test area – Low Plain.

Regard domestic wells, in the Plain are widely present private wells being part of the local culture. Their density and withdrawals vary from area to area, function of the geographical distributions of the settlements, of the type of aquifer (phreatic or artesian), the depth to water, the groundwater quality, the distance to the coast or the development of the pipe aqueduct network. Several are, in fact, the municipalities unprovided by an aqueduct network.

In particular, a huge amount of domestic wells characterizes the Low Plain. South of the resurgence belt, withdrawals are mainly interesting the shallower artesian aquifer systems (A, B and C) and have continuous flow seen that are naturally gushing wells and generally not equipped with discharge reducers. Accordingly, the withdrawals are far higher than the real demands of the population. The flow freely waters, as a rule, discharges to the sea, through the irrigation canals drainage network or are influent for the shallow phreatic waters.

North of the resurgence belt instead, the water well withdrawals for strictly domestic use has always been not widespread seen that the depth to water is higher and the water might be extracted only using submersible pumps. In recent years, this practice has further mainly reduced due to the depletion, over time, of the water quality and due to the realization of a widespread aqueduct network. The use is therefore discontinuous and withdrawals are closely linked to the real water demand.

For the evaluation of the withdrawals, has been necessary to estimate and determine the following variables:

- the total number of wells and their widespread on the territory (obtained also using data from the *XIV general census of population and houses* – ISTAT, 2001);
- the coefficients (concerning consumptions for the phreatic wells and discharge for the artesian ones) to be adopted for the withdrawals calculation;
- the sharing volume rates of the water withdrawals in the different aquifer systems.

In total were estimated 1733 wells for all the uses in the DRINKADRIA test area: 1686 in the High Plain and 47 in the Low Plain (Figure 4.1).

For the withdrawals evaluation, first it was necessary to distinguish between wells located north of the resurgence belt, considered all phreatic, and the ones located south of it, considered all confined. Of course, these assumptions are partially forced, but necessary to simplify the calculation.

With regard to phreatic wells were considered the number of persons using a domestic well with an average *per capita* consumption, set equal to 290 liters per day.

With regard to the artesian wells, to compute the withdrawn amount were used the mean discharge seen that withdrawals are completely independent from the actual water demand. Based on the data surveyed in the last decades by the Servizio Gestione Risorse Idriche of the FVG Region and from literature (GEOS, 1994; Granati et al., 2000) has been estimated a mean discharge per artesian well of 0.8 l/s. From the data present in the implemented geodatabase, using the screen depth when available or the total depth, it has been possible to assign the withdrawal rate for each artesian aquifer. From the realized analysis it came out that 80% of the wells are tapping the aquifer A, 10% the aquifer B, 2% the C, 4% the D, 2% the E, 1% the F and 1% the G.

The total amount of groundwater withdrawals in the Plain basin was obtained adding wells subjected to license withdrawals to domestic withdrawals. More than 50% of the withdrawals are due to the domestic wells.

The total withdrawals from the phreatic aquifer of the High Plain of the Isonzo/Soča river are 1,55 m^3/s. The total withdrawals amount from the confined aquifer systems of the Low Plain are 2,27 m^3/s.

In the High Plain part of the withdrawals concern the phreatic aquifer, in the Low Plain instead, almost 75% of the withdrawals are in the shallower aquifer systems named A and B. Most part of the withdrawals are for domestic/potable drinking purposes. In the High Plain, approximately 25% of the total withdrawals are instead for agricultural uses.
With this estimation, a detailed water budget was computed as presented in Figure 4.3.

Table 4.1: Withdrawals in the Friuli Venezia Giulia Region, with a focus on the DRINKADRIA test area, subdivided by aquifer systems and by type of use

High Plain / Low Plain	Aquifer	Main use	m^3/s	Total m^3/s	
High Plain	FAP	DOMESTIC	0,0425	1,5401	1,5795
	FAP	HYGIENIC AND SIMILAR	0,0220		
	FAP	INDUSTRIAL	0,1777		
	FAP	IRRIGATION/AGRICULTURE	0,0326		
	FAP	FISH BREEDING	0,0798		
	FAP	POTABLE	0,2683		
	A	HYGIENIC AND SIMILAR	0,0014		
	A	INDUSTRIAL	0,0457		
	A	IRRIGATION/AGRICULTURE	0,0006		
	A	POTABLE	0,2023		
	B	POTABLE	0,2830		
	C	HYGIENIC AND SIMILAR	0,0007		
	C	POTABLE	0,1438		
	D	POTABLE	0,2397		
Low Plain	FBP	DOMESTIC	0,0045	0,0394	
	FBP	HYGIENIC AND SIMILAR	0,0004		
	A	HYGIENIC AND SIMILAR	0,0010		
	A	POTABLE	0,0335		

Table 4.2: Withdrawals in the Isonzo/Soča High Plain area, subdivided by aquifer type and main use. FAP= Phreatic High Plain. A, B, C, D are the different aquifer systems recognized in the southern part of the High Plain

High Plain / Low Plain	Aquifer	Main use	m^3/s	Total m^3/s
High Plain	FAP	DOMESTIC	0,0515	1,5491
	FAP	HYGIENIC AND SIMILAR	0,0220	
	FAP	INDUSTRIAL	0,1777	
	FAP	IRRIGATION/AGRICULTURE	0,0326	
	FAP	FISH BREEDING	0,0798	
	FAP	POTABLE	0,2683	
	A	HYGIENIC AND SIMILAR	0,0014	
	A	INDUSTRIAL	0,0457	
	A	IRRIGATION/AGRICULTURE	0,0006	
	A	POTABLE	0,2023	
	B	POTABLE	0,2830	
	C	HYGIENIC AND SIMILAR	0,0007	
	C	POTABLE	0,1438	
	D	POTABLE	0,2397	

Table 4.3: Withdrawals in the Isonzo/Soča Low Plain area, subdivided by aquifer type and main use

WATER BODY	MAIN USE	n° withdrawing points	m^3/s
LOW PLAIN	DOMESTIC	2383	1,92
	GEOTHERMAL	3	0,01
	HYGIENIC AND SIMILAR	61	0,02
	INDUSTRIAL	7	0,02
	IRRIGATION/AGRICULTURE	110	0,18
	FISH BREEDING	7	0,05
	POTABLE	18	0,07
Total		2589	2,27

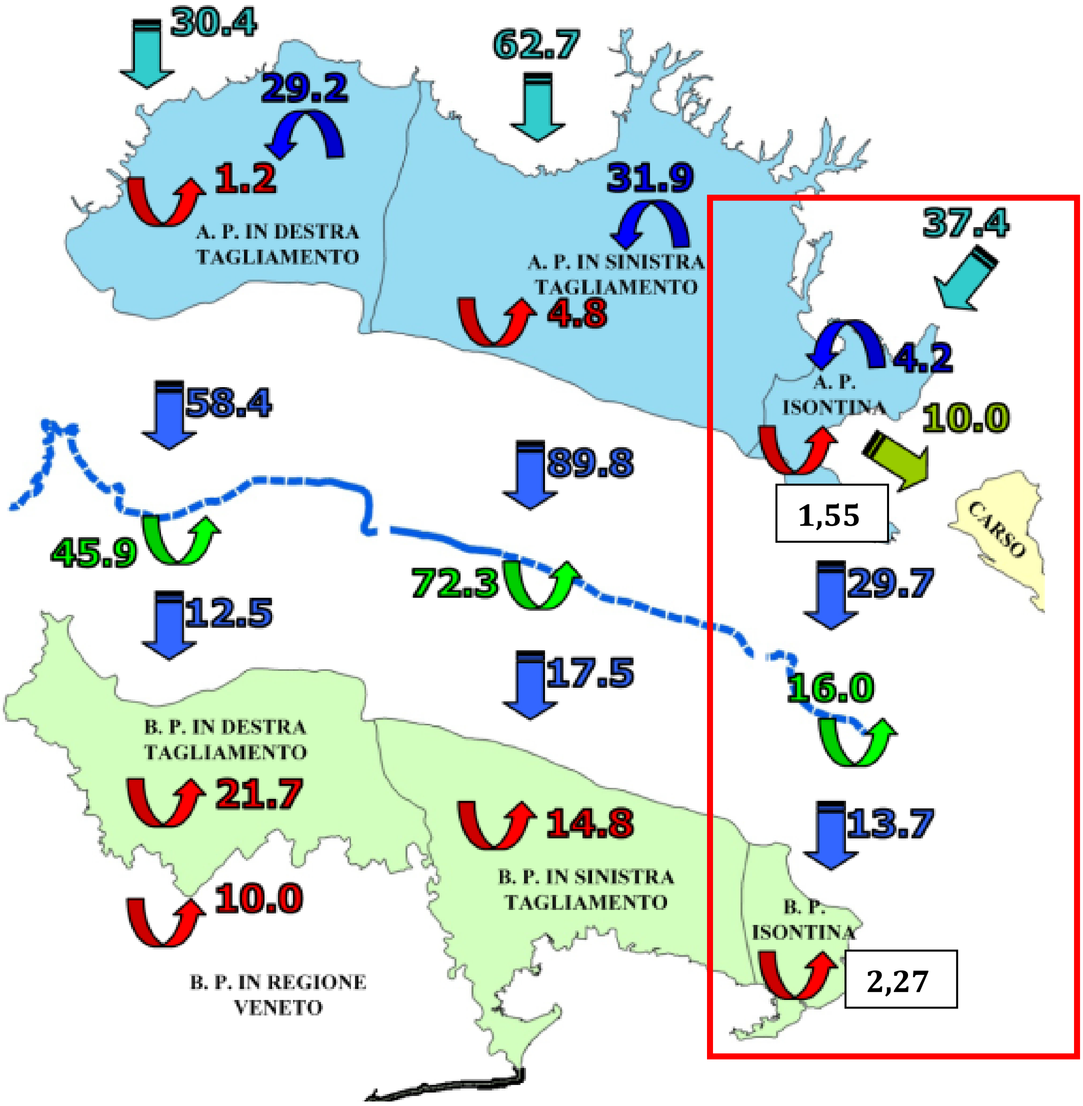


Figure 4.3: Water budget in the Friuli Venezia Giulia Low Plain. Red arrows represent the water withdrawals considering all the uses. The discrepancy in the withdrawn numbers is due to the updated resurgence belt position, located now northern than in 2010

To verify the sustainability of the actual and future use of the water resource, a speed screening analysis on the water demand has been realized.

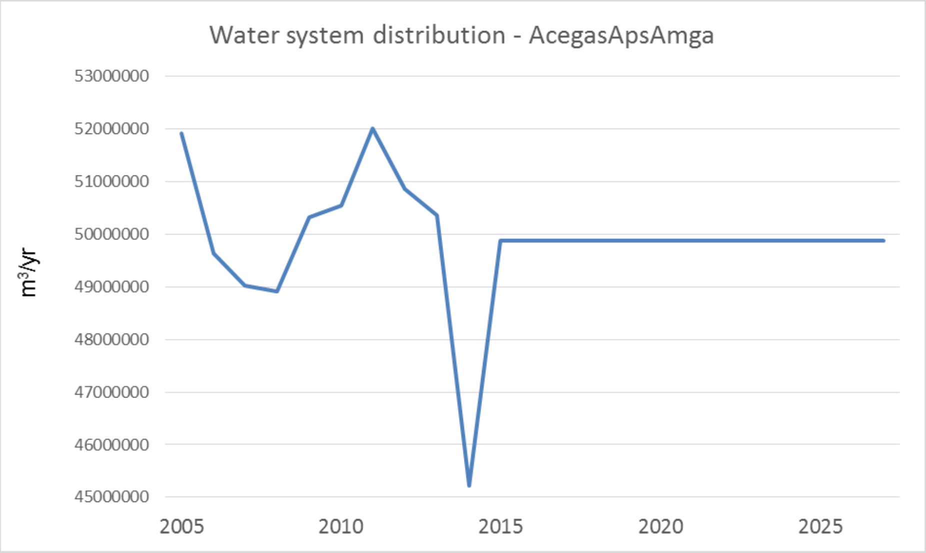


Figure 4.4: Estimated mean annual discharges elaborated for the Financial Plan by CATO TS to calculate the consumer price.

In parallel, ISTAT FVG (Dominutti & Abatangelo, 2008) in 2008, elaborated a report indicating the inhabitants growth with forecast scenarios up to 2050, by province (ISTAT, 2015).

Table 4.4: Residents in Friuli Venezia Giulia by province – expectation 2008 – 2050 (Dominutti & Abatangelo, 2008).

	Udine	**Gorizia**	**Trieste**	**Pordenone**
2007	531.603	141.229	236.512	303.258
2008	534.653	142.380	236.646	308.373
2009	537.015	143.324	236.466	312.940
2010	538.691	144.071	235.992	316.912
2015	543.851	146.681	232.696	334.169
2020	546.404	148.365	229.264	349.261
2030	547.725	150.440	223.720	374.849
2040	546.054	151.733	219.967	395.909
2050	540.321	151.720	216.455	410.745

Water demand has been measured for the period 2005-2014, while it is estimated in the period between 2015-2027. Estimations are given by the mean value of the preceding decade. 2027 is the year of the end of the license so, the Piano d'Ambito (Area Plan) is ending contextually with it. The Area Plan, economic and financial, elaborated for the costs and rates computation, is developed by AcegasApsAmga and later approved by CATO (Consulta d'Ambito Territoriale Ottimale).

Figure 4.5: Residents by province: index number comparison (2007=100) – expectation 2008-2050 (Dominutti & Abatangelo, 2008).

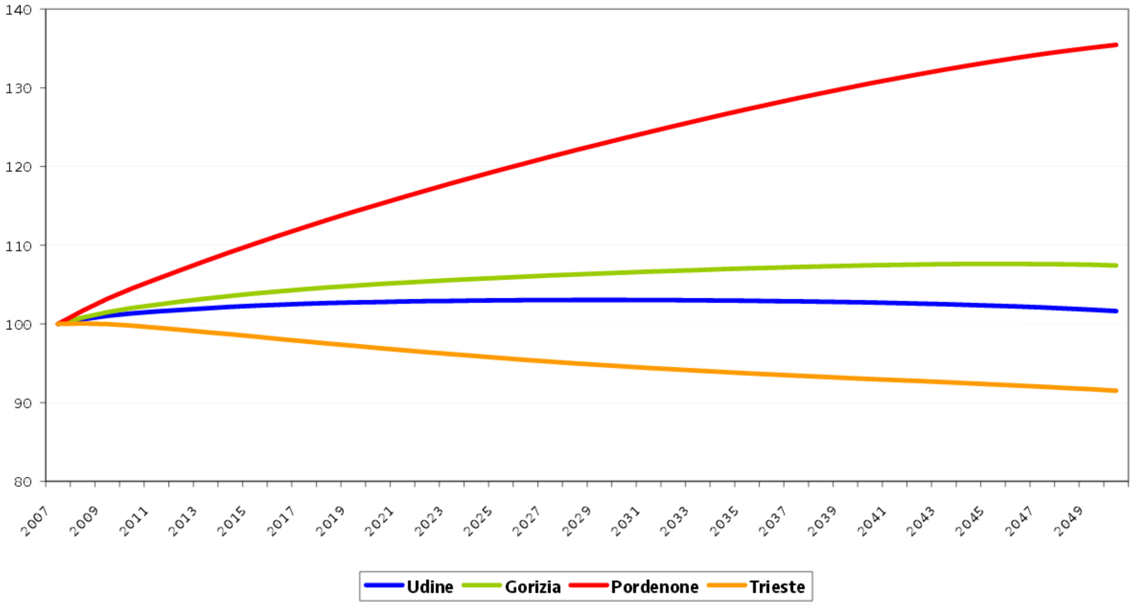


Figure 4.6: Gorizia province: analysis of the changes – expectation 2008-2050 (Dominutti & Abatangelo, 2008).

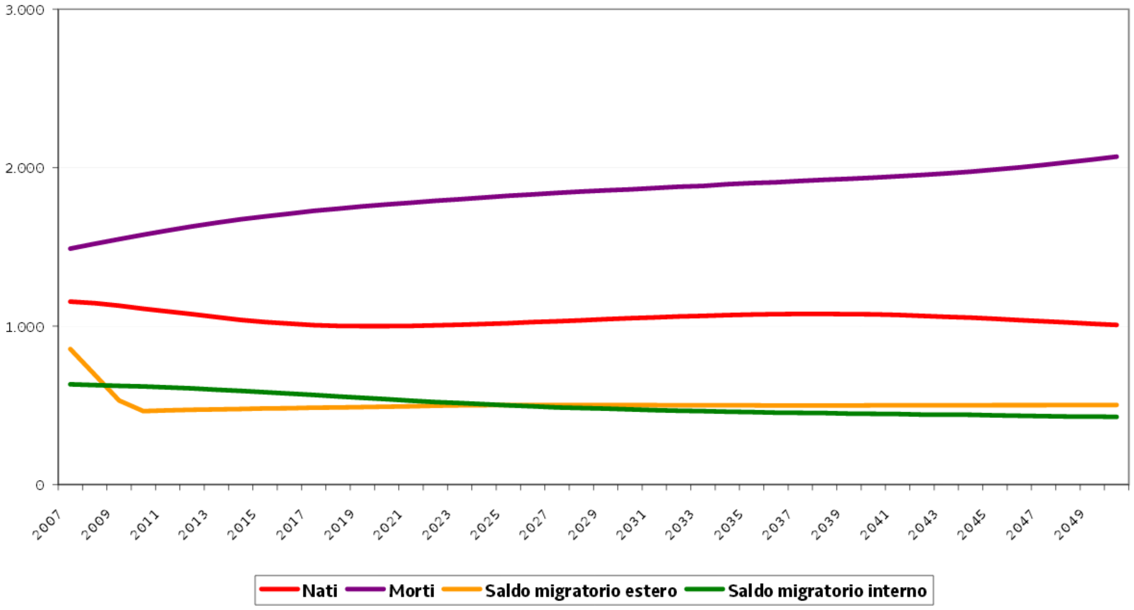
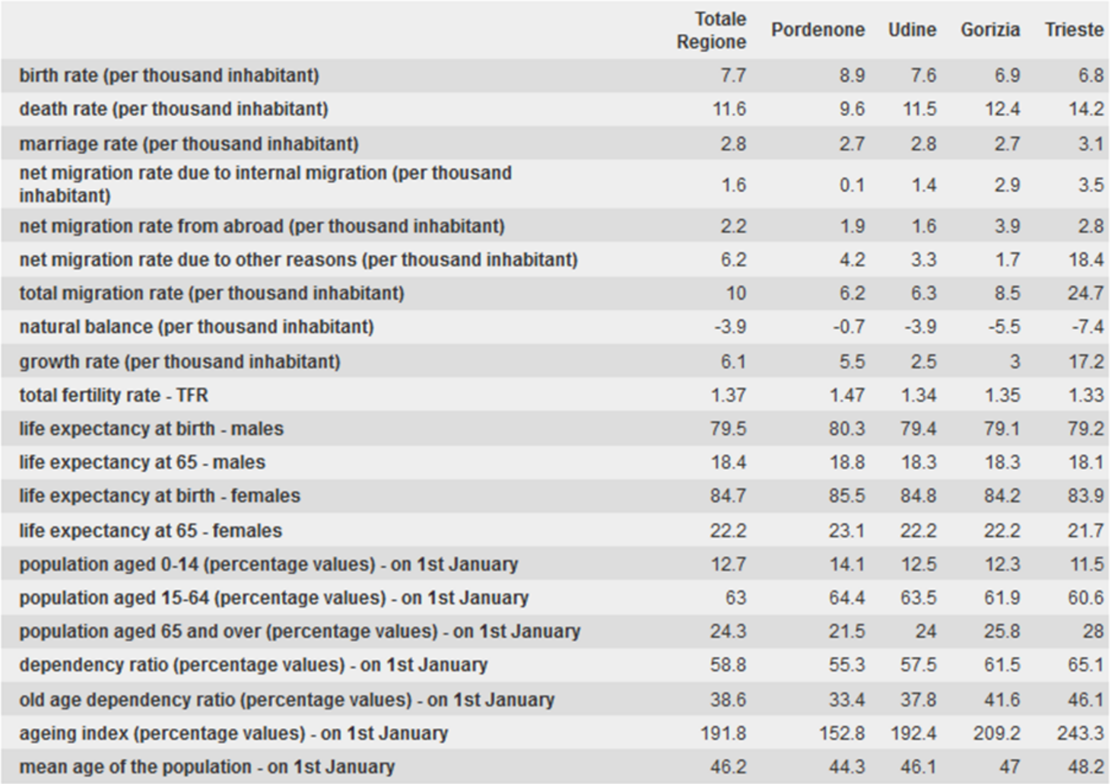


Table 4.5: Demographic indicators by province - Year 2013 (ISTAT web site, 2015)



	Totale Regione	Pordenone	Udine	Gorizia	Trieste
birth rate (per thousand inhabitant)	7.7	8.9	7.6	6.9	6.8
death rate (per thousand inhabitant)	11.6	9.6	11.5	12.4	14.2
marriage rate (per thousand inhabitant)	2.8	2.7	2.8	2.7	3.1
net migration rate due to internal migration (per thousand inhabitant)	1.6	0.1	1.4	2.9	3.5
net migration rate from abroad (per thousand inhabitant)	2.2	1.9	1.6	3.9	2.8
net migration rate due to other reasons (per thousand inhabitant)	6.2	4.2	3.3	1.7	18.4
total migration rate (per thousand inhabitant)	10	6.2	6.3	8.5	24.7
natural balance (per thousand inhabitant)	-3.9	-0.7	-3.9	-5.5	-7.4
growth rate (per thousand inhabitant)	6.1	5.5	2.5	3	17.2
total fertility rate - TFR	1.37	1.47	1.34	1.35	1.33
life expectancy at birth - males	79.5	80.3	79.4	79.1	79.2
life expectancy at 65 - males	18.4	18.8	18.3	18.3	18.1
life expectancy at birth - females	84.7	85.5	84.8	84.2	83.9
life expectancy at 65 - females	22.2	23.1	22.2	22.2	21.7
population aged 0-14 (percentage values) - on 1st January	12.7	14.1	12.5	12.3	11.5
population aged 15-64 (percentage values) - on 1st January	63	64.4	63.5	61.9	60.6
population aged 65 and over (percentage values) - on 1st January	24.3	21.5	24	25.8	28
dependency ratio (percentage values) - on 1st January	58.8	55.3	57.5	61.5	65.1
old age dependency ratio (percentage values) - on 1st January	38.6	33.4	37.8	41.6	46.1
ageing index (percentage values) - on 1st January	191.8	152.8	192.4	209.2	243.3
mean age of the population - on 1st January	46.2	44.3	46.1	47	48.2

Actually, after the last data analysis, the demographic indicators highlight a small increase in the growth rate calculated per thousand inhabitant (3 Gorizia; 2.5 Udine; 5.5 Pordenone; 17.2 Trieste). So data proposed by CATO of an almost constant water demand in the future years, can be defined a good approximation of the future scenarios.

One of the aim of the DRINKADRIA project is to define the water demand on pilot areas for drinking water and for total uses (drinking, irrigation, industry, ecological water demand) and to define three different possible scenarios. Scenario 0 represents the state of the art; Scenario 1 corresponds to a +25% of water demand; Scenario 2 represents instead a -25% of water demand.

Using the available data, a simple addition and subtraction has been realize in order to obtain the numbers expressed in Table 4.6. For the investigated area, in the High Plain, an increase in the withdrawals of the 25% will not affect the resources and the actual uses.

For the present research, the impact of climate change on the availability of water has been evaluated by comparing the predicted characteristics of the periods 2021-2050 with those corresponding to the baseline period (1961-1990). The evaluation included (i) climatic parameters (scenarios) used for the hydrological modelling, (ii) main hydrological characteristics, (iii) renewable water resources, (iv) calculation of the exploitation index. In the case of Isonzo/Soča pilot area, a porous aquifer was studied. Compared to the karstic ones, it has large buffer capacity being characterized by long-term averages recharge from precipitation.

Table 4.6: Water demand calculated for the present and future possible scenarios in the Isonzo/Soča test area expressed as m^3/s and subdivided between High Plain (HP) and Low Plain (LP).

	HP	**LP**	**TOT**
Scenario 0: State of the art	1,54 m^3/s	2,27 m^3/s	3,81 m^3/s
Scenario 1: +25%	1,92 m^3/s	2,84 m^3/s	4,76 m^3/s
Scenario 2: -25%	1,15 m^3/s	1,70 m^3/s	2,85 m^3/s

In these conditions, changes in renewable water resources can be considered equal to those of average conditions. Thus in this area are directly studied the renewable water resources. As expected, from the Table 4.7, emerges a satisfactory situation in all the Climate Change defined scenarios. The WEI indexes always remain under the value of 0,5, threshold identified by the CC-Water European Project showing a very low risk. Only a value of 0,02 separates the total from the drinking use indicating that most part of the withdrawn waters from wells are used for drinking purposes.

Table 4.7: Exploitation indexes of water resources in the test area: state of the art and future scenarios.

WEI (1)			WEI (2)		WEI (3)		WEI (4)	
Total use	Drinking water		Total use	Drinking water	Total use	Drinking water	Total use	Drinking water
0.45	0.06	RegCM3	0.45	0.06	0.46	0.05	0.43	0.08
		Aladin	0.45	0.06	0.46	0.04	0.43	0.08
		Promes	0.44	0.05	0.45	0.04	0.42	0.08

4.2.2. ATO3

From Annex 2:

ATO3 Test Area population is 356.185 inhabitants (ISTAT, 2011). The amount of drinking water supplied by Utilities distribution network is around 31,2 Mm^3/year. This water is mostly supplied by carbonate aquifers springs or abstracted from wells located in the alluvial plains and in a smaller part from an artificial reservoir located in the Northern part of the area.

The standard of supply service for drinking use is generally very good, with very few restrictions related to drought periods.

Water service main features, concerning water abstraction for drinking purposes, are summarized in the following table:

Table 4.8: ATO 3 Water Service main features

Utility	**Municipalities (n.)**	**Population (inhabitants)**	**Water abstraction (1.000 x m^3)**			
			Springs	**Wells**	**Reservoirs**	**Total**
Acquambiente M.	4	27.703	1.569	216	7.284	9.069
Astea	8	109.676	-	9826	-	9.826
APM	8	113.731	1460	4923	-	6.383
ATAC Civitanova	1	40.217	-	3691	-	3.691
ASSEM	1	13.018	1600	46	-	1.646
ASSM	5	25.589	1560	78	-	1.638
Other (Municipalities)	21	26.251	12878	160		13.038
Total	**48**	**356.185**	**19.067**	**18.940**	**7.284**	**45.291**

Out of around 31,2 Mm^3/year drinking water total consumption, the share of water consumption for touristic use, supplied by the same WSS, can be estimated in 1,8 Mm^3/year.

Concerning agricultural use, total irrigation demand is estimated in about 30 Mm^3/year. It is mostly satisfied through groundwater abstraction, by existing private wells and pumping systems, and through surface water reservoir an supply network, operated by the Regional Consortium.

Concerning the industrial water use, even if it is very hard to obtain official data, the total annual consumption can be estimated around 12,7 Mm^3, mostly supplied by private wells and just for around 4 Mm^3 by drinking water supply systems and Utilities' distribution network.

The increasing trend of population in Marche region, according to censuses from 1861 to 2011 in given in the chart below (Figure 4.7).

Figure 4.7: Population in Marche Region, 1861-2011 (ISTAT)

Marche Region Waterworks Plan predictions concerning population trends, taking into account data and elaborations of the Italian National Institute of Statistics (ISTAT), are based on the cohort component model and on the calculated trends in the period 2001-2011 (+ 8,1%). An estimation of growth of the population for ATO 3 Area is given in the table below:

Table 4.9: ATO 3 Population and Trend (2001-2011) and estimation for the next periods

Population 2001	Population 2011	Trend 2001-2011	Population 2025	Trend 2011-2025	Population 2050	Trend 2011-2050
329.641	356.185	+ 8,1%	391.804	+10%	424.929	+19,3%

Future water demand forecasts are based on resident population and tourism data, not taking into account water needs for agriculture, farming and industrial use, which can have alternative sources of supply.

Table 4.10: Optimal Territorial Areas (Marche Region) current and future water demand

ATO	Qmin (l/s)	Population (2011)	Q per capita (l/s)	Q 2025 (l/s)	Q 2040 (l/s)
ATO 1	1.339	362.583	375	2.019	2.173
ATO 2	2.012	403.827	400	2.247	2.338
ATO 3	1.683	356.185	375	2.048	2.191
ATO 4	500	120.180	350	681	711
ATO 5	995	298.544	350	1.608	1.657
Total	**6.529**	**1.541.319**	**375**	**8.603**	**9.070**

In Table 4.10 a summary of present total and per capita flow rate, compared to population, and forecasts concerning total needed flow rates in 2025 and 2050 are given.

According to the most recent forecasts concerning population trends in Marche Region, the number of inhabitants in the Test Area (about 330.000 people, nowadays) will increase up to around 425.000 people expected in 2050, so determining a consequent increase in water demand, from present about 1.700 l/s up to about 2.100 l/s in 2040.

In ATO 3 Test Area, as in many other Italian regions, groundwater represents the major source of “water intended for human consumption”. Deep groundwater resources, well protected by natural filters, can guarantee wholesome and good quality water and a safe supply. Safeguard measure are anyhow very important as the extensive and, often, unplanned land use could represent a serious danger.

The increase in population and the apparent increase in the frequency of the "drought" seasons, especially observed in the last decade, represent the most critical aspects associated with the qualitative and quantitative maintenance of water resources needed to satisfy the growing demand in the various fields of use (drinking water, agriculture, industry).

Although lack of accurate data (as already mentioned several times) makes it difficult to provide a detailed quantitative evaluation of the available water resources in the whole ATO 3 territory and about the origin of these resources, it is possible - based on bibliographic data as well as on unpublished data - to define homogeneous areas from the point of view of the water potential and of their possible use. In the "Map of the potentially exploitable areas" (Figure 4.8) in scale 1: 100.000, four classes of areas with different vocation have been distinguished:

1) Areas with high water potential, higher than the current exploitation
2) Areas with high water potential, with low or no exploitation
3) Areas with high water potential, mainly exploitable with abstracting wells.
4) Areas characterized by widespread aquifers with limited water potential, but overall exploitable for alternative uses.

The areas with high potential, higher than the current exploitation, are mainly located within the carbonate ridges. They are characterized by the presence of a fair number of abstraction points, mainly used for potable purposes, supplying the majority of the water supply networks of the area. The analysis carried out, concerning the involved hydrogeological structures and the considerations relating aquifers recharge volumes, lead to assume that the currently abstracted water quantities are still considerably less than the water potential availability. Local, specific hydrogeological condition (aquifers cut by the direction of the main drainage axes along the valleys) makes these points the most suitable ones for planning new exploitations or increase water supply (in case of existing abstraction points).

The areas with high water potential, with low or no exploitation, similar to the previous ones from the hydrogeological characteristics point of view, only differs from them for the fact of being minimally exploited. Published data show that some springs (no longer in use), also providing abundant flow rates, were present and used to feed water supply systems in the past. Even these areas could be used for the increase of the water resource intended for potable purposes.

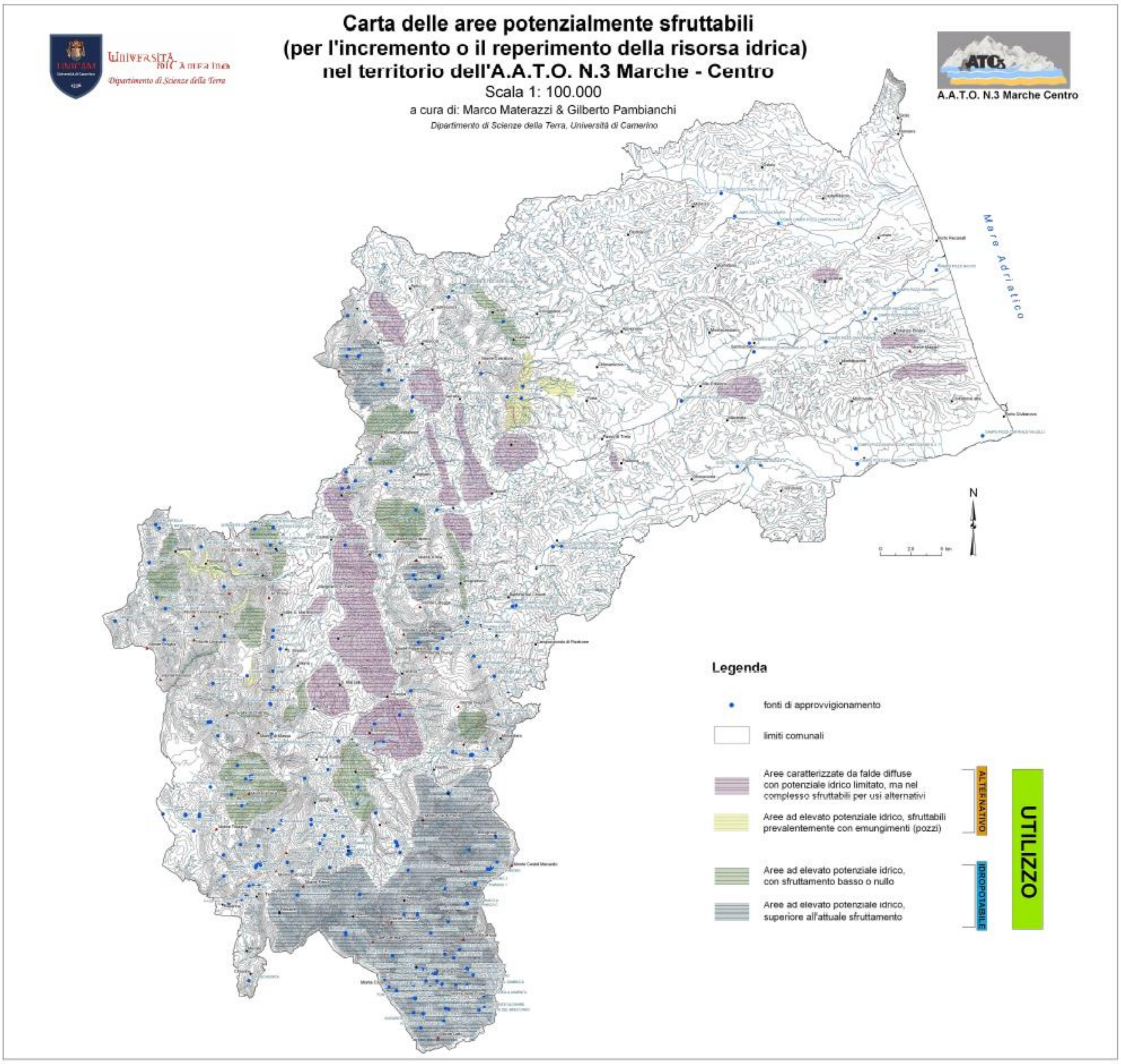


Figure 4.8: Map of the potentially exploitable areas

The areas with high water potential, mainly exploitable with abstracting wells, are predominantly located in floodplains or in the border areas, close to the calcareous ridges. The aquifers found in the recent alluvial terraces are recharged from the surrounding carbonate structures. In some cases the geomorphological evolution of some flood plains lead to the creation of multi-layered systems of great potential, with also some artesian confined aquifers, containing groundwater under pressure. Further studies should be planned, in order to quantify the real water potential of these peculiar aquifers and, in parallel, to determine quality parameters, for a better planning of the water resource exploitation and their more suitable intended use.

4.2.3. OSTUNI

From Annex 3:

The number of inhabitants in the test area is 568,959 according to the 2008 census (Table 4.11) and the drinking water consumption supplied by the regional water company AQP is estimated in 66 Mm^3/year. This water volume is mostly supplied by a system of interconnected artificial reservoirs located outside the Apulia region with a minor component coming from two karst spring located in Campania region.

Table 4.11: Drinking water demand at municipality level including doth resident and touristic water uses

MUNICIPALITY	**Sub-area**	**AREA [km^2]**	**Inhabitants 2008**	**Households (population) water use [Mm3/yr]**	**Touristic water use [Mm^3/yr]**	**Touristic/ Household**
LOCOROTONDO	ADR	48	14.167	1,563	0,004	0,2%
CAROVIGNO	ADR	106	16.050	1,696	0,216	12,8%
CEGLIE MESSAPICO	ADR	131	20.706	2,229	0,012	0,6%
CISTERNINO	ADR	54	11.914	1,344	0,020	1,5%
FASANO	ADR	130	38.460	4,429	0,200	4,5%
LATIANO	ADR	55	15.072	1,693	0,000	0,0%
OSTUNI	ADR	223	32.428	3,578	0,469	13,1%
SAN MICHELE SALENTINO	ADR	26	6.372	0,644	0,000	0,0%
SAN VITO DEI NORMANNI	ADR	66	19.947	2,239	0,010	0,4%
MARTINA FRANCA	ADR	297	49.525	5,155	0,059	1,1%
FRANCAVILLA FONTANA	ION	176	36.603	4,055	0,004	0,1%
VILLA CASTELLI	ION	35	9.059	0,899	0,003	0,4%
CAROSINO	ION	11	6.553	0,634	0,000	0,0%
CRISPIANO	ION	111	13.502	1,429	0,001	0,1%
FAGGIANO	ION	20	3.519	0,335	0,000	0,0%
GROTTAGLIE	ION	104	32.835	3,551	0,011	0,3%
LEPORANO	ION	15	7.551	0,628	0,062	9,8%
MONTEIASI	ION	10	5.484	0,542	0,000	0,0%
MONTEMESOLA	ION	16	4.190	0,409	0,000	0,0%
MONTEPARANO	ION	4	2.354	0,229	0,000	0,0%
PULSANO	ION	18	10.788	1,145	0,071	6,2%
ROCCAFORZATA	ION	47	1.845	0,164	0,000	0,0%
SAN GIORGIO JONICO	ION	23	16.014	1,710	0,002	0,1%

TARANTO	ION	265	194.021	25,729	0,237	0,9%
TOTALS		**1992**	**568.959**	**66,031**	**1,382**	**2,1%**

The water consumption for touristic use is 1.4 Mm^3/year and is mostly supplied by the same water system described above.

The standard of supply service for drinking use is very good with few restrictions occurring during drought periods (every 6-8 years on average). Some pressure failures are observed during peak touristic season in summer.

Concerning the irrigation use, the pilot area is mostly occupied by agricultural land (olive, vine grape, fruit trees, wheat and vegetables) with irrigated crops covering about 220 km^2. The total irrigation demand is estimated in 78 Mm^3/year (about 3,500 m^3/ha). Irrigation demand is fully based on groundwater with both private and collective pumping wells. Groundwater pumping is mostly concentrated along the coastal areas covering an ideal strep having width between 10 and 15 km from the sea. Concerning the industrial water use supplied by groundwater, the estimated annual water withdrawal is 4.2 Mm^3 mostly supplied by private wells. The above figure characterizing water demand for the Ostuni test area are reported in Table 2.3. The test area with the main hydrogeological features is represented in the Figure 4.9.

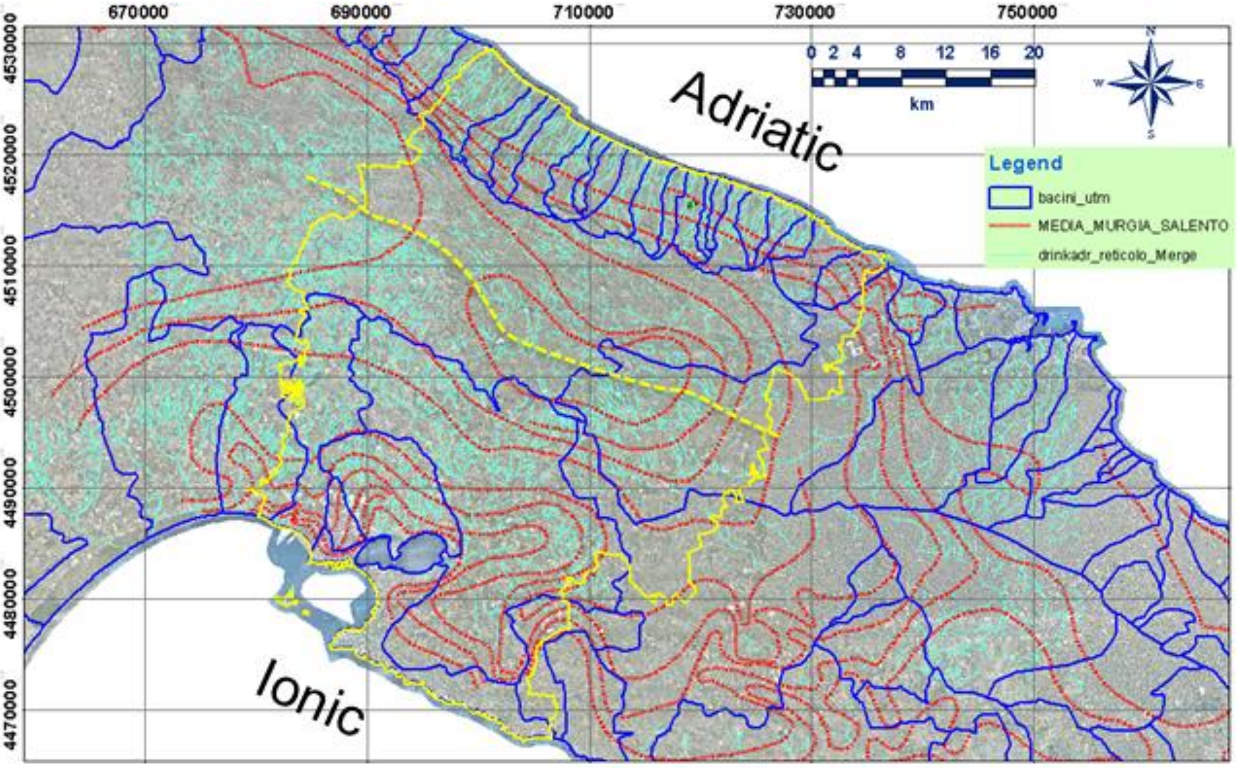


Figure 4.9: Ostuni test area with focus on groundwater resources and spatial distribution of piezometric heads showing the two sub-domains, Ostuni-Adriatic and Ostuni-Ionic, used for the assessment of present and future groundwater availability.

The total water demand on the GW systems of the Ostuni test areas, WD, is given by the different components reported above, but should also include the so called ecological water demand, also known as environmental flow, which is a very crucial step in the case of GW management studies:

WD = drinking water + irrigation + industry + ecological water demand

To be sustainable, GW use should ensure that a certain percentage of recharge is left for the remaining GW services such as feeding the base flow of streams, preventing seawater intrusion, conserving wetlands, and so on. For such reasons, defining GW sustainability strategies is an urgent need in many regions around the world where aquifer exploitation was developed far above the natural renewal rates. Beyond hydrological evaluations, GW sustainability strategies should be assessed from an interdisciplinary perspective, where ecology, geomorphology, climatology and socio-economic issues play an important role (Portoghese et al. 2013). Community involvement is essential for the success of long-term GW management strategies in which setting specific goals for GW use requires a shared understanding of the fragility of the resource.

Concerning groundwater equilibrium in the selected test area, the estimated mean annual recharge is 382 Mm^3, while mean annual groundwater exploitation is 78.1 Mm^3, corresponding to an overall groundwater exploitation around 20%. This value may be considered very unsafe for coastal aquifers for which an adequate discharge to the sea is the only way to contrast seawater intrusion.

Due to the well-known uncertainty related to the groundwater dynamics in coastal karst aquifers, and consequent limitations of available hydrogeological models, the regional authority for water resources protection has set very restrictive standards for the so called sustainable GW use for each aquifer system of the region. In quantitative terms, the allowable GW use is set between 25 and 40% of long-term average GW recharge, depending on the hydrogeological features of the system. This prudential assumption is equal to a GW environmental flow standard (i.e. ecological water demand) ranging between 60% and 75% of the long-term average GW recharge, this latter being equal to the CWR.

Based on such definitions for GW environmental flow, the water balance and sustainability conditions for the two sub-domains were evaluated, including the Water Exploitation Index (WEI) given by the ratio between WD and CWR (Table 4.12). Though GW use for drinking purposes is minimal in the test area, the sum of GW environmental flow with GW irrigation is the cause of high degree of exploitation for the two sub-domains. In Table 4.12 the so called GW safety margin is also reported, which represent the residual exploitability of GW resources, showing remarkable difference between the two sub-domains.

Results for WEI(2) and WEI(3) are dependent on the adopted climate model simulation and therefore produce multiple evaluations.

A complete evaluation of WEI scenarios corresponding to the Ostuni-Ionic sub-domain is reported in Table 4.13 for the three climate change scenarios and the two WD scenarios.

Table 4.12: GW balance components for the Ostuni test area including WEI estimates for the reference period

SUB-DOMAIN	**OSTUNI-ADRIATIC**		**OSTUNI-IONIC**	
WB COMPONENT	**Mm^3**	**m^3/s**	**Mm^3**	**m^3/s**
CWR	**196.45**	**6.23**	**165.37**	**5.24**
ENV. GW. FLOW	147.33 (75% CWR)	4.67	99.22 (60% CWR)	3.15
SUST. GW. USE	49.11	1.56	66.15	2.10
GW. IRR	15.39	0.49	57.73	1.83
GW. INDUSTIAL	2.00	0.06	2.20	0.07
GW. DRINKING	0.87	0.03	0.19	0.00
GW. SAFETY. MARGIN	30.85	0.98	6.03	0.19
GW. TOT. ABS	18.26	0.56	60.12	1.91
TOT. DRINKING	24.57	0.78	41.46	1.31
WD=DRK+IRR+IND+ENV	**165.59**	**5.25**	**159.34**	**5.05**
WEI = WD/CWR	**0.84**	**0.84**	**0.96**	**0.96**

Table 4.13: Water Exploitation Index scenarios for the Ostuni-Ionic sub-domain in comparison with the present WEI evaluations

Adopted models	**WD 0**	**WD 1**	**WD 2**
G-MAT (1961-1990)	WEI (1) = 0.96	WEI (1, WD1) = 1.20	WEI (1,WD2) = 0.72
SPEI-Q (1961-1990)	WEI (1) = 0.98	WEI (1, WD1) = 1.23	WEI (1,WD2) = 0.73
RegCM3 (2021-2050)	WEI (2) = 1.04	WEI (3) = 1.30	WEI (4) = 0.78
ALADIN (2021-2050)	WEI (2) = 1.05	WEI (3) = 1.31	WEI (4) = 0.79
PROMES (2021-2050)	WEI (2) = 1.45	WEI (3) = 1.82	WEI (4) = 1.09

The Ionic sub-domain of the Ostuni test area, whose results are reported in table 4.13, represents the most vulnerable system, having a present WEI equal to 0.96. In particular, in the first two lines of the Table 4.13 the WEI values for the reference period 1961-1990 are reported based on GW recharge simulations given by the distributed hydrological model G-MAT and the simplified multiregressive model SPEI-Q adopting in both cases climate observations as input. As expected WEI estimates for reference climatic conditions are similar for both of the two hydrological models and in all the three WD scenarios.

The WEI estimations for the three future climate scenarios were evaluated by running the SPEI-Q model using the three climate simulations as input. The three models, which predict increasingly dry climate (from RegCM3 to PROMES), produced remarkable worsening of the WEI with increase from +4% to +45% when the present water demand (WD 0) is considered. As far as concerns the adopted WD scenarios, the 25% reduction in total WD seemed to be a suitable adaptation target in order to restore the reduced GW recharge due to altered precipitation and temperature of climate change scenarios.

Table 4.14: Water Exploitation Index scenarios for the Ostuni-Adriatic sub-domain in comparison with the present WEI evaluations

Adopted models	**WD 0**	**WD 1**	**WD 2**
G-MAT (1961-1990)	WEI (1) = 0.84	WEI (1, WD1) = 1.05	WEI (1,WD2) = 0.63
SPEI-Q (1961-1990)	WEI (1) = 0.85	WEI (1, WD1) = 1.07	WEI (1,WD2) = 0.64
RegCM3 (2021-2050)	WEI (2) = 0.90	WEI (3) = 1.13	WEI (4) = 0.68
ALADIN (2021-2050)	WEI (2) = 1.08	WEI (3) = 1.35	WEI (4) = 0.81
PROMES (2021-2050)	WEI (2) = 1.13	WEI (3) = 1.42	WEI (4) = 0.85

Less prone to shortage conditions appears the Adriatic sub-domain of the Ostuni test area (Table 4.14), whose current WEI (under current water exploitation) is estimated from G-MAT equal to 0.84 and from the SPEI-Q model equal to 0.85. The WD1 increasing demand scenario under present climate conditions leads to a slight imbalance between demand and recharge to the aquifer, with values of WEI equal to 1.05 and 1.07 from G-MAT and SPEI-Q, respectively.

As for the Ionic area, the three RCM scenarios taken into account leads to different results: RegCM3 forecast possible shortages only in case of a water demand increasing (WEI = 1.13 under RegCM3 and WD1 scenarios); on the other hand, the Aladin and Promes RCM scenarios, both forecasting a decreasing trend in precipitation, by 4.9% and 6.7%, respectively, lead to a small imbalance between recharge to aquifer and exploitation under the current water demand (WEI = 1.08 and 1.13); such an imbalance significantly increases if the increased demand scenario WD1 is taken into account. As for the Ionic area, the 25% reduction in total WD seemed to be a suitable adaptation target in order to restore the reduced GW recharge.

However, while the WEI value is less than 1 adopting the RegCM3 scenario and the present WD, Aladin and Promes scenarios forecast an increase of the WEI values of 8% and 13% respectively.

Indeed, the objective of the research done was not to precisely quantify some projections of the future changes, but rather to establish a framework for water resource evaluation and management which will also take account of the potential changes in their hydrological determinants. It is to be expected in particular that an appropriate environmental flow will have to be evaluated and ensured in coastal karst aquifers in order to effectively contrast sea water intrusion and preserve as much as possible the only local water resource from quantitative and qualitative deterioration.

4.3. CROATIA

4.3.1. NORTHERN ISTRIA - SPRINGS SV. IVAN, GRADOLE AND BULAŽ

From Annex 5:

Public water supply in the Istria County covers over 95% of the population. Drinking water is distributed by three main water supply companies, covering three water supply areas (Figure 4.10):

- Istarski vodovod d.o.o. (Water Utility of Istria Ltd.) covers northern and western part of Istria County,
- Vodovod Pula d.o.o. covers south Istria, and
- Vodovod Labin d.o.o. covers eastern part of Istria County.
- In Slovenian part of Istria, water is supplied by Rižanski vodovod Koper d.o.o.

Water Utility of Istria is the largest among the three water supply systems, by the covered land area, infrastructure, population, number of people with access to drinking water, and the total water demand.

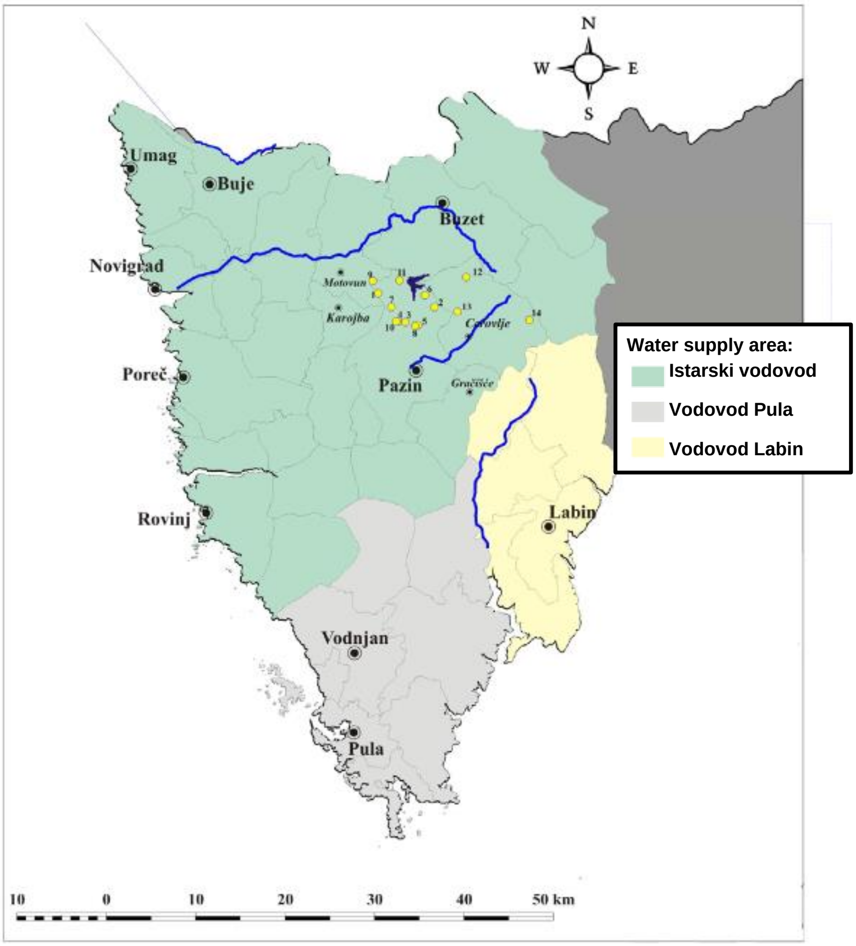


Figure 4.10: Water supply areas in Istria County (Istria County Zoning Plan, SNIŽ, 13/12)

Water supply in Northern Istria County is managed by company *Water Utility of Istria*, located in the City of Buzet. They distribute drinking water to 7 cities and 21 municipalities, they cover the land area of 1872 km^2, with population of 98.794 (99.3%) connected to public water supply system.

Water Utility of Istria prominently uses three main karst springs; Sv. Ivan, Gradole and Bulaž which is used as a back-up water abstraction site. Butoniga reservoir, with a volume of 20 million m^3, is also a major part of water supply system, but it is not taken in consideration as a part of the present assessment.

Gradole spring is the most significant groundwater spring of the Istrian water supply system. Approximately 0.469 m^{3}s^{-1}is abstracted on average for water supply. The highest average abstractions are associated with the periods of the strongest water demand, in July and August, when the spring has sufficient yield, mostly in the range between 0.7 and 0.8 m^{3}s^{-1}, sometimes even up to 0.9 m^{3}s^{-1}. The maximum daily abstractions under favorable hydrological conditions even exceed 1.1 m^{3}s^{-1}. Some water from this source is also delivered to neighbouring Slovenia to improve water supply to its coastal region. According to financial agreement *Water Utility of Istria* uses 0.5 m^{3}s^{-1}, *Vodovod Pula d.o.o.* 0.2 m^{3}s^{-1}, and *Rižanski vodovod Koper d.o.o.* 0.3 m^{3}s^{-1}.

Approximately 0.167 m^{3}s^{-1} on average is abstracted from main Sv. Ivan spring for water supply. The highest abstractions are also associated with the periods of the strongest water demand, in July and August, when the spring has sufficient yield, and they mostly exceed 0.2 m^{3}s^{-1}. The maximum daily abstractions under favourable hydrological conditions reach as much as 0.3 m^{3}s^{-1}.

Bulaž spring is a back-up water abstraction site of the Istrian water supply system and is put into exploitation by conveying the abstracted quantities to Gradole spring. Since the second half of 2012, water has been also conveyed through a newly built branch pipeline to the water treating plant of Butoniga reservoir. Since 1989, only app. 0.01 m^{3}s^{-1} has been abstracted for water supply. However, during extremely dry 2012, the average monthly abstraction amounted to 0.17 m^{3}s^{-1} in July and August, when such significant quantities were ensured by seasonal abstraction of its static water reserves.

Water demand in test area of Northern Istria was assessed using a simplified approach based on the measured data of overflown, abstracted and total discharges at Sv. Ivan, Gradole and Bulaž springs combined, for the period 1991 - 2012. Systematic hydrological observations at the analyzed springs in the Mirna river basin started in the late 1980s. They include monitoring of water level fluctuations, overflow discharges, abstracted quantities and total yields (overflow discharges + abstracted quantities). They are implemented by the Croatian Meteorological and Hydrological Service in cooperation with the water supply company exploiting the springs, Water Utility of Istria.

The assessment of water demand can be systemized in following four steps:

1. Statistical analysis of long-term data of karst springs Gradole, Sv. Ivan and Bulaž in Mirna basin

   The average monthly overflow data and abstracted quantities data of each spring in Mirna basin (Sv. Ivan, Gradole, Bulaž), for the period 1991 – 2012, was combined (summarized) in one data set. A basic statistical analysis of long-term data of combined average monthly overflow discharges and abstracted quantities was performed (minimums, means, maximums, standard deviation, and variation coefficient). The analyzed data was used to calculate and analyze annual and inter-annual distribution and trends.

2. Estimation of proportion of drinking water in total water use:

The proportion of drinking water use in total water use must be assessed accordingly for each test area and its specific characteristics. For Northern Istria test area this assessment was based on measured decrease in water demand during the extremely dry summer of 2012.

In the July of 2012 extremely unfavourable hydrological conditions and critically low discharges at karst springs in Istria resulted in mandatory water restriction. This year had a character of a low water event with a return period between 100 and 200 years (Faculty of Civil Engineering Rijeka, 2013). When the 1st degree water restriction is declared, water use is forbidden for irrigation and washing of transportation vehicles, buildings, commercial areas, public streets, etc. During this time, in Istria County, an average decrease in water use of 15% was observed (Ministry of Agriculture, 2012). This can be considered as a good indication of proportion of drinking water use in total water use for this test area, and this value was used in further analyses:

$$\textit{Drinking Water Use} = (100\% - 15\%) \times \textit{Total Water Use} \qquad (1)$$

3. Choosing appropriate statistical parameter representing water demand for Average Conditions and Characteristic Renewable Water Resources cases:

Climate change assessment of water resources was calculated separately for Average Conditions and for Characteristic Renewable Water Resources, for each of the karst springs Gradole, Sv.Ivan and Bulaž. Furthermore, average annual inflow and lowest average monthly inflow were select as representative statistical parameters for those two cases, respectively.

Appropriate statistical parameters of water demand must also be selected, for comparison to water resource data:

a) For Average Conditions, an average annual abstracted quantity was selected.
b) For Characteristic Renewable Water Resources several statistical parameters of abstracted quantities were considered; average annual discharges, long-term mean of annual maximums of monthly averages, long-term mean of seasonal (summer) monthly averages and long-term mean of a characteristic monthly averages (July or August, in this case). In case of Northern Istria test area the statistical parameter long-term mean of August monthly averages was select as representative for this case.

4. Calculation of Water Demand Scenarios

Water demand for Average Conditions and for Characteristic Renewable Water Resource, was calculated for three scenarios, one for present water use, and two for future water use scenarios.

Monthly averages of abstracted quantities from all three springs, Gradole, Sv. Ivan and Bulaž, in the Mirna river basin were analyzed. The distribution and trends of the average annual abstracted quantities and lowest and highest average monthly abstracted quantities of all springs combined are presented below (Figure 4.11). Although there has been a slight increase in population in Istria County over the observed period, a downward trend in water demand is noticeable in the same period. This can be explained by a raised awareness of more sustainable water consumption among the population, which caused a lower per capita water use. Furthermore, water losses have been reduced in the past few years, and infrastructure upgraded, which also contributed to lower water abstraction.

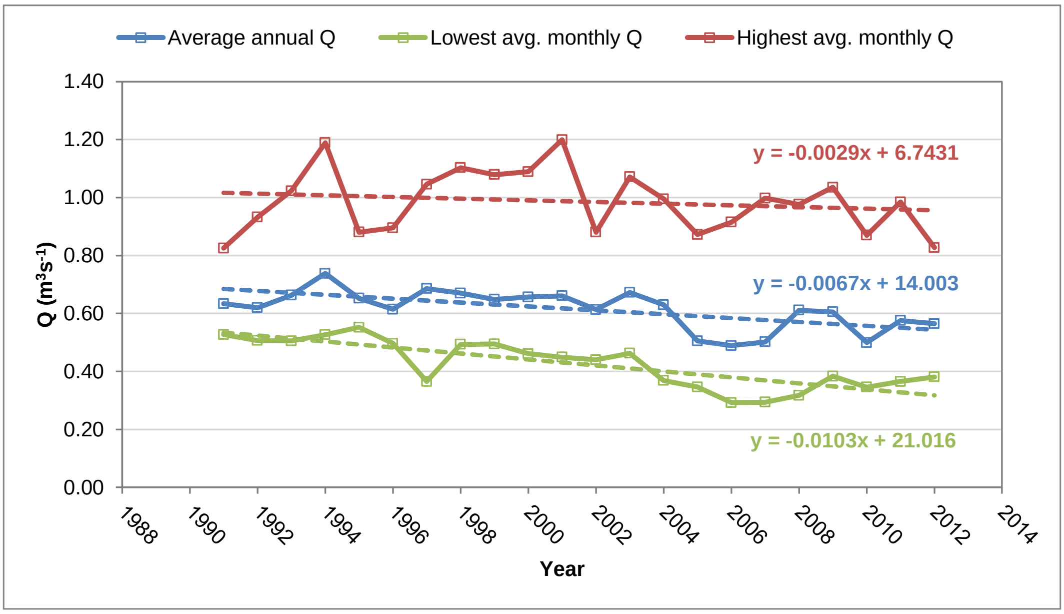


Figure 4.11: Distribution and trends of the average annual abstracted quantities and the lowest and highest average monthly abstracted quantities form springs Gradole, Sv. Ivan and Bulaž combined (1991 – 2012)

A presentation of the intra-annual distribution of the long-term maximums, means and minimums of average monthly abstracted quantities of all three springs combined is presented in Figure 4.12. All statistical parameters for average monthly abstracted quantities show the highest water demand in July and August. Those are typical summer months, with very high temperatures and low precipitation. Considering temporary population increase because number of tourists staying in Istria, and irrigation demands, it is reasonable to expect the highest total water demand in these two months. It must be emphasized that increased water demand coincides with the decrease in water resource availability (Figure 4.13).

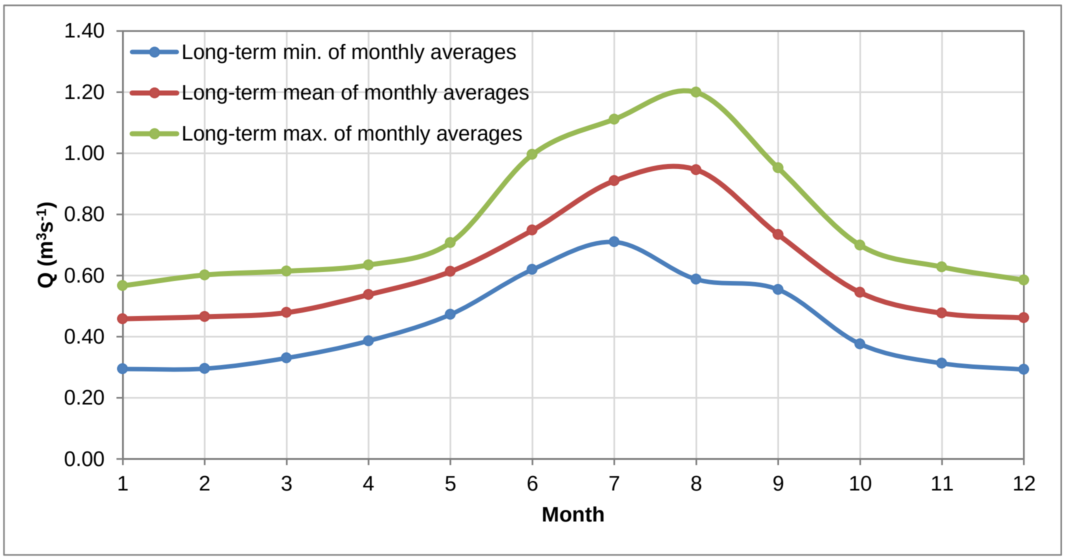


Figure 4.12: Intra-annual distribution of the long-term maximums, means and minimums of average monthly abstracted quantities from springs Gradole, Sv. Ivan and Bulaž combined (1991 – 2012)

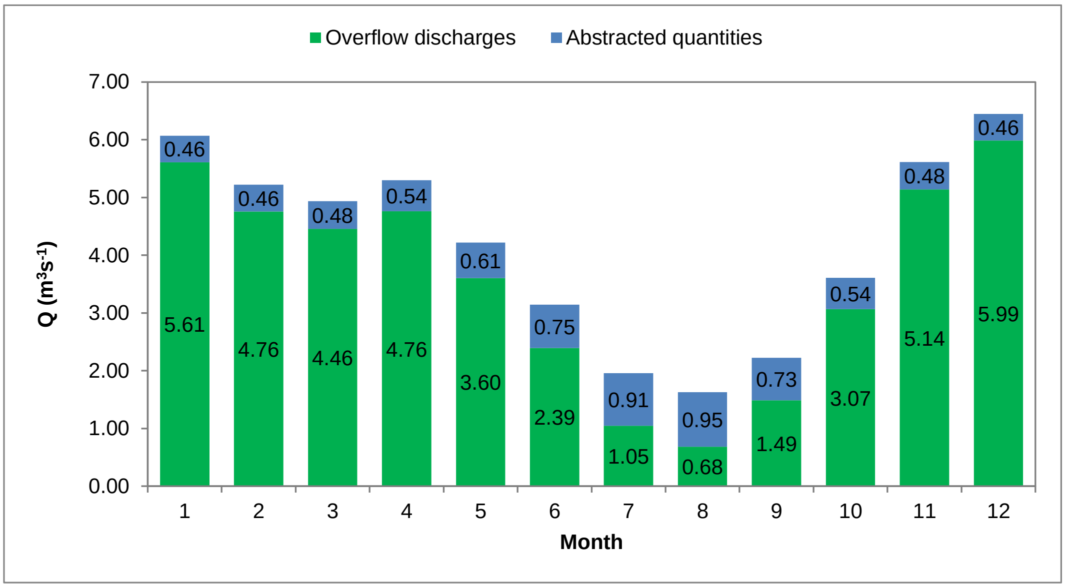


Figure 4.13: Intra-annual distribution of the long-term mean of average monthly overflow discharges and abstracted quantities form springs Gradole, Sv. Ivan and Bulaž combined (1991 – 2012)

Figure 4.13 shows the annual distribution of July and August averages of abstracted quantities in comparison to average annual and highest monthly averages of abstracted quantities of all three springs combined. From Figure 4.11 it can be noticed that for some years (1991 – 2004, 2008, 2009, and 2011) the highest water use was in August, and for some years (2005 – 2008, 2010, and 2012) in July. This difference occurs depending mostly on meteorological conditions (temperature and precipitation). In average, abstracted quantities in August were higher than those in July. Because of this, statistical parameter long-term mean of August monthly averages was select as appropriate for northern Istria test area.

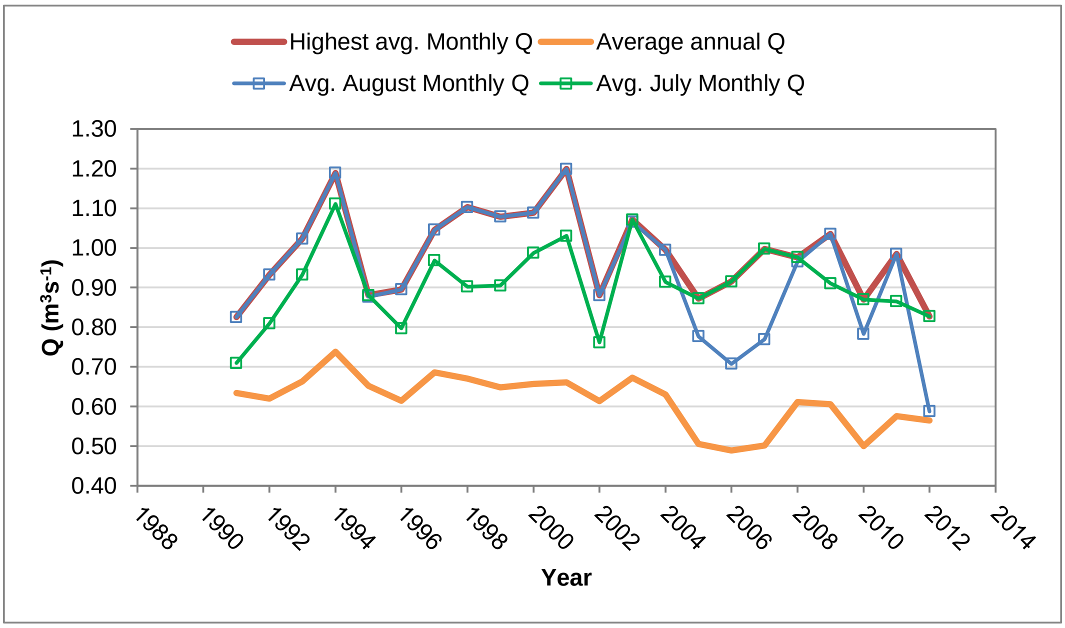


Figure 4.14: Distribution of the average annual abstracted quantities, highest monthly averages compared to July and August averages of abstracted from springs Gradole, Sv. Ivan and Bulaž combined (1991 – 2012)

All of the statistical assessments and calculations of water demand (present and future), for Average Conditions and for Characteristic Renewable Water Resource are summarized in Table 4.15 and 4.16. Total water use for average conditions is assessed based on average annual abstracted quantities from springs Gradole, Sv. Ivan and Bulaž combined. Total water use for characteristic renewable water resource is assessed based on long-term mean of August monthly averages of abstracted quantities from springs Gradole, Sv. Ivan and Bulaž combined. Drinking water use is assumed 15% less than total water use, for all cases.

In the assessment three scenarios are considered. Scenario 0 is present water demand, scenario 1 is future water demand which is calculated as 25% increase in present demand, and scenario 2 is future water demand which is calculated as 25% decrease in present demand. (Tables 4.15 and 4.16)

The water resources data from climate change assessment report was compared to water demand assessment to assess water exploitation index.

The climate change assessment report is based on average annual inflows and the lowest average monthly inflows for each analyzed karst spring Gradole, Sv. Ivan and Bulaž in Mirna basin. On the other hand, water demand assessment is based on combined data from all three springs, and not for each spring individually. Because of this, the first step is to obtain mean data of average annual inflows and lowest average monthly inflows of all three springs combined, from climate change assessment report, for registered and modelled data, respectively (Table 4.17).

Table 4.15: Water demand Scenarios for ***Average Condition*** *(average annual abstracted quantities from springs Gradole, Sv. Ivan and Bulaž combined)*

Water Demand Scenarios		Total Water Use	Drinking Water Use
		m^3/s	
Scenario 0	Present Water Demand	0.61	0.52
Scenario 1	Future Water Demand +25%	0.77	0.65
Scenario 2	Future Water Demand -25%	0.46	0.39

Table 4.16: Water demand Scenarios for ***Characteristic Renewable Water Resource*** *(long-term mean of August monthly averages of abstracted quantities from springs Gradole, Sv. Ivan and Bulaž combined)*

Water Demand Scenarios		Total Water Use	Drinking Water Use
		m^3/s	
Scenario 0	Present Water Demand	0.95	0.80
Scenario 1	Future Water Demand +25%	1.18	1.00
Scenario 2	Future Water Demand -25%	0.71	0.60

Table 4.17: Registered and model-based results for average annual and the lowest average monthly inflows from springs Gradole, Sv. Ivan and Bulaž combined (1961-2050)

	Average annual inflows (m^3s^{-1})			Lowest average monthly inflows (m^3s^{-1})		
1961- 1990 – Registered						
Mean	4.79			1.6		
2021- 2050 – Model-based						
	RegCM3	Aladin	Promes	RegCM3	Aladin	Promes
Mean	4.64	4.49	4.82	1.5	1.48	1.37

Water exploitation index (WEI) is calculated, as a ratio of water demand (4.15 and 4.16) and water resources (4.17). The results are presented in tables 4.18 – 4.21 for Average Conditions, and Tables 4.22 – 4.25 for Characteristic Renewable Water Resources.

For Average Conditions WEI indicates very low risk for all scenarios (Table 4.18 – 4.21), but for Characteristic Renewable Water Resources WEI indicates possible difficulties at present (Table 4.22) and in the future if the water demand stays the same (Table 4.23). If the water demand increases by 25% WEI indicates strong risk for total water use, and possible difficulties for drinking water use (Table 4.24). On the other hand, if the future water demand decreases by 25%, WEI indicates low risk (Table 4.25).

Table 4.18: Water Exploitation Index WEI (1) for Present Water Demand (1991 – 2012) and Measured Water Resources (1961 – 1990), for Average Conditions

Measured	Present WD (1991 - 2012)		WR	WEI	
	total water use	drinking water	1961 - 1990	total water use	drinking water
	m^3/s				
	0.61	0.52	4.79	0.13	0.11

Table 4.19: Water Exploitation Index WEI (2) for Present Water Demand (1991 – 2012) and Modelled Water Resources (2021 - 2050), for Average Conditions

Modelled	Present WD (1991 - 2012)		WR	WEI	
	total water use	drinking water	2021 - 2050	total water use	drinking water
	m^3/s				
RegCM3	0.61	0.52	4.64	0.13	0.11
Aladin	0.61	0.52	4.49	0.14	0.12
Promes	0.61	0.52	4.82	0.13	0.11

Table 4.20: Water Exploitation Index WEI (3) for Future Water Demand (+25%) and Modelled Water Resources (2021 - 2050), for Average Conditions

Modelled	Future WD	25%	WR	WEI	
	total water use	drinking water	2021 - 2050	total water use	drinking water
	m^3/s				
RegCM3	0.77	0.65	4.64	0.17	0.14
Aladin	0.77	0.65	4.49	0.17	0.15
Promes	0.77	0.65	4.82	0.16	0.14

Table 4.21: Water Exploitation Index WEI (4) for Future Water Demand (-25%) and Modelled Water Resources (2021 - 2050), for Average Conditions

Modelled	Future WD	-25%	WR	WEI	
	total water use	drinking water	2021 - 2050	total water use	drinking water
	m^3/s				
RegCM3	0.46	0.39	4.64	0.10	0.08
Aladin	0.46	0.39	4.49	0.10	0.09
Promes	0.46	0.39	4.82	0.10	0.08

Table 4.22: Water Exploitation Index WEI (1) for Present Water Demand (1991 – 2012) and Measured Water Resources (1961 – 1990), for Characteristic Renewable WR

Measured	Present WD (1991 - 2012)		WR	WEI	
	total water use	drinking water	1961 - 1990	total water use	drinking water
	m^3/s				
	0.95	0.80	1.60	0.59	0.50

Table 4.23: Water Exploitation Index WEI (2) for Present Water Demand (1991 – 2012) and Modelled Water Resources (2021 - 2050), for Characteristic Renewable Water Resource

Modelled	Present WD (1991 - 2012)		WR	WEI	
	total water use	drinking water	2021 - 2050	total water use	drinking water
	m^3/s				
RegCM3	0.95	0.80	1.50	0.63	0.54
Aladin	0.95	0.80	1.48	0.64	0.54
Promes	0.95	0.80	1.37	0.69	0.59

Table 4.24: Water Exploitation Index WEI (3) for Future Water Demand (+25%) and Modelled Water Resources (2021 - 2050), for Characteristic Renewable Water Resource

Modelled	Future WD	25%	WR	WEI	
	total water use	drinking water	2021 - 2050	total water use	drinking water
	m^3/s				
RegCM3	1.18	1.00	1.50	0.79	0.67
Aladin	1.18	1.00	1.48	0.80	0.68
Promes	1.18	1.00	1.37	0.86	0.73

Table 4.25: Water Exploitation Index WEI (4) for Future Water Demand (-25%) and Modelled Water Resources (2021 - 2050), for Characteristic Renewable Water Resource

Modelled	Future WD	-25%	WR	WEI	
	total water use	drinking water	2021 - 2050	total water use	drinking water
	m3/s				
RegCM3	0.73	0.62	1.50	0.49	0.41
Aladin	0.73	0.62	1.48	0.49	0.42
Promes	0.73	0.62	1.37	0.53	0.45

4.3.2. SOUTHERN DALMATIA – SPRING PRUD AND BLATSKO POLJE

From Annex 6:

Prud spring, which is situated in continental part of Southern Dalmatia test area, is capped for the purpose of regional water supply system Neretva-Pelješac-Korčula-Lastovo (“NPKL vodovod d.o.o”) (Figure 4.15).

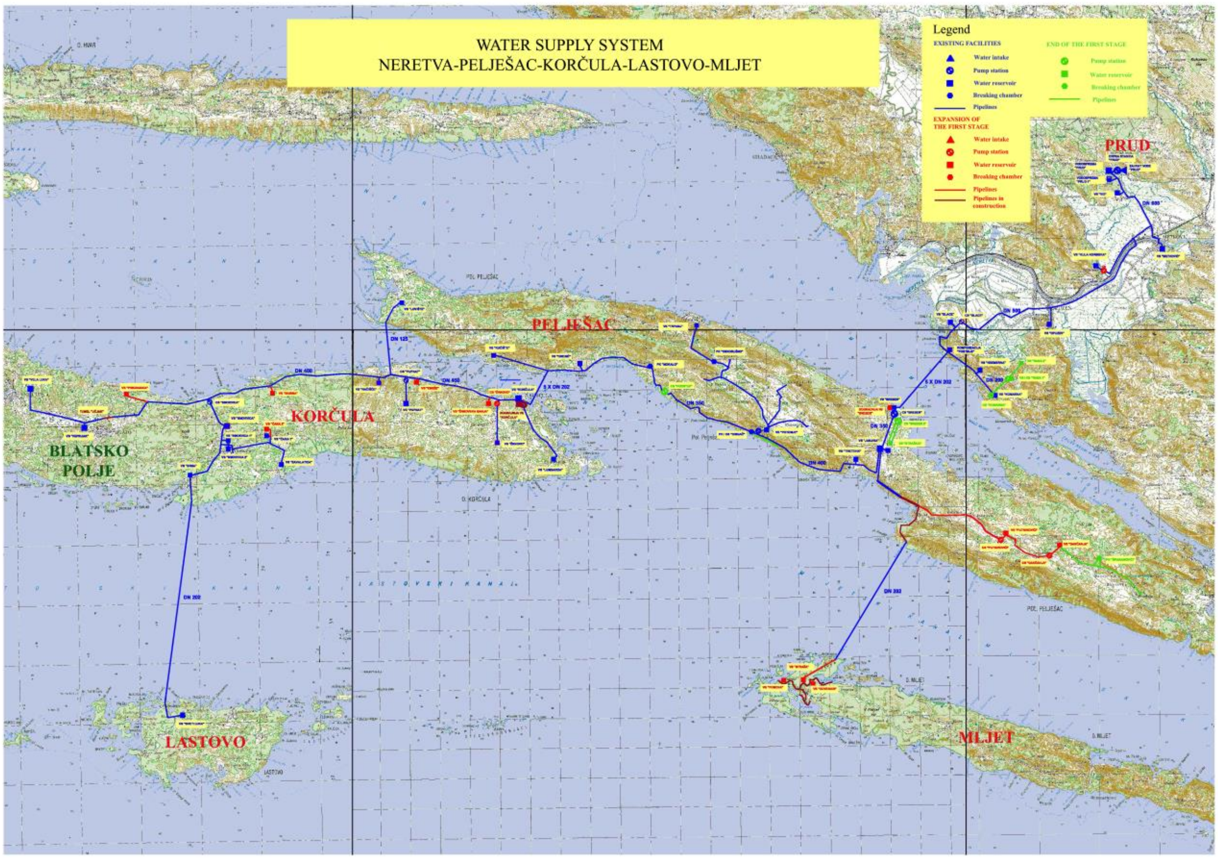


Figure 4.15: Water supply system in Southern Dalmatia test area (made according the map obtained from the NPKL water supply Company)

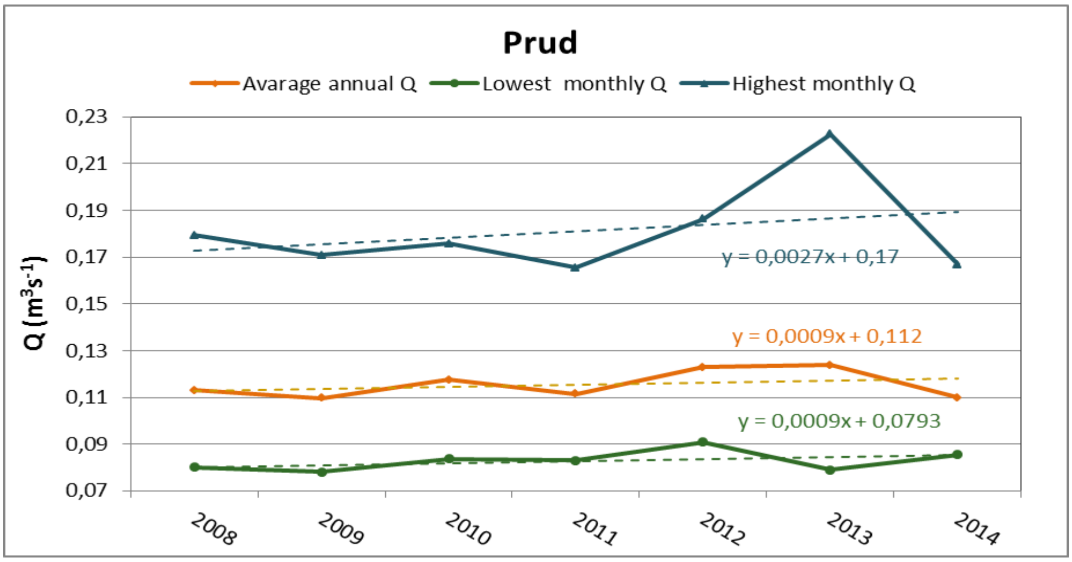
NPKL water supply system was constructed in 2004, but currently is under construction that will upgrade and increase its capacity. This will resolve the water shortages that occur during the increased consumption in the summer months. Minimum discharge of capped spring Prud is about 2770 l/s. Current possibilities of water supply system due to construction capacity are 382 l/s, while in use are 280 l/s. It supplies about 20 thousand inhabitants, but in summer season the population number double increase due to tourism. Current system upgrading will allow almost doubling water consumption on the route of this water supply system, which means water supply around 45 thousand people and just as many tourists in the top of the tourist season.

Blatsko polje, situated on the island part of Southern Dalmatia test area, Korčula island, has its own water supply system "Vodovod d.o.o. Blato". Although Blatsko polje has the capabilities to connect with NPKL system, local community has decided to get water from its own groundwater reserves in the Blatsko polje catchment area. Water supply system Blatsko polje supplies about 8000 people in the winter time which doubles in summer season. Groundwater used for public water supply is pumped from four pit wells: Studenac, Prbako, Franulović-Prcalo and Gugić. Maximal pumping rate is about 60 l/s. These rates are always extracted in the summer seasons when the need for water is increased as a result of tourism and agricultural production, while the recharge in this half of the year is usually minimal or none.

Water demand in pilot area of Southern Dalmatia was done using the same method as for Northern Istria with some small differences because of data availability.

There is no data on water quantity used for irrigation, industry and other water consumer, so it was impossible to determine how much water is used for other purposes in relation to the use of drinking water in the investigated area. Water in Blatsko polje and Prud test areas is supplied to all consumers as drinking water. In addition to use as drinking water, this water private users also use for watering gardens and any other purposes. Water supply company doesn't have the information of these amounts. However, amount of the water used for other purposes then for drinking water is very small. The port of Ploče is the only bigger water consumer in spring Prud test area, but it's not use this water to a greater extent in its production, so these quantities are not significant as well. In both test areas there are significant arable land, but these areas are not irrigated, therefore these amounts are also not significant. Thus, for the water demand assessment it is not separated the proportion of drinking water in total water use.

Based on available data of abstracted quantities, an analysis of water consumption was done. For the test area Blatsko polje analysis was done for the period of 2001- 2014, and for spring Prud test area for the period from 2008 to 2014. The distribution and trends of the average annual abstracted quantities and lowest and highest average monthly abstracted quantities from both test areas are presented below (Figure 4.16). Average abstracted quantities on the spring Prud during six years period are more or less constant. The bigger change was observed only in the highest monthly Q in 2013. Reason is overdrought that caused high salinity at the well that supply nearby village which was then connected on the Prud water supply. Blatsko polje has a continuous increase in pumping rates which are almost doubled within the observed period.



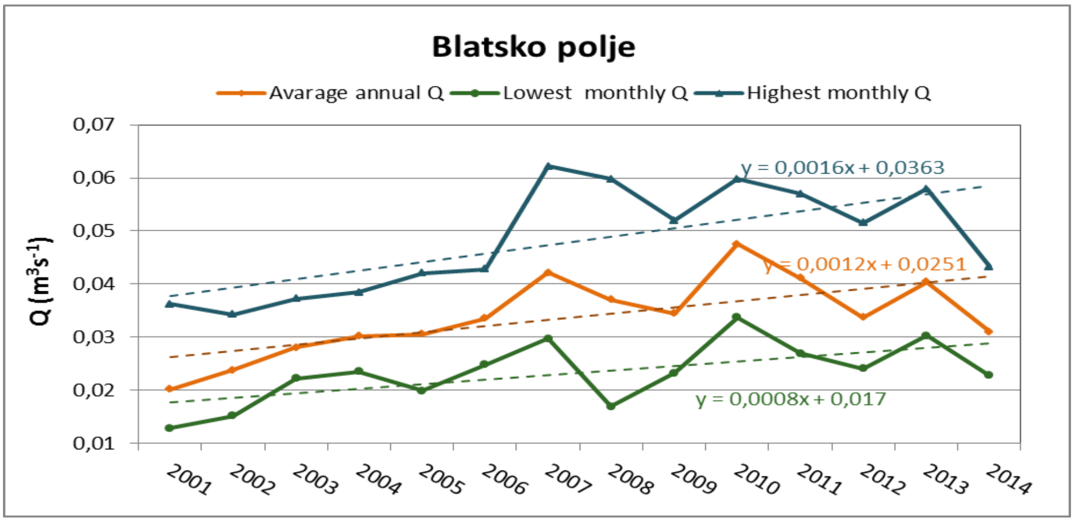
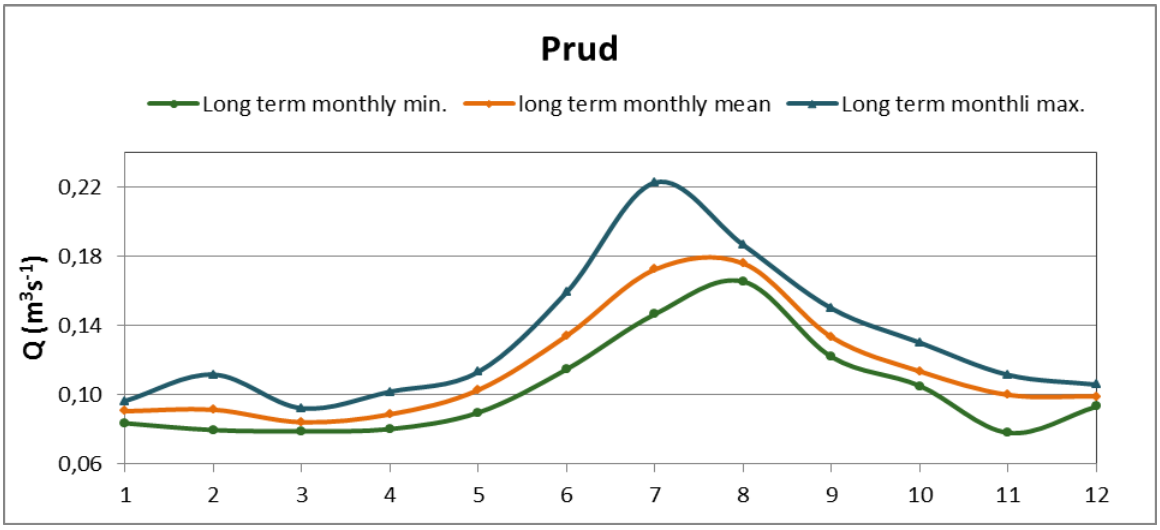


Figure 4.16: Distribution and trends of the average annual abstracted quantities and the lowest and highest average monthly abstracted quantities at Prud and Blatsko polje test areas

A presentation of the intra-annual distribution of the long-term maximums, means and minimums of average monthly abstracted quantities on the two test areas are presented in Figure 4.17. The graphs showing that, on both test areas, rates of abstracted quantities are doubled during summer season. It is common for the Adriatic coast because in these areas summer tourism is developed and during summer the number of inhabitants also doubles. The bigger difference between the value of average, lowest and highest abstracted quantities on site Blatsko polje is a result of continuous increasing of pumping rates during observed years, unlike spring Prud where the flow rates are pretty much constant throughout the year.



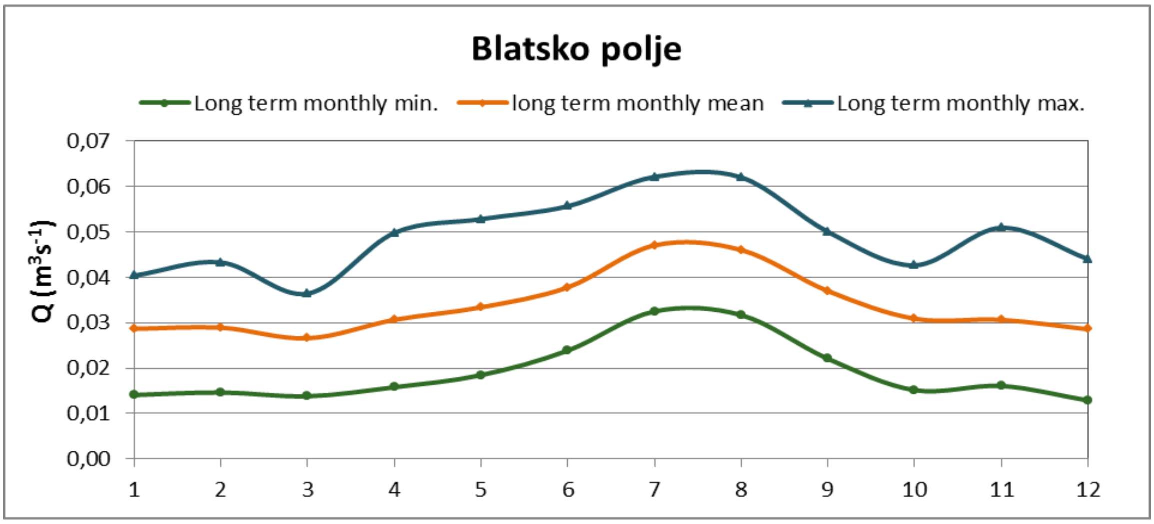


Figure 4.17: Intra-annual distribution of the long-term maximums, means and minimums of average monthly abstracted quantities at Prud (2008-2014) and Blatsko polje (2001-2014) test areas

In order to determine appropriate statistical parameter of long-term mean of monthly averages the annual distribution of July and August averages of abstracted quantities in comparison to average annual and highest monthly averages of abstracted quantities on Prud and Blatsko polje test sites was done (Figure 4.18). It can be noticed that on Prud and Blatsko polje test areas highest water use was mainly in August and July. Individual difference between two sites occurs depending mostly on local meteorological conditions (temperature and precipitation). For the Southern Dalmatia pilot area statistical parameter long-term mean of August monthly averages was selected for further analysis.

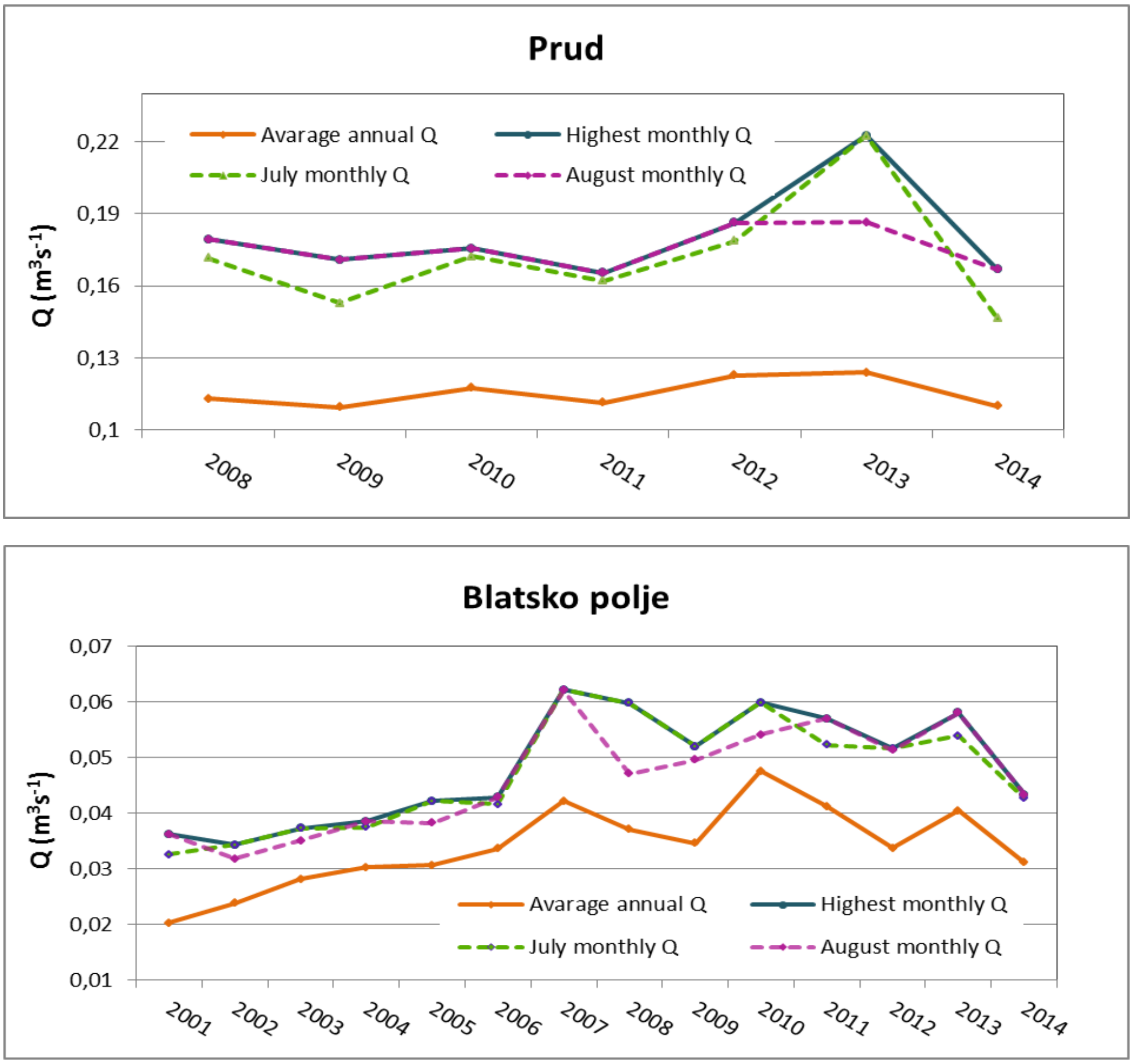


Figure 4.18 Distribution of the average annual abstracted quantities, highest monthly averages compared to July and August averages of abstracted quantities at Prud (2008-2014) and Blatsko polje (2001-2014) test areas

All of the statistical assessments and calculations of water demand (present and future), for Average Conditions and for Characteristic Renewable Water Resource are summarized in Tables 4.25 and 4.27. Total water use for average conditions is assessed based on average annual abstracted quantities of two test areas, Prud and Blatsko polje. Total water use for characteristic renewable water resource is assessed based on long-term mean of August monthly averages of abstracted quantities. Scenario 0 is present water demand, scenario 1 is future water demand which is calculated as 25% increase in present demand, and scenario 2 is future water demand which is calculated as 25% decrease of present demand.

*Table 4.26: Water demand Scenarios for **Average Condition** (average annual abstracted quantities)*

Water Demand Scenarios		Total Water Use m^3/s	
		Prud	Blatsko polje
Scenario 0	Present Water Demand	0.116	0.034
Scenario 1	Future Water Demand +25%	0.145	0.043
Scenario 2	Future Water Demand -25%	0.087	0.026

*Table 4.27: Water demand Scenarios for **Characteristic Renewable Water Resource** (long-term mean of August monthly averages of abstracted quantities)*

Water Demand Scenarios		Total Water Use m^3/s	
		Prud	Blatsko polje
Scenario 0	Present Water Demand	0.176	0.046
Scenario 1	Future Water Demand +25%	0.220	0.058
Scenario 2	Future Water Demand -25%	0.132	0.035

Water exploitation index (WEI) is calculated as a ratio of water demand (Table 4.26 and 4.27) and water resources (Table 4.28). The results are presented in Tables 4.29 – 4.32 for Average Conditions, and Tables 4.33 – 4.36 for Characteristic Renewable Water Resources.

For Average Conditions WEI indicates very low risk for all scenarios (Table 4.29 – 4.32), but for Characteristic Renewable Water Resources, WEI indicates non sustainable water supply for three scenarios at Blatsko polje test area: at present (Table 4.33), in the future if the water demand stays the same (Table 4.34), and in the case if the water demand increases by 25% (Table 4.35). In the case of 25 % of decreases of water demand WEI indicates strong risk for total water use (Table 4.36). On the other hand, for the Prud test area WEI indicates low risk for all scenarios for Characteristic Renewable Water Resources (Table 4.33 – 4.36).

Table 4.28: Registered and model-based results for average annual and the lowest average monthly inflows of Prud and Blatsko polje (1961-2050)

	Average annual inflows (m^{3}s^{-1})		Lowest average monthly inflows (m^{3}s^{-1})	
	Prud	Blatsko polje	Prud	Blatsko polje
1961- 1990 – Registered				
Mean	6,16	0,287	3,36	0,043
2021- 2050 – Model-based				
Mean				
RegCM3	5,60	0,259	3,13	0,042
Aladin	5,39	0,235	3,05	0,040
Promes	5,01	0,222	2,92	0,039

Table 4.29: Water Exploitation Index WEI (1) for Present Water Demand and Measured Water Resources (1961 – 1990), for Average Conditions

Measured	Present WD (1991 - 2012)		WR		WEI	
	total water use		1961 - 1990		total water use	
	Prud	Blatsko polje	Prud	Blatsko polje	Prud	Blatsko polje
	m^3/s					
	0,116	0,034	6,16	0,287	0,02	0,12

*Table 4.30**:** Water Exploitation Index WEI (2) for Present Water Demand and Modelled Water Resources (2021 - 2050), for Average Conditions*

Modelled	Present WD (1991 - 2012)		WR		WEI	
	total water use		2021 - 2050		total water use	
	Prud	Blatsko polje	Prud	Blatsko polje	Prud	Blatsko polje
	m^3/s					
RegCM3	0,116	0,034	5,60	0,259	0,021	0,131
Aladin	0,116	0,034	5,39	0,235	0,022	0,145
Promes	0,116	0,034	5,01	0,222	0,023	0,153

Table 4.31: Water Exploitation Index WEI (3) for Future Water Demand (+25%) and Modelled Water Resources (2021 - 2050), for Average Conditions

Modelled	Future WD + 25%		WR		WEI	
	total water use		2021 - 2050		total water use	
	Prud	Blatsko polje	Prud	Blatsko polje	Prud	Blatsko polje
	m^3/s					
RegCM3	0,145	0,043	5,60	0,259	0,026	0,166
Aladin	0,145	0,043	5,39	0,235	0,027	0,183
Promes	0,145	0,043	5,01	0,222	0,029	0,194

Table 4.32: Water Exploitation Index WEI (4) for Future Water Demand (-25%) and Modelled Water Resources (2021 - 2050), for Average Conditions

Modelled	Future WD - 25%		WR		WEI	
	total water use		2021 - 2050		total water use	
	Prud	Blatsko polje	Prud	Blatsko polje	Prud	Blatsko polje
	m^3/s					
RegCM3	0,087	0,026	5,60	0,259	0,016	0,100
Aladin	0,087	0,026	5,39	0,235	0,016	0,111
Promes	0,087	0,026	5,01	0,222	0,017	0,117

Table 4.33: Water Exploitation Index WEI (1) for Present Water Demand and Measured Water Resources (1961 – 1990), for Characteristic Renewable Water Resource

Measured	Present WD (1991 - 2012)		WR		WEI	
	total water use		1961 - 1990		total water use	
	Prud	Blatsko polje	Prud	Blatsko polje	Prud	Blatsko polje
	m^3/s					
	0,176	0,046	3,36	0,043	0,052	1,070

Table 4.34: Water Exploitation Index WEI (2) for Present Water Demand and Modelled Water Resources (2021 - 2050), for Characteristic Renewable Water Resource

Modelled	Present WD (1991 - 2012)		WR		WEI	
	total water use		2021 - 2050		total water use	
	Prud	Blatsko polje	Prud	Blatsko polje	Prud	Blatsko polje
	m^3/s					
RegCM3	0,176	0,046	3,13	0,042	0,056	1,095
Aladin	0,176	0,046	3,05	0,040	0,058	1,150
Promes	0,176	0,046	2,92	0,039	0,079	1,179

Table 4.35: Water Exploitation Index WEI (3) for Future Water Demand (+25%) and Modelled Water Resources (2021 - 2050), for Characteristic Renewable Water Resource

Modelled	Future WD + 25%		WR		WEI	
	total water use		2021 - 2050		total water use	
	Prud	Blatsko polje	Prud	Blatsko polje	Prud	Blatsko polje
	m³/s					
RegCM3	0,220	0,058	3,13	0,042	0,070	1,381
Aladin	0,220	0,058	3,05	0,040	0,072	1,450
Promes	0,220	0,058	2,92	0,039	0,075	1,487

Table 4.36: Water Exploitation Index WEI (4) for Future Water Demand (-25%) and Modelled Water Resources (2021 - 2050), for Characteristic Renewable Water Resource

Modelled	Future WD - 25%		WR		WEI	
	total water use		2021 - 2050		total water use	
	Prud	Blatsko polje	Prud	Blatsko polje	Prud	Blatsko polje
	m³/s					
RegCM3	0,132	0,035	3,13	0,042	0,042	0,833
Aladin	0,132	0,035	3,05	0,040	0,043	0,875
Promes	0,132	0,035	2,92	0,039	0,045	0,897

4.4. MONTENEGRO - NIKŠIĆ

From Annex 8:

At the present, there are approximately 66 000 users connected to Nikšić drinking water supply system. Majority of users are population (84.5 %) while other users are Industry 20% and small business 2.9 %. Average abstraction rate is 0.4 m^3/s, but during the summer it can be even 50 % higher i.e., maximum measured abstraction rate is 0.6 m^3/s. Based on available data, it is expected that number of users will reach approximately maximum of 72000 users in near future. However, based on agreed methodology for water demand calculation for future scenarios in this report 25 % increase (Scenario 1) and decrease by 25 % (Scenario 2) in demand is applied.

Table 4.37 exhibits data for 3 different scenarios for water demand at Nikšić Pilot area based on average abstraction value (AA)of 0.4 m^3/s (12.61 m^3 x 10^6) and the most conservative approach, i.e., for abstraction that includes maxim abstraction rate(AASM) of 0.6 m^3/s (14.18 m^3 x 10^6) for summer months (Jun, July and August).

Table 4.37: Water demand scenarios

Average Abstraction (AA)	
Scenario	**Demand 10^6m^3**
(0) Present	**12.61**
(1) Present + 25 %	**15.76**
(2) Present - 25 %	**9.46**

Abstraction that incorporate max values during the summer (AASM)	
Scenario	**Demand 10^6m^3**
(0) Present	**14.18**
(1) Present + 25 %	**17.73**
(2) Present - 25 %	**10.64**

Given the discrepancies of modelled precipitation it is practical to evaluate WEI for all models and trends assessment in observed data. Moreover, due to higher demand during the summer, WEI will be calculated for that season in addition to average yearly abstraction. Table 4.38 bellow summarizes all results for Pilot Area Nikšić with respect to Water Exploitation Index.

Table 4.38: Summary results for WEI for Test Area Nikšić

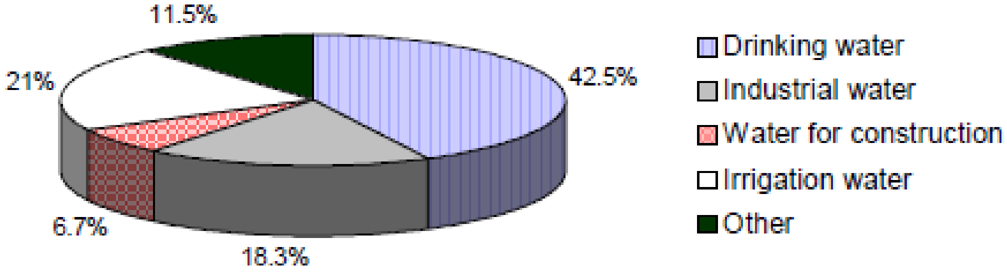
WATER EXPLOITATION INDEX						
Water Demand Scenarios	10^6m^3	Dynamic Groundwater reserves				
		WR – Pres **39.71** (10^6m^3)	WR – TOB **28.28** (10^6m^3)	WR – Ald **27.95** (10^6m^3)	WR – Pro **27.08** (10^6m^3)	WR - RCM3 **27.87** (10^6m^3)
		WEI	WEI	WEI	WEI	WEI
WD A AA present	**12.61**	**0.32**	**0.45**	**0.45**	**0.47**	**0.45**
WD AASM present	**14.18**	**0.36**	**0.50**	**0.51**	**0.52**	**0.51**
WD AA +25%	**15.76**	**0.40**	**0.56**	**0.56**	**0.58**	**0.57**
WD AASM +25%	**17.73**	**0.45**	**0.63**	**0.63**	**0.65**	**0.64**
WD AA - 25%	**9.46**	**0.24**	**0.33**	**0.34**	**0.35**	**0.34**
WD AASM - 25%	**10.64**	**0.27**	**0.38**	**0.38**	**0.39**	**0.38**

4.5. ALBANIA – DRINI BASIN

From Annex 9:

Albania's urban water supply system is plagued by problems. In addition, infiltration from parallel sewer lines causes periodic cross contaminations of the water supply. Monitoring is conducted for some fifteen physical and chemical parameters. The first National Water Strategy was formulated in 1996, a law for water resources was adopted in the same year, establishing a number of regulatory instruments, including effluent charges, drinking water fees and non-compliance fees. Despite this law, only drinking-water fees are in place today, and at very low levels.

Water resources are considerable in Albania. River discharge into the sea is estimated to be around 40km3/year with an annual specific discharge of 29lit/sec.km2, which is one of the highest in Europe. Groundwater resources represent about 23 percent of the total renewable resources. Groundwater sources are the main source for drinking water and they are also the major source for irrigation. Because of the geological structure of the Albanian mountains with developed karst manifestation and highly permeable gravelly aquifers in the lowland areas, groundwater resources are abundant and of good quality. Due to the ease of extraction, groundwater has often been unnecessarily used in industry and for irrigation in agriculture. The latter has become a reason of concern as 21 percent of groundwater extracted goes in inefficient irrigation practices. In some areas of Albania, there is a fast depletion of groundwater resources and this disastrous trend is likely to continue in the next decade. This is often associated with increased salinity and alternated hydro-chemical balances in the aquifer, indicating brackish water intrusion. Population's movement toward cities has put additional pressure on the water resources of some lowland areas, where extraction rates are increasing steadily.



Source: NEA

Figure 4.19: Use of groundwater resources during 1997-1998

In the Drini unit, three main aquifers can be defined:

- One north from Shkodra and along the Lake of Shkodra, in the district of Shkodra and Malesia e Madhe. It includes the wells of Dobraç, supplying water for the city of Shkodra with wells yielding 80 l/s of good quality water. No quantitative data are available for the rest of this aquifer, but qualitative inforDrinion shows that, in quantity and quality, the supply obtained from this aquifer is not satisfactory for the drinking water supply for Koplik and its region; other sources of supply are presently being investigated:

- One on the left side of the Drini downstream of Shkodra; no inforDrinion, either qualitative or quantitative, are available for this aquifer.
- In the district of Has water is mainly obtained from wells, but no data have been found about the resources.

Most of the groundwater in the Drini basin is taken from springs, 65 of which have a wet season discharge above 100 l/s, mainly in the district of Malesia e Madhe, Tropoje, Kukes, Diber and Bulqize. The quality of these springs is generally good; they yield a fairly stable amount of water with low hardness (5 to 8 German degrees in most cases).

The situation of water supply infrastructure in Albania is in a critical state, considering the old networks, massive leakage in all parts of the system, illegal connections, unstable supply pattern, uncontrolled rural-to-urban migration, and low maintenance due to lack of funds. The percentage of population having access to pipe water supply is uncertain. Figures vary considerably, from 90 percent in urban areas to 50 percent in rural ones. This uncertainty happens because there are no clear criteria what a water-providing infrastructure should look like. Most drinking water systems are old, corroded and provide very little, or, even no water at all to the consumers. Some complex networks have recently been divided into smaller manageable parts and their destiny, is unknown. Coverage in urban areas seems to have been higher during the 1980s than today. This is somewhat uncertain because, recently, urban areas' boundaries have been expanded in many cities with the inclusion of newly dwelt peri-urban areas, which are much less covered by water networks. This process has undoubtedly resulted in a decrease of urban coverage expressed either in terms of percentage of population served, or in terms of area covered. Unfortunately, there are no exact data to quantify coverage, however, the above-mentioned dynamics of these processes are widely accepted among experts.

Where piped systems are not available, population in rural areas mostly relies on natural springs and domestic wells to satisfy their needs. This implies enormous time and efforts spent in fetching and transporting water as the sources may be far away and because not every family has a well.

Transportation is done mainly with animals, in plastic containers that are used for transport and storage as well. This work is primarily women's and children's responsibility. Accurate data on this process are not available, however, two international NGOs have done basic surveys in rural areas where piped systems were absent Table 4.39, provides main findings.

Last decade's developments in Albania have brought many changes in the water demand pattern. Urban areas are growing fast and more drinking water is needed, while most industries – large water consumers before 1990 – are not working anymore. New industries and businesses are getting active; demand for water not only is growing steadily, but also its distribution over certain areas and its time pattern has changed. Because water produced is generally not metered and because there are no measurements in distribution networks, accurate studies on demand pattern are not available. Coverage with water meters was substantial some decades ago, especially in urban areas. Meters were Albanian made and relatively accurate for a limited number of years, but lack of maintenance led to their total dysfunction.

Table 4.39: Surveys in some rural areas on time and efforts spent in fetching water

Facts	Plan Intl.	Solidarités
Families fetching water outdoors (in summer)	84%	80%
Families fetching water outdoors (rest of the year)	?	25%
Average distance travelled per day	3.6 km	3 km (*)
Number of trips per day	4.4 trips	3.38 trips
Time spent daily for fetching water (incl. queue)	3-4 hours	4-5 hours (*)
Average water quantity transported per trip	45 lit(*)	48 lit
Average daily consumption per family	198 lit (*)	162 lit
Liters/capita a day	39.6 l/c/d (*)	32.4 l/c/d

Source: NGO's fieldwork data

Daily demand pattern in urban areas follow a three peaks' cycle of population's activities with some implication from the industry and other businesses. In rural areas, water demand depends largely on the agricultural activities and crop production cycles, while domestic consumption is much smaller. The rainfall in Albania is concentrated in winter and spring, while summer is hot and dry. Thus, most water is needed in summer, but due to insufficient rainfall, water resources are scarcer in this season. Add to this the bad practice of irrigating with drinking water and it is clear that satisfying demand with proper supply is quite a challenge.

If the availability of water at the source is expressed in liters per capita in urban areas, it is surprising to find that sources of supply are more than enough to satisfy water demand. In many cities, water availability at the source is around 500 liter per capita per day and in some cases even more.

Because of leakage and considerable wastage, only a small part of the water produced goes into necessary consumption. A wrong opinion among some professionals involved in water supply is that problems of insufficient availability can be solved enhancing production facilities and source intake. Increasing exploitation rates would seriously affect the fragile water resource balances with future repercussions and increase the cost of water supply. Albania has a distribution problem, not a production problem. In fact, almost everywhere problems of water scarcity can be considerably mitigated through metering, leakage detection and reduction, network improvements, disconnection of illegal connections and optimization of storage and supply patterns.

Sanitation is more beset with problems than drinking water. Sanitation coverage in urban areas is almost the same as drinking water coverage, while in rural areas only a small portion of the areas with piped water supply are also equipped with sewer networks. Historically, sanitation has been overlooked in terms of funding, human resources, maintenance, etc. Upgrade of sewer networks has not kept pace with the general development of infrastructure and materials and technology used has not seen any improvement. Urban areas have mostly combined sewage and storm water collection networks that discharge into nearby surface water bodies. Sewers, generally under-dimensioned, are clogged in many parts causing wastewater seepage out of the networks, thus, resulting in cross-contamination with drinking water5. Many manhole covers are missing and this has resulted in filling of these shafts with refuse material.

Presently, there is no wastewater treatment plant in Albania and discharge in water bodies, especially in the proximity of coastal tourist areas and delicate eco-systems is becoming a reason of concern for the Government, the business community and environmentalist alike. . Foreign donors have funded studies to provide feasible and sustainable solutions to minimize the environmental impact of wastewater discharge in the Ohrid Lake. This project aims at increasing the legal and logistical basis for its conservation, through the development of a sound environmental management strategy of lakes and monitoring of their water quality.

Drinking water supply systems in Albania are generally simple in terms of construction and operation, mainly due to the good raw water quality, which does not create a need for complicated treatment. Moreover, Albania relies mostly on groundwater for drinking water supply, while treated surface water is only recently being used for large human consumption6. Supply systems usually use water from natural springs, from drilled boreholes, or a combination of both. Gravity systems are widespread and economical in operation and maintenance. They are common in many rural and urban settlements, in hilly and mountainous areas. Pumped systems are built where the gravity systems cannot be used. In both cases, the only treatment foreseen and generally done is safety chlorination.

An exception is made for Tirana, where a more comprehensive treatment technology purifies the water from Bovilla Lake that is used for drinking purposes. Accurate data on pipe breaks and failures of supply are not available, mainly due to insufficient record keeping practices. In addition, there is no consistent monitoring of trunk mains and distribution networks by water companies' personnel. Citizens themselves report leakage and pipe bursts, but the water company can only respond to major breakdowns. Small defects are repaired after weeks and even months upon notification. There are cases of 'chronic' leaks that remain in this situation for years. Water companies have limited financial possibilities to cope with ever increasing failures in the water supply networks, which adds to water losses and increases the possibility for waterborne diseases.

Establishing control over the use of water resources from the basin councils and regional authorities in cooperation with the municipality will ensure for a better distribution and more rational and environmentally friendly use of water resources. Consultant recommends the need for encouraging intercommunal cooperation to address the lack of water resources, and the joint solution in the construction and operation of water supply and sewerage systems in rural areas. Informal settlements are a fait accomplishment and represent a significant percentage of the administrative territory in the jurisdiction of local units and water companies, especially as regards the major cities of the country. In these circumstances, we should consider not only the legalization of residences but also the relationship with the community of these areas in the field of water supply and wastewater service. For this reason, municipalities and water and / or wastewater companies should plan the extension of the service coverage in these areas at the same standard as in other areas of the cities where they operate.

There is little coordination among water companies and local government units, although the companies are legally under the into ownership of these units. As result, the policies of water companies for the development of the service do not necessarily match with those of local governments, but are particularly affected from GDWS, which is where the main investments for this sector comes out. Sector development will take other dimensions if ever there will be a shift, without conflict, of the attention of the management of the companies from GDWS or central institutions generally, to the factual dependence from local government units, which are the owners of these operators. WRA can play an important role in this relationship by recognizing that water and wastewater service is an own function of local government units.

4.6. GREECE – CORFU ISLAND

From Annex 10:

The River Basin Management Plan of Epirus provides water demand data for irrigation purposes for Corfu Island. The methodology used to estimate the water needs for crops follow the method Blaney-Griddle (RBMP of Epirus, Del.8) for the organized collective irrigation networks. Due to lack of water data necessary per crop cultivated the methodology used climatic data (average temperature, precipitation) and the percentage of the duration of the day hours for each month based on the latitude of each area.

For the irrigation methods used in collective irrigation networks the average values of the efficiency coefficient ware used (performance rate) as follows:

- Surface irrigation methods, 50%
- Artificial rain, flush, 87.5%
- Micro-irrigation, 85.5%

To estimate the cultivated areas and the type of crops for each water district the latest data of the annual agricultural statistical research of the Hellenic Statistical Authority for the year 2007 are used.

The results are given in Table 4.40.

Table 4.40: Water demand for irrigation from surface water bodies in Corfu (RBMP of Epirus, Del.8)

River	**Annual extraction volume (m^3)**	**Average daily consumption during the summer period (m^3)**
GR0534R000501076N	437,920	5,149

Table 4.41 presents the determination of the extraction pressure in surface water bodies (RBMP of Epirus, Del.8). For groundwater bodies the water demand for irrigation is estimated in the river basin management plan (RBMP of Epirus, Del.3) (Table 4.42).

Table 4.41: Determination of the extraction pressure in surface water bodies in Corfu (RBMP of Epirus, Del.8)

Water body code	Water body name	Natural annual runoff (Mm^3)	Natural summer runoff (Mm^3/month)	Annual extraction (Mm^3)	Summer extraction (Mm^3)	Annual volume of extraction V (% of average value of annual runoff)	Summer volume of extraction V (% of average value of summer runoff)	Extraction Pressure Stress
GR0534R000101074N	Potami	8.5	0.1	0.0	0.0	0.0%	0.0%	Negligible
GR0534R000301075N	Messagis	21.8	0.4	0.0	0.0	0.0%	0.0%	Negligible
GR0534R000501076N	Fonissa	71.6	1.2	0.4	0.1	0.6%	13.2%	Negligible

Table 4.42: Water demand for irrigation from groundwater bodies in Corfu (RBMP of Epirus, Del.3)

Water body code	Water body name	Water abstracted for irrigation (m^3/year)
GR0500010	Limestones system of Corfu island	507,434
GR0500020	Ternary breccia system of Corfu Island	3,041,935
GR0500030	Granular Aquifers of Corfu Island	9,846,869

Table 4.43: Water demand for drinking purposes from groundwater bodies in Corfu (RBMP of Epirus, Del.3)

Water body code	Water body name	Water abstracted for drinking purposes (m^3/year)
GR0500010	Limestones system of Corfu island	6,422,694
GR0500020	Ternary breccia system of Corfu Island	3,984,049
GR0500030	Granular Aquifers of Corfu Island	4,570,126

Table 4.44: Assessment of the aquifers further characterized regarding water abstraction pressure (RBMP of Epirus, Del.8)

Water body code	Water body name	Estimated total number of drillings	Average flow of drilling	Estimated total number of drinking water drilling and springs	Average annual abstraction (10^6 m^3)	Current conditions of overexploitation	Artificial recharge
GR0500010	Limestones system of Corfu island	76	40-60	86	6.9	No	No
GR0500030	Granular Aquifers of Corfu Island	221	30-40	154	14.4	No	No

The methodology used from the River Basin Management Plan (RBMP of Epirus, Del.8) to estimate the drinking water demand is based either in actual data of consumption from the water utilities or in a theoretical estimation based on population and the assumption for personal water consumption. The water demand estimation for drinking water includes the demand from the permanent population, the demand from the seasonal population and the demand from the industry. The seasonal population includes tourists staying in hotels, rental accommodation and vacationers in summer houses etc.

Table 4.43 shows the water abstraction volumes from aquifers for drinking water purposes (RBMP of Epirus, Del.3).

The assessment of the aquifers needing further characterization regarding the water extraction is provided by the River Basin Management Plan (RBMP of Epirus, Del.8) (Table 4.44).

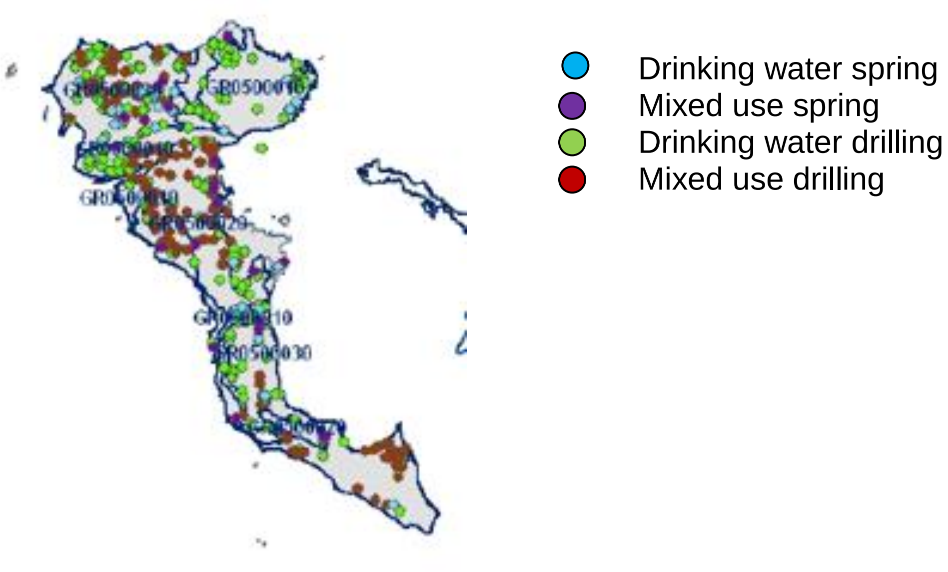


Figure 4.20: Map of quantitative status of aquifers in the test area. Spatial allocation of springs and drillings (RBMP of Epirus, Del.8)

As the water intake from surface water bodies is small (Table 4.45), the data provided refer to water abstraction volumes only from aquifers (Table 4.46). Water volumes abstracted for both uses irrigation and drinking are given in Figure 4.21. All data are average values for the period 1990-2010.

Table 4.45: Annual Water Abstraction in Corfu island (RBMP of Epirus, Del.8)

Total Annual Water Abstraction (hm^3)	
Surface water bodies	0.5
Aquifers	29

Table 4.46: Annual water supply and demand in aquifers in Corfu Island

Water body code	**Water body name**	**Type of aquifer**	**Annual water inflow (10^6 m^3)**	**Annual water abstraction (10^6 m^3)**	**Quantitative status**
GR0500010	Limestones system of Corfu island	Karstic	75	6.9	Good
GR0500020	Ternary breccia system of Corfu Island	Karstic	40	7.0	Good
GR0500030	Granular Aquifers of Corfu Island	Granular	40	14.4	Good

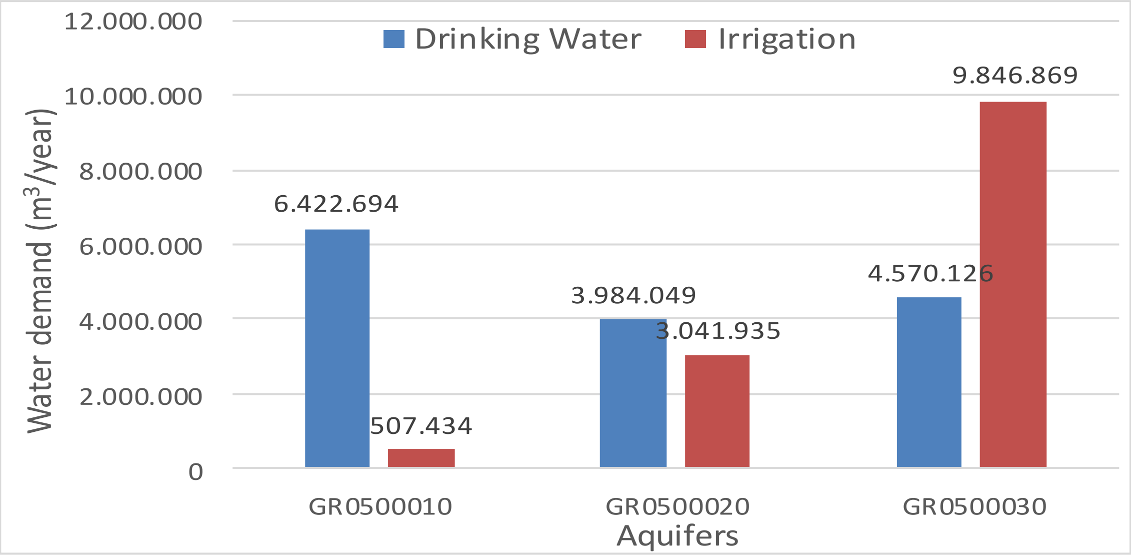


Figure 4.21: Water abstracted for irrigation and drinking purposes from the 3 aquifers in Corfu Island (average values 1990-2010) (based on data obtained from RBMP of Epirus, Del.3)

The scenarios examine the water demand variations from -25% to +25% with a step of 5% for the three aquifers. The same percentage variations (from -25% to + 25%) are also examined for water natural recharge (stated as water inflow from now on in this report).
Figure 4.22 shows the water demand variations and the water inflow variations when both variables vary from -25% to 25% at a step of 5% for aquifer GR0500010. The same variations are presented in Figures 4.23&4.24 for aquifers GR0500020 and GR0500030 respectively. The results show that in all three aquifers the water inflow is greater than water demand in all cases. In aquifer GR0500010 water inflow values range from 56.25 (-25% variation) to 93.75 (+25% variation) hm^3/year while water demand values range from 5.175 (-25% variation) to 8.625 (+25% variation) hm^3/year (Figure 4.22).

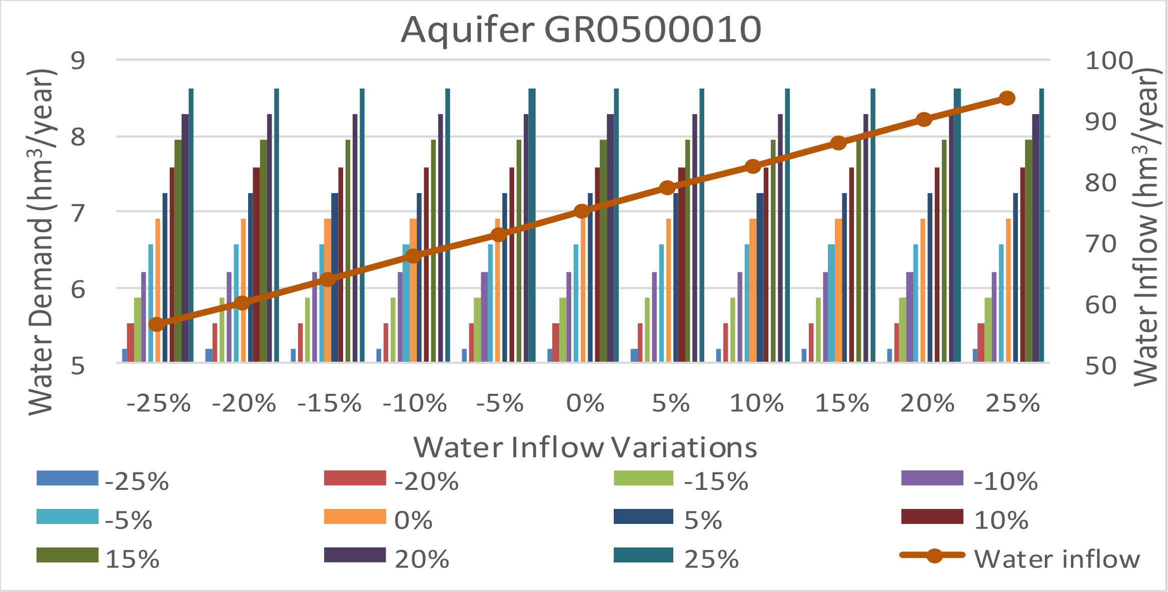


Figure 4.22: Water Inflow and Water Demand Variations (aquifer GR0500010)

In aquifer GR0500020 water inflow values range from 30 (-25% variation) to 50 (+25% variation) hm^3/year while water demand values range from 5.25 (-25% variation) to 8.75 (+25% variation) hm^3/year (Figure 4.23). In aquifer GR0500030 water inflow values range from 30 (-25% variation) to 50 (+25% variation) hm^3/year while water demand values range from 10.8 (-25% variation) to 17.28 (+25% variation) hm^3/year (Figure 4.24).

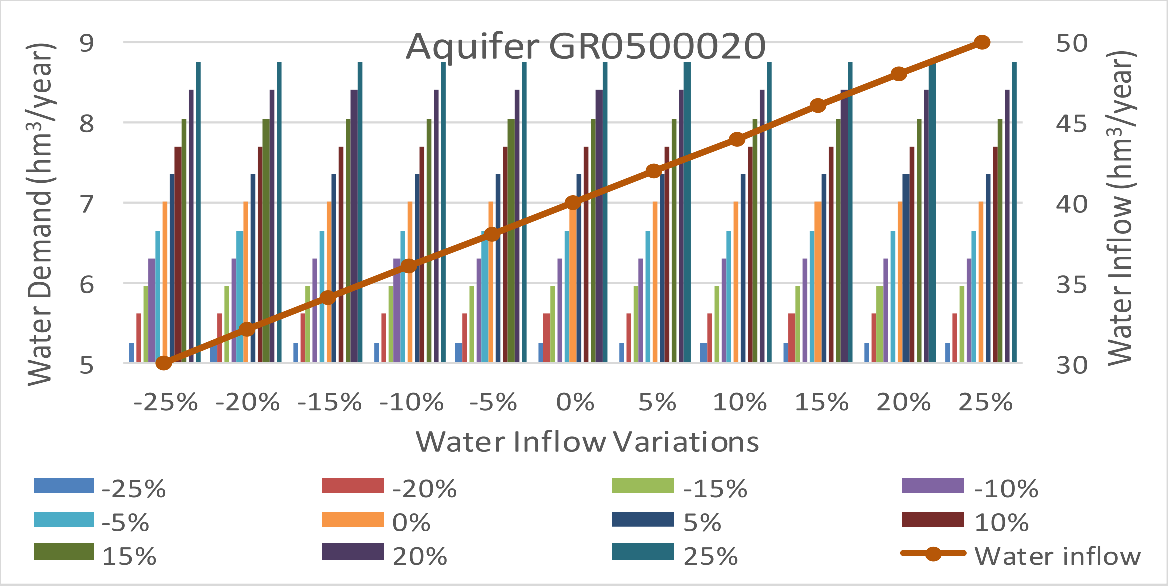


Figure 4.23: Water Inflow and Water Demand Variations (aquifer GR0500020)

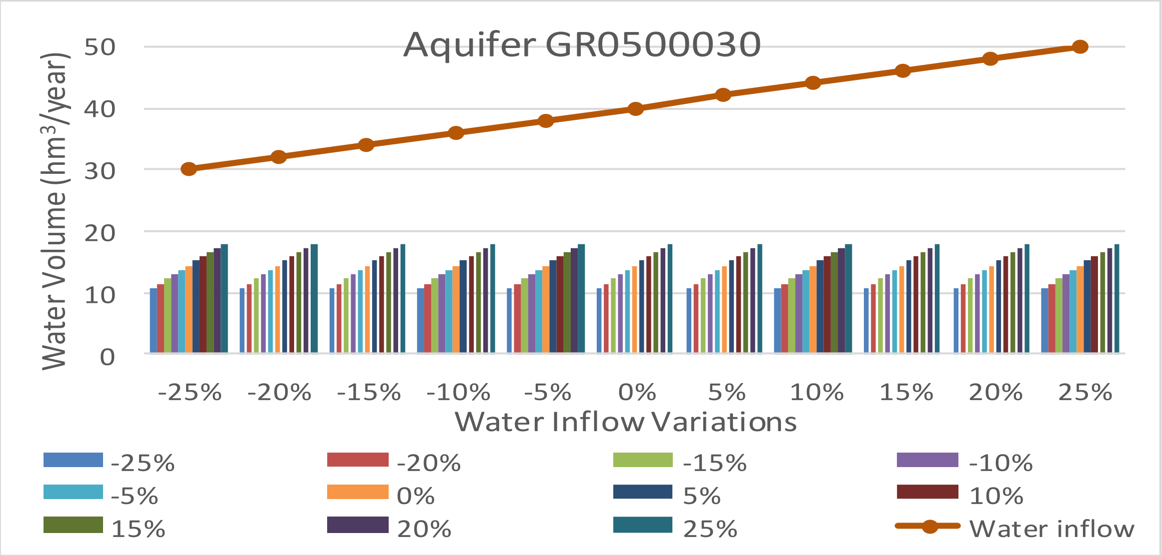


Figure 4.24: Water Inflow and Water Demand Variations (aquifer GR0500030)

From the data provided by the river basin management plan of Epirus (RBMP of Epirus, Del.10) the characteristic renewable water resources in Corfu island have been estimated as long-term average renewable water resources. The WEI for 121 scenarios has been estimated both for total water use and for drinking water use (Tables 4.47 and 4.48). WEI values for the aquifer GR0500010 ranges from 0.055 to 0.153 for total water use while for drinking water use its values range from 0.051 to 0.143 (Table 4.48). For the aquifer GR0500020 WEI values range from 0.105 to 0.292 (total water use) and from 0.06 to 0.166 (drinking water use). Finally for the aquifer GR0500030 WEI values range from 0.216 to 0.6 (total use) and from 0.069 to 0.19 (drinking water use) (Table 4.48). In all three aquifers the WEI index values are low showing that even if water demand increases by 25% and the water natural inflow reduces by 25% the aquifers will not suffer from availability problems.

Table 4.47: The 121 scenarios developed

Scenario #	WD	CWR	Scenario #	WD	CWR	Scenario #	WD	CWR
Scenario 0	present	present	Scenario 41	-10%	10%	Scenario 81	10%	-5%
Scenario 1	-25%	-25%	Scenario 42	-10%	15%	Scenario 82	10%	0%
Scenario 2	-25%	-20%	Scenario 43	-10%	20%	Scenario 83	10%	5%
Scenario 3	-25%	-15%	Scenario 44	-10%	25%	Scenario 84	10%	10%
Scenario 4	-25%	-10%	Scenario 45	-5%	-25%	Scenario 85	10%	15%
Scenario 5	-25%	-5%	Scenario 46	-5%	-20%	Scenario 86	10%	20%
Scenario 6	-25%	0%	Scenario 47	-5%	-15%	Scenario 87	10%	25%
Scenario 7	-25%	5%	Scenario 48	-5%	-10%	Scenario 88	15%	-25%
Scenario 8	-25%	10%	Scenario 49	-5%	-5%	Scenario 89	15%	-20%
Scenario 9	-25%	15%	Scenario 50	-5%	0%	Scenario 90	15%	-15%
Scenario 10	-25%	20%	Scenario 51	-5%	5%	Scenario 91	15%	-10%
Scenario 11	-20%	25%	Scenario 52	-5%	10%	Scenario 92	15%	-5%
Scenario 12	-20%	-25%	Scenario 53	-5%	15%	Scenario 93	15%	0%
Scenario 13	-20%	-20%	Scenario 54	-5%	20%	Scenario 94	15%	5%
Scenario 14	-20%	-15%	Scenario 55	-5%	25%	Scenario 95	15%	10%
Scenario 15	-20%	-10%	Scenario 56	0%	-25%	Scenario 96	15%	15%
Scenario 16	-20%	-5%	Scenario 57	0%	-20%	Scenario 97	15%	20%
Scenario 17	-20%	0%	Scenario 58	0%	-15%	Scenario 98	15%	25%
Scenario 18	-20%	5%	Scenario 59	0%	-10%	Scenario 99	20%	-25%
Scenario 19	-20%	10%	Scenario 60	0%	-5%	Scenario 100	20%	-20%
Scenario 20	-20%	15%	Scenario 61	0%	5%	Scenario 101	20%	-15%
Scenario 21	-20%	20%	Scenario 62	0%	10%	Scenario 102	20%	-10%
Scenario 22	-20%	25%	Scenario 63	0%	15%	Scenario 103	20%	-5%
Scenario 23	-15%	-25%	Scenario 64	0%	20%	Scenario 104	20%	0%
Scenario 24	-15%	-20%	Scenario 65	0%	25%	Scenario 105	20%	5%
Scenario 25	-15%	-15%	Scenario 66	5%	-25%	Scenario 106	20%	10%
Scenario 26	-15%	-10%	Scenario 67	5%	-20%	Scenario 107	20%	15%
Scenario 27	-15%	-5%	Scenario 68	5%	-15%	Scenario 108	20%	20%
Scenario 28	-15%	0%	Scenario 69	5%	-10%	Scenario 109	20%	25%
Scenario 29	-15%	5%	Scenario 70	5%	-5%	Scenario 110	25%	-25%
Scenario 30	-15%	10%	Scenario 71	5%	0%	Scenario 111	25%	-20%
Scenario 31	-15%	15%	Scenario 72	5%	5%	Scenario 112	25%	-15%
Scenario 32	-15%	20%	Scenario 73	5%	10%	Scenario 113	25%	-10%
Scenario 33	-15%	25%	Scenario 74	5%	15%	Scenario 114	25%	-5%
Scenario 34	-10%	-25%	Scenario 75	5%	20%	Scenario 115	25%	0%
Scenario 35	-10%	-20%	Scenario 76	5%	25%	Scenario 116	25%	5%
Scenario 36	-10%	-15%	Scenario 77	10%	-25%	Scenario 117	25%	10%
Scenario 37	-10%	-10%	Scenario 78	10%	-20%	Scenario 118	25%	15%
Scenario 38	-10%	-5%	Scenario 79	10%	-15%	Scenario 119	25%	20%
Scenario 39	-10%	0%	Scenario 80	10%	-10%	Scenario 120	25%	25%
Scenario 40	-10%	5%						

Table 4.48: Exploitation index at present and in the future

Country: GREECE		GR 0500010	GR 0500020	GR 0500030			GR 0500010	GR 0500020	GR 0500030
Test Area: Corfu Island					Test Area: Corfu Island				
WEI 0	Total Use	0,092	0,175	0,360	**WEI 60**	Total Use	0,097	0,184	0,379
	Drinking Water	0,086	0,100	0,114		Drinking Water	0,090	0,105	0,120
WEI 1	Total Use	0,092	0,175	0,360	**WEI 61**	Total Use	0,088	0,167	0,343
	Drinking Water	0,086	0,100	0,114		Drinking Water	0,082	0,095	0,109
WEI 2	Total Use	0,086	0,164	0,338	**WEI 62**	Total Use	0,084	0,159	0,327
	Drinking Water	0,080	0,093	0,107		Drinking Water	0,078	0,091	0,104
WEI 3	Total Use	0,081	0,154	0,318	**WEI 63**	Total Use	0,080	0,152	0,313
	Drinking Water	0,076	0,088	0,101		Drinking Water	0,074	0,087	0,099
WEI 4	Total Use	0,077	0,146	0,300	**WEI 64**	Total Use	0,077	0,146	0,300
	Drinking Water	0,071	0,083	0,095		Drinking Water	0,071	0,083	0,095
WEI 5	Total Use	0,073	0,138	0,284	**WEI 65**	Total Use	0,074	0,140	0,288
	Drinking Water	0,068	0,079	0,090		Drinking Water	0,069	0,080	0,091
WEI 6	Total Use	0,069	0,131	0,270	**WEI 66**	Total Use	0,129	0,245	0,504
	Drinking Water	0,064	0,075	0,086		Drinking Water	0,120	0,139	0,160
WEI 7	Total Use	0,066	0,125	0,257	**WEI 67**	Total Use	0,121	0,230	0,473
	Drinking Water	0,061	0,071	0,082		Drinking Water	0,112	0,131	0,150
WEI 8	Total Use	0,063	0,119	0,245	**WEI 68**	Total Use	0,114	0,216	0,445
	Drinking Water	0,058	0,068	0,078		Drinking Water	0,106	0,123	0,141
WEI 9	Total Use	0,060	0,114	0,235	**WEI 69**	Total Use	0,107	0,204	0,420
	Drinking Water	0,056	0,065	0,075		Drinking Water	0,100	0,116	0,133
WEI 10	Total Use	0,058	0,109	0,225	**WEI 70**	Total Use	0,102	0,193	0,398
	Drinking Water	0,054	0,062	0,071		Drinking Water	0,095	0,110	0,126
WEI 11	Total Use	0,055	0,105	0,216	**WEI 71**	Total Use	0,097	0,184	0,378
	Drinking Water	0,051	0,060	0,069		Drinking Water	0,090	0,105	0,120
WEI 12	Total Use	0,098	0,187	0,384	**WEI 72**	Total Use	0,092	0,175	0,360
	Drinking Water	0,091	0,106	0,122		Drinking Water	0,086	0,100	0,114
WEI 13	Total Use	0,092	0,175	0,360	**WEI 73**	Total Use	0,088	0,167	0,344
	Drinking Water	0,086	0,100	0,114		Drinking Water	0,082	0,095	0,109
WEI 14	Total Use	0,087	0,165	0,339	**WEI 74**	Total Use	0,084	0,160	0,329
	Drinking Water	0,081	0,094	0,108		Drinking Water	0,078	0,091	0,104
WEI 15	Total Use	0,082	0,156	0,320	**WEI 75**	Total Use	0,081	0,153	0,315
	Drinking Water	0,076	0,089	0,102		Drinking Water	0,075	0,087	0,100
WEI 16	Total Use	0,077	0,147	0,303	**WEI 76**	Total Use	0,077	0,147	0,302
	Drinking Water	0,072	0,084	0,096		Drinking Water	0,072	0,084	0,096
WEI 17	Total Use	0,074	0,140	0,288	**WEI 77**	Total Use	0,135	0,257	0,528
	Drinking Water	0,069	0,080	0,091		Drinking Water	0,126	0,146	0,168
WEI 18	Total Use	0,070	0,133	0,274	**WEI 78**	Total Use	0,127	0,241	0,495
	Drinking Water	0,065	0,076	0,087		Drinking Water	0,118	0,137	0,157
WEI 19	Total Use	0,067	0,127	0,262	**WEI 79**	Total Use	0,119	0,226	0,466
	Drinking Water	0,062	0,072	0,083		Drinking Water	0,111	0,129	0,148
WEI 20	Total Use	0,064	0,122	0,250	**WEI 80**	Total Use	0,112	0,214	0,440
	Drinking Water	0,060	0,069	0,079		Drinking Water	0,105	0,122	0,140
WEI 21	Total Use	0,061	0,117	0,240	**WEI 81**	Total Use	0,107	0,203	0,417
	Drinking Water	0,057	0,066	0,076		Drinking Water	0,099	0,115	0,132
WEI 22	Total Use	0,059	0,112	0,230	**WEI 82**	Total Use	0,101	0,193	0,396

	Drinking Water	0,055	0,064	0,073		Drinking Water	0,094	0,110	0,126
WEI 23	Total Use	0,104	0,198	0,408	**WEI 83**	Total Use	0,096	0,183	0,377
	Drinking Water	0,097	0,113	0,129		Drinking Water	0,090	0,104	0,120
WEI 24	Total Use	0,098	0,186	0,383	**WEI 84**	Total Use	0,092	0,175	0,360
	Drinking Water	0,091	0,106	0,121		Drinking Water	0,086	0,100	0,114
WEI 25	Total Use	0,092	0,175	0,360	**WEI 85**	Total Use	0,088	0,167	0,344
	Drinking Water	0,086	0,100	0,114		Drinking Water	0,082	0,095	0,109
WEI 26	Total Use	0,087	0,165	0,340	**WEI 86**	Total Use	0,084	0,160	0,330
	Drinking Water	0,081	0,094	0,108		Drinking Water	0,078	0,091	0,105
WEI 27	Total Use	0,082	0,157	0,322	**WEI 87**	Total Use	0,081	0,154	0,317
	Drinking Water	0,077	0,089	0,102		Drinking Water	0,075	0,088	0,101
WEI 28	Total Use	0,078	0,149	0,306	**WEI 88**	Total Use	0,141	0,268	0,552
	Drinking Water	0,073	0,085	0,097		Drinking Water	0,131	0,153	0,175
WEI 29	Total Use	0,074	0,142	0,291	**WEI 89**	Total Use	0,132	0,252	0,518
	Drinking Water	0,069	0,081	0,092		Drinking Water	0,123	0,143	0,164
WEI 30	Total Use	0,071	0,135	0,278	**WEI 90**	Total Use	0,124	0,237	0,487
	Drinking Water	0,066	0,077	0,088		Drinking Water	0,116	0,135	0,155
WEI 31	Total Use	0,068	0,129	0,266	**WEI 91**	Total Use	0,118	0,224	0,460
	Drinking Water	0,063	0,074	0,084		Drinking Water	0,109	0,127	0,146
WEI 32	Total Use	0,065	0,124	0,255	**WEI 92**	Total Use	0,111	0,212	0,436
	Drinking Water	0,061	0,071	0,081		Drinking Water	0,104	0,121	0,138
WEI 33	Total Use	0,063	0,119	0,245	**WEI 93**	Total Use	0,106	0,201	0,414
	Drinking Water	0,058	0,068	0,078		Drinking Water	0,098	0,115	0,131
WEI 34	Total Use	0,110	0,210	0,432	**WEI 94**	Total Use	0,101	0,192	0,394
	Drinking Water	0,103	0,120	0,137		Drinking Water	0,094	0,109	0,125
WEI 35	Total Use	0,104	0,197	0,405	**WEI 95**	Total Use	0,096	0,183	0,376
	Drinking Water	0,096	0,112	0,129		Drinking Water	0,090	0,104	0,119
WEI 36	Total Use	0,097	0,185	0,381	**WEI 96**	Total Use	0,092	0,175	0,360
	Drinking Water	0,091	0,105	0,121		Drinking Water	0,086	0,100	0,114
WEI 37	Total Use	0,092	0,175	0,360	**WEI 97**	Total Use	0,088	0,168	0,345
	Drinking Water	0,086	0,100	0,114		Drinking Water	0,082	0,095	0,109
WEI 38	Total Use	0,087	0,166	0,341	**WEI 98**	Total Use	0,085	0,161	0,331
	Drinking Water	0,081	0,094	0,108		Drinking Water	0,079	0,092	0,105
WEI 39	Total Use	0,083	0,158	0,324	**WEI 99**	Total Use	0,147	0,280	0,576
	Drinking Water	0,077	0,090	0,103		Drinking Water	0,137	0,159	0,183
WEI 40	Total Use	0,079	0,150	0,309	**WEI 100**	Total Use	0,138	0,263	0,540
	Drinking Water	0,073	0,085	0,098		Drinking Water	0,128	0,149	0,171
WEI 41	Total Use	0,075	0,143	0,295	**WEI 101**	Total Use	0,130	0,247	0,508
	Drinking Water	0,070	0,081	0,093		Drinking Water	0,121	0,141	0,161
WEI 42	Total Use	0,072	0,137	0,282	**WEI 102**	Total Use	0,123	0,233	0,480
	Drinking Water	0,067	0,078	0,089		Drinking Water	0,114	0,133	0,152
WEI 43	Total Use	0,069	0,131	0,270	**WEI 103**	Total Use	0,116	0,221	0,455
	Drinking Water	0,064	0,075	0,086		Drinking Water	0,108	0,126	0,144
WEI 44	Total Use	0,066	0,126	0,259	**WEI 104**	Total Use	0,110	0,210	0,432
	Drinking Water	0,062	0,072	0,082		Drinking Water	0,103	0,120	0,137
WEI 45	Total Use	0,117	0,222	0,456	**WEI 105**	Total Use	0,105	0,200	0,411
	Drinking Water	0,108	0,126	0,145		Drinking Water	0,098	0,114	0,131
WEI 46	Total Use	0,109	0,208	0,428	**WEI 106**	Total Use	0,100	0,191	0,393
	Drinking Water	0,102	0,118	0,136		Drinking Water	0,093	0,109	0,125
WEI 47	Total Use	0,103	0,196	0,402	**WEI 107**	Total Use	0,096	0,183	0,376
	Drinking Water	0,096	0,111	0,128		Drinking Water	0,089	0,104	0,119
WEI 48	Total Use	0,097	0,185	0,380	**WEI 108**	Total Use	0,092	0,175	0,360

	Drinking Water	0,090	0,105	0,121		Drinking Water	0,086	0,100	0,114
WEI 49	Total Use	0,092	0,175	0,360	**WEI 109**	Total Use	0,088	0,168	0,346
	Drinking Water	0,086	0,100	0,114		Drinking Water	0,082	0,096	0,110
WEI 50	Total Use	0,087	0,166	0,342	**WEI 110**	Total Use	0,153	0,292	0,600
	Drinking Water	0,081	0,095	0,109		Drinking Water	0,143	0,166	0,190
WEI 51	Total Use	0,083	0,158	0,326	**WEI 111**	Total Use	0,144	0,273	0,563
	Drinking Water	0,077	0,090	0,103		Drinking Water	0,134	0,156	0,179
WEI 52	Total Use	0,079	0,151	0,311	**WEI 112**	Total Use	0,135	0,257	0,529
	Drinking Water	0,074	0,086	0,099		Drinking Water	0,126	0,146	0,168
WEI 53	Total Use	0,076	0,145	0,297	**WEI 113**	Total Use	0,128	0,243	0,500
	Drinking Water	0,071	0,082	0,094		Drinking Water	0,119	0,138	0,159
WEI 54	Total Use	0,073	0,139	0,285	**WEI 114**	Total Use	0,121	0,230	0,474
	Drinking Water	0,068	0,079	0,090		Drinking Water	0,113	0,131	0,150
WEI 55	Total Use	0,070	0,133	0,274	**WEI 115**	Total Use	0,115	0,219	0,450
	Drinking Water	0,065	0,076	0,087		Drinking Water	0,107	0,125	0,143
WEI 56	Total Use	0,123	0,233	0,480	**WEI 116**	Total Use	0,110	0,208	0,429
	Drinking Water	0,114	0,133	0,152		Drinking Water	0,102	0,119	0,136
WEI 57	Total Use	0,115	0,219	0,450	**WEI 117**	Total Use	0,105	0,199	0,409
	Drinking Water	0,107	0,125	0,143		Drinking Water	0,097	0,113	0,130
WEI 58	Total Use	0,108	0,206	0,424	**WEI 118**	Total Use	0,100	0,190	0,391
	Drinking Water	0,101	0,117	0,134		Drinking Water	0,093	0,108	0,124
WEI 59	Total Use	0,102	0,194	0,400	**WEI 119**	Total Use	0,096	0,182	0,375
	Drinking Water	0,095	0,111	0,127		Drinking Water	0,089	0,104	0,119
WEI 60	Total Use	0,097	0,184	0,379	**WEI 120**	Total Use	0,092	0,175	0,360
	Drinking Water	0,090	0,105	0,120		Drinking Water	0,086	0,100	0,114

The analysis results show that the WEI index values are lower for aquifer GR0500010 and higher for aquifer GR0500030 (Figure 12).

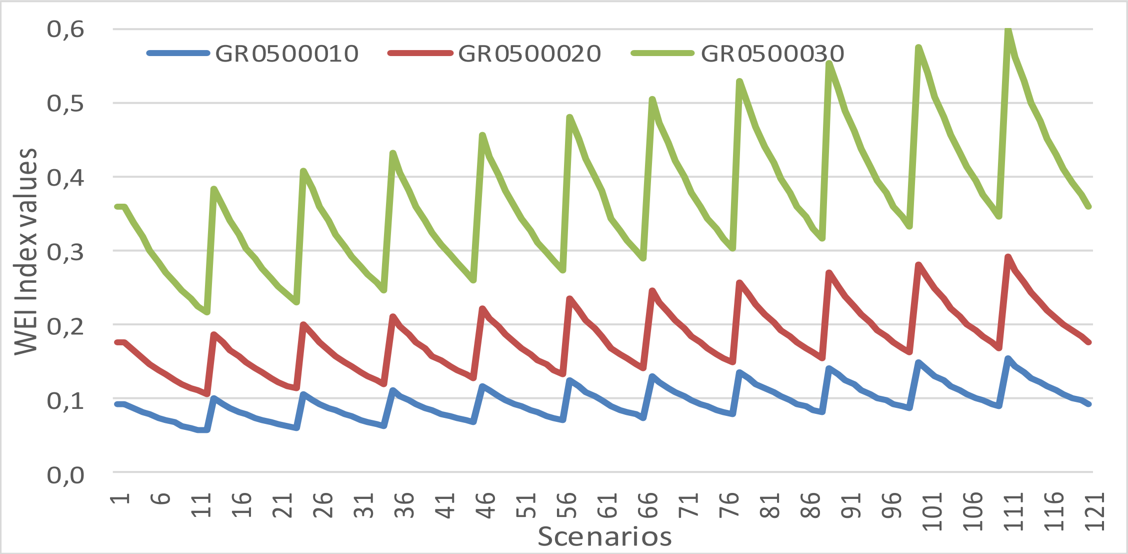


Figure 4.25: WEI Index Values for the three aquifers for all 121 scenarios (total water use)

For aquifers GR0500010 and GR 0500020 all WEI values are below 0.5 and are at low risk. For the aquifer GR0500030 most of the WEI values are below 0.5 but there are some values between 0.51-0.70 indicating that under such conditions the aquifer will face possible difficulties (according Table 4.49) and are given in Table 4.49. These values are marked in Table 4.48. When the water demand will increase from 10 to 25% while at the same time the characteristic renewable water resources will decrease from 10 to 25% then the aquifer may face some water availability difficulties.

Table 4.49: WEI thresholds for defining risks regarding water availability

WD variation	CWR variation	WEI values	WD variation	CWR variation	WEI values
10%	-25%	0.528	20%	-15%	0.508
15%	-25%	0.552	25%	-25%	0.600
15%	-20%	0.518	25%	-20%	0.563
20%	-25%	0.576	25%	-15%	0.529
20%	-20%	0.540	25%	-10%	0.500

The River basin management plan (RBMP of Epirus, Del.10) evaluated the quantitative status of the groundwater bodies in Corfu Island. According to the management plan the methodology used include the monitoring of the groundwater level in drillings and the water flow in springs. The Institute of Geology and Mineral Exploration monitors the water level in 19 drillings and the water flow in 5 springs in aquifer GR0500010 (Figure 4.26) (RBMP of Epirus, Del.10). The results show that the water volumes abstracted are low compared to the annual renewable water reserves. These abstractions do not influence the connected surface water bodies or ecosystems.

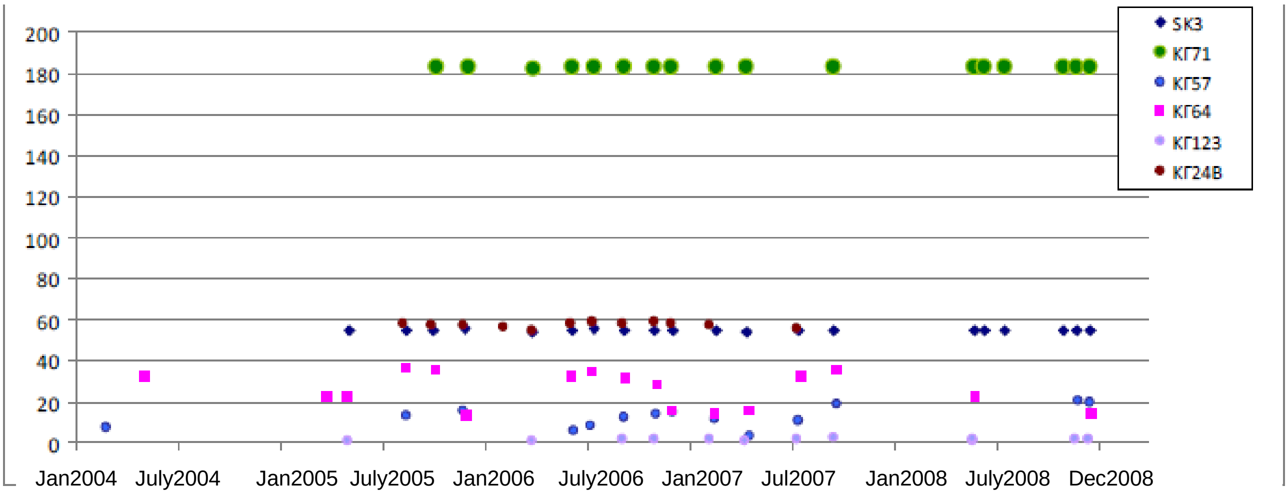


Figure 4.26: Variations of the groundwater level of drillings in GR0500010 (RBMP of Epirus, Del.10)

The obtained data show that there is no over exploitation of the aquifer. The variations of the groundwater level and the springs' flow follow the rates of the natural discharge and inflow of the aquifer. Therefore the groundwater system is evaluated to be in good quantitative status and is marked in green (Figure 4.27) (RBMP of Epirus, Del.10).

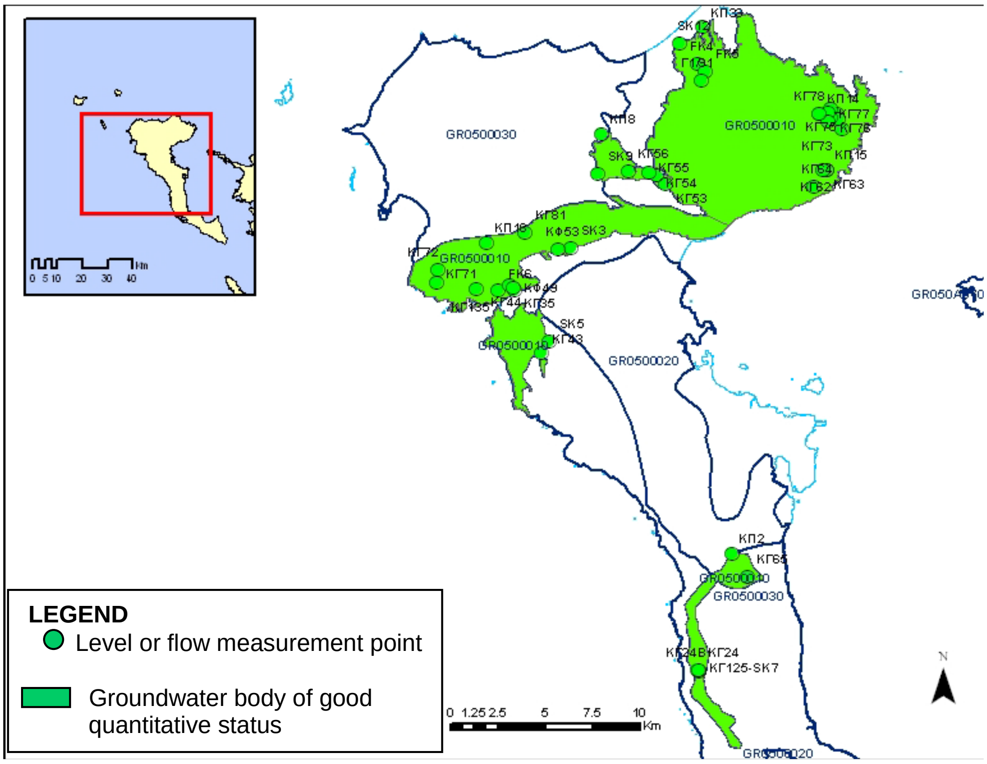


Figure 4.27: Quantitative status of the groundwater system GR0500010 (RBMP of Epirus, Del.10)

The Institute of Geology and Mineral Exploration monitors the water level in 25 drillings and in 23 wells and the water flow in 8 springs in aquifer GR0500020 (Figure 4.28) (RBMP of Epirus, Del.10). The results show that the water volumes abstracted are low compared to the annual renewable water reserves. These abstractions do not influence the connected surface water bodies or ecosystems. The obtained data show that there is no over exploitation of the aquifer. The variations of the groundwater level and the flow of the springs follow the rates of the natural discharge and inflow of the groundwater body. The system is found to be in good quantitative status and is marked in green (Figure 4.29) (RBMP of Epirus, Del.10).

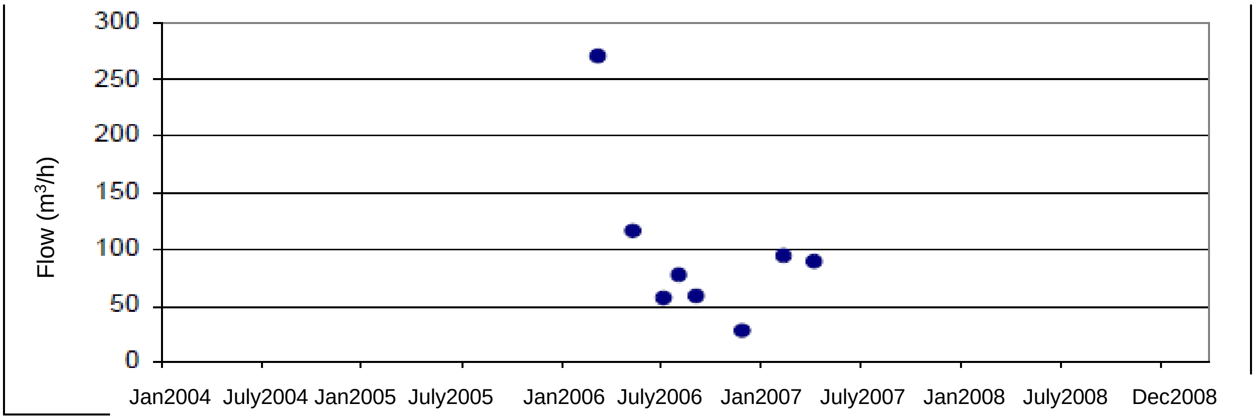


Figure 4.28: Variations of the flow in the spring KΠ29 in GR0500020 (RBMP of Epirus, Del.10)

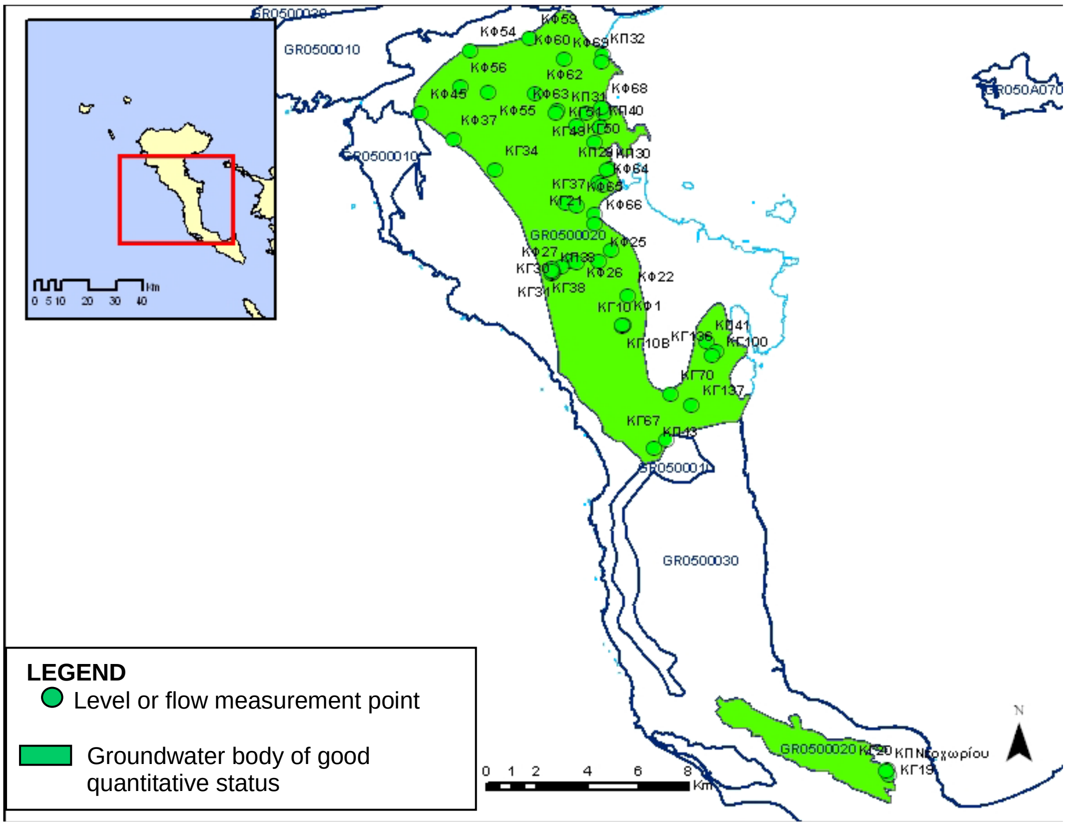


Figure 4.29: Quantitative status of the groundwater system GR0500020 (RBMP of Epirus, Del.10)

The Institute of Geology and Mineral Exploration monitors the groundwater level in 39 drillings, 51 wells and the water flow in 7 springs in aquifer GR0500030 (RBMP of Epirus, Del.10) (Figure 4.30). The obtained data show that the aquifer does not suffer from over exploitation. The variations in the groundwater level and in the water flow follow the rates of natural discharge and inflow. Thus the aquifer is found to be in good quantitative status and is marked in green (Figure 4.31) (RBMP of Epirus, Del.10).

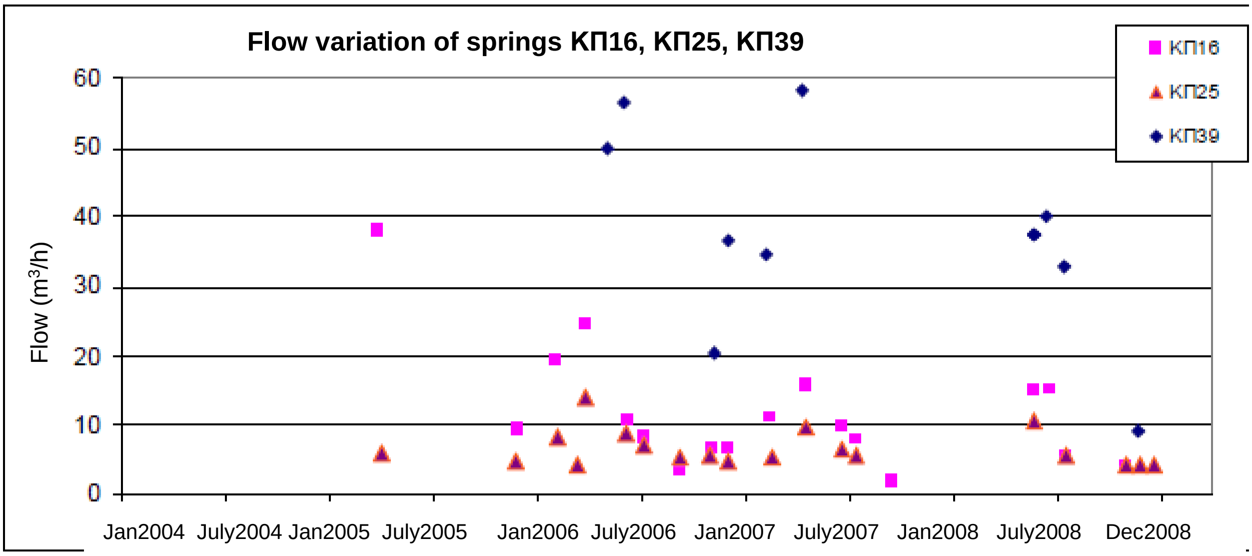


Figure 4.30: Variations of the springs' water flow in aquifer GR0500030 (RBMP of Epirus, Del.10)

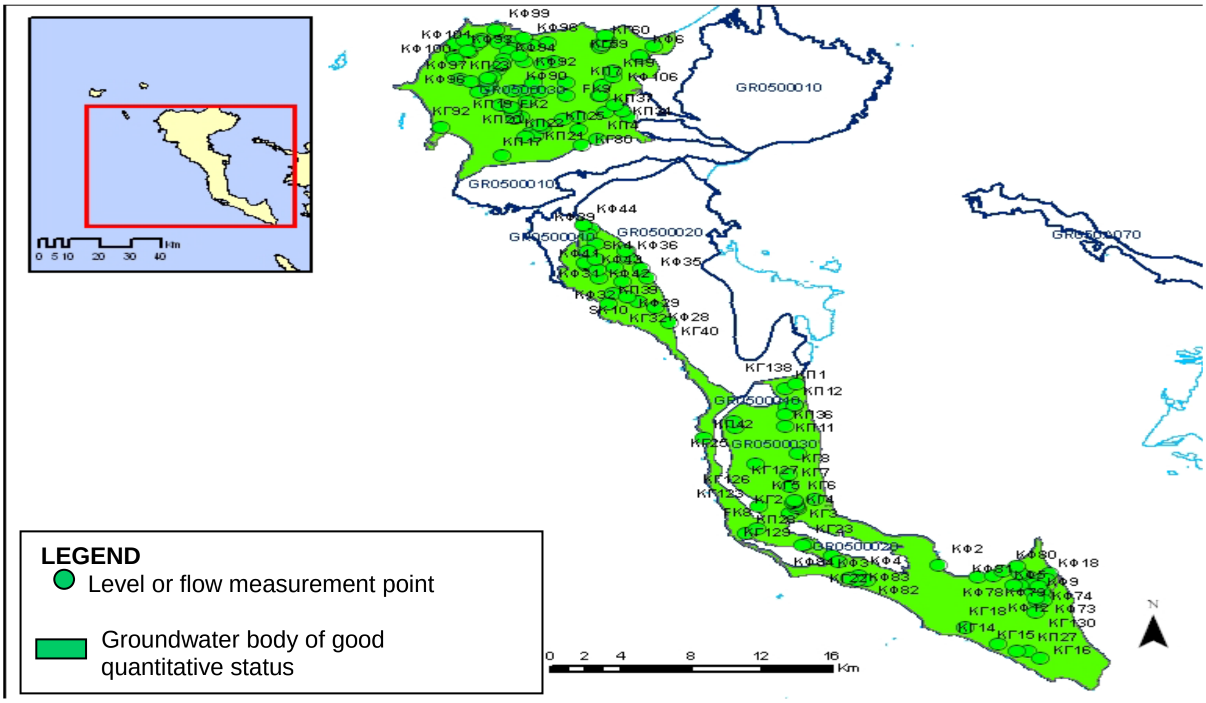


Figure 4.31: Quantitative status of the groundwater system GR0500030 (RBMP of Epirus, Del.10)

4.7. RESULTS

Isonzo plain (Italy) [Annex 1]

In the case of Isonzo/Soča pilot area, a porous aquifer was studied. Compared to the karstic ones, it has large buffer capacity being characterized by long-term averages recharge from precipitation. In these conditions, changes in renewable water resources can be considered equal to those of average conditions. Thus in this area are directly studied the renewable water resources. The situation is satisfactory in all the Climate Change defined scenarios. The WEI indexes always remain under the value of 0,5, threshold showing a very low risk. Only a value of 0,02 separates the total from the drinking use indicating that most part of the withdrawn waters from wells are used for drinking purposes.

Ostuni (Italy) [Annex 2]

The Ionic sub-domain of the Ostuni test area represents the most vulnerable system, having a present WEI equal to 0.96. In particular the WEI values for the reference period 1961-1990 are reported based on GW recharge simulations given by the distributed hydrological model G-MAT and the simplified multiregressive model SPEI-Q adopting in both cases climate observations as input. As expected WEI estimates for reference climatic conditions are similar for both of the two hydrological models and in all the three WD scenarios. The WEI estimations for the three future climate scenarios were evaluated by running the SPEI-Q model using the three climate simulations as input. The three models, which predict increasingly dry climate (from RegCM3 to PROMES), produced remarkable worsening of the WEI with increase from +4% to +45% when the present water demand (WD 0) is considered. As far as concerns the adopted WD scenarios, the 25% reduction in total WD seemed to be a suitable adaptation target in order to restore the reduced GW recharge due to altered precipitation and temperature of climate change scenarios. Less prone to shortage conditions appears the Adriatic sub-domain of the Ostuni test area, whose current WEI (under current water exploitation) is estimated from G-MAT equal to 0.84 and from the SPEI-Q model equal to 0.85. The WD1 increasing demand scenario under present climate conditions leads to a slight imbalance between demand and recharge to the aquifer, with values of WEI equal to 1.05 and 1.07 from G-MAT and SPEI-Q, respectively. As for the Ionic area, the three RCM scenarios taken into account leads to different results: RegCM3 forecast possible shortages only in case of a water demand increasing (WEI = 1.13 under RegCM3 and WD1 scenarios); on the other hand, the Aladin and Promes RCM scenarios, both forecasting a decreasing trend in precipitation, by 4.9% and 6.7%, respectively, lead to a small imbalance between recharge to aquifer and exploitation under the current water demand (WEI = 1.08 and 1.13); such an imbalance significantly increases if the increased demand scenario WD1 is taken into account. As for the Ionic area, the 25% reduction in total WD seemed to be a suitable adaptation target in order to restore the reduced GW recharge.

However, while the WEI value is less than 1 adopting the RegCM3 scenario and the present WD, Aladin and Promes scenarios forecast an increase of the WEI values of 8% and 13% respectively. Indeed, the objective of the research done was not to precisely quantify some projections of the future changes, but rather to establish a framework for water resource evaluation and management which will also take account of the potential changes in their hydrological determinants. It is to be expected in particular that an appropriate environmental flow will have to be evaluated and ensured in coastal karst aquifers in order to effectively contrast sea water intrusion and preserve as much as possible the only local water resource from quantitative and qualitative deterioration.

Northern Istria – springs Sv. Ivan, Gradole and Bulaž (Croatia) [Annex 5]
Based on long-term measured data of abstracted quantities from Sv. Ivan, Gradole and Bulaž spring Water demand was assessed for Northern Istria test area, based on long-term measured data of abstracted quantities from Sv. Ivan, Gradole and Bulaž spring. Two cases were considered, one for average conditions, and second for characteristic renewable water resource. Analyzed water demand data was compared to measured and modelled water resources to calculate water exploitation index. As expected for average conditions, i.e. average annual discharges, the water exploitation index showed very low risk. On the other hand, for characteristic renewable water resource, which analyzed water demand in critical month of August, water exploitation index showed possible difficulties for present state. If the water use increases by 25%, the water exploitation index suggests high risk, and if it decreases by the same amount, the water exploitation index shows almost no risk.

Southern Dalmatia – Spring Prud and Blatsko polje (Croatia) [Annex 6]
For the water demand assessment of southern Dalmatia test area, two cases were considered, one for average conditions, and second for characteristic renewable water resource. Analyzed water demand data was compared to measured and modelled water resources to calculate water exploitation index. For the cases of average conditions, i.e. average annual discharges, the water exploitation index showed very low risk at both test areas, spring Prud and Blatsko polje. On the other hand, for characteristic renewable water resource, which analyzed water demand in critical month of August, water exploitation index showed drastic changes for Blatsko polje test area for all cases. As Blato polje catchment area is relatively small, even small changes in water demand and water resources can lead to problems in water supply. Contrary, at the Prud test area the water exploitation index shows almost no risk in the case of characteristic renewable water resource. The reason for this is the fact that the water supply system at the spring Prud is currently using only 10% of its minimum capacity, and the number of users connected to its supply system is still very low. However, in the near future it is planned to double increase of the water supply system, and future plans include a substantially greater increase of the water supply network which could lead to problems in the water supply. Both water supply systems are typical seasonal with uneven consumption during the year which significantly increases the risk for the use of water in the summer months.

Nikšić (Montenegro) [Annex 8]
Based on results presented for Nikšić area, there is decrease in available water quantity for groundwater recharge. Significant deficit is observed in summer season given the projected decrease in precipitation for all scenarios.
With respect to dynamic groundwater recharge there are possible difficulties at the annual level for assumed maximum abstraction rate of 0.6 m3/ s during the summer season

(Scenario WD AASM), similar WEI is generated for all four future scenarios with rank of 0.51 for Aladdin and RegCM3, 0.52 for Promes and 0.5 for TOB.

For higher water demand in the future, i.e., Scenario 1, namely increase by 25 % WIE analyses indicate possible difficulties, except for Promes scenario that indicate strong risk under the decrease in precipitation and increase in demand by 25 % for most conservative scenario (AASM).

With respect to quantity of water available for recharge and resulting dynamic groundwater storage, deficit during the summer season is observed for present and all four future scenarios.

There is need for more monitoring and accurate data and hydrogeologic modeling. Although based on projections applied in this study evidence exist that water availability is at risk, specifically during the summer season it is not possible to provide accurate comments without more data on seasonal recharge data.

Based on available data, the highest risk exists during the summer season, given the deficit in groundwater storage. However there more detailed assessment is required for Test Area Nikšić water availability and water demand. Very likely, an additional quantity of water will be need in the future to sustain water supply within the system under the projected changes in water balance and increased water demand.

Corfu Island (Greece) [Annex 10]

The report deals with the water resources availability in Corfu Island test area in Greece. The water demand for irrigation in the island is 47% while for drinking purposes is 53%. The majority of the water volume needed (more than 98%) is abstracted from the aquifers for all uses. Since no data were available for the evaluation of the impacts of climate change to water resources the analysis presented in this report includes the variations of water demand and water inflow in the three aquifers from -25% to +25% at a step of 5%. The WEI is estimated for all three aquifers and for 121 scenarios both for total water use and for drinking water use. The results showed that even if the water demand increases by 25% and the water inflow decreases by 25% there is no water exploitation in the groundwater systems. The results are verified by the evaluation of the quantitative status performed in the river basin management plan of Epirus for the River basin of Corfu.

According to the common methodological approach explained in chapter 4.1. FBs had to calculate the total demand and if possible drinking water demand in test areas.

It was agreed that water demand should be calculated for three scenarios:

- scenario 0 (WD_0): present water demand
- scenario 1 (WD_1): future water demand 1 (present water demand increased by 25%)
- scenario 2 (WD_2): future water demand 2 (present water demand decreased by 25%)

From FBs' reports the present water demand on test areas (Scenario 0/WD_0) is extracted and presented in table 4.50. For all test areas the total use water demand is defined while the drinking water demand is defined for test areas: Isonzo plain, Ostuni, Northern Istria and Cofru Island.

Table 4.50: Present water demand (m^3/s) on test areas (Scenario 0 / WD_0)

Country	Test area	Scenario 0 / WD_0	
		Total use	Drinking water
Italy	Isonzo/Soča plain	3.81	1.22
Italy	Ostuni- Adriatic	5.25	0.78
Italy	Ostuni- Ionic	5.05	1.31
Croatia	Northern Istria – average annual abstraction	0.61	0.52
	Northern Istria – long-term mean of August abstraction	0.95	0.80
	Southern Dalmatia – Prud spring average annual abstraction	0.116	-
	Southern Dalmatia – Prud spring long-term mean of August abstraction	0.176	-
	Southern Dalmatia – Blatsko polje average annual abstraction	0.034	-
	Southern Dalmatia – Blatsko polje long-term mean of August abstraction	0.046	-
Montenegro	Nikšić - average annual abstraction	0.40	-
	Nikšić - abstraction that incorporate max values during the summer	0,45	-
Greece	Corfu Island GR0500010 –mean annual abstraction	0.22	0.20
	Corfu Island GR0500020–mean annual abstraction	0.22	0.13
	Corfu Island GR0500030–mean annual abstraction	0.46	0.15

Four different combinations of water demand scenarios and renewable water resources (average conditions - AC and characteristic renewable water resource – CRWR from table 3) were considered:

- $WEI_1 = WD_0 / WR_{1961 – 1990}$
- $WEI_2 = WD_0 / WR_{2021 - 2050}$
- $WEI_3 = WD_1 / WR_{2021 - 2050}$
- $WEI_4 = WD_2 / WR_{2021 - 2050}$

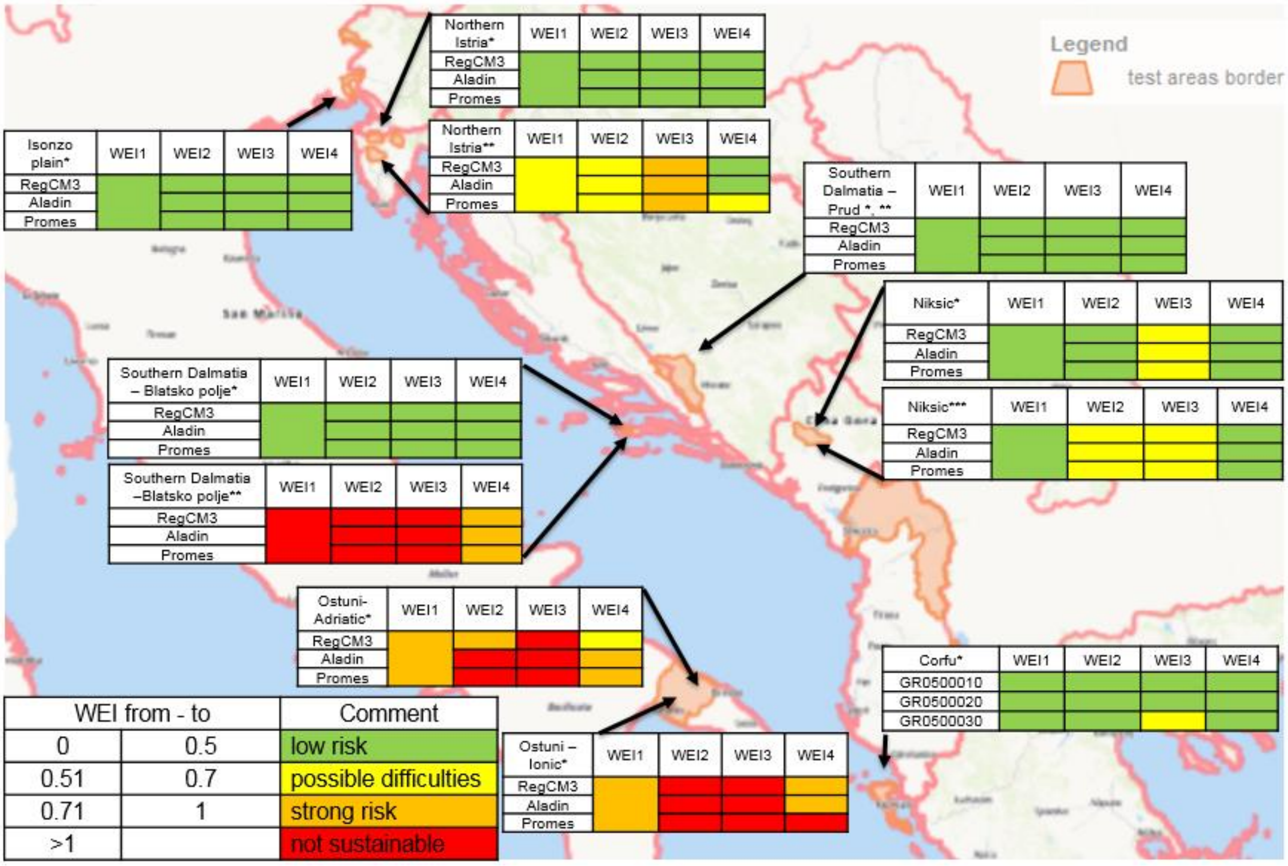
Results from calculations made for test areas according to defined common methodological approach are given in Table 4.51. and presented for total water use on Figure 4.32.

Table 4.51: Exploitation index at present (WEI_1) and in the future for different scenarios (WEI_2, WEI_3 and WEI_4)

Country	Test area		WEI_1		Climate models	WEI_2		WEI_3		WEI_4	
			Total use	Drinking water		Total use	Drinking water	Total use	Drinking water	Total use	Drinking water
Italy	Isonzo/Soča plain	AAAQ / ACWR	0.45	0.06	RegCM3	0.45	0.06	0.46	0.05	0.43	0.08
					Aladin	0.45	0.06	0.46	0.04	0.43	0.08
					Promes	0.44	0.05	0.45	0.04	0.42	0.08
	Ostuni – Adriatic*	AAAQ / ACWR	0.85		RegCM3	0.90		1.13		0.68	
					Aladin	1.08		1.35		0.81	
					Promes	1.13		1.42		0.85	
	Ostuni – Ionic*	AAAQ / ACWR	0.98		RegCM3	1.04		1.30		0.78	
					Aladin	1.05		1.31		0.79	
					Promes	1.45		1.82		1.09	
Croatia	Northern Istria - springs Sv. Ivan, Bulaž and Gradole	AAAQ / ACWR	0.13	0.11	RegCM3	0.13	0.11	0.17	0.14	0.10	0.08
					Aladin	0.14	0.12	0.17	0.15	0.10	0.09
					Promes	0.13	0.11	0.16	0.14	0.10	0.08
		LTMAMAAQ / CRWR	0.59	0.50	RegCM3	0.63	0.54	0.79	0.67	0.49	0.41
					Aladin	0.64	0.54	0.80	0.68	0.49	0.42
					Promes	0.69	0.59	0.86	0.73	0.53	0.45
	Southern Dalmatia – Prud spring	AAAQ / ACWR	0.02		RegCM3	0.02		0.03		0.02	
					Aladin	0.02		0.03		0.01	
					Promes	0.02		0.03		0.02	
		LTMAMAAQ / CRWR	0.05		RegCM3	0.06		0.07		0.04	
					Aladin	0.06		0.07		0.04	
					Promes	0.08		0.08		0.05	
	Southern Dalmatia – Blatsko polje	AAAQ / ACWR	0.12		RegCM3	0.13		0.17		0.10	
					Aladin	0.15		0.18		0.11	
					Promes	0.15		0.19		0.18	
		LTMAMAAQ / CRWR	1.07		RegCM3	1.10		1.38		0.83	
					Aladin	1.15		1.45		0.88	
					Promes	1.18		1.49		0.90	
Montenegro	Nikšić	AAAQ / ACWR	0.32		RegCM3	0.45		0.57		0.34	
					Aladin	0.45		0.56		0.34	
					Promes	0.47		0.58		0.35	
		AMS / ACWR	0.36		RegCM3	0.51		0.64		0.38	
					Aladin	0.51		0.63		0.38	
					Promes	0.52		0.65		0.39	
Greece**	Corfu - GR0500010	AAAQ / ACWR	0.09	0.09	Expert evaluation	0.12	0.11	0.15	0.14	0.09	0.09
	Corfu - GR0500020	AAAQ / ACWR	0.18	0.10	Expert evaluation	0.23	0.13	0.29	0.17	0.18	0.10
	Corfu - GR0500030	AAAQ / ACWR	0.36	0.11	Expert evaluation	0.48	0.15	0.60	0.19	0.36	0.11

ACWR – average conditions water resource
CRWR - characteristic renewable water resource
AAAQ – average annual abstracted quantities
LTMAMAAQ – long-term mean of August monthly averages of abstracted quantities
AMS- abstraction that incorporate max values during the summer
* In Ostuni test area the ecological demand was calculated within the total demand.
** For Greece (scenarios from FB16 report [Annex 10] that were used are):

WEI (2) - scenario 56 (present WD; CWR-25%)
WEI (3) - scenario 110 (future WD (present WD+25%); CWR-25%)
WEI (4) - scenario 1 (future WD (present WD-25%); CWR-25%)



Isonzo plain*	WEI1	WEI2	WEI3	WEI4
RegCM3	🟩	🟩	🟩	🟩
Aladin		🟩	🟩	🟩
Promes		🟩	🟩	🟩

Northern Istria*	WEI1	WEI2	WEI3	WEI4
RegCM3	🟩	🟩	🟩	🟩
Aladin		🟩	🟩	🟩
Promes		🟩	🟩	🟩

Northern Istria**	WEI1	WEI2	WEI3	WEI4
RegCM3	🟨	🟨	🟧	🟩
Aladin		🟨	🟧	🟩
Promes		🟨	🟧	🟨

Southern Dalmatia – Prud *, **	WEI1	WEI2	WEI3	WEI4
RegCM3	🟩	🟩	🟩	🟩
Aladin		🟩	🟩	🟩
Promes		🟩	🟩	🟩

Niksic*	WEI1	WEI2	WEI3	WEI4
RegCM3	🟩	🟩	🟨	🟩
Aladin		🟩	🟨	🟩
Promes		🟩	🟨	🟩

Niksic***	WEI1	WEI2	WEI3	WEI4
RegCM3	🟩	🟨	🟨	🟩
Aladin		🟨	🟨	🟩
Promes		🟨	🟨	🟩

Southern Dalmatia – Blatsko polje*	WEI1	WEI2	WEI3	WEI4
RegCM3	🟩	🟩	🟩	🟩
Aladin		🟩	🟩	🟩
Promes		🟩	🟩	🟩

Southern Dalmatia –Blatsko polje**	WEI1	WEI2	WEI3	WEI4
RegCM3	🟥	🟥	🟥	🟧
Aladin		🟥	🟥	🟧
Promes		🟥	🟥	🟧

Ostuni-Adriatic*	WEI1	WEI2	WEI3	WEI4
RegCM3	🟧	🟧	🟥	🟨
Aladin		🟥	🟥	🟧
Promes		🟥	🟥	🟧

Corfu*	WEI1	WEI2	WEI3	WEI4
GR0500010	🟩	🟩	🟩	🟩
GR0500020	🟩	🟩	🟩	🟩
GR0500030	🟩	🟩	🟨	🟩

WEI from - to		Comment
0	0.5	🟩 low risk
0.51	0.7	🟨 possible difficulties
0.71	1	🟧 strong risk
>1		🟥 not sustainable

Ostuni – Ionic*	WEI1	WEI2	WEI3	WEI4
RegCM3	🟧	🟥	🟥	🟧
Aladin		🟥	🟥	🟧
Promes		🟥	🟥	🟥

ACWR – average conditions water resource
CRWR - characteristic renewable water resource
AAAQ – average annual abstracted quantities
LTMAMAAQ – long-term mean of August monthly averages of abstracted quantities
AMS- abstraction that incorporate max values during the summer
* AAAQ / ACWR
** LTMAMAAQ / CRWR
*** AMS / ACWR

Figure 4.32: Exploitation index for total use at present (WEI$_1$) and in the future for different scenarios (WEI$_2$, WEI$_3$ and WEI$_4$)

5. CONCLUSIONS ON WATER RESOURCES AVAILABILITY ON TEST AREAS

In the Adriatic area 9 test areas were selected to analyse the risk on water resources availability in the future 2021-2050 period under the climate change impact in relation to the reference 30-year climatological period 1961-1990.

The availability of water resources was analysed from the aspect of total use and use for drinking purpose.

Water resources analysed within test areas have cross-border or cross-regional character and their availability can affect the water supply in more than one country or region within the country.

Temperature and precipitation scenarios from three Regional Climate Models (RegCM3, Promes and Aladin) have been developed through downscaling to observed land data by FBs in activity 4.1 (except for Albanian and Greek test areas).

In general, results from this activity show an increase of temperature in the Adriatic region and on test areas (that is statistical significant). The trends in precipitation are less reliable, showing changes in annual precipitations that decrease on some areas and increase in other. Precipitation trends are not statistically significant.

The most significant decreases in precipitation are observed in the southern areas of the Adriatic region, resulting in a stronger reduction in terms of water availability.

From water resources availability analyses conducted in activity 4.2. and presented in previous chapters it can be concluded that the climate change will have an impact on the water resources availability in the future period 2021-2050 causing the decrease in available water resources quantities. Such a decrease is mainly due to an increase in temperature.

This can be concluded from both long-term average water resources conditions and is even more emphasised on characteristic renewable water resources conditions (e.g. critical period) as on Croatian test areas. (The only exception is Bulaž spring in Croatia where, for input data from Promes climate model, the increase in renewable water resources quantity was calculated.)

From comparison of water resources availability for baseline period (1961-1990) and the future period (2021-2050) the estimated decrease on test areas varies from -0,3 to –60,3%. Test areas in the Northern part of the Adriatic region (e.g. Northern Istria) show lower changes than those in the Southern part of the Adriatic region (Southern Dalmatia, Ostuni, Drini Basin). The highest changes in water availability (-7,8 to -60,3%) can be noticed if results from the Promes climate model are used, following by Aladin (-4,1 to 29,4%). The lowest changes (-0,3 to -30,2%) are noticed if the RegCM3 climate model is used.

FBs applied different hydrological models to estimate the change in water resources availability. These models are explained in more detail in this report.

The evaluation of water demand and calculation of water exploitation indexes according to common methodology selected by FBs that include different scenarios for water demand (present and future) and take into account the decrease (and in some cases increase) in available water resources quantity, caused by the climate change impact, have shown different risks on test areas.

The selected common methodology applied on test areas has given better understanding of the impact of climate change on water resources in the Adriatic region, as well as possible risks of deterioration of water supply possibility from those resources. By analysing different scenarios for water demand in future possible problems were pointed out and analysed in order to timely implement appropriate measures.

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7. ANNEXES

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