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Water Management Strategies against
Water Scarcity in the Alps

Work Package 6
Monitoring and Modelling

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1 General overview on the aims and objectives of the workpackage

Previous projects indicate that local or regional characteristics of landscape determine different climate conditions, especially temperature and precipitation, two important elements determining natural hydro-graphic conditions. The role of the Pilot Sites within the Alp-Water-Scarce project was to evaluate such differences on a local and regional scale. As the project is trans-national, the tradition, experience, and reactions of people to water shortages are different in different countries and in different regions. Sharing the best practices for solving problems connected with water scarcity can make an important contribution to avoid problems with water in the future whether they have natural or anthropogenic origin.

Monitoring and modelling contributes to the operational methodology of the Early Warning System. It is based on the analyses of trends on long-term meteorological data (temperature and precipitation), water discharge monitoring, on pilot-site specific modelling and on the development of climate and anthropogenic scenarios for the next decades. Past runoff data and groundwater recharge were used in the analyses to evaluate the needs and threats for human populations in the Alps as well as adjacent regions. Historical hydro meteorological data were used to create scenarios for future water quantity.

WP6 is tightly connected with other work packages (Figure 1) as it receives basic data and information from WP5 (Water System Characterisation) and delivers time series of runoff, spring discharge and groundwater recharge to WP7 (Optimal Ecological Discharge) and WP8 (Water Scarcity System).

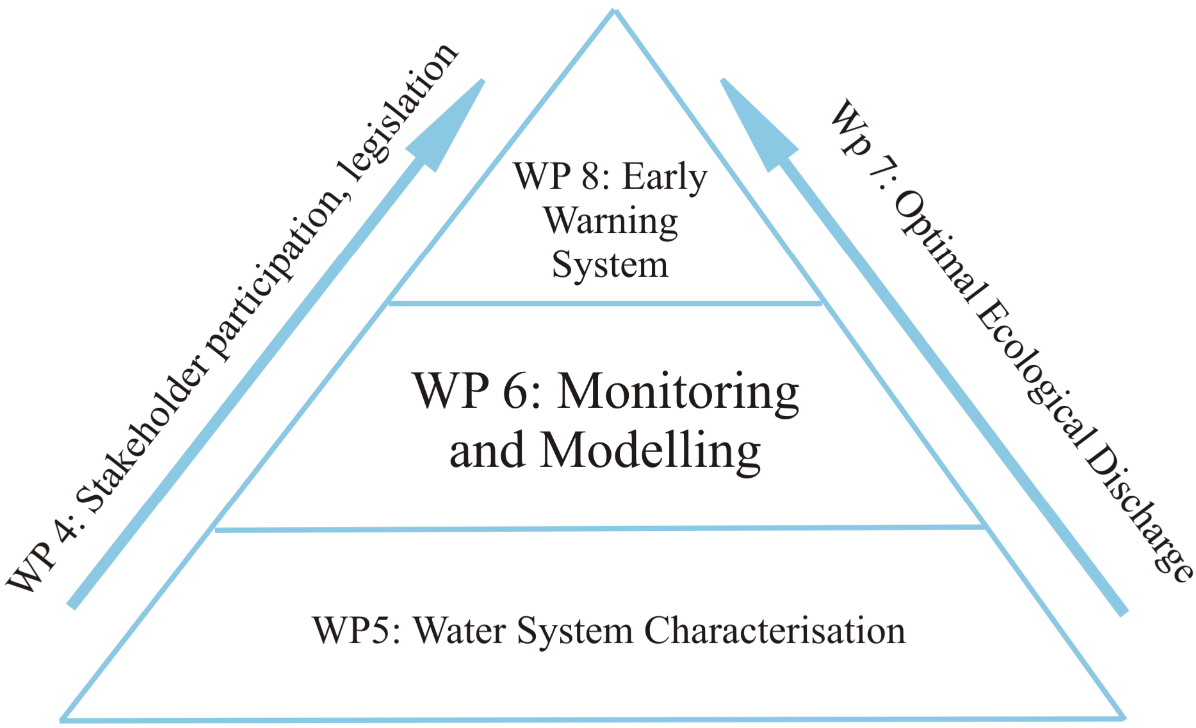


Figure 1: Links between WP6 and other work packages.

WP6 comprises four actions:

- Action 6.1: Elaborate monitoring network for hydrometeorology, hydrology, hydrogeology, ecology, water quality and water abstraction
- Action 6.2: Carry out integrated hydrological regional and sub-basin modelling
- Action 6.3: Develop/apply climate and anthropogenic scenarios for water systems with future vulnerability to water scarcity
- Action 6.4: Establish hydro(geo)logical indicators for WP 7 and 8

WP6 started at the beginning of Alp Water Scarce project (in October 2008; see Table 1) with Action 6.1 in which project partners contributed information about existing monitoring networks within their Pilot Sites. In some Pilot Sites new monitoring networks were established. During Action 6.2 the collected data about temperature, precipitation, discharge and water quality were used to build models of future climatic and hydrological conditions for each of the participating Pilot Sites. Results of Action 6.2 were used in Action 6.3 to develop climatic scenarios guidelines. Action 6.4 contributed to WP7 and WP8 by establishing hydro-geological indicators.

Table 1: Time frame of WP6.

Year	**2008**			**2009**						**2009**						**2010**						**2010**						**2011**		
Month	**10**	**11**	**12**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**
Action 6.1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Action 6.2								x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Action 6.3																x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Action 6.4																x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Total	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**

2 Monitoring (6.1)

2.1 Introduction

Monitoring the natural and anthropogenic water cycle is crucial to obtain reliable information on which to base appropriate water management actions. However, this task has proven to be particularly difficult in the regions studied by the Alp-Water-Scarce project. The Alps are characterized by significant spatial heterogeneity in terms of topography (elevations and slopes), geology (small to large mountainous aquifers with varying dynamics/storage capacities and sensitivity to climatic conditions), socio-economical concerns (various economic models sensitive to water availability and types of urban development), flora and fauna gradients, etc (for details see (SAULNIER et al. 2011a).

For monitoring at high elevations there are also several technical constraints:

- difficult physical access conditions to field sites → *danger to field researchers/technicians*
- climatic conditions vs. sensor resistance tolerance → *expensive equipment/maintenance*
- limited energy access or autonomy → *complex to build and to ensure continuity*
- topographic masks → *limited access to remote transmission*
- floods, avalanche, lightning, etc. → *sensors vulnerable to hazardous events*

In addition to above mentioned difficulties with monitoring of complex environments on the scale of the Alps there are also several more general problems connected with meteorological and hydrological monitoring.

In mountainous regions, available time-series are generally shorter than what is usually scientifically required. The length of the available time-series differed significantly for each Pilot Site resulting in different degrees of statistical robustness. Except for some regions with a particular data policy history (such as Alp-Water-Scarce partner Regional Government of Carinthia, Dpt. 8 (Competence Center Environment, Water and Nature Protection) (AT)in the region of Carinthia (AT), the difficulties and costs involved in monitoring mountainous areas generally result in short time-series for meteorological and hydrological data. Ten years of daily values may be seen as the minimum data set with which to investigate hydrometeorological inter-annual variability. Fifty years is usually considered to be the minimum time-series length for analysis of climate trends. Long-term historical time-series are extremely valuable and indeed irreplaceable to disaggregate the impact of global changes at the local level (among other uses).

Even when long-term monitoring is established, complex problems must be overcome, such as data storage, data publication and data homogenization (cf. scientific issues in the HistAlp project). Monitoring programmes are often designed independently of one another, with little concern for optimising coherence with other monitoring networks, remaining instead exclusive to the project that funds them.

According to FLINDT JORGENSEN (2007) five main constraints can be identified:

- economic: most data are usually available at a nominal cost but in some countries costs may be significant (usually for meteorological data)
- political: at times, a stakeholder might not want other organisations with conflicting interests to have access to certain data
- data formats: formats may vary widely and thus be difficult to exchange
- transboundary cooperation: it is still not always easy to obtain data from organisations in other countries
- fragmented databases: data may be available but might be spread across numerous databases which increases the complexity of collection

There is a lack of meteorological and hydrological data at high elevation in the Alps. Most meteorological sensors are installed at Alpine sites at low to medium elevations: far fewer are at high elevations. It has been observed that the precipitation above 2000 meters is poorly sampled. Whilst these poorly sampled areas may be small compared to the total area of the Alpine region they are extremely important because they receive the majority of the solid precipitation (snowfall) that will later be released during the melting period. They therefore have a significant influence on hydrological regimes and consequently on water resource dynamics. There are simple reasons for these problems:

- Rain gauges suitable for high-elevation regions are expensive. Self-heating rain gauges are often required to avoid blockage of the container that could lead to loss of data or erroneous data. However, these sensors consume energy. If this system is not possible to use or is too expensive, at the least cumulative gauges can be installed.
- Air temperature sensors should be properly sheltered from direct sunlight and wind. Otherwise, the bias in the recorded air temperature can amount to several degrees.
- Measurement of discharges remains a difficult task. In many cases, only river height is continuously measured. A long period of time may thus be required to empirically establish a rating curve linking discharge values (measured periodically, usually using the velocity-area method when discharges are not too hazardous for humans and sensors) and river heights (measured continuously). This is standard practice for medium to large rivers.

Alp-Water-Scarce contributed to the questions raised above: The project helped to launch new monitoring networks which are complementary to those who were already available. The main aim of the implementation of monitoring networks in Alp-Water-Scarce was to decide about the main concerns within each Pilot Site (e.g. drinking water supply, hydropower generation, water for agriculture etc.) in terms of expected “water scarcity types” and to adapt the monitoring network accordingly. This is a different approach compared to those were the same variables are measured for all Pilot Sites.

Furthermore the following issues shall be discussed when managing water scarcity in a specific region: the natural and anthropogenically modified water systems need to be characterised (done by WP5), available data need to be collected and a decision on variables that have to be monitored complementary needs to be taken (explaining the kind of possible analyses).

After taking the above mentioned points into account the modelling work can start depending on the issues that should be addressed.

2.2 Pilot Sites monitoring

2.2.1 Data collection (6.1)

2.2.1.1 Data availability in the Pilot Sites (6.1)

In 22 Pilot Sites of the Alp-Water-Scarce project a total of 1540 monitoring stations exist; 309 collect discharge data, 367 collect meteorological data and 864 collect groundwater table data (Table 2; for details see WP5 report). There were large differences in the number of monitoring stations between Pilot Sites with Steirisches Randgebirge-Wechsel having a total of 1051 stations and Sandey with only 2 stations. However, as the Pilot Sites differ greatly in their size (from 2,4km^2 in Sandey to 9535km^2 in Kärnten) the Pilot Sites with the largest number of stations do not necessarily have the densest network of monitoring stations.

Most of data, used within WP5 / WP6 originates from public services on state / regional level and are in principle available with no special limits. Some data are already available on websites, especially as "on-line" data collected by automatic hydrometeorological stations. Some data are available on request, where some fees are required for handling of data and include also an agreement and conditions regarding the use of data. However, there are big differences between Pilot Sites in data availability in terms of quality.

In five of the Pilot Sites new monitoring stations were built with regard to site specific needs or site specific water scarcity problems (connected with water abstraction, agriculture etc.). New monitoring station were established in the Arly river basin, in Savoie (for groundwater, at high altitudes and on the plain), in Wechsel/Styrian border mountains and in Dravsko and Ptujsko polje.

Table 2; Overview of the number of monitoring locations and of data availability within the Alp-Water-Scarce Pilot Sites. (publ.=public; priv.=private)

ID	Site	Discharge data	Meteorological data (temperature & precipitation)	Groundwater table (piezometer)
1	Savoy (FR)	8 publ.	6 publ.	3 publ.
2	Arly river basin (FR)	5 publ.	3 publ. and 1 priv.	1 publ. (details priv.).
3	Koralpe (AT)	101 priv.	5 (4 publ., 1 priv.)	
4	Karawanken (AT)	56 publ. (16 in Slovenia)	15 publ. (16 in Slovenia)	
5	Jauntal (AT)	6 publ.	3 publ.	13 publ.
6	Lower Gurktal (AT)	4 publ.	1 publ.	9 publ.
7	Steirisches Becken (AT)			

8	Steirisches Randgebirge–Wechsel (AT)	70 publ.	171 publ.	810 publ.
9	Entire Land Kärnten (AT)	surface water: >100 publ.; Springs: ~900 publ. and priv.	~130 publ.	>220 publ.
10	Pohorje with Dravsko polje (SI)	7 publ.	13 publ.	28 publ.
11	Ptujsko polje (SI)	see ID 10	see ID 10	see ID 10
12	Scrivia River Basin (IT)	2 publ.	2 publ.	
13	Julian Alps (SI)	11 publ.	10 publ.	
14	Piave River (IT)	34 (30 publ., 4 priv.)	113 publ.	3 publ.
16	Noce (IT)	6 publ.	14 publ.	
18	Entella river basin (IT)	6 publ.	6 publ.	
19	Scrivia river basin (IT)	7 publ.	7 publ.	
20	Sesia River Basin (IT)	3 publ.	9 publ.	
21	Spöl River (CH)	1 publ.	4 ((1 publ., 3 priv.)	
22	Sandey River (CH)	1 publ.	1 publ.	

2.2.1.2 Data on water quantity in the Pilot Sites (6.1)

Considering the above mentioned difficulties regarding the collection of meteorological and hydrological data in the Alps, the consortium of Alp-Water-Scarce suggested dividing the Pilot Sites according to different parameters measured into three groups: optimal, medium and minimal data sets (SAULNIER et al. 2011a). Meteorological data sets should include: precipitation, air temperature (minimal), solar radiation (medium) and wind speed, wind direction and air relative humidity (optimal). Hydrological data sets include: primary discharge, water temperature, electrical conductivity (minimal), soil moisture, basic ions (medium), secondary aquifers/spring discharges, isotopes, organic components, pH and oxygen (optimal).

Table 3 lists the meteorological and hydrological parameters measured in the different Pilot Sites of Alp-Water-Scarce . We would like to stress that the length of the available time-series differed significantly for each Pilot Site resulting in different degrees of statistical robustness.

Table 3; List of parameters, measured on each location within the Pilot Sites. (B=basic ions, H=air relative humidity, I=isotopes, L=groundwater level, O=organic compounds, M=trace metals, P=precipitation, Q=discharge, R=solar radiation, T=temperature, W=wind speed & direction)

ID	Site	Discharge data	Meteorological data	Groundwater table (piezometer)
1	Savoy (FR)	Q, T, B	P	L, B
2	Arly river basin (FR)	Q,L,I,O	P,T,R,W,H	L
3	Koralpe (AT)	Q,T,B,I,O	P,T,R,W,H	L, B, I
4	Karawanken (AT)	Q,L,B,I,O	P,T,R,W,H	L, B, I
5	Jauntal (AT)	Q,L,B,I,O	P,T,R,W,H	L, B
6	Lower Gurktal (AT)	Q,T,L,B,I,O	P,T,R,W,H	L, B

7	Steirisches Becken (AT)	Q,T,L,I,O	P,T,R,W,H	
8	Steirisches Randgebirge–Wechsel (AT)	Q,B,I,O	P,T,R,W,H	
9	Entire Land Kärnten (AT)	Q,T	P,T,R,W,H	L,T
10	Pohorje with Dravsko polje (SI)	Q,L,B,O	P,T,R,W,H	L, B, O
11	Ptujsko polje (SI)	Q,L,B,O	P,T,R,W,H	L, B, O
12	Scrivia River Basin (IT)	Q,T,B	P,T,R,W,H	
13	Julian Alps (SI)	Q,B	P,T,R,W,H	
14	Piave River (IT)	Q,B	P,T,R,W,H	
16	Noce (IT)	Q	P,T	
18	Entella river basin (IT)	Q,T,B	P,T,R,W,H	
19	Scrivia river basin (IT)	Q,T,B	P,T	
20	Sesia River Basin (IT)	Q,T,B	P,T,H	
21	Spöl River (CH)	Q,T,B	P,T,R	
22	Sandey River (CH)	Q	P,T,R,W,H	

*Adige (IT) and Fersina (IT) Pilot Sites were used only for experiments on thermo-peaking effects and are not listed in this table.

2.2.1.3 Data on ecology and water quality (surface and groundwater) (6.1)

By definition monitoring generally means to be aware of the state of a system (Wikipedia: http://en.wikipedia.org/wiki/Monitoring). In practice it means to observe, record and analyse a certain system and/or process to get information on intensity and direction of the changes in time or space. There are several types of monitoring: surveillance, operational and emissions and sometimes combined with remote sensing (from satellites).Type of monitoring depends on information needed.

For rivers and groundwater the most relevant is environmental monitoring (surveillance monitoring) where some of the parameters are measured *in situ* (such as temperature, precipitation, discharge), and some have to be processed in laboratories where samples from the field are analysed (chemical parameters, biota).

In 2000 the members of the EU adopted the "Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy" or, in short, the **EU Water Framework Directive** (hereafter WFD). The key issue of the document is to “get polluted waters again clean, and ensure clean waters are kept clean‟. The document includes minimal requirements for parameters which must be monitored, frequency of monitoring and instructions on site selections where monitoring should be performed. Within the WFD surveillance monitoring of the chemical and ecological status of surface water bodies and the chemical status and quantity of groundwater are performed.

Monitoring of water quality within the WFD “ecological status” requires the examination of morphological, biological and chemical parameters of the water body at a given site. The morphological status is referred to as the intensity of anthropogenic modification of a river bed (such as bank enforcement or dam constructions) and has effects on the biota (plants and animals) living there. The good ecological status of a river depends on quality and quantity of biota and efficient interactions among them and with the environment in a certain part of a river. Good ecological status means clean water available for human use.

Many more parameters must be monitored within different types of monitoring activities. The most common and with a long tradition are measurements on discharge of rivers. However, different countries have different traditions in monitoring the quantity of surface and groundwater. Among the partners within the Alp-Water-Scarce project, Austria, Italy and Slovenia have the longest tradition in recording rivers' discharge and level of groundwater. Some data-sets go back to the beginning of 20th century. Measuring stations are controlled either by the state, local communities or private companies, responsible for hydro-energy production, for drinking water supply or irrigation.

For other types of monitoring several chemical and/or physical parameters are usually measured. For example: phosphorus and phosphates are generally responsible for eutrophication. Although chloride and sulphates may have natural origins, sudden increases may raise an alert for pollution stemming from industrial emissions or agricultural or urban runoffs. Same can be said for nitrite, which is generally not found in natural waters. Pesticides (agricultural pollution), bacteriological factors (sewer overflows) and turbidity are other common indicators to help monitor water quality. We should be aware that polluted water can also lead to "water scarcity".

The main differences between monitoring of chemical and physical parameters used for monitoring in the past and still used for some special purposes and the complex monitoring introduced by the WFD are in amount and quality of available information. By measuring physical and chemical parameters we usually get information about the values of observed parameters only in limited time-frame. However, we do not get any information on their cumulative and long-lasting effects on biota, which is important in determination of water quality through self-purification processes. Spill of toxic or harmful compounds can happen only once and can be missed by regular monitoring of chemical properties. At the same time it can have long-lasting effect on biota which can be recorded during monitoring of biota. Organisms are thus considered as "living sensors" collecting information and reacting on environmental influences all the time. Negative effects on community structure or increase/decrease of abundance of a single species persist for a long time and can be recorded in the following monitoring.

For the effective removal of compounds responsible for eutrophication (with origin in agriculture and domestic sewage) it is important that all parts of the freshwater community are well balanced resulting in "good ecological status" of water body.

Table 4 lists water quality parameters monitored in the different Alp-Water-Scarce Pilot Sites. Most of them with existing monitoring locations include biological and chemical parameters. Among the biological parameters analysed are periphyton and invertebrates. Periphyton are unicellular or colonial algae which cover different types of substrate (stones, pebbles, dead wood) within the rivers or lakes. Invertebrates are all aquatic organisms present at certain place and certain time. The most common are different types of "worms" (flat-worms - Turbellaria and round-warms - Oligchaeta = relatives of rain-worms), groups of crabs (Crusatcea: Isopoda, Amphipoda) and larvae of insects (Insecta: Ephemeroptera, Plecoptera, Trichoptera). Seston or organic matter represents dead organic material with different levels of decomposition (this is equivalent to humus on the land). Hydrochemistry is a common name for a wide spectrum of analyses, including temperature, conductivity, pH, oxygen concentration, different phosphorus and nitrogen compounds (nitrates, nitrites, ammonium), sulphates, calcium, magnesium and others. Some specific measurements, like enzymatic activity and respiration indicate intensity of biological processes in the water body and primarily indicate amount of bacteria present, although periphyton and benthos can be measured in the same way too. All of the listed parameters help determining water quality, which is also a reflection of human impacts. Good ecological status is achieved when all above mentioned elements are balanced and work well.

As most of the Pilot Sites within Alp-Water-Scarce project are positioned on headwaters, and some of them have relatively small catchment areas, there is a lack of monitoring information from "on site". Complex analyses on water quality sensu "ecological status" are restricted either to large Pilot Sites or to lower parts of the rivers' catchment area. The lack of information is a result of the fact that such analyses are complex, time consuming and thus rather expensive (Figure 2).

Figure 2; Cost and man-labour intensive collection of biological samples in the Alpine water bodies.

On the other hand, most of the Alp-Water-Scarce Pilot Sites have permanent or temporary automatic stations for measuring water discharge, some combined with automatic meteorological stations (Table 3). This type of monitoring is rather simple, relatively cheap and the frequency of data-collection is high (usually on hourly level). Data are stored ether in data-loggers or emitted via radio-emitters to the operational centre. Such monitoring requires relatively small amount of human effort after the installation of the station.

Data collected at automatic stations are suitable for fine scale modelling of water balance both in surface rivers and groundwater. Springs as well as porous aquifers along the rivers are sources of drinking water but they are heavily dependent on a balance between discharge (including water abstraction for drinking water or irrigation) and precipitation. For efficient planning of water use in the future intensive and efficient monitoring should be established to control both quantity as well as quality of water.

Table 4 Overview of water quality parameters monitored in different Alp-Water-Scarce Pilot Sites.

ID	Site	Structural Parameters	Functional Parameters
1	Savoy (FR)	/	/
2	Arly river basin (FR)	Hydrochemistry	Invertebrates
3	Koralpe (AT)		
4	Karawanken (AT)	/	/
5	Jauntal (AT)		
6	Lower Gurktal (AT)		
7	Steirisches Becken (AT)		
8	Steirisches Randgebirge–Wechsel (AT)		
9	Entire Land Kärnten (AT)	According to the Austrian drinking water regulation, we examine physical, chemical and microbiological parameters depending on the size of the water supplier	
10	Pohorje with Dravsko polje (SI)	/	/
11	Ptujsko polje (SI)	/	/
12	Scrivia River Basin (IT)		
13	Julian Alps (SI)	/	/
14	Piave River (IT)		
16	Noce (IT)	Hydrochemistry, organic matter	Benthos and Diatom community
18	Entella river basin (IT)	Periphyton, hydrochemistry, seston, organic matter	Invertebrates, Respiration
19	Scrivia river basin (IT)	Periphyton, hydrochemistry, seston, grain size distribution, organic matter, historical habitat distribution	Invertebrates, Respiration, enzyme activity
20	Sesia River Basin (IT)	Hydrochemistry, organic matter	Invertebrates
21	Spöl River (CH)	Periphyton, hydrochemistry, seston, organic matter	Invertebrates, Respiration
22	Sandey River (CH)	Periphyton, hydrochemistry, seston, grain size distribution, organic matter, historical habitat distribution	Invertebrates, Respiration, enzyme activity

2.2.2 Data analysis

2.2.2.1 Hydrological and hydrometeorological time series modelling

2.2.2.1.1 Preliminaries

For any modelling of future events and scenario development knowledge of past climatic and hydrologic variables is needed. It is necessary to analyse and to interpret existing time series, which should be as long as possible. For these series several analyses can be performed. They are well know statistical time series procedures, among them are descriptive statistics analyses, trend analyses, sequence analyses etc.

Dealing with hydrological and hydrometeorological variables presents some difficulties due to the differences in the structure of these variables. Among them we have variables that can be understood as discrete variables (e.g. short-term precipitation data series with the resolution of one day) or continuous data series (e.g. discharge measurements). They are different also in the trends lying behind and in the frequency of data points. These are the reasons why sometimes direct comparison between different variables data series is not possible.

In the following pages some time series analyses are illustrated. They are representing only some possible analyses and can be understood as an illustration. Time series analyses applied in Alp-Water-Scarce project are illustrated by data series from the Pilot Sites of the Karavanke and the Julian Alps and their greater region. Some climatic time series available from the public record inside the Pilot Sites are too short for statistical analyses or they are not available. Therefore, observations in the near vicinity of the Pilot Sites have to be used Furthermore an extrapolation of data reduction results inside into the region. More details about statistical analyses and their results for the Karavanke and the Julian Alps region are given in the internal report of the Geological Survey of Slovenia available on the request.

Time series analyses were performed in WP6 Monitoring and Modelling. They are part of the following actions; Action 6.2. Carry out integrated hydrological regional and sub-basin modelling; Action 6.3. Develop/apply climate and anthropogenic scenarios for water systems with future vulnerability to water scarcity; Action 6.4. Establish hydro(geo)logical indicators for WP 7 and 8. Parts of the illustrated results were obtained in WP5 – Water System Characterisation.

2.2.2.1.2 Data sources

To start any analyses and interpretation of time series of any data set a basic idea of their origin and quality is needed. Dealing with climatic and hydrologic variability analyst may face the problem of different data origin and different time span. In the past data were recorded by different organizations; governmental and non-governmental. Even today in some countries the collection of hydrometeorological data is not centralised. Many data gaps can exist and during the course of time location of stations have changed. Before any analyses or interpretation the source of the data must be known.

To overcome problems with different quality of data record and the change of measurement methods homogenisation procedures were developed. They are intended to translate data in the status where also longer time sets can be used for analyses and different errors are removed. A well known data set that is based on the common homogenisation procedure are the HISTALP data series (http://www.zamg.ac.at/histalp/) which were also used in the Alp-Water-Scarce project. In the data set of HISTALP data series form the Greater Alpine region are collected, many of them are positioned inside or in the near vicinity of the Pilot Sites of Alp-Water-Scarce.

However, the HISTALP data set is not the only available homogenised data set in the region. Local agencies responsible for hydrometeorological observations (e.g. in Slovenia ARSO) perform their own homogenisation procedures. Since more detailed information about measuring procedures and locations for the particular stations is available for them one can expect differences in homogenised data sets of HISTALP and local agencies data sets for the same meteorological station.

A comparison between the HISTALP data set and the homogenised data sets of the ARSO for the meteorlogical stations of Ljubljana and Maribor meteorological stations are shown in Figure 3. Differences between the two data sets can be observed (Figure 3). They are not systematic and comparable among stations. In general HSITALP data sets are showing higher precipitation amounts than ARSO data sets, even for the period after 1970 when it is expected that data are of high quality performed on meteorological stations of the highest order.

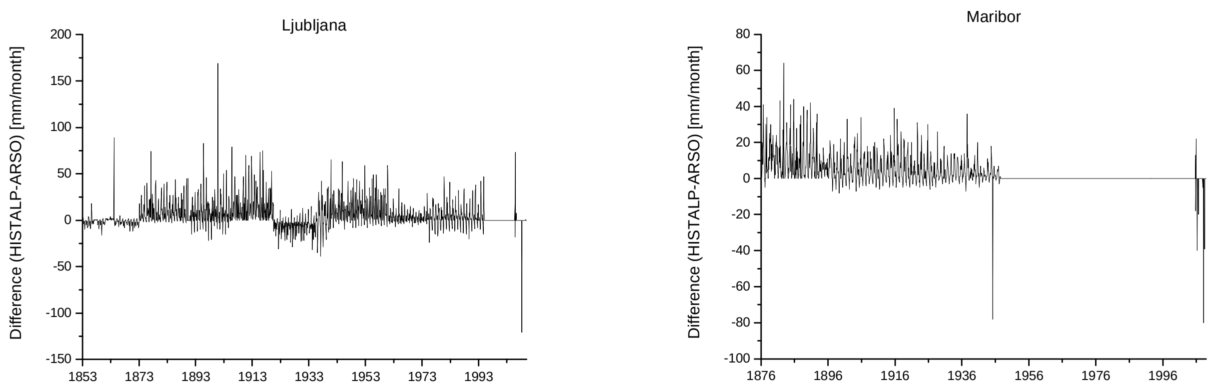


Figure 3; Comparison between HISTALP data series and ARSO data series for the meteorological stations of Ljubljana and Maribor.

The comparison between data sets of different origin and data sets based on different homogenisation procedures shows that not only climatic variability have influence on the reliability of predictions but also the variability caused by homogenisation procedures must be taken into the account. It is necessary that data originated from the same homogenisation procedures must be used.

2.2.2.1.3 Exploratory data analyses

In statistical analyses, procedures for quality checks and basic data characteristics analyses, are usually called exploratory data analyses – EDA. They include various in general very rough methods where it is tried to detect basic data characteristics.

As an example the analyses of the precipitation data set for the meteorological station Ljubljana originating from HISTALP data set are giving. The data are presented in scatter plots with non linear trends of data.

In hydrological analyses, the variable precipitation is the driving force of other hydrological components as is outflow characterised by discharge. Starting from the basic water balance calculation based on the equation

$$P - ETR = Q$$

where

P - precipitation

ETR – (real) evapotranspiration or losses of precipitation

Q – outflow

basic characteristics of the water availability can be given. Figure 4 shows the annual precipitation data series for the meteorlogical station in Ljubljana. It can be seen big scatter of precipitation which spans from 801 mm to 2415 mm with an average of 1468 mm. A small declining trend can be observed from the start of the 20th century.

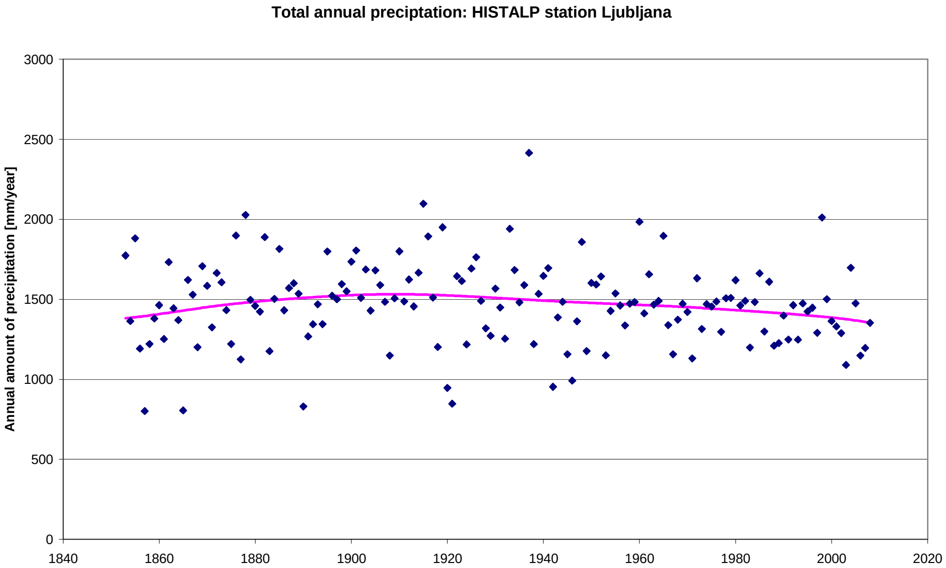


Figure 4; Total annual precipitation for the Ljubljana HISTALP station for the period between 1853 and 2008.

Evapotranspiration (ETR) data were reconstructed based on the Turc formula where input values of annual precipitation and annual average temperature are included. This very rough estimation helps to understand basic climatic characteristics. The Turc formula is often understood as climatic index which is not as reliable as other evapotranspiration equations that are based on more meteorological parameters. But because they are very demanding in parameters they are rarely available for longer time periods.

From the line representing trend a strong upward trend of the ETR can be observed from 1980 onward (Figure 5). However, even before this date, from the start of the record in 1853, a slight increasing trend is visible. The trend curve is very similar to the trend curve of temperature for the meteorological station in Ljubljana.

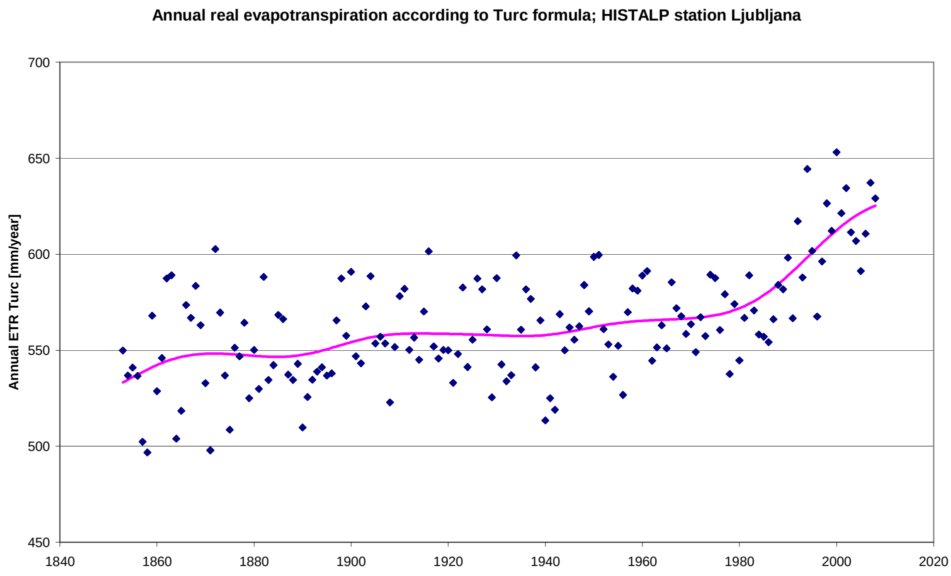


Figure 5; Total annual evaporation based on the Turc formula for the Ljubljana HISTALP station for the period between 1853 and 2008.

In hydrological data analyses we are interested in the amount of water available for the outflow Q. Anyhow, it is not the absolute measure of the outflow which can only be calculated knowledge about the recharge area is needed. Therefore difference *P-ETR* can be treated as relative measure of water availability for the outflow. In comparison to precipitation time series it can be seen that a decline in precipitation is sharper from the 1900's century than in the precipitation record and that an average trend is increasing at the end of the observation period (Figure 6).

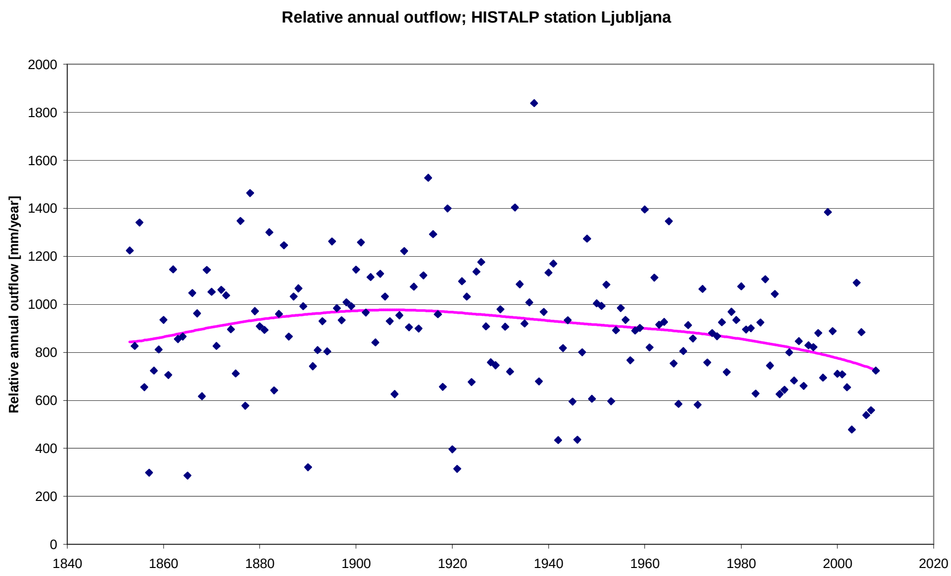


Figure 6; Relative annual outflow for the Ljubljana HISTALP station for the period between 1853 and 2008.

Similar observations and analyses can be performed also for other meteorological stations inside of the Pilot Sites.

2.2.2.1.4 Trend analyses

Dealing with hydro-meteorological time series a data analyst is looking for trends in data. In climate variability analyses linear and exponential trends are very often the only trends applied. However, there are many more trends that can be detected in time series. They can be divided into following groups: monotonic trends, periodic trends and nonlinear (variable) trends.

Imposing a linear trend on data can be very simple and sometimes very convinient. However, it can be misleading. In the diagrams below evapotranspiration time series based on Penman Monteith equation are represented for the meteorological station Kredarica and Lesce (Figure 7). In both diagrams linear trends and kernel regression trends are represented. In both cases linear trends are showing an increase in evapotranspiration. However, the kernel regression trend is showing a steep decline in evapotranspiration at the Lesce station. Such decline was not observed before and thus a simple linear transformation is not justified.

In using nonlinear trends we are very often applying kernel regression trends according to Wand and Jones. They are not based on predefined equation and therefore they are not suitable for the extrapolation of data. They are intended to be implied more as help in understanding the data structure and internal trends. We applied these trends in exploratory data analyses (see also above).

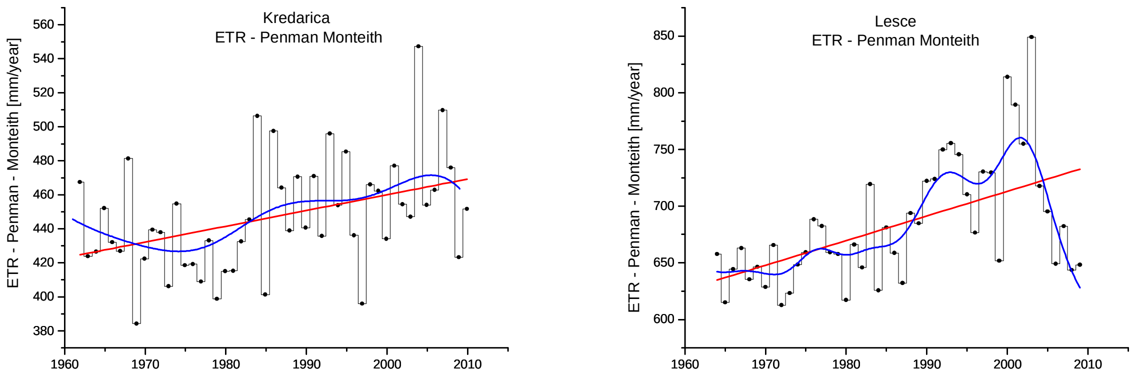


Figure 7; Trends in evapotranspiration.

In the Karavanke and Julian Alps Pilot Sites we have tried to implement slightly different trend analyses us usual. It is well known that hydrometeorological variables in the moderate climate regime of the northern hemisphere are periodic. The period of data is on average 365 days meaning that average trend is repeating every year. This concept is illustrated in Figure 8.

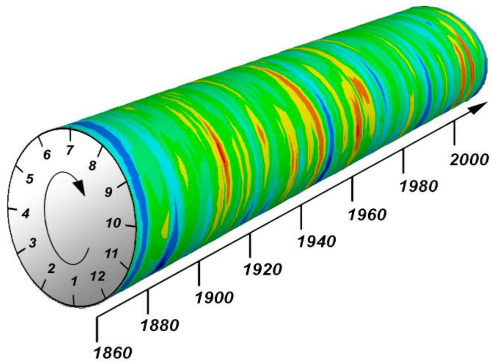


Figure 8; Axiometric representation of cylinder diagram.

Thus time series can be observed on the envelope of the cylinder. If the envelope is spread the surface is represented as rectangle which can be observed as the diagram where one axis is represented by year and other axis as consecutive month in the year. The amount of precipitation at particular point is represented by colour (Figure 9; left figure). In fact precipitation surface is very irregular (Figure 9; right figure) showing that the diagram is defined in 3D space.

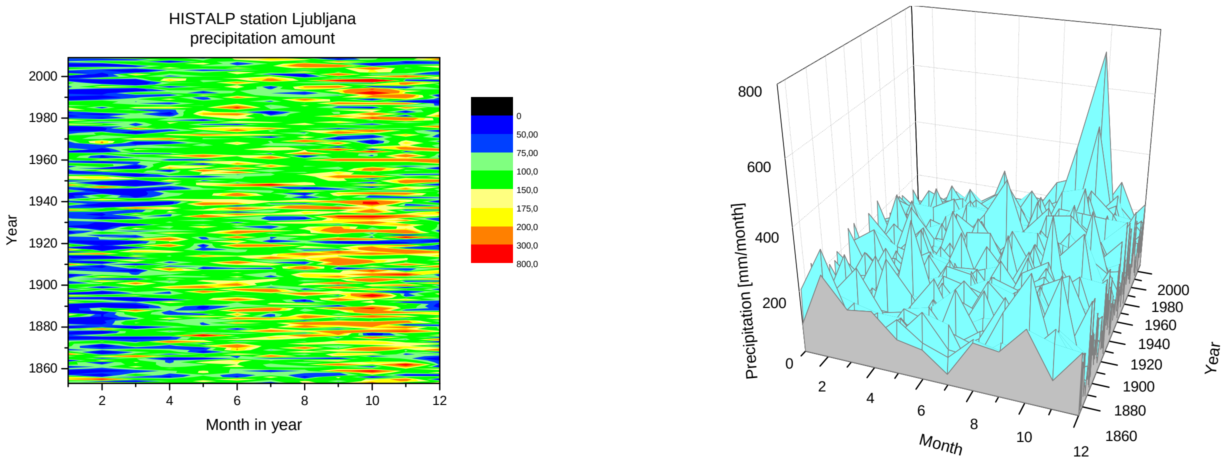


Figure 9; Cylinder diagram of the HISTALP precipitation station Ljubljana.

Dealing with data in 3D there is no longer need to fit simple trends represented by lines. Various surfaces can be fit into the data cloud of the cylinder diagram. In Figure 10 linear surface fit (P = 162.68+6,03(year)-0,04(month)) for the Ljubljana precipitation station is represented. The linear surface is not merely a fit but can help us also to understand a shift of precipitation not only on the yearly basis but also inside months. Linear surface is showing a decline in the precipitation from 1853 to 2008 and at the same time a shift of precipitation occurred from the autumn months to the summer months.

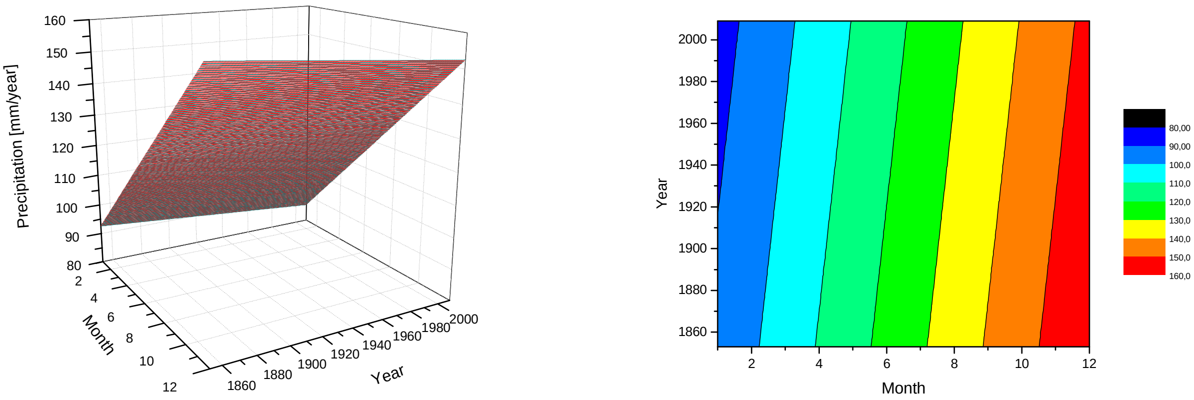


Figure 10; Trend surface for the HISTALP precipitation station Ljubljana.

2.2.2.1.5 Standardized precipitation index – SPI

A frequently used meteorological drought index is the standardized precipitation index – SPI (EDWARDS 1997; MCKEE et al. 1993, 1995). This index is based on long precipitation time series, usually consisting of a monthly amount of precipitation. The nature of SPI is designed to detect events of low frequency. With the help of this index periods of extremely low precipitation or periods with extremely high precipitation can be detected. It is based on the observation of the cumulative precipitation amount for a particular time period. The concept of the SPI can also be applied on other hydro meteorological variables where the total sum of the variable can be given.

During the calculation of the SPI with a time series of monthly precipitation data for a location the SPI for any month in the record can be calculated for the previous *i* months where *i*=1,2,3, …, 12, …, 24, …. 48, … depending upon the time scale of the interest. A 3 month SPI index is usually used for a short-term or seasonal drought index, a 12 month SPI is used for an intermediate-term drought index, and a 48 month SPI is used for a long-term drought index. Several programs for SPI calculations can be found, however the calculating procedure is a relatively simple spreadsheet calculation that can be performed with the help of macros.

The SPI of the period of the record is depended on the time scale. For example the 3 month SPI for March 1980 would have utilized the precipitation total of January, February and March. Likewise 12 month SPI for the March 1980 would utilize precipitation total from April 1979 to March 1980. More details can be found in the report of Geological Survey.

Figure 11 shows theSPI for the whole period of the Ljubljana HISTALP station. SPI values are given for the periods of 1, 3, 6, 12, 24 and 48 months. From the diagram it can be seen that time series for short SPI are relatively erratic; however the longer the SPI the more regular is the SPI time series.

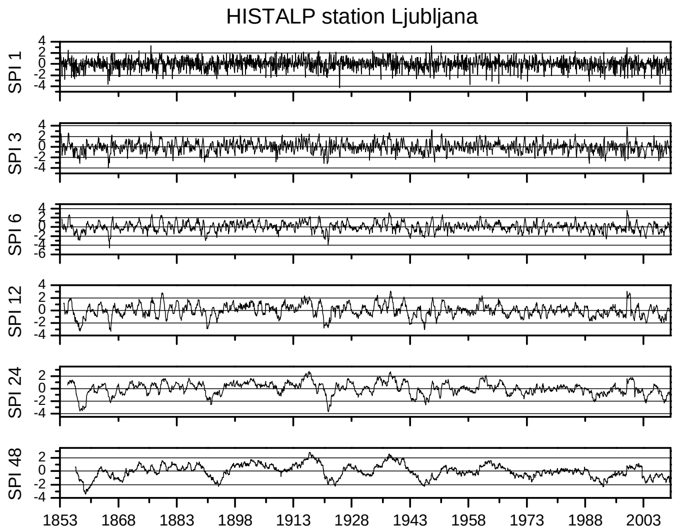


Figure 11; Standardized precipitation index SPI for the Ljubljana HISTALP station.

SPI values can help to discern usual dry events from the rare occurrence of phenomena. If the classification according to McKee (1993) modified by Moreira et al. (2008) is applied drought is classified according to Table 5.

Table 5; SPI values and corresponding Drought categories.

Code	**SPI Values**	**Drought Category**
1	SPI ≥ 0	non-drought
2	-1 < SPI < 0	near normal
3	-1.5 < SPI ≤ -1	Moderate
4	SPI ≤ - 1.5	severe/extreme

If we only use events with a SPI ≤ - 1.5 and observe only their appearance shown in Figure 12is it obvious that events with a short duration (SPI 1 and SPI 3) of drought are more frequent than events with a longer duration (SPI 24 and SPI 48).

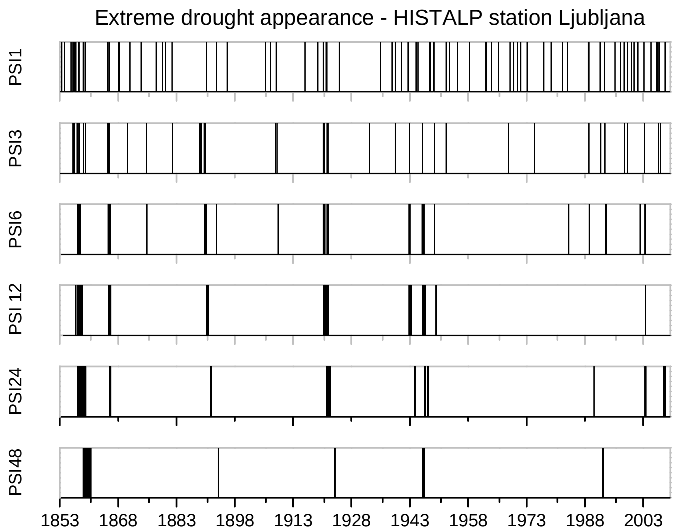


Figure 12; Drought appearance (SPI > 1,5) for the Ljubljana HISTALP precipitation station.

It was shown by statistical analyses that the frequency of extreme events has no time dependent trends. From the analyses it was also shown that very extreme meteorological droughts that appeared in the past are much more severe than droughts that appeared in the period 2000 – 2010.

If one is interesting in the whole spectrum of SPI values all values can be calculated for the particular interval. In Figure 13 the SPI values in the interval SPI1 to SP60 were calculated for the Udine HISTALP station. SPI values are illustrated by colours on the right hand side. The diagram shows the drought propagation (strong red colour – extreme drought) for the period between 1940 and 1955.

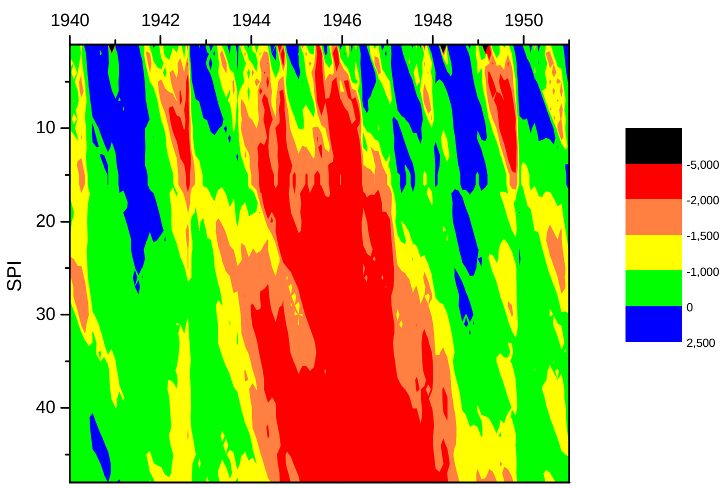


Figure 13; Complete SPI series calculation for the HISTALP precipitation station Udine.

A similar approach can be used if just extreme events and their duration are intended to be presented. For the Udine HISTALP station only extreme drought events were presented for the whole observation period from 1830 onward. We can see that extreme droughts appeared with different duration and different time extension (Figure 14).

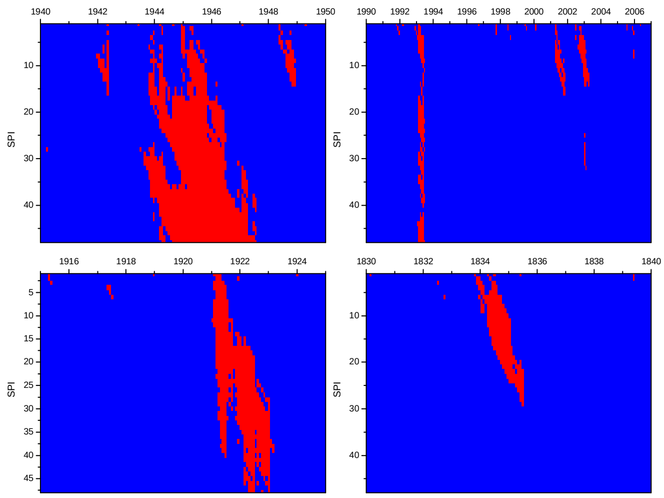


Figure 14; Appearance for extreme drought events (SPI> - 1.5) for the HISTALP precipitation station Udine.

SPI calculations are intended to compare different stations drought appearances in the region. A comparison is illustrated in Figure 15. It can be seen that short-term drought appearances are relatively similar, differ in the appearance of long term droughts, where stations with higher altitude have less sever and less frequent long-term droughts.

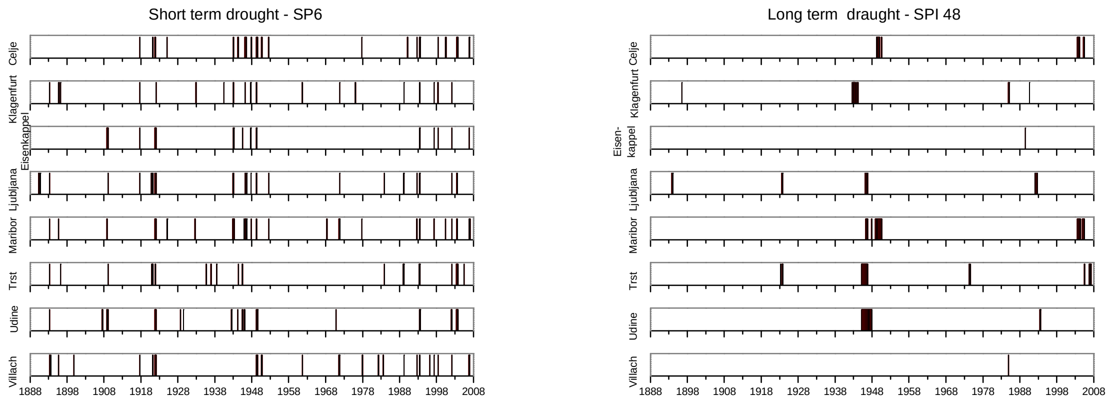


Figure 15; Comparison of short droughts (left diagram) with long-term drought (right diagram) from the HISTALP data set in the wider surrounding of the Eastern Alps.

2.2.2.1.6 Forecasting

In the statistical time series analyses various strategies for forecasting exist. Methods are based on the time extrapolation and the structure of the time series. Extrapolation methods can be divided into two common groups, short-term forecasting and long-term forecasting.

Short-term forecasting is usually based on so called auto regression models (e.g. ARMA) or empirical distribution models. Longer forecasts are mainly based on scenario building. In the following diagrams temperature for the Ljubljana HISTALP station is presented by the kernel regression trend (Figure 16).

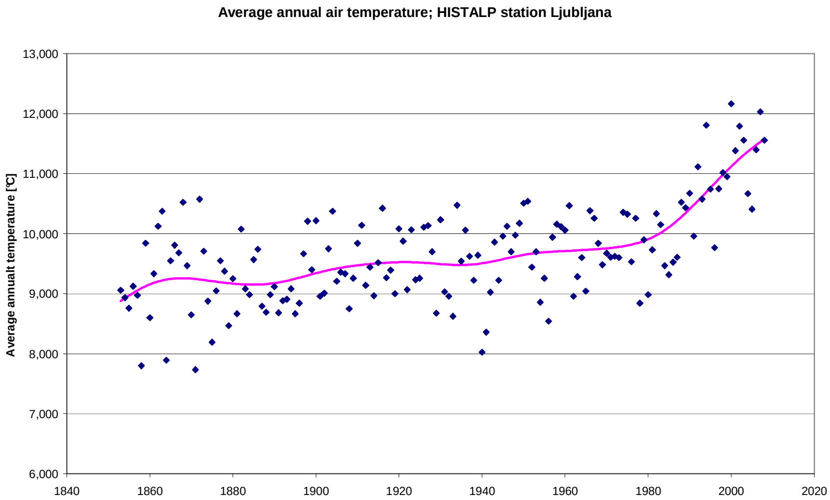


Figure 16; Average annual temperature and their trend for the HISTALP station Ljubljana.

Figure 17 shows two long-term extrapolations based on the assumption that TREND 1 is a result of the trend extrapolation from 1980 to 2008 and TREND 2 is given by the extrapolation from 2000 to 2008. It is illustrated that a small change in trend can profoundly influence the prediction.

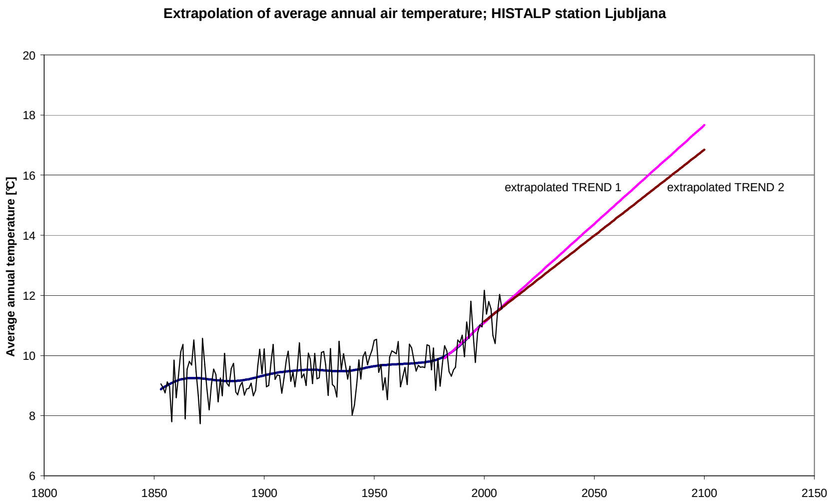


Figure 17; Extrapolation of temperature trends for the Ljubljana HISTALP station – based on two linear trends.

2.2.2.2 Water abstraction analysis (6.1)

Drought conditions can increase the risk of water scarcity, but excessive water demand can lead to the same risk. Quantitative estimations of water consumption are therefore necessary.

Water and environmental database policies differ widely across Europe. As with measurement protocols and data collection and exchange procedures, local and national administrations may have varying practices regarding public access to data ranging from long-standing policies of free access to environmental databases[6] to more restrictive data management and access policies. The various environmental and anthropogenic data collection and access policies at the regional and national levels across Europe can be seen as a limitation to collaborative transnational European water management in shared mountainous regions. In fact such anthropogenic data which is required for the estimation of water scarcity risk are, as a rule:

- difficult to obtain,
- controlled by a variety of different stakeholders and consumers, and
- available to water managers only after a period of time has elapsed.

Anthropogenic data is also needed to draw up future scenarios for water uses and to estimate the likely frequency of future water scarcity crises.

Taking into account the difficulties with the collection of water use data in the Alps, the consortium of Alp-Water-Scarce suggested dividing the Pilot Sites according to different parameters measured into three groups: optimal, medium and minimal data sets (SAULNIER et al. 2011a). Anthropogenic monitoring data sets should include: seasonal variation of the number of inhabitants for drinking water consumption estimates (minimal), economical vulnerability of industries to water restrictions (medium) and rapid actual water use measurements (optimal).

Detailed analysis of water abstraction and water use is included in the WP5 report of Alp-Water-Scarce project (SUETTTE et al. 2011).

2.3 Conclusion

In despite the difficulties of the establishment and running of meteorological and hydrological monitoring stations at high altitudes, the partners of Alp-Water-Scarce project managed the establishmet of new monitoring networks in five Pilot Sites: the Arly river basin, in Savoie (for groundwater, at high altitudes and on the plain), in the Wechsel/Styrian border mountains and in Dravsko and Ptujsko polje. Monitoring networks were adapted to the main concerns within each Pilot Site.

Within the Alp-Water-Scarce Pilot Sites where monitoring stations are already established available data was collected which was further used for modelling activities. As it was predicted in the application form large differences in data availability between the Alp-Water-Scarce Pilot Sites were detected. Furthermore the available data sets were divided according to different parameters measured into three groups: optimal, medium and minimal data sets – with such simple characterisation of data sets we were able to give guidelines to water managers for establishment of new monitoring stations in the future.

Where long-term data sets are available these data were analysed and the results were used for modelling future climate and hydrological conditions described in the next sections of this report. Models were the basis for climate scenario development which is also described in this report.

3 Modelling

3.1 Introduction

Hydrological modelling is an important complement to any significant monitoring network. Hydrological models are software programmes that represent the functioning of catchments, rivers, massifs, etc. These models can be of varying degrees of complexity. They make use of data acquired in the field, but they can also help to answer questions that cannot be resolved by field measurements alone. Models may be seen as programmes that incorporate all knowledge of catchment dynamics acquired by the technicians, engineers, and researchers, who monitor, explore, observe, and manage the natural and anthropogenic systems. For example, models may be useful in water management in order to:

- find solutions for sites where no data are available
- predict and forecast possible future scenarios
- study in detail water problems occurring elsewhere and/or in the past but which are not directly applicable
- obtain detailed information where only partial measurements are available

When modelling the natural component of water cycle in the mountains, several hydrometeorological components must be considered among them meteorology, hydrology, geomorphology, geology, and hydraulics. All these components have their own influences on the water cycle. In addition, they often involve feedback loops that in some cases have not yet been clearly quantified. Bearing in mind these most sensitive components, the following points should be considered when undertaking monitoring and modelling activities:

- meteorology (precipitation, temperature, solar radiation, cloud cover and wind)
- snowpack (ration between solid and liquid precipitation during the autum and winter seasons)
- soil-vegetation-atmosphere exchange
- surface/subsurface soil layers (vertical water infiltration and lateral subsurface water fluxes)
- groundwater (the main natural water storage)

In addition to the modelling of mountain hydrology it is necessary to understand, quantify, and parameterize anthropogenic actions. Several water uses and their inherent impacts on the water cycle can be identified. Quantity of water used differs among areas therefore water is transferred from one point to another or redistributed from one point over a large area. Water demand also differs between time periods and seasons in hydropower and artificial snow production.

The choice of a model should result from a knowledge-based decision. Stakeholders may have different degrees of human resources available to develop internal skills in model uses. Most stakeholders contract out modelling studies: for example, within the Alp-Water-Scarce project, some partners worked with subcontractors while other partners developed or used their own models. A large number of models are available, often with significantly different paradigms, but occasionally very similar. Posing certain relevant questions may help stakeholders to choose from the available models (SAULNIER et al. 2011a).

3.2 Pilot Sites modelling

3.2.1 Modelling of water quantity (6.2)

In this section different models used in the Alp-Water-Scarce Pilot Sites are listed (Table 5). Different models were also compared using four simple indicators (Table 6):

- COST: *do these models have a cost or can they be freely used, downloaded and adapted?*
- OUTPUTS: MAIN CONCERNS & TYPE OF MODEL; *what type of variables are the models able to calculate?*
- DATA COST: *do these models need a high (*+++*), medium (*++*) or low (*+*) volume of data to run?*
- USER COMMUNITY SIZE: *are these models in use by a small (*+*), medium (*++*) or large (*+++*) number of users?*

In the following summary of models a large community and low data cost are evaluated as better than small community and high data cost. Here we list just an extract of the recommendations for model use in the Alpine space from the SAULNIER et al. (2011a) booklet:

1. Physically-based models seem to be more suitable for simulating water scarcity risk in the Alps in the decades to come than statistical or conceptual models.

2. Models should be also able to simulate changing anthropogenic impacts in the future. The future extension of urban zones and the spread of water-consuming industries into new territories increase the need for models of scenarios of future anthropogenic impacts on water scarcity risk.

3. The need to exchange modelling best practices and to offer ongoing training to water management practitioners is crucial in order to define best practices at the European level.

Table 6; List of different models used in Alp-Water-Scarce Pilot Sites.

Site	Country	PP	Models
Savoy	France	IM, CG73	MRC
Arly river basin	France	SEA	TOPMODEL and GR4; 2 steps; Upworks rainfall runoff model; short timeseries
Koralpe	Austria	STMK, KTN	MIKE SHE; fractured aquifer, groundwater recharge, runoff generation
Karawanken	Austria/Slovenia	GEOZS und KTN	MIKE SHE; karst aquifer recharge, water balance
Jauntal	Austria	KTN	MIKE SHE; porous aquifer, groundwater recharge, impact agriculture
Lower Gurktal	Austria	KTN	MIKE SHE; porous aquifer, groundwater recharge, impact agriculture
Steirisches Becken	Austria	STMK	MIKE SHE; porous aquifer, groundwater recharge
Steirisches Randgebirge - Wechsel	Austria	STMK	NAM; fractured aquifer, groundwater recharge, runoff generation
Entire Land Kärnten	Austria	KTN	HBV; large scale water balance
Pohorje with Dravsko polje	Slovenia	ZAVOD MB	IRRFIB; MODFLOW; to include geological maps
Ptujsko polje	Slovenia	ZAVOD MB	IRRFIB; MODFLOW; to include geological maps
Scrivia River Basin	Italy	ProvAles	IHACRES
Julian Alps	Slovenia	GeoSz & NIB	analytical modelling, longer time series available
Piave River	Italy	ARPAV-DST	MIKE SHE; data from outside the Pilot Site needs to be included; long time series available (not for quality data)
Noce	Italy	ProvTn	GEOTRANSF; mathematical model by the Univ. Trento; temperature and prec. Longer timeseries available;
Entella river basin	Italy	GAL	HYDRO;
Scrivia river basin	Italy	GAL	HYDRO;

* Adige (IT) and Fresina (IT) Pilot Sites were used only for experiments on thermo-peaking effects; Sesia river basin (IT), Spöl river (CH) and Sandey river (CH) Pilot Sites conducted ecological studies and no models were planned to be implemented.

Table 7; Descriptions of the models used in different Alp-Water-Scarce Pilot Sites.

MODEL	COST	MAIN CONCERN	TYPE OF MODEL	DATA COST	USER COMMUNITY SIZE
MIKE-SHE	With cost.	Snow melt, funoff, infiltration, evpotranspiration, groundwater, water quality.	Comprehensive/Process studies model.	+++	+++
HBV	Free or with cost (depending on version used).	Snow melt, runoff, infiltration, evapotranspiration, water percolation.	Comprehensive model.	++	+++
HYDRSTRA	With cost.	Snow melt, runoff, dam management.	Simple/Intermediate model.	+	+
NAM	With cost.	Snow melt, runoff, infiltration, evapotranspiration.	Simple/Intermediate model.	+	+
TOPMODEL	Free.	Snow melt, runoff, infiltration, groundwater recharge, evapotranspiration.	Comprehensive/Process studies model.	+	+++
GR4	Free.	Snow melt, runoff, evapotranspiration, groundwater recharge.	Simple/Intermediate model.	+	++
IRRFIB	With cost.	Crop water consumption.	Comprehensive/Process studies model.	++	+
IHACRES	Free.	Snow melt, runoff, evapotranspiration.	Simple/Intermediate model.	+	+
MRC (Master Recession Curve)	Free.	Groundwater discharges.	Simple/Intermediate model.	+	+++
HYDRO	With cost.	Snow melt, runoff, infiltration, groundwater recharge, evapotranspiration.	Process studies model.	+++	+
GEOTRANSF	Free (GPL).	Snow melt, runoff, infiltration, evapotranspiration.	Process studies model.	+	+

3.2.2 Modelling of water quality changes (6.2)

3.2.2.1 Modelling water quality during periods of water scarcity

Very few authors tried to model the changes in water quality during periods of water scarcity (BLOOMFIELD et al. 2006; BOOTY et al. 2005; DELPLA et al. 2009; GHOSH BOBBA 2002; SINGH; KUMAR 2008). Some chances can be modelled just applying some principles of hydrology physics and basic water chemistry.

Less rain means more sunshine in Alpine recharge areas with the consequence of higher mean temperatures in the re- and discharge points (springs and wells) of drinking water. The other way round also springs were observed in the Eastern Alps with increasing discharge and dropping temperatures (KRALIK; SCHARTNER 2010).

Naturally, general temperature increase due to global change and constant discharge can cause a rise in water temperature (KRALIK; SCHARTNER 2010). General increase in water temperature has an impact on dissolution kinetics and the content of dissolved gases (e.g. oxygen) in the water. The first one causes an increase in all major ions particularly in the more easily dissolvable ones as Na and Cl in salts. However, Ca and SO_4 in sulphate and Ca, HCO_3 as well as dissolved CO_2 in carbonate systems decrease with rising temperatures. In combination all theses dissolved ions increase the electrical conductivity (EC)-value in the investigated waters.

In addition to dissolution dynamics the quantity of dissolved gases decreases with increasing temperature. So does oxygen the second main gas component of the air. The maximum dissolution of oxygen in water depends also on several physical parameters (e.g. air-pressure, turbulence, CO_2- and N-content etc.), but temperature is an important one. If all other factors are constant the maximum content of dissolved oxygen decreases approximately by 0.3 mg/L per 1 °C increase in temperature.

Although, dissolved gases decrease with increasing temperature, but soil-CO_2 increases due to more active respiration of roots, microorganisms and the decomposition of organic matter at higher temperatures as shown in summer (LAUDELOUT; ROBERT 1994) or in experimental heating sites (SCHINDLBACHER et al. 2011; SCHINDLBACHER et al. 2010).

Nearly no studies are available for organic pollutants, but the increased concentrations due to dropping groundwater levels is a common observed phenomenon. A very important question, how does microbiology changes due to increasing temperatures in groundwater, is one of the most pressing topics, but due to the limited space this has to be discussed somewhere else.

3.2.2.2 Evaluation of physical and chemical changes in 40 Alpine springs

To assess the hydro-chemical changes in groundwater due to climate change so far, springs monitored in the Austrian Water Quality System (FACHDATENBANK 2009) four times a year since 1992 were selected (see Figure 18). Out of 27 springs with suitable data-series in South – East of Austria (province of Carinthia and Styria) 19(70%) show a significant increase (Mann-Kendall Test) in water temperature of 0.5 – 1.5° C from 1992 to 2008. The binomial smoothed data of quarterly measurements spring water temperature measurements are shown in Figure 19. The annual mean air-temperatures of the "HIST-ALP"- stations (AUER et al. 2007) Graz, Klagenfurt and Villacher Alpe increase in a similar range and are shown for comparison.

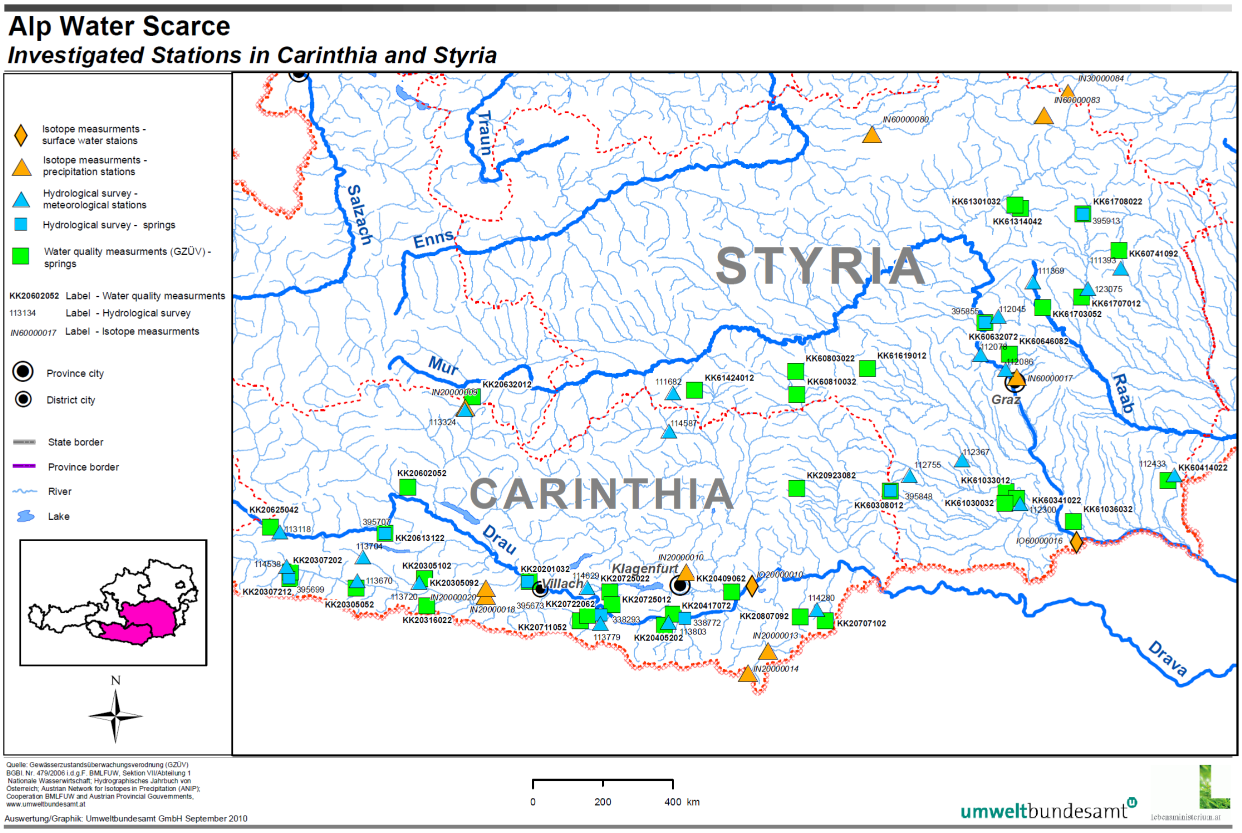


Figure 18; Investigated meteorological, spring and river stations in the area of Carinthia and Styria(KRALIK; SCHARTNER 2010).

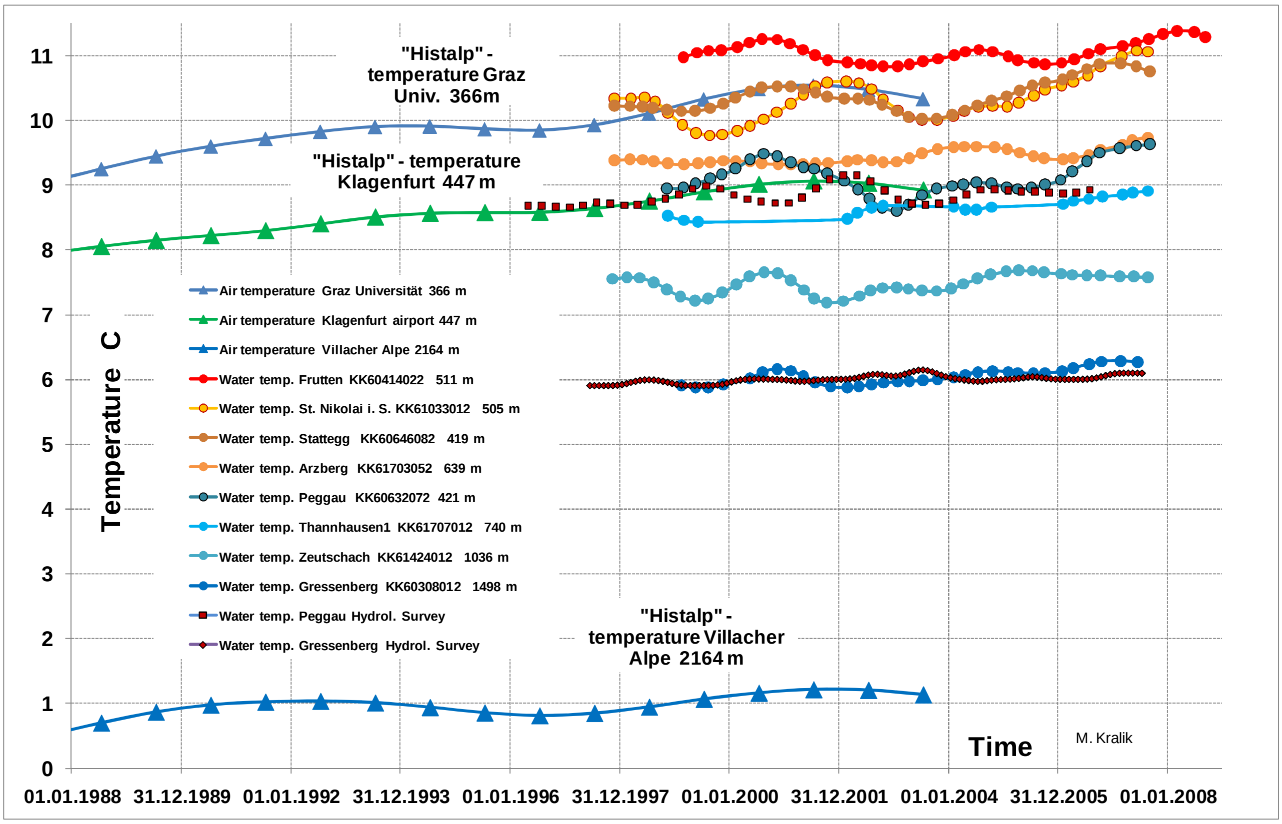


Figure 19; Binomial smoothing of quarterly measured spring water temperatures of selected springs at different discharge altitudes. Eight of 11 Styrian springs show a temperature increase of 0.5 to 1.2° C during 1992 – 2008. The annual mean air-temperatures of the "HISTALP"- stations (AUER et al. 2007) Graz, Klagenfurt and Villacher Alpe are shown for comparison (KRALIK; SCHARTNER 2010).

Oxygen-18 measurements were available from a campaign in 1996/1997 (FACHDATENBANK 2009) of all 38 investigated Styrian springs. To compare these measurements with the present situation 1-4 oxygen-18 measurements were repeated in all springs during 2009.

The delta oxygen-18 values of all the spring waters vary in the range of $\delta\ ^{18}O$ -12.5 to -8.6 ‰. Measurements of 1996/97 were compared to the one of 2009 by calculating a linear regression over these last 13 years and showing the difference. The data indicate that the mean $\delta\ ^{18}O$-value of 32 (84%) of the 38 springs increased by 0.31 - 0.34 ‰ oxygen-18. Five of them show no change and in two springs the $\delta\ ^{18}O$-value has decreased. The observed increase in air and spring-water temperature is the dominant factor for this isotope fractionation.

The most frequent trends in the physical and chemical parameters – besides temperature - are changes in electrical conductivity, dissolved oxygen and calcium content as well as changes in nitrate, chlorine and sulphate mostly at low concentrations.

During periods of droughts or strongly reduced precipitation the input of groundwater is reduced as well as the mean residence time is increased. Both factors increase the concentration of dissolved ions in many rock formations, but also present anthropogenic pollutions are more concentrated in the remaining water under certain circumstances. However, for carbonates and sulphates increasing temperatures would decrease the solubility of both. But the temperature induced accumulation of CO_2 due to biological activity (the action of roots and respiration of microorganisms) and the decomposition of organic matter could explain trends of increasing electrical conductivity frequently observed in Alpine springs during the last 17 years (KRALIK; SCHARTNER 2010). Similar effects were demonstrated by heating experiments in Alpine forest soils (SCHINDLBACHER et al. 2011; SCHINDLBACHER et al. 2010).

To estimate the expected changes in chemical composition during droughts and floods from 23 springs with good discharge data the relative difference (%) of the mean values of the analyses from the 10% with the lowest and highest discharges were calculated. From the more than 1300 samples between 1992 – 2008 the parameter EC, SO_4, Cl, NH_4 and B are significantly and Na slightly enriched during low flow. During high water situation K, NO_3, PO_4, DOC and Fe are more enriched (Figure 20). The increased values of EC, SO_4 and Cl during low flow are explained already in the previous section. The relative increase of NH_4 and B may be explained as concentration at low water levels but also due to lower oxygen concentration for the NH_4 formation compared to turbulent high water flow. K, PO_4, DOC, Fe and partly Mn seem to be increasingly transported as colloids during floods whereas NO_3 are better formed and leached under such more oxygen rich hydrological situation.

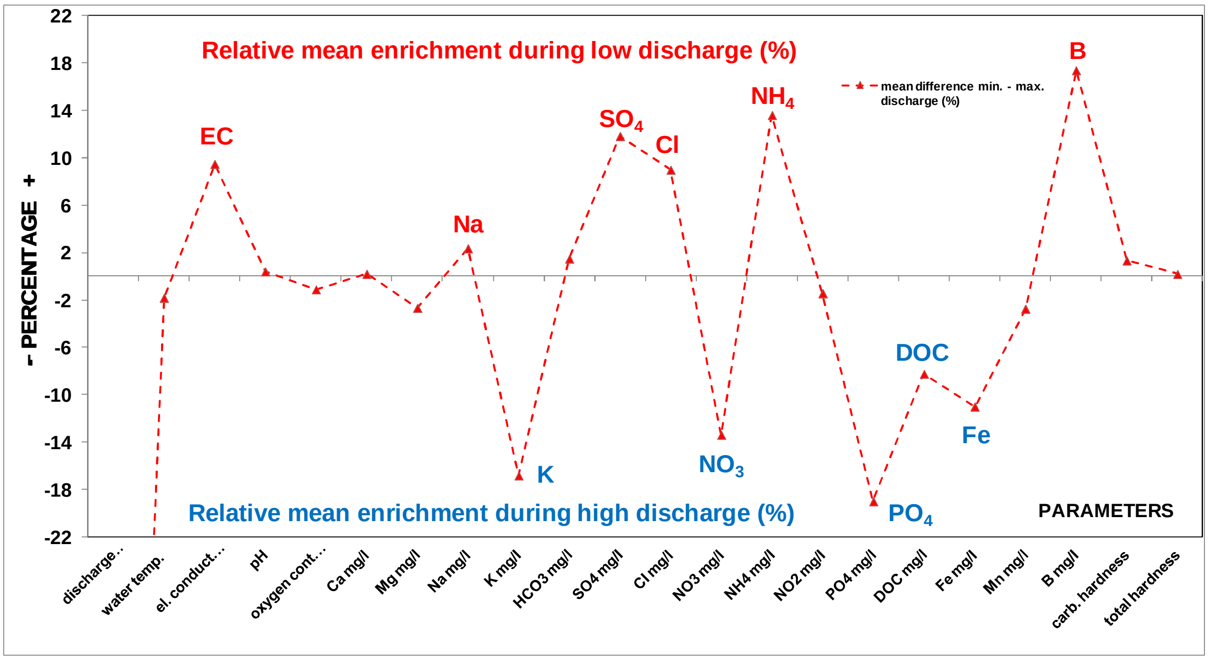


Figure 20; The relative differences (%) of the mean values of the analyses from the 10% with the lowest and highest discharges were calculated from 23 springs. Electrical conductivity, SO_4, Cl, NH_4 and B are more enriched during low discharge compared to high flow conditions.

3.2.3 Hydrological agriculture modelling (6.2)

Plant irrigation is a necessary measure in agriculture where, by adding water to the plants at the time of drought, we can provide high and good quality yields. The amount of added water depends on plants, climatic and soil conditions.

Drought in agriculture depends on:

- Precipitation: the amount, distribution and the time of precipitation
- Evapotranspiration, which depends on climate condition, solar radiation, air temperature , wind and plant phenology
- Physical properties of the soil that defines their infiltration capacity for water
- Soil depth

The irrigation is one of the biggest water consumers. It should be implemented economically and without the influence on economics of food production. If the plants are optimally supplied with water, they use nutrients more efficiently (PINTAR; KNAPIČ 2001).

During the irrigation there are relatively big losses of water with additional problems of crusty soil and risk of erosion. Therefore the method of water application to the plants is very important. The use of water could be optimised by agro technological measures like:

- Selection of suitable irrigation technology
- Timely start of irrigation
- Quantitative and timely suitable irrigation
- Change of rotation crops with the selected plants, which use less water

Generally there are three types of irrigation like:

- self- driving irrigation devices – rolomates

- systems of sprinkling nozzles
- drip irrigation

The chosen irrigation technology has to be adapted to the plants and should ensure sufficient amount of water. On the other hand the intensity of water supply should not exceed the soil permeability coefficient for water so that the water doesn't stagnate or flow away from the surface (PINTAR; KNAPIČ 2001). The quantity of irrigation depends on the soil characteristics, type of plant and depth of the roots. The soil moisture should be kept in the area of the plant roots so that the plant doesn't get to the water stress. The water quantities as well as loss of water depend also on the type and the way of water application. When choosing irrigation type also the characteristics of the soil should be considered. In addition, the following measures should be considered:

- Optimised use of nutrients and reduction of their leakeage into the ground water
- Reduction of water stress and consequently fewer diseases
- Reduced use of pesticides
- Increase in quality and quantity of harvest
- Optimising the production costs.

The use of computer knowledge as well as the knowledge of plant ecology enables improved simulations of interactive processes in the system atmosphere- soil- water- plant systems. Different models, supported by calculations of water balance, estimate the available quantity of water and the necessary quantity of water for irrigation. Although different models demand different input data and their processing ranges from very simple to very complex, their common aim is to optimize water use within the irrigation systems (Figure 21) (SUŠNIK et al. 2003).

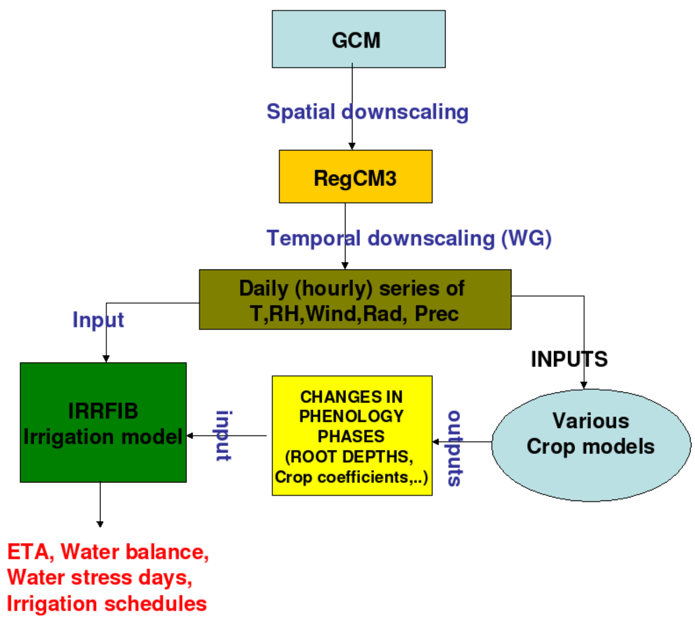


Figure 21; Flow chart of articles needed for irrigation calculations.

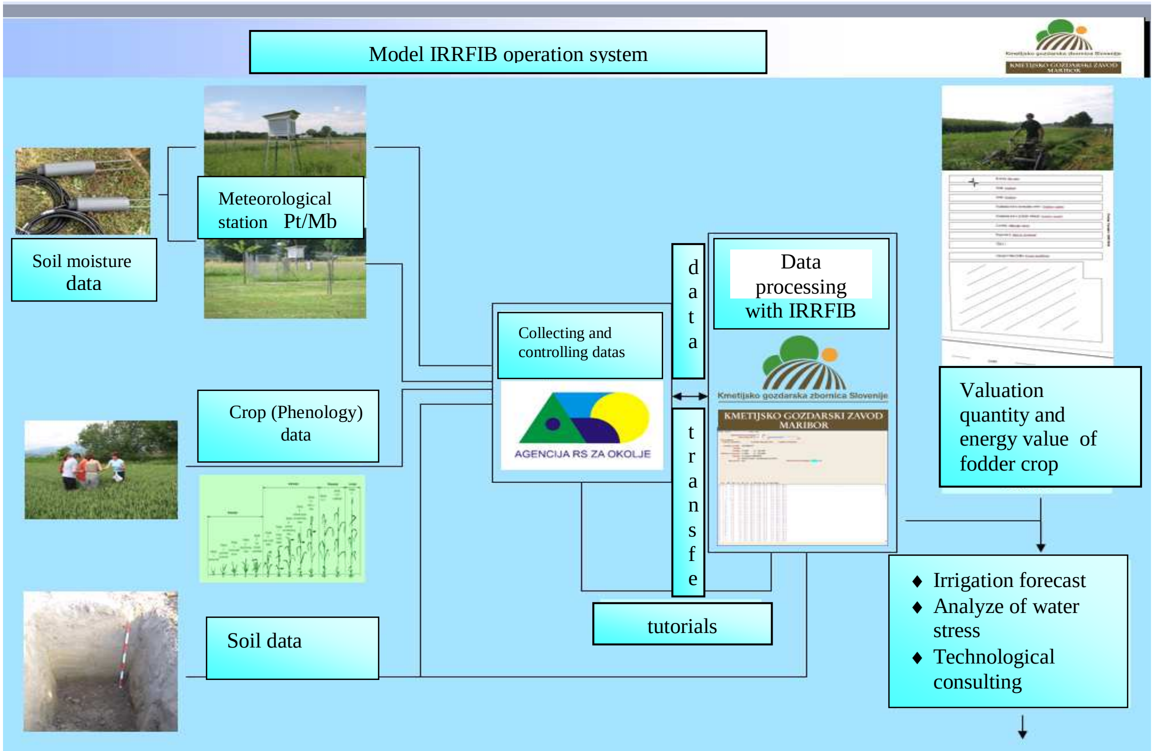


Figure 22; Chart of the IRRFIB modelling operation system.

The chart obtained by processing the input data shows the amount of water required by plants at a given phenological stage of growth. On the basis of a four day weather forecast a prediction regarding the amount of water the plants will need is created by taking into acccount the current phenological phase (Figure 22). By combining the observations of plant health, knowledge of ecology of different pests or diseases and the weather forecast, we can predict the appearance of plant diseases. By close monitoring of plants we can also predict the timely application of plant nutrients. In addition to the amount of water needed for irrigation, our forecasts include the amount and method of treatment of plants with plant protection and preventive measures against disease and pests (Figure 22).

Pilot forecast of timely and quantitative application of water to different crops within the project are carried out by the support of IRRFIB modelling system, which as an input indicator considers the amount of precipitation and the ETP data of different crops (Figure 23). The data about the soil capacity and the soil moisture in the root area was also included. During the vegetation period we also added phenological phases of selected vegetable plants (salad in different plant periods, cabbage in different plant periods, pepper, seeded onion, planted onion (from sets) and field products (cereals, maize, pumpkins, raps, potato). Output indicators based on the data about the phenological phases of chosen plants, real quantity of water in the soil and the needs of different plants take into account the weather prognosis and offer precise information about the irrigation needs in the next four days.

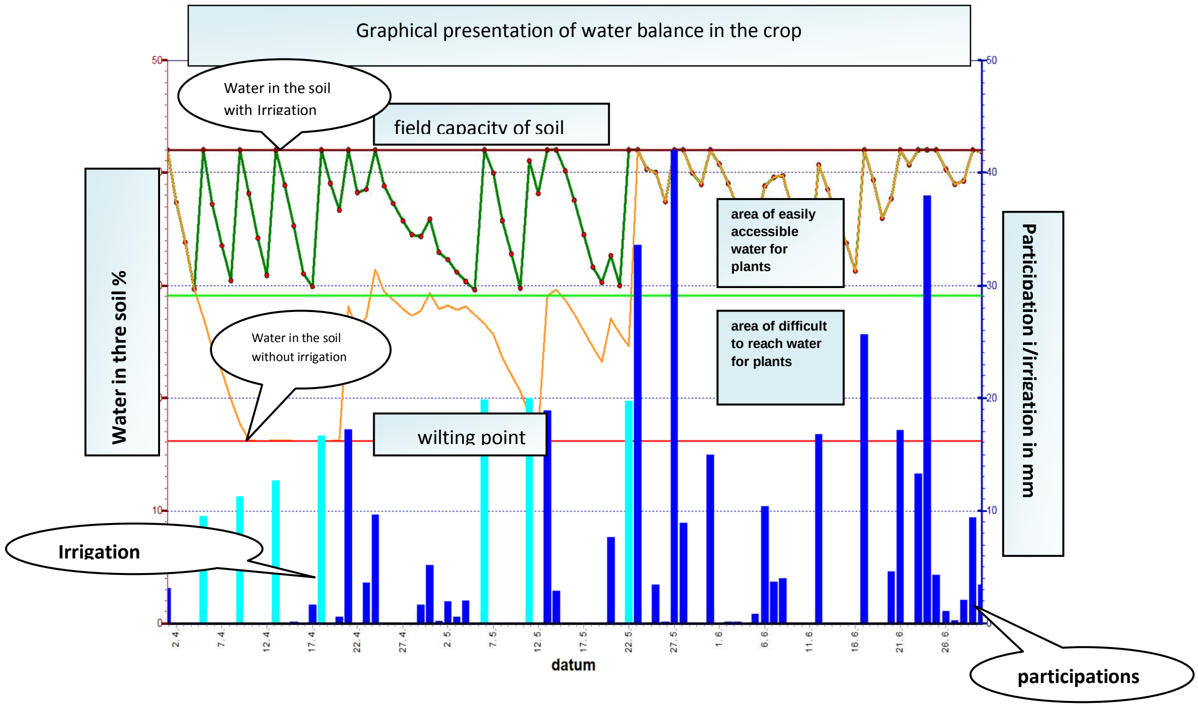
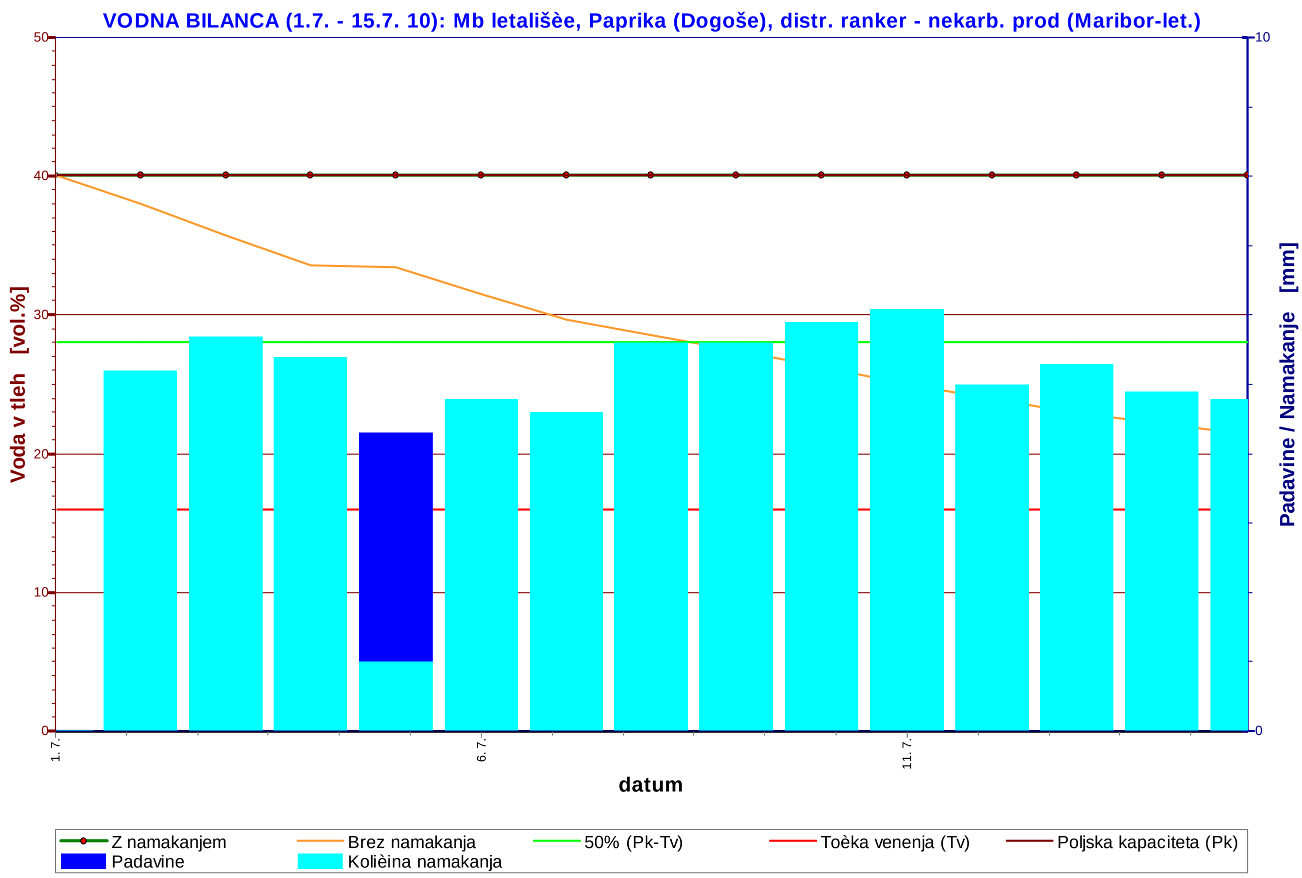


Figure 23; Graphical presentation of the water balance in the crop.

Below (Figure 24) is an example of an irrigation forecast for the farmers published on the web page of KGZS - Zavod Mb. It gives information about the recommended amount of water for irrigation and other useful advice for a specific crop.



Recommendations for farmers	
Description of water state in the soil	At the weather station Maribor airport we measured a total of 5mm of rain between 1.7.2010 to 12.7.2010. This was not enough even for one irrigation for pepper. The water condition in the soil will therefore fall below the wilting point of pepper– the first crop is close to being picked and the second and third flowering phase is beginning. For all three phases suitable, regular and adequate irrigation is necessary.
Irrigation forecast	From 12.7 to 15.7 you need to add 20mm of water to the pepper as regards to irrigation. The pepper needs to be watered twice a week, because the amount of organic substances in the soil and the depth of the profile assure that the water will remain in the area of the roots for long enough. Only regular watering will assure good vegetable quality. Irregular watering, speculation of when and how rain will fall only causes poor quality crops, bad pollination and fertilization therefore deformation of crops or irregular shape. Also injuries due to the lack of calcium are bigger and more regular if plants are not guaranteed a regular supply of water.
Other recommendations	  Stronger attacks from Thrips (Thysanoptera; see the photographs above) are expected because of a longer period of dry weather and high temperatures. They can be found in open blossoms causing damage to the ovary, which later develops into a fruit. That is why damage such as scars and rough skin can occur on the crop and strongly decrease its quality. This is why prevention is necessary. Below we list the allowed substances used to control this pest in Slovenia. These substances can only be used in the evenings as some will not work and others are very dangerous for bees and other insects.

pripravek	Odmerek/ koncentracija	Karenčna doba
Confidor SL 200	0,75 l/ha	7
Kohinor SL 200	0,75 l/ha	7
Laser	0,15 - 0,25 l/ha	3
Vertimec 1,8 %EC	1 – 1,25 l/ha	3
Match 050 EC	2 l/ha	7
Spruzit koncentrat	0,1%	4
Flora Verde	1,25 – 1,6	7
Aktiv	3%	ni potrebna
Valentin eko insekticid iz maščobnih kislin	3%	ni potrebna
Valentin eko insekticid iz maščobnih kislin - R	100 %	ni potrebna
Raptol koncentrat	10 l/h	3
Raptol spray	100 %	3

We do not expecting any fungus or bacterial diseases in these weather conditions. Because of high temperatures problems connected with the lack of calcium in the crops are already appearing (see photo below with examples of damage on the crops due to the lack of calcium). Therefore there is a need for fertilization once a week with a calcium leaf fertilizer. Adding calcium to water or directly to the roots, in these weather conditions, will not be effective.

We also recommend reinforcement of plant resistance against stress by adding a mix of aminoacid and vitamin complex or an extract of seaweed.

Figure 24; An example of the irrigation recommendations for farmers provided on the web page of KGZS - Zavod Mb.

3.3 Conclusion

The re-analysis of past events and trends using monitoring and modelling is essential in order to characterise the seasonal and inter-annual variability of the availability and demand for water resources. The estimation of flow statistics and the re-analysis of past water scarcity events contributes to the understanding of the system. It also constitutes a primary building block for short-term management and long-term planning.

Using data from newly established monitoring stations and the long-term data collected by other agencies the Alp-Water-Scarce consortium modelled the future climatic or hydrological characteristics of 17 Pilot Sites. Models with different characteristics (cost, main concerns, amount of input data and the size of user community) were used depending on monitoring data availability and its quality. Results of modelling activites for each Pilot Site are presented in the final part of this report (see section 6).

On the basis of an overview of the characteristics of the models used in the Alp-Water-Scarce project the following recommendations were given. Physically-based models seem to be more suitable for simulating water scarcity risk in the Alps in the decades to come than statistical or conceptual models. Models should be also able to simulate changing anthropogenic impacts in the future. The need to exchange modelling best practices and to offer ongoing training to water management practitioners is crucial in order to define best practices at the European level.

4 Implementation of climatic scenarios (6.3 - 6.4)

4.1 Introduction

Scenario analysis is the process of evaluating possible future events through the consideration of alternative plausible, though not equally likely, states of the world (scenarios). The definition used by the Intergovernmental Panel on Climate Change (IPCC) is representative of scenarios as applied in the natural sciences (IPCC, 2008):"A scenario is a coherent, internally consistent and plausible description of a possible future state of the world. It is not a forecast; rather, each scenario is one alternative image of how the future can unfold."

Long-term planning is especially important when making decisions regarding factors and trends of interactions and human consequences that may impact the future (SAULNIER et al. 2011b). Most scenario development efforts involve a group of people from different disciplines and organizations. While this ensures a wide range of backgrounds it can also create a communication barrier due to the different languages used in different fields and organizations. For example, the terms scenario assessment, analysis, and development often have different meanings across the literature, or are used interchangeably.

4.2 Regional indicators and risk analysis for agricultural water scarcity in representative Pilot Sites

4.2.1 General impacts of climate change on agriculture

Agriculture is one of the climate sensitive sectors of national economy. It is linked to climate change in three ways: agriculture acts as causer, solver and concerned of climate change. Water consumption in agriculture differs a lot, depending on the actual land use type (grassland, arable land, special crops, vineyards, orchards) and type of animal husbandry. Climate Change in general will have effects on the suitability of areas for agricultural use. As a consequence of the expected regional climate changes, such as higher temperatures, rising evapotranspiration and heat stress, more frequent extreme weather events, varying precipitation and water supply, decreasing duration of snow cover, changing infestation patterns, higher CO_2 and O_2 concentrations and increasing UV radiation, agriculture has to adapt to minimize the production risk. The expected climate change influences vegetation periods, quantity and quality of crops beside other indirect consequences like harvesting conditions, water and nutrients availability, transport, storage and processing of products. Climate change will influence livestock husbandry directly by effects on animal health, growth, reproduction, but indirectly by impacts on productivity of pastures and forage crops as well. Furthermore, agriculture is linked with up- and downstream industries and therefore manifold interdependencies among different economic sectors should have to be taken into account to measure the overall effects of climate change. Not only the direct effects of climate changes on agriculture, but also natural hazards, changing potentials for tourism and regional development as consequences of different climate and weather conditions may have impacts on agriculture especially in view of regional economy.

4.2.2 Regional indicator development for describing water scarcity risks in agriculture

Indicators for water use in agriculture exist already from OECD (2000) taking into account the change in total agricultural water use and the intensity of agricultural water use relative to other users. EU developed two indicators within the IRENA system: IRENA indicator no. 10 water use intensity by agriculture, which measures the irrigable area and the type of irrigated crops and the IRENA indicator no. 34.3 which measures the share of agriculture in water use. The already existing indicators are related mostly to irrigation but do not take into account the real total water usage of agriculture, which is of importance in the Alp Water Scarce project. To meet the project goals a system of most relevant agricultural indicators has been developed, including plant cultivation, livestock husbandry, soil and climate conditions:

- Water consumption for plant cultivation: Proportions of specific cultivated plants on agricultural land, weighted with the crop coefficient which comprises evapotranspiration;
- Water consumption for livestock husbandry: Proportions of specific livestock units, weighted due to specific water demand;
- Irrigation: Proportion of irrigated area on agricultural land;
- Soil: Proportion of soils weighted due to capacity of available water in soils;
- Climate: Regional and monthly aridity which is a relation of temperature and precipitation.

4.2.3 Current situation and risk characterisation of agriculture concerning water scarcity in selected Alp Water Scarcity Pilot regions

The developed indicator set has been analysed for selected Alp Water Scarce pilot regions to respresent a broad range of present and future risk patterns for agriculture concerning water scarcity. The present situation shows relatively higher risks for water scarcity due to agricultural land use and livestock in the eastern regions in Austria and Slovenia, for example in Steirisches Randgebirge, Koralpe, Dravsko-Ptujsko; there higher shares of intensively used grassland and intensive animal husbandry (milk cows, pigs, poultry) can be observed. Both activities are very water consuming. The western and southern regions of France, Slovenia and Italy, for example in Tarentaise, Scrivia, Noce, Julian Alps, are characterised by relatively worse soil and worse climate indicators related to water supply. Especially the Italian regions rely very much on irrigation. Figure 25 and Figure 27 show the current situation of agricultural land use, animal husbandry and soil conditions, each time the shares of the different classes in selected pilot regions. Not for all the regions the data sets are complete. Figure 28 gives a comprehensive picture of the risk evaluation in a standardized way which allows to show the various risks in one scale and to compare the priorities in the regions.

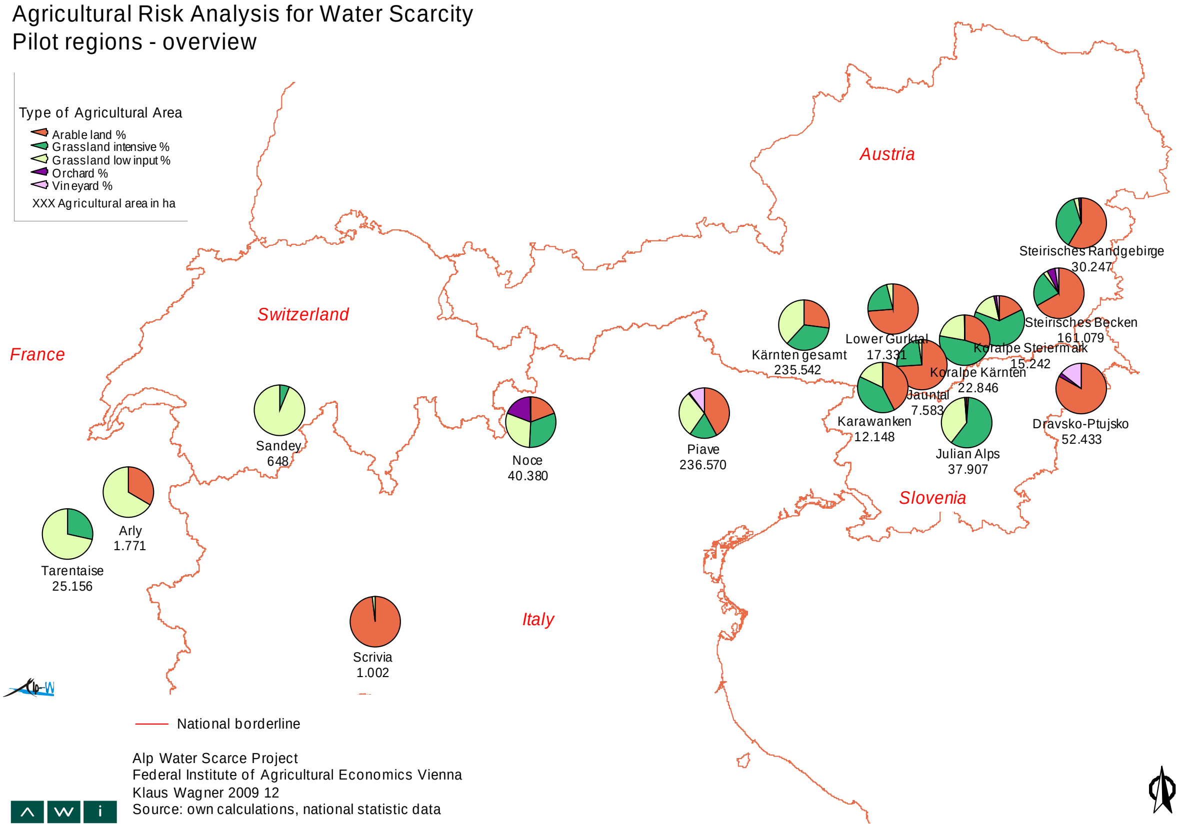


Figure 25; Current agricultural land use in selected Alp Water Scarce pilot regions

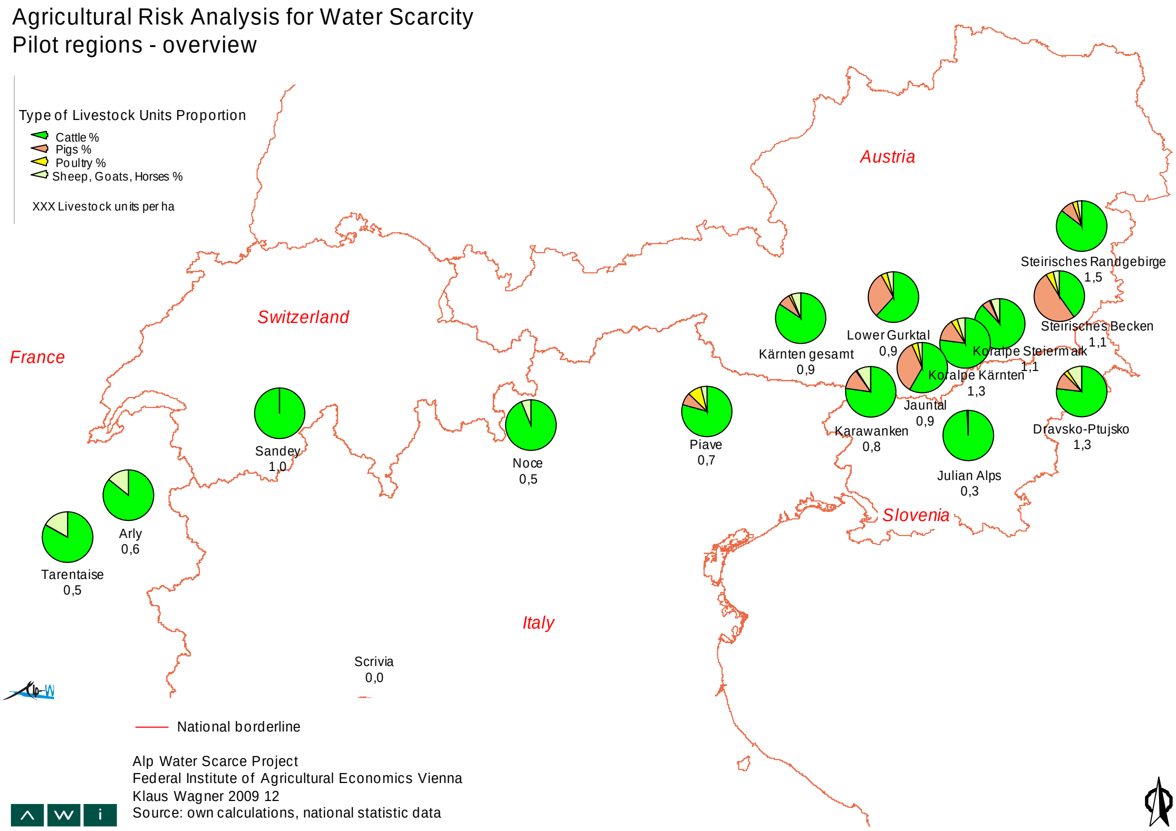


Figure 26 Current animal husbandry in selected Alp Water Scarce pilot regions

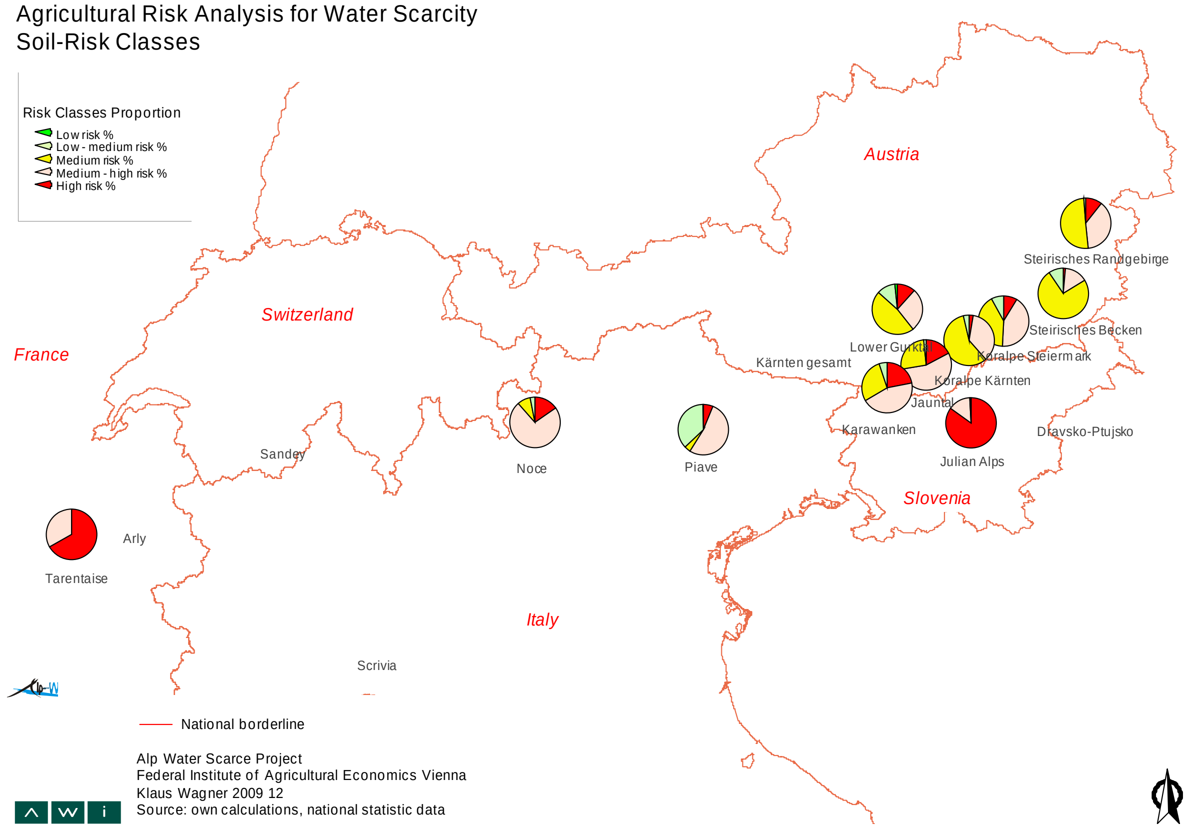


Figure 27; Soil situation on agricultural land in selected Alp Water Scarce pilot regions (high risk: high share poor soils without water saving capacity, low risk: low share of poor soils without water saving capacity)

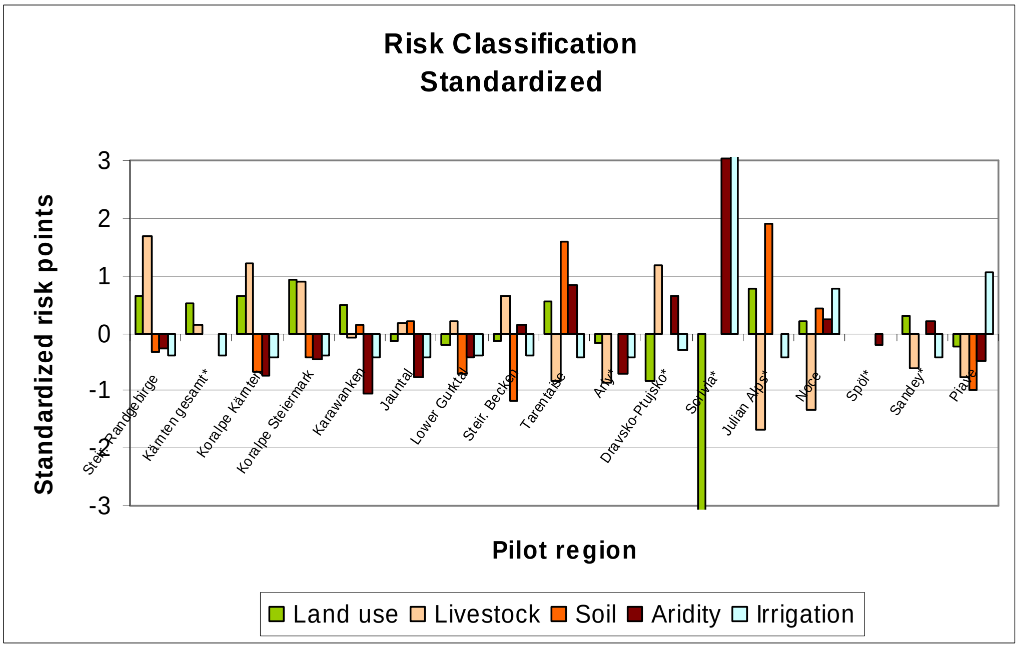


Figure 28; Standardized risk classification for selected Alp Water Scarce pilot regions, current situation;

*...data incomplete

4.3 Climatic scenarios guideline (6.3

Water scarcity is defined as a long-term imbalance between water demand and water availability (which is defined here as the water abstraction volume capacities rather than the total water available in the environment). Climate change may impact water availability as the natural water cycle is affected by changes in temperature, precipitation and evapotranspiration.

− **Temperature** affects the volumes of water stored as snow or ice during the winter season. It impacts the temporal dynamic of the release of these water volumes during the melting season.

− **Precipitations** regimes may be modified as, for example, regional weather types may be changed. Nevertheless, concerning Alpine region, impact of climate change on precipitation remains difficult to predict.

− **Evapotranspiration**: due to changes in the temperature and precipitations regimes, this variable will also likely change in the future which might affect *e.g.* agriculture and deep water recharge.

All these changes in the hydrological regimes of alpine rivers will impact on the water withdrawal facilities and thus the water demand satisfactions. Trying to assess changes of water scarcity that are linked with climatic changes is obviously a challenging task. Many projects have already addressed the quantitative assessment of likely future evolutions of Earth temperature and more recently of precipitations. Anyhow, these estimates cannot yet be used *as-they-are* at the local scale of the Alp-Water-Scarce Pilot Sites. This can be underlined by the fact that since 19th century, the average temperature of the Alps seems of having increased faster than the Earth average temperature (BENISTON 2007). It can be assumed that at smaller scale (level of a Pilot Site) the local climatic trends are even more variable compared to the global trend, and thus difficult to predict.

Scientific knowledge acquired on Earth and Alpine Arc climatic changes by other projects is needed and is used in this study. This knowledge is completed by local meteorological information collected within the Alp-Water-Scarce project. How both levels complement one another is described in the section "Method". Its technical implementation is discussed in the section "Technical guideline".

The aim of this guideline is not to depict the continuous temporal and spatial evolution of climate. This goal cannot be reached at this stage of scientific knowledge and technical means. The present study is discussing the possible situations within two future time-windows: 2040-2060 and 2080-2099. It tries to describe how could meteorological forcing evolve in these two warmer climate conditions. None of the calculations that will be presented should be understood as an accurate prediction for these very particular years that could be taken *as-they-are*. These two future time-windows should rather be understood as – for the first one –

a highly probable close future situation and − for the second one − as **a severe possible situation** that may occur if not enough is done to reduce human impacts on Earth climate dynamics.

A common method for all Pilot Sites is suggested here. It is based on a classical downscaling Approach coupled with a classical perturbation method. Other technical approaches could have been suggested with various advantages and discussions. Furthermore different methods were indeed used by partners. The goal of this common approach is to have a common basis for comparison between Pilot Sites.

Each partner was free to use also different approaches. At a given Pilot Site, comparison between scenarios building methods help in underlining the remaining uncertainty of climate changes impacts assessment.

4.3.1 Method: Capitalizing community results and Pilot Site data

The suggested methodology takes benefit of the Pilot Site monitoring efforts while compensating for the lack of large scale information using external projects results. Some results of the IPCC (IPCC), the HistAlp (HistAlp) and the ENSEMBLES (ENSAMBLES) projects are used. It proceeds in four steps:

Global scale: The IPCC results are used to set a likely scenario of temperature and precipitation changes for the periods 2040-2060 and 2080-2099. One scenario is used here: the A1B scenario. It assumes a quick raise of the world growth, with an increasing use of energies with low CO_2 emission (nuclear energy, renewable energies) and the fast introduction of new efficient technologies. The A1B scenario seems to be the closest from the forecasts of the International Energy Agency at the year 2050 (IEA). If the human impacts on the climatic changes lead to a consensus, the desegregation of these global changes at the local scale remains a scientific and technical challenge. Using one climatic scenario may be then considered as sufficient to draw round relevant future trends. Results presented here are then not at all forecasts of what will happen. They should rather be seen as types of trends of what is likely expected to happen. The amplitude of these trends remains uncertain considering the state of the art of the scientific and technical knowledge.

Alpine scale: The climatic variability is not uniform in space. In particular, the impacts of earth climate changes may have various amplitude at the Alpine Space scale. This question is addressed by a large number of research projects which make use of historical data and/or modelling results.

- Considering temperature changes, the use of the HistAlp project results is suggested. Indeed this project calculated for the years [1760-2007] seasonal averages of temperature changes in the Alpines regions with special emphasis in collecting as much as available data as possible and in homogenization complex corrections. Four meteorological sub-regions were defined (North-West, North-East, South-West and South-East) and will be used in this guideline.
- Precipitation changes prediction remains a challenging question involving highly coupled

complex natural processes. It is then highly hazardous to suggest detailed scenario of precipitation changes for the next decades/century. But it can be outlined that meteorological studies (mainly based on numerical weather/climatic models) seem to suggest low changes in precipitation rates over Alpine regions. The ENSEMBLES project confirm this fact while suggesting a clear North-South gradient at the European scale, leading to a slight increase of precipitation in the North part of the Alps and a slight decrease in the South.

Inter-annual variability: The climatic time scales are much larger than the meteorological time scales. This meteorological variability is the observed and discussed one, in particular by populations and stakeholders. It is also the time-scale of socio-economic adaptation to climatic change. Due to the availability of data in the Alp-Water-Scarce project, it was considered that this meteorological variability was reasonably sampled using a minima of 10 years time series. From the statistical point of view this is a very short period of time. Anyhow, one has to take into account the difficulties of long-term continuous monitoring in high mountain areas (already underlined (KLEMES 1990) and still discussed in 2011 at the General Assembly of the European Geosciences Union). Furthermore, during these last 10 years, the largest heat wave that hit the European territory since the last 500 years was observed (2003), a very cold winter (2005-2006) occurred as well as one of the snowiest winters of the last 30 years (2009-2010), etc. Then, as imperfect can be this assumption, this a minima 10 years sampling still embeds some meteorological variability, usable and relevant for the project.

Intra-seasonal variability: at a given Pilot Site, for each available annual time-series, adding a shift value on each daily value will generate new temperature and precipitation time series. These added values will be explained. Each of these generated time series from the original ones will be considered as a time-series that may occur in a future modified climate. These new time series will then take into account (i) the historical meteorological times series of the considered Pilot Site, (ii) the HistAlp/ENSEMBLES trends of its alpine climatic context and (iii) the forecast of the A1B climatic scenario. For each Pilot Site and for each climatic scenarios, a minima 10 annual generated time-series are available and will be used to force hydrological models. Extrapolating these data assumes then that the observed seasons variability of climatic changes during the last decades can be used for the next decades, whatever will be the amplitude of these changes. Taking into account the lack of scientific and technical knowledge so far, this assumption may be considered as reasonable, but without being able to estimate its uncertainty and bias. For example, this assumption implies to consider that the weather types frequency on a particular region remains stable (i.e. stability of the synoptic meteorological forcing variability despite the climate change). Recent climatic research results using high-resolution meteorological models seem to corroborate this assumption (BOHM 2010).

The perturbation of historical time series using some climatic scenario and seasonal variability of this climatic change has some advantages:

- This method is simpler than trying to build statistical scenario generators of daily meteorological time series or than using high-resolution non-hydrostatic meteorological models to disaggregate climatic scenarios.

- The auto-correlation between daily meteorological values is ensured. This auto-correlation is explained by local influences of the meteorological weathers that need to be taken into account.
- The correlation between temperature and precipitation temporal dynamics is preserved (but amplitude will be changed as independent perturbations are applied on both). This correlation is explained by the fact that temperature and precipitation are not independent variables but are generated by the same physical processes of the weather that generate these temperature and precipitation values at a given day.

4.3.2 Technical guideline

4.3.2.1 Step 1: Earth climate temperature scenario

The IPCC report suggest different scenario of temperature evolutions. Within the Alp-Water-Scarce project the A1B scenario was chosen. The

Figure 29 is adapted from the IPCC 2007 report (IPCC 2007). The blue line shows the multi-models global average of surface warming for the last XX century and its projection (red line) until 2100. The temperature values are temperatures changes relative to the period [1980-1999] (grey box). The two temporal projection windows ([2040-2060] and [2080-2099]) of this study are drawn in light red boxes.

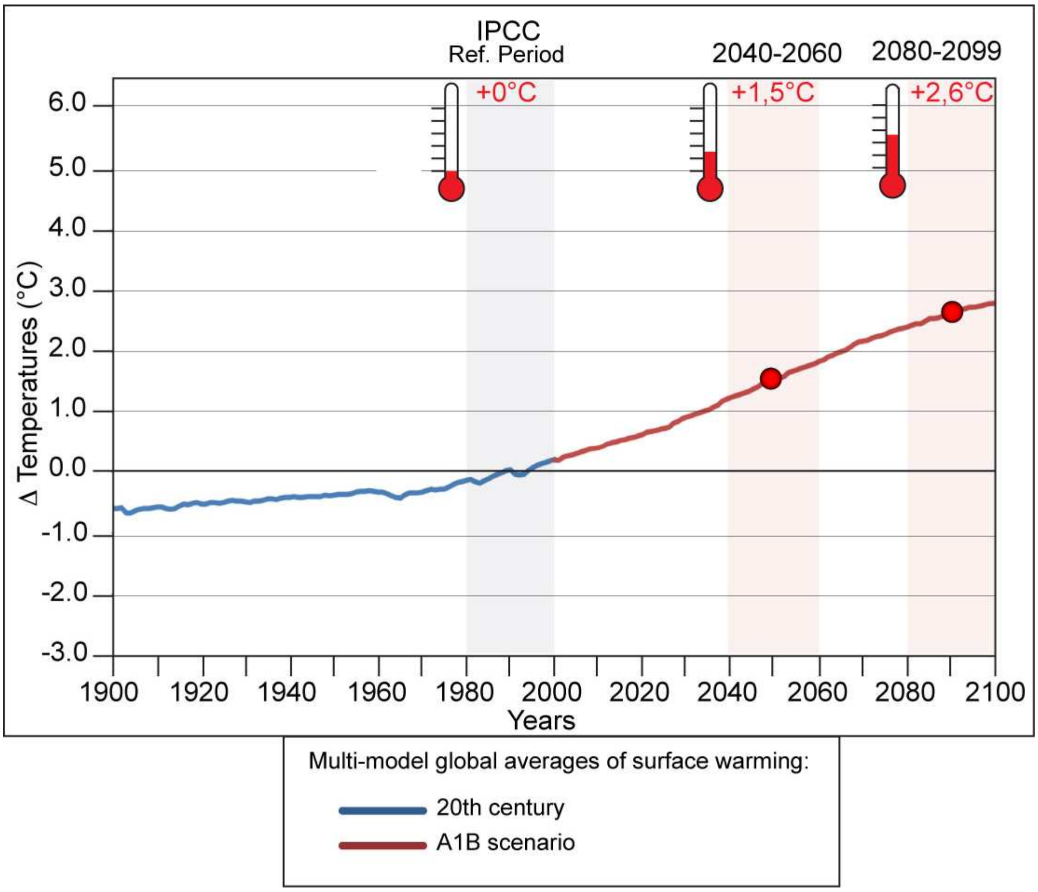


Figure 29; Multi-model global averages of surface warming (20th century + A1B IPCC scenario).

The temperatures changes relative to the period [1980, 1999] are retained in Table 1. Temperatures changes relative to other time-period can be derived from
Figure 29.

Table 8; Earth temperature changes for the periods [2040-2060] and [2080-2090].

	Earth scale
Period	Δ T (°C)
2040-2060	+1.5 °C
2080-2099	+2.6 °C

4.3.2.2 Step 2: Alpine climate temperature scenario

Local trends can be very different from the global ones. Figure 30 shows the HistAlp statistics of temperature warming of the Alps which is overlaid (green dot, thin green line) on the IPCC graph (Figure 30) for the period [1900-2007]. It can clearly be seen that the interannual variability of this statistic is higher than the average of the multi-climatic models.

The correlation between these two series can be calculated on the period [1900-2007] and extrapolated to the year 2100 (Figure 30; thick green continuous line). The uncertainty bounds $[-\sigma,+\sigma]$ with σ the standard variation of these residual embeds 75% of the uncertainty when calculating the average annual temperature of the Alps from the average of the IPCC multi-models.

Figure 30 corroborates the conclusion of various research studies dedicated to climate warming in the Alps: this region is very sensitive to global warming which means that warming is twice as faster in the Alps than those of the global scale. This is a general rate calculated at the climate temporal scale (century). It can be observed that at the meteorological scale (decade) this warming rate may have a significant variability.

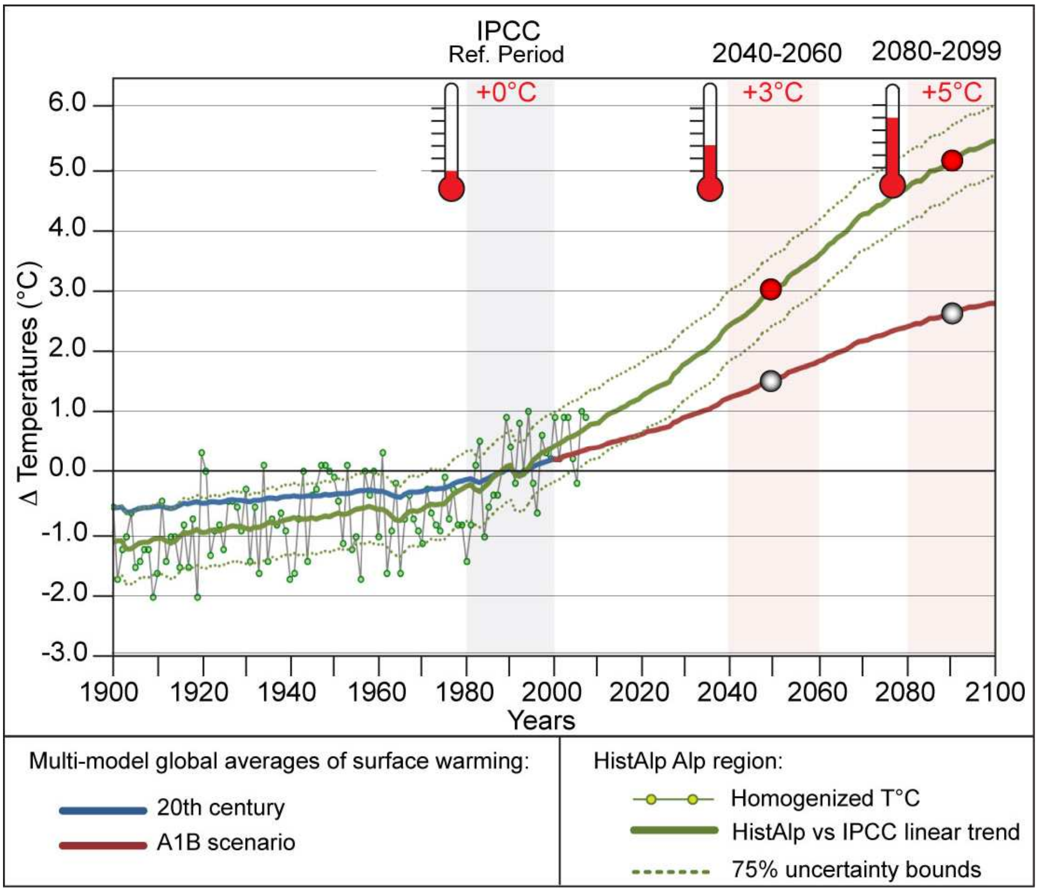


Figure 30; Alp surface warming extrapolations based on HistAlp data and A1B IPCC scenario.

The temperatures changes listed in Table 9 relative to the period [1980, 1999] are then retained.

Table 9; Temperature changes in the Alps for periods [2040-2060] and [2080-2090].

	Earth scale	**HistAlp region**
Period	Δ T (°C)	Δ T (°C)
2040-2060	+1.5 °C	+3.0 °C
2080-2099	+2.6 °C	+5.0 °C

The HistAlp project divides the Greater Alpine Region (GAL, 4–19*o*E, 43–49*o*N, 0–3500m asl) in four sub-regions: North-West (NW), North-East (NE), South-West (SW) and South-East (SE). The warming in these regions can thus be calculated from the HistAlp statistics. As shown in Table 9, the temperatures are lower than the upper-part of the Alps shift mentioned in Table 9. This is relevant as the four HistAlp sub-regions are quite large and contain low elevation stations that are not taken into account for the calculation of HistAlp average. The temperature increase in northern regions is higher than those of the south regions. This contradicts to the results obtained from the ENSEMBLES project which concludes a slight gradient NW-SE (slightly higher temperature increases in South-East regions than in North-West regions). This difference between results obtained from real data and from models (both with assumptions, limitations and uncertainties) underlines the complexity of the spatial disaggregation of climatic scenarios.

Table 10; Temperature changes retained for the four HistAlp sub-regions and for periods [2040-2060] and [2080-2090].

	HistAlp regions in the Alps				
	Alp region	N-W region	N-E region	S-W region	S-E region
Period	Δ T (°C)	Δ T (°C)	Δ T (°C)	Δ T (°C)	Δ T (°C)
2040-2060	+3.0 °C	+2.7 °C	+2.6 °C	+2.4 °C	+2.2 °C
2080-2099	+5.0 °C	+4.7 °C	+4.4 °C	+4.0 °C	+3.8 °C

Due to the weak correlation between seasonal temperatures changes in the HistAlp statistics, no seasonal desegregation of these upper annual temperature changes is suggested here. Furthermore, during the last 25 years, winters and summers have warmed at comparable rates, which is not typical for the regional climate evolution over the past 250 years as indicated by the European Environment Agency (AGENCY 2009).

4.3.2.3 Step 3: Alpine climate precipitation scenario

Predictions of precipitation changes remain highly uncertain. The Figure 31 shows the results obtained by the ENSEMBLES project. It shows the prediction of precipitation changes (in percentage) all over Europe for the period [2021-2050] relative to the period [1961-1990] for the multi-model mean of the ENSEMBLES regional climate models.

This graph also indicates that a North-South gradient in precipitation might occur in the future: higher precipitation rates in Northern regions and lower precipitation rates in Southern ones. Some *what-if* precipitation scenarios are assumed in this guideline: from 0% to 5% precipitation increases in Northern regions and from 0% to -5% precipitation decreases for Southern regions as mentioned in Table 11.

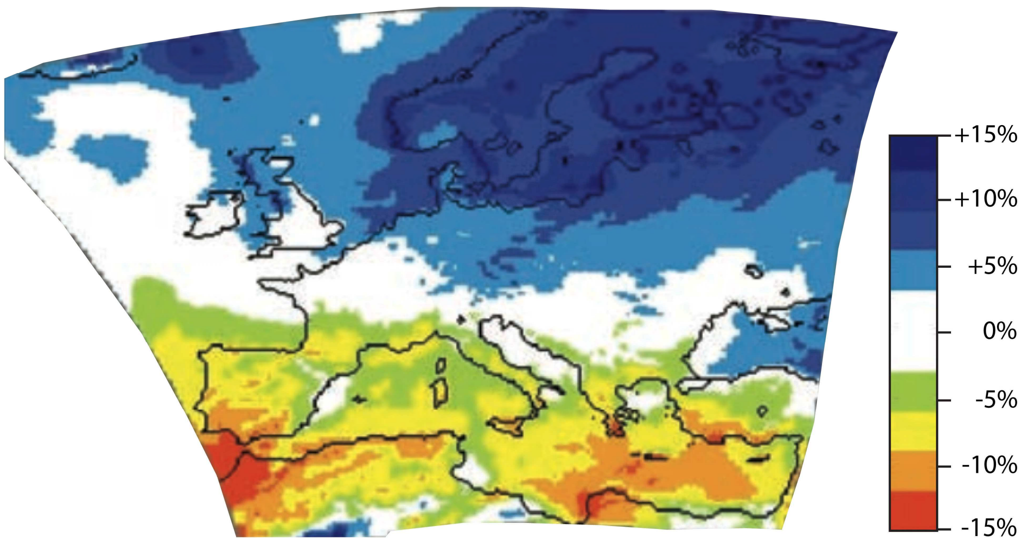


Figure 31; ENSAMBLE prediction of precipitation changes in Europe for the period [2021-2050].

Table 11; What-if precipitation changes scenarios for the four HistAlp sub-regions and for periods [2040-2060] and [2080-2090].

	HistAlp regions in the Alps

	Alp region	N-W region	N-E region	S-W region	S-E region
Period	Δ T (°C)	Δ T (°C)	Δ T (°C)	Δ T (°C)	Δ T (°C)
2040-2060	0 °C	0 °C	0 °C	0 °C	0 °C
2080-2099	0 °C	+5 °C	+5 °C	-5 °C	-5 °C

4.3.2.4 Step 4: Alpine evapotranspiration scenario

Some models need an estimation of the potential evapotranspiration as forcing variable (using various methods such as the Penman-Monteith equation). Anyhow, no scenarios are available for variables used in such potential evapotranspiration calculations (net radiation, vapour pressure deficit of air, *etc.*). If needed, it can be suggested to calculate the correlation between temperature and evapotranspiration on based on historical data and to apply this correlation to estimate scenarios of potential evapotranspiration.

This suggestion clearly leads to simplification and uncertainties. Figure 32 illustrates that such trends still exist and could be used in case of a lack of data. In Figure 32 potential evapotranspiration (FAO Penman-Monteith equation) is plotted as a function of temperature (Klagenfurt Airport station, Austria) at a monthly time step for the period [1984-2008]. If caution is taken to separate spring-summer and autumn seasons when calculating the regressions (due to the vapour pressure deficit seasonal variability), some significant statistical relationship can be derived and used for future extrapolation of potential evapotranspiration.

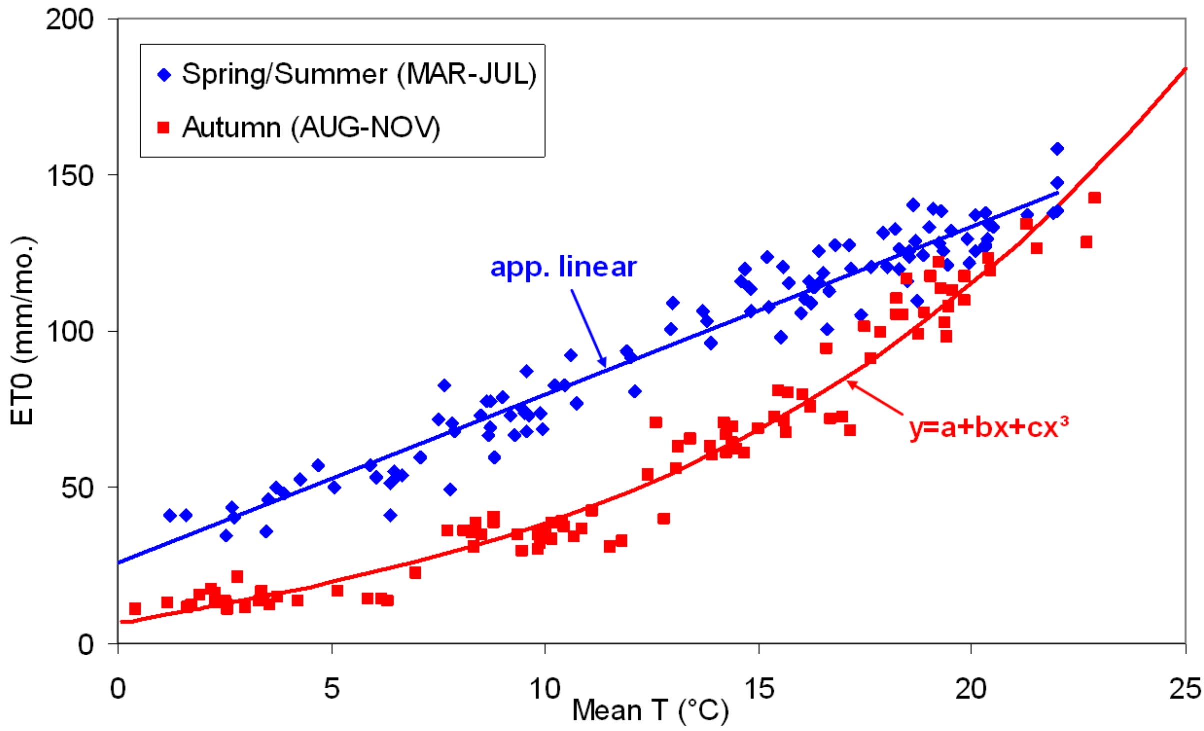


Figure 32; Comparison between ETO Penman-Monteith potential evapotranspiration and temperatures from 1984 to 2008 (Δt=1 month, Klagenfurt Airport station, Austria).

4.4 Conclusions

Monitoring and modelling activities within the Alp-Water-Scarce project were followed by a comparison of present and future risk factors among the Pilot Sites in agriculture as one of the biggest water consumers. Such risk analysis can give recommendations for changes in agricultural practices with the aim of climate change adaptation.

Furthermore, climatic scenarios for Earth climate temperature, Alpine climate temperature, Alpine climate precipitation and Alpine evapotranspiration were developed. This guideline proposes a common methodology to calculate future scenarios for all Pilot Sites within the Alp-Water-Scarce project. It is based on a classical downscaling approach coupled with a perturbation method. The goal of this approach is to have a common basis which means that the results obtained can be compared between Pilot Sites.

Additionally, considering the uncertainties in future scenarios still remaining, a comparison between methods to build scenarios can help to quantify the impacts of uncertainty of climate change impacts assessments.

5 Links with Workpackages 7 and 8 (6.4)

Within WP6 we focused on hydro-meteorological indicators of water scarcity such as water temperature, water discharge, precipitation and evapotranspiration. By measuring physical and chemical parameters we usually get information about the values of observed parameters only in limited time-frame. However, we do not get any information of their cumulative and long-lasting effects on biota, which is important in the determination of water quality through self-purification processes. Organisms are ideal indicators for long-term environmental conditions as potential negative effects on community composition or increase/decrease of abundance of a single species persist for a long time. Thus results of WP6 were the basis for the development of biological indicators for the identification of optimal ecological discharge which is the aim of WP7 of Alp-Water-Scarce.

Results of the future scenarios for physical environmental conditions (WP6) also represent the basis for predictions of changes in ecosystem component of the natural systems. Future trends of temperature rise and changes in amount of precipitation can give indications about future environmental conditions and thus indicate future synoptic forcing conditions for the ecosystems. Within WP7 the resilience of ecosystems to environmental change and potential multiple stressors were analysed. Experiments with different types of management in the Spöl, the Sandey, the Noce and the Adige Pilot Sites gave an insight into potential management adaptations to minimise the impacts of climatic and anthropogenic change.

Monitoring and modelling of environmental hydro-meteorological conditions is also the basis for the development of early warning systems to tackle water scarcity which was the aim of WP8. Within Alp-Water-Scarce, four different early warning systems were developed that address the specific needs of particular Pilot Sites: In the Arly catchment (France) the Early Warning System aims at long term water reconciliation; in Carinthia (Austria) the Early Warning System is dedicated to ensuring a sustainable drinking water supply; in the Piave catchment (Italy) it is intended help to avoid user conflicts between hydropower generation and agriculture and in Slovenia it contributes to water saving measures for agriculture.

One of the recommendations regarding the Early Warning System which originates from results of WP6 is that simulation models should be used in order to increase the prediction lead time and reduce uncertainty of the Early Warning System.

6 Monitoring & Modelling in the different Pilot Sites

This section lists the detailed activities of each Pilot Site regarding modelling. As briefly described above (see section 3.2.1) modelling activities differed between the Pilot Sites according to primary area of concern within the Pilot Site, the amount of meteorological and hydrological data available, human resources etc.

6.1 Pilot Site "Savoie"

6.1.1 Modelling

The main aim of this Pilot Site within the Alp-Water-Scarce project was to establish a reliable monitoring network, as no meteorological or hydrological data was available until now. Considering the low amount of available data and the significant efforts dedicated to establish this necessary monitoring network, no modeling of the catchments in the Pilot Site Savoy could be performed. Nevertheless, based on the new data provided by the monitoring network modeling activities will be performed in collaboration with the CNRS in the following years. In particular, when various springs and aquifers were monitored during the project, special attention was given to sample aquifers with different dynamics, geological environment, types (mountainous and valley aquifers), etc. Recession curves analyses are currently performed in each of these new measurements sites. Regionalization of these Master Recession Curves will be modeled to get regional spatially distributed water content estimates. Data on water demand that was collected within WP5 will be compared to these estimates in order to calculate water scarcity risk in the current climate situation but also in the next decades according to the climate scenarios suggested by this project.

6.2 Pilot Sites "Upper Arly River Basin"

6.2.1 Modelling

Report of the modelling results is in Annex 1 of this report.

6.3 Koralpe

6.3.1 Modelling

A report of the modelling results is in Annex 2 of this report.

6.4 Karawanke

Karawanke are the only transboundary Pilot Site within Alp-Water-Scarce project. The northern part of Karawanke lies in Austria and investigations of this area were performed in cooperation with the Regional Government of Carinthia and the Joanneum Research. A report of modeling results is in Annex 2 of this report.

The southern part of Karawanke lies in Slovenia and the modelling in this part was carried out by Geological Survey of Slovenia and is presented in the body of the text below. An abstract of all activities connected with Water System Characterisation (WP5) and Monitoring and Modelling (WP6) carried out by Slovene Geological Survey is given in Annex 3 of this report.

6.4.1 Modelling

6.4.1.1 Introduction

The Geological Survey of Slovenia performed activities in a large area in the south of Karawanke Pilot Site and in small part of the Julian Alps. A detailed report (predominately written in Slovene language) is available upon the request from Geological Survey of Slovenia.

6.4.1.2 Action 6.1. Elaborate monitoring network for hydrometeorology, hydrology, hydrogeology, ecology, water quality and water abstraction

In the Karavanke and Julian Alps occasional discharge measurements were performed. In Karavanke area simultaneous measurements together with Austrian partners were performed on nearly all watersheds – their geographical position is represented in (Figure 33). In Julian Alps measurements were performed on Rivers Radovna and Savica. At the same time sampling for stable isotopes in water were performed.

Figure 33; Watersheds where discharge measurements were performed in the Karavanke Pilot Site.

An important part of the monitoring network were field investigations of soil characteristics. 22 locations (11 in Slovenia and 10 in Austria) were investigated by the Geological Survey of Slovenia. A detailed physical description of soil was performed on site as well as in-situ measurements of soil permeability (Figure 34). In the laboratory mineralogical characteristics and soil water characteristics curves – SWCC were measured. All results are given in the separate report.

Figure 34; Permeability measurements in the field.

All available data were used for the parameterisation of the area. Some maps showing regionalised parameters are shown in Figure 35 and Figure 36. More maps are presented in the main report.

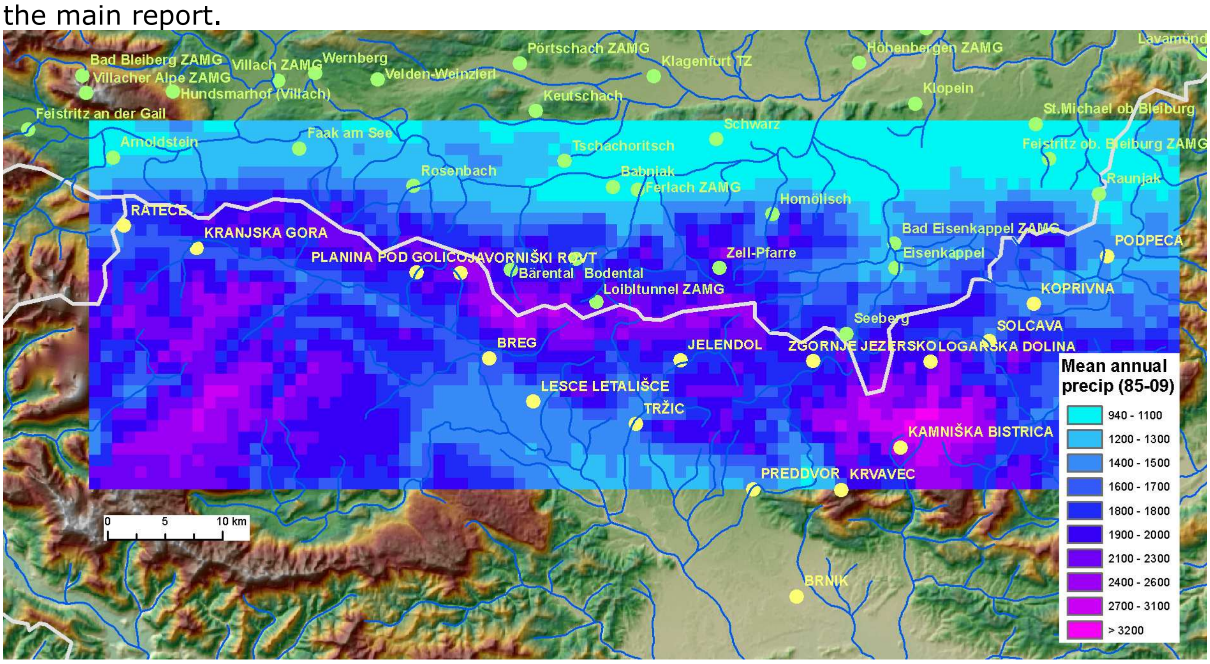


Figure 35; Mean annual precipitation regionalisation.

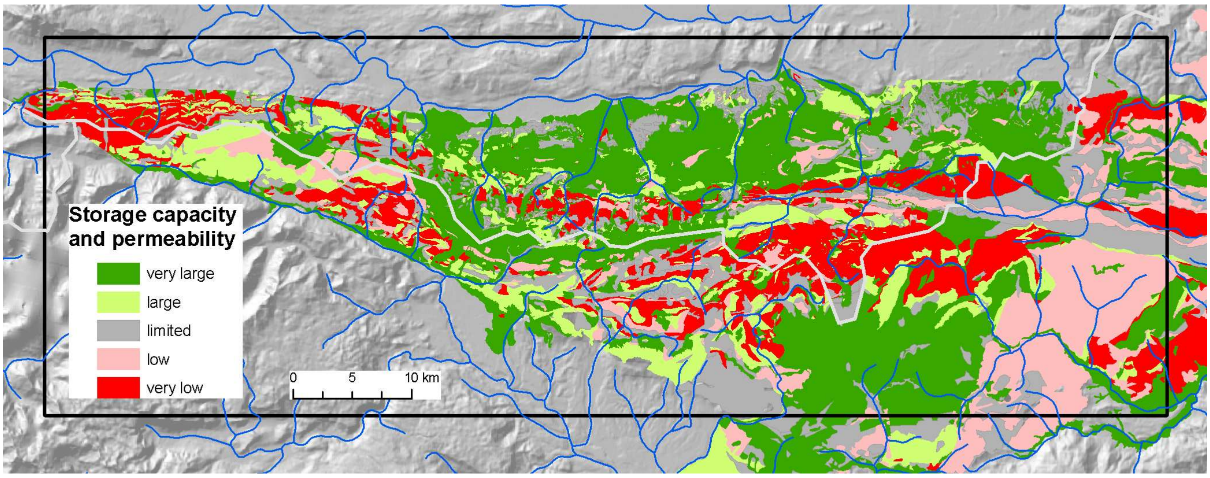


Figure 36; Storage capacity and permeability of soil and rock.

6.4.1.3 Action 6.2. Carry out integrated hydrological regional and subbasin modelling

The spatially distributed physically based model MIKE SHE was applied to simulate runoff and groundwater recharge based on distributed vegetation and soil data.
The model is used for:

- Data prolongation using HISTALP data
- Analysis of the water balance
- Calculation of scenarios ("what-if" with different input (future change)

For the pilot site of Karavanke the modelling concept has been worked out taking into account the special and complex conditions in mountainous areas. One objective of modelling is the simulation of long term changes of the water balance (especially groundwater recharge and catchment runoff) and the simulation of scenarios of future changes. The modelling system MIKE SHE is used, which is a distributed grid-based runoff model using partly physically based algorithms. The model describes the main processes of actual evapotranspiration and infiltration (both depending on climate parameters, land use and soil properties) and the runoff components surface runoff and base flow (i.e. groundwater flow). Main processes are the actual evapotranspiration and the runoff components. The models are calibrated to runoff gauge data. The cell size is 500 x 500 m for Karawanken. Relevant components for water resources management in the catchments are the deeper groundwater recharge into the two baseflow storages, i.e. percolation, and the corresponding outflow of the storages (groundwater flow). Thus, one of the main objectives of the model application is to quantify overland and interflow components and separate them from the groundwater flow.
The following data have been collected and regionalized:

GIS-Data:

- DEM (Digital Elevation Model)
- Geological Units
- Soils, weathering layer, thickness
- Land use
- Stream network
- Catchment areas of gauged catchments and sub-catchments

Time series of hydro-meteorological data:

- Precipitation
- Air temperature
- Potential (grass reference) evapotranspiration (ET0 according to PENMAN-MONTEITH)
- Discharge of rivers and springs for calibration

Unsaturated zone:

- Thickness of soil horizons
- General soil parameters (fraction sand-silt-clay, humus, stones)
- Soil physical parameters

Saturated zone:

- Hydro-geological units: hydraulic properties of the underground material

Evapotranspiration:

- Leaf Area Index (LAI)
- Root distribution (Root depth, root vertical distribution)
- Crop factor kc according to FAO (ALLEN ET AL., 1998)

For the input parameter of the potential evapotranspiration the equation for the grass reference evapotranspiration after FAO-PENMAN-MONTEITH is used on station base (data from ZAMG and ARSO). The potential crop evapotranspiration is calculated based on the land use systems
Unlike for the flat lands for the flow in the unsaturated zone the full Richard´s equation (one-dimensional in vertical direction) cannot be used due to the dominance of lateral flow processes in mountainous areas (steep slopes), but also due to the high uncertainties of parameter identification in a regional context. Therefore the simplified gravity driven flow approach is used, where the pressure head component in the Richard's Equation is neglected ("Gravity Flow"). The macropore module was used. Macropore flow plays a major role in runoff generation on the hillslope, particularly in the forested areas due to a large amount of macropores or pipes induced by dead roots and small animals (worms).

Due to insufficiently available data in a mesoscale catchment, flow in the saturated zone was not simulated by a detailed hydraulic model. For the flow in the saturated zone the linear reservoir method is used. It is a conceptual approach consisting of several storages in parallel and in series: The interflow storage and two groundwater reservoirs. The storage coefficients and the exchange rates of the different reservoirs are calibrated to runoff data.

For future scenarios, estimations of a temperature change and precipitation change referring to past changes and several future climate change studies in the Alps were used. For the parameter of the potential grass reference evapotranspiration (ET0) such estimations are not reasonable, since the potential evapotranspiration depends on many climate factors such as radiation, wind, relative humidity etc. which is impossible to predict for the future. Therefore a simple relationship between monthly ET0 data and air temperature was defined by historical data analyses.

<u>Implementation of distributed catchment data into the hydrological model.</u> Vegetation and land cover data from the CORINE data set (100 m resolution) were used. In the region forest (coniferous and mixed forest) dominates, in high elevation regions often bare rock or slope debris areas with no vegetation and no soil covering occur. In a further step, the 100 m data set was aggregated to the 500 m model raster. The used 500 m raster in the model is a

compromise between the resolution of the available vegetation data (100 m), the extent of the stations where meteorological information is available (interpolated on a 1 km^2 grid) and the expected computation time.

The evapotranspiration (ET) parameters Leaf Area Index (LAI), effective root depth and crop factor for the different vegetation classes were determined according to the FAO guidelines. A typical annual cycle is chosen. However, particularly for the parameter of the LAI, the annual cycle in large parts of the model region is not very significant, because coniferous and mixed forest occurs.

Calibration and validation. Since the modelling activities are carried out on both sides of the Karawanken massif, in Austria and Slovenia, a general strategy for parameter identification between Joanneum Research (JR) and Geoloski zavod Slovenije (GeoZS) was discussed to take into account expert knowledge of particular sub catchments and the local data situation. The discussions focused on the vegetation-evapotranspiration parameters, the pedo-hydrotope classification described above and the soil hydraulic and bypass parameters (i.e. pixel scale parameters). After preliminary test calculations a priori parameter set on pixel scale has been defined to represent the general water balance and runoff dynamics observed at selected gauges. This set-up is then fixed, so that the further calibration procedure can be carried out individually. The parameters, which are changed and fine tuned are those representing processes on sub catchment scale. For each sub catchment overland flow and saturated zone flow (interflow and baseflow) is simulated in a lumped manner. The corresponding parameters in have only minor effects on the general water balance simulation, but affect the separation of the simulated runoff into the different runoff components (temporal dynamics). This will be important for estimating long term water storage characteristics in a water resources management context. Also, initial values and plausibility limits for each parameter were set during the common model set up discussion.

6.4.1.3.1 Results of modelling

Water balance components. The results of distributed water balance components are shown in the next figures (Figure 37) the mean annual groundwater recharge in the whole Karawanken region is plotted. In principle, the distribution follows the distribution of the annual precipitation. Annual precipitation amounts of more than 3200 mm/year lead to annual groundwater recharge values of up to 2900 mm/year in the summit region of the Karawanken massif. The simulated actual evapotranspiration (ETa) is in the order of 600 to 700 mm/year in the valleys and around 300 mm/year in the summit region (Figure 38). These are values very close to the potential Evapotranspiration ET0. The mean annual ET0 is around 700 mm/year in an elevation of 350 m a.s.l. (lowest elevation in the model region) and around 470 mm/year in an elevation of 2500 m a.s.l.. These large values of the actual ET show, that particularly in the valleys there is enough water in the soils available that the potential crop evapotranspiration is almost reached all over the year.

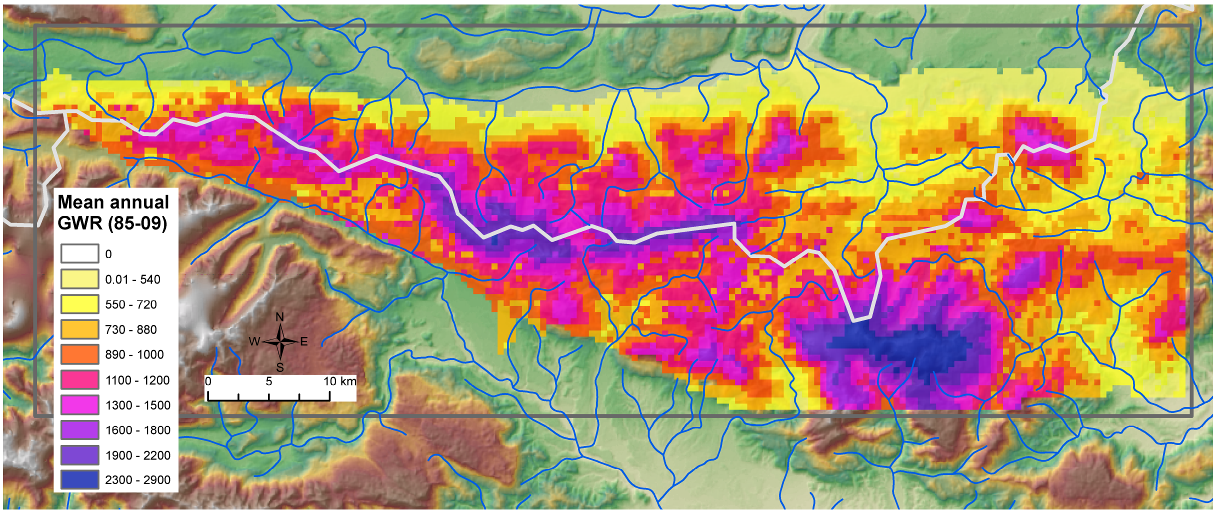


Figure 37; Simulated mean annual groundwater recharge (GWR) for the period 1985 to 2009.

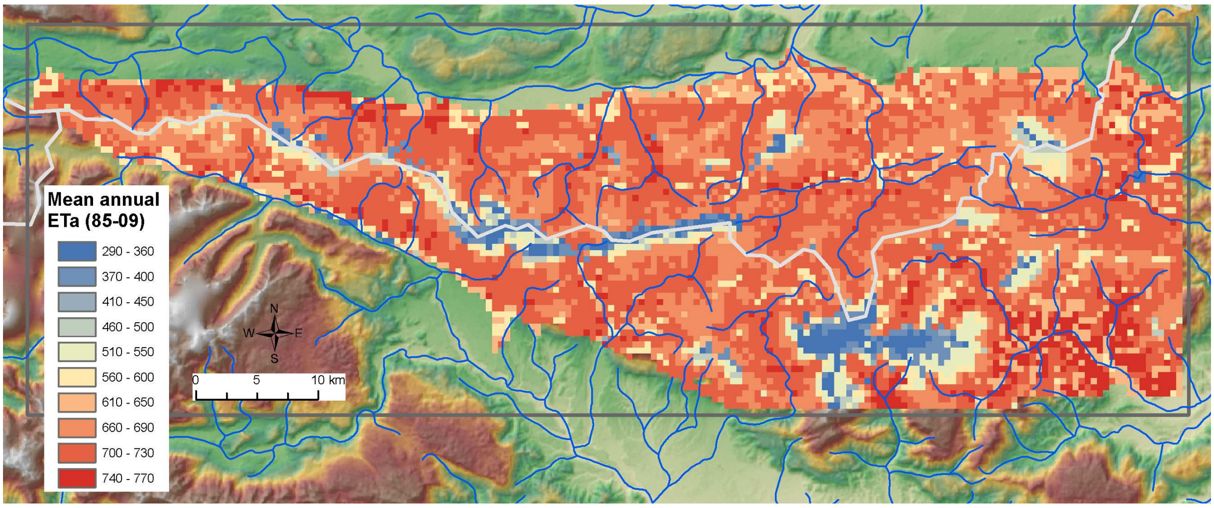


Figure 38; Simulated mean annual actual evapotranspiration (ETa) for the period 1985 to 2009.

Figure 39 shows as an example the simulated and observed runoff depths for the Črna River and Figure 40 the Kokra River. Total calibration period is 2000 to 2007. So the rest of the years can be used to validate the simulated water balance. The plot shows that the water balance is simulated relatively well.

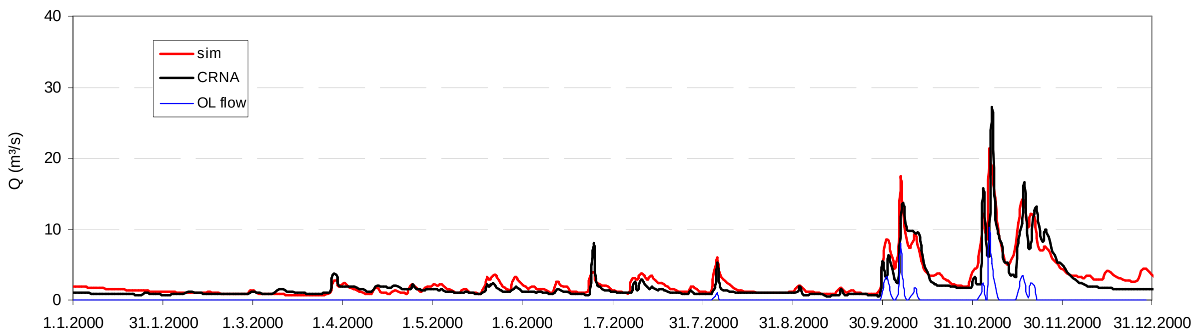


Figure 39; Simulated and observed runoff depths for river Črna – Mežica.

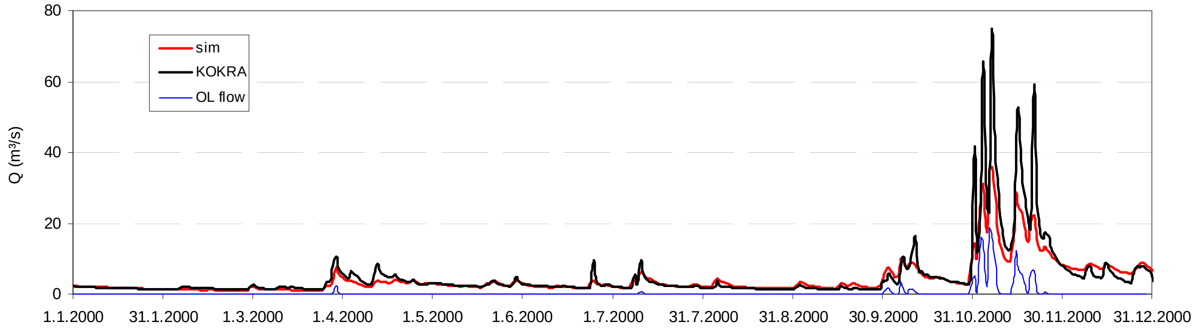


Figure 40; Simulated and observed runoff depths for the river Kokra.

Table 12 shows the mean water balance components for the Slovenian side for the period of 2001 to 2007.

Table 12; Water balance components of the Slovenian side of Karavanke.

Watershed	**Precipitation**	**ETR**	**Underground srorage**	**Underground otflow**	**Surface outflow**
	[m³/s]	**[m³/s]**	**[m³/s]**	**[m³/s]**	**[m³/s]**
BLATNICA	0.116	-0.054	0.003	-0.064	-0.001
BELA	0.348	-0.109	0.006	-0.241	-0.004
UKOVA	0.223	-0.090	0.003	-0.111	-0.021
JAVORNIK	1.024	-0.355	0.016	-0.654	-0.031
JESENICA	1.141	-0.432	0.017	-0.638	-0.078
MLINICA	0.453	-0.158	0.009	-0.290	-0.012
JUREŽ	0.131	-0.050	0.003	-0.084	-0.001
JERMAN	0.276	-0.098	0.006	-0.184	-0.002
KROTNJEK	0.180	-0.075	0.002	-0.094	-0.012
BELCA	0.982	-0.359	0.020	-0.625	-0.019
HLADNIK	0.537	-0.194	0.011	-0.351	-0.006
TREBIŽA	0.164	-0.072	0.002	-0.085	-0.009
ČRNI POTOK	0.263	-0.114	0.007	-0.155	-0.001
BEGUNJŠČICA	0.438	-0.164	0.011	-0.280	-0.005
ZAVRŠNICA	1.112	-0.324	0.024	-0.810	-0.007
PRESKA	6.636	-2.493	0.119	-4.092	-0.140
SOLČAVA	3.702	-1.240	0.046	-2.367	-0.118
ČRNA	4.121	-1.929	0.049	-2.172	-0.053
KOKRA I	5.898	-2.166	0.092	-3.684	-0.112
VMESTNI 1	0.592	-0.207	0.013	-0.389	-0.009
VMESTNI 2	0.430	-0.175	0.009	-0.239	0.009
VMESTNI 3	0.476	-0.191	0.009	-0.267	-0.024

6.4.1.4 Action 6.3. Develop/apply climate and anthropogenic scenarios for water systems with future vulnerability to water scarcity

For the estimation of possible future changes the following scenarios have been defined using the delta change approach of 10 years monthly averages. Due to the high uncertainties of climatic projections mainly what concerns precipitation the scenarios can be understood only as What-If estimations for the period 2040-2050 and not as projections to the future.

- Scenario 1: Delta T and Delta PET from the trend detected in HISTALP data (50 years, i.e. 1960 until today) and assuming a linear extrapolation of this trend into the future.
- Scenario 2: Scenario 1 with a decrease in precipitation of 5% equally distributed over the year
- Scenario 3: Scenario 1 with a decrease in precipitation of 10% equally distributed over the year

6.4.1.5 Action 6.4. Establish hydro(geo)logical indicators for WP 7 and 8

As hydrological indicators in the Karavanke and Julian Alps the Standardised Precipitation Index - SPI was applied. It is based on long-term precipitation time series, usually consisting of the monthly amount of precipitation. The nature of SPI is designed to detect events of low frequency. With the help of this index periods of extremely low precipitation or periods with extremely high precipitation can be defined. It is based on the observation of the cumulative precipitation amount for the particular time period. The concept of the SPI can be applied on other hydro meteorological variables where the total sum of the variable can be given.

6.5 Pilot Site "Jauntal"

6.5.1 Modelling

Report of the modelling results is in Annex 4 of this report.

6.6 Pilot Site "Lower Gurktal"

6.6.1 Modelling

Report of the modelling results is in Annex 4 of this report.

6.7 Pilot Site "Steirisches Becken"

6.7.1 Modelling

Report of the modelling results is in Annex 5 of this report.

6.8 Pilot Site "Steirisches Randgebirge"

6.8.1 Modelling

Report of the modelling results is in Annex 5 of this report.

6.9 Pilot Site "Entire Land Kärnten"

6.9.1 Modelling

The main focus of the modelling activities was to develop and operationally implement methodologies for an early warning system against water scarcity in drinking water supply in the Pilot site "Entire Land Kärnten". A further aspect of the activities is the assessment of possible future developments in water management and the development and definition of scenarios of future water use and their impact on alpine regions with water scarcity.

Together with expert knowledge and experience about the hydro-geological specialities in the different regions of the project area the hydro-meteorological database provides the basis for the development of an appropriate hydrological modelling system. According to the available amount of rain gauges and discharge measurements in the study area we have chosen to use a spatially distributed model configuration. In order to capture the driving processes to simulate low flow during dry periods with water scarcity a soil moisture accounting scheme has to be one of the main components of the modelling system. Additionally the spring runoff at the characteristic sites is compared the results of the spatially distributed hydrologic model and the space born soil moisture estimates. The aim of this comparison is to find applicable relations between the continuous model results and the measured spring discharges in order to map the model predictions for diverse low flow and water scarcity scenarios back to the spring sites again.

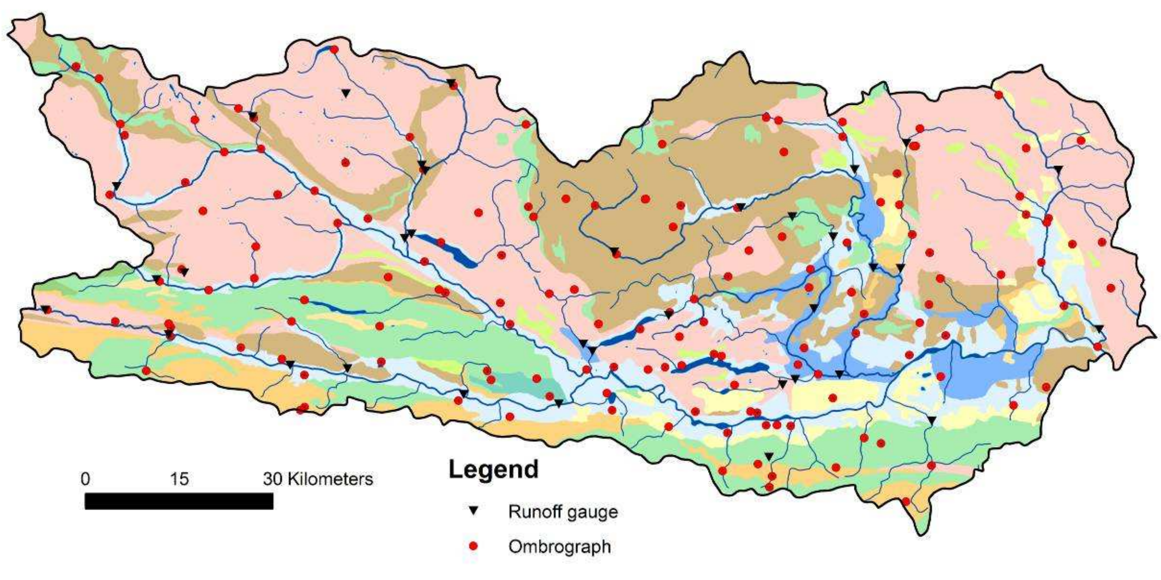


Figure 41: Hydro-geologic map of the study area. Precipitation gauges are plotted as red points and stream gauges are indicated as black triangles. The study area covers entire Carinthia

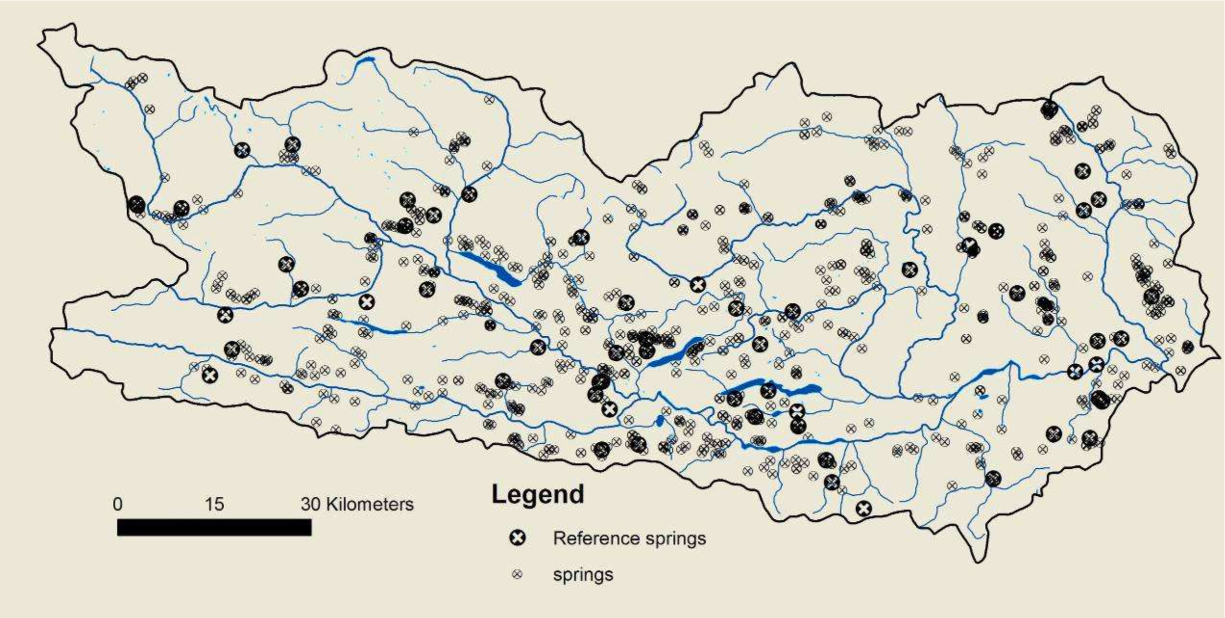


Figure 42: Monitored spring sites in Carinthia. Small black circles show the location of monitored spring sites. Spring sites with a good temporal sampling resolution and good data quality are plotted as thick black circles. The study area covers entire Carinthia.

The definition of the catalogue system is based on the initial conditions as well as the meteorological scenarios are based on statistical analysis of monthly precipitation amounts, mean temperature, simulated spring discharges and soil moisture. Different quantiles of monthly precipitation and simulated spring discharge are used to define the very dry, dry and normal initial conditions and meteorological scenarios.

In order to assess the future development of potential situations of water scarcity, depending on effects of possible climate change processes in the study area, different future scenarios are analysed. As a reference scenario the simulated spring discharges at sixty reference spring sites are used.

6.9.1.1 Model structure

6.9.1.1.1 Concept

According to the available amount of rain gauges and discharge measurements in the study area we have chosen to use a spatially distributed model configuration. In order to capture the driving processes to simulate low flow during dry periods with water scarcity a soil moisture accounting scheme has to be one of the main components of the modelling system. In the study area snow accumulation and snow melt processes do have an important impact on ground water recharge and stream flow runoff. Therefore the implementation of a snow accumulation and snow melt component in the hydrological model is necessary. Therefore a conceptual model structure based on a soil moisture accounting scheme with snow accumulation and snow melt components is used for simulating and forecasting soil moisture, discharges and internal model states within the entire project area in southern Austria. The model concept is based on the well known and wide spread HBV model from Sweden (Bergström, 1976). As mentioned before the main component of the conceptual model is the soil moisture accounting scheme. The root zone soil moisture is simulated with precipitation and snow melt as an input. The local evaporation is estimated using the Blaney-Criddle method with air temperature and information about local slopes, elevation and aspect on input. The soil moisture accounting scheme is mainly defined by three model parameters defining the soil storage capacity, the effect of evaporation and the non linear behaviour of runoff generation. The snow accumulation and snow melt is calculated by a modified version of the simple degree day method. In order to represent the influence of solar radiation in higher alpine regions the spatial distributed potential clear sky radiation is included in the snow melt calculation. The calculation of effective rainfall, namely the fraction of rainfall which becomes runoff, is linked to the simulated soil moisture. In case of very low soil moisture only a small fraction of the precipitation becomes runoff. The other fraction becomes part of the soil storage and leads to an increase of soil moisture. The effective rainfall is routed through a cascade of reservoirs representing the different temporal reactions in the soil and groundwater bodies. The model structure includes a cascade of linear reservoirs (nash cascade).

The spatial resolution of the model is 1 km. A regular grid covering the entire region of Carinthia and parts of eastern Tirol is used to describe the project area. The temporal resolution of the model is defined by a daily time step. The model is driven by spatially distributed precipitation, temperature and potential evaporation inputs. The model parameters are defined for different hydrologic response units. The parameterisation of the model is based on hydrologic response units (HRU). For each of the hydrologic response units a set of model parameters is defined. Figure 43 shows the spatial distribution of the hydrologic response units in the study area. This model structure was necessary for parameter calibration against runoff data. This parameter set describes the expectable rainfall-runoff behaviour of similar hydrologic regions within the project area. For example urban areas, saturation areas, glaciered areas and ground water bodies are defined as such hydrologic response units with similar hydrologic behaviour. The model parameters are adjusted by the use of time series of observed stream gauge data within in the project area. For the calibration of the snow accumulation and snow melt module observed snow depth and satellite borne measurements of snow cover (MODIS data) are available.

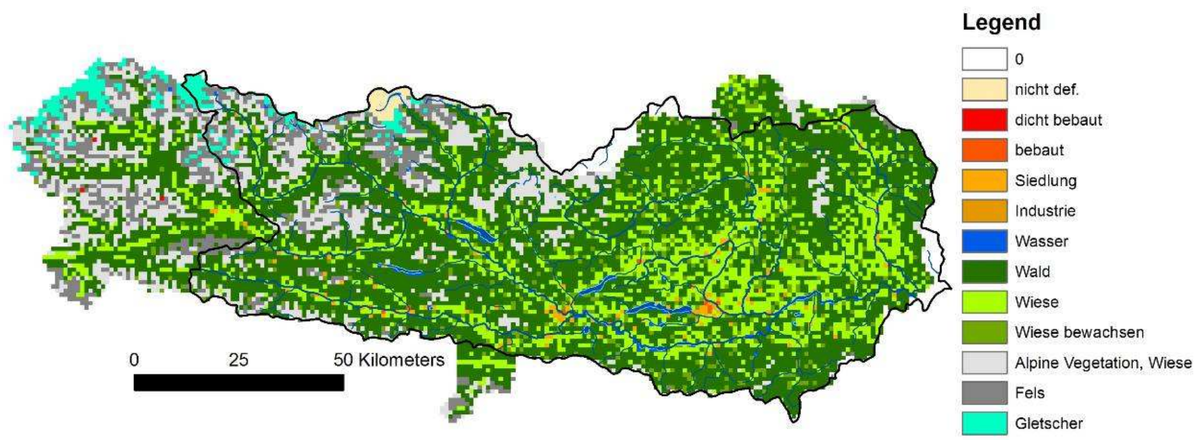


Figure 43: Spatial distribution of the hydrologic response units. Brown lines are the sub-catchment boundaries (necessary for a priori calibration of the snow module and soil moisture accounting scheme – against runoff data at stream gauges).

6.9.1.1.2 Pixel scale processes

The catchments are represented by a total of 12026 square grid elements (Figure 43). For each grid element, snow processes, soil moisture processes and hillslope scale routing are simulated. These processes are formulated directly at the model element scale of 1 km².

6.9.1.1.2.1 Snow model

The snow routine represents snow accumulation and melt by a simple degree day concept. Precipitation input P at each pixel is partitioned into rain P_r, and snowfall P_s, based on air temperature T_a:

$$P_r = P \qquad \text{if} \quad T_a \geq T_r$$

$$P_r = P \cdot \frac{(T_a - T_s)}{(T_r - T_s)} \qquad \text{if} \quad T_s < T_a < T_r$$

$$P_r = 0 \qquad \text{if} \quad T_a < T_s$$

$$P_s = P - P_r \tag{X.1}$$

where T_s and T_r are the lower and upper threshold temperatures, respectively. Melt starts at air temperatures above a threshold T_m:

$$M = (T_a - T_m) \cdot D \qquad \text{if} \quad T_a > T_m \quad \text{and} \quad S_{WE} > 0$$

$$M = 0 \qquad \text{otherwise} \tag{X.2}$$

where M is the amount of melt water per time step, D is a melt factor and S_{WE} is the snow water equivalent. In Austria, large melt rates are known to occur during rain-on-snow events (see Sui and Koehler, 2001). This enhanced melting is represented in the model by increasing D by a factor of 2 if rain falls on an existing snow pack. The catch deficit of the precipitation gauges during snowfall is corrected by a snow correction factor, C_s. Changes in the snow water equivalent from time step i – 1 to i are accounted for by

$$S_{WE,i} = S_{WE,i-1} + (C_s \cdot P_s - M) \cdot \Delta t \tag{X.3}$$

where Δt is the time step. This simple degree day concept was extended according to Hock (1997) in order to account for higher melting rates due to global radiation in the mountainous regions. Potential clear sky direct solar radiation is incorporated into the model formulation in the following way:

$$M = (T_a - T_m) \cdot (b_S \cdot M_F + a_S \cdot I) \qquad \text{if} \quad T_a > T_m \quad \text{and} \quad S_{WE} > 0$$

$$M = 0 \qquad \text{otherwise} \tag{X.4}$$

where M_F is the melt factor (mm d-1 °C-1), a_S is a radiation coefficient different for snow and ice surfaces and I is the potential clear-sky direct solar radiation at the surface (W m-²) and b_S is a seasonal multiplication factor. The melt factor and the radiation coefficient and the seasonal multiplication factor are empirical coefficients, I is calculated as a function of top of atmosphere solar radiation, an assumed atmospheric transmissivity, solar geometry and topographic characteristics (Hock, 1999). The seasonal multiplication factor was introduced at the glaciered pixel elements, in order to increase the melt rates during the summer months for this exposed ice covered raster elements.

6.9.1.1.2.2 Soil moisture accounting

The sum of rain and melt, $P_r + M$, is split into a component dS that increases soil moisture of a top layer, S_s, and a component Q_p that contributes to runoff. If the sum of rain and melt exceeds the infiltration excess threshold X_I, the excess water Q_I directly contributes to pixel runoff and is the outflow of a surface water reservoir with very quick response behaviour defined by the storage coefficient k_I . The remaining amount of liquid water, the minimum of the sum of rain and melt and the infiltration excess threshold, is split to the components Q_P and dQ as a function of S_s :

$$Q_p = \left(\frac{S_s}{L_s}\right)^{\beta} \cdot (P_r + M) \qquad \text{(X.5)}$$

L_s is the maximum soil moisture storage. β controls the characteristics of runoff generation and is termed the non-linearity parameter. If the top soil layer is saturated, i.e., $S_s = L_s$, all rainfall and snowmelt contributes to runoff and dS is 0. If the top soil layer is not saturated, i.e., $S_s < L_s$, rainfall and snowmelt contribute to runoff as well as to increasing S_s through $dS > 0$:

$$\begin{aligned} dS &= P_r + M - Q_p - Q_{by} && \text{if} \quad P_r + M - Q_p - Q_{by} > 0 \\ dS &= 0 && \text{otherwise} \end{aligned} \qquad \text{(X.6)}$$

where, additionally, bypass flow Q_{by} is accounted for. Analysis of the runoff data indicated that for flow that bypasses the soil matrix and directly contributes to the storage of the lower soil zone is important for intermediate soil moisture states S_s. For $\xi_1 \cdot L_s < S_s < \xi_2 \cdot L_s$ (with ξ_1=0.4, ξ_2=0.9) bypass flow was assumed to occur as

$$\begin{aligned} Q_{by} &= \alpha_{by} \cdot (P_r + M) && \text{if} \quad \alpha_{by} \cdot (P_r + M) < L_{by} \\ Q_{by} &= L_{by} && \text{otherwise} \end{aligned} \qquad \text{(X.7)}$$

while no by pass flow was assumed to occur for dry and very wet soils. Changes in the soil moisture of the top soil layer S_s from time step i – 1 to i are accounted for by

$$S_{s,i} = S_{s,i-1} + \left(dS - E_A\right) \cdot \Delta t \qquad \text{(X.8)}$$

The only process that decreases S_s is evaporation E_A which is calculated from potential evaporation, E_P, by a piecewise linear function of the soil moisture of the top layer:

$$\begin{aligned} E_A &= E_P \cdot \frac{S_s}{L_P} && \text{if} \quad S_s < L_p \\ E_A &= E_P && \text{otherwise} \end{aligned} \qquad \text{(X.9)}$$

where L_p is a parameter termed the limit for potential evaporation. Potential evaporation was estimated by the modified Blaney-Criddle method as a function of air temperature. This representation of potential evaporation was compared to other methods in (PARAJKA et al. 2003) suggesting that it gives plausible results in Austria.

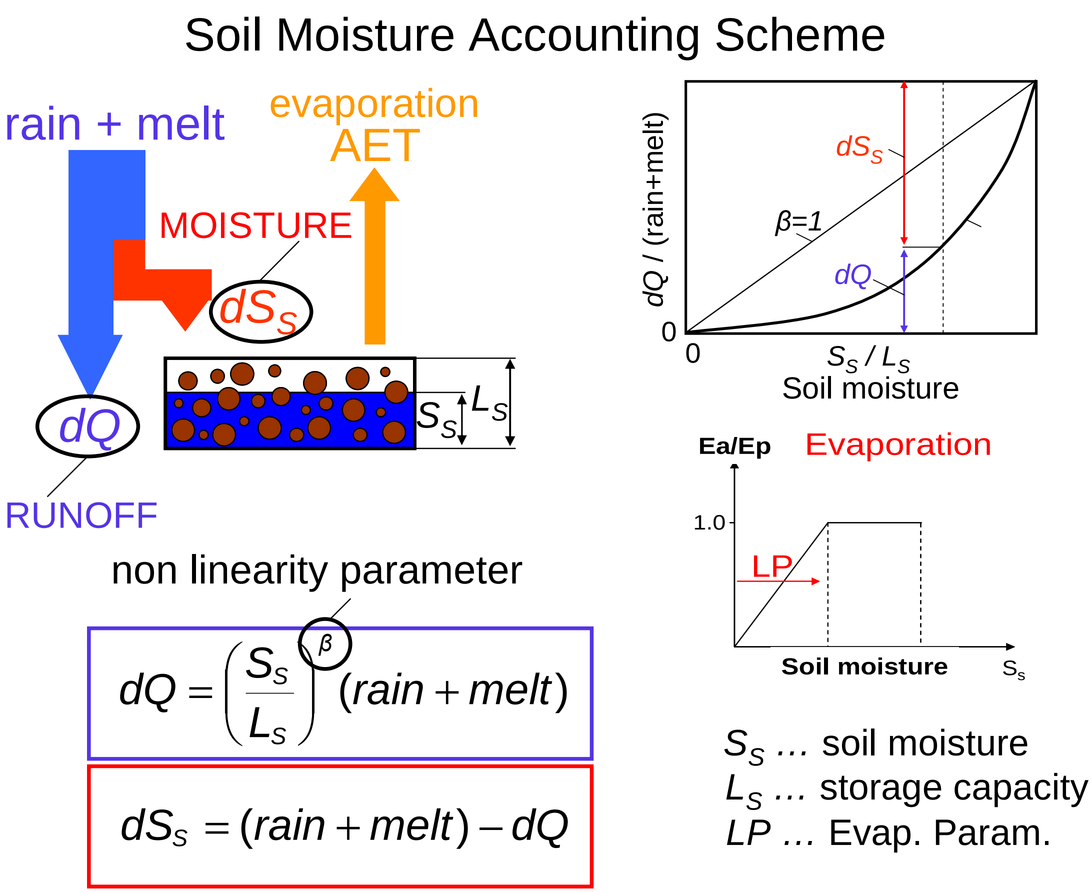


Figure 44: Structure of the soil moisture accounting scheme of the rainfall runoff model on the pixel scale.

6.9.1.1.3 Runoff routing

In a second step the runoff routing at the pixel scale, as used in the original model structure and during the parameter calibration process against observed stream gauge data, is replaced by a cascade of linear reservoirs (Nash Cascade – see Figure 45).

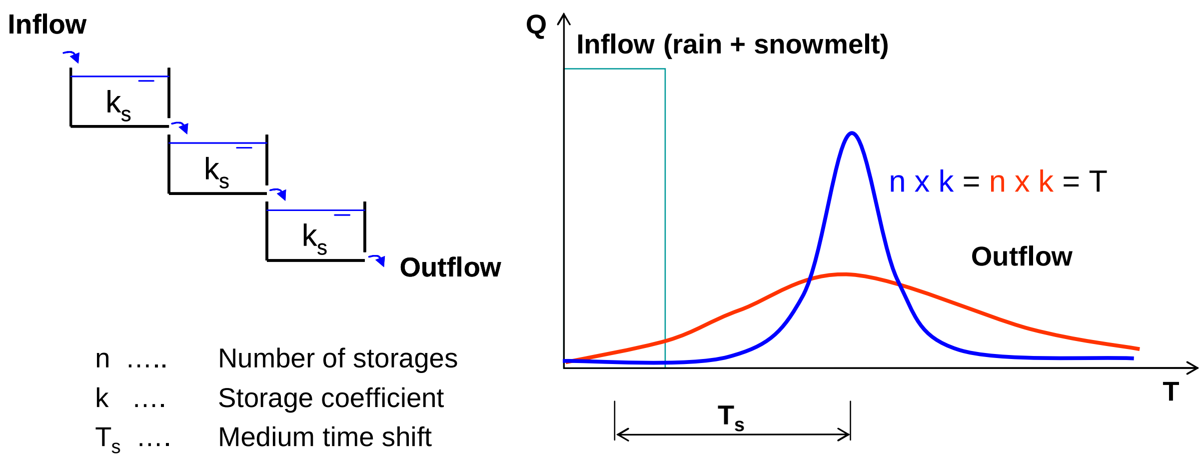


Figure 45: Scheme of the linear storage cascade (Nash-Cascade).

The Input for this Cascade of linear reservoirs is calculated from a five by five element area around each reference spring site (Figure 46). The mean value of the simulated direct runoff from this HRUs is used as input for the storage cascade. The Nash-Cascade is parameterised by two parameters, the number of reservoirs *n* and the recession coefficient *k* of the reservoirs.

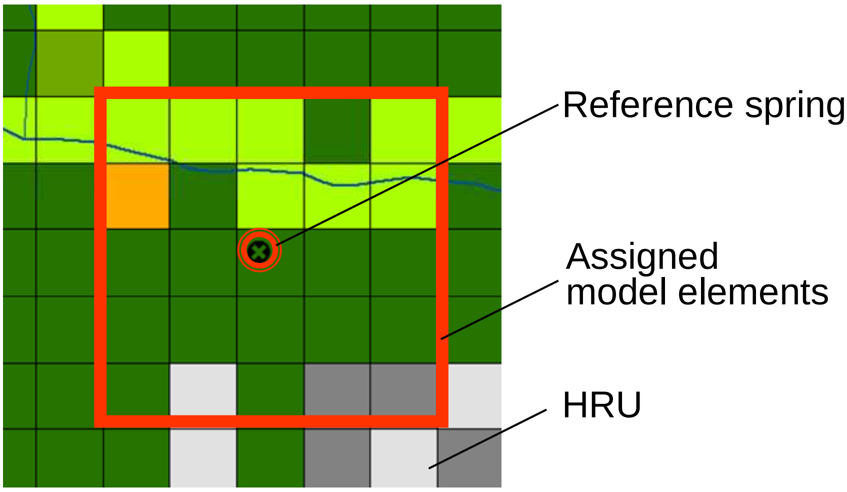


Figure 46: Defined area of influence for the model simulation of local runoff at the reference spring locations. The red circle shows the location of the reference spring. The coloured squares represent the HRUs. The mean runoff from the calculation elements inside the red box are used as input for the Nash Cascade.

6.9.1.1.4 Calibration

In order to adjust the parameters of the storage cascade to the different types of spring regimes, widely varying in the study area, numerous parameter sets were used to simulate different sets of the spring discharges for each of the reference springs. The temporal behaviour, namely the response time to precipitation and evaporation forcing, of the spring discharges varies from a few day up to years. Therefore the choice of adequate model parameters is the basis for a meaningful early warning system for water scarcity. For each of the sixty reference spring sites 188 model runs for the period of 1970 to 2010 are performed. The number of reservoirs n was varied from 1 up to 200 and recession coefficients from 1 to 1000 are used. Figure 7 shows an example for the correlations between the modelled spring discharges and the observed values for a reference spring site in the study catchment. Out of the punch of parameter sets that one best correlated to the observed spring discharge data is chosen for further analysis and catalogue calculations.

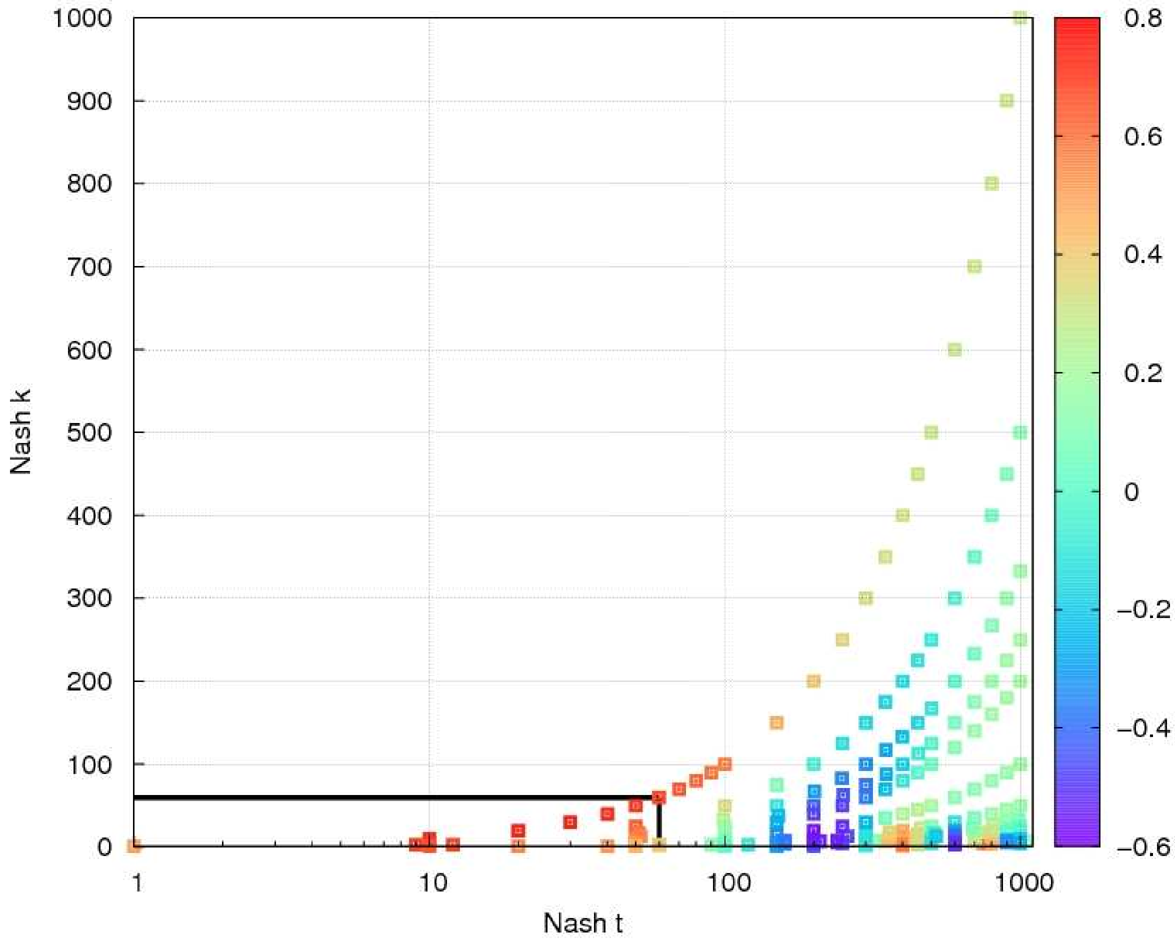


Figure 47: Linear correlation between a set of model simulated spring discharges and the observed values. Each coloured square indicates a different parameterisation of the linear storage cascade. The colour scale represents the linear regression coefficient *r*.

6.9.1.2 Correlations between reference springs and "normal springs"

Out of the pool of the available gauging stations about sixty characteristic spring gauges were chosen to represent the runoff behaviour of neighbouring springs. Each of the spring sites is assigned to one of the neighbouring reference springs. The basis for the allocation is the similarity of the temporal runoff dynamics of the neighbouring spring sites. As a measure for the similarity between a pair of springs (spring and reference spring) the cross correlation for different time lags was evaluated.

Figure 48 shows the cross correlations r_{xy} for springs in the north eastern part of the study area. The colour and size of the circles shows the best cross correlation coefficient r_{xy} between the discharges of the spring and the neighbouring (< 30 km) reference spring. The location of the reference springs is illustrated by the black crosses. Additionally the spring runoff at the characteristic sites is compared the results of the spatially distributed hydrologic model and the space born soil moisture estimates. The aim of this comparison is to find applicable relations between the continuous model results and the measured spring discharges in order to map the model predictions for diverse low flow and water scarcity scenarios back to the spring sites again.

The meteorological scenarios are defined on the basis of statistical analysis of daily precipitation and air temperature data in the time period of 1970 to 2010.

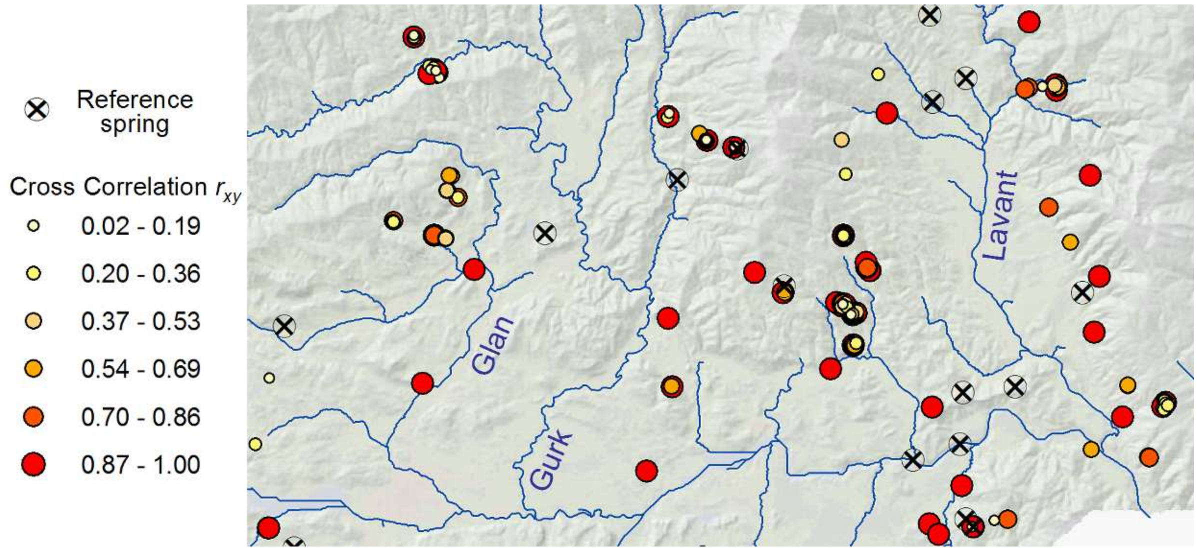


Figure 48: Map of the north eastern part of the study area. The colour and size of the circles shows the best cross correlation coefficient r_{xy} between the discharges of the spring and the neighbouring reference spring. The location of the reference springs is illustrated by the black crosses.

6.9.1.3 Scenario catalogue

On the basis of the hydrological modelling an easy and efficient early warning system for situations with potentially water scarcity within the province of Carinthia was developed.

The catalogue system is based on hydrologic model simulations for each of the sixty reference springs. All other spring sites are linked to this reference spring sites and therefore predictions for all regions in Carinthia can be made. A comprehensive meteorological and hydrological data set is used to drive the model simulations and to classify initial conditions and input scenarios. The catalogue is based on the combination of three different initial conditions and three different meteorological input scenarios. Figure 49 shows the principle of the scenario catalogue system approach.

Basic idea of the scenario catalogue for dry conditions

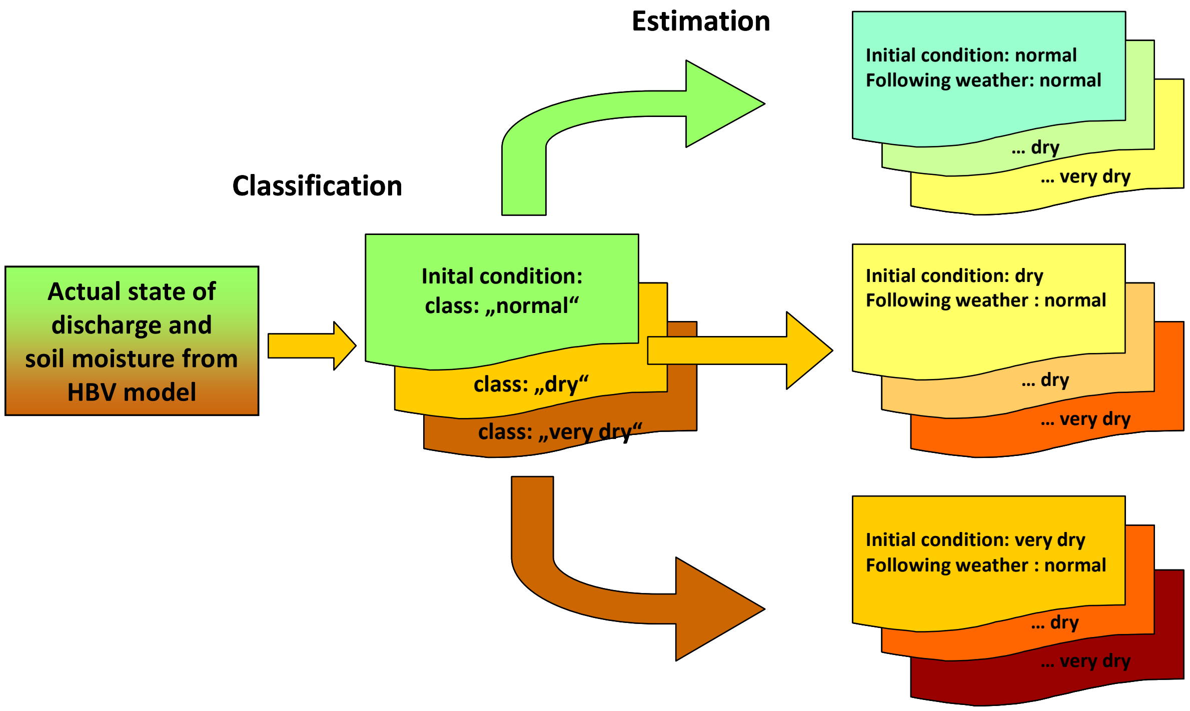


Figure 49: Basic scheme of the scenario catalogue system for the early warning system of situations of water scarcity in Carinthia.

The initial conditions as well as the meteorological scenarios are defined based on statistical analysis of monthly precipitation amounts, mean temperature, simulated spring discharges and soil moisture. Therefore daily values for the time period from the beginning of 1970 to the end of 2010 are analysed. The quantiles of monthly precipitation and simulated spring discharge are used to define the very dry, dry and normal initial conditions and meteorological scenarios. This evaluation is done for each month separately. The hydrologic model is run for each possible combination of initial condition and meteorological forcing. An example of seasonal differences in available water based an statistical analysis of 40 years of simulated spring discharges at a reference spring in Carinthia is shown in Figure 50.

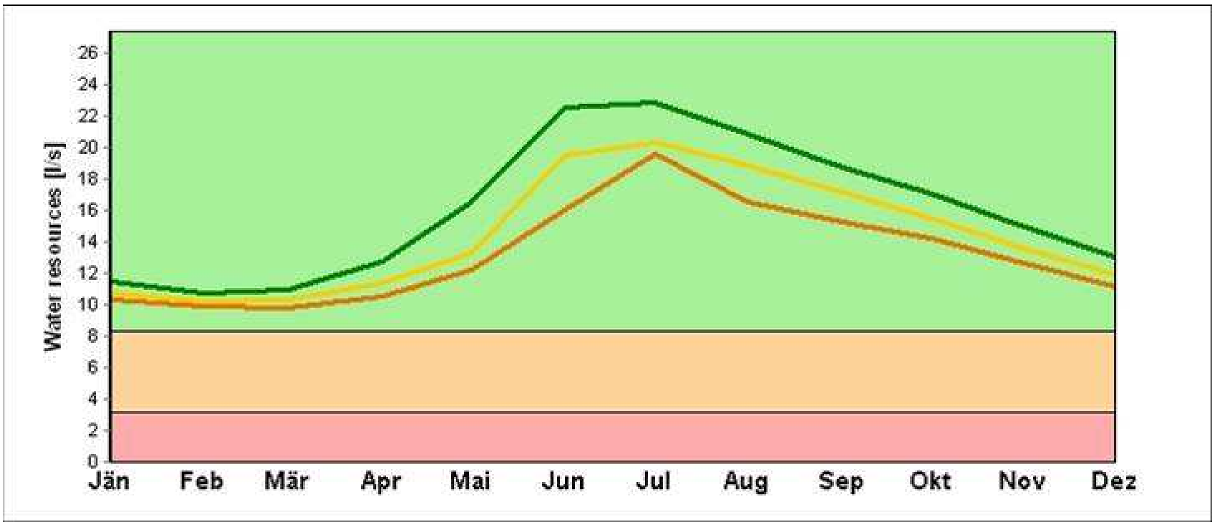


Figure 50: Example of seasonal differences in available water based on statistical analysis of 40 years of simulated spring discharges at a reference spring in Carinthia.

The model runs for actual month and the consecutive two month with the same class of meteorological input (very dry, dry or normal). Therefore a total number of 108 different drawers of the catalogue are filled with the simulation results of the hydrologic model runs. A typical forecast initiated in May 2011 for dry initial conditions is shown in

Figure 51. The simulation results for the very dry, dry and normal meteorological scenarios are plotted as brown, yellow and green lines in

Figure 51.

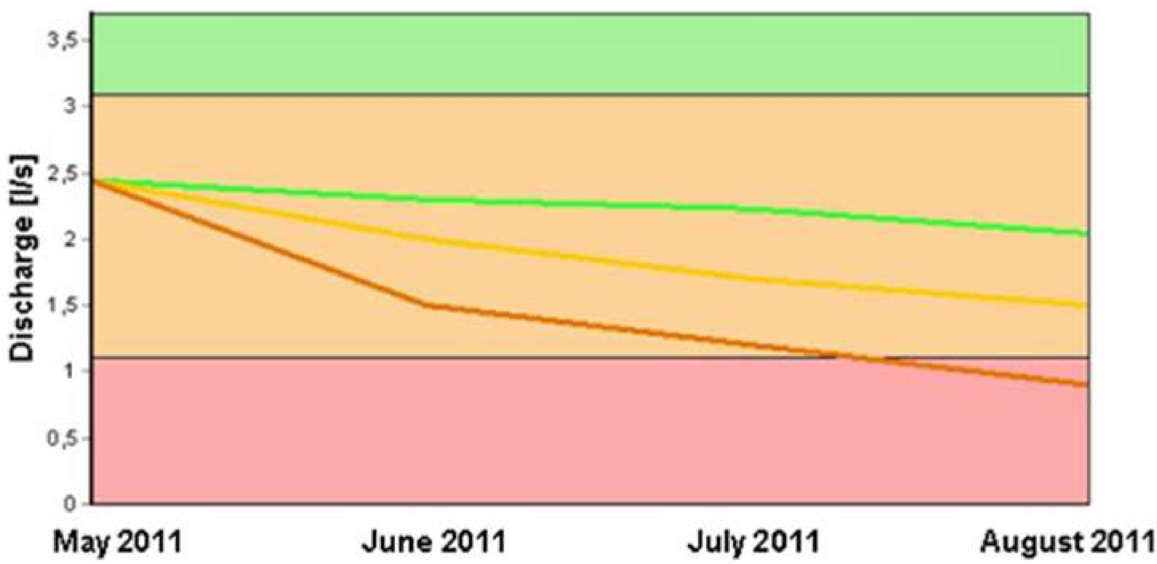


Figure 51: Example for the spring discharge prediction in May 2011. The spring discharge is predicted for a three monthly time period. The three lines represent different meteorological forcing. The lines are simulated spring discharges under normal (green line), dry (yellow line) and very dry (brown line) meteorological conditions.

6.9.1.4 Long time future scenarios – "climat change scenarios"

In order to assess the future development of potential situation of water scarcity depending on effects of possible climate change processes in the study area different future scenarios are analysed. As a reference scenario the simulated spring discharges at sixty reference spring sites are used. The reference time period is from 1970 to 2010. The model is rerun with modifications of the air temperature and the precipitation forcing. To account for global warming scenarios with higher air temperature than the reference run is created. Therefore the air temperature on model input is increased for 1, 2 and 4 °C. At the other hand scenarios with decreasing annual precipitation are evaluated. Scenarios with a 5, 10 and 20% reduction of annual precipitation are calculated. Additionally the combination of increased air temperature and decreased annual precipitation is considered as a possible future scenario. An overview of the different simulated climate change scenario is shown in

Figure 52.

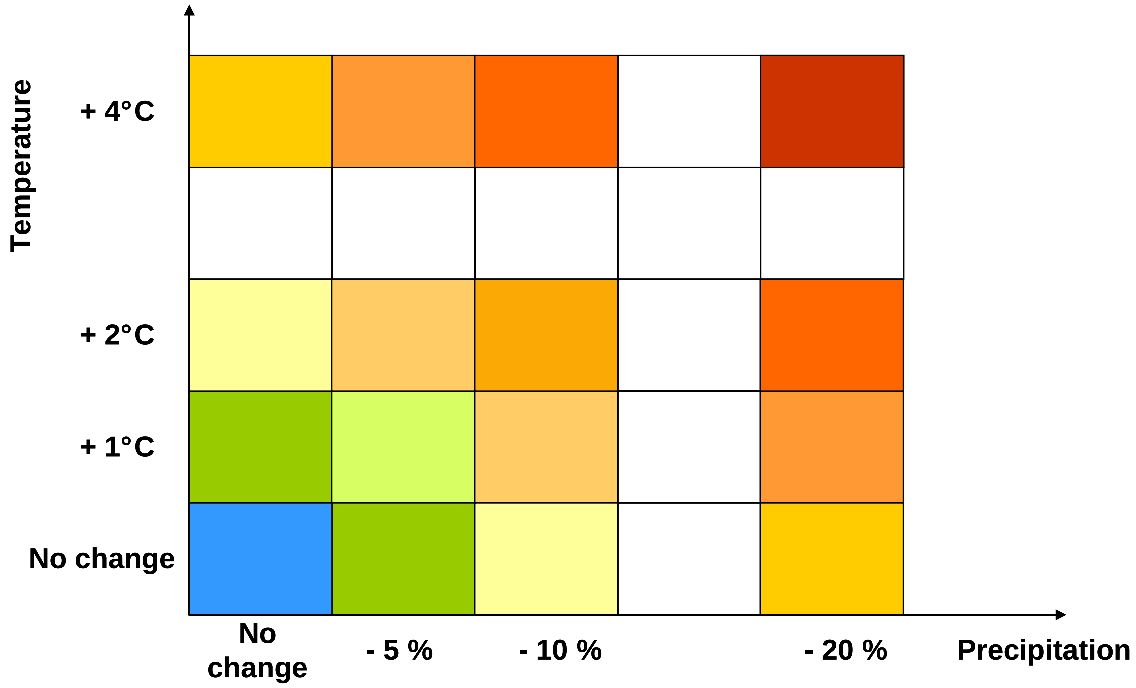


Figure 52: Simulated climate change scenarios.

The seasonal shift in snow melt induced by the rise of the air temperature is shown in Figure 53. Looking at the scenario with no change in precipitation and a temperature rise of 2°C it is obvious that because of the earlier snow melt higher discharges, about 120% of the reference run, are simulated during the winter month. In spring and summer the simulated discharge drops below 80% of the reference model run.

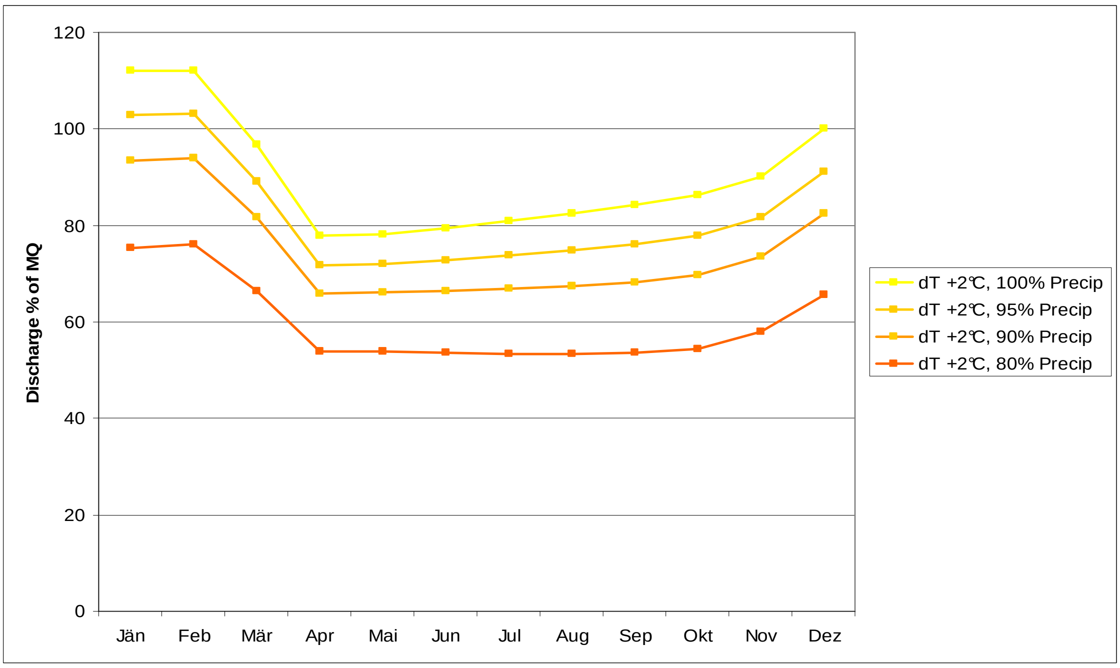


Figure 53: Seasonal reductions of the climate change scenarios.

6.10 Pilot Site “Pohorje with Ptujsko and Dravsko polje”

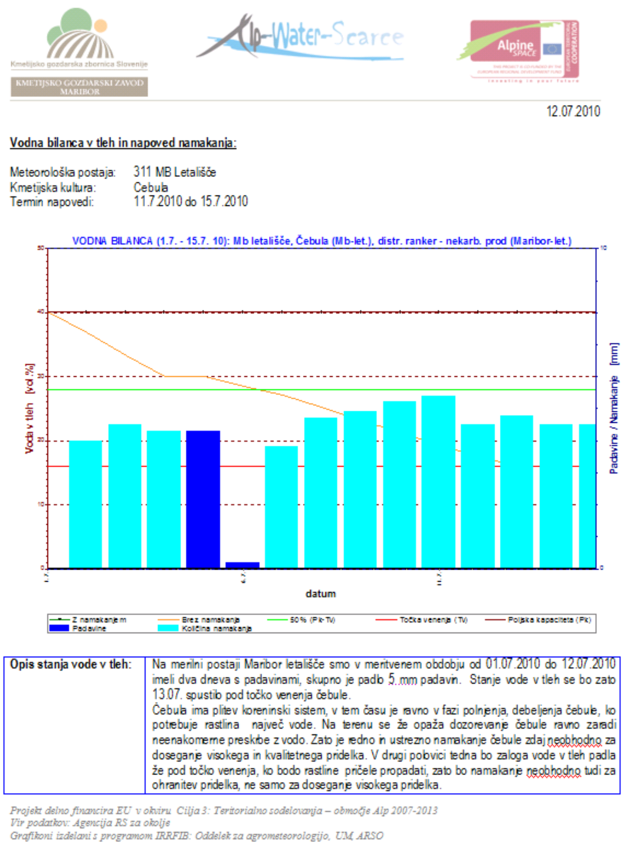
6.10.1 Modelling

Although Slovenia extends over around 20273km², there are very different circumstances for the food production in several Slovenian regions. One of the most important regions with mostly arable land is around Dravsko and Ptujsko Polje in the north-eastern part of Slovenia. These two Pilot Sites were chosen because of their importance of available water resources. Besides being the largest ground water basin in Slovenia, the river Drava is the most important source of renewable energy production. The discharge regime of the main river over recent years does not indicate any significant deviation from the average long term values. Furthermore, recent temperatures and precipitation levels have not deviated greatly from the long term average. Despite that, periodical short-duration droughts occur almost every year.

Apart from the frequency of precipitation, detailed soil analysis has shown that the availability of water for plants depends on the quality of the soil. Four soil analyses in different soil profiles, carried out by a professional laboratory of the biotechnical faculty in Ljubljana, have shown the importance of the plant selection and the regular timing of irrigation.

Very low topsoil and very high permeability of soil limit vegetation growth and the consequence is lower production and higher production costs. From experience, irrigation systems are generally employed too late – that is to say, at the time when the consequences of drought are already visible on plants. Plant stress mostly begins before the visible effects occur.

The aim of our project activities has been to develop an early warning system for the scarcity of water in agricultural production. In cooperation with Slovenian environment agency (ARSO), four meteorological stations were installed. The particularity of these stations is that they have water content sensors at different soil levels. Hourly measurements of precipitation, air temperature and water content are sent to the central processor and are processed within the IRRFIB application. Combined with the data of evapotranspiration and the phenological phases of specified plants, a chart of water availability for main important crops is produced (Figure 54). For the plant producers the most important data is the irrigation forecast for the next few days as well as the plant protection measures, depending on weather conditions and the phonological phases of the plant (Figure 54).


12.07.2010

Vodna bilanca v tleh in napoved namakanja:

Meteorološka postaja: 311 MB Letališče
Kmetijska kultura: Cebula
Termin napovedi: 11.7.2010 do 15.7.2010

Opis stanja vode v tleh:	Na merilni postaji Maribor letališče smo v meritvenem obdobju od 01.07.2010 do 12.07.2010 imeli dva dneva s padavinami, skupno je padlo 5 mm padavin. Stanje vode v tleh se bo zato 13.07. spustilo pod točko venenja čebule. Čebula ima plitev koreninski sistem, v tem času je ravno v fazi polnjenja, debeljenja čebule, ko potrebuje rastlina največ vode. Na terenu se že opaža dozorevanje čebule ravno zaradi neenakomerne preskrbe z vodo. Zato je redno in ustrezno namakanje čebule zdaj neobhodno za doseganje visokega in kvalitetnega pridelka. V drugi polovici tedna bo zaloga vode v tleh padla že pod točko venenja, ko bodo rastline pričele propadati, zato bo namakanje neobhodno tudi za ohranitev pridelka, ne samo za doseganje visokega pridelka.

Projekt delno financira EU v okviru Cilja 3: Teritorialno sodelovanja – območje Alp 2007-2013
Vir podatkov: Agencija RS za okolje
Grafikoni izdelani s programom IRRFIB: Oddelek za agrometeorologijo, UM, ARSO

Figure 54; Example of an early warning system for onion, raised from seeds. Forecast includes a chart, irrigation advice and framework agro-technical measure and plant protection advice for the next few days.

The first experimental year has shown that the water scarcity or drought situation could be mitigated by the correct timing of irrigation and by other anthropogenic activities, such as the selection of plants with similar production yields as well as cost effectiveness. The first positive effect of the part of the project is increased interest among our target stakeholder groups, measure by the frequency of web page visits.

On the other hand, the last two years have seen above average precipitation, which caused many short-duration floods and other abnormalities in both Pilot Sites. This also explains why the expected results from the field test are not optimal. Nevertheless, the long term experience has shown the unsuitability of maize production, although the question of economic rights to selected substitute plants raised by expert public has yet to be answered.

6.11 Pilot Site "Scrivia River Basin"

6.11.1 Modelling

The Scrivia torrent rises in the Ligurian Apennine, in the province of Genoa, at the mount Prelà slants, (1.416 m a.s.l.), meeting Po, a bit upstream of the Lombard town of Voghera, after having gathered its own tributaries waters, among them Spinti, Borbera, Ossona and Grue. While its first is characterized by an Apennines typical landscape and then by a hilly one, after that by a very narrow valley, approaching the plain the torrent gets a meander-like morphology, typical of the plain environment (Figure 55).

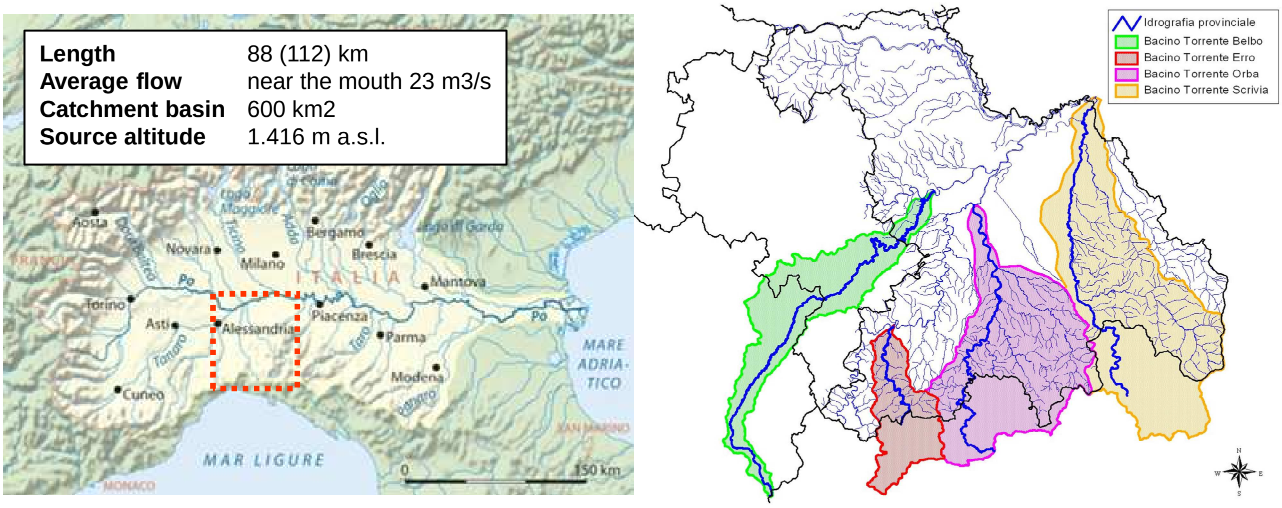


Figure 55; Geographical features of Scrivia stream.

Most of the plain zone is **strongly anthropized**, characterized by a certain landscape monotony and having a limited natural vegetable cover, relegated in the main water-course river-bed and in the residual edges of the plain wood. But generally the pebbly shore of the torrent Scrivia is one of the best examples, with regard to naturalness and territorial extension, of the fluvial habitat well preserved in Piedmont, almost completely avoided the water-courses generalized artificialization (Figure 56). In particular, a part of the Scrivia pebbly shore, because of its own high environmental valency, has been defined **Site of Community Interest according to the Habitat Directive 92/43/CEE**.

Figure 56, Scrivia stream: a natural reach versus an heavily urbanized reach.

The aim of this case study has been the research for a better management of Water Resources within Scrivia River Basin to face scarcity situations, giving due value to nature conservation of the fluvial ecosystem (Community Interest Site - CIS) and looking for feasible trade-offs amongst conflicting needs. In order to foster this target, we could not put in place a real-time emergency tool if we have established previously a better management policy of the overall system. Hence our focus is on **planning the management, but keeping in mind**

emergency situations linked to scarcity. According to this, main operational objectives have been: to aquire knowledge on how our system works; to share and consolidate it with relevant stakeholders, possibly including inter-regional dialogue (Piemonte-Liguria); to investigate the space for improving water resources management by acting on a number of candidate decision variables.

Within the case study, a conceptual framework has been adopted, capable of seeing relevant users (fine spatial scale), drought situations and persistency (daily time step) and relevant decision variables. The overall conceptual scheme is reported in the following figure (Figure 57).

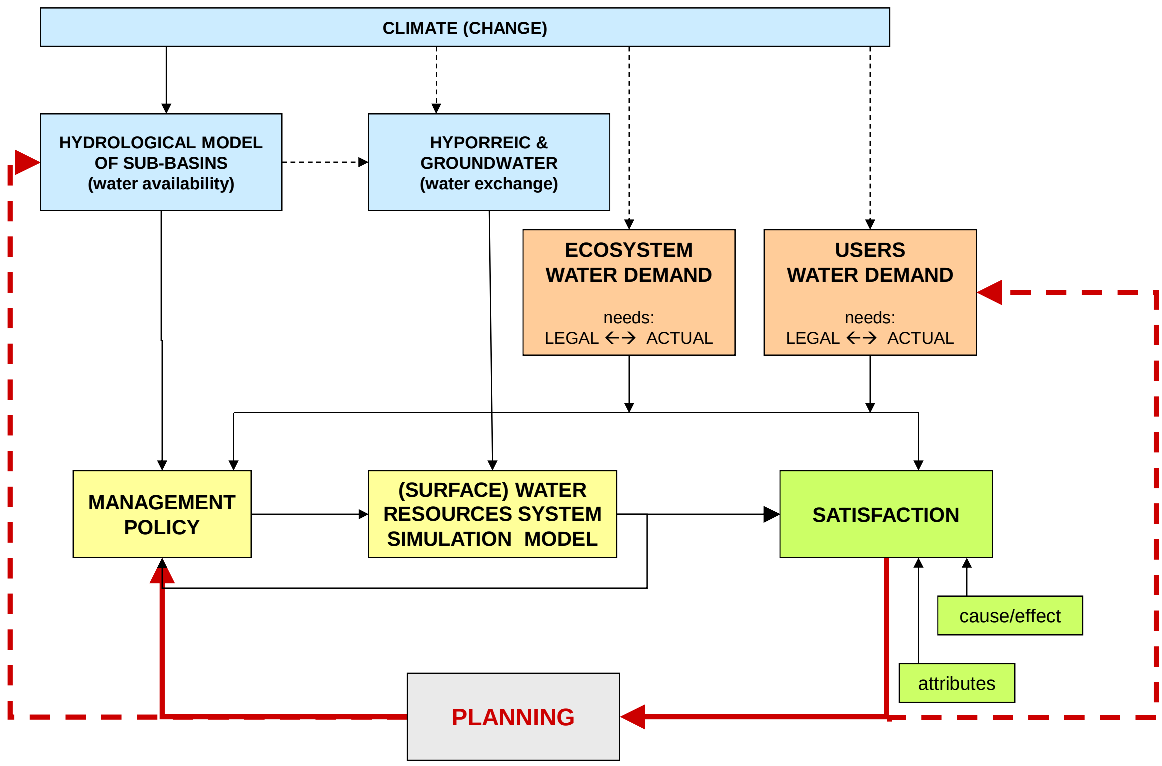


Figure 57; Conceptual modelling framework of Scrivia stream case study.

The figure shows how the core of the modelling structure (in yellow) is feed both with planning measures and with hydro(geo)logical constrains. The key issue of the framework is the satisfaction evaluation through a specific modelling step that take into account both the ecosystem and the water users demands. A dedicated modelling software (MS-Excel based) has been developed and five management alternatives have been investigated, as summarized in the following table (Table 13).

Table 13; Alternatives investigated within the case study.

alternative	Description
NATURALE	no human water-uses
ATTUALE	human water-uses as simulated according to the actual knowledge (very limited, no physical measure available)

DMV PTA	human water-uses all respecting Minimun Vital Discharge
RID GLB	human water-uses all respecting Minimun Vital Discharge and reduction of all water abstraction at 80% of their actual allowance

The following figure illustrates (Figure 58) the final results of the simulation. In the X_{es} you can read the satisfaction of human water users, in the Y_{es} you can read the satisfaction of ecosystem demand.

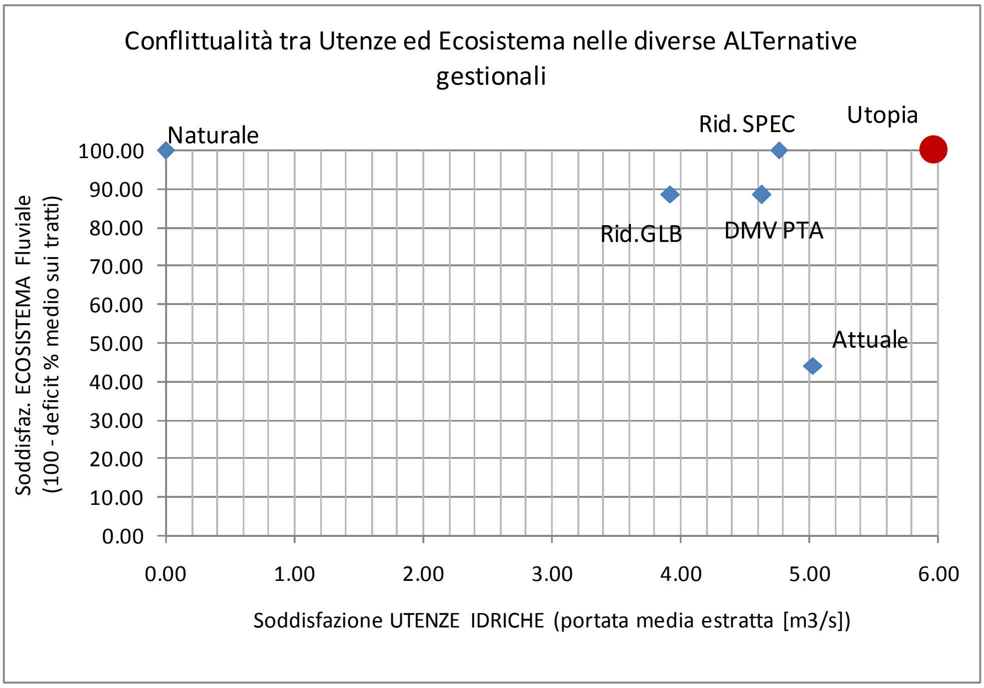


Figure 58; Conflicts amongst different management alternatives.

The figure shows that the assumption on actual water uses doesn't seem to be equilibrate if looking at ecosystem demand, but further information need to be collected in order to verify the real water allocation system. The alternative that assumes the fulfil of Minimum Vital Discharge at every relevant section of abstraction seems not to be fully satisfactory in term of ecosystem demand (i.e. not all the stream reaches face a acceptable hydrological state). Even the "global reduction" alternative seems not to give good results, but the "specific reduction" alternative perform the accomplishment of environmental (minimum) requirements together with an acceptable water users satisfaction (slightly lower than actual one).

In spite of the consciousness of further improvement to be done (both in data collection and in modelling performance), the case study has provided relevant results that have been discussed within the Water Management board of Scrivia stream (within the ongoing participatory process called Contratto di Fiume).

6.12 Pilot Site "Julian Alps"

6.12.1 Modelling

The hydrological model for the Julian Alps is based on time series statistical modelling and data of longer time series available from the data base of Agency for the Environment of Republic of Slovenia (air temperature, precipitation, discharges and evapotranspiration). At the same time available data of the Pilot Site is compared with data from the HISTALP data base. For the calculation purposes the commercial statistical package STATISICA 6.0 and the statistical programming environment R were used.

The analyses were performed in two steps. In the first step time series structure of the particular time series was determined by statistical tools based on the autoregression prediction models (e.g. ARMA). Among the structure of data series deterministic trends (e.g. periodic and linear trends) as well as random component characteristics were calculated. Data of longer time series from HISTALP were correlated with short time data and regression models were established. Regression models were also constructed for the comparison of discharge and climate time series. These regression models were used for the extrapolation of short time series with the help of longer time series. The second step consists of forecast modelling where deterministic trends were used for the extrapolation and on these trends random components were imposed.

The aim of the applied models is to predict time series trends of available amount of water at existing monitoring points. The applied models are robust and simple, prone to large predicting uncertainties. The available longer climatic time series data are of good quality, however local climatic regime of Julian Alps is very heterogeneous with high variability that prevent building good long term forecasting models. With the applied model it is intended to establish only general trends of water availability in rivers and creeks of the pilot region.

For detailed model description and graphical presentation of modelling results for the Julian Alps Pilot Site please see section 2.2.2.1.

6.13 Pilot Site "Piave River"

6.13.1 Modelling

One of the expected outputs of the Alp-Water-Scarce project was the development of an"Early Warning System" (EWS). ARPAV has developed a multi-criteria method based on a statistical analysis of the main hydro-meteorological parameters in 8 alpine sub-catchments of the Piave river (3900 km^2). The reference period is the last 25 hydrological years. This analysis is based on the quantiles for each of the parameters at a specific date and the output is the Water Scarcity Index.

The parameters considered are:

- PRECIPITATION: the quantiles of the accumulated amount of the precipitation are calculated both since the starting of the hydrological year and since the 1st December, that represent the winter precipitations.
- SNOW: both the snowpack (Snow Water Equivalent) and the accumulating amount of fresh snow are taken in account since the start of hydrological year.
- TEMPERATURE: the quantiles of this variable are calculated considering both the average temperature since the start of the hydrological year and the average temperature since the 1st March, in order to detect more in detail the snow melt period.
- TOTAL RADIATION: this is a parameter that can be used in alternation with temperature.
- DISCHARGE: the base flow since the start of the hydrological year (1st October), the one at the actual date and the accumulated amount of discharges since the 1st January are considered for the 8 natural sections.

All these variables are calculated for each of the 8 mountain catchment where the discharges are evaluated. These variables are weighted in order to give more importance for example to the amount of snow rather than to the solar radiation. All the quantiles are then summed obtaining the "Water Scarcity Index" (WSI). When this is performed for the current hydrological year, automatically the WSI is also calculated for the past hydrological years (since 1990-91) in order to obtain the reliability of the WSI evaluated at the actual date.

Concerning the application of the EWS, in the last three years the WSI has never indicated a potential situation of water scarcity (Figure 59). Only in 2011 the index is decreased in April and May due to high temperatures and low precipitations, but has then inverted the trend in June. The comparison with 2003 indicated that this index is representative if it remain below a threshold value for a long period (Figure 60). The second half of August 2011 was very hot and dry, but the late spring and early summer were propitious for a good water storage in artificial lakes: the EWS can't predict the summer weather but detect the hydrological variables in the most important period for the filling of the lakes. As a matter of fact, a warning should induce decision-makers to guarantee enough storage in lakes until the end of June.

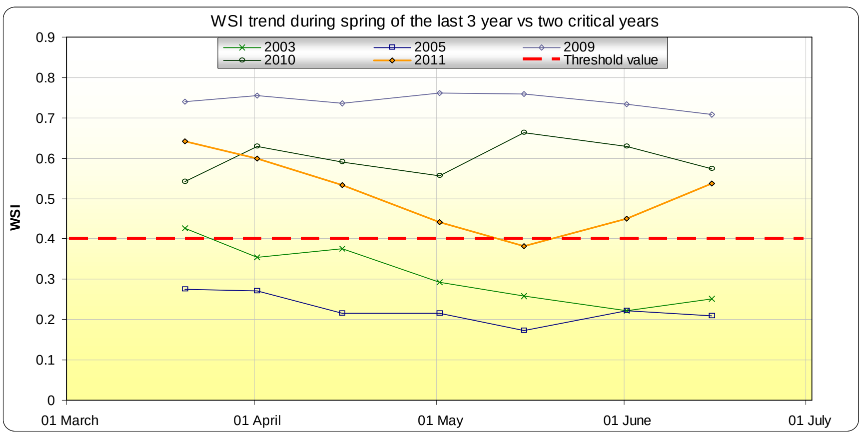


Figure 59; WSI trend during spring oft he last 3 years versus two critical years (2003 and 2005).

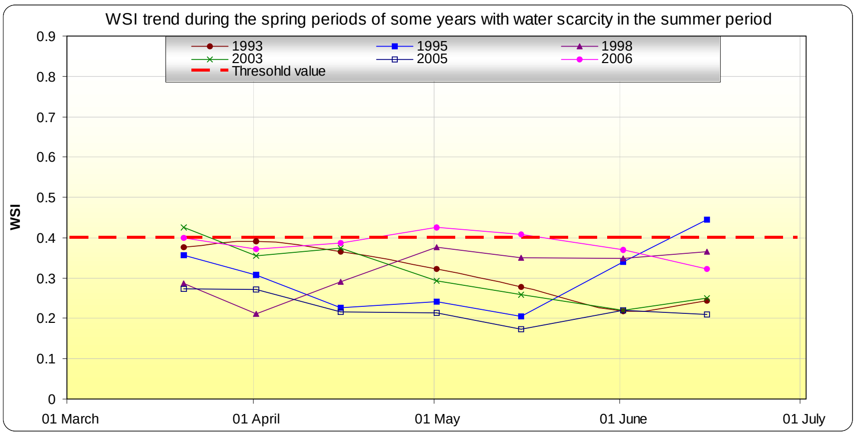


Figure 60; WSI trend during the spring periods of some years with water scarcity in the summer period (1993, 1995, 1998, 2003, 2005 and 2006).

6.13.1.1 Analysis of trends of precipitation and discharges

During the project "Alp Water Scarce" were also compared the dataset of the period 1923-62 with that of the period 1984-2010, considering precipitation and discharges.

Concerning annual precipitation, in the catchment of the Piave river the difference of precipitation between 1984-2010 and 1923-62 is quite constant (-2%, 25 mm), but the differences vary from +15% (+213 mm) to -10 % (-119 mm).

Concerning the spatial distribution there is a slightly decreasing in the upper part of the catchment (-4%, - 56 mm) and an increasing (+3%, +36 mm) in the prealpine area.

Concerning the monthly precipitation the results are the following (Figure 61):

- from January to June: there is a decreasing, especially in February (mean difference: -37%, up to -50% in five places, four of them in the high part of the catchment of Piave), that mean a lower amount of snow;
- from August to November: there is an increasing, with absolute differences smaller than the decreasing. More in detail, August is the only month with a sensible increase in all the monitoring sites, up to more than 50% (only in one site). In another monitoring site (Feltre) there is also in November an increment greater than 50%.

The decreasing of precipitations is greater in winter (-21% from January to March) that in spring (-7% from April to June).

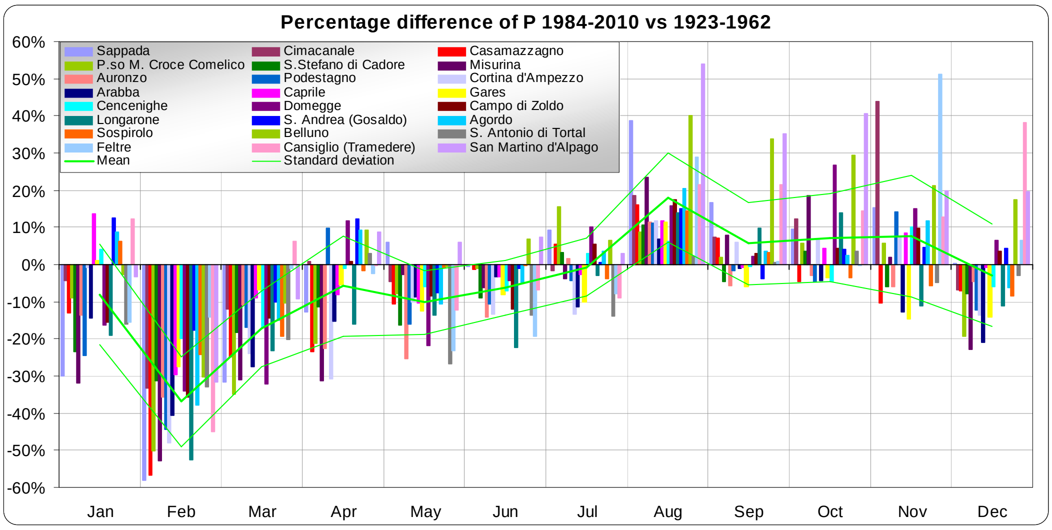


Figure 61; Percentage difference of precipitation between 1984-2010 versus 1923-1962 period in different areas of Piave river basin.

Concerning the discharges, the mean annual discharges are decreased of an average value of -16%, with extreme values of -21% (Padola at Ponte Padola) and -13% (Fiorentina and Sonna, that is the only river in the pre-alpine area) (Figure 62). Concerning the mean monthly discharges, from March to September there is a general and substantial decreasing (average -20%), especially in June (up to - 40 %). From October to February: there are smaller and more variable differences than in the other periods. The greatest decreasing is in June, because both of the lower precipitations in winter / spring and of the longer duration of the summer (early snow melt in May) (Figure 62).

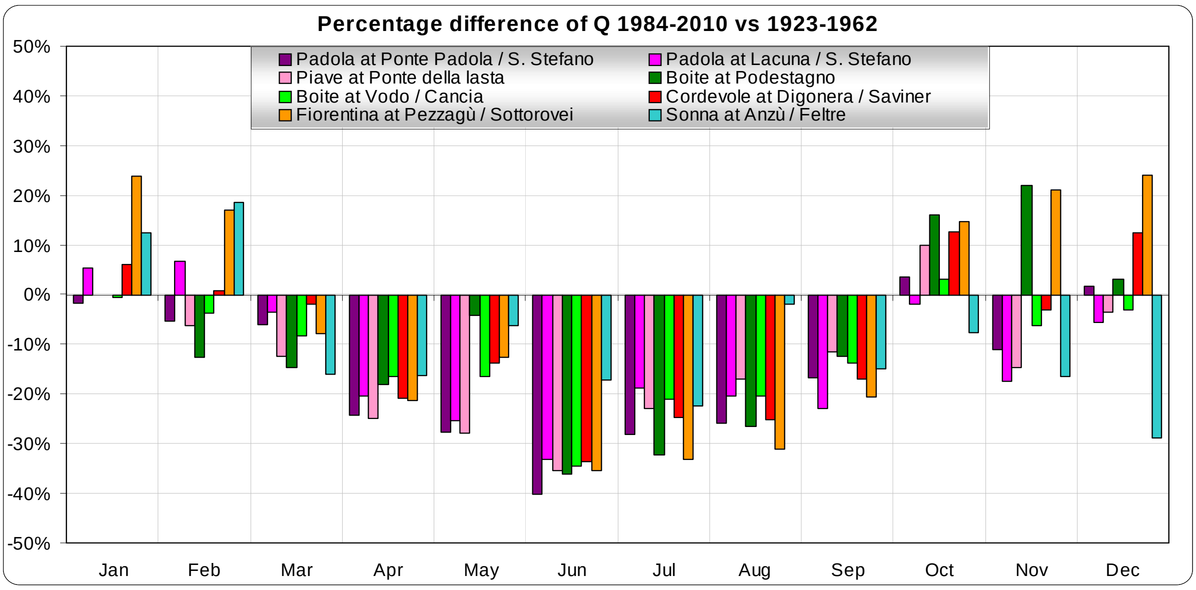


Figure 62; Percentage difference of discharge between 1984-2010 versus 1923-1962 period in different areas of Piave river basin.

6.14 Pilot Site "Noce"

6.14.1.1 Modelling

In the context of the activities of the Autonomous Province of Trento, a mathematical model called GEOTRANSF has been applied to support the implementation of the water balance of the River Noce. Some results of the water balance can be provided for this project. The GEOTRANSF model, developed by the hydrology group of the Department of Civil and Environmental Engineering of the University of Trento, is a model capable of simulating continuous hydrological processes on a small to large scale in a fast yet efficient way, by employing a semi-distributed approach based on the residence time conceptual model.

Input Data: The model requires basic information such as terrain maps (DTM, geological and land use data), precipitation, air temperature and water discharge data collected in the study area.

Particle Swarm Optimization (PSO): The calibration of the model performed by using the Particle Swarm Optimization (PSO) technique, capable of minimizing a suitable objective function which represents the comparison between simulated and observed water discharges in a certain control section, enables us to obtain the parameterization of the basic processes that characterize the water movement from small to large basins. Such processes are simulated using simplified models representing both surface and subsurface water transport phenomena.

Continuous and semi-distributed: The study area is conceptualized as a number of sub-basins interconnected by the river network. Precipitation and temperature are appropriately spatialized on every sub-basin, where the runoff production is accurately simulated by taking into account several processes such as snow-melt, water infiltration (subsurface runoff), evapotranspiration and surface runoff production.

Runoff generation in headwater basins is the result of surface and subsurface flows occurring at several spatial and temporal scales with the coupling between unsaturated and saturated flows introducing nonlinearities which add further complexity to the overall picture. Finally, the model routes the runoff produced by sub-basins to the river network by using the Geomorphological Instantaneous Unit Hydrograph (GIUH) approach, leading to the simulation of the overall system hydrological response in a selected basin control section.

The model can also deal with manmade infrastructures such as dams and withdrawal channels. Also, a number of different types of water uses can be simulated in a simplified yet efficient way (e.g. artificial snow, fish farming, diversions due to the presence of small hydroelectric power plants, irrigation, well extraction).

Modular: Finally, the modular structure of the GEOTRANSF model allows for easy implementation of new submodels for single hydrological processes.

With the aid of the GEOTRANSF model we could reconstruct the hydrological behaviour of the Noce river basin, closed at the confluence with the River Adige, also considering the effect of private and public concessions for water withdrawal. The model has been calibrated on the period 2000 – 2006, taken as a reference for modelling, and allowed the simulation of three scenarios:

PRESENT STATE - with current concessions;

NATURAL STATE - without concessions;

LARGE HYDROELECTRIC - with current concessions for only large hydroelectric power plants.

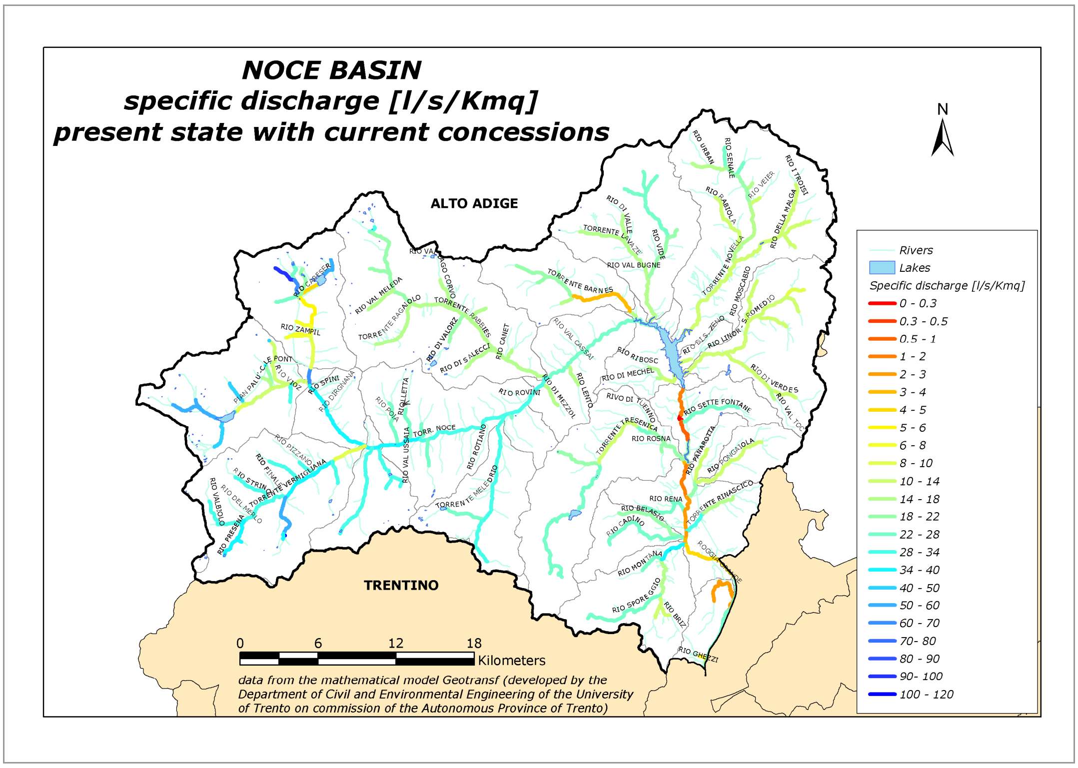


Figure 63: Average annual specific discharge calculated by the model, corresponding to the PRESENT STATE scenario.

The "present state" highlights areas where water use affects the natural discharge.

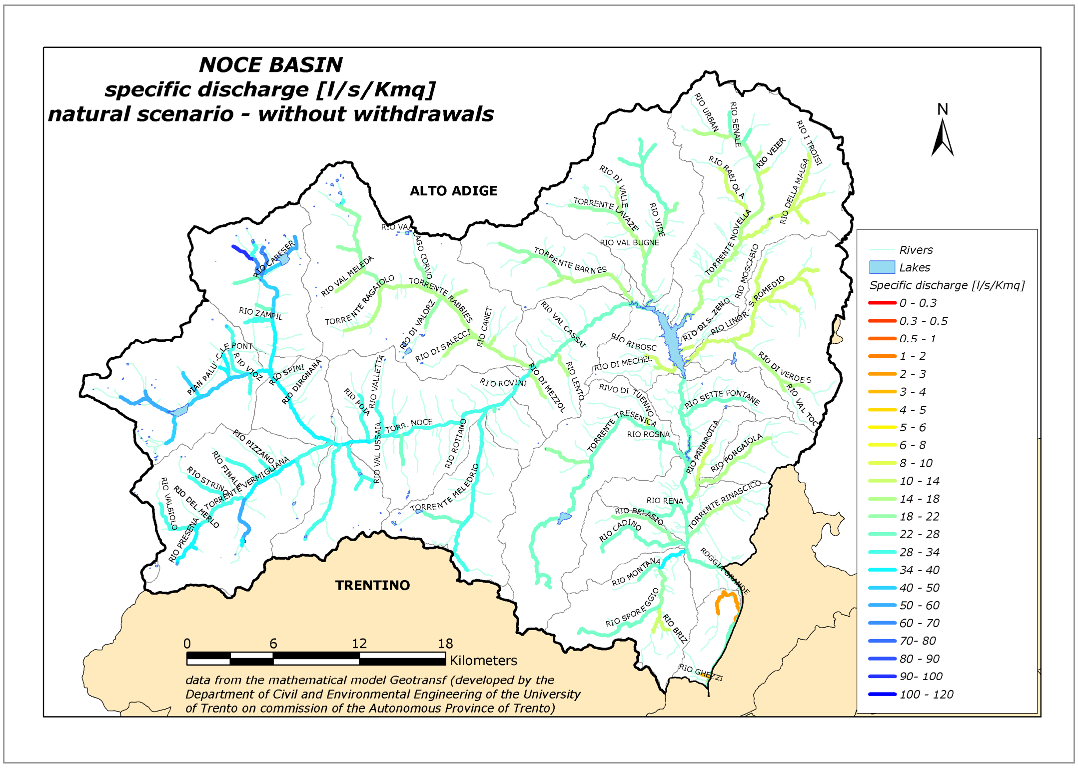


Figure 64: Average annual specific discharge calculated by the model, corresponding to the NATURAL STATE scenario.

The differences between the PRESENT STATE and LARGE HYDROELECTRIC scenarios are very small.

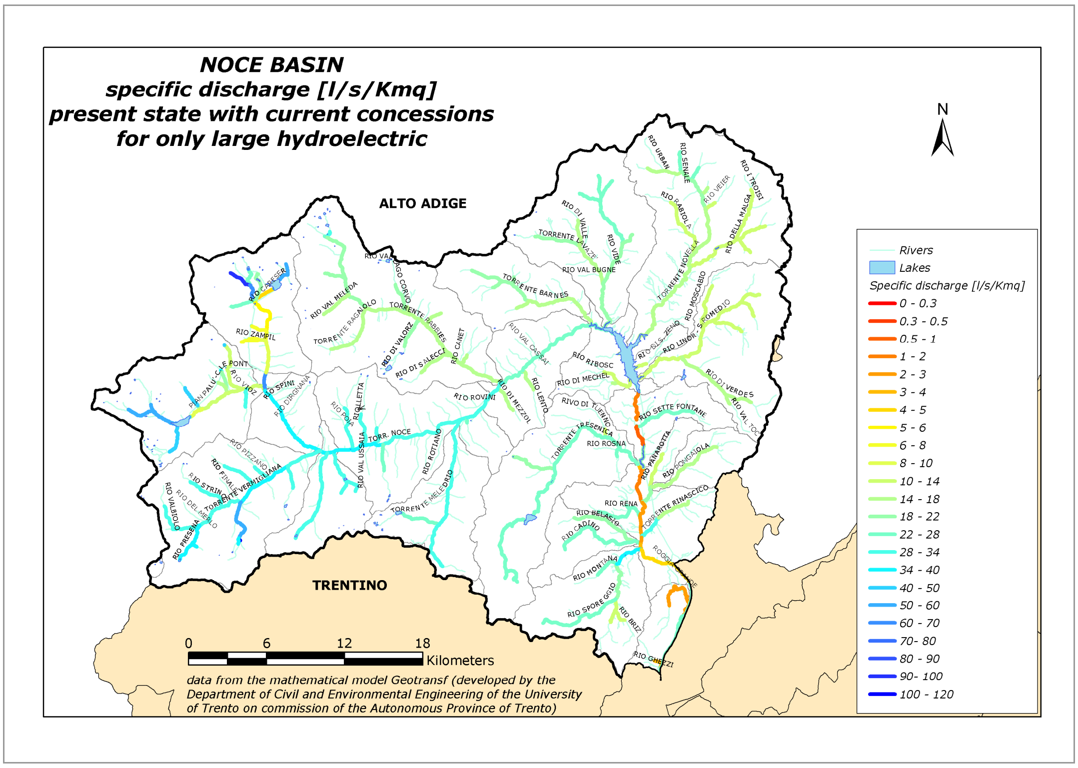


Figure 65: Average annual specific discharge calculated by the model, corresponding to the LARGE HYDROELECTRIC scenario.

Furthermore, the influence of the large hydroelectric plants on natural outflows is important.

Maps of this kind, more detailed in terms of spatial resolution and related to periods shorter than one year, can be used by our Province to assist water management.

6.15 Pilot Site "Entella and Scrivia River Basins"

6.15.1 Modelling

For WP6, the Development Agency GAL Genovese did not develop a new model, but collected information about the model used by the Regional Authorities for planning. The model used is the HYDRO-CO MODEL - Hydro computerised water balance model.

6.15.1.1 HYDRO MODEL, Description of the model

The most common used tool is the" Hydro computerised water balance" which enables a wide range of information on the catchment features. By means of a schematization of the whole Ligurian region, this model offers details regarding each precise area of the territory, with its varying features (physical- geographic, climatic, and so forth). This information is then fed back, according to a series of information categories present in the database. Furthermore, it is possible to identify the subtended catchment basin and get to know the main physical and water balance characteristics, setting off from any chosen closure section that the user selects on the waterway network.

In the following a summary of starting data required for this model and the possible data subsequently obtained is listed. The structure of this model foresees the splitting up of the territory into cells, each of which represents a basic unit that will be used for the representation, characterization and development of the area under study. An assessment of the water balance is carried out by means of the Thornthwaite & Mather method (1955), which is based on the concept of potential evapotranspiration and the splitting up of an average year into a wet season (meteoric influx > potential evapotranspiration) and a dry one (meteoric influx < potential evapotranspiration).

6.15.1.2 References

General section, Extract Water Balance – Province of Genoa (2009)

Entella basin plan, Extract Water Balance – Province of Genoa (2009)

Scrivia basin plan, Extract Water Balance – Province of Genoa (2009)

6.15.1.3 Input Parameters

The following input parameters are used in the HYDRO MODEL:

- Digital Terrain Model (DTM) with a resolution of 220-230 m
  - Rainfall and average monthly and yearly temperature for rain - thermometric stations in Liguria and surrounding areas ('50-'80) opportunely geo-referred.
  - Capacity measured by hydrometric stations present along regional waterways and relative duration trends ('50-'70) opportunely geo-referred.
  - Derived capacity, defined according to catchment type and use.
  - Lithology (classification according to 10 classes)

- Use of ground surface (classification in 11 classes)
- Population Census

6.15.1.4 Output

Here we list the output parameters of the HYDRO model used for the Entella and Scrivia river basins:

- Physical characteristics of the catchment and the dipstick with min. and max. quotas, rod length, slope gradient, catchment area, resident population etc.
- Average annual meteorological flow, calculated according to the Average Hydrological Year ('50-'80)
- Average annual and monthly flow (inclusive of superficial flow and sub-alveous).
- Potential and actual evapotranspiration (Average monthly and yearly values).
- Accumulative derived capacity.
- Duration capacity trends.
- Longitudinal profile of each fluvial rod

The outputs of the model can be seen in Figure 66 and Figure 67.

PORTATA MEDIA MENSILE	
Mese	Portata [m^3/s]
gen	13.0963
feb	13.0569
mar	12.7544
apr	11.8036
mag	10.0829
giu	6.9163
lug	5.1515
ago	4.0984
set	6.2539
ott	12.8124
nov	14.4485
dic	13.3654

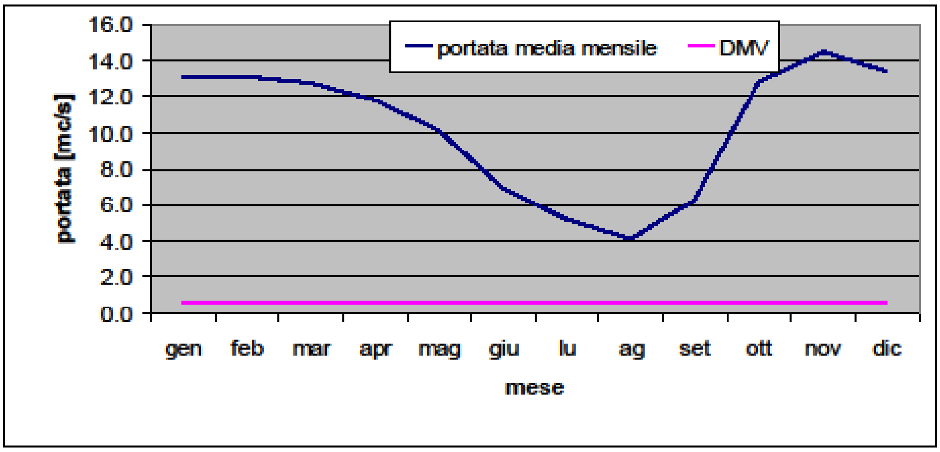
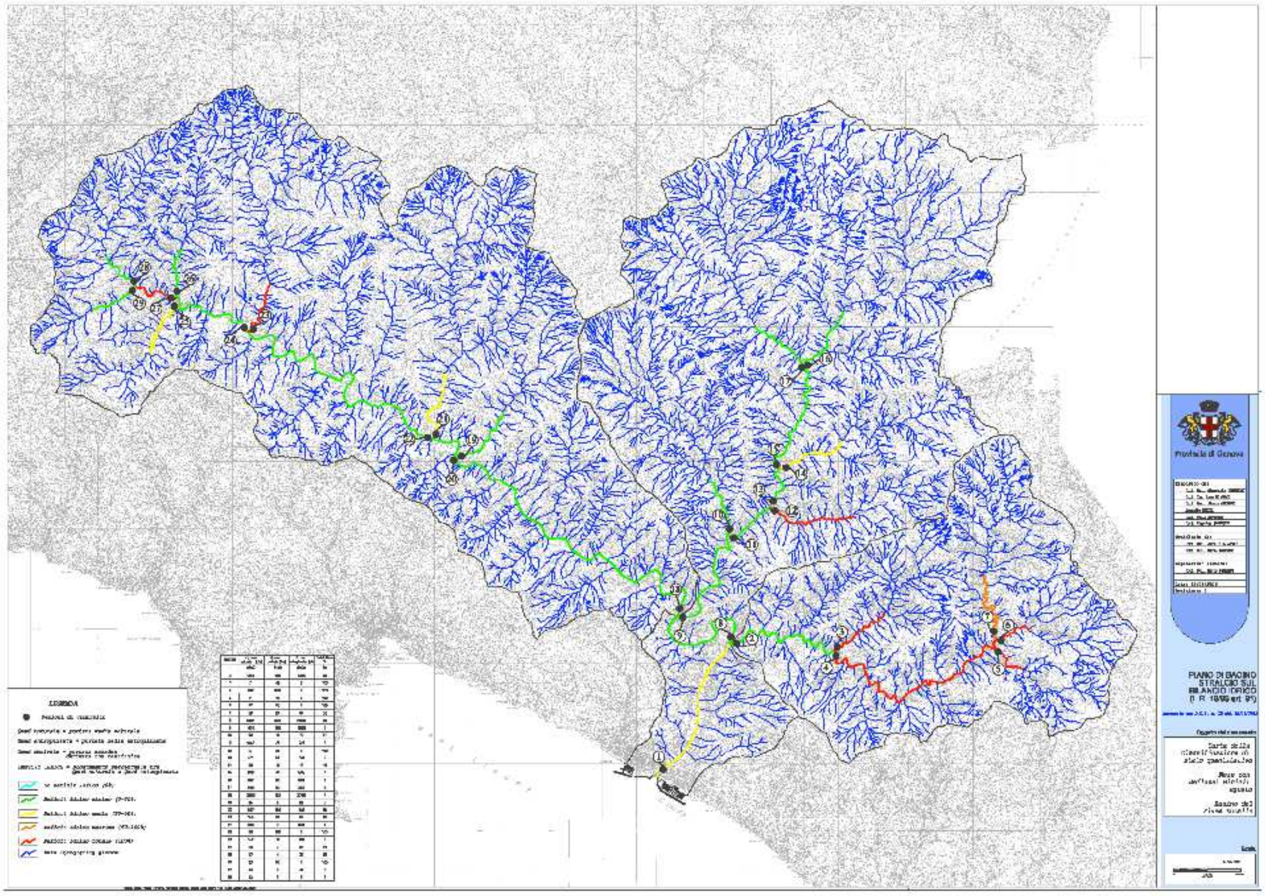


Figure 66; Graphical output of the HYDRO model – average monthly discharge data.



COLOUR	WATER DEFICIT	%
(light blue)	no water deficit	0
(green)	minimum	0-20
(yellow)	medium	20-50
(orange)	maximum	50-100
(red)	total	100
(blue)	minor hydrological system	-

Figure 67; Graphical output of the HYDRO model – differences in water deficit in water bodies of Entella and Scrivia river basins.

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