WP6.1 Discharge estimation in basins with no direct water flow monitoring

Report

PP11 Uni Stuttgart

Summary

SHORT DESCRIPTION

This document intends to describe the various methods used in the participating countries of SHARE to examine water discharge in natural basins.

Document Control

Project	SHARE - Sustainable Hydropower in Alpine Rivers Ecosystems (ref. 5-2-3-IT)
Action	WP6 – action 6.1
Deliverable	YES : WP 6.1
Due date	
Delivery date	27/07/12
Dissemination	Internal
Origin	PP6 – TUG
Author	Clemens DORFMANN, Ivan DRUSCOVIC, Helmut KNOBLAUCH, Ianina KOPECKI, Sara PAVAN, Sašo ŠANTL, Josef SCHNEIDER, Christopher SCHREIBER

VERSION	DATE	AUTHOR	AUTHOR'S ORGANIZATION	DESCRIPTION/CHANGES
v01.00	24/07/2011	SCHREIBER	TUG	1st version
V01.1		DRUSCOVIC		Section Italy
V01.2		BELLEUDY		Section France
V01.3		PAVAN		Section Italy
V01.4		ŠANTL		Section Italy
V01.5		KOPECKI		Section Germany
V01.6		SCHNEIDER		Editing
v02.0	25/07/2012	SCHNEIDER	TUG	2nd version, editing, technical details

1. Table of contents

2.   Introduction

This report describes the different approaches for determining the discharge in the partner countries. Besides a short synopsis about methodologies for velocity measurements different modelling aspects are highlighted. Starting from simple models like the Kreps methodology which is well-known in Styria more sophisticated models like distributed rainfall runoff models are described. The diverse approaches in the partner countries are apparent in the different chapters. It can be seen that there are complex approaches besides simple procedures. However, a European similar approach is not given. Therefore, this report should help to understand and to compare the different methods. It should help to learn from each other and maybe to find a common approach in the future.

The evaluation of the natural river capacities and the determination of the water discharge are very important for the planning and dimensioning of a new hydropower plant (HPP). The present report aims to describe different approaches and methods from various countries throughout the Alpine region. Selected project partners will report on their own experiences and methods.

The natural runoff is not a constant value, but depends on different factors. For runoff estimation models the magnitude of the runoff components surface flow, interflow and base flow should be evaluated.

The most important influencing factors are:

- Weather and climate conditions
- Ground sealing
- River regulation
- Settlement of natural flood retention areas
- Size of the catchment area

Figure 1 shows the process of runoff generation and runoff concentration and the different influencing factors.
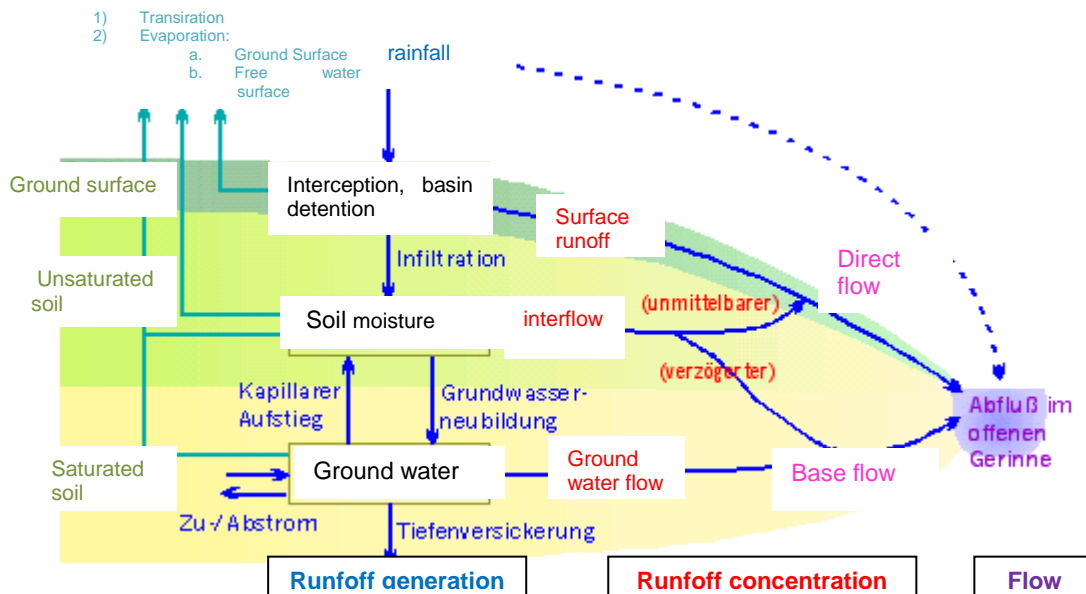

Figure 1: Runoff generation and concentration (Hydroskript, M. Schöniger and J. Dietrich)

The flow of water in an open channel is expressed as units of volume per time and is often estimated by determination of the flow velocity for a given cross-section. Alternatively, the flow can be routed through a

measurement device and measured directly or by using appropriate measurements and mathematical models.

The flow velocity can be determined using current meters to measure the energy of the moving water expressed as a pressure, rotational velocity etc. Impeller meters e.g. relate the flow velocity to the speed at which a submerged impeller rotates in the current.

The flow velocity is not constant throughout a given cross-section. The roughness of the channel side and bottom decrease the speed of the nearby water. For the estimation of the mean natural discharge, the mean flow velocity over the cross-section has to be determined. A modern technique for the measuring of flow velocity is the ADCP (Acoustic Doppler Current Profiler) measurement.

Another method for the determination of flow velocity is the use of tracers, especially at small rivers. A common tracer material is sodium chloride (NaCl). The tracer is put in the river, upstream of the measurement section. At the gauging cross-section, the variation of concentration of the tracer is measured. In the case of NaCl as tracer, the indicating value is the conductivity.

At installed gauge stations along the river, the fluctuation of the water level is observed over time. With the availability of rating curves, the correspondent discharge value can be reproduced. To build the rating curve a great amount of data is needed, including peak discharge during flood events and low runoff during dry periods.

The characteristic annual flow duration curve of a watercourse is called runoff regime. A simple classification can be made according to Pardè (1933) by:

- Supply source of the river:
    - Pluvial (precipitation)
    - Nival (snow)
    - Glazial (glacier)
    - Combination
- Number of runoff-minima and –maxima
- Fluctuation coefficient of the mean monthly discharges $SK=MQ_{month}/MQ_{year}$

For more detailed approaches the meteorological data (precipitation, air temperature, relative air humidity, wind speed, global radiation and air pressure besides others) are collected and calculated, using climate models over a long-time period for most regions. The amount of precipitation, in combination with the duration of the rainfall event and the absorbing capacity of the in-situ soil are largely responsible for the development of the river-runoff. While the precipitation amount is available from collected data, the relevant duration of the event is hard to identify and different approaches are possible.

The influence of the size of the catchment area is related to the infiltration and absorption capacities of the ground. Although a greater amount of water discharge in succession of the same precipitation event should be expected for a larger catchment area compared to a smaller one, the bigger size of the area serves as a buffer due to absorption and evaporation. High infiltration rates can even prevent the development of a flood event. The infiltration capacity of the ground depends on the permeability and saturation of the upper soil layer and its thickness. A low storage capacity and a high permeability of the ground, (e.g. sand) leads to high proportions of interflow and groundwater-runoff.

The regulation of the river course and the composition of the bed, as well as structures for hydropower production, flood regulation, etc. influence the natural flow capacities, especially in the case of a flood event.

For the estimation of the water discharge there are generally two different types of methods:

- Statistical estimation methods for the maximum runoff
- Precipitation-runoff models considering also time-dependence of water discharge (important for the dimensioning of flood retention structures)

Because of different boundary conditions for every catchment area, it is not possible to determine a generally admitted simple formula for the prediction of water discharge; hence regionalization of statistical data and the calibration of input parameters are very important. Due to increased computer power and data storage capabilities the recently developed models consider more parameters and are more detailed. Most of them are physically based distributed models and are occasionally used together with GIS (Geographic Information Systems). However, this requires a large amount of input data, which is not available for all areas. Also note, that every model is an approximation of reality and the reviewed process is highly non-stationary. A high degree of detailing does not necessary gives a better result, due to uncertainties in the input data.

Especially the prediction of water flow of ungauged catchment sites is a difficult and challenging task for hydrologists. It requires an understanding of natural processes for the application of numerical calculation methods due to lack of recorded data. This is a central point in the Alpine region, because many storage reservoirs of hydropower plants and flood retention basins are located at ungauged areas at the upper course of the river.

Estimation formulas for the development of a flood should have following features:

- The determination of the parameters should be easy and exact
- The formula should have a probability indication and allow for a calculation of *n*-annual events with a regional distribution
- The coefficients of the formula should be easy to calibrate
- The scope of application should be exactly indicated (geography, area-type, annuality of the event,…)
- The number of reference gauges should be a multiple of the number of parameters

The used parameters can be grouped into parameters for the description of topography, hydrography, surface condition and precipitation. In empirical formulas precipitation parameters usually are not used, because the maximum runoff is not influenced by the mean temperature or the annual rainfall.

For the description of the topography following parameters are used: size of the catchment area in [km²] or [km] (circumference), length of the gaining stream to the watershed L [km], mean slope, altitude index [m a.sl.] and a factor for the mean orientation.

The hydrography is determined by the drainage network density [km/km²], branching density [-/km²], number of lakes in the catchment area, slopes between 10% and 85% of the length L, the Taylor-Schwarz-Index and the proportion of the channelized area. The parameters for the topography and hydrography can be gathered from maps or with the help of digital image processing.

The surface conditions are described with the soil-index B, the area of the soil type A_B [km²], the proportion of the sealed area and a vegetation index. The determination of the soil index B is time-consuming and difficult, but permeability, soil layer thickness and geology are most relevant for the development of flood events. The infiltration capacity also depends on the humidity of the soil, which is not possible to consider in an empirical formula. Vegetation generally has a restraining effect on the runoff.

CORINE land cover (http://www.umweltbundesamt.at/umwelt/raumordnung/flaechennutzung/corine/) uses satellite images to provide data about land use (categories: artificial surfaces, agricultural areas, forest and semi-natural areas, wetlands and waterbodies).

These parameters are combined in multiple formulas, which are applicable for different regions. Most empirical estimations were developed for special areas or specific catchment area types. It is always necessary to prove validity and to calibrate the parameters.

3. Discharge estimation at natural basins used in PP countries

Italy - Aosta Valley, Piedmont

Estimation of natural flow of rivers

The definition of the river discharge curve used to design the HP plants is usually done using flow rate time series assessment. Daily discharge data definition and their elaboration (even if comparing similar or nearby basins) is the master way used by HP plant designers during the plant setting up. We can define three main different assessment approaches commonly used from HP plant designers to define flow rate patterns:

1. The flow rate curve definition is done analyzing discharge time series of existing measuring stations within the basin concerned by the HP exploitation project *very close* to the future withdrawal point; the proximity between the equipped station and the future point of withdrawal is qualitatively assessed, considering the surface of the basin and the length of the river stretch bypassed; smaller basin generally needs closer points: i.e. in a 20 km^2 basin the equipped station can be considered close to the future withdrawal point if standing less than 1 km from each other; in a 1000 km^2 basin the equipped station can be considered close to the future withdrawal point if standing 1 - 5 km of linear distance along the river;
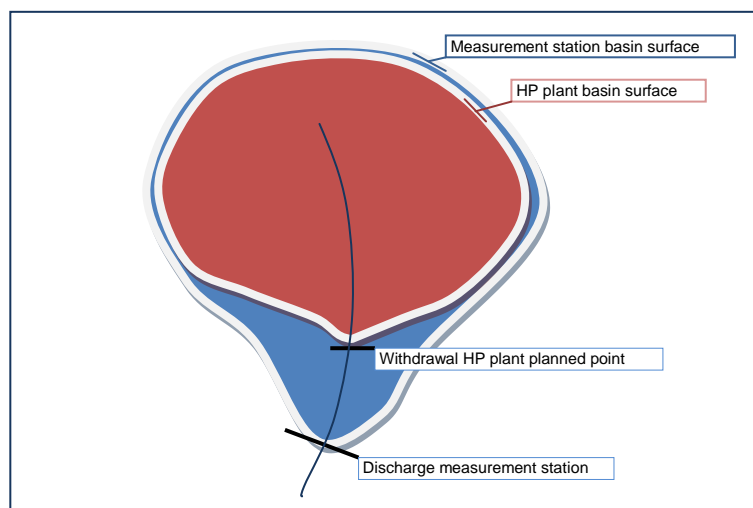
Figure 2: HP plant and measurement point surface basins scheme for very close or relatively far patterns

2. The flow rate curve definition is done by analyzing discharge time series of existing measuring stations within the basin concerned by the HP exploitation project *even if relatively far* from the future withdrawal point. If those data series are available and considered affordable for the specific point of future withdrawal, the daily flow rate assessment is currently carried out considering the proportion between the basin monitored and the basin considered by the future exploitation.

3. If no discharge data are available in the basin concerned by HP plant design, other flow rate data series related to near basins are considered. In this case, the daily flow rate assessment is currently carried out considering data series, elaborated by taking into account the surface proportion, orientation compared to the prevailing winds and precipitation amount. The discharge diagrams obtained from this rough assessment generally imply a degree of uncertainty and they often need to be validated by direct measurement campaigns. Rainfall time series related to the basin concerned are also used for data series calibration and tuning. Smaller basins very often need direct flow rate measurements to calibrate and validate data series previously calculated.
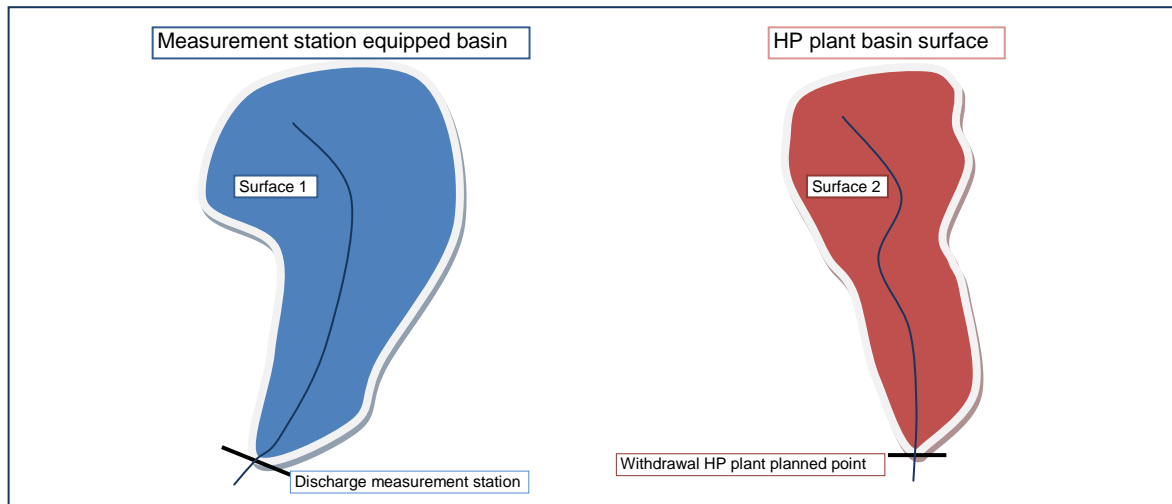
Figure 3: Measurement station equipped and HP plant basins; near basin data elaboration case

When no previous data series are available or affordable, the main approach to assess water discharge to be used for HP plant design is to carry out a field campaign of direct flow rate monitoring, using mechanical current meter. More details are available in the ESHA handbook (ESHA 2004).

The general approach to the flow rate curve definition is by using the above described methods; only in particular cases and conditions more sophisticates modelling methods are applied.

Minimum Instream Flow calculation methods – Aosta Valley region

In the Aosta Valley Region the water withdrawals from water bodies have to release a Minimum Instream Flow as national and regional laws require. The legislative Decree 152/1999 defines the MIF as "the flow which, in a water body, must be present downstream of the water catchment in order to maintain the viability of the conditions of functionality and quality of the ecosystems concerned".

The official River Basin Management Plan (Piano di Tutela delle Acque), approved by law, considers three different criteria to determine the MIF.

Criterion n. 1 for the determination of the MIF discharges

The minimum instream flow (MIF) in a given section of the water body is calculated using the following formula:

$$MIF = k*q_{MEDIA}*S*M*Z*A*T \ [l/s]$$

where: k = experimental parameter determined for single hydrographic areas

For the Aosta Valley following parameters are applied, deriving from the Basin Authority of the Po River Decree 7/2000 and adapted for basin surfaces minor than 100 km²:

Table 1: Parameters for the Aosta valley

K	S = BASIN SURFACE SUBTENDED BY THE SECTION OF THE WATER BODY (KM²)
0.06	S < 10 km²
0.08	10 < S < 100 km²
$-2.00 \times 10^{-5} \times S + 0.14$	100 < S < 1000 km²
0.12	S > 1000 km²

S = basin surface subtended by the section of the water body (km²)

q_{MEDIA} = annual average specific flow for a basin surface unit (l/s)

The above mentioned flow is assessed on the basis of regionalization of measured discharges at the station of regional water body surfaces:

Table 2: Discharge data Qmean

Water bodies	q_{MEDIA} (l/s/km²) H = average basin altitude (m a.s.l.) A_{MA} = annual average afflux on the basin (mm) calculated through the data listed in picture 1
Dora Baltea from Villeneuve to Pont-Saint-martin	q_{MEDIA} = 28.51
Other water bodies	q_{MEDIA} = 0.004204856 * H 0.02302933 * A_{MA}

Furthermore it is possible that the value of the q_{MEDIA} is determined with discharge data, referred to the diversion section or to the diverted river, considered hydrologically sufficient to represent the flow conditions (5 monitoring years minimum), adequately validated and validable, provided by the applicant. It is better if the diversion requests are accompanied by a monitoring of punctual discharge conditions for adequate time (two years minimum) in comparison with the data resulting from regionalization curves and to guarantee to the correct individuation of differentiable quantities. Figure 4 shows a map of the mean annual isohyet.

Figura 1: Carta delle isoiete medie annue (mm)
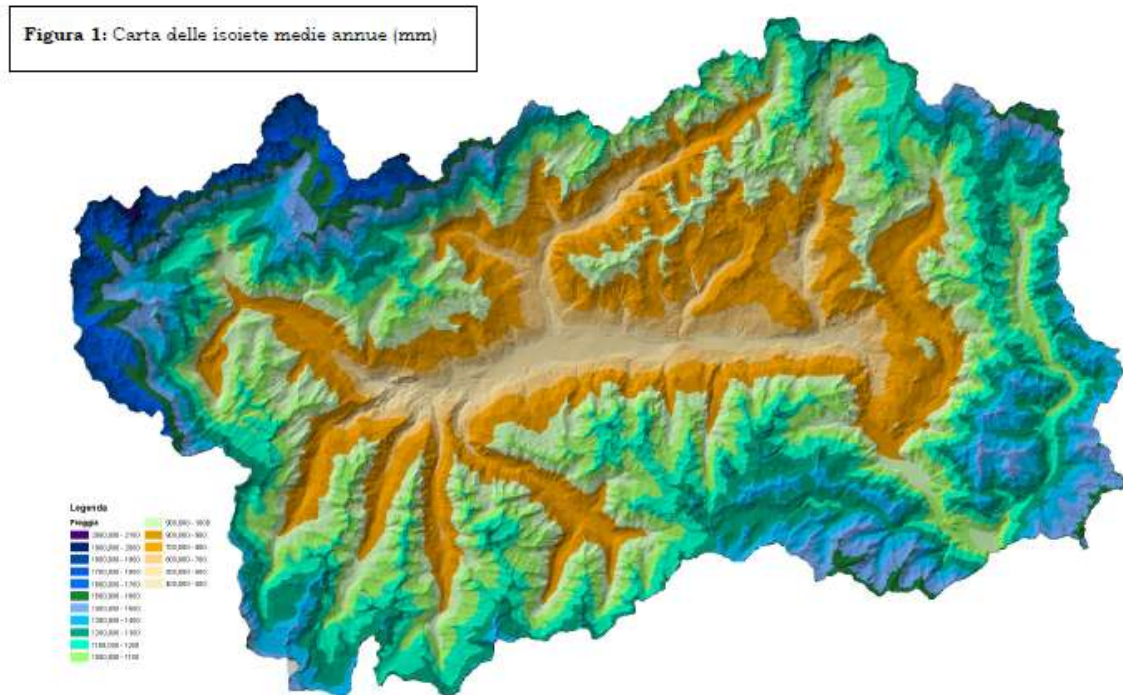
Figure 4: Map of the mean annual isohyet [mm]

M = morphological parameter

The morphological parameter M is identified in function of the geomorphologic index defined in a Regional Special Project defining precautionary values as shown in Table 3:

Table 3: M- values

BASIN	M VALUE
Dora Baltea	1.2
Buthier, Evançon, Lys, Ayasse	1.1
Artanavaz, Marmore, Dora di Verney; Dora di Rhêmes, Dora di Valgrisenche, Savara, Grand Eyvia	1

Those values are taken in account as representatives of the whole hydrographic basin and assumed as valid for all rivers. If the Fluvial Functionality Index (IFF) is used in the calculation of the Z parameter, the value of M is equal to 1 for all watercourses.

Z parameter

The Z parameter (which includes the three parameters N, F and Q) introduces the element of assessment of the overall environmental quality in the watercourse stretch considered and subtended by the diversion.

For sites of higher environmental quality it is necessary to provide conditions for greater protection. At the same time greater protection is provided to the environments with present naturalistic value, but also in the case where it is expected as objective the naturalistic recovery of environment in degradation, overturning the previous setting.

For every significant surface water body it is defined in the River Basin Management Plan the ecosystem quality indicator grouping the features of the water bodies connected to the water quality (IBE), to the riparian vegetation and to the ichthyofauna distribution and the Fluvial Functionality Index (IFF).

For MIF discharge determination the environmental quality is defined as:

- for significant water body, the environmental quality value of the withdrawn stretch corresponds to the Fluvial Functionality Index (IFF) value or to the worst condition of the subtended stretch level (when available) if water release when the diverted water are returned in a more downstream IFF reach (as described in the third point).

- in case of lack of IFF datasets, the Z parameter can be determined in two ways:
  - assuming a fix value equal to 1,30 (or 1,40 for the more natural water bodies)
  - through the Fluvial Functionality Index (IFF) according to the procedure indicated to the following point.

- for any water body it is possible to determine the environmental status through the Fluvial Functionality Index (IFF), assuming as representative of the quality status the stretch subtended from the withdrawal as shown below:
  - evaluation of the functionality levels
  - assessment of recurrence rates of the functionality levels for each bank in the diversion subtended stretch
  - determination of the recurrence rates of the functionality levels for the whole subtended stretch, assuming for each portion the worst value between the right and left bank
  - selection of the functionality level more recurrent between high, good, mediocre, low and very poor adding the recurrence rates that cover each level (eg. %(good) = %(high-good) + %(good) + %(good-mediocre) – %(mediocre) = %(good-mediocre) + %(mediocre) + %(mediocre – low).

The ecosystem quality index is represented in the "Quality ecosystem" map.

In relation to the specific objectives established, not only the ecosystem conservation but also the restoration of the environment, the Z parameter are defined following values as described in Basin Authority of the Po river studies, in the activity of the Special Project 2.5 inherent the determination of N, Q and F coefficients.

Table 4: Z parameter value for the significant water bodies

STATUS REPRESENTED BY THE ECOSYSTEM QUALITY		Z PARAMETER VALUE	STATUS REPRESENTED BY THE FLUVIAL FUNCTIONALITY INDEX (IFF)
Very high quality	High quality	1.30	High
	Satisfying quality	1.25	Good
Mediocre quality	Mediocre quality with contrasts	1.20	Mediocre
Bad quality	Bad quality with contrasts	1.20	Low
	Very poor quality	1.20	Very poor

For water bodies of particular value (cf. Annex to the implementing rules "Classification of the Regional Water Bodies and Specific Protection Areas") the Z parameter values are higher as shown in Table 5.

Table 5: Z parameter value for the water bodies of particular value

STATUS REPRESENTED BY THE ECOSYSTEM QUALITY		Z PARAMETER VALUE	STATUS REPRESENTED BY THE FLUVIAL FUNCTIONALITY INDEX (IFF)
Very high quality	High quality	1.40	High
	Satisfying quality	1.35	Good
Mediocre quality	Mediocre quality with contrasts	1.25	Mediocre
Bad quality	Bad quality with contrasts	1.25	Low
	Very poor quality	1.25	Very poor

A = parameter relating to the interaction between surface and underground waters.

The A parameter is equal to 1 for all the surface water bodies.

T = parameter relating to the time modulation of the MIF.

The T modulating factor of the flow has to be referred to the natural trend of the flow in the considered stream. In a first approximation the parameters are indicated in the following table:

T = 1.00 in the months of January, February, March, October, November and December

T = 1.05 in the months of April, May and September

T = 1.15 in the months of June, July and August.

Criterion n. 2 for the determination of the MIF discharges

The criterion 2 for the determination of the MIF is finalized in particular to guarantee the compatibility of the withdrawal with the environmental conditions of the stream.

The value of the MIF is variable for each month and is determined on the base of the following formula, composed by a hydrologic component variable for each month of the year and by the $Z_{DECIMAL}$ corrective factor:

$$MIF_{monthly} = q_{MONTHLYAVERAGE} \, S * Z_{DECIMAL} \, [l/s]$$

$q_{MONTHLYAVERAGE}$ = **monthly average specific flow per surface unit of the basin [l/s/km^2]**

$q_{MONTHLYAVERAGE}$ is defined on the base of the regionalization of measured flow on the following way: the quoted values are valid for basins with an area of more than 10 km^2, as the regionalization takes in account basins with an area >10 km^2; tests of this criterion demonstrate that under this threshold the extrapolation results are heavily affected by errors.

Table 6: Discharge values for the Dora Baltea river

DORA BALTEA RIVER – FROM VILLENEUVE TO PONT SAINT MARTIN: $q_{MEDIAMENSILE}$[L/S/KM²]											
q_{jan}	q_{feb}	q_{mar}	q_{apr}	q_{may}	q_{jun}	q_{jul}	q_{aug}	q_{sep}	q_{oct}	q_{nov}	q_{dec}
9.47	8.76	9.84	17.31	41.08	70.42	60.05	46.61	31.06	20.22	15.98	11.38

Other water courses: $q_{MOUNTHLYAVERAGE}$ [l/s/km²]

H = average altitude of the basin (m A.M.S.L.)

$Q_{MEDIA} = 0.004204856 * h + 0.02302933 * A \; [l/s/km²]$

$q_{january}$	$0.231656449 * q_{MEDIA}$	q_{july}	$0.034169591* H$
$q_{february}$	$0.211382342 * q_{MEDIA}$	q_{august}	$0.025126331 * H$
q_{march}	$0.245702885* q_{MEDIA}$	$q_{september}$	$0.01019068 * H + 0.380281169 * q_{MEDIA}$
q_{april}	$0.457959942 * q_{MEDIA}$	$q_{october}$	$0.703911596 * q_{MEDIA}$
q_{may}	$1.478190999 * q_{MEDIA}$	$q_{november}$	$0.434878021 * q_{MEDIA}$
q_{june}	$0.012059623 * H + 1.92348292 * q_{MEDIA}$	$q_{december}$	$0.286993259 * q_{MEDIA}$

Furthermore it's possible that the q_{MEDIA} is determined with the flow data referred to the diversion section, statistically representing the flow average conditions (5 years sampling minimum) adequately validated, provided by the applicant.

It's *desirable* but not compulsory that applicants also provide a direct flow monitoring dataset for at least two years.

S = surface of the basin subtended by the section of the water body – km2

$Z_{DECIMAL}$

The $Z_{DECIMAL}$ corresponds to the decimal part of the Z parameter defined for criterion 1.

The monthly values of the MIF ($MIF_{monthly}$) have to be compared with the MIF value calculated with the criterion n. 1: all the values of $MIF_{monthly}$ minor than the MIF of the criterion 1 are increased by 20%.

The values obtained represent the value curve of the flow of Minimum Instream Flow related to each month.

Some monthly values can be integrated:

- increasing (till the monthly mean value) when it's demonstrated that the regime determined is not able to satisfy a specific need of:
  - specific protection of the ichthyofauna
  - social touristic fruition
  - protection of a specific component of the landscape
  - dilution of pollutant
- decreasing (in the maximum limit of 50%) if in the subtended stretch by the diversion subsist geomorphologic reasons or particular natural conditions.

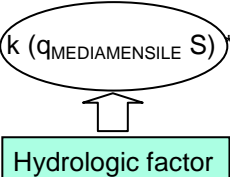# Criterion n. 3 for the determination of the MIF discharges

The criteria n. 3 for the determination of the MIF discharges is finalized to guarantee the compatibility of the withdrawal with the environmental conditions of the stream through local specific evaluation.

The evaluation methodology of the flows of MIF according to the criterion n. 3 is different for *ex-ante* or *ex-post* assessment of hydropower facilities.

New withdrawal

For basins with an area >10 km², the structure of the formula remain the same like for criteria n. 2, while the corrective factors are determined through the methodology shown below:

$$DMV = (k \, (q_{MEDIAMENSILE} \, S)) * (Corrective \, factors) \ [l/s]$$

Hydrologic factor

The hydrologic factor is determined as in the criteria n. 2, leading to the determination of 12 flow values, one for each month of the year.

The methodologies used to pick out the values of the corrective factors to solve local environmental criticalities have to forecast an advanced analysis of the sectors (partially independents) of the water quality, of the aquatic biocenosis and of the overall naturalistic status of the fluvial system.

This analysis is based on direct investigations of river status, interferences and mitigating actions between diversion presence and hydrologic sector. In this way the environmental considerations, related to the existence of water abstraction, are objectified, analyzing them and making them more verifiable and repeatable, identifying the main impacts on the watercourse and the water resource overall. All the components involved are identified in order to find a compromise, by indicating the appropriate actions, between costs and benefits (environmental, socials and economics), trying to make effective impact assessments.

The correctives factors have values equal or upper than 1, but not values below 1.

The method also suggests that mitigations and compensations can be done to provide the maximum environmental compatibility of the plant, taking in account the existing situation.

- Water quality

The problems of control of the qualitative status of the watercourse are evaluated from the pollutant loads, measured from the macrodescriptor parameters required from regional set of laws. The evaluating procedure has to allow the definition of all the aspects of qualitative criticality of the river stretch under consideration, including those not directly related to the loads of the macrodescriptor parameters and assessable by specific surveys required from local set of laws in relation to specific chemical pollutants, accumulation processes in the sediments and in the biota, to the eco-toxicological tests.

These analyses allow determining the effectiveness of the integrative releases and deciding possible integrative releases also for limited temporal period.

- Biological sector

The knowledge of biocenosis have to be deepening, combined to the way to integrate the hydrological component of MIF, through methods of definition of the biological quality and referred to specific monitoring protocols and indicators required from local set of laws.

- Modulation

The modulation of the releases depends on protection objectives of the river stretch. In general, setting rules of modulation is difficult as not all of the diversion structures are able to modulate a released flow.

The main factors potentially requiring a modulation action are listed below:

- o Necessity of ichthyofauna protection during the critical periods of reproduction and in the first phase of the life cycle
- o Recreational tourism function
- o Dilution of pollutants
- o Diversification of the flow regime

- Verification and maintenance of hydraulic continuity

The MIF determination regards a specific hydrographic stretch, characterized by morphological and environmental knowledge of significant river stretch on which are assessed all the calculation parameters of the minimum Instream flow.

Specific rules are provided to verify the hydraulic continuity identifying a sub-section of the stretch.

- Interaction with groundwater

Negative or positive interactive flows with the groundwater have to be evaluated in order to regulate the diversion release with the purpose to compensating them. Direct flow measurements have to be done along the diverted stretch.

Existing withdrawal

The experimentation project has to define the component of hydro-system to be considered, the dynamics and the released levels, the interventions to be implemented to make the diversion structures suitable to the MIF releases and the relating controls. All those actions have to be arranged with the regional administration.

The environmental status has to be assessed using Fluvial Functionality Index (IFF) and local environmental criticalities through an advanced analysis of the water quality sectors and aquatic biocenosis.

Minimum Instream Flow calculation methods – Piedmont region

The Piedmont Region assigns defined minimum Instream flows for determinate stretches of the main rivers of the region: MIF calculations are available for the hill and plain part of the Po and the Tanaro rivers.

For the other natural water bodies, the MIF is determined in a given section with the following formula by a method very close to that of the Aosta Valley:

$$MIF = k*q_{MEDIA}*S*M*Z*A*T \ \ [l/s]$$

where:

k = annual average flow fraction (experimental parameter determined for homogeneous areas)

> The k factor depends on homogeneous areas that are listed with values between 0.07 and 0.15.

Q_{MEDIA} = natural average specific flow for surface unit of the subtended basin [l/s/km2]

> The q_{MEDIA} flow is determinated using some formulas based on regionalization models and defined mainly by altitude and annual average meteor influx (H and A factors).

S = surface of the basin subtended by the water body [km²]

M = morphological parameter

> The morphology of the basins is divided in 4 classes detectable on the specific charts of the Piano di Tutela delle Acque.

A = parameter that taking into account of interaction between surface and underground waters

> In order to estimate this parameter it is possible to consult a specific table of the Piano di Tutela delle Acque.

Italy – Region Veneto

The *Regional Hydrographic Service (SIR)* of the Dept. of Landform Safety (*DRST*) of ARPA Veneto operates a continuous monitoring activity along the regional hydrographic network. Such discharge measurements and their analyses are accomplished by reports and by publishing data on the website: <http://www.arpa.veneto.it/temi-ambientali/idrologia/file-e-allegati/rapporti-e-documenti/idrologia regionale/idrologia-regionale-la-rete-idrometrica> (Figure 5 and Figure 6).
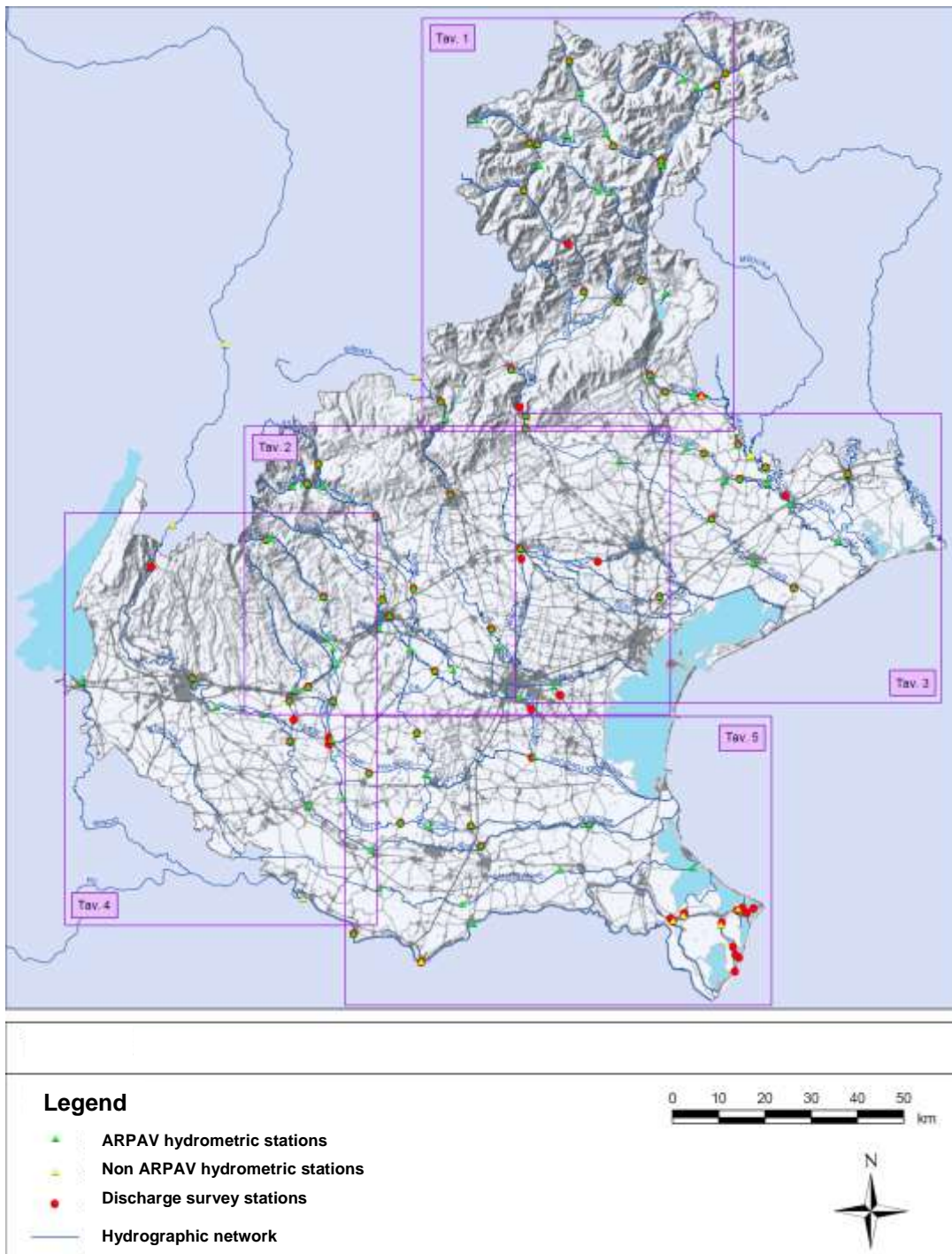

Legend

▲ ARPAV hydrometric stations
△ Non ARPAV hydrometric stations
● Discharge survey stations
— Hydrographic network

Figure 5: Gauge stations and discharge monitoring sections along Cordevore and Astico rivers
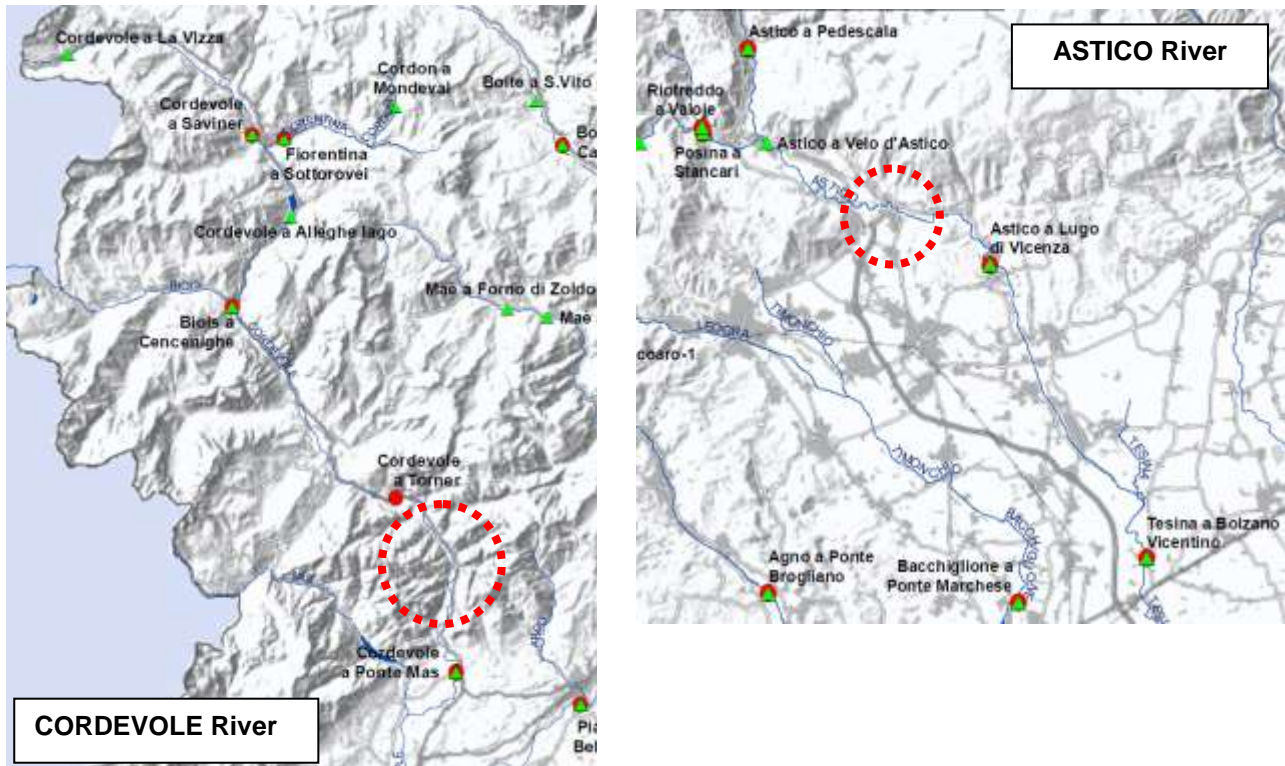
Figure 6: Gauge and discharge monitoring sections along Cordevole and Astico rivers

Discharge monitoring

In the period from 2004 to 2010 ARPAV conducted discharge monitoring surveys along 120 sections of the regional hydrographic network. The monitoring surveys were made according to the main normative and technical references, which are:

- ISO/FDIS 748/2007 (Hydrometry – Measurement of liquid flow in open channels using current-meters or floats).

- ISO/CD 24578 (Hydrometry - Guide to the Application of Acoustic Doppler Current Profilers for Measurement of Discharge in Open Channels)

- UNI EN ISO 6416/2005 "Idrometria - Misurazione della portata mediante metodo acustico ad ultrasuoni".

- ISO 9555-1/1994 "Measurements of liquid flow in open channel – Tracer dilution methods for the measurement of steady flow" - Part 1.

- ISO 5168/2005 "Measurement of fluid flow - Procedures for the evaluation of uncertainties"

The discharge measurements have the basic aim to define the rating curves for different rivers. The rating curve gives the possibility to obtain, for station equipped with hydrometer, the discharge value associated to the correspondent hydrometric value.

This can be useful for a set of analyses:

- Flood events hydrological and hydraulic characterization;

- Basins hydrological and hydraulic characterization;

- Water balance evaluations;

- Water source points quantification;

- Sediment transport evaluations.

The discharge monitoring is a good support for water quality analysis, both for physical-chemical aspects as well as for biotic elements. The measures are made during different hydraulic regime conditions, in order to evaluate the wet and dry periods along the interested river reaches.

Furthermore, direct measurements are made:

- downstream deriving and restitution points;

- to evaluate and/or control the minimum instream flow (MIF);

- to evaluate habitat quality for fish species.

The discharge measures made by ARPAV-SIR in the period 2004 to 2010 were obtained using different methodologies, in relation to hydrometric, morphologic and environmental river conditions, such as:

- current meter techniques;

- measures using Doppler based instruments (ADCP);

- measures using salt dilution method.

Current meter techniques

The method is based on field surveys of flow velocity in correspondence of a chosen channel section which, linked to the channel section geometry, allows the discharge value estimation. The velocity measurements are conducted for several points along the section, using classic current meters and/or electromagnetic current meters (ECM) (Figure 7). ARPAV-SIR's surveys are made applying different techniques (Figure 8):
- wading;
- from bridge;
- cableway.

Figure 7: Current meters; classic and electromagnetic (ECM, Nautilus C2000) ones

Field data (flow velocity and section geometry) are then elaborated through specific softwares (*Software Q* by SEBA Hydrometrie) for the discharge value and other hydraulic parameters estimation (Fig. 5).

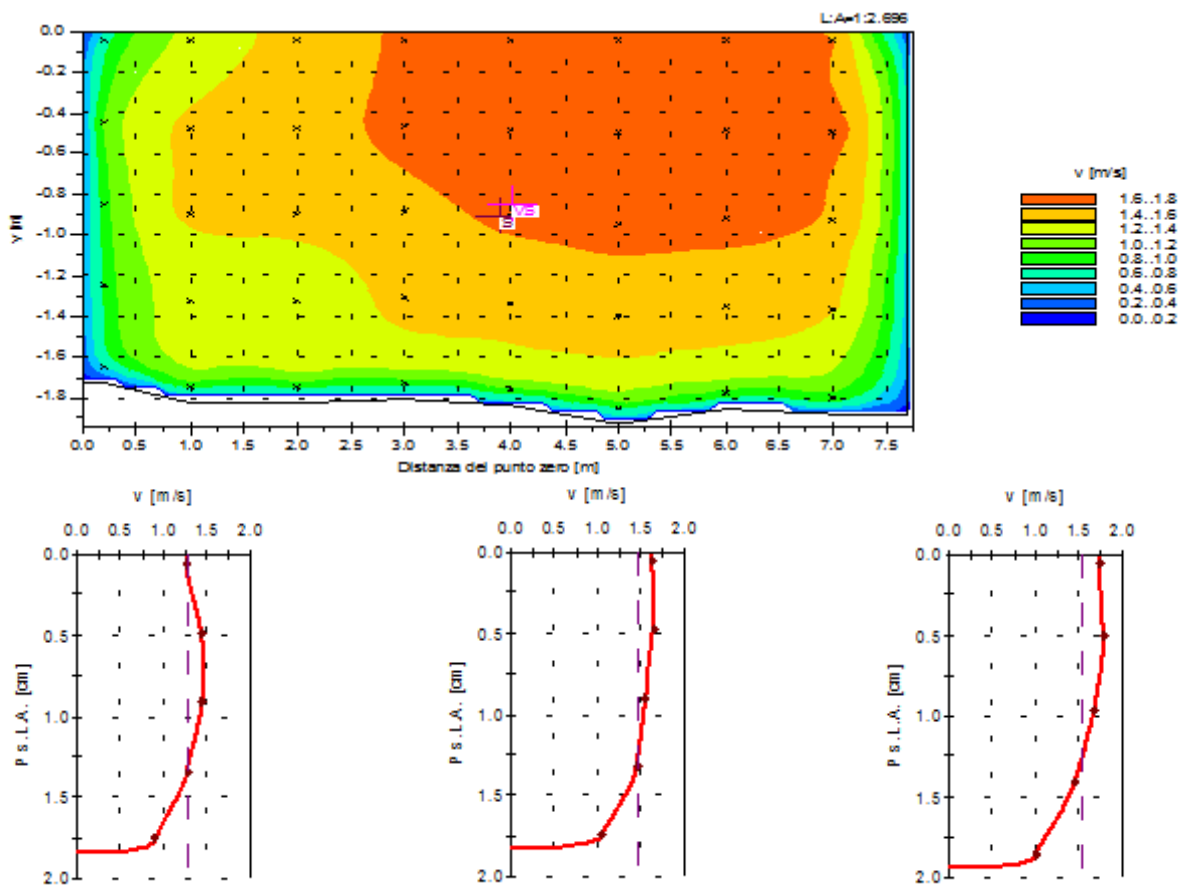**Figure 8: Different techniques for flow velocity measurements; from bridge and using a cable**

Figure 9: Graphic elaboration of SoftwareQ for the discharge value estimation along a channel section

Measurements using Doppler based instrument (ADCP)

ADCP instruments (Acoustic Doppler Current Profiler) for discharge measurements estimate the flow velocity using the Doppler effect. The discharge is derived using a specific algorithm starting from the velocity distribution along the vertical profile and the whole channel section (Figure 10).

Figure 10: ADCP RioGrande (for moderate/high flow depths) and StreamPro (for low/moderate flow depths) models
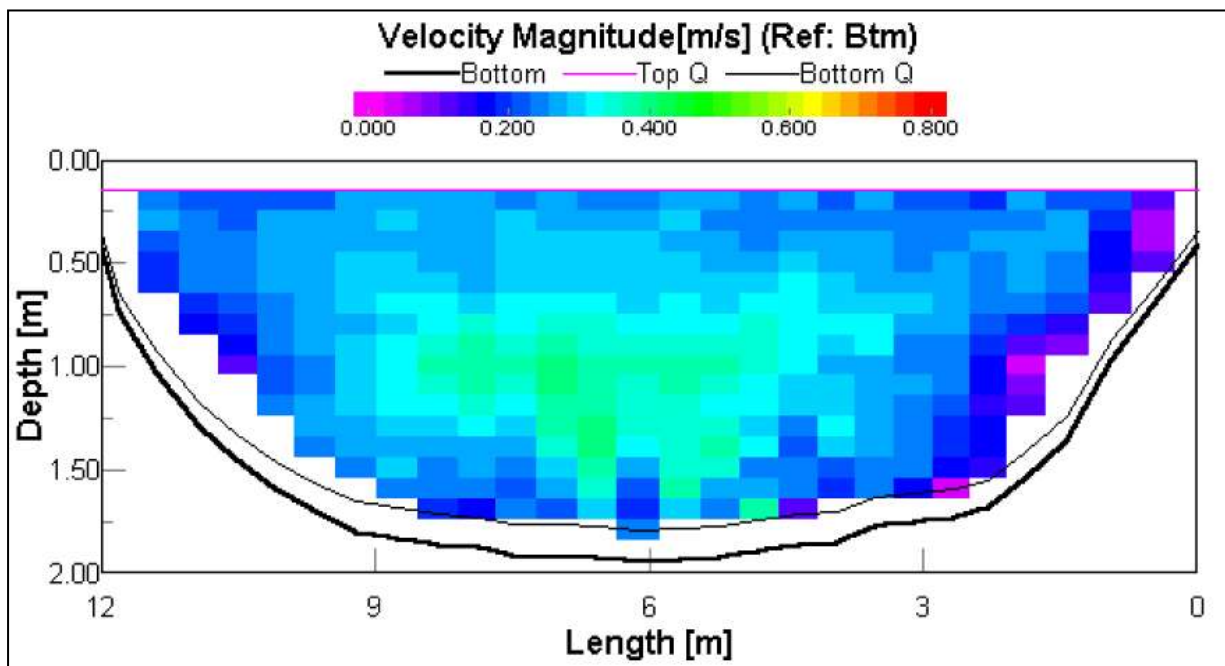

Figure 11: Graphic elaboration of ADCP measurement along a channel section

ARPAV-SIR's surveys with ADCP are made by applying different techniques (Figure 12):

- measurements from bank to bank
- measurements from a bridge
- cableway
- by small boat and canoe

Figure 12: ADCP measurements from bank to bank and by canoe

The ADCP method can be applied for several evaluations, such as:
- discharge measurements for water balance evaluation;
- discharge measurements along mountain streams;
- discharge measurements under bankfull/peak flow conditions;
- discharge measurements on water source points;
- discharge measurements in the lower portion of hydrographic network, affected by tidal level

Measurements using salt dilution

The method is based on the hypothesis that a solute in the water maintains its mass along the channel reach. The variation of conductivity of the salt (solute) depends on the volume of water responsible of its dilution (Figure 13). The discharge can be estimated from the conductivity variation curve taking into account the volume and concentration of the salt solution, and measuring the conductivity variation during the time through a conductivity meter. The discharge is calculated applying the formula:

$$Q = \frac{C_i V_i}{\int_0^\infty C(t)dt}$$

Such technique is applied by ARPAV-SIR in case of moderate discharge values, generally along mountain channel reaches, and where the conditions for the use of classic current meters don't exist.
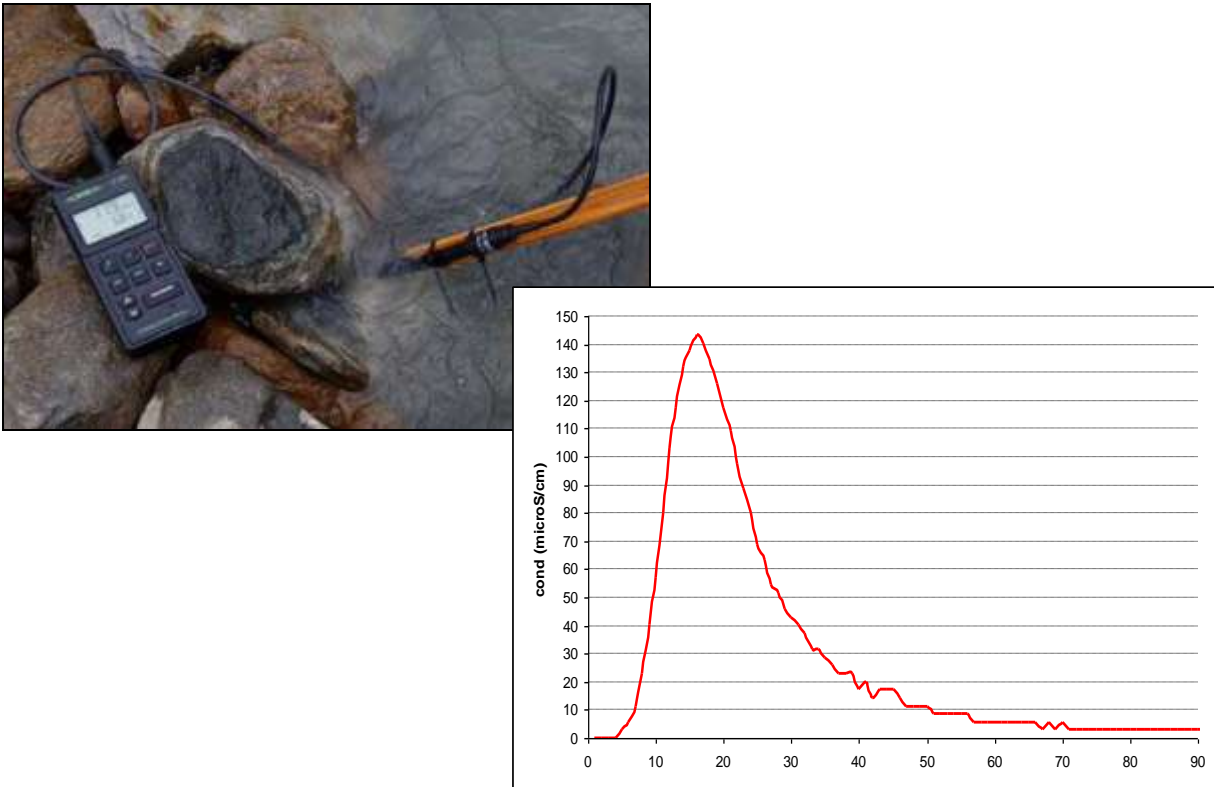

Figure 13: Salt dilution method; conductivity meter and concentration curve

Hydrometric references

A water level gauge is generally associated to the correspondent discharge value. The hydrometric reference used by ARPAV-SIR is, where present, the water level recorded by the automated water level gauge stations and by hydrometric rods. Automated water level gauge stations use different typologies of sensors:

- ultra-sound water level gauges (Figure 14);
- pressure water level gauges.

The instruments allow to continuously monitor the water level, with time recording of 30 min.

The hydrometric rods (Figure 14) are important for the comparison with the water levels registered by the automatic water level gauge stations.

Figure 14: Hydrometric references; echo sounding automatic system and hydrometric rod for water level gauge

Aims of discharge measurements

Rating curves

The discharge measurements have the aim to build the rating curves for different channel reaches (Figure 15). The rating curve availability allows, in the case of channel sections provided with automated water level gauges, to find out the correspondent discharge value (Figure 16). The rating curve building needs a sufficient number of water level data, including low discharge and peak discharge conditions.
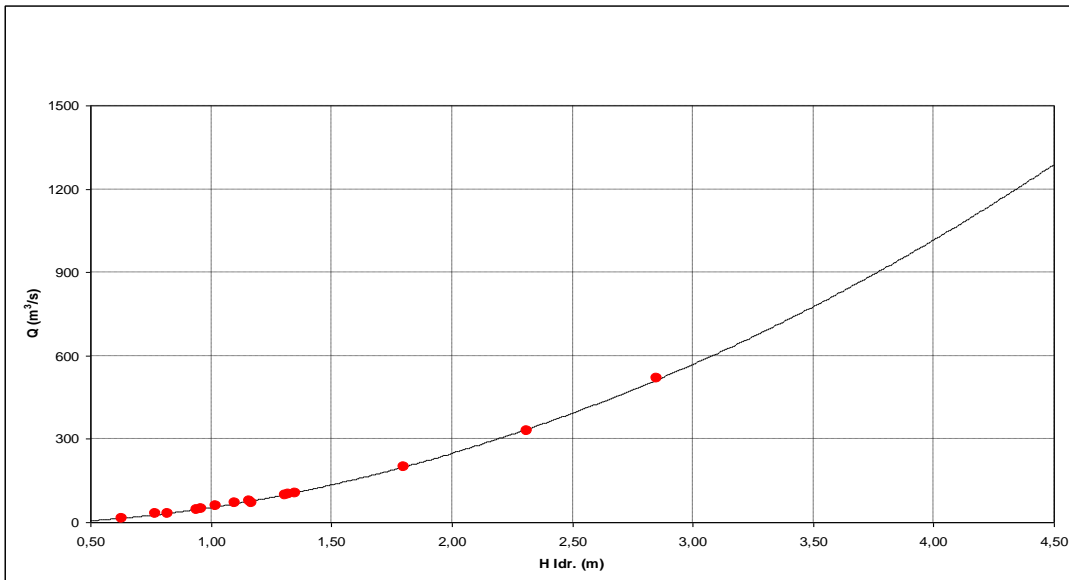

Figure 15: Rating curve of Brenta River at Barziza gauge section

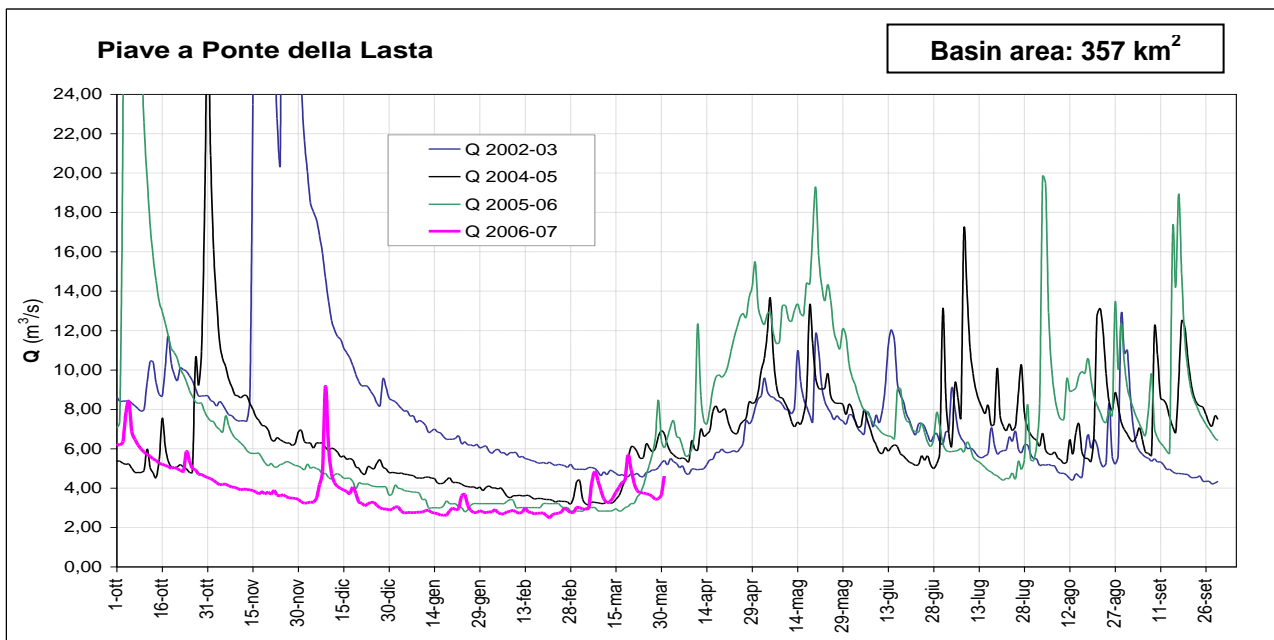**Figure 16: Piave River; discharge variation [m³/s] during different years at Ponte della Lasta gauge station**

The data discharge recorded and/or derived from rating curves can be used, among all the various analyses, for the realization of discharge duration curves. They can be obtained if a daily water level measurement is made or recorded, in correspondence of automated gauging stations. Such curves are important for:

- the evaluation of dominant water regimes specific for each river basin;

- the evaluation of mean yearly discharge and for different *Qxx*, that are the discharge values that are exceeded for xx days during the year;

- the evaluation of a MIF value for the river, depending on the frequency of discharges lower than a particular value.

Some discharge duration curves, characteristic for small mountain tributaries of Cordevole basin, are presented in the following diagrams (Figure 17).
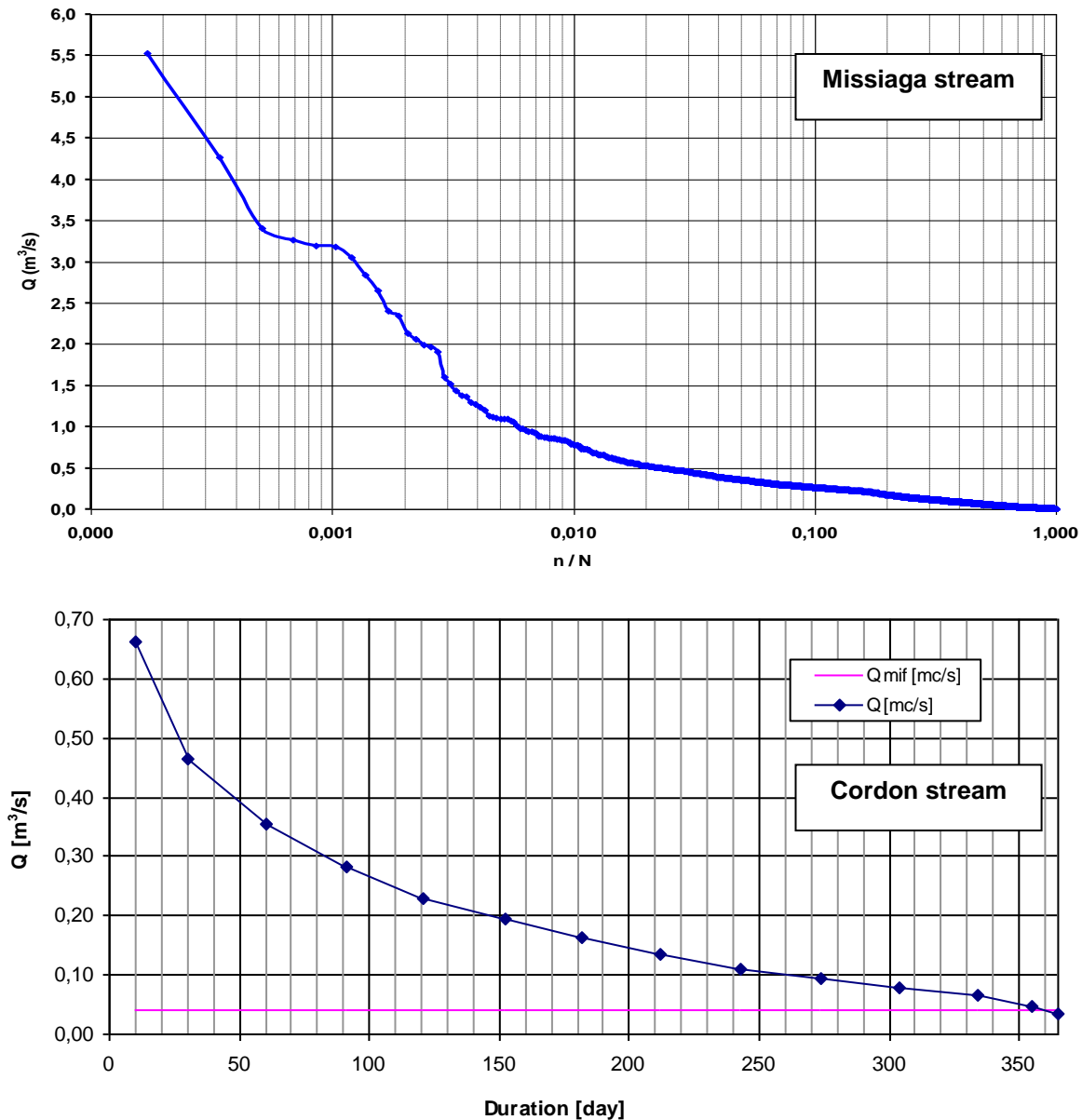

Figure 17: Discharge duration curves of Missiaga and Cordon basins (Cordevole River basin)

Water quality monitoring measurements

The discharge monitoring is useful for the water quality evaluation, both for chemical aspects and biological components. The evaluation of biological river quality needs the entity and the acknowledgment of previous flood events.

Discharges during dry periods

Discharge measurements are regularly made by ARPAV-SIR in correspondence of channel sections in order to evaluate the flow regimes during dry periods, which is the evolution of water availability along river reaches of particular interest. Discharge measurements are conducted downstream of deriving and restitution points of hydropower plants, with the aim to evaluate and/or control the MIF along a channel reach and to evaluate habitat quality for different fish species.

Other aims

Field surveys are conducted by ARPAV-SIR in order to evaluate the balance between superficial and drained discharge along channel reaches of Veneto Region where the water infiltration phenomenon (gravel-bed rivers) is important. Furthermore, discharge measurements are made in correspondence of water source points and along artificial channels.

In Table 7 the channel sections for discharge monitoring surveys are presented, along different rivers of Veneto Region, developed by ARPAV-SIR for the year 2010 (ARPAV, 2012).

Table 7: Channel sections for discharge monitoring surveys, along different rivers of Veneto Region, developed by ARPAV-SIR for the year 2010 (ARPAV, 2012)

| BASIN | RIVER | SITE | HYDROMETRIC REFERENCE | | MEASURES (NR.) | AIMS | | | | RATING CURVES | | |
			WATER LEVEL GAUGE	HYDR. ROD	2010	GENERAL	WATER QUALITY SUPPORT	HYDROLOGICAL REGIME	OTHER	AVAILABLE	FROM	TO
Lemene	Lemene	Portogruaro	X		3				F4	S4		
Lemene	Malgher	Corbolone		X	4				F4	S3		
Livenza	Meschio	Vittorio Veneto	X	X	4	F1				S3		
Livenza	Meschio	Borgo Campion	X	X	5	F1				S2	20/10/09	31/12/10
Livenza	Meschio	Ponte della Muda	X	X	5	F1	F2			S3		
Livenza	Livenza	Portobuffolè	X	X	8	F1	F2			S3		
Livenza	Livenza	Meduna di Livenza	X	X	10	F1	F2			S1	1/1/04	31/12/09
Livenza	Monticano	Fontanelle	X	X	8	F1				S1	1/1/04	31/12/09
Livenza	Monticano	Gorgo al Monticano	X		6		F2			S4		
Piave	Padola	S.Stefano	X	X	7	F1	F2			S1	01/01/86	31/12/10
Piave	Piave	Ponte della Lasta	X	X	6	F1	F2			S1	01/01/89	31/12/10
Piave	Boite	Podestagno	X	X	4	F1				S1	01/01/89	31/12/10
Piave	Boite	Cancia	X	X	5	F1	F2			S1	01/10/85	31/12/10
Piave	Boite	Perarolo	X	X	1				F4	S4		
Piave	Piave	Perarolo	X	X	4		F2	F3		S2	01/01/04	06/05/10
Piave	Piave	Ponte nelle Alpi	X	X	6		F2	F3		S2	04/11/00	31/12/10
Piave	Piave	Belluno	X	X	11	F1				S1	26/10/94	31/12/10
Piave	Cordevole	Saviner	X	X	10	F1				S1	01/01/85	31/12/10
Piave	Fiorentina	Sottorovei	X	X	8	F1				S1	12/02/92	31/12/10
Piave	Biois	Cencenighe	X	X	9	F1	F2			S2	14/11/06	06/03/08
Piave	Cordevole	Torner		X	6		F2			S2	16/11/06	31/12/10
Piave	Cordevole	Ponte Mas	X	X	2	F1				S2	26/11/02	31/12/10
Piave	Sonna	Feltre	X	X	8	F1	F2			S1	09/05/85	31/12/10
Piave	Fium	Vas		X	2		F2			S4		
Piave	Piave	Segusino	X	X	14	F1	F2			S1	01/01/04	31/12/10
Piave	Piave	Ponte di Piave	X	X	2	F1	F2			S1	1/1/04	31/12/07
Piave	Piave	Eraclea	X		1				F4	S4		
Sile	Sile	Santa Cristina		X	6		F2	F3		S3		
Brenta	Brenta	Enego	X	X	10	F1	F2			S2	07/12/05	31/12/10
Brenta	Brenta	Barziza	X	X	9	F1	F2			S1	1/1/04	31/12/10
Brenta	Brenta	Curtarolo	X		9	F1	F2	F3		S3		
Brenta	Muson dei Sassi	Castelfranco Veneto	X	X	10	F1				S1	1/1/04	31/12/10
Brenta	Muson dei Sassi	Castelfranco-Treville		X	5		F2			S3		
Brenta	Brenta	Vigonovo		X	5	F1	F2			S3		
Bacchiglione	Bacchiglione	Ponte Marchese	X	X	3	F1				S4		
Bacchiglione	Bacchiglione	Vicenza	X	X	8	F1	F2			S1	1/1/04	31/12/08
Bacchiglione	Astico	Pedescala	X	X	9	F1	F2			S1	01/06/85	31/12/10
Bacchiglione	Rio Freddo	Valoje	X	X	3				F4	S4	01/01/90	04/11/08
Bacchiglione	Posina	Stancari	X	X	10	F1				S1	01/06/85	08/09/10
Bacchiglione	Astico	Lugo di Vicenza	X	X	7	F1	F2			S3		
Bacchiglione	Tesina	Bolzano Vicentino	X	X	8	F1	F2			S1	1/1/04	31/12/08
Bacchiglione	Bacchiglione	Montegalda	X	X	9	F1	F2			S1	1/1/05	31/12/09
Bacchiglione	Bacchiglione	Ponte S.Nicolò		X	11	F1	F2			S3		
Bacchiglione	Bisatto	Vo	X		3	F1				S3		
Bacchiglione	Cagnola	Bovolenta			5		F2			S3		
Agno-Guà-Fratta-Gorzone	Agno	Recoaro (Stazione Rete CAE)	X	X	4	F1				S2	01/01/07	31/12/09
Agno-Guà-	Agno	Ponte Brogliano	X	X	6	F1				S3		

Basin	River	Location				F1	F2	F3	F4	S	Start	End
Fratta-Gorzone												
Agno-Guà-Fratta-Gorzone	Guà	Lonigo	X	X	7	F1				S3		
Agno-Guà-Fratta-Gorzone	Frassine	Borgofrassine	X	X	8	F1				S3		
Agno-Guà-Fratta-Gorzone	Togna	Cologna Veneta-via S.Michele		X	5	F1	F2			S1		
Agno-Guà-Fratta-Gorzone	Togna	Cologna Veneta-via Predicale			6		F2			S1		
Agno-Guà-Fratta-Gorzone	Fratta	Valli Mocenighe	X		2				F4	S4		
Agno-Guà-Fratta-Gorzone	Gorzone	Stanghella	X	X	11	F1	F2			S1	1/1/04	31/12/09
Adige	Adige	Rivalta-Brentino Belluno		X	3		F2	F3		S3		
Adige	Adige	Verona	X	X	6	F1				S1	1/1/04	31/12/09
Adige	Chiampo	S.Vito Veronese	X	X	8	F1				S1	1/1/07	31/12/08
Adige	Alpone	Arcole		X	5		F2	F3		S3		
Adige	Alpone	S.Bonifacio	X	X	1				F4	S4		
Adige	Adige	Albaredo d'Adige	X		6	F1				S3		
Adige	Adige	Boara Pisani	X	X	9	F1	F2			S1	1/1/04	31/12/10
Po	Delta del Po	Busa di Scirocco			1				F4	S4		
Po	Delta del Po	Busa di Tramontana			1				F4	S4		
Po	Delta del Po	Busa Dritta			1				F4	S4		
Po	Delta del Po	Busa Storiona monte			1				F4	S4		
Po	Delta del Po	Busa Storiona valle			1				F4	S4		
Po	Delta del Po	Po di Gnocca	X	X	2				F4	S4		
Po	Delta del Po	Po di Maistra	X	X	1				F4	S4		
Po	Delta del Po	Po di Pila	X	X	3				F4	S4		
Po	Delta del Po	Po di Tolle	X	X	1				F4	S4		
Po	Delta del Po	Po di Tolle Scardovari			1				F4	S4		
Po	Delta del Po	Bocca di Tolle			1				F4	S4		
Po	Delta del Po	Po di Venezia			2				F4	S4		
Po	Po	Ficarolo	X	X	1	F1				S3		
Po	Po	Pontelagoscuro	X	X	1			F3		S1	---	---

LEGEND					
Aims:			**Rating curves:**		
F1	Hydrological regime characterization and rating curves definition		**S1**	Available for every hydrological regime	
F2	Water quality support		**S2**	Available for dry periods	
F3	Hydrological regime characterization during dry periods		**S3**	under elaboration	
F4	Other		**S4**	Actually not expected	

MIF evaluation methods

The evaluation of minimum instream flow discharge (MIF) is basic along several reaches of the hydrographic network of Veneto Region, where the pressure due to hydropower exploitation is important, above all in the mountain portion of the territory (Figure 18).
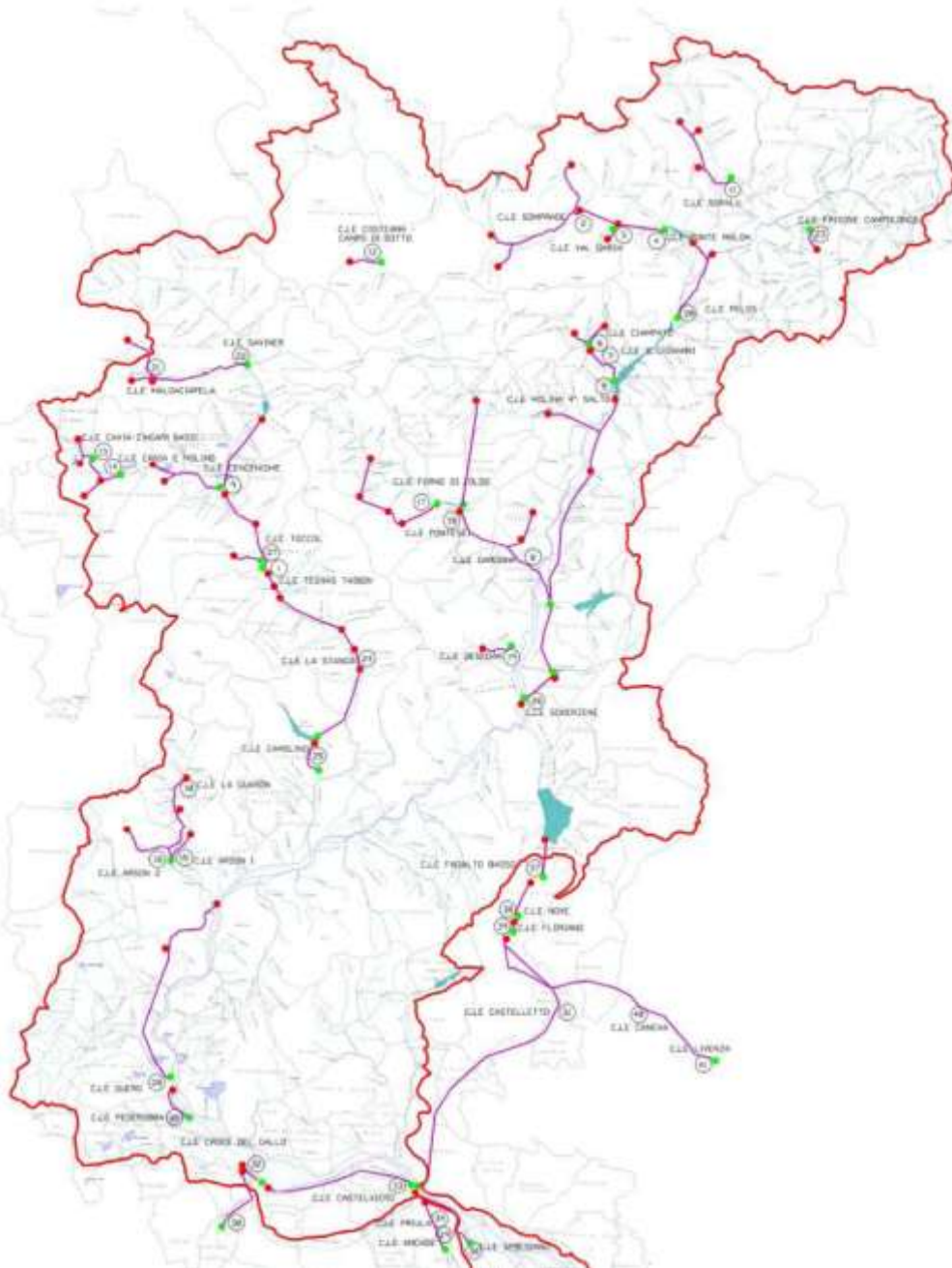

Figure 18: Piave river basin (Veneto Region); lines along the hydrographic network represent the artificial pipelines of the HP exploitation system

The river discharge evaluation alone is not enough; it is also important to evaluate:

- the portion of natural discharge diverted by HP plants;
- the portion of natural discharge released by HP plants, generally correspondent to MIF;
- the volumes of water stored in the artificial reservoirs.

ARPAV-SIR, under the task of the River Basin Authority (RBA) of Veneto Region, carries out MIF measurements downstream water release or diversion works. During the year 2004, for example, ARPAV-SIR made the calibration of MIF release works in correspondence of some hydropower plants (dams) located along the Piave River (Figure 19).

Figure 19: HP exploitation; reaches downstream MIF release points

Examples of MIF measurements are given by the dam located at Alleghe along the Cordevole River (Piave basin) and main Piave River channel at Nervesa. ARPAV-SIR executed direct measurements of the discharge just upstream the Alleghe dam (through ADCP method) and just downstream of the dam (through salt dilution method) (Figure 20 and Figure 21).

Figure 20: MIF measurements at Alleghe dam (Cordevole River)

downstream: ADCP

Figure 21: MIF measurements just downstream Nervesa dam (Piave River)

The MIF evaluation downstream of the Mis dam (Piave basin) is made by ARPAV-SIR applying two methods: ultra-sound instrument for the discharge evaluation passing into the pipeline, and current meter or salt dilution along the downstream reach (Figure 22).

Figure 22: MIF measurements along the pipeline and just downstream Nervesa dam (Mis River)

Discharge indirect estimation

MIF evaluation – algorithms for indirect estimation in Veneto region

The Legislative Decree no. 152/2006 established that the rules for MIF's calculation have to be defined in the regional WPPs (Water Protection Plan), which are approved by the single regions in accordance with the general objectives proposed by the local RBA. This is the reason why in Italy there is no a standard methodology in assessing MIFs. Generally, it consists of a basic hydrological component, proportional to the mean annual discharge, corrected by means of some coefficients that take different environmental aspects into account (morphology of the riverbed, functional uses, quality objectives defined by the Water Protection Regional Plans). In Italy, the methodologies used for MIF evaluation can be subdivided into three major categories:

- Expeditious regional methods that use hydrological data to quantify the basic hydrological component of the MIF; these methods can be subdivided into three different approaches of MIF calculation:

    o the hydrological and morphological approach uses variables and data of the river basin;

    o the hydrological approach uses river annual medium flow data;

    o the statistical approach uses natural flow duration curve of the river;

- Experimental methods that aim to determine the relation between flow and habitat quality; these methods generally concern the predetermination of reference species;

- Hybrid methodologies that include biological data.

Expeditious regional methods are useful to quantify MIF's hydrological component, while experimental methods can provide an estimate of the correction factors. Hybrid methodologies are often used in pilot case studies.

Other more experimental methods use different variables, such as:

- Non-transformed hydraulic variables: these methods are based on the assumption of existing correlations between flow dependent hydraulic variables and aquatic ecosystem improvement;

- Biologically transformed hydraulic variables: these methods use more than one hydraulic and structural variable, such as e.g. PHABSIM microhabitat method;

- Biologically transformed multiple variables: these methods use a multiple regression approach to define optimum habitat characteristics for reference species;

In the Veneto Region, MIF discharge is regulated by the WPP approved in November 2009.

PO River

in 2002 the Po RBA established the qualitative objectives for the Po river basin and quantitatively defined the MIF and the modalities for its implementation. These general criteria were adopted by the regions located in the Po river basin and implemented in the regional WPPs through the quantification of the site-specific parameters. These are the site-specific parameters for the MIF's basic hydrological component, which is applied in the Veneto Region in the territory included in the Po river basin.

Art. 42 of the Veneto Region's Water Protection Plan states that for the Po river basin the MIF is quantified as determined with the law no. 7/2002 issued by the Po RBA:

The general expression for MIF is based on the quantification of a basic hydrological component proportional only to hydrological parameters and of an environmental component which takes into account ecological aspects:

$$MIF = MIF_{HYDRO} \cdot K_1 \cdot K_2 \cdot \ldots \cdot K_n \quad [l/s]$$

where:

> MIF_{HYDRO} = MIF's hydrological component which is generally proportional to the mean annual discharge and to the catchment area;
>
> K_i = environmental correction factors quantified on the basis of ecological considerations or experimental activities on pilot case studies.

The above mentioned general criteria were established in the Bylaw no. 7/2002 issued by the Po RBA, which computed the MIF as follows:

$$MIF = k \cdot MQ_{sp} \cdot S \cdot M \cdot Z \cdot A \cdot T \quad [l/s]$$

where:

> k = experimental parameter function of each hydrographical area (~ 0.08 - 0.12);
>
> MQ_{sp} = the specific average inter-annual flow rate (l/s/km^2);
>
> S = the catchment area (km^2);
>
> M = the morphological parameter (0.7 – 1.3); it expresses the need for adaptation of the MIF's hydrological component to the specific riverbed morphology and local runoff regime; it considers the riverbed slope, morphological types, presence of pools and permeability of the substrate;
>
> Z = the maximum value among the three parameters N, F and Q, where:
>
>> N = the naturalistic parameter (≥1, the higher the natural value of the river is, the higher the value of the parameter); it expresses the need to protect areas characterized by a high degree of naturalness. It can assume values greater than 1 in presence of water bodies located in national parks or regional natural reserve, in areas identified in the Ramsar Convention, Nature 2000 or characterized by significant scientific, natural, environmental and productive interests.
>>
>> F = the fruition parameter (≥1, the higher the fruition of the river for other uses (e.g. tourism, fishery) is, the higher the value of the parameter); The fruition parameter (F) expresses the need to guarantee adequate water quantity in areas characterized by tourism and social uses (also bathing).
>>
>> Q = the water quality parameter (≥1, the higher the pollution of the river is, the higher the value of the parameter); it expresses the need for dilution of pollutants derived from human activities and can assume values greater than 1 if specific quality objectives have to be reached.
>
> A = parameter related to the interaction between surface and underground water (0.5 - 1.5; lower value if water table contributes to reserved flow, higher value otherwise); it considers the groundwater's contribution in the formation of MIF. Analysis to verify the interaction between surface and underground water have to be carried out at least for water bodies characterized by highly permeable substrate.
>
> T = parameter related to the time modulation of reserved flow, due to particular exigencies during the time of the year (fish spawning, tourism, etc.).

For new water concessions, the imposition of the whole MIF (hydrological and environmental components) is contemporary to the concession grant, while the existing water concessions have to respect the hydrological component by 31 of December 2008 and the application of correction factors by 31 of December 2016. In particular, the hydrological component is proportional to the mean annual discharge, so the amount of water required to sustain healthy aquatic ecosystems is strictly connected with flow regime.

The formula obtained by the Po RBA is the most exploited in Italy for its ease of application and cheapness. It considers several important factors, such as the quality and natural value of the stream; its limit is the major simplification made for a complex biological balance such as a watercourse. The formula was derived by comparing theoretical and experimental data collected in ten sub-basins, which were considered sufficiently representative of climatic, hydrological and geomorphologic aspects within the Po river basin. Since the correction factors have not to be applied until 2016, the following parameters are defined for the basic hydrological component:

MQ_{sp} = 30 l/s/km^2;

k = 0.14

The Bylaw no. 7/2002 issued by the Po RBA suggests increasing water releases in the river bed during critical periods for fish populations as e.g. the first phase of the life cycle and reproduction periods. These periods depend on the basin's characteristics, species of reference and climatic parameters (Tab. 2). During reproductive phases, abrupt discharge fluctuations must be avoided in the riverbed, since they could cause dry zones on reproductive areas or changes of the runoff regime, incompatible with the required balance for the reproductive habitat. The diversification of the flow regime may instead be required in order to mitigate stress on biological communities, caused by the constancy of the hydraulic regime.

Table 8: Critical periods for fish

FISH SPECIES	CRITICAL PERIOD
Salmonids in Apline area	November – January
Salmonids in Apennine area	December – February
Cyprinids	May - July

PIAVE River

Art. 42 of the Veneto Region's WPP states that for the Piave river basin the MIF value is estimated with the specific bylaws issued by the RBA responsible for the Isonzo, Tagliamento, Livenza, Piave and Brenta-Bacchiglione rivers. MIF consists of a basic hydrological component (MIF_{HYDR}), proportional to the mean annual discharge, corrected by means of some coefficients (k_{BIOL}, k_{NAT}) that take different environmental aspects into account:

$$MIF = (k_{biol} + k_{nat}) \cdot MIF_{HYDR.} \quad [m^3/s]$$

where

k_{BIOL} = biological index; it increases the MIF's hydrological component proportionally to ecosystem stress and is expressed as a weighted sum of three sub-indices:

k_{BENT} = the benthic index, identifying five categories of ecological quality, taking values between 0.2 and 1. Its quantification is based on the assessment of macro invertebrates' trophic structure;

k_{FISH} = the ichthyological index, considering the different fish species present in the river stretch and assesses their habitat needs, modulating the released water quantity; it is equal to zero if fishes are naturally absent;

k_{MORP} = the morphological index correcting the released water quantity on the basis of the prevalent granulometry. It's equal to zero in presence of concrete river bed.

k_{NAT} = naturalness index; it increases the MIF's hydrological component proportionally to the naturalistic value of the considered area (

Table 9):

Table 9: Values of naturalness index, depending on type of territory

K_{NAT}	TYPE OF TERRITORY
0.5	National/regional/local river parks
0.4	National parks
0.3	Regional park and natural reserve
0.2	Protected landscape regional area of provincial jurisdiction
0.1	Protected landscape regional area of local jurisdiction
0.0	Areas not included in the previous categories

MIF_{HYDR} = MIF's hydrological component, which is calculated as follows:

$$MIF_{HYDR.} = \mu \cdot \rho \cdot \Pi \cdot S \cdot (MQ_{sp}/1000) \quad [m^3/s]$$

where

S = catchment area;

μ = coefficient which modulates the MIF's hydrological component as a function of the catchment area;

ρ = reduction coefficient of Q_{355};

π = perpetuity index, equals to the ratio between Q_{355} and the mean discharge;

MQ_{sp} = specific average inter-annual flow rate (l/s/km^2).

In particular, the coefficients ρ and π are set equal to 0.33 and μ is expressed as a function of the catchment area as follow:

$$\mu = 1.62 \cdot S^{-0.15}$$

MIF is definitely expressed as:

$$MIF = (k_{BIOL} + k_{NAT}) \, 1.62 \cdot S^{-0.15} \cdot 0.33 \cdot 0.33 \cdot S \cdot (MQ_{sp}/1000) \quad [m^3/s]$$

that is:

$$MIF = (k_{BIOL} + k_{NAT}) \, 177 \cdot S^{0.85} \cdot MQ_{sp} \cdot 10^{-6} \quad [m^3/s]$$

The values of the parameters are defined for each homogeneous section of the river and vary, depending on the season. The biological index k_{BIOL} and the naturalness index k_{NAT} respectively increase the MIF's hydrological component, proportionally to ecosystem stress and naturalistic value of the considered area. The sum of these site-specific parameters, which are listed for each homogeneous section of the Piave river, is always greater than one. However, the RBA has conventionally established that, during periods characterized by natural low discharges (between 1st June and 31th August and between 1st December and 28th February), the MIF has to be decreased and limited to the hydrological component. This is achieved by requiring that the sum of the correction parameters is equal to unity. In particular, this restriction has been introduced just to reflect the natural seasonal variability of the river flow.

For the Tagliamento river basin, the MIF is quantified as determined with the specific bylaws, issued by the RBA responsible for the Isonzo, Tagliamento, Livenza, Piave and Brenta-Bacchiglione rivers. It divides the basin into four homogeneous areas (A, B, C, D) and defines the following specific (per unit area) minimum flow rate which has to be released after diversion works:

- Area A = 4 l/s km^2;

- Area B = 5 l/s km^2;

- Area C = 6 l/s km^2;

- Area D = 3 l/s km^2.

These values have been calculated for each homogeneous area by multiplying the specific discharge Q_{355} with a reduction coefficient equal to 0.33. MIF is quantified multiplying the value of the catchment area (calculated upstream diversion works) for the corresponding specific minimum flow rate. Finally, with reference to the rivers for which the MIF was not determined (e.g. Brenta river), the reference values to ensure downstream diversion works are:

4 l/s/km^2 for a catchment area < than 100 km^2;

3 l/s/km^2 for a catchment area > than 100 km^2;

These values are not calculated but are reasonable for the purpose.

Different alpine regions (also outside the Veneto Region) are carrying out "experimental" methods (such as increasing releases, fix or time modulated) to define adequate MIF. Following, some examples for methods are given:

- *PHABSIM:* the method is based on the knowledge of the combination of the parameters water depth, flow velocity, temperature and sediment preferred by the most part of the fish species. Under these presuppositions, once known the range of preference and defined the desired spectrum of fish species, the necessary reserved flow can be calculated.

- *Habitat Quality Index (IQH):* model based on multiple regressions. It links the so called bearing capacity for Salmonids of a river stretch with a set of ecological parameters and requires collection of a great number of different environmental data necessary to calculate the biomass of Salmonids which can live in the river stretch.

- *Pool Quality Index*: model derived from the IQH method, based on the maximisation of the hydraulic diversity: the higher the number of pools in a torrent, the lower the reserved flow is. Depending on the percentage of pools in the active channel bed, the method supplies the following values for MIF (Table 10).

Table 10: Percentage of MQ depending on percentage channel bed pools

% POOLS							
0	10	20	30	40	50	60	70
MIF (% MQ)							
8.7	8.2	7.9	7.6	7.4	7.2	7.0	6.9
MIF (% Q$_{355}$)							
70							50
MIF (l/s/km^2)							
4.3							3.6

A best practice example in the Veneto hydrographic network is presented as follows.

Cordevole River

Between 1996 and 1998 the RBA responsible for the Isonzo, Tagliamento, Livenza, Piave and Brenta-Bacchiglione rivers planned experimental activities, financed by the National Body for Electric Energy (ENEL) and aimed at quantifying MIF in the Cordevole river basin (catchment area of approximately 868km^2). The Cordevole river basin is characterized by the presence of four barrages along the main stretch and numerous water withdrawals. In order to assess the effects on river ecosystem induced by fixed water release (600l/s) from the Ghirlo dam and S.Cipriano's barrage, a river stretch, included between the Alleghe reservoir and La Stanga's barrage, was identified for the following monitoring activities:

- Morphological investigations:
    - River width;
    - Water depth;
    - Substrate;
    - Bottom and surface vegetation cover;
    - Habitat types (pool, run or riffle);
    - Number of discontinuities;
    - Chemical and biological analysis;
    - Quantitative fish sampling using electric fishing method;
    - Quantitative macro-benthonic sampling;
- *Periphyton* cover assessment:
    - Quantification of the "Extended Biotic Index" at 12 monitoring stations;
    - Chemical measurements collected at 6 monitoring stations;
- Hydraulic measures:
    - To assess surface runoff's alterations due to infiltration's phenomena;
    - To quantify the flow regime of the Cordevole river;
    - To calibrate hydraulic models for fishing habitat simulations (micro-habitat method);

The application of the micro-habitat method (PHABSIM) was also planned in order to quantify the optimal water release from the Ghirlo dam and S.Cipriano's barrage. The PHABSIM method is based on the assumption that stream fish prefer a certain range of depths, velocities, substrates and cover types, depending on the species and life stage, and that the availability of these preferred habitat conditions varies with streamflow. With input from streamflow, substrate, and cover type measurements, PHABSIM will quantify habitat availability over a range of flows.

The most commonly used output from PHABSIM is WUA. This habitat measure is a combination of physical microhabitat quantity and quality. WUA is expressed in units of microhabitat area per unitized distance along a stream. This method, applied to the Cordevole river, demonstrated that a fixed water release of 600l/s could be sufficient at the maintenance of a good quality condition for salmonid's habitat.

For different simulated flow rate, WUA index was assessed with micro-habitat method in five different river stretches and expressed as a percentage of the total wet surface per 1000m of river length. These functions showed a low influence of water discharge on habitat quality for different brown trout's vital stages (fry, juvenile, adult) and it was confirmed in all stations by the flatness of the curves. Instead, "egg stage" presents a greater sensitivity to discharge variations, showing WUA values generally higher than the other life stages. Analysis on the Orth's optimization curves, representing minimum relative WUA envelope trend for different vital stages, together with the information about minimum flows in absence of artificial water releases, enhanced that in every season a 350l/s water release satisfies the minimum flow condition suggested by Orth and always leads to WUA values larger than 40% of optimal WUA or simulation's maximum. Although the calculated values are lower than the selected EF which was conservatively fixed at 600l/s, this study showed that water releases of at least 350 to 400l/s are sufficient at the maintenance of a good quality condition for brown trout's habitat during its life stages.

Before water releases, the Cordevole river was characterized by widespread and abundant fish and benthonic populations. Water quality was generally good, but significantly worsened downstream the main barrages. Since water releases downstream from the Ghirlo dam and S.Cipriano barrage, the river maintained its continuity even in situations of natural water scarcity. Quantitative macro-benthonic sampling didn't show significant density's variation related to water release. As regards salmonid biomass, the value of 10.3 to 26.6g/m^2, recorded prior to releases in March 1996, remained constant during the subsequent sampling. This demonstrated that the fish population has improved proportionally with the increase of the wetted area.

In accordance with Art. 42 of the Veneto Region's WPP, MIF within Piave river basin is currently quantified as determined with the specific bylaws issued by the RBA responsible for the Isonzo, Tagliamento, Livenza, Piave and Brenta-Bacchiglione rivers. The above mentioned experimental activities were useful to quantify the site-specific parameters for each homogeneous section of the rivers. In particular, the following values are in force:

Cordevole river (from the confluence with Sarzana river to La Stanga barrage):

$q_m = 35l/s.km^2$; $k_{BIOL} = 1.6$; $k_{NAT} = 0.4$;

At the moment, the activity relating to the river basins' characterization has been completed but the monitoring activities in order to define the water bodies' current ecological status have not been completed.

Expected improvements occurred during the experimental monitoring phase. However the above mentioned case studies were considered only experimental activities useful for evaluating the interaction between the amount of water released and ecological aspects. EF assessment at basin scale was subsequently established in the RWPP.

In the above mentioned case study the following ecological assets have been identified:

- *River morphology*: morphological investigations showed a significant increase of the wetted area, river width (+3m - Cordevole river case study) and water depth (+0,12m - Cordevole river case study);
- Biological quality:
  - Fish population: fish community structure displayed a positive variation proportionally with the increase of the wetted area;
  - Macroinvertebrates: quantitative macroinvertebrates sampling didn't show significant density variations related to water release;
  - *Periphyton*: a cover assessment after water release showed values near 100% at all monitoring stations.
- *Chemical water quality*: there wasn't a clear improvement of water quality before and after water releases.

Although there were no other conditions threatening the achievement of the good ecological status in the above mentioned practice examples, the following problems are common:

- Dams can create variations in the physic-chemical characteristics of the water released downstream which, in turn, affect the abundance and species composition of the benthic invertebrate fauna. The upstream reservoir slows the water flow and water and sediment are accumulated for long periods of time. As a consequence, the physic-chemical characteristic of the water can be altered, with changes in water temperature, reduction in dissolved oxygen, changes in salinity, and increase in nutrient concentrations.
- The presence of dams can enhance accumulation and transformation of specific pollutants (heavy metal, pesticides, etc) which, in certain conditions, can be released in critical concentrations in the downstream reaches.
- The release of a constant discharge (or with very little variations compared to the natural regime) can affect the biological communities through the limited renewal of populations and habitats, and the excessive growth of few species. So, there are important differences between the methods based on hydrological parameters without any ecological significance and often characterized by a constant minimum flow, and those based on the quantitative evaluation of the effects on the biota.
- The impact of hydropeaking on the aquatic biota, which is unable to adapt to such quick and repeated variations, is usually dramatic;
- Released water usually has a different temperature than the receiving water body and in certain phases of the fish life cycles or in certain seasons, even a change of few tenths of degree Celsius can affect the choice of the direction to follow.

- Dams can create a sediment deficit and a possible alteration of geomorphologic dynamics and morphological conditions at a wider scale.

Although no other measures for the improvement of the ecological status were performed in the above mentioned examples, the following measures are often combined with EF assessment:

- Construction of appropriate fish passes in mountain rivers, allowing the longitudinal movements of fish fauna from upstream and downstream and vice versa;

- Prohibition of fishing during specific period;

- Seasonal fish repopulation.

Discharge evaluation – algorithms for indirect estimation

Several methods for an indirect estimation of discharge (peak flow data, hydrographs, etc.) have been developed in literature during time. Such methods can provide a good discharge estimation for those hydrographic network reaches where water level monitoring systems are absent.

One diffused method is the SCS Runoff Curve Number Method, developed by the United States Department of Agriculture (USDA) Soil Conservation Service (SCS); it is a method of estimating rainfall excess from rainfall. The method is described in detail in National Engineering Handbook (2004). The method is used widely and is accepted in numerous hydrologic studies. The SCS method originally was developed for agricultural watersheds in the mid-western United States; however it has been used throughout the world far beyond its original developers would have imagined.

The basis of the curve number method is the empirical relationship between the retention (rainfall not converted into runoff) and runoff properties of the watershed and the rainfall. Mockus found an equation appropriate to describe the curves of the field measured runoff and rainfall values (National Engineering Handbook, 2004):

$$\frac{F}{S} = \frac{Q}{P}$$

Where: $F = P - Q$ = actual retention after runoff begins;
Q = actual runoff
S = potential maximum retention after runoff begins ($S \, ^3 \, F$)
P = potential maximum runoff (i.e., total rainfall if no initial abstraction).

For most applications, a certain amount of rainfall is abstracted. The three important abstractions for any single storm event are rainfall interception (Meteorological rainfall minus through fall, stem flow and water drip), depression storage (topographic undulations), and infiltration into the soil. The curve number method lumps all three abstractions into one term, the Initial abstraction (I_a), and subtracts this calculated value from the rainfall total volume (Fig. 18). The total rainfall must exceed this initial abstraction before any runoff is generated. This gives the potential maximum runoff (rainfall available for runoff) as $P - I_a$:

$$\frac{P - Ia - Q}{S} = \frac{Q}{P - Ia}$$
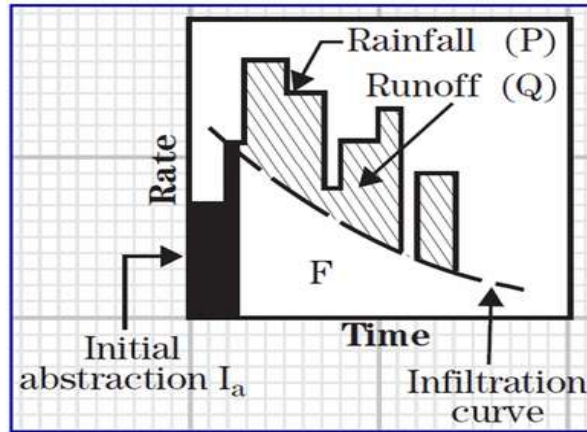
Figure 23: Components of SCS runoff equation

It is important to note the potential maximum retention term, "S", excludes I_a. Hence, for a given storm, maximum loss of rainfall is S plus Ia. Rearranging terms of previous equation for Q gives:

$$Q = \frac{(P-Ia)^2}{(P-Ia)+S}$$

The SCS provided the following empirical equation, based on the assumption that I_a is a function of the potential maximum retention S:

$I_a = 0.2\ S$

The potential maximum retention S is related to the dimensionless parameter CN in the range of $0 <= CN <= 100$ by:

$$S = \left(\frac{1000}{CN}\right) - 10)$$

CN has a range from 30 to 100; lower numbers indicate low runoff potential while larger numbers are for increasing runoff potential. The lower the curve number, the more permeable the soil is. Rearranging the previous equations, we obtain:

$$Q = \frac{(P-0.2S)^2}{(P+0.8S)}$$

S can be determined by curve number tables published by the SCS. The solution of the SCS runoff equation is shown below (Figure 24).
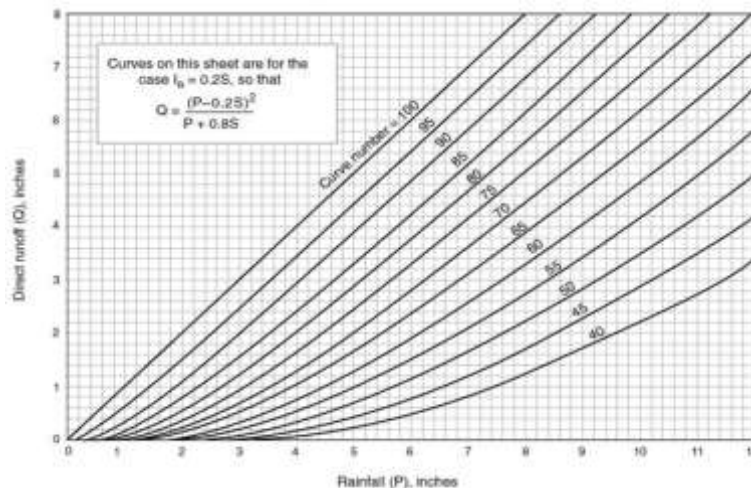
Figure 24: CN variation table (Source: TR-55, 1986)

Runoff is affected by the soil moisture before a precipitation event, or the antecedent moisture condition (AMC). A curve number, as calculated above, may also be termed AMC II or CN(II), or average soil moisture. The other moisture conditions are dry, AMC I or CN(I), and moist, AMC III or CN(III). The curve number can be adjusted by factors to CN(II), where CN(I) factors are less than 1 (reduce CN and potential runoff), while CN(III) factor are greater than 1 (increase CN and potential runoff). The AMC factors can be looked up in a reference table (United States Department of Agriculture, 1986).

The method is often used for discharge estimation in mountain rivers, starting from rainfall values observed and from basin characteristics (elevation and slope maps, flow accumulation, time of superficial flow propagation - Tc - and CN maps, Figure 25). One example of SCS application is that of the Missiaga basin, a tributary of the Cordevole River basin.
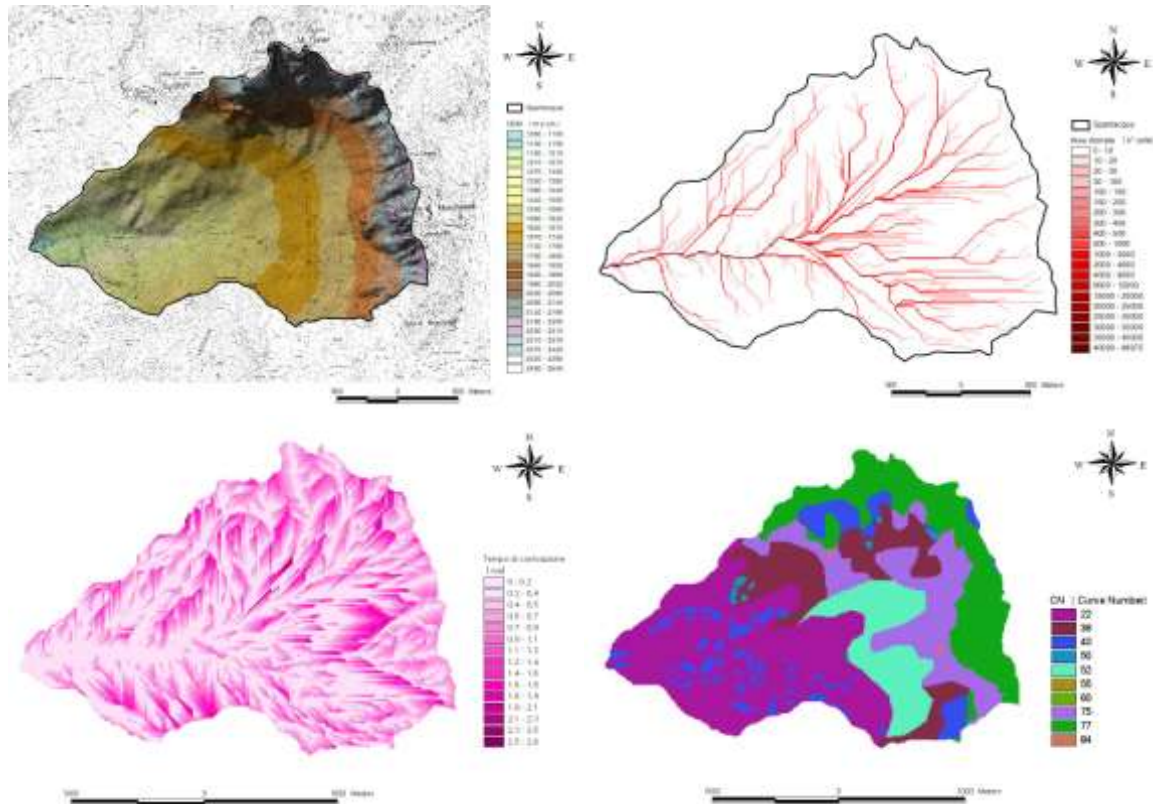
Figure 25: Missiaga basin (Cordevole River basin); digital elevation model, flow accumulation map, superficial flow distribution time (Tc) and CN raster maps

The results of SCS application is the discharge peak hydrograph, correspondent to a rainy event registered by a pluviograph located inside the basin (Figure 26).
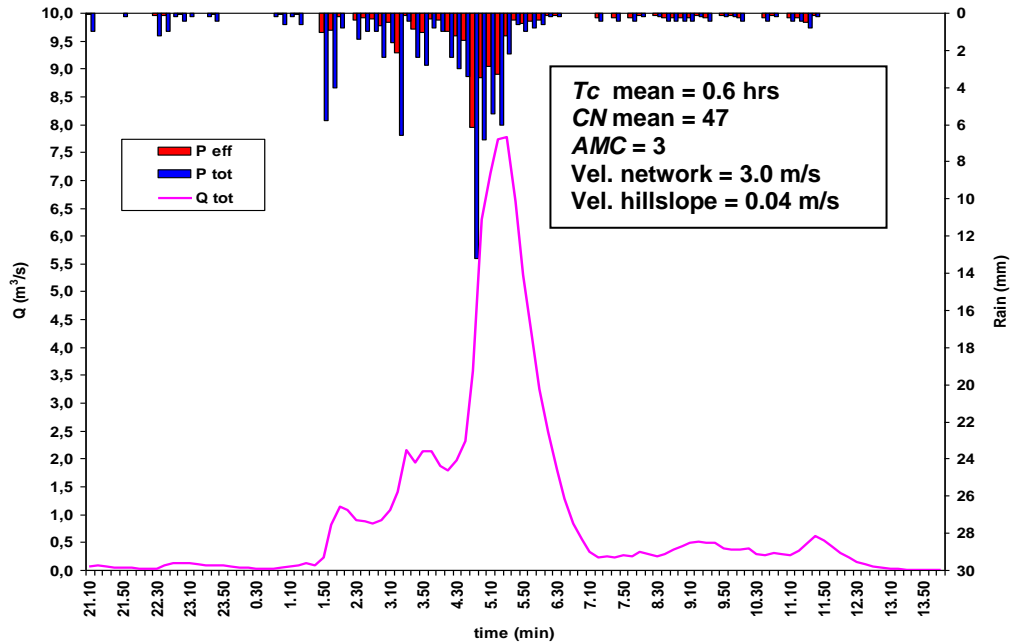
Figure 26: Missiaga basin; discharge hydrograph and rain distribution applying the SCS method; P eff. Is the portion of total rain (P tot) that produce superficial runoff

Discharge assessment for hydropower plant planning

Hydropower plant design is composed by different phases and calculations; an important and basic evaluation is the assessment of the available discharges in different periods of the year at the potential capitation point of the hydropower plant.

In the Veneto Region, this evaluation is normally based on the results obtained in a scientific investigation carried out by Tonini (1970) and referred to hydrological data measured within Brenta, Piave, Tagliamento, Livenza and Agno-Guà river basins by the Magistrato alle Acque (Managing Water Authority) of Venice, ex SADE and ENEL.

Tonini (1970) has built, starting from rainfall data collected by the Hydrolological Service of the Ministry of Public Works, the map representing the mean annual rainfall for each basin considered in the investigation; in Figure 27 a rainfall map related to the Piave river basin is shown. On the basis of the mean annual rainfall map, Tonini (1970) has divided the main basins in several sub-basins and for each one the mean specific discharge was assessed; figure 28 shows the subdivision for the Piave river basin. For each sub-basin Tonini (1970) has calculated some additional parameters: mean altitude, close section's altitude and area.

In order to calculate the mean average annual discharge, it is enough to multiply the mean specific discharge by the basin area closed at the potential capitation point. The trend of mean daily discharges during the year is computable by multiplying the discharge by appropriate tabulated coefficients reported in Tonini (1970). The planner has to choose the coefficient related to a measuring station closest to the potential location of the hydropower plant.
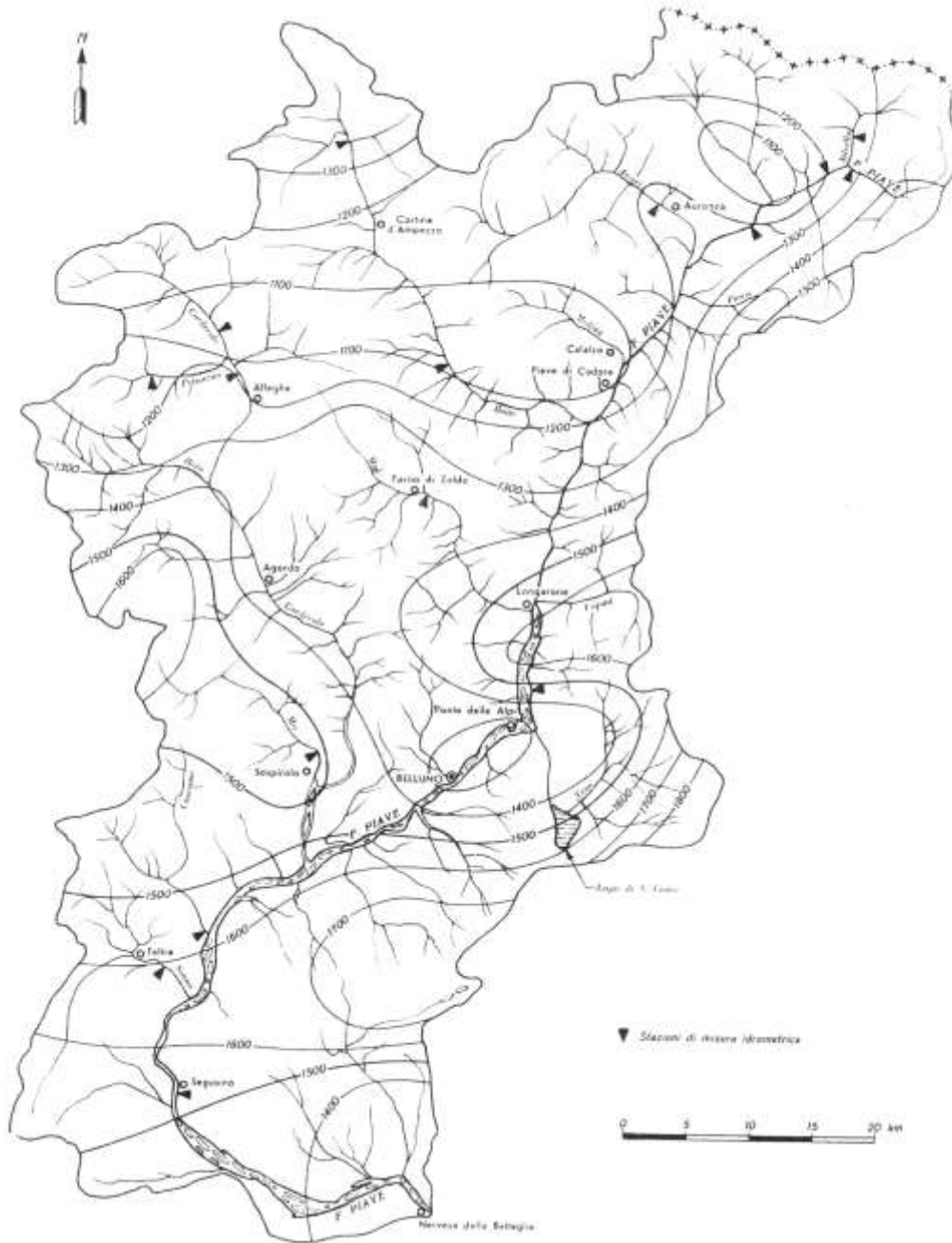
Figure 27: Mean annual rainfall map for the Piave river basin (Tonini, 1970).
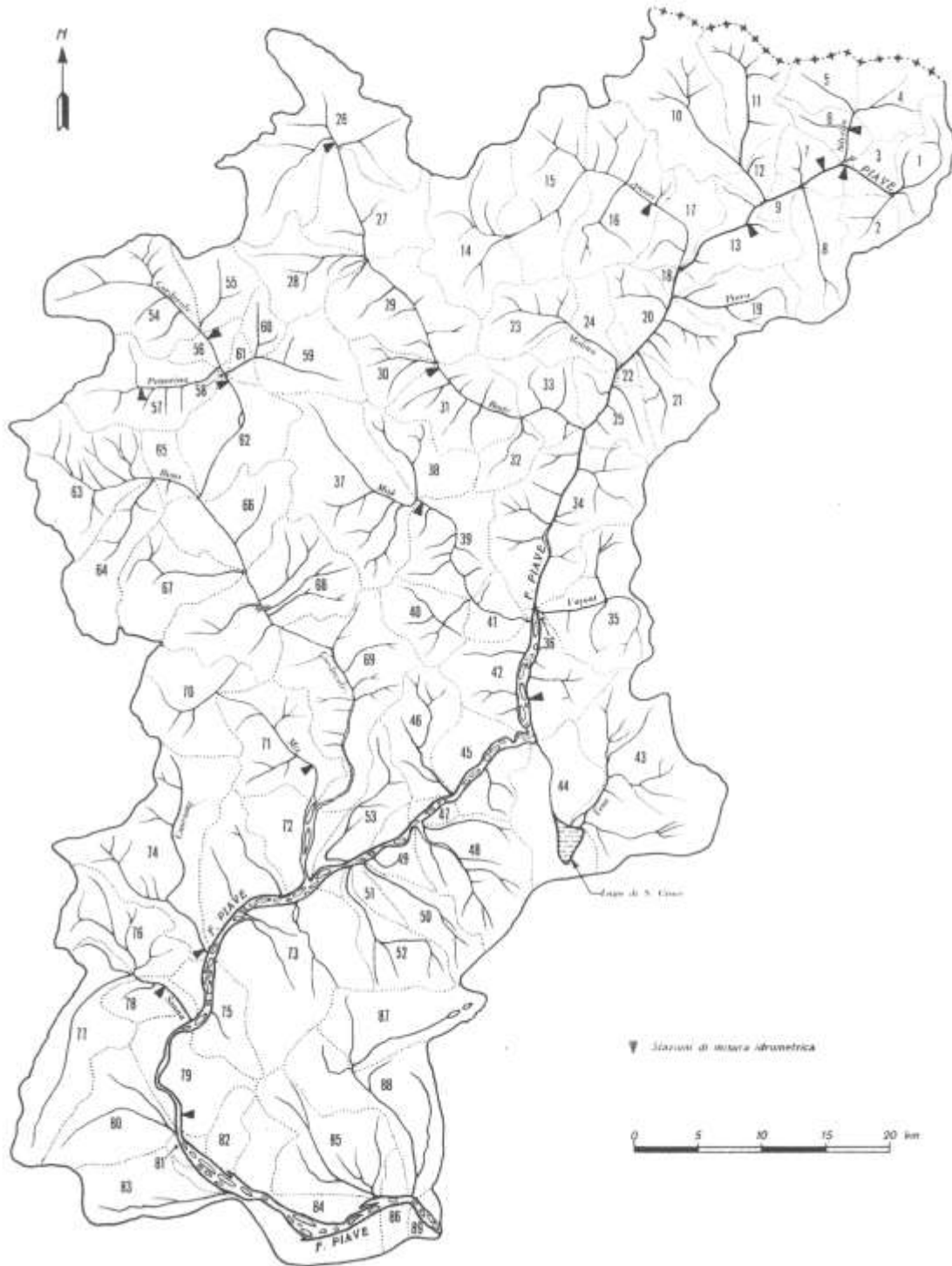
Figure 28: Piave River basin divided into sub-basins (Tonini, 1970)

Below a short calculation example is presented related to the Rio Cordon small hydropower plant design (ARPAV case study). The area of Rio Cordon basin is inside the sub-basin that Tonini (1970) has classified with number 59 (Figure 28); for this sub-basin the mean specific discharge is equal to:
$q = 30$ l/s km^2

The mean annual discharge at the capitation point is calculated doing the multiplication between the mean specific discharge and the Rio Cordon basin surface ($S = 6.9$ km^2):
$Q_{MEAN} = 30$ l/s km^2 * 6.9 km^2 = 220.8 l/s = 0.221 m^3/s

The trend of mean daily discharges during the year is computable by multiplying the discharge by appropriate tabulated coefficients reported in Tonini (1970). For the reach of the Cordon stream in which is located the small hydropower plant capitation, the closest significant and representative station is Caprile (Cordevole river). Therefore, the duration curve was calculated by using the mean annual discharge Q_{MEAN} and the coefficients related to the Caprile reference station. In Table 11 all values related to the duration curve are summarized, in which the Minimum Instream Flow Q_{MIF} = 0.035 m^3/s and the maximum discharge that can be diverted is 0.195 m^3/s.

Table 11: Rio Cordon duration curve data at the captation point of the small hydropower plant; for each duration are reported: coefficient related to the Caprile reference station (Tonini, 1970), natural discharge assessed (Q), maximum discharge available for hydropower production (Q-QMIF), discharge diverted (QDIV) and Q released (QREL)

DURATION [DAY]	COEFFICIENT [-]	Q [M^3/S]	Q-Q$_{MIF}$ [M^3/S]	Q$_{DIV}$ [M^3/S]	Q$_{REL}$ [M^3/S]
10	3.00	0.662	0.627	0.195	0.467
30	2.10	0.464	0.429	0.195	0.269
60	1.60	0.353	0.318	0.195	0.158
91	1.28	0.283	0.248	0.195	0.088
121	1.04	0.230	0.195	0.189	0.041
152	0.88	0.194	0.159	0.153	0.041
182	0.74	0.163	0.128	0.122	0.041
212	0.61	0.135	0.100	0.094	0.041
243	0.50	0.110	0.075	0.069	0.041
274	0.42	0.093	0.058	0.052	0.041
304	0.36	0.079	0.044	0.039	0.041
334	0.30	0.066	0.031	0.025	0.041
355	0.22	0.049	0.014	0.008	0.041
365	0.16	0.035	0.000	0.000	0.035

The values in Table 11 are also shown in Figure 29 (duration curve), Figure 30 (curve of the derivable discharge) and Figure 31.
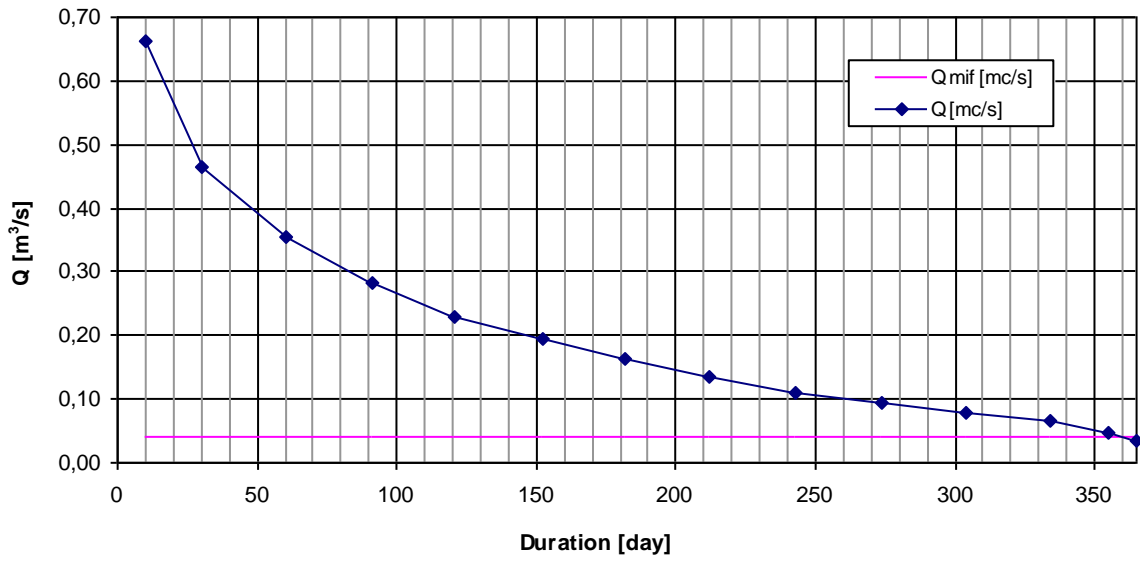
Figure 29: Rio Cordon duration curve and QMIF at the captation point
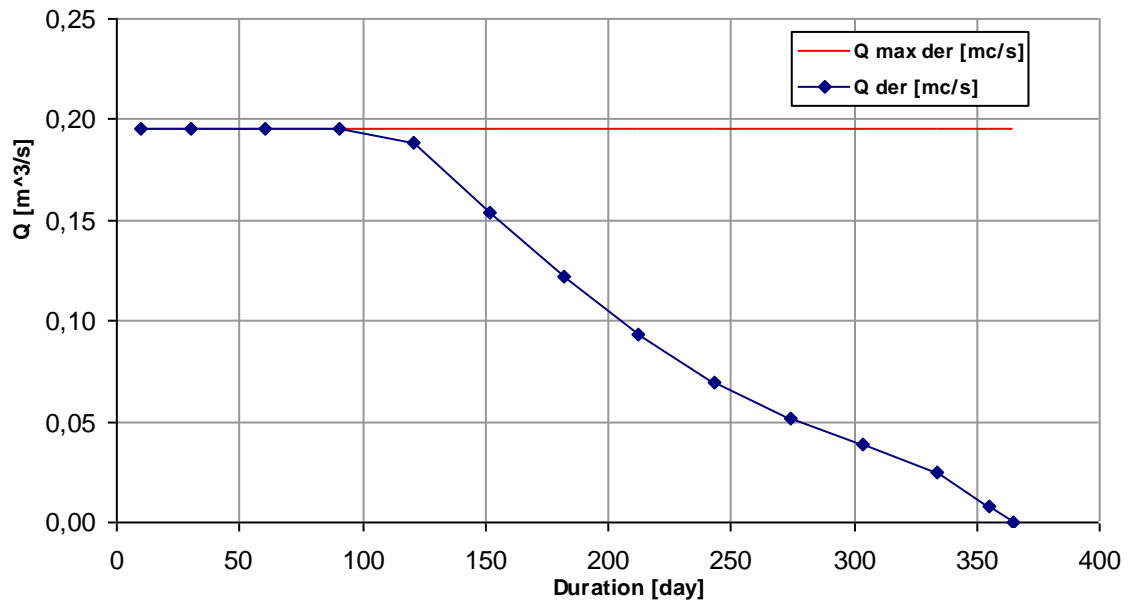
Figure 30: Rio Cordon at the captation point; duration curve of derivable discharges maximum derivable discharge
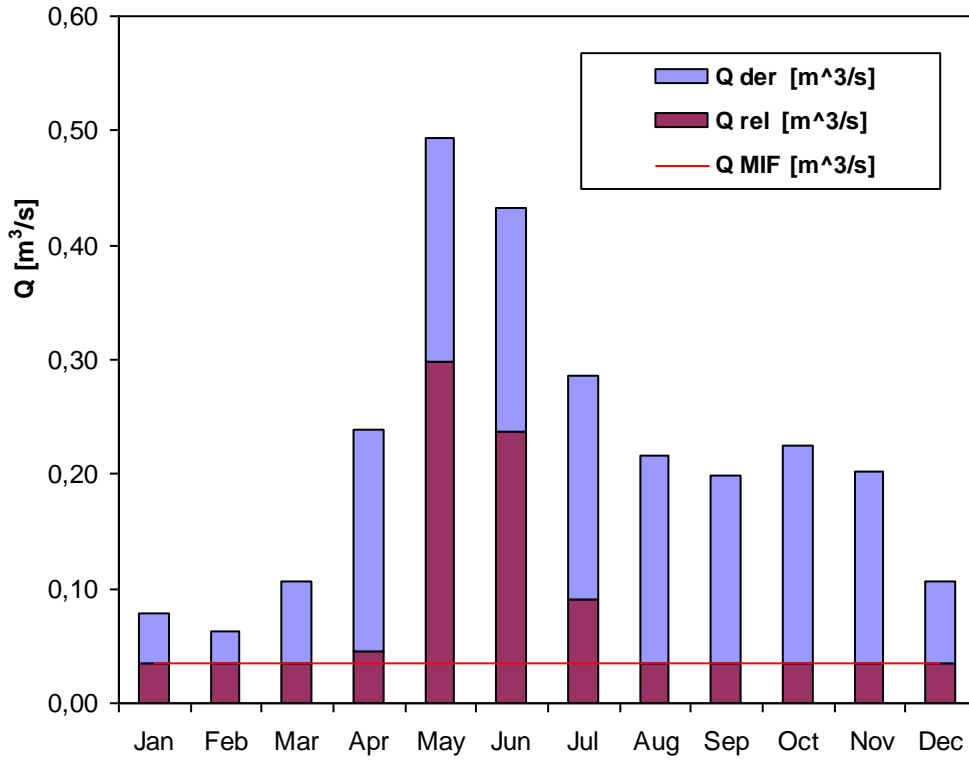
Figure 31: Rio Cordon at the captation point: for each month are reported the derivable discharge, the Q released and the Minimum Instream Flow (MIF)

Slovenia

Description of models and methods

The rainfall-runoff process is difficult to simulate precisely. Models usually use the concept of the effective rainfall where rainfall hyetograph is divided into losses and effective part (Sraj et al., 2010). The effective rainfall is then used as the model input to provide runoff hydrograph. Most often used models in Slovenia are HEC-HMS, HBV and MIKE-SHE.

The HEC-HMS model (HEC-HMS, 2011; US ACE, 1994) is a widely used model and it belongs to the semi-distributed hydrological models. It was applied in many studies in different environments all over the world. It was developed by the U.S. Army Corps of Engineers and is a Windows version of HEC-1. It is designed to simulate both single events and the continuous development over long periods of time. The main advantage of semi-distributed models is that their structure is more physically-based than the structure of lumped models, and that they are less demanding on input data than fully distributed models. Simple mathematical relationships are intended to represent model component functions such as meteorological, hydrologic and hydraulic processes. These processes are divided into precipitation, interception/infiltration, transformation of precipitation excess to sub-basin outflow, addition of base flow and flood hydrograph routing. The HEC-HMS model has a number of options for these processes.

The HBV model is a distributed conceptual model for continuous calculation of runoff used to simulate hydrological forecasting. It was originally developed in the 1970's at SMHI, the Swedish Meteorological and Hydrological Institute (IHMS, 1999). The idea was to create a model of optimum complexity in connection of operational demands and available data. Today, it is being used in more than 40 countries around the world for the calculation of river flows, flood forecasting, hydropower planning, irrigation, dam safety and, finally, studies of the effect of changing climate conditions. The wide usage of the HBV model around the world testifies to its practicability under different climate conditions. Next to geographical data, the observations of precipitation, air temperature, potential evapotranspiration and flow are needed. The HBV-96 model consists of routines for calculation of snow accumulation and melt, a soil moisture procedure and the transformation function for hydrograph calculation (Lindström et al., 1997). The model enables calibration as well as forecasting for each sub basin separately. In the HBV model the time step is usually one day, however, it is possible to use shorter time steps (Bergström, 1995; IHMS, 1999), which must not be shorter than one hour. The HBV-96 model is based on the equation:

$$P - E - Q = \frac{d}{dt}\left[SP + SM + UZ + LZ + lakes \right]$$,

Where P is precipitation, E evapotranspiration, Q runoff, SP snow pack, SM soil moisture, UZ upper groundwater zone, LZ groundwater zone and "lakes" is the lake volume. The runoff is generated by the response function, which transforms excess water from soil into runoff. The influence of direct precipitation and evaporation on a part which represents lakes, rivers and other wet areas is also considered. The response function consists of the upper non-linear reservoir, and one lower, i.e. linear reservoir. These reservoirs represent the quick and the slow runoff components of the hydrograph – direct and base-flow. The routing between the sub-basins is described using the Muskingum method or, simply, time lags. Each particular sub basin has its own response function.

Data and computational requirements

The Slovenian Environment Agency (ARSO) takes care of the national meteorological and hydrological data archive. About 170 traditional rainfall stations with 24 hours observation and 37 recording rain gauges with continuous registration are currently in operation in Slovenia (Figure 32).
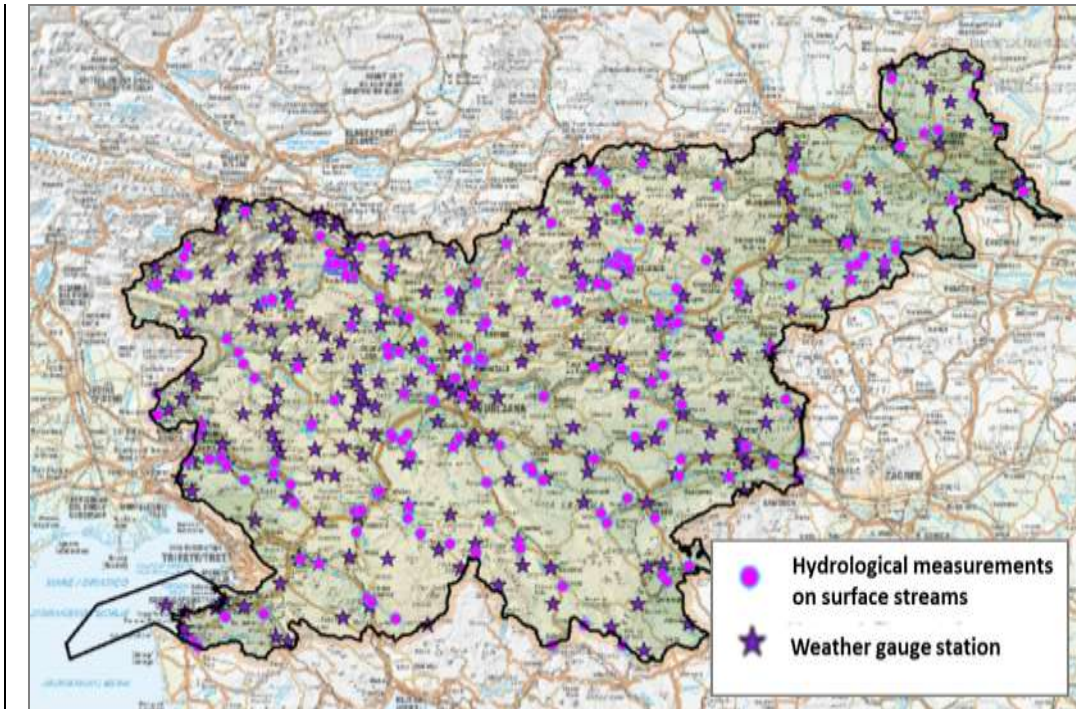
Figure 32: Network weather gauge and hydrological measurements stations in Slovenia

More historical data exist in the archives for the stations, which have been operated during other periods. The climatological data are available from 38 locations. In addition, there is a network of 63 automatic stations, where some meteorological parameters can be derived in real time, including precipitation. The coverage with recording rain gauges and automatic stations is not dense enough, especially in mountainous areas where the spatial variability of the precipitation amounts is usually the highest. The data from the automatic stations are transmitted every half hour to the agency's headquarters, where the automatic procedure is used for rough quality control and inclusion to the database. Data are also accessible on the agency web site (http://meteo.arso.gov.si/met/sl/service/).

Besides the rain gauges Doppler weather radar is used as another source of information for precipitation. The radar is situated in the central part of the country on the Mount Lisca. The advantage of using radar for precipitation measurement is the coverage of a large area with high spatial and temporal resolution. A rain gauge network can miss significant rainfall, especially rainfall associated with intensive convective storms. The radar measurements are available every 10 minutes. The precipitation accumulations are available in different time intervals (from 1 hour to 24 hours accumulations). The space resolution is 1 km by 1 km. The radar coverage is 400 km in diameter, but the applied radius for precipitation measurements is up to 100 km.

The active hydrological network for Slovenian rivers consists of 185 hydrological stations. 147 are the recording stations and thereof 54 stations are automatic stations with real time data transfer. There is more historical data available in the archives of the stations, being operated in different periods of the previous century. The daily data of water levels and discharges and hourly data of recording gauges are available in the database of Slovenian Environment Agency. Continuous data sets of water levels and discharges are generally available for the period since 1955; however, few stations have longer sets of data. The data from automatic stations is transmitted to the data centre every 30 minutes with a 15-minutes delay. The automatic stations cover real time monitoring of the most important rivers.

Data requirements for the rainfall-runoff models usually do not satisfy the needs of the models, especially on the small watersheds. Regarding the development of needs and demands for flood risk management and prevention, both the hydrological and meteorological networks are in the phase of optimization and modernization in Slovenia (Kobold, 2010).

Hydrological models for runoff calculation

In the literature there are many models to simulate runoff, ranging from simple empirical methods based only on the relationship between precipitation and runoff, to complex models that illustrate the physical processes of water cycle (Singh, 1995). These complex models require a large input of data, which usually appear as a large number of parameters to be determined in the calibration procedure. Practice has shown that selection of the critical shortage of data required for calibration and later for operational use is most important in making predictions and not the selection of model itself (Kobold, 2007). This is reflected especially in torrent flood modelling, where the temporal resolution of the model is one hour or less and the lack of data is a major obstacle in the modelling and design for later use.

In Slovenia, there is no special model that would be versatile and widely used. Models are mostly based on the objective of modelling, data availability, a measure of the occurrence and knowledge of the system and mathematical tools. Development of hydrological models has been and is still subjected to the needs and requirements of water management. Many models have been developed for specific basins and it is usually difficult to use them on some other environment too. A model that is used to simulate runoff in a particular basin needs to be pre-calibrated and verified. The number of input and output variables and the number of parameters to be calibrated depend on the type of model. Basically, there are:

- Empirical models based on experiments and observations. These models usually include regression relationships between precipitation and runoff, taking into account certain variables such as pre-wetted soil.

- Conceptual models that deal with a simplified physical processes and include elements of the hydrological cycle, for which is assumed to be relevant for the expected usage of models. For reasons of simplification it is necessary to introduce empirical coefficients which need to be set in the process of model calibration.

- Physically based models, which describe the whole physical process in the basin mathematically by partial differential equations.

- Models of black boxes in which the relationship between input and output variables is purely mathematical, without physical bases. This includes methods of machine learning and neural networks. This type of models is gaining ground in hydrology.

Various projects made several comparisons of different models, which allow simulation of runoff (Kobold, 2007). Results of these analyses indicate that the simpler models also simulated basin runoff satisfactorily as more rigorous models did. Most models for the calculation of the runoff have installed a large number of parameters in order to simplify the description of natural processes, allowing them flexibility in the calibration and it is always possible to find a satisfactory agreement between the simulated and measured runoff.

However, there are differences in the utility of models. More complex models usually allow the calculations and display of the other hydrological variables in the basin (areal precipitation, evapotranspiration, soil water reserves, etc.). Technological development and the development of meteorological models encourage the development of these types of models, as we can provide a comprehensive overview of events in the basin on the basis of all available variables.

Review of the implementation of the hydrological models in the work of ears

Because of the need for flood forecasting and providing timely warnings, the Slovenian national hydrological service has constantly strive to develop and modernize the measuring points and the development of hydrological modelling in the world has been monitored. The World Meteorological Organization has established a multi-purpose hydrological system HOMS (Hydrological Operational Multipurpose System) in the late 1970s and in early 1980s, where the information on the available hydrological instruments, measurement methods, data processing techniques and models was gathered.

The system was designed to transfer technological developments to operational hydrological services and is updated and in use today. The transfer of models was not easy in those years, since the first computer systems were cumbersome and the input of data files had to be manually prepared. Frequent changes of computers and operating systems have required an on-going adaptation of programs and input files as well as knowledge of computer languages. This is the reason why development and use of first hydrological models in the Slovenian national hydrological service did not flourish. The first models were designed for simulation of mean daily flow, since the availability of data was not sufficient for modelling smaller time scales.

The problem in predicting water quantities in Slovenia is the torrential character of the streams. Amounts of water can grow quickly and also quickly drain, since Slovenia is characterized by high rainfall variability. Diverse types of ground, dynamic orographic effects in intense frontal precipitation and diversity of geological structures cause extremely diverse hydrological phenomena that cannot be covered, no matter how dense the measuring grid is. It is much harder to predict torrent floods than flooding of major river systems. Quantity of water, with the exception of Karst Rivers and Mura and Drava rivers, increases and regresses rapidly (Figure 33). The major precipitation amount, causing the flood wave during a rainfall event, happens within a few hours. The peak of the wave is very short; it usually lasts only a few minutes. Therefore it is important to understand the mechanisms that lead to flooding and to know the different types of precipitation, which can cause flood events.
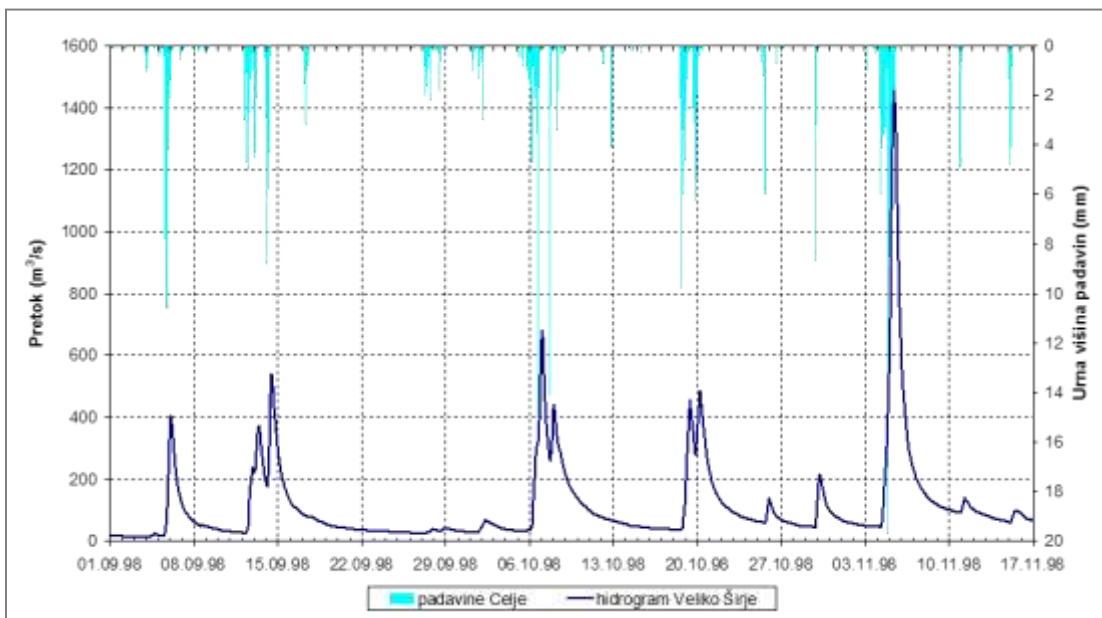
Figure 33: Torrential character of the Savinja River

The most important variables in forecasting floods are:
- Discharge of flood peak and water level,

- Term of peak occurrence and

- Flood volume.

The forecast must be accurate and on time in order to prevent losing human lives, injuries and property damage. The accuracy of forecast equals the accuracy of prediction of the size of the flood wave or water level and timing of peak wave. The more accurate the forecast, the more you can prepare for flooding and mitigate its consequences. Reliability of the prediction is also important. The system must reliably predict the occurrence of the flood and cannot predict it if it does not come up. The accuracy and reliability of the predictions influence the decision making process in emergency situations. The longer the early warning period, the more possibilities are to control or mitigate flood damage. If prediction of flooding is accurate it is given enough time to evacuate residents of the affected area.

In the Netherlands, in 1993 the river Maas flooded. A warning came three days in advance and they managed to evacuate about 100,000 people from deprived areas (Bruen, 1999). Such a long warning period is probably not possible for small basins. People can usually just move their valuables to higher floors and possibly protect themselves by dikes or dams in those situations. There is a conflict between wish for longer warning time and for greater accuracy and reliability of forecasts. Generally spoken: if the warning time for flood is longer, prediction of the flood is less accurate and reliable (its time and location).

The introduction of empirical models

The first models operatively used in the hydrological services were classical regression models (Lalić, 1994; Polajnar and Weiner, 1998). These were used for the purpose of issuing forecasts and warnings. The development of these models goes back to the last decade of the last century. Models are based on the relationship between precipitation (usually 24-hour precipitation) and maximum runoff (peak) wave, which takes into account the previous wetness of the ground and the initial flow rate (Figure 34). Most of the major rivers in Slovenia (Savinja Ljubljanica, Krka, Kupa, and Vipava) are covered with these models. It is possible to predict the movement of the flood wave with these models, but not the time of beginning or duration of the peak. Analyses of the flood waves travels along the main rivers between gauging stations were made in addition to the analysis of these models. These analyses were made to determine the time of the wave travel.
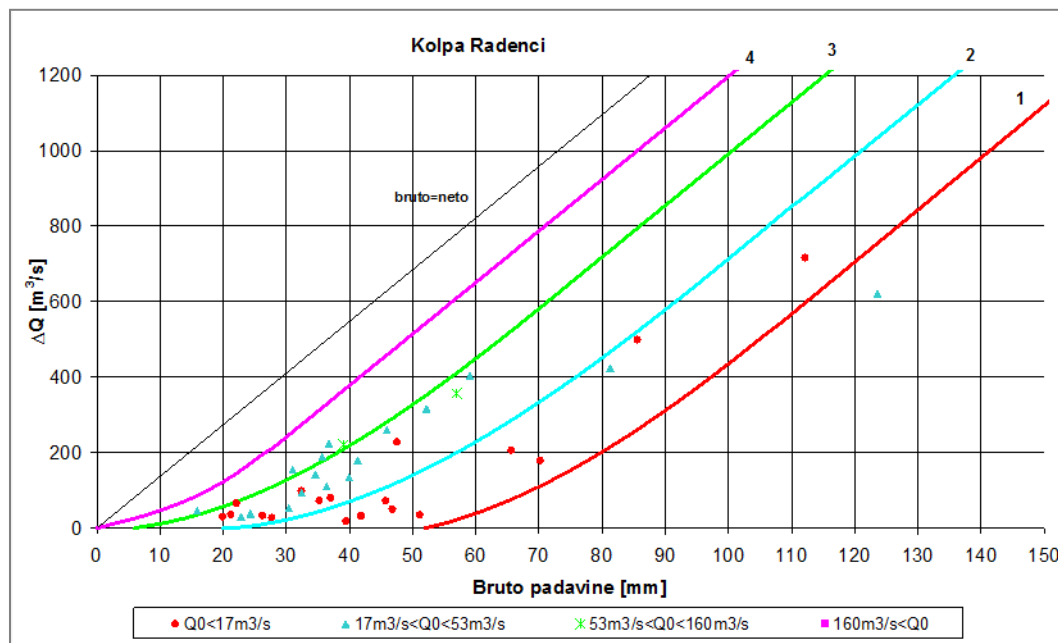
Figure 34: Regression model for the Kolpa (Radenci)

Conceptual models experience

In 1998 the hydrological prognostic department of Slovenia decided to introduce conceptual models for precipitations - runoff. Market research at that time led to the software tool WMS (Watershed Modelling System), which is a complex system for hydrological analysis and modelling (WMS, 1997). It was developed at the University of Brigham (Brigham Young University) in the Engineering Computer Graphics Laboratory in cooperation with the U.S. Army (U.S. Army Corps of Engineers).

The tool is convenient because it merges tools for geographic information systems for basins modelling with standard hydrological models. It is possible to build a model of the river network, its basins and sub-basins from the digital relief model and to calculate geometric attributes that are requested for hydrological models. WMS supports several hydrological models, from simple ones, as the rational method, to more complexes, such as HEC-1 and TR-20. WMS supports also the NFF model for the assessment of recurrence periods based on the regression equations.

The HEC-1 model is one of the oldest and most popular programs for runoff simulation. It was developed by the U.S. military in the early sixties (Feldman, 1995). HEC-1 is modelling individual precipitation, storms with duration from 5 minutes to 10 days, as opposed to programs that are modelling continuous, long (multiannual) sets of precipitations and run-offs. It is not possible to simulate runoff over long periods of time with long intervals without rain because it does not take into account moisture recovery and moisture reserves in soil. The HEC-1 model transforms precipitation in the hydrograph, based on mathematical relationships that represent the hydrologic and hydraulic processes in the relationship between precipitation and runoff.

Modelling of the extremely complex basin is also possible with the model HEC-1. The majority of Slovenian basins are considered to be complex basins. Basins are divided into smaller, homogeneous sub-basins with the same hydraulic and hydrologic characteristics. The number and size of sub-basins affect the variability of hydro meteorological processes and characteristics of catchments. Although the HEC-1 model is primarily constructed for analysis of flood waves, it can also be used for flood forecasting. Basic input data for the model is the precipitation. It is necessary to determine the proportion of precipitation that doesn't contribute to runoff.

A number of river basins were modelled with software package WMS and HEC-1: Gradašica, Savinja and the river Sava to the confluence with Soča and Savinja. The problem with operative use of the HEC-1 model is the determination of precipitation losses in each wave, since the loss of precipitation varies from event to event. This was also the reason that the model has been used more for analytical purposes and less for forecasting. Several model calculations have been effectively performed with WMS and HEC-1 model. Two of these calculations are worth mentioning:

- The reconstruction of the hydrological situation of the basin of Koritnica in November 2000 when the landslide Mangart Mountain triggered and buried the village of Log pod Mangartom after prolonged rains (Kobold et al., 2001).

- The catastrophic flood of Selška Sora in Železniki on 18th September 2007 has affected the hydrological measurement stations and the flood wave hasn't been recorded. The runoff of the flood Železniki was successfully simulated with the HEC-1 model (Figure 35). Input data for the pre-calibrated model with precipitation measurements on rain gauges on the Sora and the surrounding area catchment.
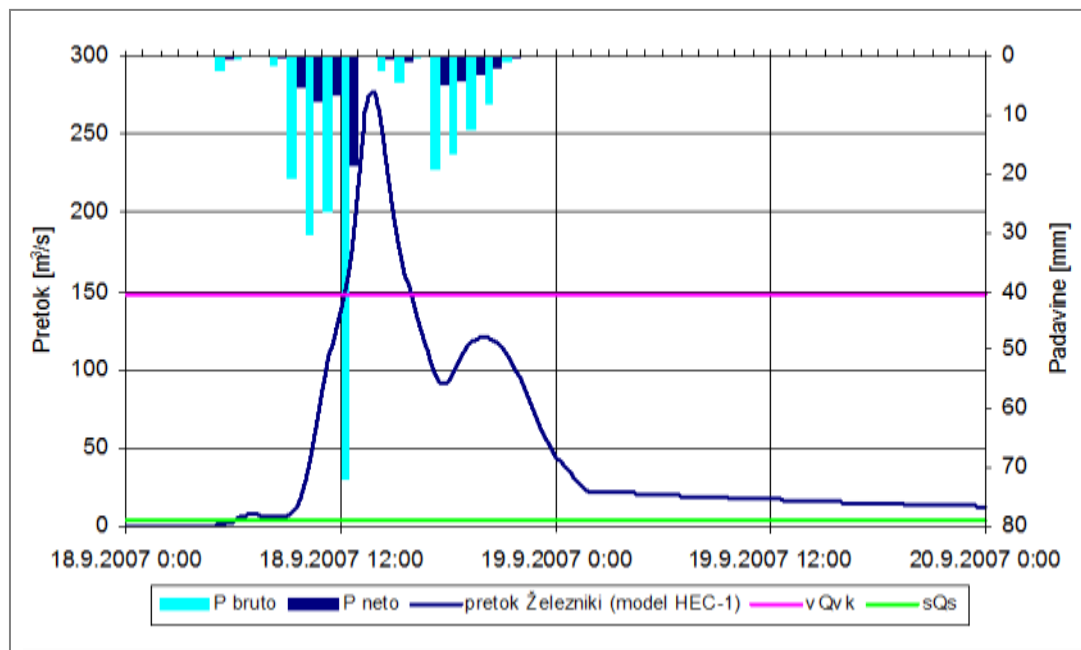
Figure 35: Hydrograph Selška Sora in Železniki calculated with the HEC-1 model and periodic medium and largest discharge and areal precipitation in Železniki

The participation in the international project "European Flood prognostic system" in 2002 and 2003 (Kobold et al., 2003) was also used to test the Swedish HBV model (Bergström, 1995). It was developed at the Swedish Meteorological and Hydrological Institute in the Department for water balance of the Office of Hydrology (Hydrologiska Byrans Vattenbalansavdelning). The basic version of this model was developed in the early 1970s. It is one of the semi-distributed conceptual models of precipitation - runoff. It allows distribution of river basins into smaller units (sub-basins). Each sub-basin can be divided further into areas divided by altitude and also by vegetation. However, the division by vegetation is rather coarse because it distinguishes only two categories, forest and non-forested areas. The division by the vegetation zones is taken into account in the procedures for calculating snow and soil moisture. The model allows the continuous calculation of runoff, which is important for operational hydrological prognostic ARSO (EARS) service where there is effort to publish quantitative forecast outflows, not only in the event of high water situations, but also in the case of decreasing flows and low-flow situations. First operational forecasts were prepared for the catchment in northern Sweden in 1975.

The latest version is the model HBV-96, which is integrated into the hydrological system IHMS (Integrated Hydrological Modelling System). Different versions of the HBV model are used in more than forty countries around the world, in different climatic conditions and for different sizes of basins, from 1 km² to over 100,000 km². The model is used to predict the river discharges, for the operation of hydropower, the water resources assessment and especially in the case of high water and floods. The model is based on the water balance equation. The data used are usually daily precipitation, daily air temperature and monthly estimation of potential evapotranspiration. It is also possible to use a shorter time step.

The HBV model was calibrated on the Savinja river basin. It was used to carry out the simulations of the largest flooding of the river Savinja, to analyse the effects of hydrological variables on runoff and to assess the impact of incorrect estimations of precipitation on runoff forecasting (Kobold, 2007). A model of HBV was later calibrated by the Faculty of Civil Engineering on the basin of the Sava River in Slovenia. It was used to calculate the maximum possible flow from different precipitation scenarios on the Sava river basin (Primozic, 2007).

The project EFFS was the beginning of the European flood alert system EFAS (European Flood Alert System), which was developed at the JRC (Joint Research Centre) in Ispra (De Roo and Thielen, 2004). The system is based on the LISFLOOD model with distributed parameters (De Roo et al., 2000). System EFAS serves for major rivers early flood warning. These products are used in Slovenia for hydrological prognosis made by ARSO (EARS) for the River Sava, Drava and Mura (Figure 36). The system provides information on potential flood risk a few days before the event and serves as pre-warning, but does not provide current discharges or water levels.
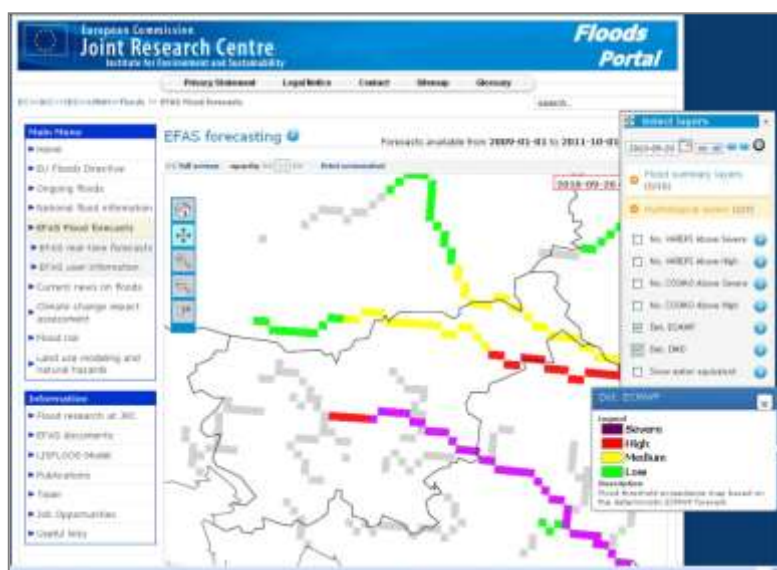
Figure 36: Flooding risk in the EFAS system

Prognostic systems development

The first hydrological prognostic system which significantly contributed to the operational hydrological forecasting services of the ARSO (EARS) in 2006 was designed to predict the cross-border discharges of the River Mura in the EU INTERREG IIIB CADSES program. The project involved the Hydrological Service of Slovenia and the Hydrological Service of Styria (Ruch et al., 2006). The software package MIKE 11 by the Danish company DHI was used. MIKE 11 includes the NAM hydrological model. NAM is a conceptual model, which is suitable for continuous computing of runoff with the data input of the precipitation, potential evapotranspiration and air temperature. Air temperature is particularly important in snowmelt modelling. The main result is the water runoff from the basin. This was the first conceptual hydrological prognostic system, which has been introduced by the Hydrological Services of Slovenia and Styria into their operational work (Figure 37).
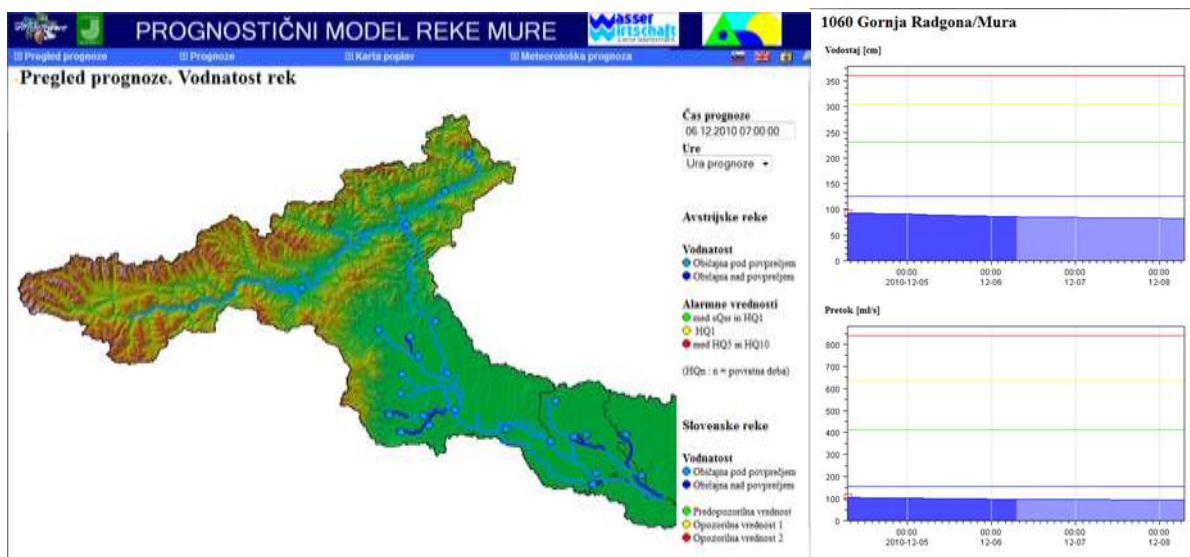
Figure 37: Results of the international prognostic system for Mura River

ARSO launched an upgrade of the system for monitoring and analysing the aquatic environment in Slovenia in 2009 through the cohesion funds of the European Union. The project is called BOBER (Better Observation for Better Environmental Response) (ARSO, 2010).

One of the expected results of the project is to establish a system to predict the hydrological state of the rivers Sava and Soča. The prognostic tool is MIKE and the system integrates hydrological observations, meteorological observations and meteorological models (ALADIN / SI, ECMWF, NAM). This model is used to monitor the current water levels at national monitoring gauging stations and to forecast discharges up to six days in advance. The system of the Sava, Soča and Mura river basins will serve as a basic tool for review of current hydrologic conditions, preparation of hydrological forecasts and flooding warnings.

Sensitivity of hydrological models on precipitation

The basic input data for hydrological runoff models is precipitation, which is also the main source of error in estimating runoff due to incorrect estimation of basin precipitation. Hydrological processes are happening in 3D space and the determination of areal precipitation from gauge station point data is one of the basic problems in hydrology. The Thiessen polygons method is still the method used most often for the calculation of areal precipitation. The data for calibrating the operational hydrological model are air temperature measured with automatic weather stations and precipitation and air temperature forecasted from meteorological models. Although the areal precipitation measurements by means of remote measurement (radar and satellites) allow precise monitoring of the development of precipitation events, they did not significantly improve determination of the quantitative estimation of precipitation amount on the ground.

Sensitivity analysis of hydrological runoff models showed that the runoff models are very sensitive to the precipitation input data. If there is an error in precipitation data, the error in the simulated runoff is not 1:1, but it is larger. Dependence between the error in precipitation and runoff is polynomial (Kobold, 2007) and does not depend on the size or type of basin model (next figure). This means that the deviation of simulated from measured discharge can be quite high. For example, if forecasted precipitation is overestimated by 20%, the deviation of calculated flow rates is around 36%. Overestimation in precipitation by 50% nearly doubles the runoff error. This is why forecast models of the rivers Sava and Soča were designed in several versions with different input data (Pogacnik et al., 2012). Reliability of forecasts will be based on these versions.
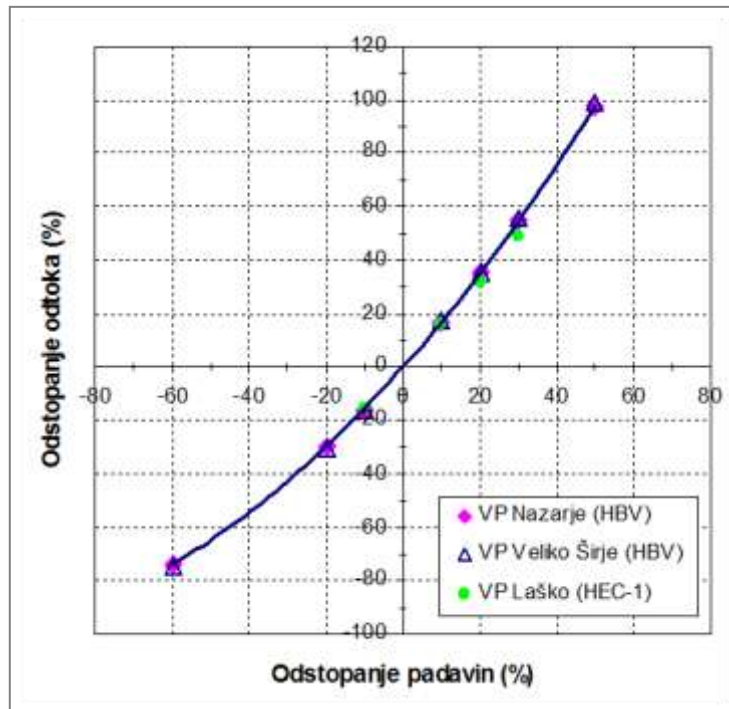
Figure 38: Runoff deviation depending on precipitation

It is important to emphasize that the availability and quality of meteorological and hydrological data and the timely transmission of data in real-time performance of forecasts models are important in order to produce reliable hydrological forecasts. This is an integrated process because complex hydrological models cannot provide reliable hydrologic forecasts without the relevant data.

Conclusions for Slovenia

Hydrological and hydrodynamic models are increasingly becoming important in the ARSO's operational practice. It will be possible to predict flooding of major rivers a few days before the phenomenon starts because of prognostic systems that are established in the ARSO. The development of meteorological models with better spatial resolution and the development of very short (now-casting) forecasts will lead to better forecasts of precipitation. Products of precipitation - runoff are reliable only with accurate estimation of precipitation models, which is particularly characteristic for small basins.

Torrent flooding is a relatively unpredictable event. It occurs unexpected and it is difficult to issue accurate warnings. With the current operational models and existing systems forecasting torrent flooding in small basins can't be successfully predicted. Therefore, within the project BOBER in the second stage of the prognostic system for Sava and Soča, a system for torrent flooding is being provided.

Austria – Carinthia, Styria

Measurement network

The *Hydrographische Dienst Österreich* (hydrographic service of Austria) operates a basic measurement network to monitor the most important components of the water cycle. In accordance with the Water Rights Act (§ 59c, Abs. 3) it is the duty of the BMLFUW (*Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft*) to collect these data and to publish them in an appropriate manner. This is accomplished by reports and by publishing the data on the Internet <http://www.lebensministerium.at/wasser/wasser-oesterreich/wasserkreislauf/hydrographische_daten/jahrbuecher.html>.

The data of the relevant parameters is collected in the hydrographic yearbook Austria, which is available for download.
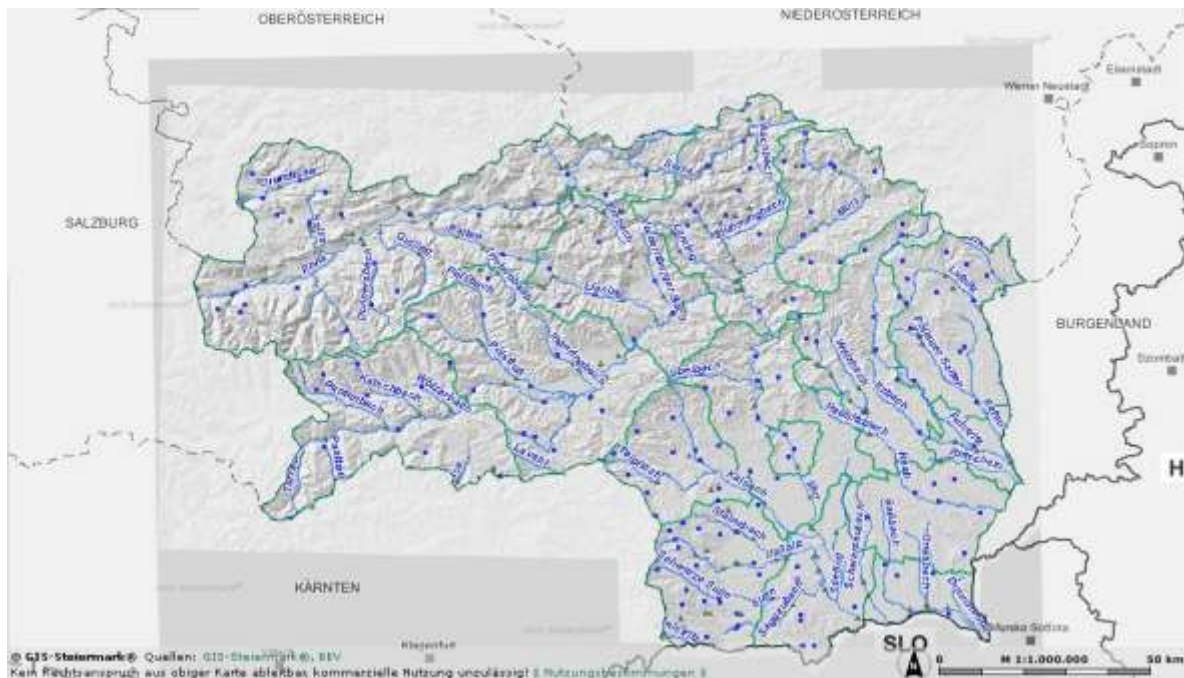
Figure 39: Measurement network (water level information, precipitation) of the federal state of Styria (GIS Steiermark)

Estimation of discharge

The hydropower production of the Austrian energy provider Verbund is dominated by seasonal and temporary fluctuations. The estimation of the natural runoff is there for an important topic since the year 1969, when the first runoff-estimation model was used at the river Drau. The estimation of natural discharge is not only important for the operators of hydro power plants to manage flood events, but also for energy-efficient operation planning. For the power plant chains at the rivers Drau, Enns and Salzach such estimation models are already in use.

Table 12: Energy-efficiency criteria for hydropower plants

PP CRITERIA TYPE	RIVER RUNOFF PP	RIVER RUNOFF PP WITH HYDRO-PEAKING	DAILY STORAGE	ANNUAL STORAGE
DEPENDING ON ACTUAL INFLOW	Very high	high	Mostly independent	In practice independent
POSSIBILITY OF DISPLACEMENT	none	Few hours	days	seasonal
CAPACITY AVAILABILITY	Depending on inflow	Depending on inflow	High for a short term	high
REGULATION PURPOSES	Primary control	Primary control	-	Secondary control
RESERVES	no	no	Short-term	yes
BASE LOAD RANGE	yes	yes	no	no
COVERAGE PEAK LOAD	no	no	Short-term	yes
SPECIFIC COSTS	low	average	average	high

The Verbund decided to develop a discharge-estimation model for the rivers Inn and Donau for an energy-efficient operation of hydropower plants, which also satisfies the requirements of power trading. A 4-day forecast with high reliability could only be achieved by taking into account precipitation data and combining three different types of models: wave-discharge-model, precipitation-runoff-model and regression model. The catchment area was divided into several parts according to hydrological and meteorological aspects. Meteorological data was provided from Zentralanstalt für Meteorologie und Geodynamik (ZAMG) according to measurements and prediction models ECMWF and ALADIN-Vienna.

Wave- and Precipitation-Discharge Model

The model HYSIM, developed at the Technical University of Vienna is able to describe flood-wave-development, wave-development considering precipitation, precipitation-runoff performance of inlets, interaction of multiple inlets, modeling of drawdown in case of a flood event and calculation of power output. The model is applicable for the estimation of discharge for 24 to 36 hours in the future and external prognoses can be implemented. Historical discharge and meteorological data provided by ZAMG was used for the calibration of the parameters.

Precipitation-Discharge Model

The P2R model is a continuous, deterministic model which represents the catchment area for each gauge by a series of linear reservoirs considering the soil layers and a possible snow cover. The calculated parameters are mean values, but it can be distinguished for different altitudes.

Snow- and ground-discharge model

A snow- and ground-humidity model is implemented in the multiple linear regression model to calculate the different discharge components: surface runoff, interflow and base flow.

Regression model

It evaluates the statistical connections using the method of least squares.

All approaches were combined and implemented in the system EPV. For different sites multiple estimation methods using continuously updated discharge, meteorological and precipitation data are applied and compared by calculating an insecurity-coefficient. By means of the discharge estimation an effective power prediction is possible.

Discharge-estimation model for the river Mur

Because of different boundary conditions for every catchment area, regionalization of statistical data and the calibration of input parameters are very important. For different regions different models were developed to account for this situation, with the goal to apply the developed estimation methods to ungauged area.

In the context of the INTERREG IIIB-project "Flussraumagenda Alpenraum" a flood prediction model for the river Mur catchment area was developed, which is in operation in Austria and Slovenia since 2006. The simulation of discharge is based on real-time measurements of precipitation, air temperature and water-levels, the meteorological forecast of ZAMG (Zentralanstalt für Meteorologie und Geodynamik, Wien) and ARSO (national Slovenian agency for environment) and the precipitation- and temperature-prediction model ALADIN. All data are implemented in the model via ftp (file transfer protocol) on an hourly basis. In addition to the global system every country has a local system with the possibility to calculate additional scenarios.

The principle of run-off formation can be seen in Figure 40 below:
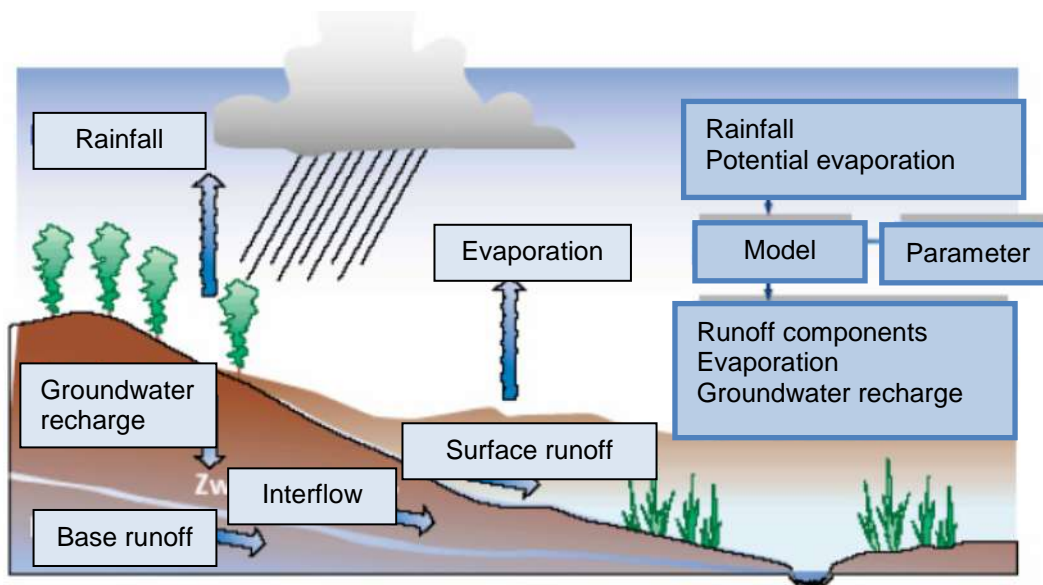
Figure 40: Precipitation discharge in NAM (DHI, water and environment; modified)

The estimation model is based on "MIKE FLOOD WATCH" (DHI), consisting of three elements:
- Hydrological model "NAM": precipitation-runoff model based on 4 different storage zones: snow (depending on elevation), surface (vegetation, small channels and lakes), lower zone (soil until root zone) and groundwater. For each zone the time-series of precipitation and possible evaporation has to be known to calculate the saturation.
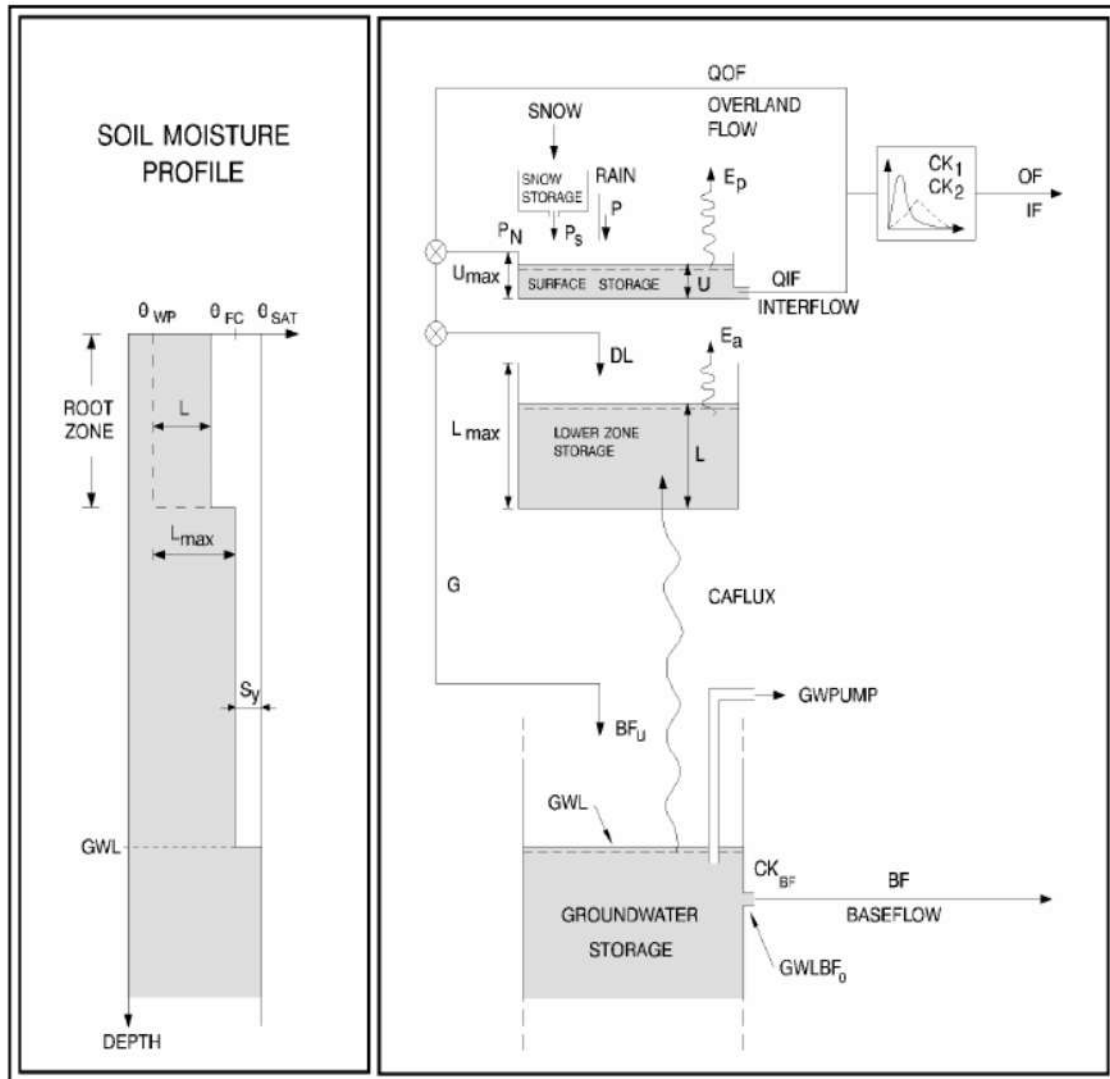
Figure 41: NAM-model (DHI, Water and enviroment, 2004B)

- One-dimensional hydrodynamic model "MIKE11": uses the data from NAM as input to calculate the runoff based on a digital hydrography (including operation of regulation structures). The simulated runoff is compared and adapted to measurements.

- Decision support system "MIKE FLOOD WATCH" with an user-interface for ARCVIEW and ARCGIS

The estimation model is based on:

- A digital elevation model (DEM) divided into regional catchment areas

- CORINE land use data for estimation of evaporation (classification: forest, grassland, field, sealed surfaces)

- Digital hydrography with main contributing streams

- River cross sections

- Hydropower plants and other hydraulic structures

- Definition of partial catchment areas

- Time series: water-levels and discharge, precipitation and temperature, potential evaporation

The boundary conditions of the model and uncertainties in the available data make a calibration of every hydraulic model necessary. The parameters are adapted to fit the measured data. As calibration period the time between October 1998 and December 2002 was chosen. In this time no relevant flood occurred, therefor the flood events of August and October 2005 were also considered.
The model was calibrated with 12 gauged catchment areas shown in Figure 42 below:
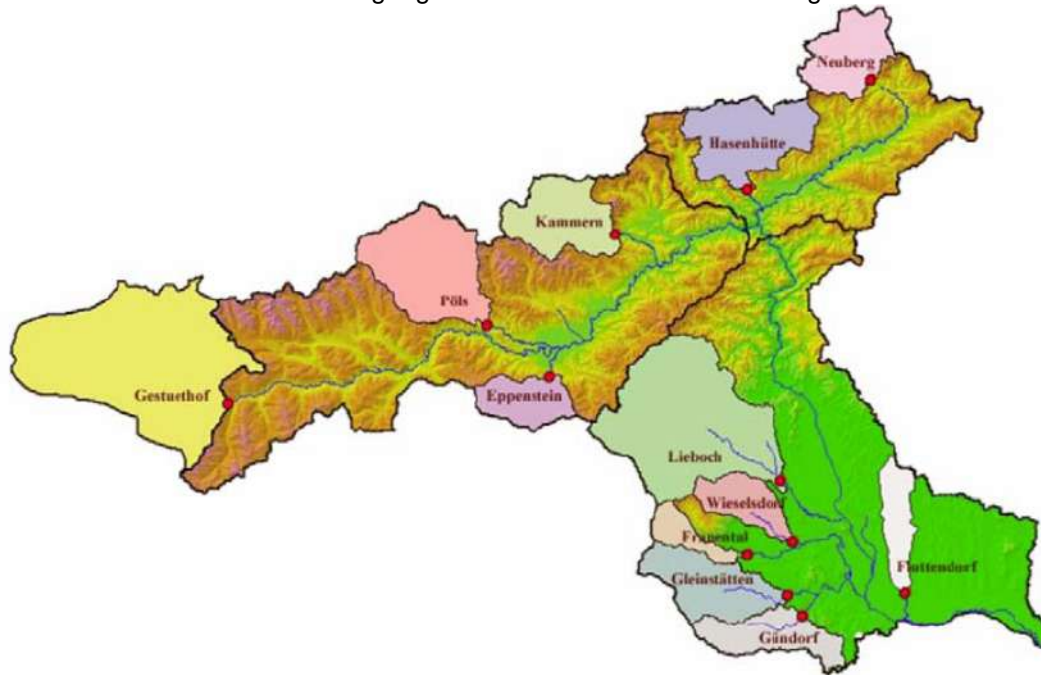
Figure 42: Catchment areas of the river Mur (hydrographic service Styria)

Regionalization of Data

A determination of the water discharge for the ungauged catchment areas should be possible by using the regionalized data, adapted from the measurements and experiences from nearby areas. Especially in the alpine region the transferability of data is afflicted with uncertainties due to territorial heterogeneity. There are 3 different categories of methods for hydrological regionalization in connection with the determination of input data and parameters for the precipitation-runoff-model:

- Interpolation method

- Interpolation methods using additional data, e.g. precipitation in combination with altitude

- Analogy observation for homogeneous regions

The choice of the right method is especially important for regions with only few available data. Regression approaches between the available regional data (e.g. soil type or land use) and expected model parameters are often used. The relations are taken from literature or nearby areas. Personal experience can also be considered by using observation, resulting in more accurate parameters.

However, the similarities are hard to quantify for an automated approach. The regionalization by means of envelope curves is used for extreme events in homogeneous regions, e.g. design storm and discharge. The problem is to determine the annuality of the event. Gutknecht et al. (2002) used this method to determine extreme design storms with different durations (30 minutes to 9 hours) for Austria. The results were more suitable for the design than alternative methods (Kreps und Schimpf, 1965).

Available regional data in Austria

- Topographic data: digital catchment area boundaries are available for approximately 20,000 natural catchment areas and 800 gauged areas (Behr, 1996; http://www.tuwien.ipf.ac.at) based on the map ÖK 1:50 000. The costs vary depending on the degree of resolution. Derived topographical parameters, e.g. soil moisture index, are also available.

- Additional information can be gathered from satellite images, as the CORINE land cover data base of the European Environment Agency with 250m screen width.

- Geological maps are available for the whole country of Austria in the scale 1: 500 000. A more detailed map is in progress.

- Hydrological Data are collected by the "Hydrographischen Zentralbüro" at the "Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft" and the hydrographic agencies of the regions and publicated in the „Hydrographisches Jahrbuch". The mean daily discharge is recorded since 1971. Regional interpreted data is only sporadically available.

- The anthropogenic manipulation of the rivers is usually an explicit part of the model.

Standards for the estimation for small catchments areas in Carinthia

Discharge estimation for small ungauged catchment is areas usually only possible by regionalized data. The estimation of a 100-year flood is even more complex, because a 100-year rainfall does not lead to a 100-year flood event; the relation is influenced by more factors. The precipitation-runoff results have to be calibrated with extreme value statistics.

$$GF100 = \frac{HQ_{100}}{A_E^{0,6}} \quad \text{bzw.} \quad HQ_{100} = GF100 \cdot A_E^{0,6}$$

According to Wundt (1949):

GF100	100-year regional index
HQ_{100} [m³/s]	100-year peak flood value (based on extreme value statistical analysis of representative gauges)
A_E [km²]	size of catchment area

The inclination of the discharge curve is here related with the exponent 0.6 to the size of the catchment area. An important parameter is the regional factor GF100, depending on the size of the catchment area, the position of the river in the water network (e.g. feeder) and its retention potential.
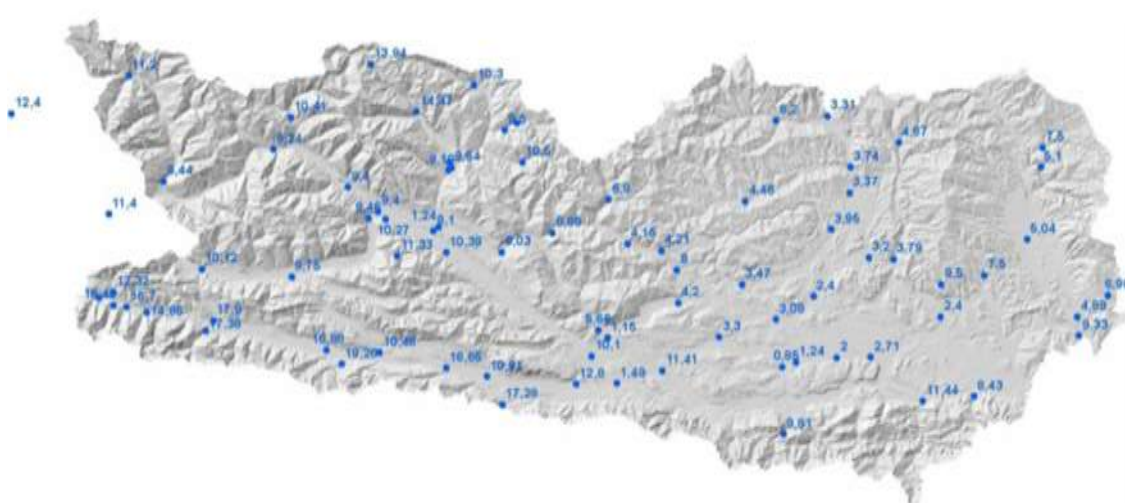
Figure 43: GF100 for gauges in Carinthia

For the characteristic flood and precipitation data a considerable south-west/north-east divide exists:

- Gail valley (south-west) $\rightarrow$ GF100 = 15 – 19.5

- Gurk- and Glan valley (middle, north-east) $\rightarrow$ GF100 = 3 – 6

Since for small streams no continuously recorded data is available, the use of representative values of larger rivers with similar hydrological characteristics may be favourable.

There are different approaches for the determination of the characteristic precipitation rate. In most cases the design depth of precipitation is used. The time of concentration is the time the water needs to flow from the boundary to the outlet of the catchment area and depends on the shape of the area, the length and the slope of the watershed and the territorial and temporal distribution of the rainfall. It is the relevant duration of the precipitation event and can be calculated according to Kirpich (1940), Kreps (1975), Specht (1915), Izzard (1946) et al. Due to various influencing factors, the time of concentration is always just an approximation and not a constant value.

MOSER – HD Kärnten (empirisch, für kleine Einzugsgebiete; <50 km²):

$$Tc[h] = t_O + t_G = \frac{\dfrac{150}{vO} + \dfrac{L \cdot 1000 - 150}{vG}}{3600} \qquad (9)$$

Where:

T_c… time of concentration as flow time of direct runoff [h]
t_O… time of concentration of the surface runoff (assumption: 150m until channel-like runoff); surface runoff time [h]
t_G… time of concentration of the channel runoff (channel runoff time) [h]
L… decisive length, based on the main contribution area of the catchment area [km]
v_O… flow velocity at the surface to the channel [m/s]
v_G [m/s]… flow velocity in the channel

The discharge coefficient gives the ratio of direct runoff to precipitation amount. It depends on the type of soil, vegetation, land use, soil moisture etc. and the annuality of the flood event.

For standardized HQ_{100} Wave Model for small catchment areas the build-up time corresponds to the rainfall duration and the descent of the wave to the time of concentration.

The specific HQ_{100} discharge coefficient is calculated with the following formula:

$$\varphi_{100} = \frac{(0,8 \cdot RD + 0,75 \cdot Tc) \cdot 1,8 \cdot Q_S}{N_{100} \cdot A_E}$$

RD… duration of rainfall [h]
Tc… time of concentration [h]
Q_s… HQ_{100}- peak value [m³/s]
A_E…size of catchment area [km²]
N_{100}… design depth of precipitation (reduced value depending on surface area)
With $Q_s = HQ_{100}$ and RD=Tc

$$Q_S = \frac{\varphi_{100} \cdot N_{100} \cdot A_E}{(0,8 \cdot RD + 0,75 \cdot T_C) \cdot 1,8}$$

The result of this estimation method for the determination of HQ_{100} for small ungauged catchment areas has a broad scatter of 20-30% depending on the quality of the input and calibration values. The parameters should be revised at least every 10 years.

Standards for the estimation of discharge in Styria

Kreps method

The method from Kreps (1975) is used by *Hydrographischer Dienst Steiermark* (hydrographic service of Styria) for creating hydrological reports. With this method it is possible to determine the mean annual temperature of each watershed. The mean idea of Kreps (1975) was to find a relationship between mean annual temperature, the mean annual rainfall and the mean annual runoff. In the year 1937, W.Wundt described a relationship between the mean values of precipitation, runoff, evaporation and air temperature for earth land areas. Kreps realized that this relationship doesn´t work for landscape in Styria so well but there was a connection between mean air temperature and runoff. With the help of many existing measured data it was possible to create charts with a lot of points. By using an approximation with an offset of 10 percent, Kreps was able to create a balance line.

A lot of tables of many different watersheds could be built by knowing these relationships and so the mean runoff for every point where the mean annual temperature is common.

Table 13: Mean annual runoff (MQ) [l/s*km²] depending on the mean annual temperature (t) of the watershed „River Enns without Palten and Erzbach" (Kreps 1975).

t [°C]	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0					46	45	43.6	42.5	41.5	40.5
1	40	39.4	38.8	38.1	37.5	37.2	37	36.7	36.1	35.6
2	35.1	34.9	34.6	34.4	34.1	33.9	33.7	33.7	33.3	33.1
3	32.9	32.7	32.5	32.3	32.2	32.1	32	32	31.9	31.9
4	31.8	31.7	31.7	31.6	31.5	31.5	31.4	31.3	31.3	31.1
5	31	30.9	30.8	30.8	30.7	30.6	30.5	30.4	30.4	30.3
6	30.2	30.1	30.1	30	29.9	29.8	29.8	29.8	29.7	29.7
7	29.6	29.5	29.5	29.4	29.4	29.3	29.2	29.2	29.2	29.1
8	29									

Table 14: Comparison between mean annual temperatures (t) of the watershed above with the mean annual runoff (Mq) of single gauging stations (Kreps 1975).

SUBBASIN	STATION	E	H$_N$	T	MQ MEASURED.	MQ FROM TABLE	ERROR-RATE
		km²	mm	°C	l/s*km²	l/s*km²	%
	Tetter/Untertalbach	63	1640	0.6	43.3	43.6	0.69
	St. Nikolai/Sölk	58	1560	1.4	39.2	37.5	4.53
	Volksschule/Obertalb.	55	1600	0.9	40.7	40.5	0.49
	Stein an der Enns/Sölk	284	1510	1.7	33.3	36.7	9.26
SMALL ARMS OF RIVER ENNS	Oppenberg/Gollingbg.	73	1520	2.0	38.3	35.1	9.12
	Mitterndorf/Salza	81	1400	4.0	30.5	31.8	4.09
	Tauplitz/Grimmingbach	62	1600	2.0	38.3	35.1	9.12
	Hinternberg/Salza	81	1400	4.0	32.9	31.8	3.46
	Tuckbauer/Krungl	19	1350	4.5	33.2	31.5	5.40
	Brodjäger/Triebenbach	56	1300	2.7	32.4	33.5	3.28

The method implemented by Kreps (1975) is a very fast method to identify the runoff. The user just needs the Kreps table from the specific watershed and the mean annual air temperature of the certain point where he wants to calculate the runoff. The disadvantage of this method is its precision with an error rate up to 10%.

The next chapter is an introduction of the software, used to simulate the precipitation-runoff process of watershed systems.

Hydrologic Engineering Center´s Hydrologic Modeling System (HEC-HMS)

HEC-HMS was designed by the U.S. Army Corps of Engineers to simulate the precipitation-runoff process of dendritic watershed systems. Due to its wide field of application is it usable for many different geographic areas, especially for small alpine river watersheds. The main idea is to separate the hydrologic cycle into manageable pieces and to construct boundaries around the watershed of interest. Different mathematical models are available for balancing mass or energy flow.
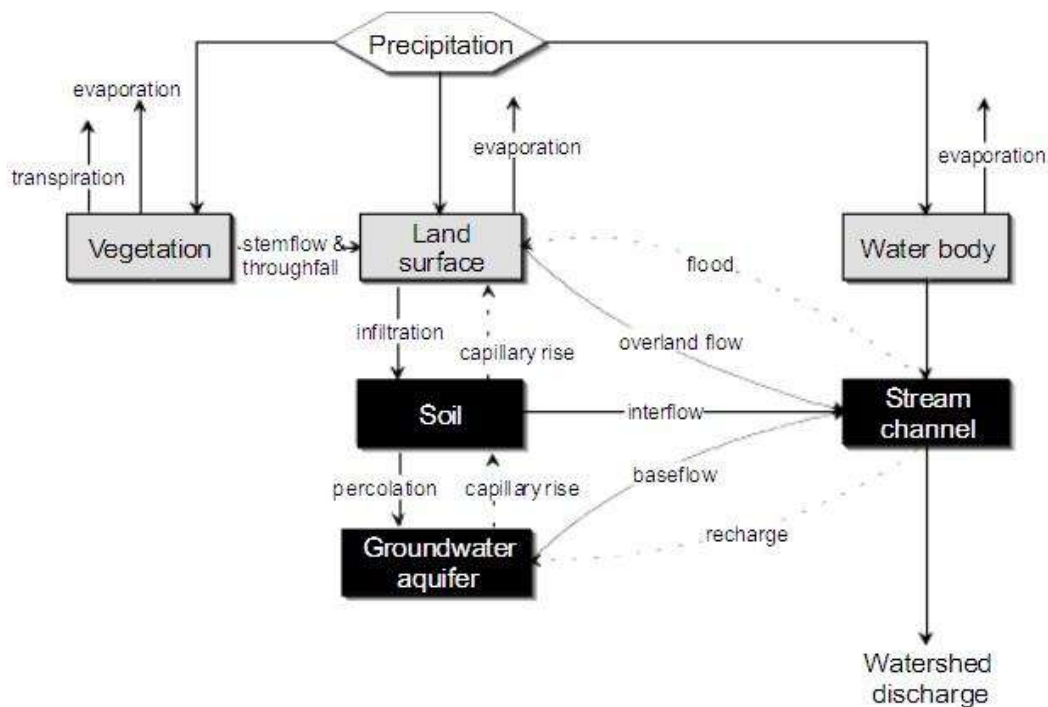
Figure 44: Diagram of the model of the runoff process in HEC-HMS (after Ward, 1975)

Input

The HEC-HMS software is based on a variety of different model components like the Basin Model Component, the Meteorological Model Component, the Control Specifications Component and the Input Data Components.

- Basin Model Component

A basin model could be created by adding and connecting hydrologic elements like sub basins, junctions and sinks. The attributes which are used to declare the size and for example the surface of the watershed have to be found with the help of GIS Software (ArcGIS, Mapwindow, GrassGIS) and an digital elevation model.
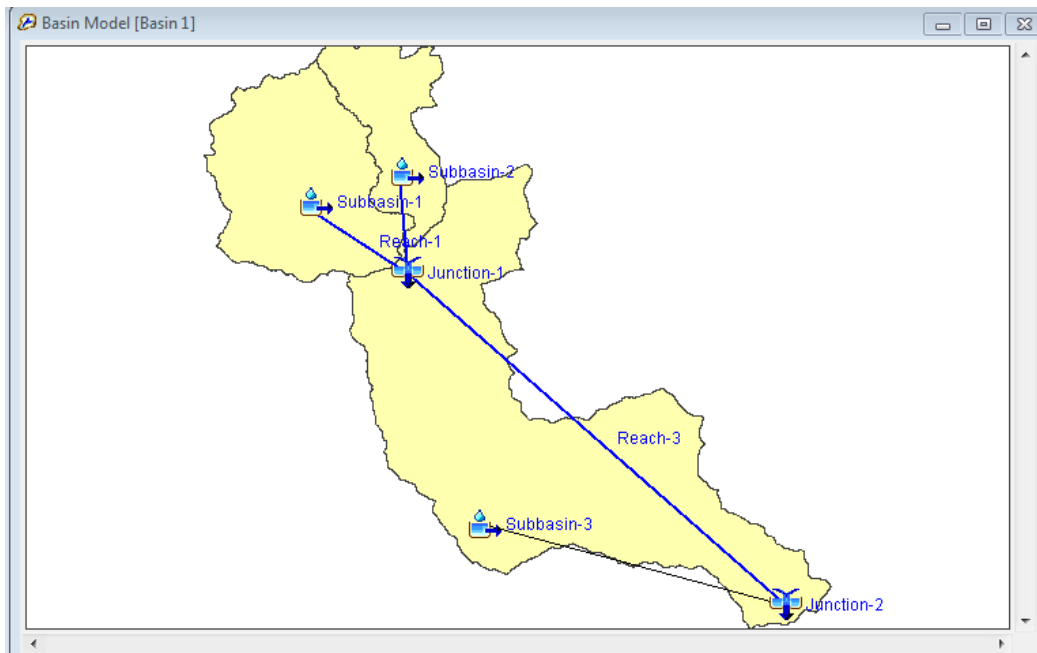
Figure 45: Watershed with three sub basins and two junctions

- Meteorological Model Component

This component defines the form of precipitation which can be point or gridded precipitation. Depending on the used method, the user could define other important factors which can affect the results of modeling like the evaporation and snow melt. With these factors the model is able to create exact results when simulating long term hydrologic response in a watershed.

- Control Specifications Component

The starting date and time, ending date and computation time step can be defined with this component.

- Input Data Component

This component contains the data from different gaging stations inside or close to the watershed area. Data can be entered manually or as HEC-DSS table format file.

Model results

After a simulation run, results can be shown in a summary table, a time-series table or a graph for every sub basin and every junction.
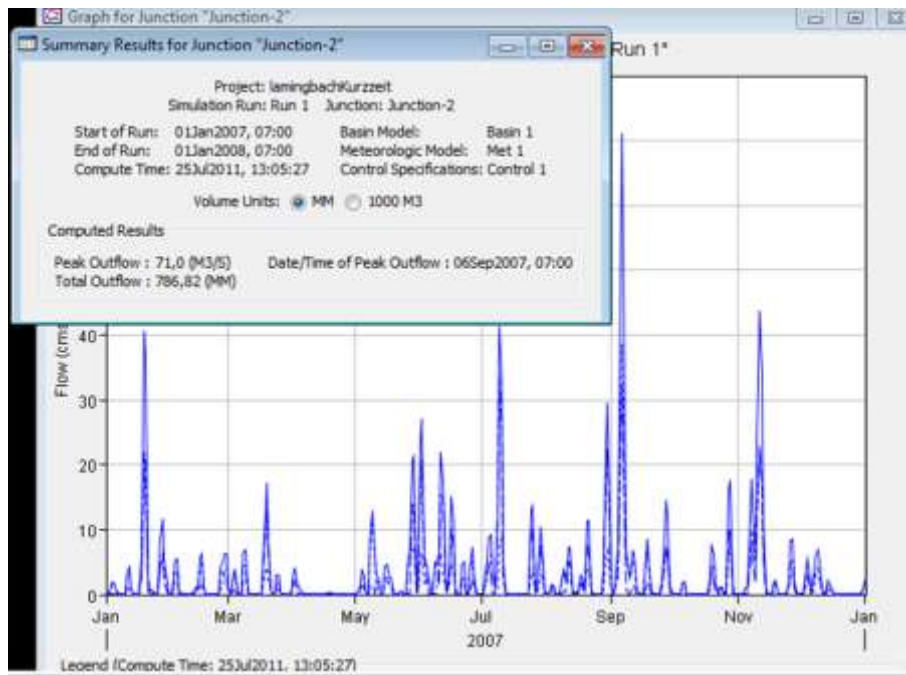
Figure 46: Summary results and graph of junction (2) in 2007
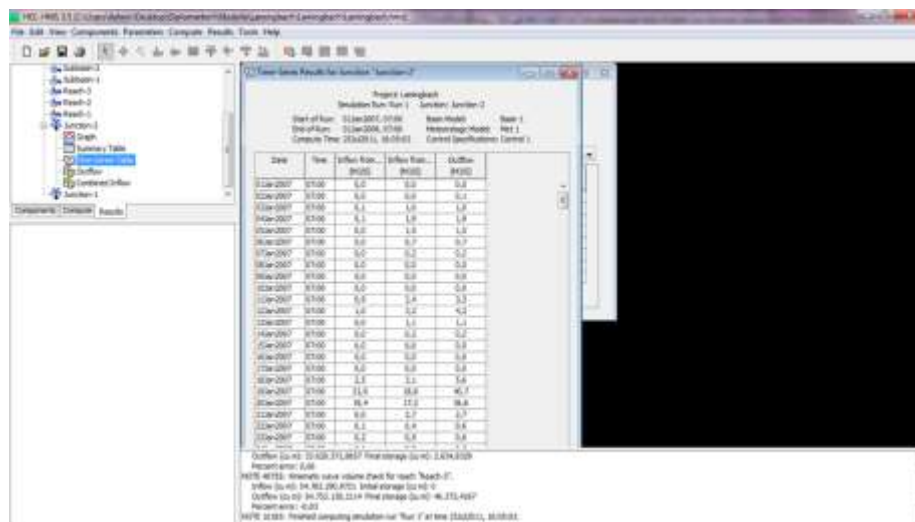
Figure 47: Time-series results for junction (2)

Summary

The modeling software HEC-HMS is open source software and easy to use if the user wants to have a quick rainfall-runoff model. For high quality results there is a lot of more detailed data additionally necessary, for example details about losses, the surface of the watershed or base flow.

France

The present section has not the pretention to relate the last developments of the active research on these methods, but rather to present the traditional methods which were settled by the French administration or the historical electricity producer EDF in the years 1970-1980. Those methods are widely in use in France since that time.

For the calculation of usual floods (average return period T≤10 years), the distinction is made of the two basic physical processes which are on the one hand the estimation of the objective rainfall input of the basin, and on the other hand the calculation of the runoff consequent to this rainfall input.

For unusual and extreme flood discharges (average return period T>10 years) statistical methods are available for the pre-determination of the maximal runoff and for giving a probability to flood discharges at the outlet of the watershed.

Estimation of the rainfall-input

The Montana formula is frequently used for the calculation of the maximum intensity of a rain I (mm.h^{-1}) whose average return period is 10 years.

$$I_{t_c} = \frac{H}{t_c} = at_c^{\,b}$$

t_c is the duration of the rain event (in minutes).
a and b are coefficients which were determined by statistical analysis. For the French Alps, recommended values are in Table 15:

Table 15: Duration of rain fall events

		t_c=[6 min – 30 min]		t_c=[15 min – 360 min]	
	Town	a	b	a	b
REGION PROVENCE ALPES CÔTE D'AZUR	Marignane	159	0.257	360	0.515
	Nice	216	0.240	443	0.474
	Salon	302	0.349	-	-
RHÔNE-ALPES	Challes-les-Eaux	285	0.469	512	0.658
	Grenoble	273	0.397	766	0.716

A map is also available for the determination of rain intensity I_{10} (return period 10 years, in mm.day^{-1}). The values have been determined by a statistical analysis.

As the characters of the climate are highly variable in the mountains because of orographic phenomena, a third method is available for the determination of I_{10} from the value of $P_{annual,}$ which is the annual cumulative rainfall and more often available.

Rainfall-Runoff models

For ungauged rural basins several methods are popular for the predetermination of project flood discharges. Each of it gives an estimation of the peak discharge QIXA10 for an average return period of 10 years from a geomorphological description of the watershed and local climate indexes.

Méthode rationnelle
This method is based on a linear relation between the peak discharge and the rain intensity:

$$Q = C_r I_m A$$

where Q is the peak discharge at the outlet of the watershed, C_r is a characteristic runoff coefficient for the watershed, I_m is the rain intensity, A is the area of the watershed.

Based on physical consideration, I_m is the intensity of the rain event whose duration is equivalent to the concentration time of the watershed.

This method is sometimes used for the calculation of the hydrogram Q(t) at the outlet of the watershed, as the result of a more complex rain event, with the use of the method of the unit hydrograph for example.

The "méthode rationnelle" has been adapted to take account of the saturation of soils for extreme rain events, with an assumption of a runoff coefficient C_r =1 for some part of the rainfall intensity.

CRUPEDIX (Ministère de l'Agriculture, 1980-1982, Moallemi-Pour, 1989)

The method is based on a statistical analysis of data from 187 watersheds and has been calibrated of a set of 630 watersheds. It is recommended for watershed areas in the interval [2 km²-2000 km²].

The peak discharge QIX for an average return period of 10 years is obtained by the formula:

$$QIX = A^{0.8}\left(\frac{P_d}{80}\right)^2 R$$

Where A is the area of the watershed, P_d is the daily (mm, return period 10 years), R is a regional coefficient, equal to 1 in the French Alps. The advantage of a very simple formulation is balanced with the poor physical justification for the duration of the rain event.

A more complex method (SOCOSE) has been proposed at the same time by the French administration. It uses the Soil Conservation Service method for the calculation of a net runoff (USDA-SCS, 1972) and allows the calculation of the hydrograph at the outlet from a given rainfall intensity pattern.

Pre-determination of unusual flood discharges

For unusual and extreme flood discharges (average return period T>10 years), the Gumbel law allows the determination of the probability of flood discharges. Application of this method to all hydrometric stations can be found on the Banque Hydro (http://www.hydro.eaufrance.fr/).

With the same idea that above for the Méthode rationnelle, it is admitted that for exceptional events plays a negligible role and that the runoff is directly related to the rainfall. Several methods are available for the determination of the probability of extreme floods. The method in use is the Gradex method (Guillot et Duband, 1967, CFBG, 1994) with a distribution of extreme discharges following the distribution of extreme rainfalls.

Germany – Baden Württemberg

Estimation of the key hydrological characteristics at a potential site is essential for the planning of a new HPP (ESHA, 2004). Low, mean and flood discharges and their return periods have to be known for the determination of design, technical minimum, flood and residual discharges discharge and overall plant capacity.

In an ideal situation, these values can be derived from stream gauge records. However, usually a potential site is situated quite far away from river gauging stations. Hydrological methods such as regionalization and rainfall-runoff (more general: water balance) modelling techniques can help in this situation. The other category of discharge estimation/forecasting is the operative flow forecasting. The latter is also based on application of catchment water balance models. The principals and an applied model for operative discharge forecasting in the German States Baden-Württemberg and Bavaria are also briefly described below.

Regionalization concept and database for Baden-Württemberg

The regionalisation concept for Baden-Württemberg has been developed at the Institute of Water and River Basin Management of the Universität Karlsruhe (TH) on behalf of and in close collaboration with the Institution of Environment, Measurements and Conservation of the federal state of Baden-Württemberg (Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg). This concept allows the determination of flood, mean or low flow parameters for 10,790 sites of the river network in the federal state of Baden-Württemberg, Germany (36,000 km²) and an evaluation of the predicted climate change impact on the flood characteristics (Blatter et al., 2007).

The regionalisation concept is based on a multiple, linear regression approach, which is the extension of a formula by Wundt (Wundt, 1953). The formula takes into account such parameters as catchment area, percentage of urban area, percentage of forest area, weighted slope, channel-segment lengths, characteristic channel-segment lengths, average annual rainfall and landscape factor.
The corresponding regression coefficients have been fitted by using the results of statistical analyses of more than 400 long-term flow series from the available gauges.

The results of the regionalisation cover a large amount of data including following main parameters:

- flood flows of different return periods (HQ2–HQ100)

- factors to evaluate extreme floods (f200–f10 000)

- climate factors (fK,2–fK,1000) to consider predicted climate changes

- mean flow (MQ) and low flow values of different return periods (MNQ, NQ2–NQ100)

- mean low flow durations (ND2–ND100).
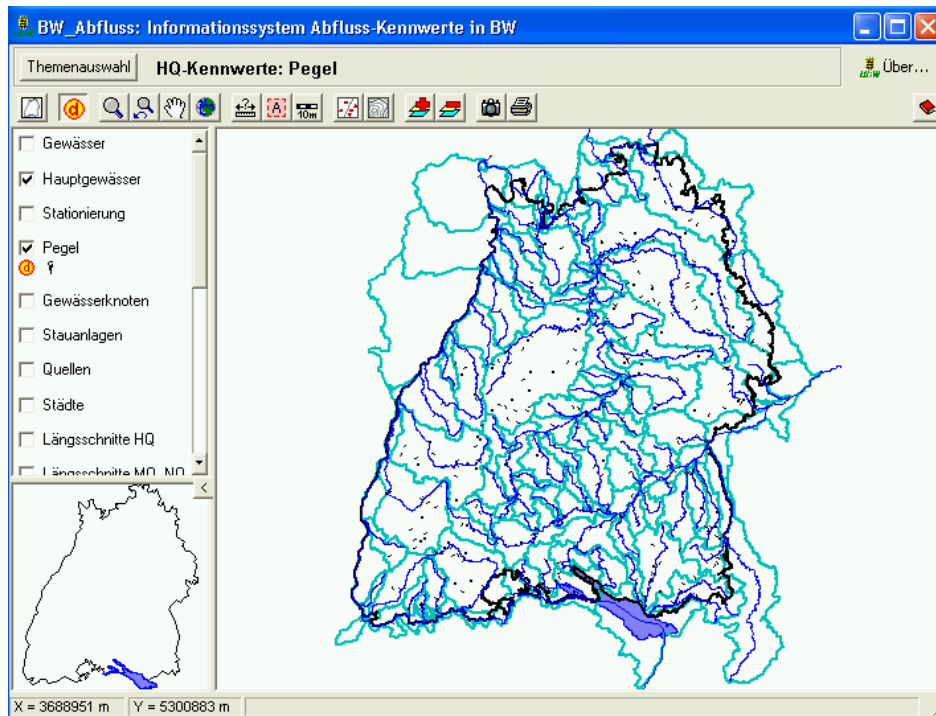
Figure 48: BW-Abfluss software: general window to navigate through Baden-Württemberg with common GIS functions directly linked to the result window.
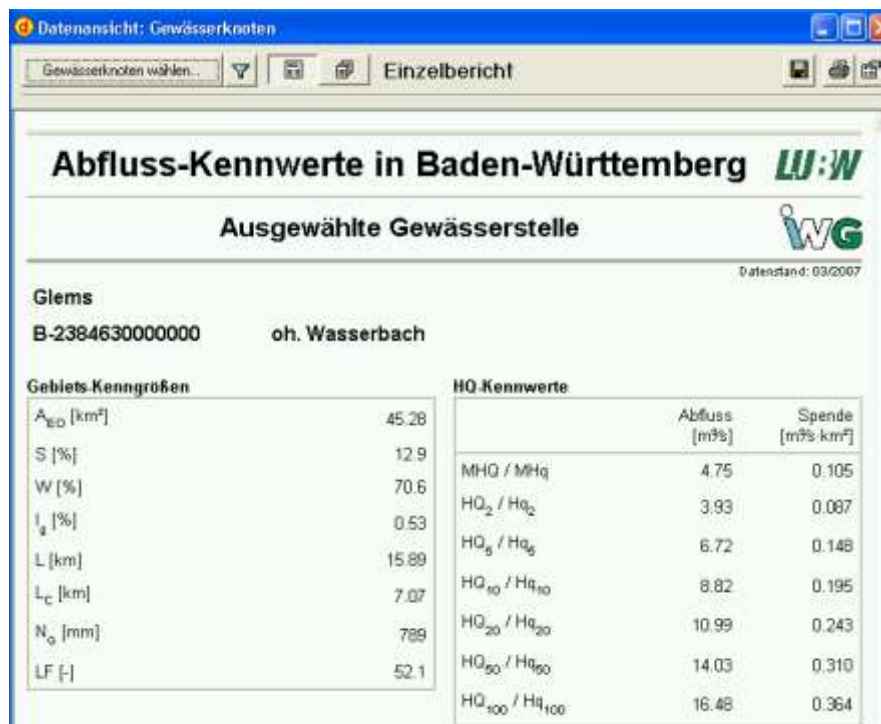
Figure 49: BW-Abfluss software: Example of a result report for a single location within Baden-Württemberg.

Figure 49 shows a screenshot from the BW-Abfluss software. The table on the left side summarizes the relevant characteristic values of the catchment (area, percentage of urban area, percentage of forest area, ...), the table on the right side shows the estimation of hydrologic parameters (in this case flood discharges).

A special function within the regionalization software allows the calculation of flow parameters for intermediate sites within a river sub-catchment, given the particular river kilometre. Results of regionalisation concept are published in electronic form and include commercial stand-alone geo-information software for the retrieval of data. The regionalization software can be purchased on the LUBW site <http://www.lubw.baden-wuerttemberg.de/servlet/is/14020/>.

There are some restrictions for the application of a regionalisation model (LFU, 2005), in particular, it cannot be applied or can only be applied with restrictions for:

- rivers of Upper Rhine Plain; for these river the differently acquired flood flows (HQTn values) are valid;

- karst areas (uncertain catchment areas);

- very small catchments ($A < 5$ km^2);

- complex river systems with bifurcations, backwaters with low flow velocities, areas with strong retention potential;

- areas with strong influence of settlements or very inhomogeneous surface areas (especially by small catchments);

- catchments with water construction works.

In all above mentioned cases a rainfall-runoff model (or more general: hydrological water balance model) for discharge estimation should be used.

Long term and operative flow forecasting using hydrological water balance models

The hydrological (water balance) simulation models are the common tools in Germany for the discharge forecasting. In particular in Baden-Württemberg, Bavaria and also some other States the model LARSIM (Large Area Runoff Simulation Model) is used for such predictions.
Water balance models are mathematical calculation methods used to describe and quantify the spatial and temporal distribution of essential water balance components such as precipitation, evapotranspiration, percolation, water storage and runoff/flow.
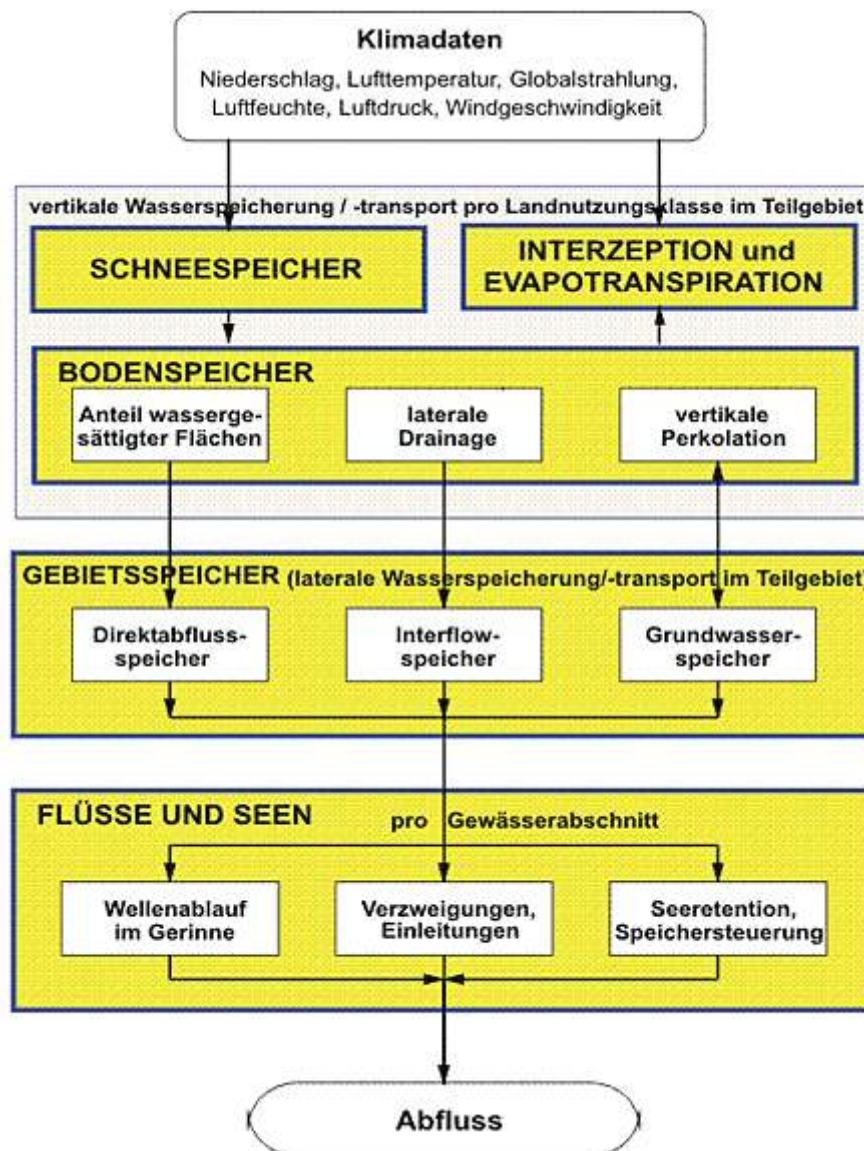
Figure 50: LARSIM model schema

In the water balance models for Baden-Württemberg, in a grid-based area resolution of 1 x 1 km, the following hydrological sub-processes are described: interception, evapotranspiration, snow accumulation, compaction and thaw, soil water replenishment, storage and lateral water transport within the area and translation and retention in channels and lakes (see LARSIM model schema, Figure 50). In addition, methods are used to correct and convert meteorological measured variables.
More detailed information on the LARSIM model principles and model applications at various spatial scales is given in (Ludwig & Bremicker, 2006).

Hydro-meteorological input data

The meteorological input data for the model are time series for precipitation, air temperature, relative air humidity, wind speed, global radiation and air pressure, measured or calculated using climate models. The LARSIM model is directly coupled with the REMO atmosphere model (BMBF project BALTIMOS) in collaboration with the Max-Planck-Institute for Meteorology, Hamburg. However, it can also be used with the output data of other atmosphere models.

Measured flow data at gauging stations and details of water transfers and water resource management measures (e.g. reservoir operation) can be taken into account in LARSIM as hydrological input data.

System setup for the LARSIM water balance model

Preparation of the model is to a large extent computer-aided task on the basis of extensive digital spatial data (digital elevation model, vectorised river network, satellite classification of land use, field capacities of the soils, see Figure 4).
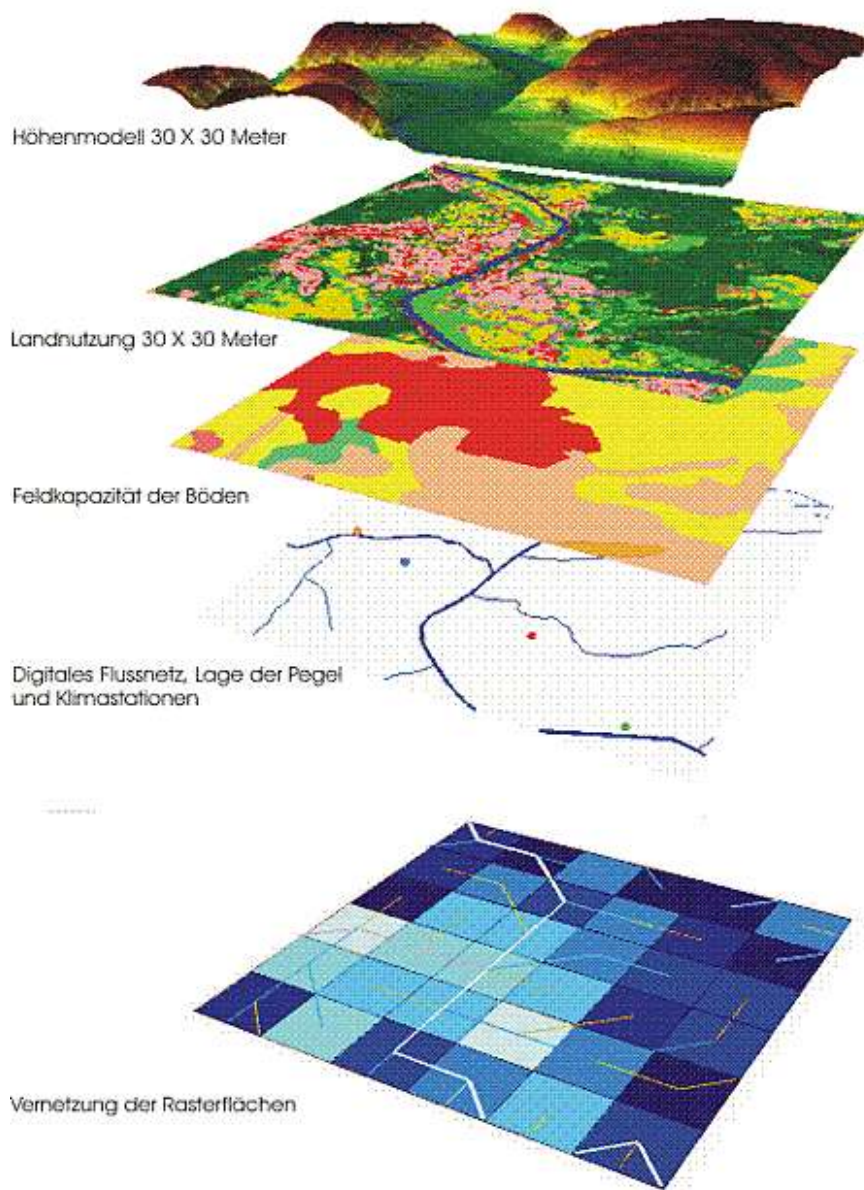
Figure 51: System data used for the Baden-Württemberg water balance model

Up to 16 different land use types with their specific evapotranspiration and run-off properties are recorded for each individual grid area (Figure 52). ArcView interfaces can also be used to define possible land use scenarios, in order to calculate their effects on the water balance.
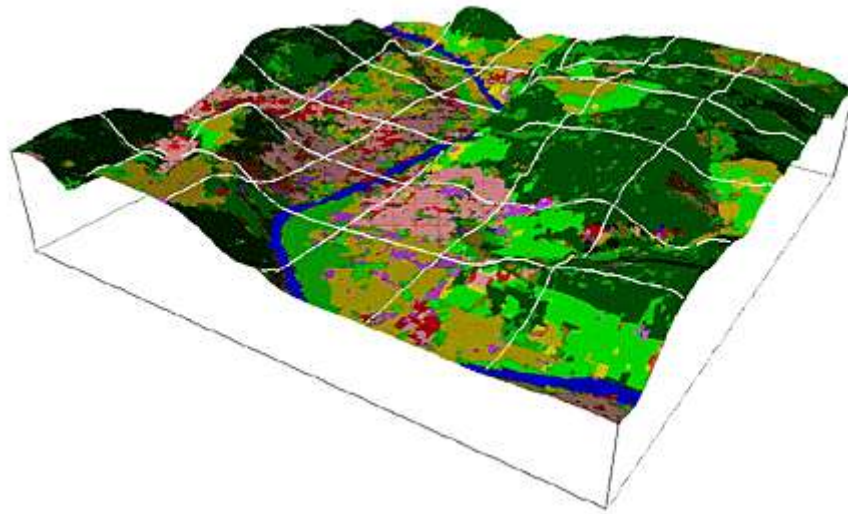
Figure 52: Preparation of the LARSIM system data in GIS using the example of data records for elevation, land use and river network.

Simulation of the real river network (by connecting the grid areas) is realised by computational intersection of the digitized river network with the model grid (Figure 53). Geometric details of the river length, hydraulic gradient in the river as well as width and height of the mean river cross-sections are contained in the LARSIM system data record for each sub-stretch of surface waters.
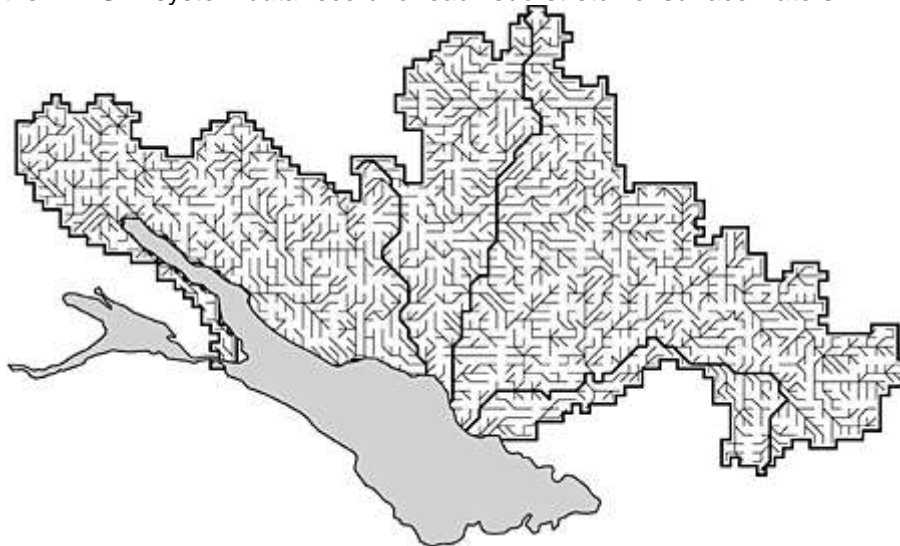
Figure 53: Schematic diagram of the river network in the water balance model of the Baden-Württemberg Lake Constance inflows

Calculation results

Based on the meteorological input data, the water balance model calculates detailed spatial and temporal information for the land-bound components of the water cycle such as evapotranspiration, soil moisture and formation of runoff. The model's calculation results of the actual climatic condition are verified by comparison between measured and calculated discharges at the gauging stations (Figure 54). Separate modelling of the different flow components: base flow, interflow and direct flow (Figure 55) enables coupling with models for substance output.
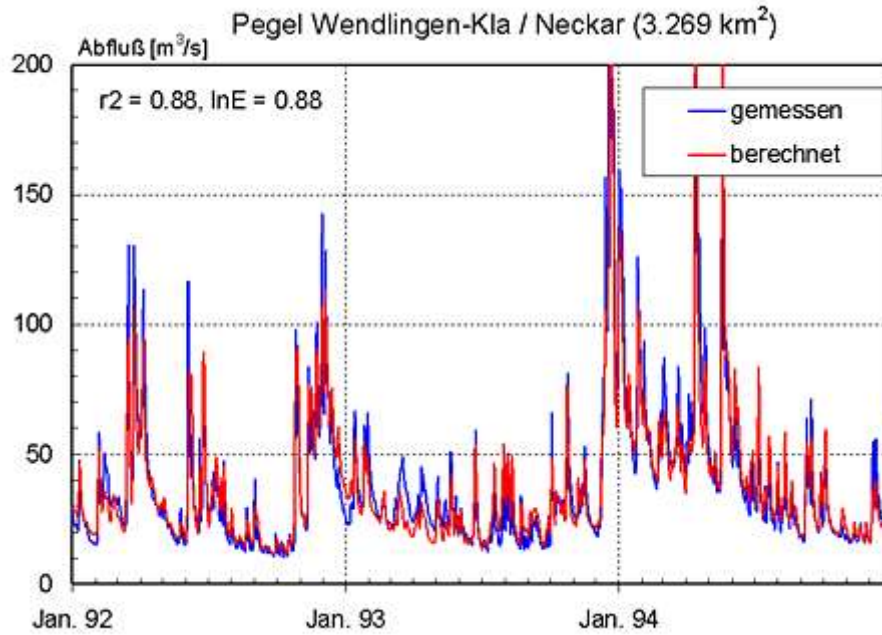
Figure 54: Comparison between calculated and measured flows
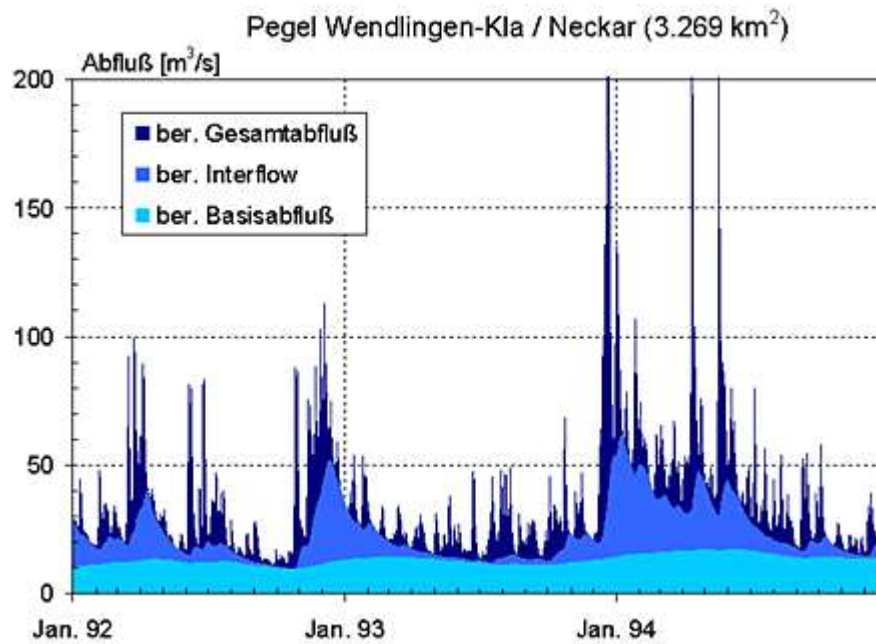
Figure 55: Diagram showing flow components determined by the model.

Among other things, calculation results aggregated over time can represent maps of the annual evapotranspiration and the mean annual ground water recharge (Figure 56).
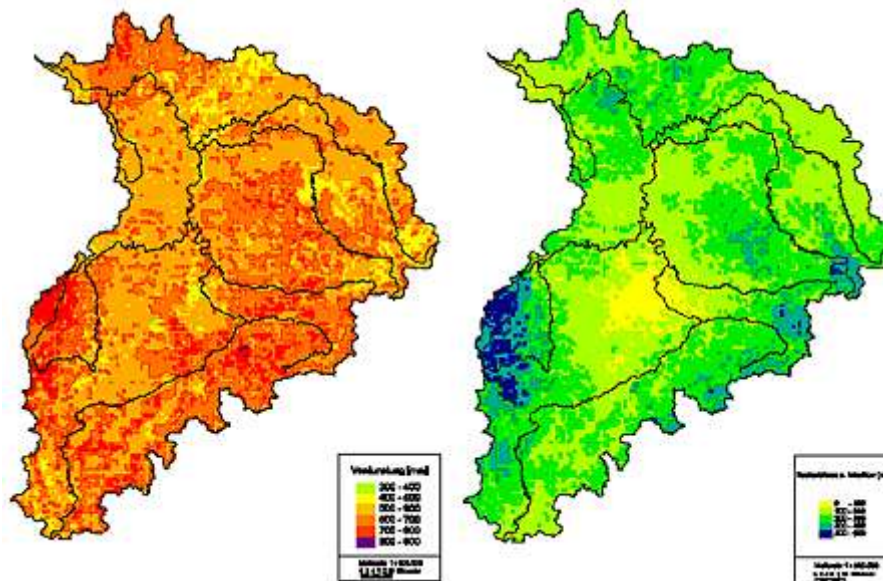
Figure 56: Mean annual evapotranspiration (left) and groundwater recharge (right) in the period 1987 - 1996 in the Neckar catchment area, calculated using LARSIM.

The LARSIM water balance models can be used for the following purposes (selection):
- Assessment of the effects of environmental changes, e.g. possible climate changes or land use changes on the water balance (such as runoff, percolation and evapotranspiration).

- Continuous runoff prediction for low, mean and flood flow conditions for practical applications such as water and risk management (for needs of ecology, energy sector, navigation and flood protection).

- Provision of widespread percolation and runoff data for water quality models (e.g. MONERIS).

- Forecasts and scenarios for surface water development planning.

- Large-scale determination of ground water recharge as the basis for sustainable resource management.

The model results are produced on daily basis, these values can be aggregated to obtain weekly, monthly or annual values. For the operative flood forecast the calculations are performed using an hourly time interval.

LARSIM in the "river basin model" calculation mode is used at the HVZ (Baden-Württemberg flood forecasting centre) for operational flood forecasting for numerous river basins. In the "water balance model" calculation mode it allows operational low flow and mean flow forecasts. The input data here are the 48-hour forecasts of the LM model and the 172 hour forecasts of the GME model of the German Weather Service.

The operative flood flow forecast can be used for *early flood warning* and the *actual flood forecast* (Ludwig & Bremicker, 2006), (Luce et al., 2006). Intention of the *early flood warning* is to give information at an early stage (several days before a flood) to the water resources authorities, the emergency management authorities and the interested public. Because of the long forecast time period and the uncertainties of the precipitation forecast, the early warning is only an estimation of a probably imminent flood with a low quality of forecasted peak flood values with an uncertainty of some decimetres. On the other hand, the *actual flood forecast* should give information shortly before and during a flood situation, which is as exact as possible to ensure the effectiveness of short-term flood relief actions. These two forecast types have different publication time intervals (once a day vs. hourly), forecast time periods (up to 7 days vs. 4 to 25 hours) and forecast quality (+/- 50 cm vs. +/- 10 cm).

4. References

AMT DER KÄRNTNER LANDESREGIERUNG (2011): Standard zur Abschätzung von HQ100 kleiner Einzugsgebiete in Kärnten. Klagenfurt

ARPAV (2012): Misure di portata eseguite da ARPAV nell' anno 2010. Relazione n. 01/12

ARSO (2010): Predstavitev projekta »Nadgradnja sistema za spremljanje in analiziranje stanja vodnega okolja v Sloveniji«, Predstavitvena publikacija projekta BOBER, Agencija RS za okolje;

BACHHIESL M., PIRKER O. (2006): Zuflussvorhersage im Verbund, Wiener Mitteilungen: Band 164: Niederschlags- und Abflussmodellierung, Simulation und Prognose, Bd. 164, Wien .

BERGSTRÖM, S. (1995): The HBV model. V: Computer Models of Watershed Hydrology (ur. V. P. Singh), Colorado, USA, Water Resources Publications, str. 443-476;

BLATTER, S., LIEBERT, J., PREUSS, P. A., SZABADICS, J. and IHRINGER, J. (2007): Information system "BW Abfluss": regionalisation of flood, mean and low flow parameters. Adv. Geosci., 11, 57–61, 2007.

BLÖSCHL G., MERZ, R. (2006): Methoden der hydrologischen Regionalisierung im Zusammenhang mit der Niederschlag-Abflussmodellierung, Wiener Mitteilungen: Niederschlag-Abflussmodellierung, Simulation und Prognose, Bd. 164, Wien.

BRUEN, M. (1999): Some General Comments on Flood Forecasting. Proc. of Euroconference on Global Change and Catastrophic Risk Management: Flood Risks in Europe. IIASA, Laxenburg, Austria, 37 str., http://www.iiasa.ac.at/Research/RMP/june99/presentations.html (12.11.2011)

CFGB (1994) : Les crues de projet des barrages : méthode du Gradex. Design Flood Determination by the Gradex Method. 18e congrès CIGB-ICOLD, Bulletin du Comité Français des Grands Barrages, (2), 96 p.

DE ROO, A., THIELEN, J. (2004): The European Flood Alert System, 2nd EFAS workshop, Book of abstracts, Ispra, Italy, Joint Research Centre

DE ROO, A., WESSELING, C.G., VAN DEURSEN, W.P.A. (2000): Physically-based river basin modelling within a GIS: The LISFLOOD model. Hydrological Processes 14, str. 1981-1992

DRAXLER, J. (2005): Abflussmodellierung für die Einzugsgebiete des steirischen Grabenlandes, Diplomarbeit, KF Universität Graz und Johanneum Research, Graz.

ESHA (2004): Guide on How to Develop a Small Hydropower Plant. http://www.esha.be/fileadmin/esha_files/documents/publications/GUIDES/GUIDE_SHP/GUIDE_SHP_EN.pdf

FEDERAL MINISTRY OF AGRICULTURE, FORESTRY, ENVIRONMENT AND WATER MANAGEMENT, (2010): Hydrographisches Jahrbuch 2008.

FELDMANN, A.D. (1995): HEC-1 Flood Hydrograph Package. V: Computer Models of Watershed Hydrology (ur. V. P. Singh), Colorado, USA, Water Resources Publications, str. 119-150

GUILLOT; P., DUBAND; D. (1967): La méthode du Gradex pour le calcul de la probabilité des crues à partir des pluies. Colloque international sur les crues et leur évaluation, Leningrad, 15 au 18 août, IASH.

KLING, H. (2006): Spatio-temporal modelling of the water balance of Austria. Ph.D. Dissertation, University of Natural Resources and Applied Life Sciences, Vienna, Austria. Available online at: http://iwhw.boku.ac.at/dissertationen/kling.pdf, Accessed July 2011

KOBOLD, M. (2007): Vpliv napake ocene padavin na napako napovedi odtoka pri napovedovanju poplav, Doktorska disertacija, UL FGG, Ljubljana

KOBOLD, M., SUSELJ, K., ŠTRAVS, L., BRILLY, M. (2003): Razvoj evropskega poplavnega prognostičnega sistema, Mišičev vodarski dan 2003, Zbornik referatov, Maribor, VGB, str. 39-47

KOBOLD, M., SUŠNIK, M., UHAN, J. (2001): Hidrološki model povodja Koritnice, Mišičev vodarski dan 2001, Zbornik referatov, Maribor, VGB, str. 29-36

KÖLLA, E. (1986): Zur Abschätzung von Hochwassern in Fliessgewässern an Stellen ohne Direktmessung, Dissertation, Eidgenössische Technische Hochschule Zürich, Zürich, 1986

LALIĆ, B. (1994): Visokovodni valovi v odvisnosti od padavin, vegetacije in predhodne namočenosti za reko Savinjo, Razprave, Ljubljana, Društvo meteorologov Slovenije, str. 61-74

LANDESANSTALT FÜR UMWELTSCHUTZ BADEN-WÜRTTEMBERG (LFU, now LUBW) (2005): Festlegung
des Bemessungshochwassers für Anlagen des technischen Hochwasserschutzes. Guidelines, Karlsruhe, 91 p.

LUDWIG, K. & BREMICKER, M. (Eds.) (2006): The Water Balance Model LARSIM. Freiburger Schriften zur Hydrologie, Band 22 Institut für Hydrologie der Universität Freiburg.

LUCE, A., HAAG, I., BREMICKER, M. (2006): Einsatz von Wasserhaushaltsmodellen zur kontinuierlichen Abflussvorhersage in Baden-Württemberg. Hydrologie und Wasserbewirtschaftung, 50 (2), S. 58-66.

MINISTÈRE DE L'AGRICULTURE (1980-1982) : Synthèse Nationale sur les crues des petits bassins versants. Fascicule 1 : éléments de pluviométrie ; fascicule 2 : la méthode SOCOSE ; fascicule 3 : la méthode CRUPEDM : fascicule 4 : caractéristiques averses-crues.

MOALLEMI-POUR A., MICHEL C. (1989) : Contribution à un meilleure estimatin des paramètres d'une crue décennale : la méthode DELTAQIX. Hydrol. continent., vol.4, n°2, 1989 :113-122.

POGAČNIK, N., PETAN, S., SUŠNIK, M., POLAJNAR, J., JORGENSEN, G. (2012): Sistem hidrološko – hidravličnega modeliranja za napovedovanje hidroloških razmer na Savi, Soči in Muri, Ta številka Slovenskega vodarja, Ljubljana

PRIMOŽIC, M. (2007): Umerjanje HBV modela za porecje reke Save v Sloveniji, Dipl. nal., UL FGG, Ljubljana

ROŠKAR, J. (2008): 60 let slovenske državne meteorološke službe, Posebna številka biltena Agencije RS za okolje, Ljubljana

RUCH, C., POGAČNIK, N., POLAJNAR, J., SUŠNIK, M., JORGENSEN, G., HORNICH, R., SCHATZL, R. (2006): Mednarodni sistem za napovedovanje pretokov reke Mure, Mišičev vodarski dan, Zbornik referatov, Maribor, VGB, str. 26-33

SACKL, B., (1994): Ermittlung von Hochwasser-Bemessungsganglinien in beobachteten und unbeobachteten Einzugsgebieten, Schriftenreihe zur Wasserwirtschaft, TU Graz, Graz, Juni 1994

SCHATZL, R., Ruch C.(2006): Internationales Hochwasserprognosemodell Mur. Wiener Mitteilungen: Hochwasservorhersage - Erfahrungen, Entwicklungen & Realität, Bd. 199, 7-23, Wien.

SINGH, V.P. (1995): Computer Models of Watershed Hydrology Colorado, USA, Water Resources Publications

SUŠNIK, M. and POLAJNAR, J. (1998): Simple hydrological forecasting models: operational experience, Proceedings of XIXth Conference of the Danube Countries, Osijek, Croatia, Hrvatske vode, str. 31-36

TONINI (1970): Elaborazione dei dati idrologici dei bacini: Brenta, Piave, Tagliamento, Livenza-Agno-Guà. L'ingegneria elettrica, Vol. 6.

WMS (Watershed Modeling System) 5.0 (1997): Reference manual and tutorials, Brigham Young University, Engineering Computer Graphics Laboratory, Utah

WARD, R. C. (1975): Principles of Hydrology, Second edition, McGraw-Hill, London, 367 pp.

WUNDT, W. (1953): Gewässerkunde, Berlin u.a.: Springer-Verlag OHG, 1953.

5. List of Figures

6.   List of Tables