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JRC TECHNICAL REPORT

Water models and scenarios inventory for the Danube region

Support to the Danube Water Nexus

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Foreword by Alberto Pistocchi

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Abstract

This technical report presents an inventory of existing models currently used in the Danube Region by local, regional, national authorities and scientific institutes for the development of a hydro-economic multi-model ensemble for the Danube with a common database. It also presents a first identification of regional scenarios of policy options relevant for river basin management planning.

Contents

Part 1: Danube Scenarios Study

Part 2: Danube Model Inventory

Abbreviations

EU – European Union

EUSDR - European Union Strategy for the Danube Region

DAN - Danube Air Nexus

DBN - Danube Bio-energy Nexus

DLSN - Danube Land and Soil Nexus

DWN - Danube Water Nexus

JRC - Joint Research Centre

MS – Member States

WFD – Water Framework Directive

Foreword

In 2014, the JRC has asked experts from the Danube region to collect information and provide insights on a number of aspects and, particularly, the water scenarios of interest for the Danube region, and the hydrological and water quality models currently used in the basin.

These initial insights provide relevant material and are necessary for the development of the work the JRC is conducting in support to the European Union Strategy on the Danube Region (https://ec.europa.eu/jrc/en/research/crosscutting-activities/danube-strategy), and particularly the scientific flagship cluster of the "Danube Water Nexus". In this context, we aim at defining two important decision support elements for the planning and management of the Danube basin. These are:

1) A comparison ("benchmarking") of existing assessments (quantitative description of the state of the water bodies in the Danube region, the pressures acting on them and the respective drivers)

2) Relevant scenarios of water allocation across competing usages, their environmental and economic impacts.

A shared baseline picture cannot stem from a single point of view and from application of a single water modelling system. In the Danube region, several studies have focused on specific aspects of the water cycle, water use and eco-hydrology. It is therefore essential that models are compared ("benchmarked") in order to identify facts, agreed-upon interpretations and areas of uncertainty/ignorance possibly deserving further investigation.

Also, the elicitation of scenarios to be simulated in the assessment of water and river basin policies is a process that requires incorporating viewpoints from the regional institutions and Danube region countries.

This technical report assembles the contributions of the two experts, J. Fehér and M. Muerth, contracted by the JRC in order to (a) identify relevant scenarios for the Danube region and (b) collect information on existing models that have been applied in the region for the assessment of water resources.

Ispra, 09 April 2015

Alberto Pistocchi

Project Leader, Danube Water Nexus

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Danube Water Nexus

Scenarios

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1. Introduction

The *Blueprint to Safeguard Europe's Water Resources*[1] has identified agriculture and energy as the priority sectors in which water saving and efficiency should be improved in order to ensure a balance between future water demand and supply. This general conclusion for Europe matches the findings of the 2009 River Basin Management Plan for the Danube, where hydropower generation, physical modification and overexploitation of water bodies and diffuse pollution from agriculture have been identified as significant pressures with cross border impacts.

In 2013 the Joint Research Centre (JRC) of the European Commission has launched an initiative aiming to provide scientific support to the European Union Strategy for the Danube Region (EUSDR). The objective is to gather important scientific expertise and data to help decision-makers and other stakeholders of the Danube Region to identify the policy measures and actions needed for the effective implementation of the Danube Strategy. The JRC has identified concrete priorities, which were grouped into four thematic clusters, namely: The Danube Water Nexus (DWN); The Danube Air Nexus (DAN); The Danube Land and Soil Nexus (DLSN); The Danube Bio-energy Nexus (DBN).

Water has been recognised as a central issue of the *"Scientific Support to the European Union Strategy for the Danube Region"* programme. Addressing the water challenges posed by the *Blueprint* and the *Danube Region Strategy* requires integrated solutions going beyond sectoral divides and matching the needs of water of the different users in the region. The project called Danube Water-Agriculture-Energy-Ecosystems Nexus (Danube Water Nexus) aims to provide input to decision makers and managers in the region about sustainable futures of water resources use.

In December 2013 the JRC has appointed János Fehér to act as free-paid expert to the Danube Water Nexus project and carry out scenario studies for specific modelling topics. This report summarizes the outcomes of the scenario studies, which have been carried out so far in 2014, in three major chapters, such as i) Scenarios identified for Danube Water Nexus modelling; ii) Indicators ideally be included in the Danube Water Nexus Analysis and iii) Overview of scenario studies in the Danube Basin, as well as provides relevant references to each topic.
In this report each chapter has a similar structure. In the first part of a chapter, whenever it is relevant, a brief general overview is given about the topic discussed. The brief general overview is followed by a text box, which gives a summary of parameters of the actual scenario JRC used in its impact assessment for the "Blueprint to Safeguard Europe's Water Resources". Finally, in the third part of the chapter an assessment is given about the findings of the identified references, which deals with the actual scenario in connection with the Danube River Basin. It should be noted that most of the texts have been used from the original source of information, because the primary objective of this work was to compile an information base about scenarios used in previous studies, as well as to advise - wherever it is possible - on feasible scenarios

[1] Communication From The Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - A Blueprint to Safeguard Europe's Water Resources. COM(2012) 673 Brussels, 14.11.2012. http://ec.europa.eu/environment/water/blueprint/index_en.htm

that could be applied by the Danube Water Nexus project. It should be also noted that the focus of this scenario study was on information relevant to the Danube Basin as a whole.

2. Scenarios identified for Danube Water Nexus modelling

The task definition for the JRC appointed fee-paid expert for scenarios states that a collection of scenario definitions has to be established that are essential within the Danube region, and need to be taken into account into the Nexus study. Specifically, it was required to define what were the most preferred scenario calculations to be carried out within the Danube Nexus project. The following issues had to be assessed: desalination, irrigation efficiency increase, water re-use by industry, treated urban waste water re-use for irrigation, increase of mini-hydropower, increase of large hydropower facilities. The following chapters are based on intensive reference and document search related to the actual topic. Texts are mostly citations form the references used.

2.1 Desalination

Desalination is the process of removing salts and/or other minerals from water. Desalination technology is becoming increasingly economically feasible and efficient. This coupled with an increasing water demand is making this method of “creating” fresh water much more popular. Traditionally, desalination is a very energy intensive process. The energy bill can be 50-75% of total operational costs.

Desalination processes are divided into (i) thermal methods (which can be *Multistage Flash Distillation*; or *Multi-Effect Distillation; or Vapour Compression Distillation*) and these involve heating water to produce water vapour, and (ii) membrane processes (such as *Reverse Osmosis* or *Electro-dialysis*) where membranes are used to separate salts from fresh water under high pressure.

"Growth in desalination has increased significantly over the past 20 years as countries seek to augment natural water supplies and as the combined energy and industrial costs have reportedly dropped to below US$0.50/m3 (IRENA, 2012*a*). There are currently more than 16,000 desalination plants worldwide, with a total global operating capacity of roughly 70 million m3/day. Some industry observers have suggested operating capacity could nearly double by 2020. Desalinated water involves the use of at least 75.2 TWh/year, which is about 0.4% of global electricity consumption (IRENA, 2012*a*). Although this technology may be appropriate for supplementing water supplies for some domestic and industrial users in middle and high income regions near the coast, it is currently not an affordable alternative for the poorest countries, for large water consuming sectors such as agriculture, or for consumption at a distance from the plant due to transportation costs. There are promising advances in desalination though at the same time it is recognized that increased salinity levels in seawater caused by desalination can have negative impacts on local marine ecosystems." (UNESCO, 2014)

At present, the combined production capacity of all seawater desalination plants worldwide is 36 million cubic meters per day. It is expected that this capacity will double in the next decade. 61% of the water is produced by thermal processes, mainly in the Gulf region, while 34% is produced by reverse osmosis, which is the first choice in many countries that start to use desalination. Worldwide, reverse osmosis desalination capacity for both sea and brackish water represents 60% of the total desalination capacity. (International IWA Conference on Desalination, Environment and Marine Outfall Systems, 13-16 April 2014, Muscat, Sultanate of Oman)

In this Scenarios report the use of desalination technologies is considered only for producing freshwater from seawater, though seawater desalination probably not the most cost-effective method and are only being employed as a last resort.

JRC used some desalination scenarios in its impact assessment for the "Blueprint to Safeguard Europe's Water Resources", which included the Danube River Basin, as well. The considerations were:

- non-specified number of desalination plants defined the initial condition
- 15 additional desalination plants were added in the scenario analysis
- assumed capacity of each plant was 15 000 m^3/day
- max. delivery distance of desalinated water was set to 150 km inland
- costs of delivery: 0.04 Euro/m^3/100 km in distance and 0.04 Euro/m^3/100 m

Scenario assessment for the Danube River Basin

- It is only Romania and Ukraine, which have Black Sea coastline belonging to the Danube Basin. Currently no desalination plant exists in either country.
- Slovenia does not plan to built desalination plant either, though the country has Adriatic Sea coastline, but that area does not belong to Danube River Basin.
- Black Sea water resources, although very important, cannot be taken into account for the time being because of the technical and economic difficulties in seawater desalination.
- Recommended seawater desalination scenarios:
  - no seawater desalination plant is built till 2030.
  - one seawater desalination plant is constructed after 2030 with the parameters used in the Blueprint modelling

References to Desalination

IRENA (International Renewable Energy Agency).(2012a). *Water Desalination Using Renewable Energy.* IRENA and IEAETSAP (International Energy Agency Energy Technology Systems Analysis Programme) Technology Brief I12. Abu Dhabi.

UNESCO (2014) The United Nations World Water Development Report 2014. Water and Energy, Vol. 1 -4., Paris, France. ISBN 978-92-3-104259-1, ePub ISBN 978-92-3-904259-3.

Recommended links:
Review of the Desalination and Water Purification Roadmap. National Research Council. Washington, D.C.: National Academies Press, 2004.
http://www.nap.edu/catalog.php?record_id=10912#toc

2.2 Irrigation efficiency increase

Not all water taken from a source (river, well) reaches the root zone of the plants. Part of the water is lost during transport through the canals (Evaporation from the water surface; Deep percolation to soil layers underneath the canals; Seepage through the bunds of the canals; Overtopping the bunds; Bund breaks; Runoff in the drain; and Rat holes in the canal bunds) and in the fields (Surface runoff, whereby water ends up in the drain; Deep percolation to soil layers below the root zone). The remaining part is stored in the root zone and eventually used by the plants. In other words, only part of the water is used efficiently, the rest of the water is lost for the crops on the fields that were to be irrigated.

The *scheme irrigation efficiency* (e in %) is that part of the water pumped or diverted through the scheme inlet which is used effectively by the plants. The scheme irrigation efficiency can be sub-divided into:

- the *conveyance efficiency (ec)* which represents the efficiency of water transport in canals, and
- the *field application efficiency (ea)* which represents the efficiency of water application in the field.

The conveyance efficiency (ec) mainly depends on the length of the canals, the soil type or permeability of the canal banks and the condition of the canals. The field application efficiency (ea) mainly depends on the irrigation method and the level of farmer discipline.
The *scheme irrigation efficiency (e)* can be calculated with the following formula:

$$e = \frac{ec \times ea}{100}$$

(FAO Document Repository: http://www.fao.org/docrep/t7202e/t7202e08.htm)

JRC used some *irrigation efficiency increase* scenarios in its impact assessment for the "Blueprint to Safeguard Europe's Water Resources", which included the Danube Basin, as well. The considerations were:

- It was assumed that current irrigation *(field application)* efficiency was improved from the current average 74% (Eastern Europe) - 77% (Western Europe) to 93% by applying drip irrigation everywhere where it has not applied yet.
- Costs were estimated at 153 Euro/ha where drip irrigation has not applied yet.
- According to the literature, currently drip-irrigation areas cover 3% in Eastern Europe, and 18% in Western Europe.
- Costs were again adjusted for national price levels.

Scenario assessment for the Danube River Basin

- In the EU, in average, 13% of the agricultural land is irrigated (Figure 1).
- In the Danube countries the total area of irrigated agricultural land practically did not change during the last 10-15 years (Figure 2).

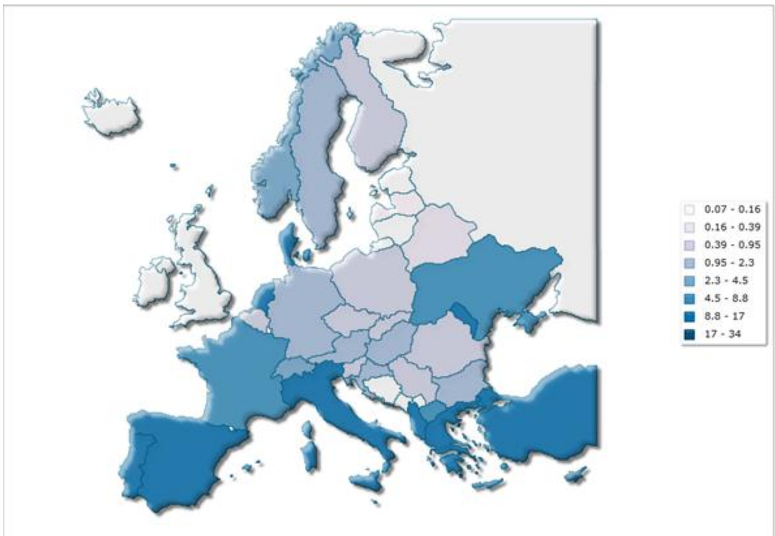


Figure 1. Agricultural irrigation land (% of total agricultural land) (Source: World Bank, World Development Indicators - http://www.indexmundi.com/facts/indicators/AG.LND.IRIG.AG.ZS/map/europe)

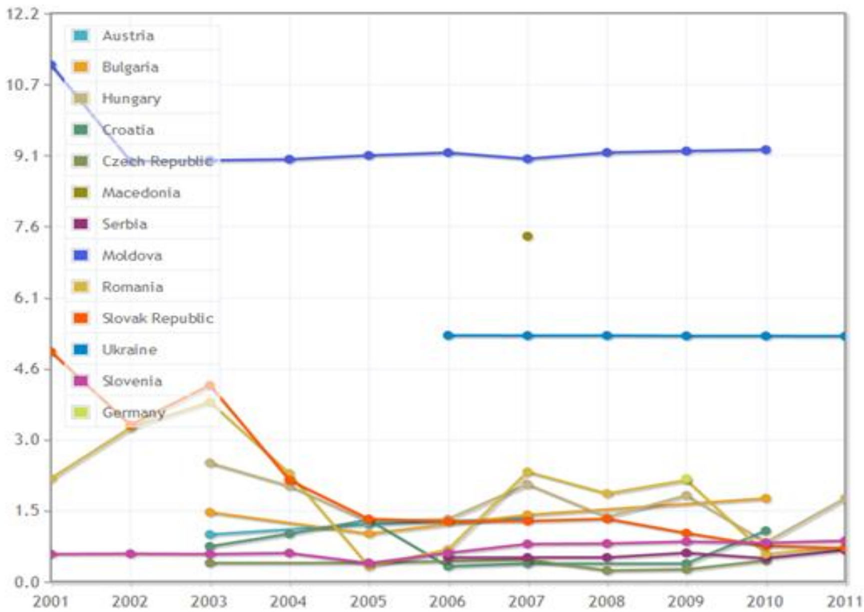


Figure 2. Agricultural irrigation land (% of total agricultural land) (Source: World Bank, World Development Indicators - http://www.indexmundi.com/facts/indicators/AG.LND.IRIG.AG.ZS)

- Irrigation efficiency reflects the state of irrigation technology within a country. Irrigation field efficiency and irrigation project efficiency have to be differentiated. Irrigation project efficiency (EF_{proj}) is more applicable compared to irrigation field efficiency as it additionally considers conveyance losses, field sizes and management practices, while irrigation field efficiency mainly results from the irrigation practice (e.g. surface, sprinkler, micro irrigation) EF_{proj} typically ranges between 0.3 and 0.8, whereas 0.8 means that 80% of the water delivered to the crop is actually absorbed by it. T. aus der Beek et al., 2010 provides data for 14 Danube Basin countries on real irrigated area, area equipped for irrigation, irrigation project efficiency, reported gross irrigation requirement (Table 1).

Table 1. Country based RIA (Real Irrigated Area), AEI (Area Equipped for Irrigation), EF_{proj} (irrigation project efficiency), GIR_R (reported Gross Irrigation Requirements).

Country	RIA	AEI	EF_{proj}	GIR_R
	[km2]	[km2]	[–]	[mil m^3]
Austria	400	970	0.62	100
Bosnia-Herzegovina	30	46	0.42	missing
Bulgaria	540	5450	0.45	1185
Croatia	30	58	0.71	20
Czech Republic	170	506	0.61	60
Germany	2670	4970	0.62	163
Hungary	1000	2920	0.61	1010
Moldova	2560	3070	0.38	760
Romania	4230	21500	0.55	4200
Serbia and Montenegro	570	1650	0.42	760
Slovakia	1110	2250	0.62	321
Slovenia	28	156	0.57	6.6
Ukraine	10 000	23 960	0.61	2400

(Source: T. aus der Beek et al., 2010)

- Since 1989 Bulgaria has undergone profound political, social and economical changes, which have affected irrigation in an extremely negative way. By now, the actually irrigated land is only 5-10% of the area equipped for irrigation. Water is supplied only to vegetables, orchards, tobacco and some other profitable crops, which cannot be grown without irrigation. Due to the decreased water consumption, the Governmental agency "Irrigation Systems" Inc. cannot provide all financial resources for maintaining of the irrigation and drainage infrastructure. On the other hand, Bulgarian Government tends to maintain low prices of irrigation water in favour of the agricultural producers, including subsidizing of part of the water primary cost. During the period of political and economic reforms that started in 1990, a number of legislative initiatives were implemented in order to re-establish the normal irrigation and drainage activities in Bulgaria, including (1) The Ownership and Use of Farmland Act 1992; (2) The Water Act -2000; and (3) The Water User Associations Act. Recently, a group of scientists, irrigation specialists and managers (Petkov et al., 2000) offered a program on the development of irrigation in free market environment, which was approved by the Collegiums of the Bulgarian Department of Agriculture and Forestry (Vodoprivreda, 2003, vol. 35, br. 1-2, str. 86-90).

  Bulgaria wants to work out - in the frame of a World Bank project - a national irrigation strategy by making a review of existing legislation and assessing available irrigation facilities and their potential.
  http://www.focus-fen.net/news/2014/02/13/327115/world-bank-might-consult-bulgaria-on-irrigation.html

- In Bosnia and Herzegovina according to Coric, 2011 "The plot irrigation efficiency is about 55% using 1990 data. Data were available only for year 1990, and not for post-war period (1995–2008). Data included only surface irrigated area through big irrigation systems managed by agriculture enterprises. They do not include fields irrigated by local (uncontrolled) irrigation systems. It was estimated that such

(locally) irrigated fields covered about 3580 ha. So, the total irrigated area was more than 10 000 ha."
http://planbleu.org/sites/default/files/publications/national_report_water_bh.pdf

- In Croatia according to Devic, 2011: "irrigation water efficiency index can be just roughly estimated, as the product of assessed efficiency of irrigation water transport and distribution and theoretical plot irrigation efficiency. It is supposed that transport losses for small-scale irrigation systems are not too high, and that the efficiency of the water transport and distribution might be around 90%. The theoretical plot irrigation efficiencies of 50, 75 and 85% are assessed for the surface, sprinkler and localized irrigations, respectively. In line with such assumptions, estimates for the irrigation water efficiency index in the analyzed period vary between 45 and 50% (Figure 3)".

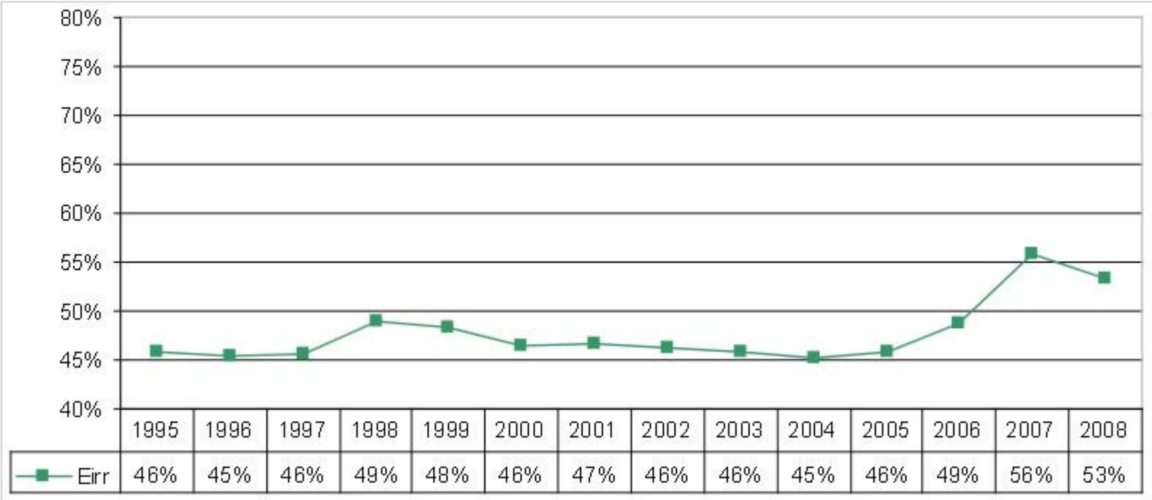


Figure 3. Irrigation water efficiency index achieved in the period 1995-2008 in Croatia. (Source: Sasa Devic: Water use efficiency and economic approach. National study Croatia., 2011, Plan Blue, UNEP/MAP Regional Activity Centre. http://planbleu.org/sites/default/files/publications/national_report_water_hr.pdf)

- Moldova: There is an ongoing Irrigation Sector Reform Services to improve the productivity and sustainability of irrigated agriculture in Moldova by improving water delivery to the higher value commercial crops. According to strategic documents the target for the coming 5-7 years is to improve irrigated infrastructure for around 60 000 ha agricultural lands in different parts of the country.
http://www.mathematica-mpr.com/international/moldova.asp

  http://www.feedthefuture.gov/article/irrigation-reform-and-rehabilitation-supports-high-value-agriculture-moldova

- In Hungary the Ministry of Regional Development in cooperation with the Hungarian Chamber of Agriculture conducted a national survey during the first quarter of 2014 among the agricultural producers (farmers, agricultural cooperatives, companies) on their current irrigation water use and future irrigation plans and irrigation water needs. 4000 questionnaires were returned via a newly developed web site. Comprehensive database was compiled, from which thematic maps (Figures 4 and 5), graphs and tables can be made (Table 2).

Table 2. Outcomes of national irrigation survey of Hungary in 2014.

	No.	Requested amount of water (m^3/year)	Irrigated area (ha)
Farms which have water rights permit and actively do irrigation	1 052	228 685 933	109 226
Farms which have water rights permit, but do not irrigate	88	3 783 762	4 036
Farms without water rights permit, and indicated that they would irrigate, and there is available water resources for them	3 031	280 862 452	126 117
Farms without water rights permit and indicated that they would irrigate, but there is no available water resources*	2 740	119 098 966	91 604

Source: Hungarian National Water Authority (2014): National irrigation survey.

* Note: No available water resources means that either there is no water body from which irrigation can be solved or the water body is not in good or better status according to the Water Framework Directive classification. No water rights permit can be gained for irrigation if the water body is not in good or better status.

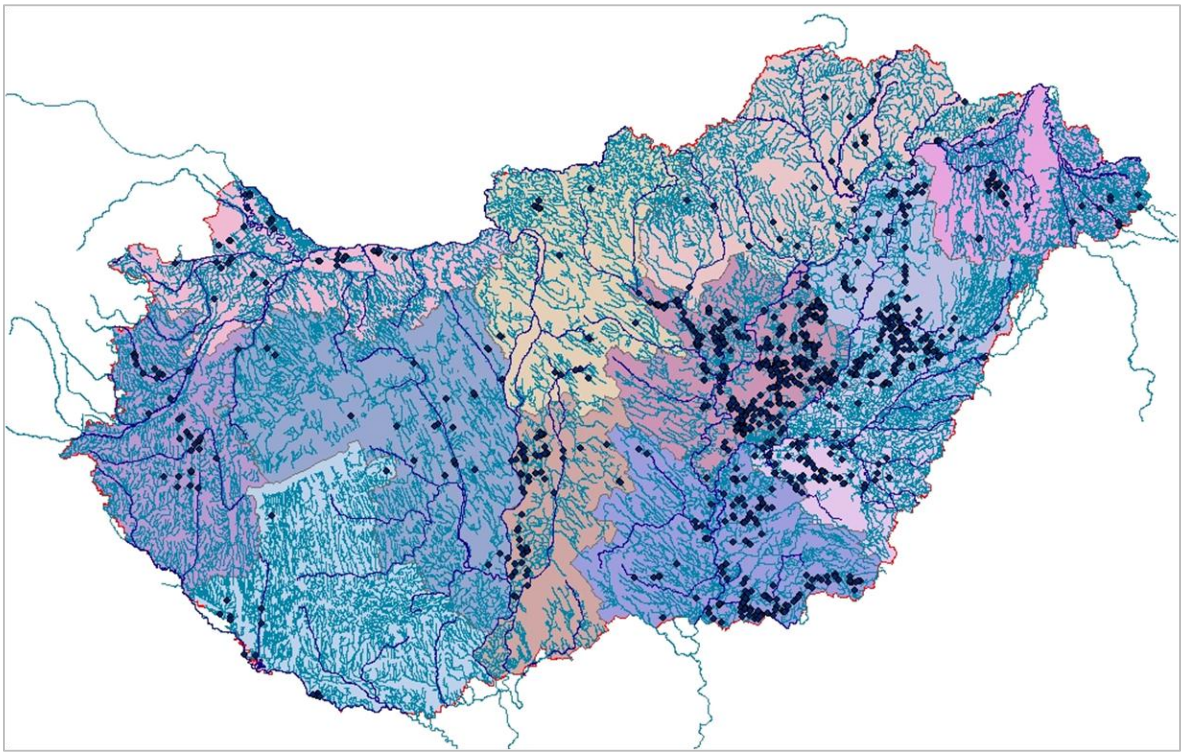


Figure 4. Location of farms in Hungary with water rights permit and actively do irrigation. (Source: National Irrigation Survey, 2014; OVF National Water Authority, Hungary.)

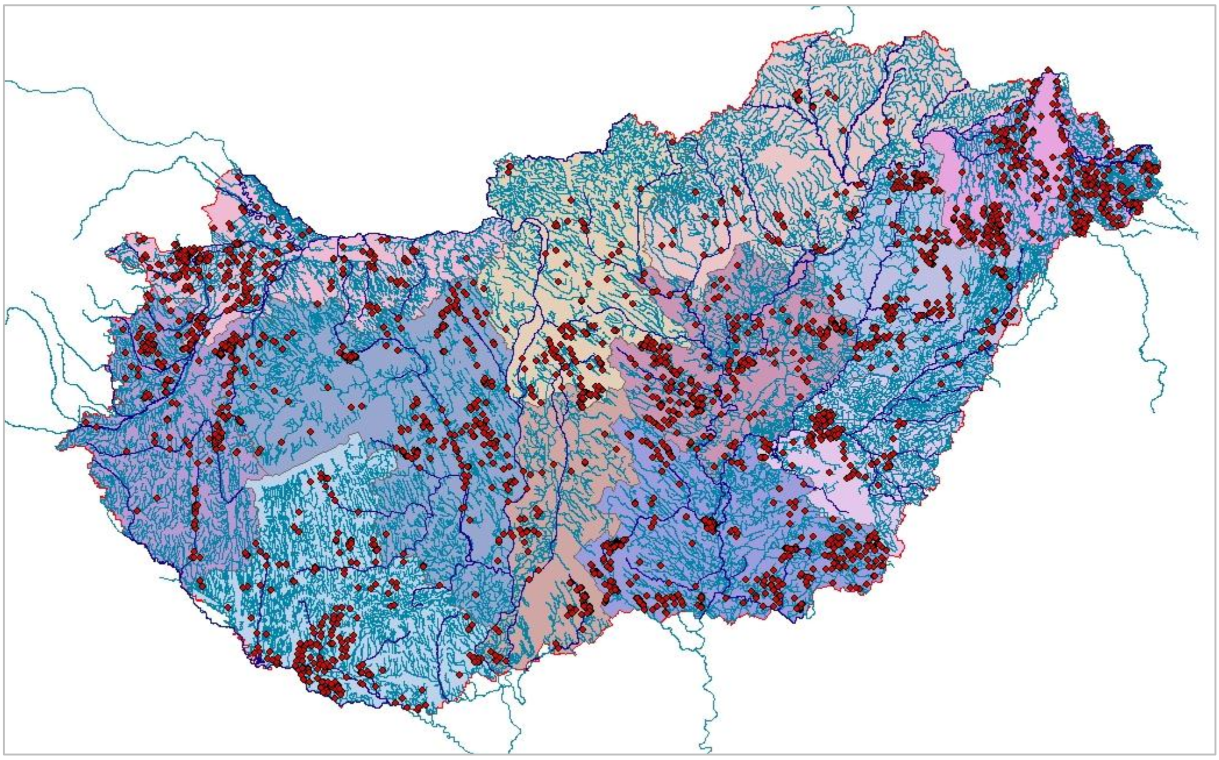


Figure 5. Location of farms in Hungary without water rights permit and indicated that they would irrigate, but there is no available water resources. (Source: National Irrigation Survey, 2014; OVF National Water Authority, Hungary.)

In Hungary the following figures represent the irrigation efficiency:
- Surface irrigation methods: 25-35%
- Sprinkler irrigation 75-80%
- Drip irrigation 85-95%.

- In Romania irrigation will become the main water consumer in agriculture and one of the most important one on national scale, requiring, on the average, about 35 - 45 % of water resources (Bucur et. all, 2010). The average irrigation rates ranged between 840 - 1060 m3/ha, being lower in North and higher in South.

- In Slovenia, currently only 5300 ha of agricultural land is being irrigated in comparison with 63,000 hectares where irrigation would be possible. Only 1% of water consumption (2.2 mio.m3/year) is used for irrigation. Agricultural sector is making strong pressure to increase irrigation systems, but a big problem is the bureaucratic procedure for obtaining permits for this type of water use. Figure 6 shows the irrigation water use potential for surface waters, reservoirs and groundwater in Slovenia.

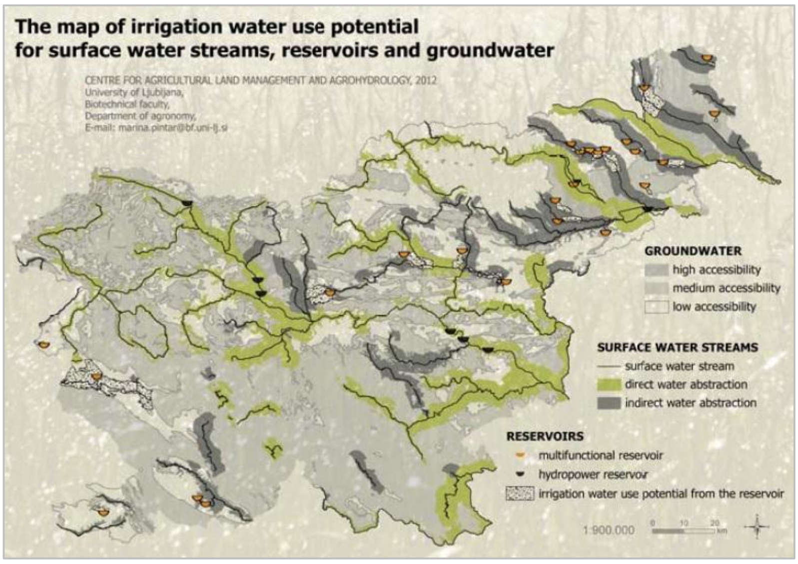


Figure 6. Map of Slovenia with irrigation water potentials. (Source: (http://www.bf.uni-lj.si/fileadmin/users/1/agronomija/V4-1066/p117-119_Marina_Pintar_1.pdf).

References to Irrigation efficiency increase

Bucur D., S. Cîmpeanu, C. Ailincăi, P. Konvalina and J. Moudry (2010): Aspects regarding the energetically efficiency of irrigation of some crops in North-East Romania. Annals. Food Science and Technology, pp. 50-53., Vol. 11, Issue 1. http://afst.valahia.ro/docs/issues/2010/issue%201/2010-2-5-BucurD.pdf

Coric, E. (2011): Water use efficiency and economic approach. National study Bosnia and Herzegovina, Plan Blue, UNEP/MAP Regional Activity Centre. http://planbleu.org/sites/default/files/publications/national_report_water_bh.pdf

Devic, S. (2011): Water use efficiency and economic approach. National study Croatia., Plan Blue, UNEP/MAP Regional Activity Centre. http://planbleu.org/sites/default/files/publications/national_report_water_hr.pdf

National Irrigation Survey, 2014; OVF National Water Authority, Hungary

FAO Document Repository. http://www.fao.org/docrep/t7202e/t7202e08.htm

T. aus der Beek, M. Florke, D. M. Lapola, R. Schaldach, F. Voß, and E. Teichert (2010): Modelling historical and current irrigation water demand on the continental scale: Europe. Adv. Geosci., 27, 79–85, 2010 http://www.adv-geosci.net/27/79/2010/adgeo-27-79-2010.pdf

World Bank, World Development Indicator http://www.indexmundi.com/facts/indicators/AG.LND.IRIG.AG.ZS

2.3 Water re-use by industry

Industrial wastewater re-use can be classified as cooling, boiler feed, and process water. Cooling water accounts for 90 percent of the total industrial consumption. Recycling cooling water is the backbone of any savings practice. Simple engineering design modifications, changes in nozzles to reduce flow rates, a shift from continuous to intermittent systems, sequential reuse, and monitoring for leaks are some of the basic techniques. Impurities such as suspended solids can be treated relatively easily and reused in the same process. Reclaimed municipal wastewater can be used for cooling with some minor treatment (Visvanathan, C. and Takashi Asano, 2013).

JRC used some *scenarios of water re-use by industry* in its impact assessment for the "Blueprint to Safeguard Europe's Water Resources", which included the Danube Basin.

- It was assumes that 50% of the water abstracted for industry is reused, which led to a reduction in freshwater abstraction.
- Costs were assumed at 0.013 Euro per m^3 for re-used water, and adjusted for national

Scenario assessment for the Danube River Basin

Statistics on industrial yearly freshwater use (abstraction) is available from national Statistical Offices (Authorities) and Eurostat. Contrary to freshwater use statistics no data is reported officially on water re-use by industry by either organisation.

EEA Report No.1/2010 states that the available information base is still too weak to provide regional assessment of past trends and of prospects for the use of water resources for the Western Balkan countries of the Danube Basin (Bosnia and Herzegovina, Croatia, Montenegro, Serbia).

A comprehensive study on EU water saving potential by Dworak et al., 2007 states that "The use of water varies greatly from country to country and from region to region. Data on water use by regions and by different economic sectors are among the most sought after in the water resources area. Ironically, these data are often the least reliable and most inconsistent of all water-resources information6. The availability of good data directly aggregated even at national level was a major constraint.
It has been stated before by other studies that reliable and comprehensive data on water supply and demand is hard to come by.
The following data gaps and major uncertainties for industrial sector were found:

- Water consumption and demand varies widely among the different subsectors;
- Rates of industrial water reuse were poorly reported."

In the international literature no publication was found which deals with the general assessment or statistics of water re-use by industry for the Danube River Basin. Only scattered publications are available, which discuss specific industrial sector water reuse for some countries or regions.

References to Water re-use by industry

Dworak Th., M. Berglund, C. Laaser, P. Strosser, J. Roussard, B. Grandmougin, M. Kossida, I. Kyriazopoulou, J. Berbel, S. Kolberg, J. A. Rodríguez-Díaz and P. Montesinos (2007): EU Water saving potential (Part 1 –Report), Ecologic - Institute for International and European Environmental Policy, In co-operation with ACTeon, National Technical University of Athens and Universidad de Córdoba. ENV.D.2/ETU/2007/0001r

EEA European Environmental Agency (2010): Environmental trends and perspectives in the Western Balkans: future production and consumption patterns. EEA Report No. 1/2010, Copenhagen, DK. ISSN 1725-9177. http://www.eea.europa.eu/publications/western-balkans (Accessed 4 June 2014.)

Visvanathan, C. and Takashi Asano (2013): The potential for industrial wastewater reuse http://www.worldwewant2015.org/node/303908

2.4 Treated urban waste water re-use for irrigation

JRC used some *scenarios of treated urban waste water re-use for irrigation* in its impact assessment for the "Blueprint to Safeguard Europe's Water Resources", which included the Danube Basin, as well. The consideration was:

- 50% reduction in the use of deep groundwater for irrigation; instead treated urban wastewater is used for irrigation

A state-of-art overview on Natural Technologies of Wastewater Treatment was published by Global Water Partnership Central and Eastern Europe (Rozkošný et al., 2014) including a chapter on "*Reuse of Treated Wastewater for Irrigation*", which discussed in sub-chapters

i) Suitability of Wastewater for Irrigation
ii) Hygiene Directive on Wastewater Irrigation
iii) Irrigation Regime during Wastewater Irrigation
iv) Wastewater Irrigation Arrangement
v) Design of Irrigation (Irrigation Detail)
vi) Gravity Irrigation Methods for Treated Wastewater

Scenario assessment for the Danube River Basin

- No comprehensive statistics found so far for the Danube Basin.
- Experts estimate: 5-7 % of collected urban wastewater is re-used for irrigation.
- In the international literature no publication was found which deals with general assessment or statistics on treated urban waste water re-use for irrigation for the Danube River Basin. Only scattered publications are available which discuss specific elements of treated urban waste water re-use for irrigation for some countries or regions.

In the next assessment phase more detailed specification should be given on what actual information would be needed for the DWN purpose.

References to Treated urban waste water re-use for irrigation

Miloš Rozkošný, Michal Kriška, Jan Šálek, Igor Bodík, Darja Istenič (2014): Natural Technologies of Wastewater Treatment. Global Water Partnership Central and Eastern Europe, p. 138., ISBN: 978-80-214-4831-5. http://www.gwp.org/Global/GWP-CEE_Files/Regional/Natural-Treatment.pdf

2.5 Increase of mini-hydropower

The assessment on hydropower issues (mini-hydropower discussed in this sub-chapter and large hydropower facilities discussed in the next sub-chapter) had to be based on regional criteria included in the ICPDR document on Guiding Principles on Sustainable Hydropower Development in the Danube Basin (ICPDR, 2013). The following general criteria are used for sustainable hydropower development:

- hydropower development needs to respect the principle of sustainability
- hydropower should be part of a holistic approach of energy policy
- national / regional hydropower strategies should be elaborated
- public interests should be handled in transparent, structured and reproducible way
- a hydropower project is not automatically of overriding public interest
- role of citizens and citizens' groups, interested parties and non-governmental organisations is crucial to optimize planning
- hydropower development has to take into account effects of climate change

JRC used no *scenarios of increase of mini-hydropower* in its impact assessment for the "Blueprint to Safeguard Europe's Water Resources", which included the Danube Basin.

No scenarios were reported on increase of mini-hydropower.

Scenario assessment for the Danube River Basin

In 2013 ICPDR has carried out a comprehensive assessment on hydropower generation in the Danube Basin (ICPDR, 2013a and b). These documents provide up-to-date information on the existing small and medium and large hydropower stations, inter alia on their locations (Figure 7), contribution of different hydropower plant categories to electricity generation (Figure 8) and Total number of existing hydropower plants for different plant sizes (Figure 9).

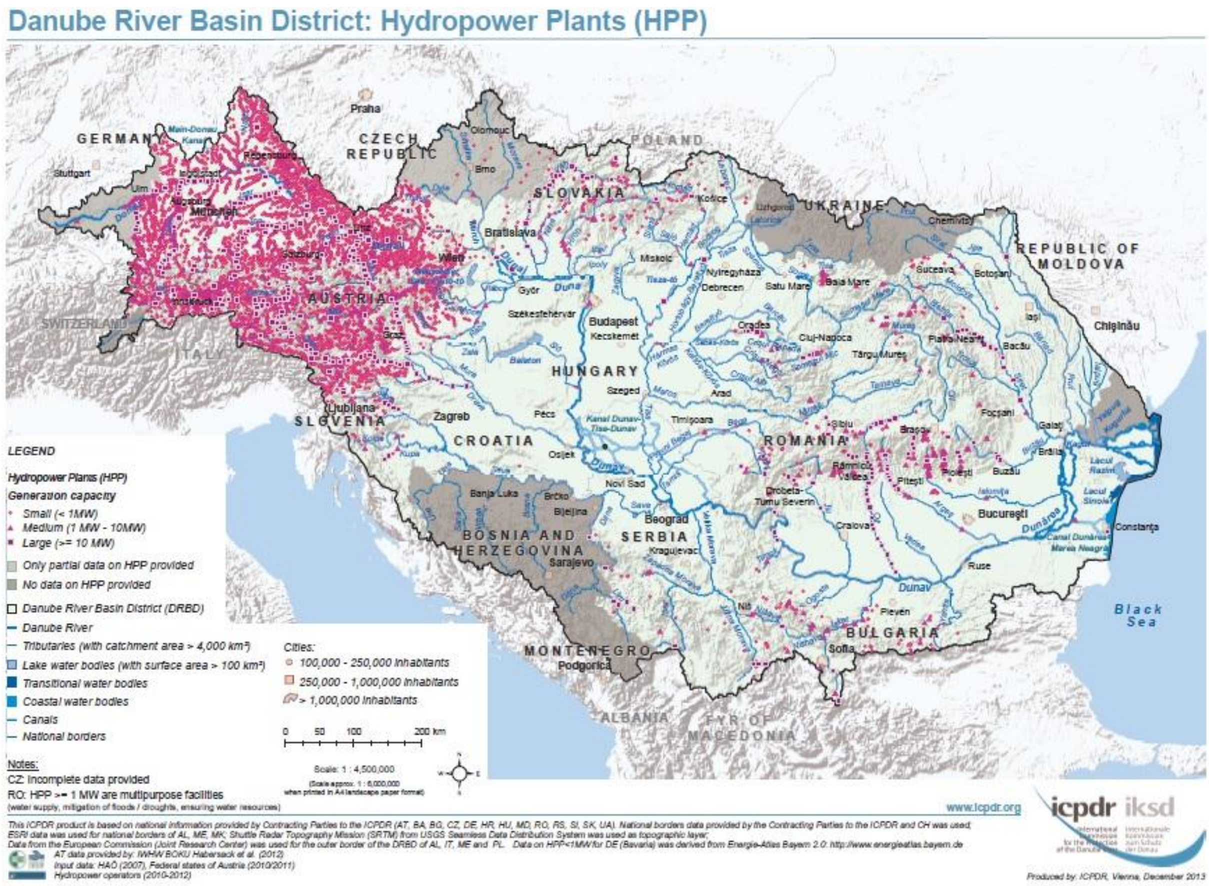


Figure 7. Location of hydropower plants in the Danube Basin. (Source: ICPDR, 2013b)

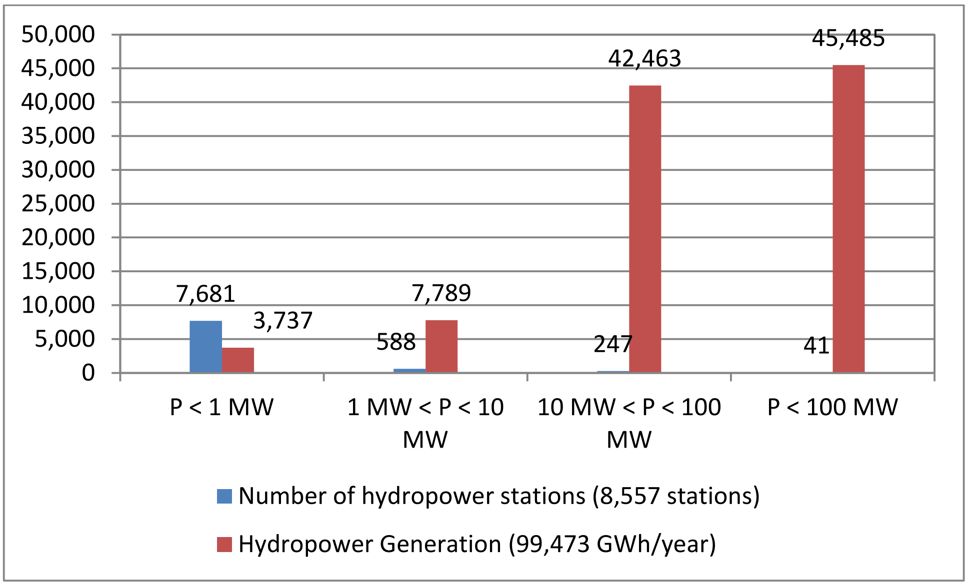
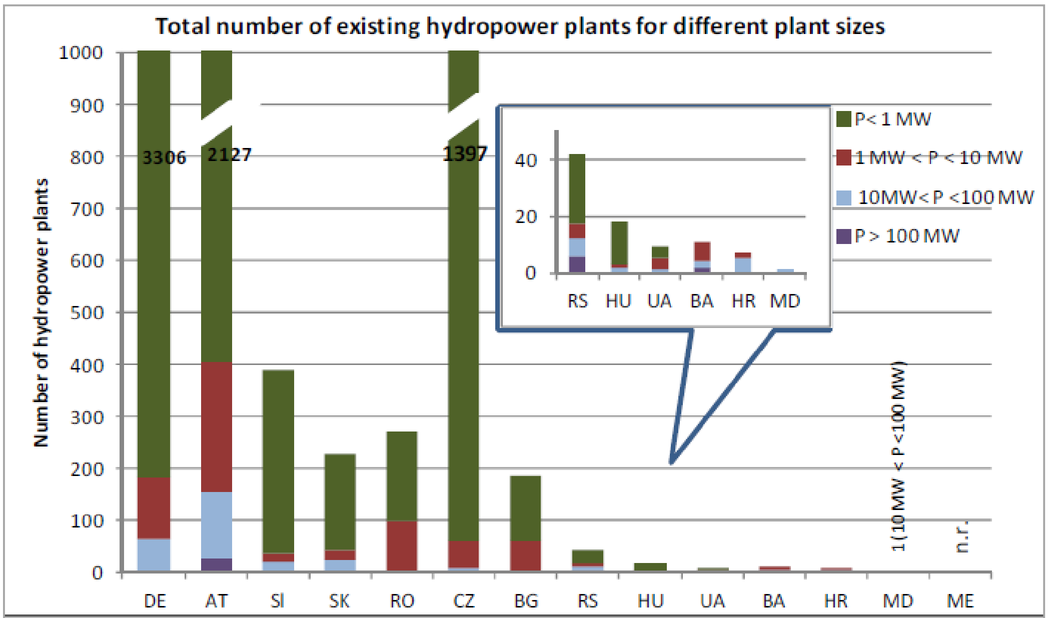


Figure 8: Contribution of different plant categories to electricity generation from hydropower (Source: ICDPR, 2013b).



Notes:
- AT, BG, HU, MD, RS, SI and SK reported data for the whole country. RO data are relevant both for the Romanian part of the Danube River Basin as well as for the whole country.
- BA, DE, HR and UA reported data for the national part of the Danube River Basin only.
- CZ reported data for the whole country. Separate CZ data for P > 100 MW are not available; the data are included in category "10 MW < P < 100MW".
- RS: This value includes Kosovo - a territory defined by the United Nations resolution 1244 (1999) as an autonomous province of the Republic of Serbia administered by the UN.

Figure 9: Total number of existing hydropower plants for different plant sizes. (Source: ICDPR, 2013b).

Table 2 gives a summary of Danube countries source of contribution by hydropower to the 2020 renewable energy targets.

Table 2. Danube countries source of contribution by hydropower to the 2020 renewable energy targets (Source: ICPDR, 2013b)

	Main source of contribution	**Minor source of contribution**	**Negligible source of contribution**
Construction of new hydropower plants	AT, BA, HR, RO, RS, SK, SI: (HPP>10 MW), UA	CZ, DE, SI: (HPP < 10 MW)	
Refurbishment of plants	CZ, DE, HU	AT, BA, HR, RO, RS, SI	SI, UA
Modernisation and maintenance of plants	CZ, DE, HU, RO	AT, BA, HR, RS, SI	BA, SI

Complementary information from EU Danube countries

Hungary:

- Extension of Paks Nuclear Power Station? (Maybe there will be a need for a hydropower station the south Hungarian Danube section)
- There a long time considered water transfer from the Danube to the Tisza River, called the Danube -Tisza Channel. If it will be constructed some of the elements of the system will be used for hydropower generation as well.
- Another long time considered scheme is a hydropower station construction at the lower Hungarian section of the Tisza River.

Slovenia:

- Small hydro power plants are no more desirable, because too many negative effects on environment appeared in the past.

Complementary information from Non-EU Danube countries

Hydropower is one of the most important energy source for electricity production in most of the South East Europe and therefore it is an energy source with a great strategy importance. Hydro sources have a predominant share in power generation in Bosnia-Herzegovina, Croatia, Montenegro and Serbia. However, the existing hydro power plants provide inadequate electricity supply for these countries. It is expected that refurbishment of existing old hydro power plants will improve the power generation output and the economics. Currently the installed capacity of small hydro power in the region is 1 700 MW, but the actual potential is much higher.

Bosnia and Herzegovina has ambitious plans for several hydro power plants, e.g. on the Neretva (Non-Danube river) and Drina and a cascade on the Bosna River (McGarath et al., 2010).

The Croatian government has developed its new energy strategy, which foresees investments in coal, gas, hydropower and possibly nuclear, in spite of the country's lack of coal resources. Renewable energy is marginalised and there is no commitment for an overall increase by 2020 (McGarath et al., 2010).

References to Increase of mini-hydropower

Alpine Convention (2011): Situation Report on Hydropower Generation in the Alps focusing on Small Hydropower, platform "Water management in the Alps", 2011 http://www.alpconv.org/documents/Permanent_Secretariat/web/WG/2011_Situation_Report.pdf

ICPDR (2013a): Sustainable Hydropower Development in the Danube Basin. Guiding Principles. (http://www.icpdr.org/main/sites/default/files/nodes/documents/icpdr_hydropower_final.pdf)

ICPDR (2013b): Assessment Report on Hydropower Generation in the Danube Basin. (http://www.icpdr.org/main/activities-projects/hydropower)

McGrath, F., P. Gallop and A. C. Lesoska (2010): Can the international financial institutions do more to support new renewables and energy efficiency in Southeast Europe? Analytical Journal, Vol.3, Issue 2, December 2010, pp. 8-34. http://www.analyticalmk.com/files/04-2010/journal_06.pdf

2.6 Increase of large hydropower facilities

JRC used no *scenarios of increase of large hydropower facilities* in its impact assessment for the "Blueprint to Safeguard Europe's Water Resources", which included the Danube Basin.

No scenarios were reported on increase of large hydropower facilities.

Scenario assessment for the Danube River Basin

Montenegro is moving ahead with plans for a new 240 MW installed capacity HPPs on the River Moraca (Non-Danube) (tender underway) and a 170 MW one on the River Komarnica (Non-Danube). These investments are associated with a planned cable for export of electricity to Italy (McGarath et al., 2010).

Slovenia: Construction of hydro power plants on the rivers Mura and its Soča there are still unresolved issue about the use of both rivers and the construction certainly will not be realized until the 2021.

References to Increase of large hydropower facilities

McGrath, F., P. Gallop and A. C. Lesoska (2010): Can the international financial institutions do more to support new renewables and energy efficiency in Southeast Europe? Analytical Journal, Vol.3, Issue 2, December 2010, pp. 8-34. http://www.analyticalmk.com/files/04-2010/journal_06.pdf

3. Indicators ideally be included in the Danube Water Nexus analysis

Environmental indicators have been defined in different ways but common themes exist. "An environmental indicator is a numerical value that helps provide insight into the state of the environment or human health. Indicators are developed based on quantitative measurements or statistics of environmental condition that are tracked over time. Environmental indicators can be developed and used at a wide variety of geographic scales, from local to regional to national levels."
"A parameter or a value derived from parameters that describe the state of the environment and its impact on human beings, ecosystems and materials, the pressures on the environment, the driving forces and the responses steering that system."
(http://en.wikipedia.org/wiki/Environmental_indicator)

All Danube countries are members of the European Environmental Agency (EEA), which elaborated 146 environmental indicators and maintains them using data flows from 33 EEA members states and six cooperating countries.
EEA published an overview of the used indicators in its *Environmental Indicator Report 2013. Natural resources and human well-being in a green economy.* The report is accessible at http://www.eea.europa.eu/publications/environmental-indicator-report-2013 while actual indicators can be accessed at: www.eea.europa.eu/data-and-maps/ indicators.

EEA indicators can be grouped according to indicator focus using DPSIR concept or indicator type (A - Descriptive indicators: 'What's happening?; B - Performance indicators: 'Does it matter?', 'Are we reaching targets?'; c - Efficiency indicators: 'Are we improving?'; D - Policy effectiveness indicators: 'Are the measures working?'; E - Total welfare indicators: 'Are we on the whole better off?'). The 146 environmental indicators cover 12 thematic areas, such as agriculture, air pollution, biodicersity, climate change, energy, transport, waste, water, green economy, household consumption, fisheries, and land and soil.

The Danube Water Nexus modelling work will be based on the methodology JRC has developed for the support the preparation of EU Blueprint document. JRC published its scientific and policy report of that work with the title "*A multi-criteria optimisation of scenarios for the protection of water resources in Europe. Support to the EU Blueprint to Safeguard Europe's Waters*". Indicators used by JRC are listed in Table 3 together with the recommended relevant EEA indicators.

Table 3. JRC used indicators and their corresponding EEA indicators

Indicator type	JRC used indicators	Relevant EEA indicators
Environmental indicator	Env10 (days) Environmental Flow: number of days per year with discharge less than 10-percentile	River flow (CLIM 016)
	Env25 (days) Environmental Flow: number of days per year with discharge less than 25-percentile	River flow (CLIM 016)
Economic indicators	- Total estimated loss due to water scarcity for agricultural sector	Not available.
	- Total estimated loss due to water scarcity for the manufacturing-inductry sector	Not available.
	- Total estimated loss due to water scarcity for the energy-production sector	Not available.
	- Total estimated loss due to water scarcity for the domestic sector.	Not available.
	- Total estimated flood damage of a 100-year return period flood.	Not available.
Water indicators	- Water Exploitation Index	
	- NO3 average annual concentrations in rivers	Nutrients in freshwater (CSI 020)
	- PO4 concentrations in rivers	Nutrients in freshwater (CSI 020)
	- River flow (m^3/s) for 50-year return period flood	River flow (CLIM 016) River floods (CLIM 017)

	Total amount of water abstracted for use by various sectors (region total per year)	Use of freshwater resources (CSI 018)
	Total amount of water consumed by various sectors (region total per year)	Use of freshwater resources (CSI 018)
	Total amount of deep (geological) groundwater abstracted by various sectors (region total per year)	Use of freshwater resources (CSI 018)

Water quality indicators

In the Danube River Basin a TransNational Monitoring Network (TNMN) was established under the Danube River Protection Convention by the contracting countries. The TNMN is based on national surface water monitoring networks and includes 79 monitoring locations with up to three sampling points across the Danube and its main tributaries river (Figure 10). The minimum sampling frequency is 12 times per year for chemical determinands in water and twice a year for biological parameters. The TNMN was formally launched in 1996. It aims to provide a well-balanced overall view of pollution and long-term trends in water quality and pollution loads in the major rivers in the Danube River Basin. The TNMN database is operated in the frame of ICPDR. (http://www.icpdr.org/main/activities-projects/tnmn-transnational-monitoring-network). Yearbooks from 1996 till 2011 and their corresponding data annexes can be found in download form at http://www.icpdr.org/main/publications/tnmn-yearbooks. Table 1 of the latest available yearbook (2011) gives a list of the monitorings sites with detailed information about their location.

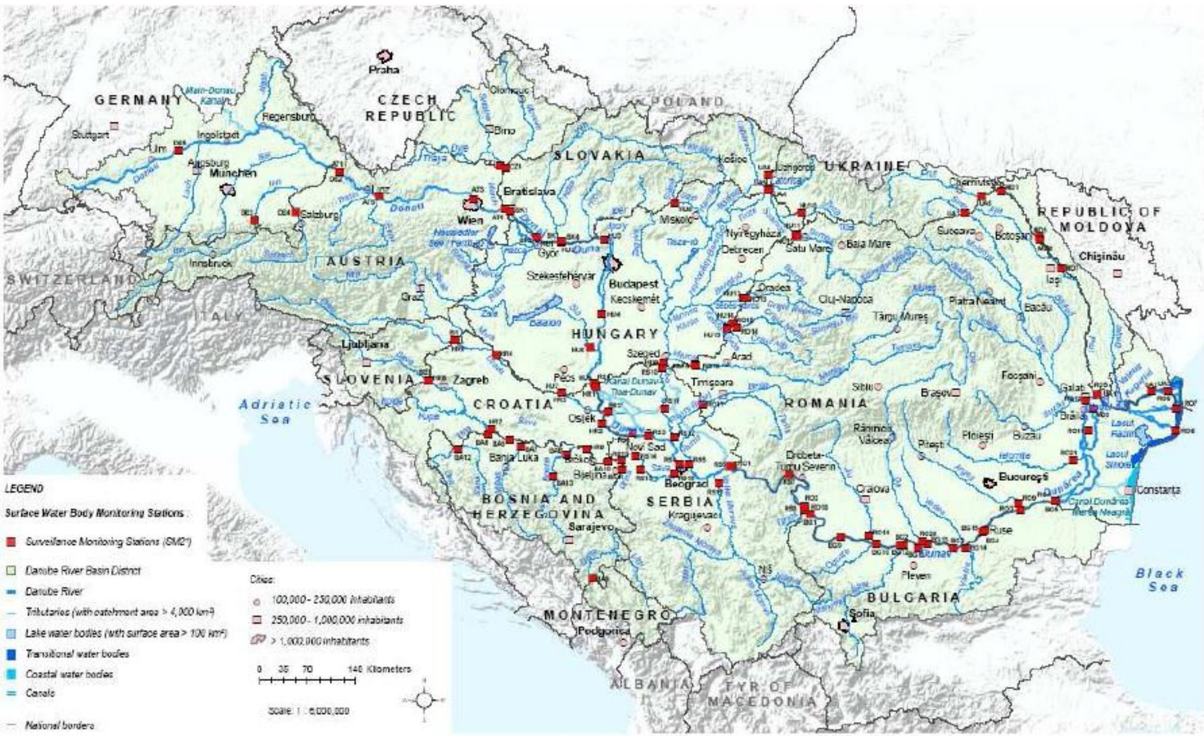


Figure 10. The Danube Stationmap TNMN (Source: ICDPR Water Qaulity in the Danube River Basin 2011 - TNMN Yearbook 2011. http://www.icpdr.org/main/publications/tnmn-yearbooks)

The assessment of loads in the Danube contributes greatly to estimates of the influx of polluting substances to the Black Sea, and provides vital information to support policy development. A special load assessment programme was started in 2000, with pollution loads calculated for BOD5, inorganic nitrogen, ortho-phosphate-phosphorus, dissolved phosphorus, total phosphorus, suspended solids, and - on a discretionary basis – chlorides. These indicators could be ideally used in the Danube Water Nexus analysis.

It is suggested to consider using additional water indicator in the DWN project. Water poverty index. The index can be defined by an expert. Five indices must be defined in the process: water resources (amount and quality), availability (the distance to water source, time of exploitation, existing conflicts), ability to obtain water (ability to cover the costs of water purification, the kind of water management, existing water cooperatives), use of water (rules of water management), environment (evaluation of the dependency between water and the environment, the state of ecosystem, erosion).

References to indicators

EEA European Environmental Agency (2010): Environmental trends and perspectives in the Western Balkans: future production and consumption patterns. EEA Report No. 1/2010, Copenhagen, DK., p. 171., ISBN 978-92-9213-091-6. http://www.eea.europa.eu/publications/western-balkans (Accessed on 4 June 2014.)

EEA European Environmental Agency (2012): Water resources in Europe in the context of vulnerability. EEA Report No. 11/2012, Copenhagen, DK., p. 92., ISBN 978-92-9213-344-3. http://www.eea.europa.eu/publications/water-resources-and-vulnerability (Accessed on 4 June 2014.)

EEA European Environmental Agency (2013): Environmental Indicator Report 2013. Natural resources and human well-being in a green economy. Copenhagen, DK., p. 148., ISBN 978-92-9213-412-9. http://www.eea.europa.eu/publications/environmental-indicator-report-2013

4. Overview of previous scenario studies in the Danube Basin

This chapter provides information in a predefined structure about those projects (mostly already finished, but some of them are still ongoing), which dealt with aspects of water resources management (surface and or groundwater), and have middle or long term scenario element as well as relevance to the Danube River Basin.

The following information is covered for each identified project: i) area covered by the project; ii) purpose of the study; iii) summary of the study; iv) year (project period); v) point of contact; and vi) website of the study.

At this stage only those projects were selected, which were accessible in English and electronically via internet. No projects were searched and selected, which had local character or information was available only in local language(s).

4.1 GLOWA - Danube: Impact of Global Change on the Upper Danube

Area covered by the project: Upper Danube Basin

Purpose of the study: GLOWA-Danube is a research and development program focusing on the comprehensive analysis of the future of water resources of the Upper Danube. The aim of GLOWA-Danube is to investigate with different scenarios the impact of change in climate, population and land use on the water resources of the Upper Danube and to develop and evaluate regional adaptation strategies. For this purpose the decision support system DANUBIA was successfully set up within the first and second project stage (2001-2006).

Summary of the study: As part of the GLOWA Danube project, a computer-aided integrated simulation tool was developed whose basic structure made it suitable for use in alpine catchments in temperate latitudes. The system's key feature is that it integrates both the results and observations of the various research disciplines (natural and social sciences) involved in the project.

Year: 2001 - 2010

Point of contact:

Prof. Dr. Wolfram Mauser
Dr. Sara Stoeber
Department of Geography
LMU Munich
Luisenstraße 37
80333 Munich
phone: +49 (0)89 2180 6684
fax: +49 (0)89 2180 6675
email: stoeber@iggf.geo.uni-muenchen.de

Website of the study: http://www.glowa-danube.de/eng/projekt/projekt.php

4.2 daNUbs - DAnube Nutriens Black Sea

Area covered by the project: The whole Danube River Basin

Purpose of the study: Mismanagement of nutrients in the Danube Basin has led to severe ecological problems including deterioration of groundwater, surface waters and the Black Sea. These problems are related to social and economic issues (e.g. water supply, tourism, fishery, agriculture). daNUbs was a multinational EU research project carried out under the leadership of the Technical University of Vienna. The results from this project include estimates of nutrient inputs into the river network (MONERIS), as well as an assessment of the loads of nitrogen, phosphorus and silica transported via the river network. These results indicate that the nutrient status in the Black Sea has significantly improved since the 1980s. The project delivered a basis for a proper management of nutrients in the Danube Basin.

Summary of the study: The project has

(i) achieved an improved process understanding on the sources, pathways and sinks of nutrients in the Basin and on the Black Sea ecosystem effected by nutrient discharges,

(ii) developed, improved and combined quantitative models on nutrient emissions, their transport along the rivers and their impact on the Black Sea and

(iii) evaluated appropriate socio-economic tools for strategy implementation. Results of the project will be methodological approaches suitable for large river systems influencing sensitive seas as well as tools for decision making in nutrient management

Year: 2001-2005

Point of contact:

Leibniz-Institute of Freshwater Ecology and Inland Fisheries in the Forschungsverbund Berlin e.V.
Müggelseedamm 310
12587 Berlin
IGB-website
Questions concerning MONERIS:
Dr. Markus Venohr
Telephone: +49 (0)30 64 181 683
E-Mail: m.venohr(at)igb-berlin.de

Website of the study: http://moneris.igb-berlin.de/index.php/danubs_en.html

4.3 FLOODRISK - Danube Flood Risk project

Area covered by the project: The whole Danube Basin

Purpose of the study: The overall objective of the FLOODRISK project was to develop and produce high quality, stakeholder oriented flood hazard and flood risk maps for the transnational Danube river floodplains to provide adequate risk information for spatial planning and economic development activities.

Summary of the study: Transnational methodology and models will be defined and implemented for flood risk assessment and mapping. This results in proposals for flood mitigation measures, adjustments of spatial development plans, assessment tools for economic development in flood plains and raised awareness of flood risk of stakeholders, politicians, planners and the public. Infrastructures at risk like industry, power stations and supply infrastructure will be considered in the project.

Year: 2009-2011

Point of contact:

MM- Ministry of Environment
Contact person: Dr. Mary-Jeanne Adler
Scientific Director
National Institute of Hydrology and Water Management
Senior adviser Ministry of Environment and Forests
Tel: +40 722 66 11 30
Fax: +40 21 317 99 95
e-mail mj.adler@hidro.ro
mj.adler@mmediu.ro
mj.adler@yahoo.com
Phone: 0040 (21) 316 21 05
Fax: 0040 (21) 316 02 82

Website of the study: http://www.danube-floodrisk.eu

4.4 The EnviroGRIDS @ Black Sea Catchment project

Area covered by the project: Danube Basin

Purpose of the study: EnviroGRIDS was clearly going beyond the state of the art in the Black Sea region by adopting a catchment approach and by tackling several societal benefits areas together. By using the most powerful computer network of the world it was clearly showing the direction on how to analyse the increasing amount of global data made available throughout the planet. It was bringing crucial information in a relatively data-poor region on future scenarios of expected climate, demographic and land cover changes. Based on the outputs of these scenarios it was building geoprocessing services in key societal benefits areas that will be connected back to the GEOSS.

Summary of the study:

Main innovations:

- Contribute to free publicly-funded data through interoperable databases and services
- Streamline data process from data warehouses, to scenarios, hydrological models, impacts assessments and finally to disseminations tools.
- Use grid enabled computer technology to store and analyse environment data
- Gridify the code of hydrological model calibration and validation
- Create regional scenarios of development in function of expected climate, land cover and demographic changes
- Build efficient virtual and life trainings on EnviroGRIDS main topics
- Make available useful open source software and data on DVD and on Internet
- Raise public and decision-makers awareness through innovative collaborative systems
- Provide an early warning system to inform the citizens and decision-makers on environmental vulnerability and risks associated to selected Societal Benefit Areas

Year: 2011-2013

Point of contact:

Universite de Geneve
Switzerland
Rue du General Dufour 24
Geneve 4, Switzerland

Administrative contact: Nicolas Ray
Tel.: +41-223790021
Fax: +41-223790744
E-mail

Website of the study: http://www.envirogrids.net

4.5 ESPON 2013 programme

Area covered by the project: European Union

Purpose of the study: Applied Research Projects, conducted under Priority 1 of the ESPON 2013 Programme, are thematically defined by the demand of policy makers. The projects create European wide, comparable information and evidence on territorial potentials and challenges focusing on opportunities for success for the development of regions and cities. Cross-thematic applied research is a major activity integrating existing thematic analysis and adding future analysis of new themes. Territorial impact studies of EU policies were another focuses under this priority.

Summary of the study:
Scenarios on the territorial future of Europe. ESPON project 3.2
http://www.central2013.eu/fileadmin/user_upload/Downloads/Tools_Resources/General/Espon_Scenarios_1.pdf

The report began with a description of the territorial trend scenario for 2030, followed by that of the competitiveness-oriented and the cohesion-oriented scenarios. The respective pictures of the European territory by 2030 were described by a virtual observer living in that period who had been witness to all of the changes that have taken place since the beginning of the 2000s. In the final chapter, a desirable though not unrealistic territorial image of Europe in 2030 is presented. This was complemented by an outline of the likely policy path necessary to achieve it. In Chapter 4.4 the report discussed scenarios on environmental sustainability in transport, settlement structures, energy, adaptation to climate change and general environmental protection.

Year: 2013
Point of contact: -
Website of the study:
http://www.espon.eu./main/Menu_Projects/Menu_AppliedResearch

4.6 ECCONET - Effects of climate change on the inland waterway networks

Area covered by the project: Danube Basin
Purpose of the study: The project built on past and ongoing research in meteorology, hydrology, infrastructure operation, ship-building, transportation, and economics to assess the various effects of climate change on navigation conditions and to analyse adaptation measures to decrease the sensitivity of inland waterway transport to climate change.
Summary of the study: The project evaluated recent climate change scenarios, leading to predictions on the weather conditions in the future.

In the next step of the project the transport model was calibrated to the current climate and economic conditions. Then, the effect of changes in the economy (increase in demand for transport) and changes in climate conditions on the costs and reliability of inland waterway transport and other transport modes were evaluated, thereby referring to a time horizon 2050. These calculations formed the basis for a reference scenario, where no adaptation strategies related to IWT are assumed. Possible changes in transport flows and further economic impacts (e.g. in terms of a welfare changes) were also investigated.

In parallel with the construction of the reference scenario, proper adaptation strategies for coping with possible climate change effects on IWT were identified. The project assessed them with respect to their applicability, implementation and costs.

As a result of the previous steps, the project established policy guidelines and a development plan for IWT. This provides targeted input to the European IWT infrastructure development plan to be elaborated within the FP7 project PLATINA, which is dedicated to the implementation of NAIADES. The results of the project were disseminated during workshops organised within each work package and communicated to a larger group of stakeholders.

Year: 2010-2012
Point of contact: Project coordinator:
Christophe Heyndrickx

christophe.heyndrickx@tmleuven.be
+32 16 74.51.21
Website of the study: http://www.ecconet.eu/partners/index.htm

4.7 CC-WARE

Area covered by the project: South-East Europe
Purpose of the study: CC-WARE aimed at developing an integrated transnational strategy for water protection and mitigating water resources vulnerability. This strategy built the basis for an implementation of national and regional action plans. The concept for national action plans transferred the achieved and developed knowledge and resulting measures into the regions and on local level to strengthen the institutional capacity and human resources at national, regional and local level. A framework was setup on national level with respect to legislation as well as national and regional institutional structures to enable the implementation of the strategy developed on transnational level smoothly after project duration to assure a long term impact of the CC-WARE project.
The main objectives of the project CC-WARE are:

- The development of an integrated transnational strategy for water protection and mitigating water resources vulnerability as basis for an implementation of national / regional action plans
- Transfer of the achieved and developed knowledge and resulting measures into the regions and on local level to strengthen the institutional capacity and human resources at national, regional and local level
- Setup of a framework on national level in regard to legislation and national / regional institutional structures to be able to implement the strategy developed on transnational level smoothly after project duration to assure a long term impact of CC-WARE project
- The extension of the promotion of implementing national activities for mitigating vulnerability of drinking water supply based on a jointly developed transnational strategy to the entire SEE area with special regard to pre-accession countries
- The upmost dissemination of the gained knowledge regarding the strategy how to implement national action plans to relevant policy makers and stakeholder particularly of pre-accession countries through consultations, workshops and publications.

Summary of the study: -
Year: 2012-2014
Point of contact: Susanne Belihart
susanne.belihart@prisma-solutions.at
Website of the study: http://www.ccware.eu/

4.8 CC-WaterS

Area covered by the project: South-East Europe
Purpose of the study: Climate change affects fresh water resources and may have significant influence on public drinking water supply. Land use activities exert pressure on water resources and will change according to climate change. It is crucial for safeguarding future water supply to anticipate these climate and land use changes and to assess their impacts on water resources.

Transnational action is needed to prepare the South East European Space for the challenge of ensuring water supply for society for several decades. Policy makers and water suppliers are required to develop sustainable management practices for water resources, considering existing and future influences of climate change. Therefore CC-WaterS identified and evaluated resulting impacts on availability and safety of public drinking water supply for several future decades.

Elaborated measures to adapt to those changes build the ground for a Water Supply Management System regarding optimization of water extraction, land use restrictions, and socio-economic consequences under climate change scenarios for water suppliers in SEE.

The joint actions to produce this technical system were performed on a transnational level in the Alps, Danube Middle and Lower Plains and coastal areas representing different SEE-characteristic climates and topography.

In CC-WaterS, SEE governmental bodies, water suppliers and research institutions work together and implement jointly developed solutions, hence to be applied on a regional or local level in SEE. The complementary knowledge of the partners, enhanced by further applicable results of past projects, provided a strong background.

Capitalising already existing knowledge and data from EU-funded scientific projects and eliminating parallel investigations, CC-WaterS made information applicable for concrete solutions, develop tools and instruments for public water supply and implement safeguarding measures. An accessory dissemination strategy ensured that CC-WaterS' durable results were transferred to the relevant users.

Summary of the study:

Year: 05. 2009 - 04. 2012

Point of contact: Ms Marina Mader
marina.mader@prisma-solutions.at

Website of the study: http://www.ccwaters.eu/

4.9 Danube Study - Climate Change Adaptation

Area covered by the project: Danube River Basin

Purpose of the study:

The purpose of the study was to provide foundations for a common, Danube-wide understanding and procedure for adaptation to water resources management related climate impacts with the aim to develop suitable adaptation strategies in the Danube River Basin. The outcomes of the study had to provide a basis for the development of a basin-wide adaptation strategy in the Danube River Basin with the ICPDR team of experts.

Summary of the study:

The study was divided into the following four work packages:

1. Compilation of results and data of research and development projects as well as adaptation activities in relation to water related impacts of climate change in the Danube River Basin.
2. Analysis of the data collection to comprise
   a) commonalities, contradictions in results and approaches
   b) dependencies, competing interests and possible conflicts
   c) deficits of knowledge

3. Derivation of requirements for integrative, sustainable ("no regret measures") adaptation to climate change in water related issues in the Danube River Basin on national, regional and international level.
4. Suggestions as basis for development of a basin-wide adaptation strategy to climate change in water related issues in the Danube River Basin with / for the ICPDR team of experts.

Year: 1. 12. 2010 - 31. 1. 2012.

Point of contact:

Project coordinators: Prof. Dr. Wolfram Mauser (w.mauser@lmu.de)
Dr. Monika Prasch (m.prasch@lmu.de)
Department of Geography
Chair for Physical Geography and Remote Sensing
Ludwig-Maximilians-Universitat Munich
Luisenstr. 37
80333 Munich
Germany

Website of the study:
http://www.icpdr.org/main/activities-projects/climate-change-adaptation

4.10 Global Warming Induced Water-Cycle Changes and Industrial Production - A Scenario Analysis for the Upper Danube River Basin

http://cesifo-group.net/DocDL/IfoWorkingPaper-94.pdf.

Area covered by the project: Upper Danube River Basin

Purpose of the study:

For the Upper Danube catchment covering Germany and Austria the project aimed on answering the following questions:

- Climate change is one of the main global issues for sustainable development, but is it also an issue for German and Austrian regions?
- What are the regional causes for water scarcity: climate or society?
- How can society compensate for climate change and how can differing policy scenarios be evaluated with respect to sustainability?
- What are the small-scale effects and regional differences? E.g. how do cities perform versus rural areas?
- What are the effects of climate change on economic development given the close interconnection of climate change and the water-cycles?

Summary of the study:

Using the AFiD Panel the project calibrated the environmental decision support system DANUBIA and simulated the effects of *different climate change and socioeconomic scenarios up to 2025*. The results show a general decline in water usage accompanied by worsening conditions in natural water-cycles. Thus, climate change is an issue for the sustainable development in German and Austrian regions although it is comparatively moderate. The project observed large regional disparities in the extensively analyzed upper Danube River Basin. These are mainly caused by climate change, but also by society. The results showed that cities were economically less affected by climate change than rural areas. The results allow the identification of regional hot spots and a quantification of the effects of various policy measures that aim at compensating society for climate change with respect to economic and environmental sustainability.

However, the potential improvements in the observed socio-economic scenarios are limited since their effect is minor compared to the impact of climate change.

Year: 2010

Point of contact: Christoph J eBberger
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Website of the study: www.cesifo-group.de

4.11 SCENES - Water Scenarios for Europe and Neighbouring States

Area covered by the project:

Purpose of the study:

SCENES was a multi-faceted integrated project that aimed to address the complex questions about the future of Europe's water resources. The approach aimed at combining and balancing the many dimensions of Europe's water futures, including hydrological, ecological, economic, cultural, social, climatic and financial dimensions. SCENES operated on multiple scales including analysis at the pan-European, regional, and pilot scales and on their interactions. The overarching objectives of SCENES were firstly to improve different methodologies for developing scenarios of Europe's waters and to develop and analyze a set of comprehensive scenarios of Europe's fresh waters up to 2025 and 2050 through a participatory process. Furthermore, SCENES aimed at evaluating the socio-economic, environmental and ecological impacts of the different water scenarios, and increasing the stakeholder awareness on the water scenarios. Finally, SCENES initiated an on-going process in Europe of scenario development.

http://www.wise-rtd.info/sites/default/files/d-2008-05-07-SCENES_brochure.pdf

Summary of the study:

SCENES provided input to the development of water-related policies in Europe, and indirectly, to water-related standards and regulations. On European scale, SCENES identified and addressed key policy questions that had to do with the future of Europe's water resources. For example, it was expected that European Commission (EC) agencies, such as the various Directorates and the European Environment Agency, would be able to use information from SCENES scenarios. Through the four SCENES case study regions, the project had an opportunity to generate region-specific and region relevant information. A direct way to bring SCENES results forward to both pan-European and regional key stakeholders (ca. 250 persons) went through their participation in the SCENES panels. The use of state-of-the-art techniques in water use, water availability and water quality modelling on appropriate spatial and temporal scales together with consolidated data sets from across Europe allowed to disentangle the effects of various drivers and stressors.

Year: 1. 11. 2006. - 31. 10. 2010.

Point of contact:

Co-coordinators:

Prof. Juha Kämäri
Finnish Environment
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Prof. Joseph Alcamo
Institute University of Kassel
alcamo@usf.uni-kassel.de

Website of the study:
http://www.wise-rtd.info/en/info/water-scenarios-europe-and-neighbouring-states

4.12 ClimateWater

Area covered by the project:
Purpose of the study:
ClimateWater's main objectives were analysing and synthesising data and information on the likely (known, assumed, expected, modelled, forecasted, predicted, estimated) water-related impacts of changes in climate with special regard to their risk and to the urgency of preparation to combat these changes and their impacts. The Project identified adaptation strategies that were, and could be, developed in Europe (and also globally) for handling (preventing, eliminating, combating, mitigating) the impacts of global climate changes on water resources and aquatic ecosystems, including all other water-related issues of Society and Nature. Research needs in the field of climate impact on the water cycle and water users will be identified. The most important output of the project was the identification of gaps that would hinder the implementation of the EU water policy in combating climate impacts on water.
Summary of the study:
The Project has reviewed the water-related climate change impacts as they were identifiable by other relevant projects and international literature, both net-based and traditional. The Project also reviewed the needs of adaptation and damage mitigation strategies and measures over the entire range of water-related human activities. The strategies identified also consider how these demands can be satisfied by the water-related policies. International conventions, regulations and policies are also considered. Strong emphasis was laid on the research needs to identify science-policy gaps and also on that of water-sciences in general. The Project reviewed all European water-related policies breaking down to tasks and topics according to main policy fields, with strong emphasis on identifying their ability and capacity of adaptation to climate change impacts and how these can be taken into account in the (re)formulation of current and future policies, thereby proposing recommendations and solutions to identified shortcomings.
Results: Climate change impacts on the hydrological cycle, water resources and water management have already been reviewed for major topic categories: a) Impacts on society and economy as direct impacts on life and health of the population; b) Indirect impacts on the society through direct impacts on economic activities; c) Water related impacts on nature, terrestrial and aquatic ecosystems. Condensed versions of the results of this analysis are available on the website. Adaptation strategies were the most important expectable results, being reviewed in 6 major categories: a) water demand side, b) supply side, c) damage prevention, d) water industries, e) adaptive capacities and f) control of water pollution. Next results were the identification of research needs, where 11 very important new or novel fields were considered, such as ecohydrology. The final output was a list of advice to upgrade water-impact related EU policies, such as a novel approach to WFD/RBMP and new strategies for flood control.
Year: 01 November 2008. - 31. October 2011.
Point of contact: Prof. Géza Jolánkai
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Website of the study:
www.climatewater.org

4.13 SARIB - Sava river basin: sustainable use, management and protection of resources

Area covered by the project: Sava River Basin (Sub-basin of Danube River)

Purpose of the study:

The Sava River (945 km) is the biggest tributary to the Danube River and has 95551 km2 large catchment. It extends over four countries, Slovenia, Croatia, Bosnia and Herzegovina and Serbia and Montenegro. In the development of the river basin management pl an all countries are already collaborating under the International Commission for the Protection of the Danube River (ICPDR) guidance. Until 1991, the methodological bases for data collection have been reasonably unified over the catchment, but lacking of today's important aspects such are ecological character of the river and its tributaries, inventory of pollution sources, dangerous substances, socio-economic parameters, cost and benefit implications and similar. For the later period a lot of data are missing due to insufficient monitoring (financing, recent warfare) and weak institutional and legal control over use of water and land resources of the Sava River catchment. Many aspects of the river quality need scientific investigations. Furthermore, there is a need to link the knowledge of river quality state and environmental and health risk with pressures and their driving forces to propose efficient and beneficiary actions and measures for protection. In the project specific tools based on combination of chemical analysis and biological effect methods will be developed and validated for the pollution of sediments and impact on water biota. Geographical distribution of pollution will be identified and historical trends defined. Integrated prediction model about the behaviour of hazardous chemical substances will be integrated with the socio-economic prediction model to serve as a base for the elaboration of scenario, remediation measures and best practice techniques. For that purpose an expert data an d information management system will be developed.'

Summary of the study:

SARIB project achievements included a prediction model for the behaviour of hazardous toxins. The model was integrated with a socioeconomic system to be able to analyse different scenarios, remediation measures and best practice methods. Importantly, tools were developed with which to identify, mitigate or distribute critical loads according to ecological vulnerability potential and predictions for optimal economic exploitation of catchment resources. The SARIB researchers have extended interdisciplinary, synergistic collaboration of researchers, scientists and other stakeholders involved in the management of this important river base resource. Overall, with this input together with the newly developed modelling tools, the future of the Sava basin looks promising for its wildlife and residents.

Year: 1. 8. 2004. - 31. 7. 2007.

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Website of the study: http://cordis.europa.eu/project/rcn/74218_en.html

4.14 REFORM - REstoring rivers FOR effective catchment Management

Area covered by the project: Europe including Danube Basin
Purpose of the study:
REFORM is targeted towards development of guidance and tools to make river restoration and mitigation measures more cost-effective and to support the 2nd and future River Basin Management Plans (RMBPs) for the WFD. Aims of REFORM are (1) to provide a framework for improving the success of hydromorphological restoration measures and (2) to assess more effectively the state of rivers, floodplains and connected groundwater systems. The restoration framework addresses the relevance of dynamic processes at various spatial and temporal scales, the need for setting end-points, analysis of risks and benefits, integration with other societal demands (e.g. flood protection and water supply), and resilience to climate change.

The consortium comprises scientists and practitioners covering a wide range of disciplines (hydrology, hydraulics and geomorphology, ecology, socio-economics). The workplan is organized in three modules: (1) natural processes, (2) degradation, (3) restoration. Data from monitoring programmes and restoration projects will be pooled and linked with landscape-scale hydromorphological and physiographic data and catchment models. Targeted field and experimental studies using common protocols will fill data gaps on the role of scale in restoration success. A wide range of statistical modelling approaches will improve indicators for hydromorphological change and factors determining restoration success. All work packages are multidisciplinary and will feed into products for application in river basin management, e.g. guidelines for successful restoration and a web-based tool for exchanging experiences with river restoration measures facilitated and enhanced through consultation with stakeholders.
In addition to its impact on the RBMPs, REFORM will provide guidance to other EU directives (groundwater, floods, energy from renewable resources, habitats) to integrate their objectives into conservation and restoration of rivers as sustainable ecosystems.

Summary of the study:
The **specific objectives** of REFORM are:

- To select WFD compliant hydromorphological and biological indicators for cost effective monitoring that characterise the consequences of physical degradation and restoration in rivers and their services.
- To evaluate and improve practical tools and guidelines for the design restoration and mitigation measures.
- To review existing data and information on hydromorphological river degradation and restoration.
- To develop a process-based, multi-scaled hydromorphological framework on European rivers and floodplains and connected groundwaters.
- To understand how hydromorphological pressures interact with other pressures that may constrain successful restoration.

- To assess the significance of scaling effects on the effectiveness of different adaptation, mitigation and restoration measures to improve ecological status or potential of rivers, floodplains and connected groundwaters.
- To develop instruments to analyse risk and assess benefits of successful river restoration, including resilience to climate change and relations to other socioeconomic activities.
- To increase awareness and appreciation for the need, potential and benefits of river restoration.

Year: 1. 11. 2011. - 31. 10. 2015.
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Website of the study: http://www.reformrivers.eu

4.15 UNDP/GEF Danube Regional project

Area covered by the project: The whole Danube River Basin
Purpose of the study:
The overall goal of the *Danube Regional Project (DRP)* was to improve the environment of the Danube River Basin, protect its waters and sustainably manage its natural resources for the benefit of nature and people.
The DRP helped 13 Danube countries implement the *Danube River Protection Convention* primarily through reducing nutrient and toxic pollution and strengthening trans-boundary cooperation in the most international river basin in the world.
Summary of the study:
The Danube Regional Project was implementing 22 project components with large number of specific activities in the Phase 1 and 2. The five main area of actions were:

- Policies Development (objective 1: Creation of sustainable ecological conditions for land use and water management)
- Capacity Building and Transboundary Cooperation (objective 2: "Capacity building and reinforcement of transboundary cooperation for the improvement of water quality and environmental standards in the Danube River Basin)
- Public Participation and Awareness (objective 3: "Strengthening of public involvement in environmental decision making and reinforcement of community actions for pollution reduction and protection of ecosystems")
- Monitoring and Evaluation (objective 4: "Reinforcement of monitoring, evaluation and information systems to control transboundary pollution, and to reduce nutrients and harmful substances")
- Pilot Projects and Case Studies (objectives 1, 2 and 4)

The project was carried out in two phases. The phase 1 of the project was a preparatory one, focused on creation of inter-ministerial committees, concept development for implementation of policies in agriculture, industry, wetlands, legal and economic

instruments, methodologies, mechanisms for monitoring and evaluation and development of programmes for awareness raising and NGO strengthening. It was finalized in May 2004.
Building on achieved results, the phase 2 - the implementation phase has set up institutional and legal instruments at the national and regional level, implement pilot projects, carry out public awareness activities, etc. to assure nutrient reduction and sustainable management of water bodies and ecological resources, involving all stakeholders and building up adequate monitoring and information systems.
Year: 1. 12. 2001. - 30. 11. 2006.
Point of contact:

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Website of the study: http://www.undp-drp.org/drp/index.html

JRC Scientific Support to the Danube Region Strategy

Danube Water Nexus

Model Inventory

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Co-author of model descriptions:
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1. Introduction

1.1. Main topics of the Danube model study

In December 2013, JRC-IES initiated this meta-study to collect all available information on past and on-going hydrological model studies as a knowledge base for the later-on benchmarking of JRC "Danube Water Nexus" model results with existing quantitative assessments of the water resources. As indicated in the expert contract, the major goal of this work was to provide a catalogue of already executed and still on-going large scale modelling studies in the Danube River Basin (DRB) and in its large sub-catchments. The sub-catchment targeted by the study, its purpose, the project duration, the website of the study and the point of contact were provided for each study, as well as the main aim of the model application. Furthermore, this study tried to include additional models with or without spatial dimension addressing water resources focusing on economy, ecosystems, river-aquifer interaction, etc. Yet, at the scale of the Danube River Basin or its major sub-basins little information could be gathered on systematic approaches focusing on the water-related topics.

A deeper understanding of the validity and the limits of the outputs provided by the hydrological models is needed for the future comparison of model results at the Danube basin scale. Hence, a short description of the models is needed, which is provided in an additional catalogue of models and a spread sheet data base providing details more details. In general, the model data base describes

- spatial & temporal resolution
- processed included
- main variables simulated
- main data sources and inputs

of all models applied and indicates, if the main aim of application was either

- forecasting of floods, droughts, etc.
- climate and/or land use change impacts assessment on the water cycle
- improving dam and reservoir control or
- water quality assessment

In the end, the availability of core results in digital and spatially explicit form for later-on use to benchmark them with JRC simulations needed to be checked as far as possible. Therefore, an important part of the meta-study was to connect to the people that had run a relevant project or are still taking care of model applications and main results. In general, there was a lot of willingness to provide data sets for the upcoming benchmarking study as far as points of contact could still be identified.

1.2. Work plan for the creation of the Danube model database

For creating a database of existing models and their large scale application in the Danube region, this study pursued the following steps:

(1) The definition of the subcatchment size to be investigated is chosen based on the size which is relevant for the International Commission for the Protection of the Danube River (ICPDR) with regard to the implementation of the European Water Framework Directive (WFD). Hence, only studies of catchments larger than 4.000 km^2 were included in this meta-study.

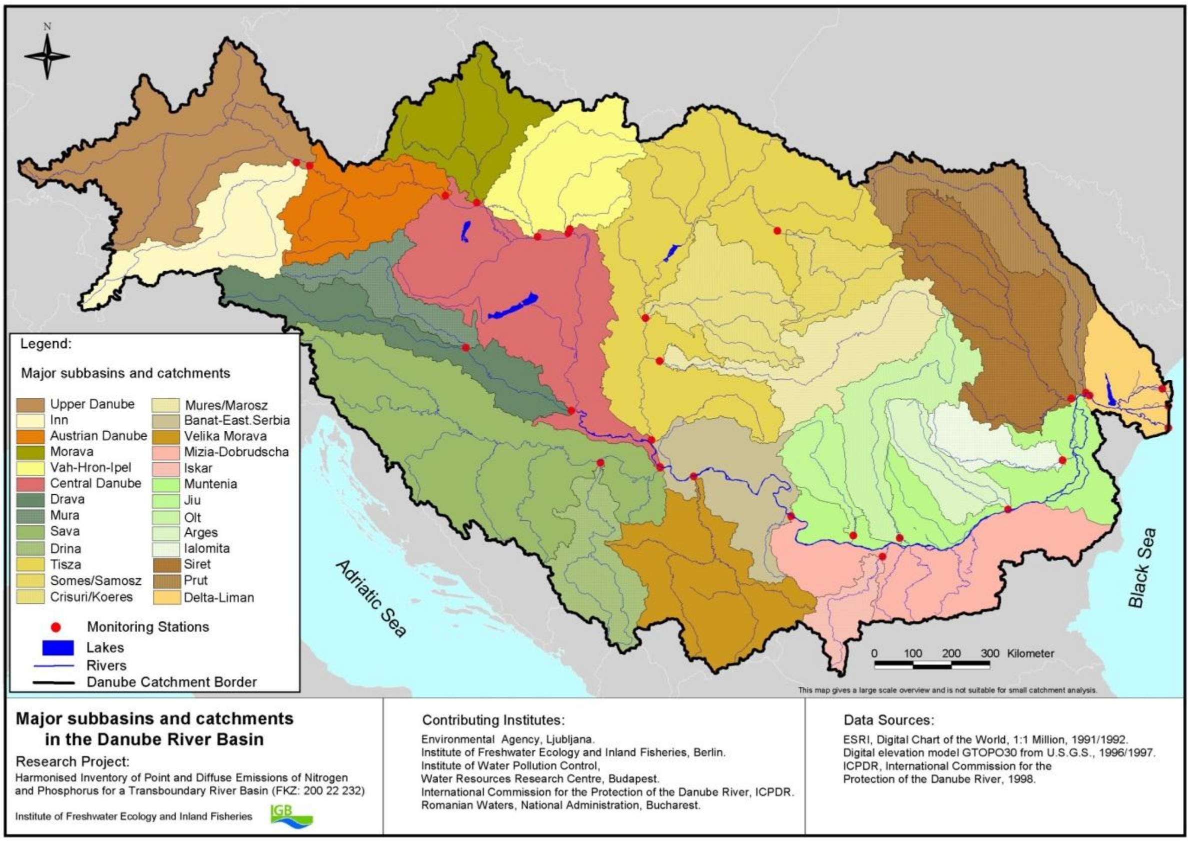

Figure 1: Major subbasins and catchments in the Danube River Basin. (http://moneris.igb-berlin.de/index.php/uba_en.html#danube)

(2) To compare different types of hydrological models that have been used in project studies, a set of attributes to classify these models has to be defined. In general, hydrological models can be classified by

- The domain they represent
- Their structural type and complexity
- The natural (and anthropogenic) processes they integrate
- The data they use as input and/or boundary conditions
- The type of results that are meaningful simulated

(3) An intense search for descriptions of model setups and their application in scientific literature as well as in project reports at the European and national level. Finally, contacts have to be established to institutions that are active in hydrologic modelling as well as water resource management and research to get into details and to provide potential contacts.

(4) For future comparison/benchmarking of JRC model results with data from the identified relevant modelling studies, a first contact to potential data providers has to be established. In this first round of negotiation it is assumed that

- Studies that used data-driven approaches could eventually provide robust input data for local or regional comparison of driving data used by JRC.
- Studies that applied sophisticated models and parameter sets may provide reference data from their simulations that are not available from measurements in the spatial or temporal detail needed by JRC.

1.3. Hydrological model classification

The comparison of simulation results is not trivial, as a variety of hydrological models has been developed and applied in the past based on very different theoretical constructs, aims of application and with diverse constraints with regard to available input and validation data. This has led to a variety of model structures that can be classified in many ways, often using general terms. One widely used classification uses just three general terms (e.g. Willems, 2000), each integrating a set of structural criteria:

White Box – detailed physically-based equations, which need a large amount of spatially distributed input data and model parameters (see also process-based models below)

Grey Box – conceptual models, which represent the major storages and fluxes of water; Yet, because of the lack of detailed process equations and data they need calibration

Black Box – empirical (mathematical, statistical) models; often of lumped spatial structure, because structure depends on the available data; new methods in input-output data analysis (e.g. neural networks) that keep some physical meaning to empirical variables employed have spawned a new family of empirical models, the so-called ‘data-driven models’.

Besides the definition of structure, model attributes as shown in Figure 2 will be used (and further subdivided). For integrated and multi-domain models, the attributes are applied to all sub-models they contain.

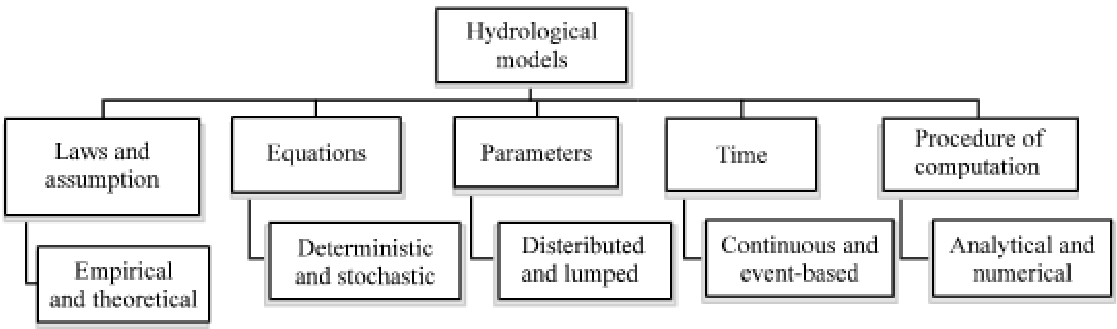

Figure 2: Hydrological model classification by criteria (Jajarmizadeh et al., 2012).

Process-based (integrated) models

Process-based models are defined as being dynamic, (semi-)distributed and continuous in time, for short and long-term simulations integrating the interactions between different parts of the hydrologic system. They can include physical, biogeochemical and/or biophysical processes, but also river routing and hydraulic processes. These are especially important for large areas, as routed river runoff is one of the few area-averaging variables measured with confidence. When applied to (large) basins, usually distributed (effective) parameters are employed to describe spatial heterogeneity. As there is still considerable uncertainty, especially regarding input parameters, a mixture of (bio-)physical and geochemical process equations and empirical/conceptual descriptions are employed. Compared to empirical and conceptual models, which are often calibrated on output variable accuracy, process-based models are applied using generalized calibration and/or parameter estimation methods (e.g. using remote sensing data or generalized mapped information). Some examples are the models SWAT (Neitsch et al., 2011a), SWIM (Krysanova et al., 2005), PROMET (Mauser and Bach, 2009), WaSiM-ETH (Schulla and Jasper, 2007) and others.

Because of the explicit representation of the different processes of the hydrological cycle, this type of models can be combined well with climate and weather-forecast models as well as socio-economic models for integrative research (Figure 3).

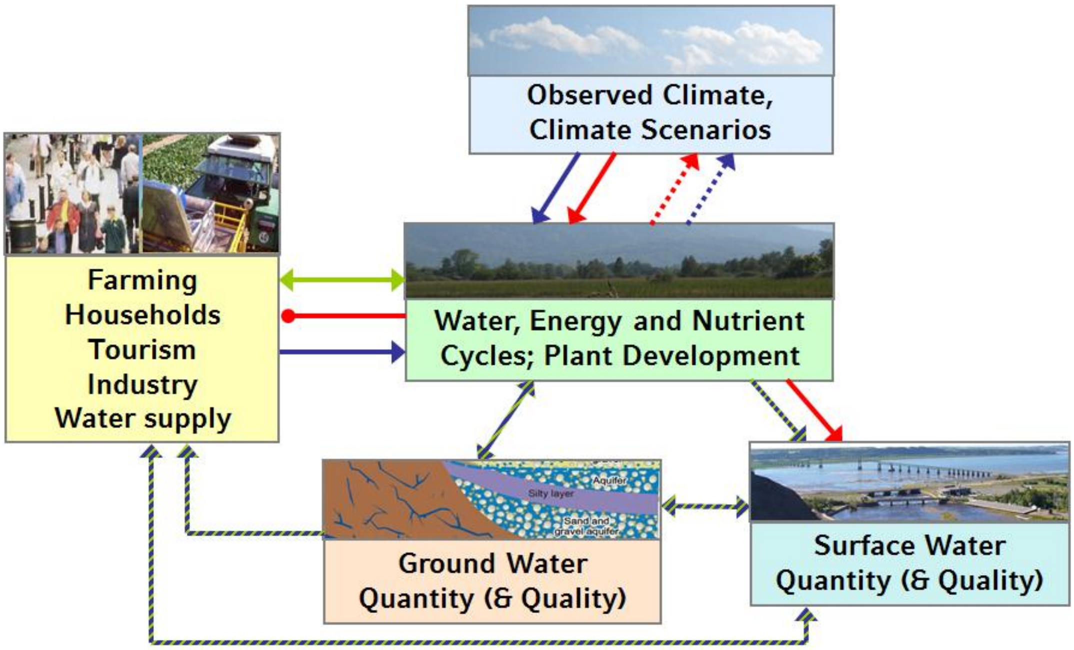

Figure 3: Potential integrative view on the hydrological cycle.

2. Overview of studies and models

In the following, a short overview is given of the hydrological models and project studies identified so far (Table 1), including the main references and aims of the model applications. The detailed description of the structure of the models, the problem specific setup and the main driving variables as well as the outputs that have been used for assessing water resources and runoff characteristics are given in the model catalogue.

Table 1: Overview of model studies in major subbasins and catchments of the Danube River Basin.

Project	Application	Catchment	Model	Domain	Complexity	Space	Time
daNUbs	Water Quality assessment	DRB	DWQM	water quality	conceptual	lumped	monthly
daNUbs	Water Quality assessment	DRB	MONERIS	water quality	conceptual	lumped	annual
enviroGRIDS	CC + Water Quality	DRB	SWAT2009	water quality	process-based	HRUs	daily
IHP UNESCO	Water resources assessment	DRB	WatBal	water balance	conceptual	lumped	monthly
JRC study	Water Quality management	DRB	EPIC	water quality	conceptual	semi-distributed	
JRC study	Water Quality management	DRB	GREEN	water quality	conceptual	lumped	annual
JRC study	Flood protection	DRB	LISFLOOD	water quantity	process-based	1x1 km	hourly / daily
JRC study	Climate & Policy Impacts	DRB	SWAT	water quality	process-based	1x1 km	daily
PRUDENCE	Climate Change Impacts	DRB	HD (MPI-M)	water quantity	process-based	0.5°	daily
WATCH	Climate Change Impacts	DRB	VIC-RBM	runoff + temperature	process-based	0.5°	daily
CC-WATERs	Water resources management	DRB*	n/a	water balance	conceptual	GW bodies	monthly
AdaptAlp	Climate Change Impacts	Inn	COSERO	water quantity	conceptual	semi-distributed	monthly
AdaptAlp	Climate Change Impacts	Inn	WaSiM-ETH	water quantity	process-based	1x1 km	daily
Austrian Science Funds	Climate Change Impacts	Inn	HBV	water quantity	conceptual	elevation zones	daily
Morava FAP	Flood protection	Morava	HYDROG	water quantity	empirical	lumped (xx sub-basins)	event-based
INTERREG IIIB CADSES	Flood forecasting	Mur	NAM-Mike11	water quantity	conceptual	lumped (xx sub-basins)	variable
CECILIA	Climate Change Impacts	Mures	CONSUL	water quantity	conceptual	lumped	6 hours
CECILIA	Climate Change Impacts	Ialomita/Buzau	WatBal	water quantity	conceptual	lumped	monthly
WATCAP	Flood protection	Sava	HEC-HMS/RAS	water quantity	empirical	lumped	event-based
BOBER	Flood protection	Sava	Slovenia HFS	water quantity	conceptual	lumped (xx sub-basins)	event-based
GLOBAQUA	Aquatic ecosystems	Sava	(unclear)	quantity and quality	?	?	?
UNECE Flood Risk & CC	Flood protection	Sava	HBV	water quantity	conceptual	lumped	daily
Vrbas catchment study	Scenario analysis	Sava (Vrbas)	MIKE BASIN + ASM	quantity & quality	conceptual	lumped (xx sub-basins)	variable
CLEANWATER	Non-point pollution	Siret (Barlad)	SENEQUE + SIDASS	water quality	process-based	?	continuous
NL-RO Partners for Water	Flood protection	Timis-Bega	HEC-HMS/RAS	water quantity	empirical	lumped (20 sub-basins)	event-based
Tisza River Project	Flood protection	Tisza	VITUKI-NHFS	water quantity	conceptual	lumped (xx sub-basins)	?
HYDROInform	drought monitoring	Tisza	DIWA	water quantity	process-based	1x1 km	
ECLISE	Climate Change Impacts	Tisza (Somes)	WatBal	water quantity	conceptual	lumped	monthly
CLAVIER	Climate Change Impacts	Tisza tributaries	VITUKI-NHFS	water quantity	conceptual	lumped (xx sub-basins)	?
Bavarian Flood Forecast	Flood forecasting	UDRB	LARSIM	water quantity	conceptual	?	?
GLOWA-Danube	Global Change impacts	UDRB	DANUBIA	water quantity	process-based	1x1 km	hourly
GLOWA-Danube	Global Change impacts	UDRB	PROMET	water quantity	process-based	1x1 km	hourly
KLIWA project B3.3.1	Climate Change Impacts	UDRB	GWN-BW	soil water balance	process-based	1x1 km	daily
KLIWAS	CC + Navigation	UDRB	COSERO	water quantity	conceptual	semi-distributed	monthly
KLIWAS	CC + Navigation	UDRB	LARSIM_ME	water quantity	conceptual	5x5 km	daily
PIK studies	Climate Change Impacts	UDRB	SWIM	water quantity	process-based	HRUs	daily
KLIWA	Climate Change Impacts	UDRB (Bavaria)	WaSiM-ETH	water quantity	process-based	1x1 km	daily
KLIWA	Climate Change Impacts	UDRB (B-W)	LARSIM	water quantity	process-based	1x1 km	daily

2.1. Danube River Basin (DRB)

Besides the models developed and applied by the Joint Research Centre (JRC) for DRB GREEN, SWAT, LISFLOOD, EPIC), the following model studies covering the whole basin have been identified until the year 2014:

a) The European Framework Program 5 (FP5) financed daNUbs project (2001 to 2005) mainly used the model MONERIS (Schilling et al., 2005) to identify major sources of nutrients and potentials to improve water quality in the Danube for the ICPDR.

Schrittwieser et al. (2014) present results with an improved version of MONERIS (Venohr et al., 2011) to assess the actual and near-future nutrient pollution in the Danube river for the upcoming final stage of the first cycle of the EU WFD.

b) Within the FP6 project WATCH (2007 to 2011) the VIC-RBM model was used globally to assess Climate Change impacts on river runoff and water temperature (van Vliet et al., 2012). The global model setup was also evaluated for the DRB with regard to risk analysis, climate change impact assessment and decision support.

c) The recently finished FP7 enviroGRIDS project (2009 to 2013) applied the model SWAT2009 (Neitsch et al., 2011b) to the DRB and the Black Sea region using the automated calibration tool SUFI-2 in a grid computing environment (Gorgan et al., 2012). The main aims of this large project (27 partners) was the integration of earth observation and simulation technologies and the assessment of ecosystems, human well-being, agriculture and energy supply under the pressure of climatic, demographic and land cover changes in the next 50 years.

d) The South-East Europe (SEE) transboundary cooperation project CC-WATERs (2009 to 2012) investigated drinking water supply under changing future boundary conditions. Yet, regarding hydrological modelling, only a simple water balance model to simulate groundwater recharge at different locations within the DRB was used (Simonffy, 2012).

e) Some hydrological results on climate change impacts were also produced within the FP6 project PRUDENCE with the coarse-scale, process-based HD model (Hagemann and Jacob, 2007).

f) In the frame of a hydrological assessment of the DRB for the IHP-UNESCO a water balance computation for the period 1951-2000 was published by Petrovic et al. (2010).

2.2. Upper and Austrian Danube, including the Inn catchment

Within the upper parts of the Danube region some modelling studies mostly from Austrian and German research groups have been finished.

a) The German Federal Ministry of Education and Research (BMBF) project GLOWA-Danube (2001 to 2010) was an integrative research project (Mauser and Muerth, 2008) using the hydrological model PROMET (Mauser and Bach, 2009) at its core. The main aim was the identification of future changes of the natural and the anthropogenic water (use) cycle in the Upper Danube River Basin (UDRB; including the Inn catchment) imposed by Global Change (climate, land use, consumption patterns, etc.) in the next 50 years.

b) The Potsdam Institute for Climate Impact Research (PIK) did some studies in the Upper Danube River Basin using the integrated, semi-distributed model SWIM as summarized in Krysanova et al. (2014). Main aims of the studies were also future changes in water availability and runoff, as well as hydro-power generation and water quality.

c) The project KLIWAS (2009 to 2013), funded by the German Federal Ministry of Transport (BVBS), investigated the future of shipping and the hydrology in the Upper and Austrian Danube region using the models COSERO (Kling et al., 2012), and

LARSIM (Ludwig and Bremicker, 2006). This project also provided results to the collaborative EU-FP7 project ECCONET.

d) In Southern Germany there is also a long-term cooperation between the federal states Bavaria, Baden-Württemberg and Rhineland-Palatine on the impacts of climate change on water resources called KLIWA, in which the models GWN-BW, WASIM-ETH (Schulla and Jasper, 2007) and also LARSIM (Ludwig and Bremicker, 2006) are applied to the UDRB. The two latter models have been chosen, because they are already operationally used for flood forecasting in these states.

e) Within the ETC financed AdaptAlp project, the models COSERO (Kling et al., 2012) and WASIM-ETH (Schulla and Jasper, 2007) were applied to the Inn River and its subbasins to investigate future climate change impacts.

f) Financed by the Austrian Science Funds, (Merz et al., 2011) applied the conceptual, well-known HBV model on the Inn River and investigated parameter stability of a calibrated model under Climate Change conditions.

2.3. Sava subbasin

a) Various projects on flood protection, mainly run by water management institutes in the Sava subbasin, have set up models to improve flood forecasting and mitigation. The operational Slovenia HFS (Hydrological Forecast System) was based on MIKE-11/NAM within the BOBER project co-financed by EU cohesion funds and the Slovenian Ministry of Agriculture and Environment.

b) Yet, the flood forecast system of the International Sava River Basin Commission (ISRBC; www.savacommission.org) was based on the HEC-HMS/RAS model developed by the US Army Corps of Engineers (Scharffenberg, 2013).

c) Furthermore, there was a study by (Primožič et al., 2008) that used HBV to continuously simulate runoff behaviour instead of MIKE-11 (see above) in the Slovenian part of the Sava river basin.

d) For the support of the EU WFD in Bosnia-Herzegovina and Serbia, Ireson et al. (2006) did a case study to investigate water resource management options using a loosely coupled system including MIKE-BASIN for surface waters and ASM to model ground water in the Vrbas catchment.

e) Finally, the upcoming GLOBAQUA project funded by EU FP7 will investigate the actual state and future development of aquatic ecosystems in six European basins including the Sava subbasin. Yet, the project started in February 2014 and until now it is not clear which models will be used for the investigation.

2.4. Tisza and Lower Danube subbasin

a) In the Tisza subbasin, the conceptual rainfall-runoff model VITUKI-NHFS was applied on the whole basin within the EU funded 'Tisza River Project' (Jolankai and Pataki, 2004) besides other models on smaller subbasins to investigate water resource management decisions. The model was also applied on some parts of the Tisza within the FP6 CLAVIER project (www.clavier-eu.org) to investigate Climate Change impacts.

b) The Someş catchment as part of the Tisza has been investigated in the EU-FP7 ECLISE project (2011-2013) using the conceptual WatBal model and EURO-CORDEX climate simulations at 25 km resolution (www.eclise-project.eu).

c) For future flood and drought risk management in the Tisza basin, the distributed, process-based DIWA model (Szabó, 2007) was applied. The work was financed by the Hungarian and Swiss Hungarian Cooperation Programme funds and led by the Hungarian General Directorate of Water Management OVF (www.ovf.hu).

2.5. Other subbasins or catchments larger than 4,000 km^2

a) The management of flood risk mitigation measures in the **Timis-Bega catchment** with the HEC-HMS model system was supported by a 'Partners for Water' collaborative project between the Dutch and Romanian governments (Popescu et al., 2010).

b) Flood protection in the **Morava subbasin** is supported by modelling activities with LISFLOOD supported by JRC (Feyen et al., 2008) and HYDROG for the ICPDR Morava Flood Action Plan (ICPDR, 2009).

c) The nitrate pollution in the **Barlad catchment** as a part of the Siret subbasin is investigated within the still on-going LIFE+ CLEANWATER project of the National Institute for Hydrology and Water Management of Romania (www.lifecleanwater.ro) using a model chain including MODFLOW (Harbaugh et al., 2000).

d) Transboundary flood forecasting on the **Mur subbasin** (Ruch et al., 2007) has been conducted with the simple rainfall-runoff NAM as a part of the hydrodynamic MIKE-11 model of the Danish Hydrological Institute within the INTEREG CADSES program.

e) Climate Change assessment of water resources have also been conducted with the CONSUL model on the **Mureş catchment** as a part of the Tisza subbasin (Corbus et al., 2011) and with the WatBal model for the Ialomita and Buzau catchments in the Lower Danube subbasin (Mic et al., 2013).

3. Catalogue of model studies in the Danube region

The appraisal of the results of the model comparison to be conducted in the Danube region needs to take into account different factors besides the processes included in a hydrological model and its structure, which are described in the following chapter. Spatial patterns and time series produced with hydrological models are greatly affected by the approaches that have been or had to be chosen during model set-up. Usually, the following questions arise when a specific model has been chosen and is applied on a catchment:

- Which input data at which spatial and temporal resolution is available?
- Which pre-processing shall be applied on the inputs?
- Which post-processing shall be applied on the results?
- Which parameter retrieval methods are applicable?
- Which automatic or manual calibration method needs to be applied?

Therefore, this catalogue of model studies tries to take into account that application-related meta-information provided in scientific publications, project reports and internet resources as far as possible for a better comparison of model results.

3.1. Model studies in the whole Danube River Basin (DRB)

3.1.1. WATCH – Integrated Project Water and Global Change

The main aim of the EU-FP6 WATCH project (2007-2011) was to bring together the hydrological, water resources and climate communities to analyse, quantify and predicted the components of the current and future global water cycles and related water resources states. Furthermore, they evaluated the uncertainties and clarified the overall vulnerability of global water resources related to the main societal and economic sectors (www.eu-watch.org).

As part of the WATCH project, eight global hydrological model simulations of 20th century climate have provided produced hydrological variables with a spatial resolution of 0.5° covering the whole globe for WaterMIP (Water Model Intercomparison Project) (Haddeland et al., 2011). While most WATCH models produced results for 1963-2000, WaterMIP investigated the time period 1985-1999 driven by WATCH Forcing Data (Weedon et al., 2011). The eight Global Hydrological Models provided by WATCH include VIC and MPI-HM besides others (Hagemann et al., 2013). For simulations that included the human use of water, monthly irrigation, water withdrawals and reservoir variables have been included. The variables produced, stored and analysed on a daily time scale are:

- Potential and total evapotranspiration
- Surface, subsurface and slow subsurface runoff
- Soil moisture, groundwater and surface water storage
- River discharge
- Snow water equivalent

Yet, an explicit analysis of model results for the Danube basin (and others) was only published by van Vliet et al. (2012) using the VIC-RBM model, an advanced version of VIC including water temperature processes. Data from the hydrological and land surface models driven with both WATCH Forcing Data and 21st century climate scenarios are available at: https://gateway.ceh.ac.uk

3.1.2. enviroGRIDS – Building Capacity for a Black Sea Catchment Observation and Assessment System supporting Sustainable Development

The main aim of the recently finished EU-FP7 enviroGRIDS project (2009 to 2013) was the integration of earth observation and simulation technologies in a Grid-enabled Spatial Data Infrastructure (GSDI) and the assessment of ecosystems, human well-being, agriculture and energy supply under the pressure of climatic, demographic and land cover changes in the next 50 years. This large research project (27 partners) was concentrating on building the capacity of scientists to use emerging information technologies for a Global Earth Observation System of Systems (GEOSS), the capacity of stakeholders to use it and the capacity of the general public to understand important issues (www.envirogrids.eu).

Within this context, the model SWAT2009 (Neitsch et al., 2011b) was applied to the DRB and the Black Sea region using the automated calibration tool SUFI-2 on a grid computing environment compatible with the European INSPIRE directive 2007 (Yalew et al., 2013). SWAT2009 is run on a daily time step, using 1224 sub-basins including 69,875 HRUs for the 801,093 km^2 DRB catchment (Gorgan et al., 2012). The integration of the Danube SWAT setup in the gSWAT environment allows for the creation of scenario simulations based on the base-data obtained through the original SWAT application (Gorgan et al., 2012).

Input data was prepared from different sources: DEM was derived from SRTM90 data (Jarvis et al., 2008) aggregated to 700 metre grids, soils were parameterized based on the FAO-UNESCO Global Soil Map with 5 km resolution. For land over different sources were compared and finally the MODIS 500x500 m^2 produced by USGS was found to be the best option using 14 different land cover classes. For the description of the river network the European Catchments and Rivers Network System (ECRINS) was employed and EUROSTAT was used to describe past point-source emissions. Meteorological drivers are taken from the Climate Research Unit (CRU), which was tested against available station data beforehand with GRDC (Global Runoff Data Centre) runoff time series (taken from enviroGRIDS Deliverable 4.11).

Integrated scenarios

The Global Change perspective of enviroGRIDS called for integrating regional development scenarios into the result analysis based on the IPCC-SRES scenario ideas (see Figure 4). Besides the socio-economic changes in this figure, also the impact of EU policies, the existence of an East-West gradient and the stage of transition in ex-socialist countries were included. Hence, simulation results relating to SRES scenarios generally related not only to the respective climate model driving data, but also to the respective set of management data related to the above considered factors (see enviroGRIDS Deliverable 3.4 and 4.11). The actual scenario data on demography and land use development besides climate change are detailed in enviroGRIDS Deliverable 3.8. The climate change meteorological drivers were produced with a delta method applied on the monthly probability functions of minimum and maximum air temperatures and precipitation intensities. The change factors for these distribution functions were extracted from simulations run with the RCM HIRHAM driven by the GCM HadAM3H for the investigated SRES scenarios A2 and B2 (enviroGRIDS Deliverable 3.6).

Scenarios	CO2 Emissions (ppmc yr 2100)	GDP growth	Population growth	Technology development	Forest	Agriculture	Urban
A1	Highest (1210)	Highest (20)	Low	High	Decrease	Increase or stable	Strong Increase
B1	Low (650)	High (15)	Low	High	Increase	Increase	Increase
A2	High (1020)	Lowest (7)	High	Low	Decrease	Increase	Smoothly Increase
B2	Medium (810)	Medium (11)	Medium	Medium	Decrease	Increase	Smoothly Increase

Figure 4 : Major driving forces of environmental change (enviroGRIDS based on www.IPCC.ch)

Scenario simulation results

In the end results were produced for the past period 1973-2006 and for the future period 2071-2100, yet for now only past period results have been presented in deliverable 4.11 on:

- Precipitation distribution
- Average temperature distribution
- Blue water
- Green water storage
- Green water flow
- Water scarcity
- Yield barley
- Yield wheat
- Nitrate released into river from HRU
- Nitrate leached below the soil profile
- Nitrate transported by surface runoff into reach
- Nitrate contributed by HRU to groundwater into reach
- Temporal distribution of green water flow
- Temporal distribution of green water storage
- Temporal distribution of blue water
- Crop yield per country

Regarding data availability, the project coordinator Professor Dr. Anthony Lehmann (Anthony.Lehmann@unige.ch) has been contacted. The list of core datasets made available through the enviroGRIDS project on the Black Sea catchment is available online http://envirogrids.grid.unep.ch/geonode. Furthermore, data sets are accessible with tools based on GeoNode open-source codes.

3.1.3. PRUDENCE – Prediction of Regional scenarios and Uncertainties for Defining European Climate change risks and Effects

The main aim of the EU-FP5 project PRUDENCE (2001-2004) was to provide 10 regional climate model (RCM) simulations for Europe at about 50 km spatial resolution for the time periods 1961-1990 and 2071-2100 (Christensen and Christensen, 2007). The data sets produced were replaced in the meantime by the follow-up projects ENSEMBLES (www.ensembles-eu.org) and EURO-CORDEX (www.euro-cordex.net). Within these projects, hydrological variables have also been produced with the land surface modules included in RCMs at spatial resolutions of 13, 25 and 50 km (0.11° up to 0.44°). Yet, until now no evaluation of these variables for the Danube is published.

For PRUDENCE, the Hydrological Discharge (HD) model driven by various RCMs has been analysed for the Rhine and Danube basins as well as for the Baltic Sea catchments (Hagemann and Jacob, 2007). Average monthly means of precipitation, evapotranspiration and discharge results showed a large spread of RCM-driven simulations, but ensemble means related quite well to observations. As the results are comparably old, data sets are no more available, yet likely Dr. Hagemann (stefan.hagemann@mpi-met.de) can be contacted for further information.

3.1.4. daNUbs – Nutrient management in the Danube basin and its impact on the Black Sea

The main aim of the EU-FP5 funded project daNUbs (2001-2005) was to improve knowledge about sources, effects and pathways of nutrients in the DRB, to develop and combine management tools and provide them scenario analysis in the frame of the EU-WFD (http://moneris.igb-berlin.de/index.php/danubs_en.html).

Nutrient emissions by point and diffuse sources were calculated with MONERIS (Schreiber et al., 2003) for 388 subcatchments of the Danube for the years 1998-2000. To simulated downstream water quality and emissions into the Black Sea, the Danube Water Quality Model (DWQM) developed and applied by van Gils and Bendow (2000) was fed by MONERIS.

Data used as input for MONERIS needs extensive pre-processing and a lot of measured variables. Therefore, the Harmonised Inventory of Point and Diffuse Emissions of Nitrogen and Phosphorus for the DRB conducted involved water institutes of most Danube countries. Static input data was the GTOPO DEM at resampled 200 m resolution and CORINE Land Cover at 100 m resolution. The river network was taken from Digital Chart of the World and catchment boundaries from the Trans National Monitoring Network (TNMN) published by ICPDR in the year 2000. Furthermore, the FAO Soil Map, the Hydrogeological Map of Europe and Global Precipitation Climatologies of the GPCC et al. were used. (Schreiber et al., 2003)

A recent assessment with MONERIS (Schrittwieser et al., 2014) for the ICPDR looked at the achievements of the EU-WFD regarding water quality improvement in the DRB and the near-future outlook. First of all, the assessment used the updated model version of (Venohr et al., 2011) and extended the analysed time period from 1996 to 2008. Secondly, five different management options for the reduction of nutrient pollution were investigated and three different scenarios of agricultural fertilizer use until 2015 were projected. Both, ground water and river water quality as well as emissions into the Black Sea were produced.

The original link to data of DaNUbs (http://danubs.tuwien.ac.at/) is unfortunately no more active, but data is still archived at the ICPDR secretariat. Bilateral data exchange between JRC and ICPDR is still negotiated to the author’s knowledge.

3.1.5. IHP-UNESCO – Basin-wide Water Balance in the DRB

The main aim of the project (2002-2005) funded by the National Contact-points of the IHP-UNESCO, the ICPDR contracting countries and Slovak Agency for Science and Technology was to provide a data-based water balance for the whole Danube in 110 subregions with a mean area extent of 7239 km^2. The simple water balance model WatBal of the US EPA (Yates, 1996) was used with an extensive set of national precipitation and runoff data sets to investigate the period 1951-2000 and map the period 1961-1990. The scientific work was documented in Petrovic et al. (2010), yet the data would have to be requested from the IHP UNESCO bodies in the Danube countries.

The main static component, the topographic information was derived from the USGS-HDRO1k DEM at 1 km spatial resolution. Distributed precipitation was achieved with extended drift kriging of 1901 stations to achieve monthly values. Air temperature and humidity were distributed with linear regression, actual and potential evapotranspiration with the Budyko-Zubenokova method. In the end water balance was compared with runoff data. In some regions results was unsatisfactory due to data scarcity or not plausible results (e.g. Hungary).

3.2. Model studies in the Upper Danube River Basin (UDRB)

3.2.1. GLOWA-Danube – Global Change of the Water Cycle at the Upper Danube

The main aim of the GLOWA-Danube project (2001 to 2011) was the identification of future changes of the natural and the anthropogenic water (use) cycle in the UDRB including the Inn (at gauge *Achleiten*) imposed by Global Change (climate, land use, consumption patterns, etc.) between 2011 and 2060. To achieve this, the DANUBIA framework and its components were developed. The interdisciplinary group of researchers was funded by the German Ministry of Education and Research (BMBF) between 2001 and 2010. Within the DANUBIA framework models for groundwater flow, agricultural land use and production as well as for water supply and use by households and industry were coupled to the land surface model, integrating the hydrological land surface model PROMET.

All models integrated in DANUBIA were run on 1x1 km^2 grid (catchment area: 76,673 km^2) and exchanged data at this grid scale. The natural hydrological cycle was computed at a time-step of 1 hour, while some components of DANUBIA have longer time steps, e.g. farming actions once a day. Spatially distributed input parameters for topography were produced from SRTM data sets, soil physical parameters for water and energy transfer were pre-processed from the 1:200,000 soil map of Germany using the pedotransfer functions of (Wösten et al., 1999). The basic land cover was extracted from remote sensing data, while the agricultural land use was simulated dynamically by the farming Actor component. Ground water aquifers were parameterized based on the hydro-geological map of Southern Germany, runoff pathways, streams and river sections were extracted from DEM data using the software TOPAZ. Meteorological drivers for the reference period were interpolated and corrected for topography, climate scenarios were produced with a stochastic weather generator based on station data and climatic trends from regional climate models. Both model parameterization and creation of meteorological drivers are described in the

GLOWA-Danube Online Atlas (www.glowa-danube.de/atlas/), also published in English soon.

Simulation results

Results for a past time period from 1971 to 2000 were evaluated and scenario projections for the future time period were analysed for classical hydrological results of the land surface water cycle and river runoff from output variables of the PROMET model. These include the analysis of results of future daily river runoff (Mauser and Bach, 2009), low-flow conditions (Mauser et al., 2008) and hydro power generation (Koch et al., 2011). Furthermore, snow and glacier development (Prasch et al., 2013; Weber et al., 2010) as well as soil moisture and ground water recharge (Jie et al., 2011; Muerth et al., 2010) have been analysed for past and future periods based on climate data produced with the stochastic weather generator included in the DANUBIA model system.

The application of the whole DANUBIA decision support system concentrated on issues like drinking water availability (Barthel, 2011) and pollution in the ground water domain due to agricultural land use (Barthel et al., 2012). An overview of results of climate change impacts on the natural environment is given in (Barthel et al., 2011b). Furthermore, the analysis of the interactions and conflicts between climate change, water supply and water use in households, tourism and industry is presented by Soboll et al. (2011) and Barthel et al. (2011a). The specific impact of climate change on tourism is presented in Soboll et al. (2012), a deeper analysis of the impacts of regional development and climate change on agriculture can be found in Henseler et al. (2009).

The spatially explicit results are available in German online at www.glowa-danube.de/atlas/, soon also in English. Both the Online Atlas and the *OpenDanubia* repository are still hosted by the Department of Geography of the Ludwig-Maximilians-University Munich, Germany. The official contact for the software codes and data requests is Dr. Christoph Heinzeller (c.heinzeller@lmu.de). Provision of spatially explicit, temporally aggregated data was approved by the project coordinator Professor Dr. Wolfram Mauser (w.mauser@lmu.de).

3.2.2. PIK– Potsdam Institute for Climate Impact Research studies

The main aim of studies conducted by PIK is the development of tools for Climate Change impact assessment and the investigation of regional impacts on natural and socio-economic systems. For this reason, the semi-distributed SWIM model was developed at PIK based on the widely known SWAT model and applied in case studies to different larger catchments in Germany including the UDRB at gauge Achleiten. Studies published include analysis of changes in the water balance, of high flows and low flows as well as of the hydropower potential along the Upper Danube. For an overview of past studies see Krysanova et al. (2014). A recent application within the recently finished (2010-13) EU-INTERREG IV project HABIT-CHANGE also aimed at providing CC impacts on the water balance for the whole DRB (Stagl et al., 2013). Yet, no official results are published to date.

Input parameters for simulations in the UDRB were derived from the SRTM-DEM. For the hydraulic inputs, the standard sub-basin and stream network maps from the German Federal Environment Agency were used. On the basis of the DEM and the stream network, an average drainage area of 100 km was chosen as a threshold to discretize areas of the UDRB outside of Germany into sub-basins, because the standard sub-basin map for Germany has approximately the same discretization. Soil parameters were generated from the general soil map of Germany 1:1,000,000 and the European soil database of JRC. Nine land cover types are obtained from the CORINE 2000 land cover data set: water, urban, cropland, grassland, wetland, bare soil and coniferous, deciduous and mixed forest (Huang et al., 2010). Climate Change impact simulations were based on station data and for the future climatic conditions on the statistical downscaling tools STAR (Orlowsky et al., 2008) and WETTREG (Enke et al., 2005), but also on the "German" regional climate models REMO (Jacob et al., 2008) and CCLM (Rockel et al., 2008).

The pages of the Potsdam Institute provide information on the model and its applications (www.pik-potsdam.de/research/climate-impacts-and-vulnerabilities/models/swim), yet no spatially explicit data is provided. Involved in the development of SWIM as well as the above mentioned applications in the Upper Danube region is Dr. Fred Hattermann (hattermann@pik-potsdam.de). Data requests are handled at the moment by Judith Stagl (judith.stagl@pik-potsdam.de).

3.2.3. KLIWA – Climate Change and consequences for water management

The main aim of the KLIWA project (since 1999) is the estimation of consequences of climate change on the water cycle of the German Rhine and Danube river basins for water management and policy. Therefore, the water agencies of the German federal states of Bavaria, Baden-Württemberg and Rheinland-Pfalz have agreed with the German Weather Service (DWD) on joint, long term cooperation for regional studies on the subject (www.kliwa.de). Special interest is laid on the subjects flood danger and flood protection, water availability for water supply plus river protection, development and management. For this purpose an action plan was initiated that includes analysis of the actual state of water resources and past changes and a monitoring programme to register future changes. To achieve 'climate change proof' water management, surface and ground water budget as well as river runoff of meso-scale catchments are modelled driven by regionalized outputs of Global Climate Models (GCMs).

In general, two different hydrological models are implemented for individual catchments. Baden-Württemberg has done preliminary work on the concept of the LARSIM water balance model (Ludwig and Bremicker, 2006) and therefore uses this model. Bavaria has made substantial contributions to the development of the ASGi water balance model in the mid-1990s, which is methodologically similar to the now used WASIM-ETH model (Schulla and Jasper, 2007). Both models are modular systems, which have clear conceptual parallels and in part also use comparable sub-process descriptions. They were also compared with each other to identify differences in model behaviour for common studies in shared river basins.

All hydrological models used in KLIWA are run on a 1x1 km^2 grid at a daily time step. Meteorological data is usually interpolated stations data and regionalized climate projections produced with WETTREG2006 or WETTREG2010 (Kreienkamp et al., 2010) statistical downscaling tools. Model parameters are based on the CORINE2000 land clover classification, the German 1:200,000 soil map and 1:50,000 official topographic maps. For the simulation of ground water recharge and soil water balance with GWN-BW, an analysis of the distance of the ground water table to the surface and of the baseflow-to-total-runoff ratio was performed based on the 1:200,000 hydrogeological maps of Southern Germany.

Aggregated results of water balance variables for past and future time periods as well as the validation of model setups are published in the KLIWA project report series, especially in Volume 17 reporting on the soil water balance model GWN-BW and Volume 19 reporting from the latest KLIWA conference including a paper of Gerlinger and Meuser (p. 154) on water balance simulations with LARSIM and WASIM-ETH in the German Rhine and Danube river basins.

Project work within the KLIWA context is partly transferred to SMEs, but the main contacts are the DWD as well as the state agencies for environment. The official contact at the Bavarian State Agency for Environment is Dr. Holger Komischke (Holger.Komischke@lfu.bayern.de), which stores daily data sets of WaSiM-ETH simulations, also used in the AdaptAlp project (see below).

3.2.4. KLIWAS – Impacts of climate change on waterways and navigation – Searching for options of adaptation

The main aim of the KLIWAS project (2009-2013) was to analyse the potential consequences of climate change for navigation on inland and coastal waterways and to formulate appropriate strategies for adaptation to changed environmental conditions in the future. Targets of this research effort were to safeguard the efficiency of this mode of transport and, furthermore, to preserve water quality and habitats in rivers, canals, lakes and coastal waters (www.kliwas.de). The project was financed by the German Federal Ministry of Transport, Building & Urban Development (BMVBS) and conducted by its research institutions

- the Federal Institute of Hydrology (BfG),
- the Federal Maritime and Hydrographic Agency (BSH),
- the German Weather Service (DWD), and
- the Federal Waterways Engineering and Research Institute (BAW)

Besides providing, validating and evaluating climate projections, hydrological changes in the water balance of the Upper Danube have been investigated using the hydrological models COSERO (Klein et al., 2011) and LARSIM_ME for analysis upstream of the gauge Achleiten within KLIWAS (Klein et al., 2010). COSERO was also applied on the UDRB upstream of gauge Vienna (Kling et al., 2012) for the KLIEN project funded by the Austrian Federal Ministry for Transport, Innovation (BMVIT). These projections were also used in the European FP7 project ECCONET, which did not develop model applications, but analysed available results regarding for Rhine and Danube.

LARSIM_ME was run on a 5x5 km^2 grid with daily resolution, while COSERO uses 61 HRUs in 16 sub-basins based on 1x1 km^2 gridded topographic data and meteorological drivers at the monthly time scale which are temporally disaggregated during simulation. Unfortunately, not much information is given on the input parameters for the models, yet it is clear that the simulation scale and the pre-processing and calibration of the models can modify the original spatial inputs to a large extent. Besides station data for past conditions, COSERO was also run with HISTALP monthly time series (Auer et al., 2007) to cover a long period for the KLIEN project. For future Climate Change assessment up to the year 2100, simulations were performed using Regional Climate Model results of the ENSEMBLES database (Van der Linden and Mitchell, 2009), but also the statistical downscaling tools STAR and WETTREG (Klein et al., 2011).

Also the homepage of the project provides a lot of information on potential impact of Climate Change impacts, monitoring and analysis, no spatially explicit data is provided. Manager of the KLIWAS research task 4 “Changes in the hydrological system” was Dr. Thomas Maurer (email: thomas.maurer@bafg.de) from the German Federal Institute of Hydrology (BfG). The actual research work was also done at BfG in project task 4.01 “Water balance, water levels and transport capacity” with the help of academic partners. Data requests are handled by Dr. Enno Nilson (nilson@bafg.de) of the German Federal Institute of Hydrology in Koblenz. He is also able to provide results of the European scale ECCONET project, which mainly used the resources of KLIWAS and other national projects to achieve larger scale shipping related results.

3.2.5. AdaptAlp – Adaptation to Climate Change in the Alpine Space

The main aim of the AdaptAlp project (2008-2011) financed by the European Regional Fund for the Alpine Space was to address the question of how to adapt to the risks of natural hazards within the changing environment of the highly complex and sensitive Alpine region (www.adaptalp.org). One of the goals of the project was to improve information on the potential impact of climate change at the regional or local level using state-of the-art approaches. Hence, five catchments, the Alpine Rhine, the Upper Soca, the Adda, the Durance and the Inn were chosen for hydrological impact studies. For the Inn, two regional hydrological models were used for both water regime analysis of the past and climate change scenarios of the future (see Adapt Alp WP 4 Summary available at adaptalp.org).

Application of WaSiM-ETH on the Inn catchment at daily temporal and 1x1 km^2 spatial resolution (Korck et al., 2012): Meteorological station data was interpolated with an extended Inverse Distance Weighting procedure developed within AdaptAlp for Alpine regions. This data was used to calibrate WaSiM-ETH and bias correct dynamically downscaled climate scenarios. Both statistical and corrected dynamical climate model data was used for Climate Change impact assessment based on the periods 1971-200, 2021-2050 and 2071-2100. Due to the fact that the project mainly aimed at risk assessment, model results were analysed on potential future changes of mean, high and low flows of the Inn River.

Application of COSERO on the Inn catchment at monthly resolution (Kling et al., 2012): Main features of the input data used for this study is a) the remarkable HISTALP monthly meteorological data set of the past from 1887 to 2007 for the Alpine Region (Auer et al., 2007) and b) the nearly complete ENSEMBLES simulations data set until 2100 (Van der Linden and Mitchell, 2009). Hence, although the model COSERO itself is run only at monthly time steps, a coarse spatial resolution of 16 subbasins split into 61 hydrological response units and needs potential evapotranspiration as an input, runoff of the Upper Danube including the Inn catchment down to the city of Vienna has been simulated and analysed.

Which data sets are actually available for model comparisons is not absolutely clear, but Dr. Enno Nilson (nilson@bafg.de) of the German Federal Institute of Hydrology in Koblenz is able to provide data from AdaptAlp research. Furthermore, data of the precursor project ClimChAlp (Climate Change, Impacts and Adaptation Strategies in the Alpine Space; 2006 to 2008; www.climchalp.org) on the German Alpine region is also potentially useful to identify regional hydrological characteristics. Furthermore, the Bavarian Environmental Agency stores daily data sets at 1 km resolution produced with WASIM-ETH simulations, which can be provided by Dr. Holger Komischke (Holger.Komischke@lfu.bayern.de). Besides six major meteorological variables, these are gauge runoff time series, potential and actual evapotranspiration, snow melt and direct runoff.

3.2.6. Austrian Science Funds project for the Inn catchment

The main aim of study conducted by Merz et al. (2011) and financed by the Austrian Science Funds was similar to the work of (Korck et al., 2012), but with the more conceptual model HBV (SMHI, 2006). The Inn catchment was simulated at daily time steps for the period 1976-2006 with a spatial granularity of about 60 subcatchments together with about 210 other Austrian gauged catchments investigated in this study. Analysis of results was mainly based on river runoff time series, data can likely be provided by Dr. Juraj Parajka at the Technical University in Vienna (parajka@hydro.tuwien.ac.at).

3.3. Model studies in the Sava subbasin

3.3.1. BOBER – Better Observation for Better Environmental Response

The BOBER project (2010-2015) is 85% funded by the European Cohesion Fund and aims at 'Upgrading the system for monitoring and analysing the state of the water environment in Slovenia' (Pogacnik, presented in Zagreb 2013). It is run by the Slovenian Environment Agency (ARSO) to produce real-time flood forecasts from monitoring and simulations for the Sava and Soça rivers. The project manager for the BOBER project is Dr. Gregor Sluga (gregor.sluga@gov.si), who is generally open to provide further information and data.

The Slovenian Hydrological Forecasting System (HFS) is based on two model components which are part of the DHI (Danish Hydrological Institute) MIKE11 Software – the hydrological NAM rainfall-runoff model and a 1-dimensional hydrodynamic model that simulates water flow in the rivers. The area of 11,735 km^2 of the Slovenian Sava catchment is divided into 40 subcatchments, and MIKE11-NAM is calibrated with 129 precipitation stations, 35 temperature stations and 43 locations with potential evapotranspiration estimates. Model outputs consist of catchment runoff and groundwater flow, furthermore soil moisture content, ground water recharge and snowmelt (Pogačnik et al., 2011).

3.3.2. UNECE Flood Risk and Climate Change assessment

Regarding a general Flood Risk Management Plan for the Sava River Basin (SRB) in the view of the European Flood Directive (EFD), the International Sava River Basin Commission (ISRBC) implemented the 'Pilot project on climate change adaptation: Building the link between Flood Risk Management planning and climate change assessment in the Sava River Basin' (2010-2013) financed by the UNECE, "which has provided outcomes regarding the possible climate change impacts on the flood management as well as some recommendations on possible adaptation measures" (ISRBC, 2014). Within this study, the widely-known, conceptual HBV model was implemented in the Sava basin (Brilly et al., 2015), as was done before to simulate discharge and snow cover in the Slovenian part of the Sava basin by Primožič et al. (2008). No information on data availability could be achieved, yet it is most likely that data requests should be sent to the Deputy Secretary for integrated river basin management and water planning of the Sava Commission, Dragan Zeljko (dzeljko@savacommission.org).

3.3.3. WATCAP – Water and Climate Action Plan

The second project within the framework of building a Flood Risk Management Plan for the Sava River Basin was the 'Water and Climate Adaptation Plan for the Sava River' (WATCAP) financed by the World Bank (2010-2014). The aim was to set up a 'Sava River Basin Hydrological Model' based on the HEC-HMS hydrological model and HEC-RAS model for unsteady (channel) flow and considering hydropower, navigation, flood control, agriculture and economics in the analysis. The final project report was under public consultation until September 14, 2014 (see Annex 1 at: www.savacommission.org/news_detail/151).

The hydrological HEC-HMS/RAS model was implemented with 14 catchments consisting of 44 sub-catchments based on gauging stations. The model was calibrated and validated at 35 runoff stations having data in the period 1969-1984. Also future climate change simulations were produced based on 5 GCM/RCM combinations, likely taken from the ENSEMBLES database as no reference is given in the draft of the final report, Annex 1. Likely, the ISRBC will be responsible for decisions regarding data availability and cooperation.

3.3.4. Vrbas catchment study

The study by Ireson et al. (2006) used a combination of MIKE11-NAM (DHI, 2009) with the 2-dimensional ASM ground water model, an originally educational tool, to simulate the state of ground water resources in the 6385 km^2 Vrbas catchment, a tributary of the Sava river in Bosnia and Herzegovina (BiH). Main aim of the study was to investigate, how well such a coupled surface-ground water system could help to understand and manage a data-scarce catchment in the view of the EU-WFD. Model setup was based on the years 1971-1972, in which enough data was measured to use as a basis. Model setup and analysis was achieved by integrating the models in ArcView GIS developed by ESRI.

The project was financed via the World Bank from Norwegian and other donors from 2010-2013 (www.wb-vrbasstudy.com). As no feedback came from the scientific contractor, we assume that the results and/or the model system is still used or archived by the ISRBC (www.savacommission.org) or the Ministry of Agriculture, Forestry & Water Management of BiH (www.fmpvs.gov.ba).

3.4. Model studies in the Tisza and Lower Danube subbasin

3.4.1. The Tisza River Project – Real-life scale integrated catchment models for supporting water and environmental management decisions

The aim of the EU funded Tisza River Project (2002-2004) was to save the water resources and ecological values with the help of integrated catchment management tools and to secure the sustainable use of the resources of the Tisza River Basin (Jolankai and Pataki, 2004).

The conceptual rainfall-runoff model VITUKI-NHFS containing the hydrological rainfall-runoff model TAPI and the 1-dimensional hydraulic model TISZA was applied on the whole basin within the EU funded 'Tisza River Project' (Jolankai and Pataki, 2004). Furthermore, other foreign models (e.g. WetSPA) were applied on smaller subbasins to investigate water resource management decisions. Unfortunately, the detailed report on hydrological and hydraulic models development (Zsuffa et al., 2004) does not give much information on the temporal and spatial dimensions and the data actually used for model setup. Besides those models, also water quality models were set up, with SENSMOD of VITUKI again being the one applied to the whole catchment area. Yet, descriptions of these water quality models and results should be found in the Danube Water Quality report produced within the Danube Water Nexus activities. The VITUKI-NHFS model was also applied on some parts of the Tisza within the FP6 CLAVIER project (www.clavier-eu.org) to investigate Climate Change impacts.

As the Hungarian water management institute VITUKI is no more active, information and possible data requests should be sent to the ICPDR, namely Igor Liska (icpdr@unvienna.org).

3.4.2. ECLISE – Enabling Climate Information Services for Europe

ECLISE (2011-2013) is a collaborative FP7 research project under the Environment Programme of the European Commission. The central objective is to take the first step towards the realisation of a European Climate Service. ECLISE provides climate services for several climate-vulnerable regions in Europe, organized at a sectorial level: cities, water resources, coastal defence and energy production. The project will define, in conceptual terms, how a pan-European Climate Service could be developed in the future, based on experiences from local services and the involvement of a broader set of European decision makers and stakeholders. (www.eclise-project.eu)

Within work package 5.7, potential climate change impacts on the 15,740 km^2 Someş catchment as a part of the Tisza basin was investigated with the conceptual, continuous WatBal model (Mic and Corbus, 2014; Yates, 1996). The modelled runoff in the Someş catchment was calibrated and assessed based on 33 river sections (ECLISE deliverable 5.10). Monthly runoff results for future climatic conditions (2020-2050) were produced with 7 RCM simulations at 25 km resolution of the EURO-CORDEX project (www.euro-cordex.net) and one of its predecessor ENSEMBLES and compared to the past period 1971-2000 (ECLISE deliverable 5.11).

Although acknowledged for CECILIA project funding, also the work of Mic et al. (2013) uses the WatBal model to investigate climate change impacts in the Buzau and Ialomita catchments covering 14,392 km^2 driven with climate model simulations (see below).

3.4.3. Other projects

The project 'Development of a Flood Control Information System in the Upper-Tisza River Basin' (2012) was financed by the Hungarian and Swiss Hungarian Cooperation Programme and led by the Hungarian General Directorate of Water Management OVF (www.ovf.hu). For future flood and drought risk management in the Tisza basin, the distributed, process-based DIWA model was applied (Pongrácz et al., 2013). Basin responses to extreme events (for the 100/200 years return periods) under present and future climate and land-use conditions were tested, using GIS-based modelling approaches (contractor: www.HYDROInform).

Noteworthy may also be the study by Horvát et al. (2009) that investigated land use changes on the water balance of sub-catchments of the Tisza in Slovakia using the conceptual rainfall-runoff model FRIER. The study was supported by the Slovakian Agency for Research and Development. Although the single catchments are smaller than 4,000 km^2, 5 of those 6 investigated belong to the Tisza basin. The FRIER model is a physically-based, distributed model (Horvát, 2008) based on the well-known WetSPA model (Wang et al., 1996) adjusted to Slovakian conditions. Runoff conditions were modelled at 100 m spatial resolution and hourly time steps to evaluate land use and climate change conditions.

3.5. Studies in other subbasins or catchments larger than 4,000 km²

3.5.1. CECILIA – Central and Eastern Europe Climate Change Impact and Vulnerability Assessment

The aim of the CECILIA project (2006-2009) funded under the EU-FP6 program was to improve the understanding of local climate change in Central and Eastern Europe and its impacts on forestry, agriculture, hydrology and air quality. One aim was the provision of regional climate change data sets at 10 km resolution and to study hydrology, water quality, and water management, focusing at medium-sized river catchments and the Black Sea coast (www.cecilia-eu.org).

Climate Change assessment of impacts on water resources has been conducted with the CONSUL model on the Mureş catchment as a part of the Tisza subbasin by comparing REMO-ECHAM5 driven hydrological simulations of the A1B emission scenario for the past 1951-200 and 2001-2050 (Corbus et al., 2011). The estimation of the impact of climate change and climate variability upon the peak flow regime of the **Mureş River** was based on long-term simulations carried out with the hydrologic model CONSUL at a time step of 6 hours and a gridded spatial resolution. The 6-hourly discharge time series were analysed comparatively in order to estimate the impact of climate change on the maximum flows of the Mureş River.

Furthermore, the WatBal model (Yates, 1996) was used to investigate climate change impacts in the Lower Danube catchments **Buzau and Ialomita** covering 14,392 km^2 driven with climate model simulations of the CECILIA project (Mic et al., 2013). The two catchments were subdivided in 17 subcatchments calibrated and run with RCM data for the periods 1971-2000 and 2021-2050. In the end changes in monthly discharge values were analysed. The model CONSUL is also used in the project CLIMHYDEX (2011-2014) of the Romanian Meteorological Service (climhydex.meteoromania.ro), yet results are not published to date.

Data availability is not clear at the moment, but inquiries should most likely be sent to Dr. Rodica Mic of the Romanian National Institute of Hydrology and Water Management (rodica.mic@hidro.ro).

3.5.2. ICPDR Morava Flood Action Plan

Flood protection in the **Morava subbasin** is supported by modelling activities with LISFLOOD supported by JRC (Feyen et al., 2008) and the model HYDROG for the Czech Republic as reported in the ICPDR Morava Flood Action Plan (www.icpdr.org). Meanwhile, the HYDROG model is used for operational forecasting in the Czech Republic, yet exact information in scientific literature is hardly available. One good example is the application of HYDROG with rainfall radar data by (Salek et al., 2006). Regarding contacts and data inquiries, two agencies are given in the ICPDR FAP that deals with the Morava catchment: The Czech Hydrometeorological Institute (www.chmi.cz) and Morava Waters (www.pmo.cz).

3.5.3. NL-RO Partners for Water project

The model-based management of flood risk mitigation measures in the **Timiş-Bega catchment** with the HEC-HMS model system was supported by a 'Partners for Water' collaborative project between the Dutch and Romanian governments (Popescu et al., 2010). The hydrological model was coupled with the 1-dimensional HEC-RAS hydraulic model (Brunner, 2010) for small channels and the 2-dimensional SOBEK model (Horritt and Bates, 2002) for downstream flood wave analysis. This resulted in a decision support system (DSS) for flood mitigation and control that is also able to simulate the effects of e.g. dyke breaches (Popescu et al., 2010). The catchment area of the Bega tributary is 2,878 km^2, while the main river Timiş drains an area of 13,085 km^2 and is 359 km long. As usual, the DSS is applied event-based at short time steps and was run on 20 lumped subcatchments for the whole basin. Data was provided by Romanian Waters, Banat region, while the modelling was conducted at the UNESCO-IHE Institute for Water Education in Delft, NL (www.unesco-ihe.org/projects/decision-support-system-flood-management-romania). Regarding data and results availability, project manager Dr. Ioana Popescu at UNESCO-IHE in Delft (i.popescu@unesco-ihe.org) should be contacted.

3.5.4. CLEANWATER

The main aim of the still ongoing LIFE+ CLEANWATER project (2010-2014) of the National Institute for Hydrology and Water Management of Romania (www.lifecleanwater.ro) is to investigate nitrate pollution in the **Barlad catchment** with regard to achieving good status of the ground water for the EU-WFD until 2015. The Barlad catchment is as a part of the Siret subbasin in the North-Eastern part of the DRB and has four main ground water bodies, which are at risk mainly due to intense agricultural emissions. The surface area of the catchment is 7220 km^2 and about 116 km of the river length are at ecological risk (Trifu et al., 2012).

The assessment of ground water quality development is based on GIS-enhanced data collection and a simulation model system (lifecleanwater.ro/modelling.html) based on the SENEQUE model (Ruelland et al., 2007) for catchment-scale bio-chemical functions in surface waters, the SIDASS model of soil nitrogen processes and transport (Simota et al., 2005) and a complex 2-dimensional approach to nitrate transport in aquifers based on MODFLOW (Harbaugh et al., 2000).

Main contact is the CLEANWATER project manager Dr. Maria Cristina Trifu of the National Institute of Hydrology and Water Resources in Bucharest, Romania (cris.trifu@hidro.ro).

3.5.5. INTERREG-IIIB CADSES project

The main aim if the INTEREGIIIB-CADSES funded 'Flussraumagenda Alpenraum' project was the improvement of transboundary flood forecasting on the **Mur subbasin** between Austria and Slovenia (Ruch et al., 2007). To this end, the conceptual, lumped rainfall-runoff NAM (DHI, 2009) as a part of the hydrodynamic model MIKE-11 of the Danish Hydrological Institute has been applied on the about 14,000 km^2 large catchment that also covers small parts of the Hungarian and Croatian territory. Again the model setup for flood forecasting is event-based and highly calibrated on 52 subcatchments in Austria and Slovenia, but includes 9 hydropower structures. For better visualization the model was also integrated with the

MIKE FLOOD WATCH system to produce near real-time flood information for the Mur and only Raab rivers.

For this study on the Mur River as well as the Raab River a group led by Christophe Ruch from Joanneum Research was sub-contractor in charge to develop the forecasting models. For information on data availability Dr. Robert Schatzl (robert.schatzl@stmk.gv.at), Head of the Hydrological Service of the Styria Region has to be contacted.

4. Catalogue of models applied in the DRB

4.1. Black Box Models – Mathematical/statistical models

4.1.1. VITUKI-NHFS – VITUKI National Hydrological Forecast System

The VITUKI-NHFS models were developed by VITUKI (Hungarian National Hydrological Forecasting Service) for the Tizsa River Project (Zsuffa et al., 2004). The conceptual, continuous, and semi-distributed models include the TAPI precipitation-runoff model, the HOLV snowmelt model, the Discrete Linear Cascade Model (DLCM) for channel flow, and the hydrodynamic channel flow model TISZA (Zsuffa et al., 2004). Altogether, the model system allows for simulation of total runoff and its components (surface runoff, interflow, subsurface runoff and baseflow), routing, snowmelt, and channel flow (Zsuffa et al., 2004).

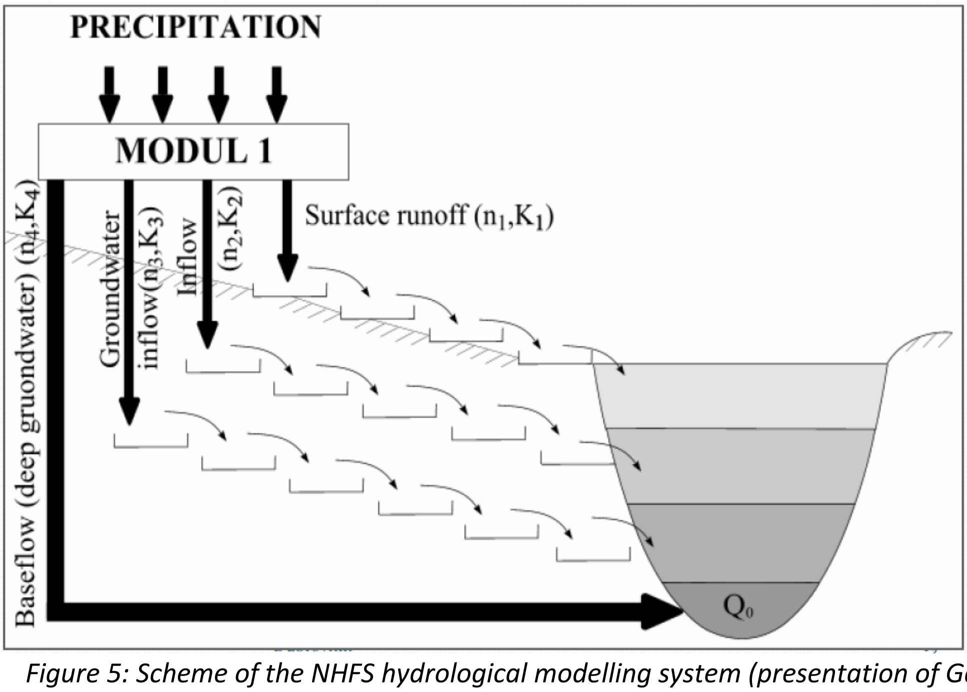

Figure 5: Scheme of the NHFS hydrological modelling system (presentation of Gábor Bálint, 2009)

Model structure and complexity

The VITUKI-NHFS model components (Figure 5) apply mostly empirical to conceptual methods (except for the snow model where an energy balance approach can be used depending on the available inputs) using storage approaches (Zsuffa et al., 2004). Therefore, the model is considered to be a 'Black-Box' model with little demand on data pre-processing e.g. from mesoscale meteorological models or radar observations at various time steps.

Input data

The model components require at least the preparation of precipitation and temperature inputs. In order to use the energy balance mode of the HOLV model further requirements are cloudiness, dew point and wind speed (Zsuffa et al., 2004). Further the catchment has to be divided into several subbasins to determine which of the channel flow models should be applied at a specific subbasin.

Simulation results

The VITUKU-NHFS modelling system produces section-mean discharges, water levels and stream velocities distributed in time and along the course of the river channels (Zsuffa et al., 2004).

4.1.2. MIKE11-NAM (Nedbør-Afstrømnings-Model)

The MIKE11-NAM hydrological model simulates the rainfall-runoff processes occurring at catchment scale (DHI, 2009; Ruch et al., 2007). It is characterized as a deterministic, lumped, conceptual, and continuous model which simulates water content in four different and interrelated storages (snow, surface, root zone, groundwater) (DHI, 2009; Ireson et al., 2006). Furthermore, NAM allows for modelling man-made interventions in the hydrological cycle in terms of irrigation and groundwater pumping (DHI, 2009).

Model structure and complexity

The NAM model components (Figure 6) use a set of linked mathematical statements describing - in a simplified form - the behaviour of the land phase of the hydrological cycle (DHI, 2009). Since these mathematical statements are based on conceptual approaches, the model is further classified as a 'Black-Box' model with moderate input data requirements. Further details about the methods used for each component is given in the model database.

Input data

The model computes its outputs on catchment or subcatchment scale. Hence, model parameters and initial conditions have to be provided for each computational unit (CU) which represents the modelled (sub-)catchment. Furthermore, NAM requires time series of meteorological data which include precipitation, potential evapotranspiration, air temperature (for snow modelling), and radiation (optional for snow modelling) (DHI, 2009). The model calculates weighted averages per CU from values of different stations (DHI, 2009). In order to calibrate/validate the model, measured stream flow data are needed as well. Time series of irrigation or groundwater abstraction have to be provided to model the corresponding processes.

Simulation results

The major purpose of the NAM model is to represent the land phase of the hydrological cycle. Hence, the main results comprise catchment runoff and groundwater flow values, soil moisture content, and ground water recharge (Ruch et al., 2007). The resulting catchment runoff is divided conceptually into overland flow, interflow, and baseflow components (Ruch et al., 2007).

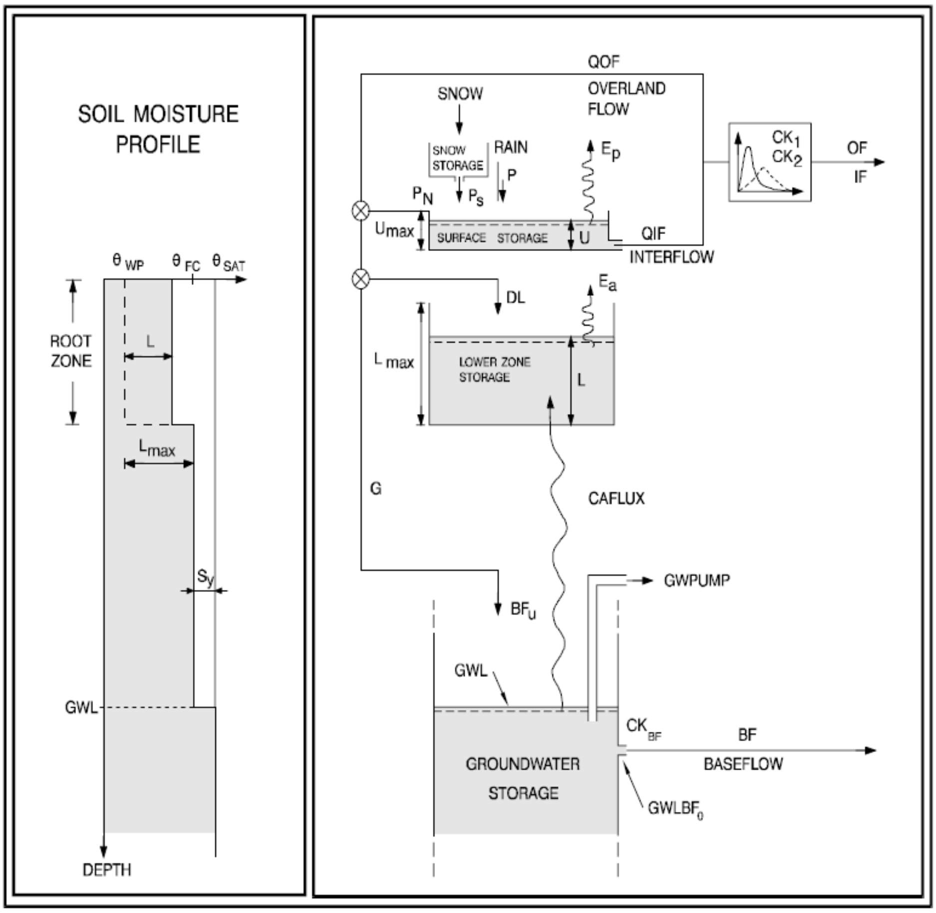

Figure 6: Structure of the NAM hydrological model (Ruch et al., 2007).

4.1.3. HYDROG – Hydrograph

HYDROG (Starý, 1991-2005) is a distributive event rainfall-runoff model which has been in use routinely in the Czech Hydrometeorological Institute since 2000 for operative discharge prediction in the Dyje catchment (Brezková et al., 2007). It performs calculation of the rainfall-runoff process one-dimensionally as the catchment is subdivided into subcatchments with constant properties (slope, roughness, hydraulic conductivity in the saturated environment) (Brezková et al., 2007; Salek et al., 2006). The water flow through a subdivided catchment (spatial-surface runoff and concentrated runoff) is simulated by application of the Saint-Venant Equations (continuity equation and an equation based on the law of motion preservation) simplified by a kinematic wave approximation to describe the dynamic performance of the system (Brezková et al., 2007; Salek et al., 2006). The computation of dynamic change of groundwater runoff is accomplished by a conceptual regression model after McCuen and Snyder (1986) using only groundwater storage (Brezková et al., 2007; Salek et al., 2006). The infiltration loss is modelled using the modified Horten method (Jacobson, 1980), which estimates the amount of initial infiltration from the precipitation sum that occurred in the preceding period (Brezková et al., 2007; Salek et al., 2006). Additional losses are included in the initial threshold value, when the aerial surface runoff is triggered off only after this values exceeded (Brezková et al., 2007; Salek et al., 2006).

4.2. Grey Box Models – Conceptual Models

4.2.1. HEC-HMS/RAS – Hydrologic Engineering Center – Hydrologic Modeling System

The HEC-HMS model is a deterministic, continuous, and semi-distributed model developed by the US Army Corps of Engineers (Feldman, 2000; Scharffenberg, 2013; Zhang et al., 2013). Former releases were based on empirical and conceptual models which were complemented by physically-based approaches in order to be applicable for ungauged cases (Scharffenberg et al., 2010). The model allows for simulation of precipitation, infiltration, surface runoff, baseflow, and open channel flow as well as snowmelt, potential evapotranspiration, and reservoirs (Scharffenberg et al., 2010). Hence, HEC-HMS offers several methods for its model components. The model can simulate individual storm events as well as continuous precipitation input at minute to daily time steps (Zhang et al., 2013).

The HEC-RAS (River Analysis System) allows for performing one-dimensional steady, unsteady flow hydraulics, sediment transport/mobile bed computations, and water temperature modelling (Brunner, 2010).

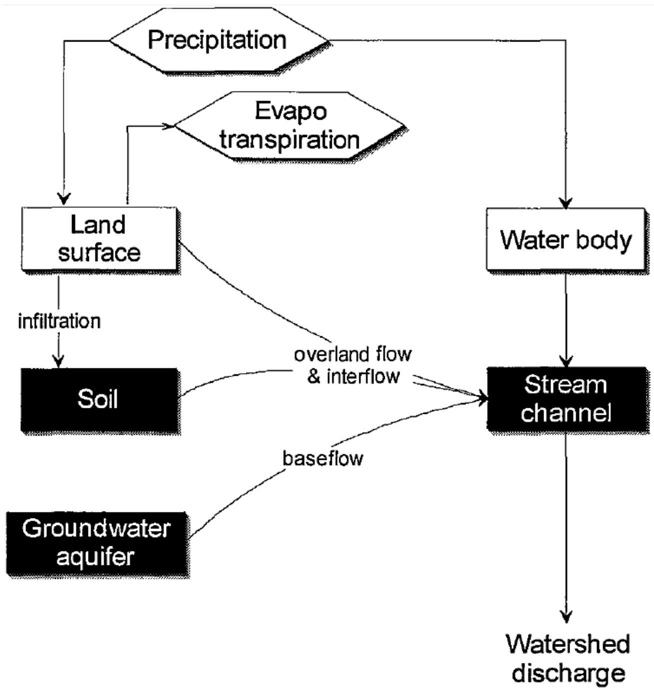

Figure 7: Typical HEC-HMS representation of watershed runoff (Feldman, 2000).

Model structure and complexity

In general, HEC-HMS is separated into several model components that mainly use empirical or conceptual approaches and parameters (except for a few physically-based methods) to numerically compute their outputs. Hence, it is classified as a 'Grey-Box' model with moderate demand on input data which have to be prepared in advance. A detailed overview of the various methods of each model components is given in the model database.

Input data

The mostly empirical approaches require only precipitation inputs. Further meteorological data may comprise snowmelt, shortwave radiation and monthly evapotranspiration averages. The meteorological data analysis is further performed by the meteorological model (Scharffenberg, 2013). Using underlying DEM information the model partitions the basin into sub-watersheds (Zhang et al., 2013). Further inputs include boundary conditions and initial values, infiltration, surface runoff, baseflow in the subbasins, and channel routing (Singh et al., 2010).

Simulation results

The main application of the HEC-HMS model is to simulate the hydrological response of a watershed subject to a given hydro-meteorological input (Zhang et al., 2013). Therefore, the basic simulation results comprise precipitation per subbasin, infiltration and surface excess, surface runoff, discharge, subbasin outflow, stream flow, and baseflow (Singh et al., 2010).

4.2.2. COSERO – Continuous Semi-distributed Runoff model

COSERO is a continuous, semi-distributed, deterministic precipitation-runoff model which considers the processes of snow accumulation and melt, melt of glaciers, reservoirs, actual evapotranspiration, soil storage, and separation of runoff in different flow components (Enzinger, 2009; Klein et al., 2011). The overall concept is similar to the HBV model by Bergström (1995) (Enzinger, 2009).

Model structure and complexity

Each component of the COSERO model (Figure 8) is part of a cascade of linear and non-linear reservoirs applying mostly deterministic conceptual approaches to calculate the water balance elements (Kling, 2006). Hence, COSERO can be classified as a 'Grey-Box' model with moderate demand on input data. Details of each model component as applied to the UDRB projects is given in the model database.

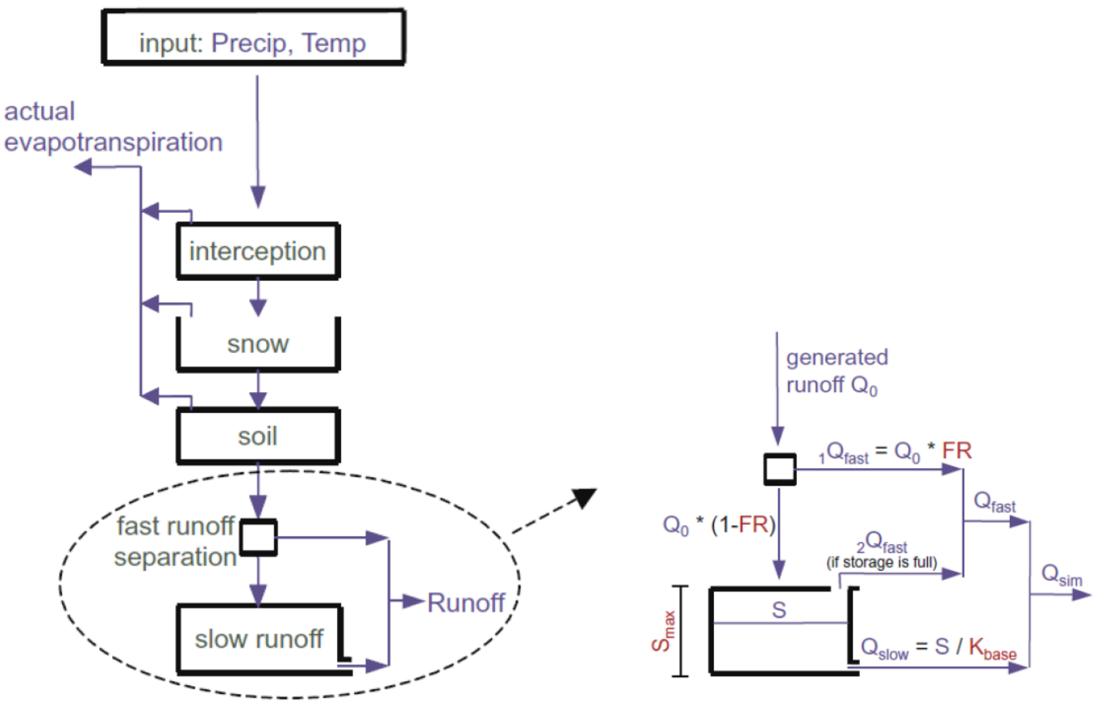

Figure 8: Modules of the water balance model COSERO (Kling and Nachtnebel, 2009).

Input data

COSERO requires spatially distributed information about precipitation, air temperature, and potential evapotranspiration as meteorological drivers at either daily or monthly time steps.

Other spatial model inputs comprise the division of the catchment into subbasins and zones (Kling, 2006). These information have to be prepared in advance by the user.

Simulation results

The main application of the COSERO model is the calculation of the water balance for climate change impact studies (Klein et al., 2011; Kling et al., 2012). Hence the major outcomes comprise the components of the water balance – precipitation, runoff, actual evapotranspiration and storage change. Additional components include amongst others rainfall and snowfall, various runoff components, interception, and soil storage (Kling, 2006). Furthermore, Stanzel et al. (2008) applied the model for real time flood forecasting in Alpine Danube tributary catchments.

4.2.3. EPIC – Environmental Policy Integrated Climate Model

EPIC is a process-based, continuous computer model that simulates the physico-chemical processes that occur in soil and water under agricultural management (Gassman et al., 2005; Gerik et al., 2014). The area modelled may be of any size consistent with required hydrological land use unit (HLU) (Gerik et al., 2014). Furthermore, the model operates solely in time having no spatial component (Gerik et al., 2014). The EPIC model can be subdivided into nine separate components defined as weather, hydrology, erosion, nutrients, soil temperature, plant growth, plant environment control, tillage, and economic budgets (Gassman et al., 2005). Therefore, EPIC produces outputs including water, nutrient, and pesticide flux in the HLU (Gerik et al., 2014). The model is part of the modelling framework of the project FATE (Bouraoui et al., 2006).

Further information about the EPIC model and its application within the JRC hydro-economic model platform is given in Burek et al. (2012).

4.2.4. GREEN – Geospatial Regression Equation for European Nutrient losses

GREEN is a simplified conceptual model which relates the nutrient loads to spatially referenced nutrient sources and basin characteristics (Grizzetti and Bouraoui, 2006). The GREEN model was developed at the European Commission's Joint Research Centre (Institute for Environment and Sustainability, Rural, Water and Ecosystem Resources Unit) in the context of the project FATE, a wider modelling approach to address the problem of nutrient in the environment (Grizzetti and Bouraoui, 2006).

Further information about the GREEN model and its application within the JRC hydro-economic model platform and the JRC FATE project is given Burek et al. (2012) and in Grizzetti and Bouraoui (2006) respectively.

4.2.5. HBV – Hydrologiska Byråns Vattenbalansavdelning

The HBV model is a semi-distributed, continuous, and conceptual model for the calculation of runoff and to simulate hydrological forecasting (Brilly et al., 2014; SMHI, 2006). The model consists of several fundamental hydrological routines, accounting for simulation of snow, soil moisture, evapotranspiration, groundwater, and runoff as well as routing (Primožič et al., 2008; Seibert, 1997; SMHI, 2006). It was originally developed in the 1970's at the Swedish Meteorological and Hydrological Institute (SMHI) by Bergstrom (1976) (Brilly et al., 2014). HBV-96 offers several interpolation methods for meteorological inputs (SMHI, 2006). The model allow for a separate run for each subbasin and adding the contributions from all subbasins (SMHI, 2006).

Model structure and complexity

The model consists of subroutines (Figure 9) using storage and reservoir approaches, as well as conceptual descriptions such as response functions to simulate the hydrological processes numerically (Primožič et al., 2008; SMHI, 2006). Hence, HBV is classified as a 'Grey-Box' model with moderate demand on input data and their preparation. The main characteristics of HBV as applied to studies of the Sava catchment are given in the model database.

Input data

In order to run HBV the model requires precipitation and temperature as meteorological drivers (Primožič et al., 2008). Furthermore, potential evapotranspiration has to be provided, either as mean monthly or daily values (SMHI, 2006). Spatially distributed data comprise elevation bands and vegetation zones which usually consist of open areas, forests, lakes, and glaciers (SMHI, 2006). For calibration purpose, the model also requires measured discharge values at the given time step (SMHI, 2006).

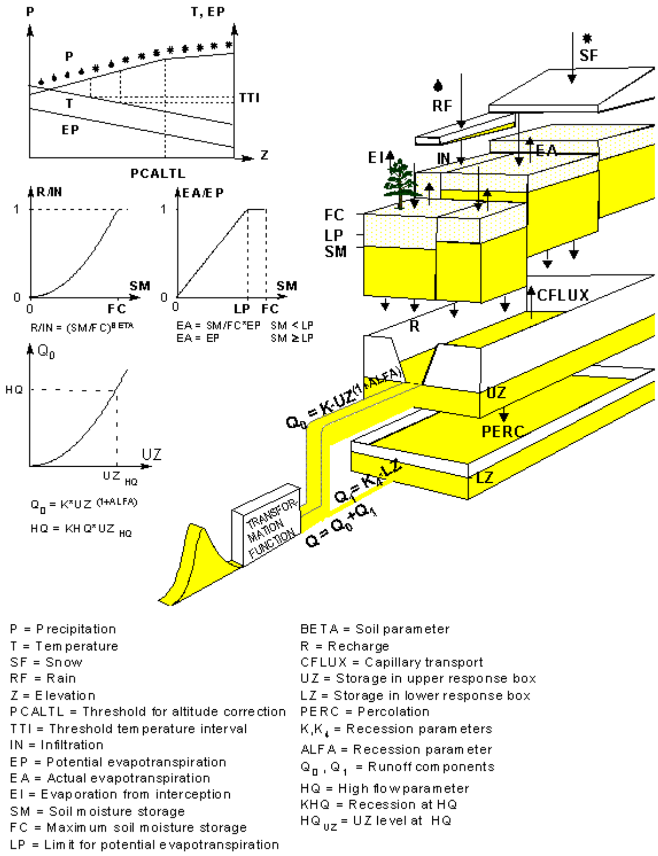

Figure 9: Schematic structure of the subbasin in the HBV-96 model (Lindström et al., 1997), with routines for snow (top), soil (middle) and response (bottom) (SMHI, 2006).

Simulation results

The HBV model has been applied in numerous studies, e.g. to compute hydrological forecasts, for computation of design floods or for climate change studies (Primožič et al., 2008; Seibert, 1997). Therefore, the model standard outputs include discharge, streamflow, reservoir inflow, basin average temperature, precipitation, evapotranspiration, soil moisture content and snow pack (Primožič et al., 2008). Most of those values can also be presented for all land use types in all elevation zones (Primožič et al., 2008).

4.2.6. LARSIM – Large Area Runoff Simulation Model

LARSIM is a deterministic, continuous (or event-based, depending on the operation mode), distributed, and conceptual model (Ludwig and Bremicker, 2006). It accounts for the simulation of the terrestrial part of the water cycle, including interception, snow accumulation, compaction and melt, evapotranspiration, soil-water movement, runoff generation, runoff concentration, and river routing as well as retention ponds, reservoirs, lakes, and withdrawal and water addition (Haag and Luce, 2008; Ludwig and Bremicker, 2006). LARSIM internally interpolates meteorological forcing variables from point measurements (Haag and Luce, 2008). Figure 10 illustrates the model scheme with its different components.

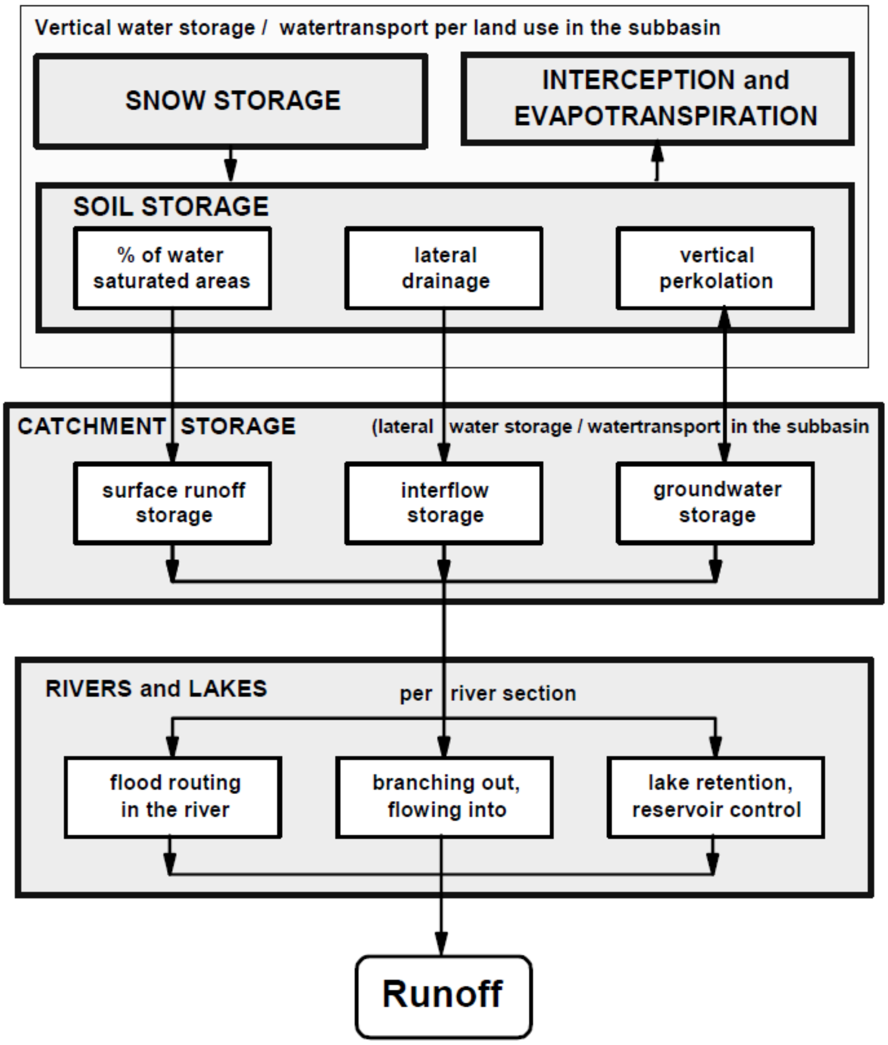

Figure 10: Scheme of the water balance model LARSIM (Ludwig and Bremicker, 2006).

Model structure and complexity

LARSIM uses relatively simple, but as far as possible physically based components (sub-models, Figure 10) consisting of storage approaches and theoretical laws to describe the land-bound water transport (Ludwig and Bremicker, 2006). Hence, LARSIM is classified as a

'Grey-Box' model. However, it requires intense data pre-processing. More details about the several model components are given in the model database.

Input data

If LARSIM is used for event based flood forecasting, precipitation is the only meteorological driver needed for simulation (and air temperature if snow plays an essential role) (Ludwig and Bremicker, 2006). For continuous simulation of the water balance, further drivers include global radiation (or sunshine duration), relative air humidity (or dew point temperature), air pressure, water temperature (Ludwig and Bremicker, 2006). Spatial distributed information is derived from digital elevation maps, digital maps of land cover and soil classification, digital river networks and geometrics along with additional information about retention ponds and reservoirs (Haag and Luce, 2008).

Simulation results

LARSIM applications are mainly concerned with analysis of climate change impacts on the water balance (e.g. the projects KLIWA and KLIWAS) and flood forecasting (Ludwig and Bremicker, 2006).Thus, model outputs include gauge based results regarding runoff components and discharge, and spatially distributed values of evapotranspiration, snow water equivalent soil water components, precipitation and runoff components.

4.2.7. LISFLOOD

LISFLOOD is a GIS-based physically based, spatially-distributed hydrological rainfall-runoff and channel model developed at the JRC (Dankers et al., 2007; De Roo et al., 2000; Van der Knijff and De Roo, 2008; Van der Knijff et al., 2010). The processes simulated by the model are amongst others snow melt, infiltration, interception of rainfall, leaf drainage, evaporation and water uptake by vegetation, surface runoff, preferential flow, exchange of soil moisture, and drainage to the groundwater (Van der Knijff et al., 2010). The model can be run at any desired time interval and any grid size (Van der Knijff et al., 2010).

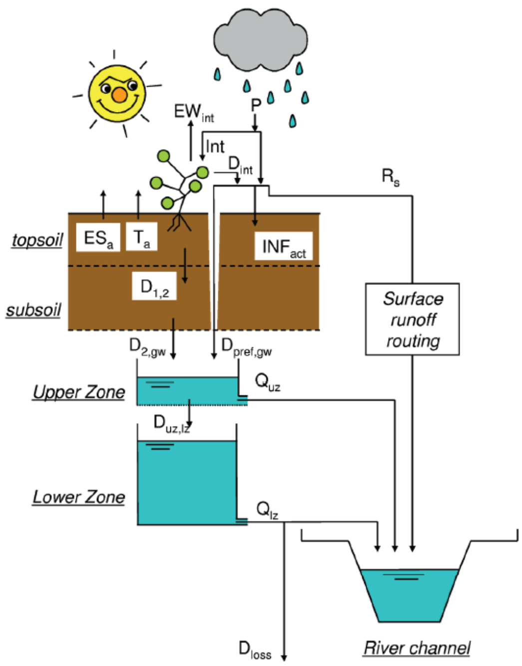

Figure 11: Schematic of the LOSFLOOD model developed at the JRC (Van der Knijff and De Roo, 2008).

Further details about LISFLOOD and its components are given in the model data base. Information about the model application within the JRC program is available at the JRC website and Burek et al. (2012).

4.2.8. MONERIS – MOdelling of Nutrient Emissions in RIver Systems

The Geographical Information System (GIS)-oriented model MONERIS is an semi-empiric, conceptual model, which allows the quantification of nutrients emissions via various point and diffuse pathways into river basins (Behrendt et al., 2002; Behrendt et al., 2007; Venohr et al., 2011). It was developed in the research group of the Leibniz-Institute of Freshwater Ecology and Inland Fisheries (IGB Berlin) (Behrendt et al., 2007). A scenario manager was developed with the capability to calculate the effect of measures on the nutrient input into river systems for different pathways and for different spatial bases (Behrendt et al., 2007).

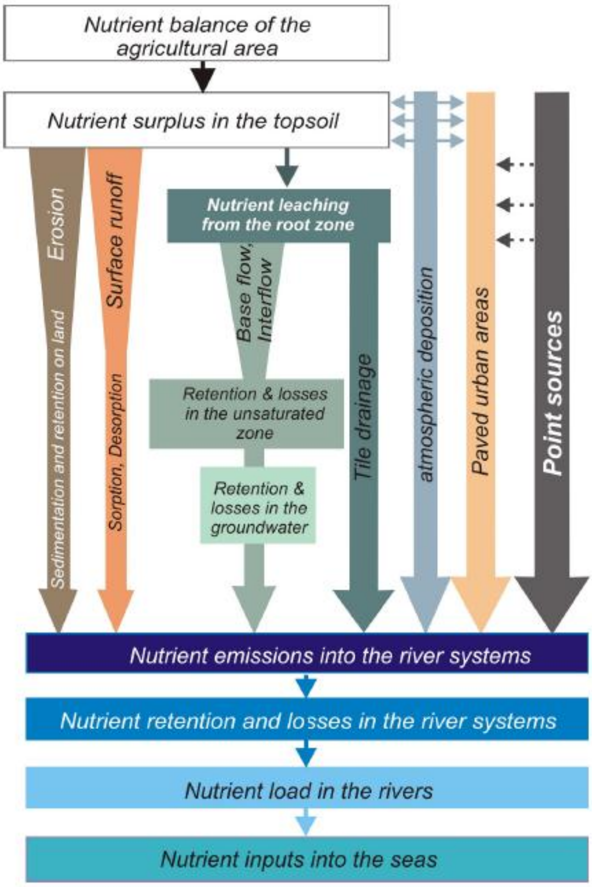

Figure 12: Pathways and processes in MONERIS (Behrendt et al., 2007).

Model structure and complexity

As shown Figure 12, MONERIS considers seven pathways (one point source of emissions, six for diffuse emissions) as well as the retention in rivers (Behrendt et al., 2007). The calculations are based on conceptual approaches. Therefore, MONERIS is classified as a 'Grey-Box' model. However, the model requires intense data pre-processing. The hydrological approaches applied in MONERIS are given in the data base.

Input data

Regarding meteorological drivers, MONERIS only uses annual precipitation maps. Furthermore, additional spatial inputs include catchment boundaries, elevation, river network, drainage data, population density, land use data, soil data, soil erosion data, hydrogeological data, hydro-meteorological data, and atmospheric deposition (Venohr et al., 2009). Statistical data input comprises amongst others additional population data, nitrogen excess, phosphor accumulation in the soil, agricultural data, and length of the channel network ((Venohr et al., 2009).

Simulation results

The model operates on a yearly or monthly temporal resolution. The model results are calculated for the analytical units which are sub-catchments in a river basin (Behrendt et al., 2007). Since its main objective is to identify source of nutrient emissions on regional basis and analyse transport and retention of nutrients in river systems, the results comprise amongst runoff mostly water quality data such as total emissions, agricultural and urban sources.

4.3. White Box Models – Process-based, Integrated Models

4.3.1. DANUBIA – Upper Danube Integrated Model System

The integrated decision support system DANUBIA was developed based on essential models from different natural-science and socio-economic disciplines connected by a UML (Universal Modelling Language) framework developed within the GLOWA-Danube project (Ludwig et al., 2003a). Besides coupling process models via its *Core Framework* (Hennicker et al., 2010), DANUBIA also contains a so-called *DeepActor Framework* developed to connect actor models representing spatially distributed human decisions with the natural environment (Barthel et al., 2008).

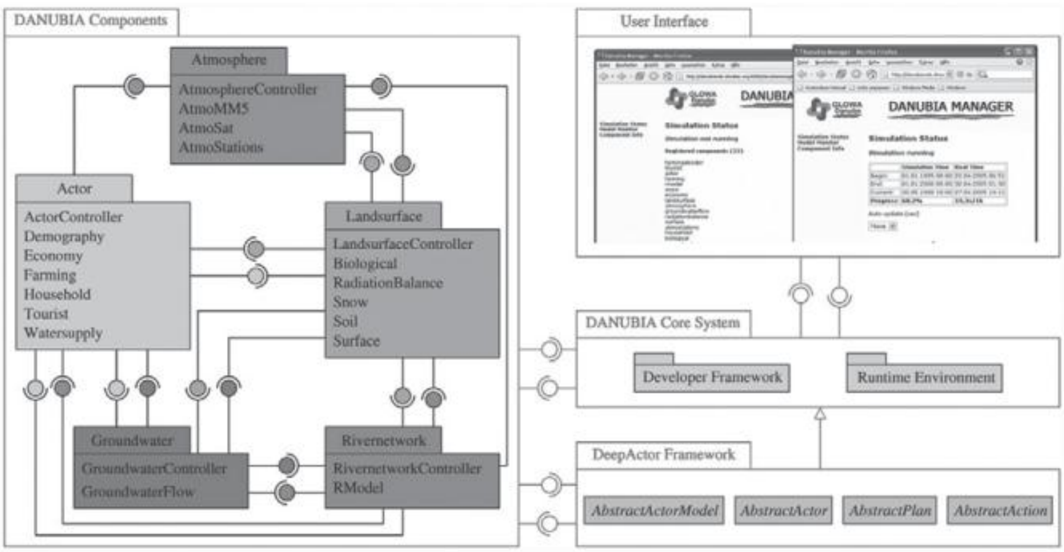

Figure 13: Components of the decision support system DANUBIA (Mauser and Muerth, 2008)

Model structure and complexity

As can be seen in Figure 13, the complex structure of the model system can be supervised by a simple user interface to set up simulation runs. Basically all interactions including the computational hierarchy and the data transmissions between the different components of DANUBIA are controlled by the core system, and if needed, by the DeepActor Framework.

All interfaces are defined in UML using the universal JAVA language, which has enough options to integrate models of various decent (Hennicker et al., 2010). Within the different system components, models adjusted to DANUBIA or developed during the GLOWA-Danube project are contained:

The *Landsurface* component basically includes the hydrological model PROMET (Mauser and Bach, 2009) also described below and the glacier model SURGES (Weber et al., 2010). For the soil component, the process-based nitrogen transformation model SNT (Klar et al., 2008) was added to *Landsurface*, and for dynamic crop simulations Lenz-Wiedemann et al. (2010) adopted a combination of the well-known models GECROS and CERES crop models.

The *Groundwater* component was originally based on MODFLOW-2000 (Harbaugh et al., 2000; Wolf et al., 2008) to simulate ground water flow and nitrate transport. But due to the complexity of processes and lack of data an approach using water table fluctuations (Jie et al., 2011) and indicators for ground water zones (Barthel, 2011) was adopted.

The *Rivernetwork* component has two options, one using the Muskingum-Cunge scheme as described in Todini (2007) as in the PROMET model, the other a combination of the classical Muskingum-Cunge approach for small rivers with the DAFLOW model for larger channels developed by the US Geological Service (Jobson and Harbaugh, 1999).

The *Atmosphere* component includes three choices: a) a station interpolation algorithm similar to PROMET (see below), b) an interface to downscale global and regional climate model data (Marke et al., 2011) and c) a stochastic weather generator for climate scenarios based on measured station data and future trends of air temperature and precipitation (Mauser et al., 2007).

The framework structure of the *Actor* component is described in (Barthel et al., 2008) and includes a model for water supply infrastructure (Barthel et al., 2010) using flags to communicate with the water users simulated by the other models. The subcomponents *Tourism* and *Households* are strongly connected to the water supply model (Soboll et al., 2011), while demographic and economic development are dynamic boundary conditions (see description on www.glowa-danube.de/atlas/). The Farming model which also simulates agricultural land use decisions is based on a agro-economical approach (Henseler et al., 2008) and an actor model (Apfelbeck et al., 2007).

Input data

Due to the complex structure of the model system, it needs a variety of social data sets besides the GIS layers and meteorological drivers used for the natural environment components. Social and economic data needed includes spatially explicit information on the demographic structure and income level of households, farm types and crop statistics, water-intense industrial sites, location of water supply structures and extraction wells, and relevant touristic infrastructure like golf courts and skiing areas. Yet, the modular structure allows for running a subset of the models to decrease the input data amount.

Simulation results

Besides the classical hydrological results for the land surface water cycle and river runoff (including high and low flows and hydro power productivity), which are similar to the output variables of PROMET (see below), the application of DANUBIA concentrated on ground water availability and pollution and the interactions and conflicts between climate change, water supply and water use in households, tourism and industry (see project description).

Open Source availability

At the end of the third Project phase of the GLOWA-Danube project, the coupled, integrated simulation model DANUBIA was transferred into the open source project *OpenDanubia* (opendanubia.glowa-danube.de). This approach provides both the core system (Core Framework, Actor Framework) as well as all major model components to the general public. This will enable decision makers from government, business and management to use *OpenDanubia* as a tool for proactive management of water resources in the context of global change. Furthermore, the model framework and all simulation models of *OpenDanubia* in the scope of GLOWA-Danube are further available for future developments and research questions (Muerth et al., 2012; Waldmann et al., 2012).

4.3.2. GWN-BW – Grundwasserneubildung-Baden-Württemberg

The GWN-BW model can be classified as a process based, spatially distributed, and deterministic kind of model (Arbeitskreis KLIWA Heft 17, 2012). It includes modules for spatial interpolation of meteorological drivers, radiation, snow, interception and transpiration, and a soil module (Figure 14). A routing component is not implemented within the model framework. GWN-BW gains total runoff through solving the water balance equation.

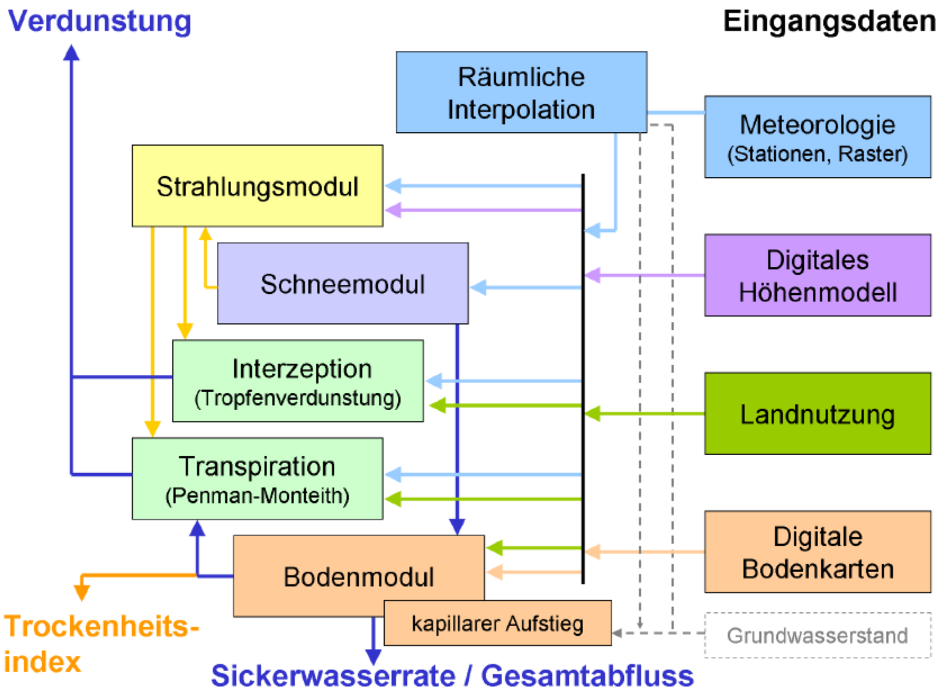

Figure 14: Modular structure of the soil water budget model GWN-BW and schematic illustration of required input data (Arbeitskreis KLIWA Heft 17, 2012).

Model structure and complexity

The different components of the GWN-BW model apply physically based or conceptual approaches to calculate actual evapotranspiration and leakage water rates (which is considered to represent groundwater recharge) (Arbeitskreis KLIWA Heft 17, 2012). The results of each component are computed numerically based on these mathematical descriptions. Therefore, GWN-BW is considered to be a 'White-Box' model with a moderate demand on data to be pre-processed. A more detailed characterization of each component is given in the model database.

Input data

GWN-BW requires spatially distributed information about the elevation, land use and soil. Further information needed for the simulation (field capacity, baseflow, etc.) index is then provided by these inputs. The meteorological drivers are either point measurements or readily spatially distributed daily values of precipitation, temperature, relative air humidity, sunshine duration, and wind intensity (wind speed and global radiation are accepted as well) (Arbeitskreis KLIWA Heft 17, 2012). Furthermore, GWN-BW provides several interpolation approaches to distribute the station values.

Simulation results

The model was developed to simulate the actual evapotranspiration, the soil water budget, and the amount of leakage water below the rooted soil zone for three German states (Arbeitskreis KLIWA Heft 17, 2012). Therefore, the important model outputs are mainly limited to terms of the water balance equation. For the KLIWA project these components were analysed using spatially distributed model results.

4.3.3. MODFLOW2000 – USGS Model of 3-D ground-water flow

MODFLOW is a model that numerically solves the three-dimensional ground-water flow equation for a porous medium by using a finite-difference method (Harbaugh et al., 2000). MODFLOW-2000 simulates steady and non-steady flow in an irregularly shaped flow system in which aquifer layers can be confined, unconfined, or a combination of confined and unconfined (Figure 15) (USGS, 2011). Flow from external stresses, such as flow to wells, areal recharge, evapotranspiration, flow to grains, and flow through river beds, can be simulated (USGS, 2011). Specified head and specified flux boundaries can be simulated as can a head dependent flux across the model's outer boundary that allows water to be supplied to a boundary block in the modelled area at a rate proportional to the current head difference between a "source" of water outside the modelled area and the boundary block (USGS, 2011).

Model structure and complexity

It has a modular structure that allows it to be easily modified to adapt the code for a particular application. These modules apply physical approaches to describe the processes of the system. The equations are solved numerically requiring a great amount of inputs. Thus, MODFLOW-2000 is considered to be a 'White-Box' model. MODFLOW-2000 is part of the DANUBIA modelling framework concerning the UDRB, responsible for groundwater related calculations.

Input data

The model input data to be provided to MODFLOW comprise aquifer properties for each cell (USGS, 1997). Furthermore, initial conditions, information about wells, rivers, and other inflow and outflow features for cells corresponding to the location of the features have to be specified in advance (USGS, 1997, 2011).

Simulation results

The major purpose of MODFLOW-2000 is to simulate common features in ground-water systems (USGS, 1997). Therefore, the model results consist of head (ground-water level) at every cell in the aquifer system, water budget, and flow rates (USGS, 1997). A complete listing of the input data is also part or the simulation results (USGS, 2011).

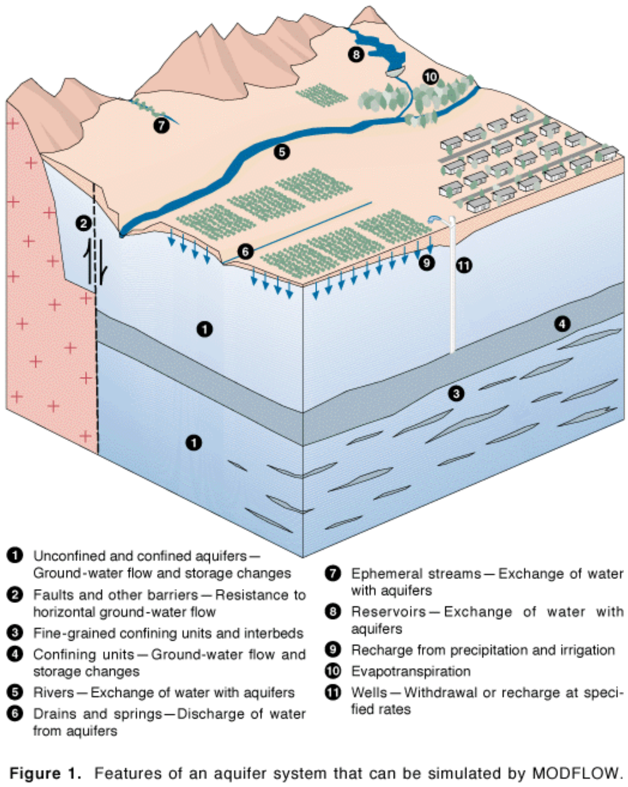

Figure 15: Features of an aquifer system that can be simulated by MODFLOW (USGS, 1997).

4.3.4. PROMET – PROcesses of Mass and Energy Transfer

PROMET is a grid distributed, continuous, integrated model including modules for snow and ice accumulation, actual land surface water and energy balance, vegetation growth, soil moisture and temperature, runoff formation and channel routing (Mauser and Bach, 2009). Furthermore, it can be coupled to regional climate models (Marke et al., 2011) and the grid-based groundwater flow model MODFLOW-2000 (Harbaugh et al., 2000). It also includes a component for man-made reservoirs and water transfer systems with the ability to compute hydro-power generation from river runoff and reservoir power plants (Koch et al., 2011).

Structural complexity of PROMET and its components

In general, PROMET, as well as its components, is a process-based, distributed model using deterministic equations of physical and biophysical processes and distributed input parameters and meteorological drivers. All output variables are computed numerically mostly based on theoretical laws and assumptions. Hence, it can be classified as a 'White Box' model that uses a large amount of data that has to be pre-processed, e.g. from general maps and remotely sensed data using generalized parameter estimation methods. The main characteristics of PROMET as applied to the UDRB as well as the main outputs and references are given in the model database (see below).

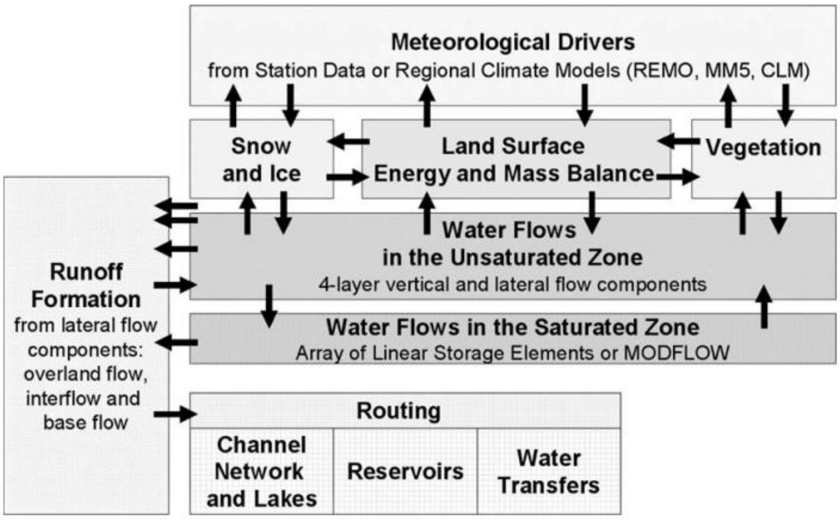

Figure 16: Schematic diagram of the components of PROMET and the interfaces between them. Boxes indicate components and arrows indicate interfaces of data exchange (Mauser and Bach, 2009).

Input data

The spatially distributed properties of the land surface have to be prepared in advance from digital elevation models, land cover, soil and ground water aquifer maps or remote sensing data. Physical parameters of standard soil and land cover classes are provided in data tables. Both the interpolation of meteorological station data and the disaggregation of climate model data are integrated in PROMET for the computation of hourly drivers during runtime (Mauser and Bach, 2009).

Simulation results

The main aim of model application is the assessment of the land surface water and energy balance (e.g. evapotranspiration, soil moisture and temperature, runoff formation), dynamic plant growth (e.g. leaf area index, yield, and transpiration) and river runoff characteristics. It is mainly used for long term analysis of catchments and the assessment of the impacts of climate and/or land cover changes on the natural water cycle. Besides the results produced for the GLOWA-Danube project, e.g. runoff indicators produced with PROMET for two catchments located in Southern Germany and Eastern Canada were compared with other hydrological models (Velázquez et al., 2013). In the agricultural and plant growth domain it has been used for testing the impacts of a dynamic phenology on the water balance (Hank et al., 2007) and a global plant suitability evaluation (Zabel et al., 2014) for example. Yet, it is also used for investigate (operational) short-term forecasting methods for snow cover (Appel et al., 2007), runoff (Ludwig et al., 2003b), soil moisture (Schlenz et al., 2012) and yield estimates (Migdall et al., 2009) in conjunction with remote sensing data.

4.3.5. SWAT – Soil and Water Assessment Tool

SWAT (Version SWAT2009) is a semi-distributed (using hydrological response units - HRUs), physically based, and continuous time model (Neitsch et al., 2011b). It performs plant growth processes as well as water quantity and quality (Abbaspour and Rouholahnejad, 2013). Thus, the model simulates surface runoff, evapotranspiration, snow cover and melt, soil water and groundwater movement, nutrient and sediment transport, different types of water bodies, and management practices (Neitsch et al., 2011b). Furthermore, a weather generator is included (Neitsch et al., 2011b). The following short description will focus on the hydrological components.

Model structure and model complexity

Each of the SWAT inherent components uses one of several more or less physically based approaches which require specific information about weather, soil properties, topography, vegetation, and land management practices occurring in the watershed (Neitsch et al., 2011b). Therefore, depending on the kind of method used for a specific component, SWAT can be very demanding regarding spatial and temporal input data that have to be prepared in advance. Since all calculations of its outputs are numerically SWAT can be classified as a 'White-Box' type of model. In general the hydrology is divided into two parts, a land phase, controlling the amount of water (see Figure 17), and the routing phase, responsible for the water movement. Details about the different methods available and those used for the enviroGRIDS hydrological modelling approaches can be found in the Danube model database.

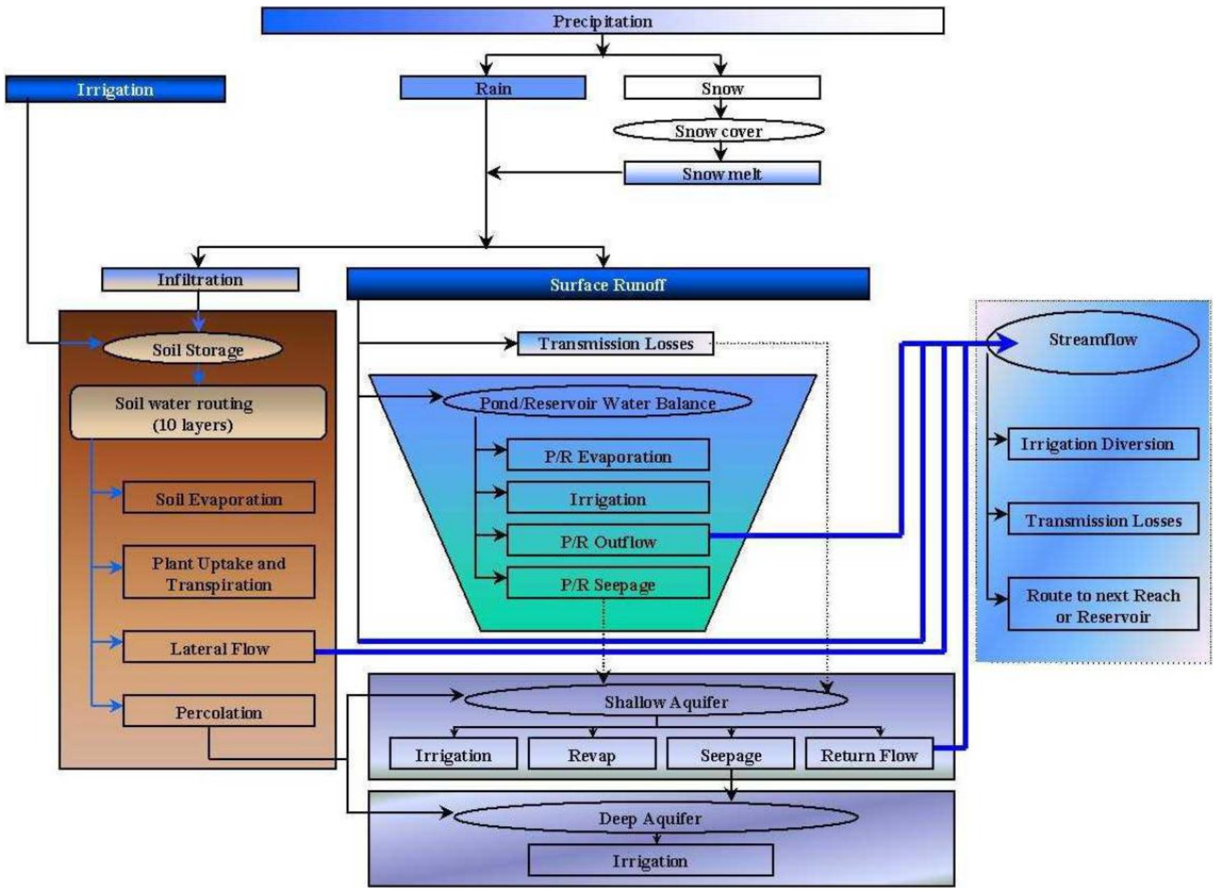

Figure 17: Pathways for water movement within the SWAT model (Neitsch et al., 2011b).

Input data

The input information is organized into the categories climate, HRUs, ponds and wetlands, groundwater, and the main channel draining the subbasin (Neitsch et al., 2011b). Each HRU comprises a unique combination of homogeneous slope, land use, and soil characteristics

(Abbaspour and Rouholahnejad, 2013). The meteorological input is either provided by measured data or can be gathered by applying the included weather generator. Spatial distributed inputs with information about soil characteristics and land use have to be prepared in advance, as well as reservoir, water management, and agricultural data.

Simulation results

The major purpose of the SWAT model is to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods (Abbaspour and Rouholahnejad, 2013; Neitsch et al., 2011b). Hence, the model produces manifold outputs regarding water quantity and quality. However, for hydrological processes the main results cover canopy storage, surface runoff, infiltration, evapotranspiration, lateral flow, tile drainage, and average daily stream flow (Arnold et al., 2012).

4.3.6. SWIM – Soil and Water Integrated Model

SWIM is a continuous-time, semi distributed, and process based eco-hydrological model which integrates hydrological processes, vegetation growth (agricultural crops and natural vegetation), nutrient cycling (C, N, and P), and sediment transport at the river basin scale (Krysanova et al., 2014). The model is based on two previously developed tools – SWAT (Arnold et al., 1993) and MATSALU (Krysanova et al., 1989) (Krysanova et al., 2000). Thus, the SWAT and SWIM model have many similar descriptions with only minor differences (Krysanova et al., 2014). However, SWIM does not account for pesticides, reservoirs or ponds, and lake water quality (Krysanova et al., 2000).

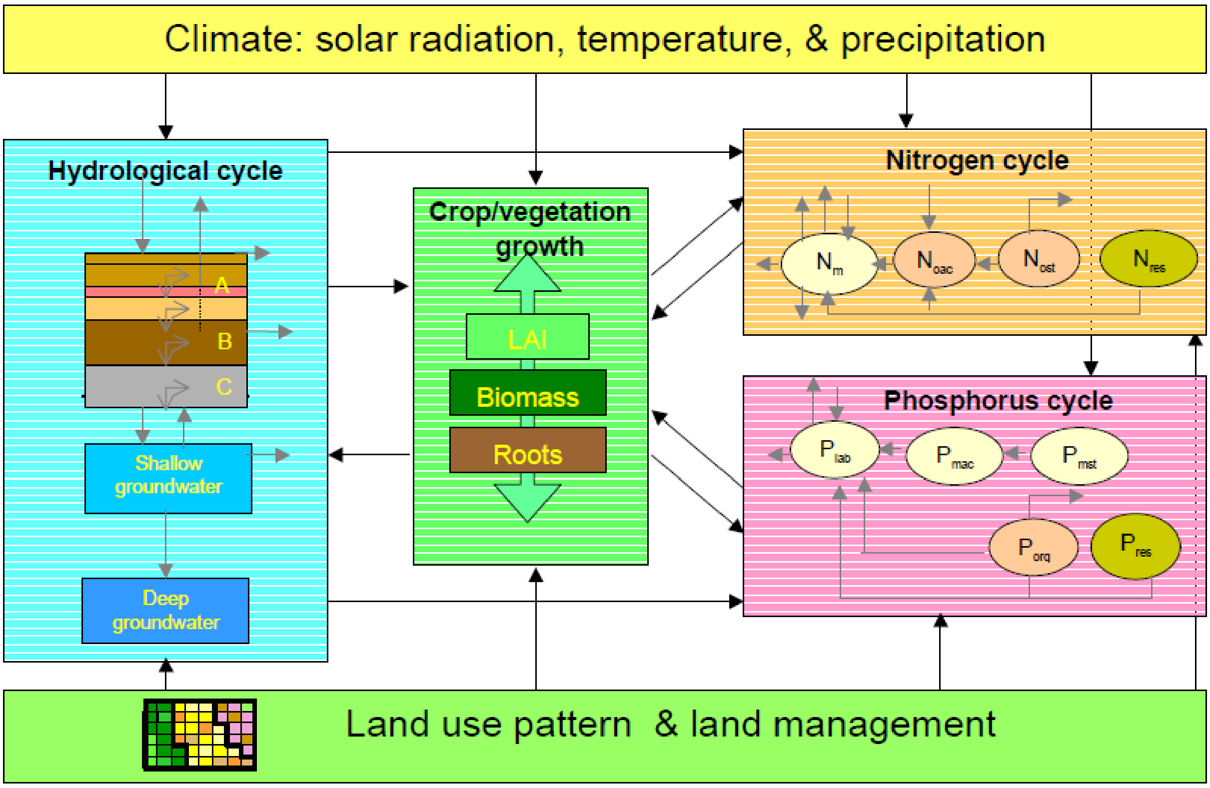

Figure 18: Flow chart of the SWIM model, integrating hydrological processes, crop/vegetation, and nutrient dynamics (Krysanova et al., 2000).

Model structure and complexity

As described above, SWAT and SWIM share many similar process descriptions. Thus, SWIM also belongs to the process based models with intermediate complexity (more complex than HBV (Bergström, 1992), simpler than MIKE SHE (Abbott et al., 1986)) (Krysanova et al., 2014). Figure 18 illustrates the model components. Using mathematical descriptions for the numerical calculation of the inherent processes which require preparation of numerous inputs, the SWIM can be considered as a 'White-box' model. The model has been applied within several studies concerning the UDRB carried out by the Potsdam Institute for Climate Impact Research (PIK) (Krysanova et al., 2014; Stagl and Hattermann, 2014; Stagl et al., 2013). Its major characteristics are given in the model database.

Input data

Spatial input data include a land use map, soil map and parameterization of its layers, and a digital elevation model (Krysanova et al., 2014). Climate data needed for simulation comprise air temperature (min, max, average) precipitation, air humidity, and solar radiation. Furthermore, management data, water discharge, and water quality data have to be provided (Krysanova et al., 2014). SWIM includes interfaces to GRASS GIS (Neteler and Mitasova, 2008) and MapWindow (http://www.mapwindow.org/) which serve to extract spatially distributed data and regarding MapWindow for interpolation of climate data using either inverse distance or kriging method (Krysanova et al., 2014).

Simulation results

The model was developed to investigate climate and land use change impacts at the regional scale, where the impacts are manifested and adaptation measures take place (PIK, 2014). Hence, SWIM applications are mainly concerned with modelling of hydrological processes, extreme events (high and low flows), water quality, and crop yield (Krysanova et al., 2014). It provides a wide range of different outputs including river discharge, crop data, and nutrient concentrations and loads (PIK, 2014).

4.3.7. VIC-RBM – Variable Infiltration Capacity – River Basin Model

The VIC-RBM model is a modelling framework for large-scale daily river discharge (VIC) and water temperature modelling (RBM) that was developed and tested within the WATCH project (Polcher et al., 2011). VIC is a semi-distributed (grid-based at macro-scale), continuous, and process-based hydrological model (Chen et al., 2011; van Vliet et al., 2012). It solves the surface energy as well as the water balance equations and represents subgrid variability in vegetation, elevation and soils by dividing each grid cell into land cover and elevation classes (van Vliet et al., 2012). Routing of surface runoff and baseflow along the stream network follows the approach after Lohmann et al. (1998). The model is coupled with the deterministic, process-based one-dimensional RBM model developed by Yearsley (2009) (Polcher et al., 2011; van Vliet et al., 2012). The following description will focus on the VIC hydrological model.

Model structure and complexity

All the applied methods included in the VIC model are based on fundamental hydrological processes which include interaction of the atmosphere with the vegetation and soil (Chen et al., 2011). These processes are described by physically based, deterministic equations and the model results are calculated numerically. Therefore, VIC is classified as a 'White-Box' model which requires preparation of numerous input data. The model database shows the main characteristics of the VIC model that are used for the WATCH project (DRB).

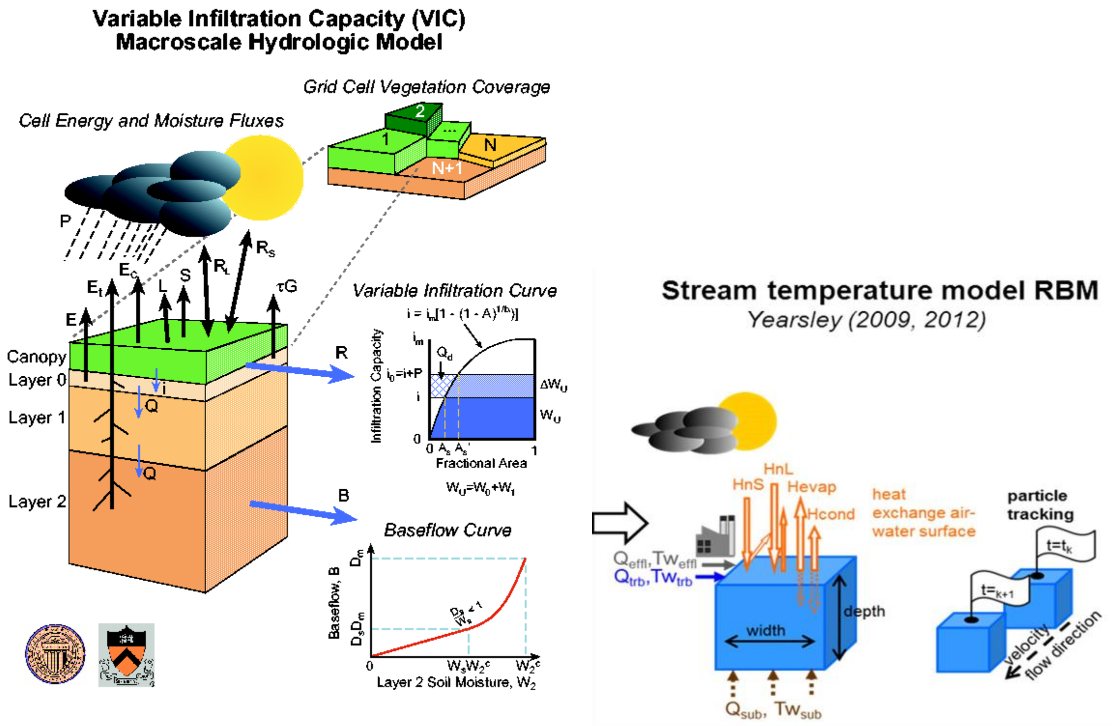

Figure 19: Left: Grid cell schematic of the Variable Infiltration Capacity (VIC) model. Right: Schematic of the River Basin Model (RBM) (http://www.hydro.washington.edu/Lettenmaier/Models/VIC/Overview/ModelOverview.shtml).

Input data

The hydrology VIC model requires spatially distributed data that include soil parameters (which can be calibrated) as well as vegetation types and parameters. Usually, the model assumes grid cells are flat and does not simulate lakes or other impoundment of surface water. Thus, the information about elevation bands and lakes are optional. Also, the model allows for gridded meteorological drivers but point values from measurement stations are suitable as well. These data comprise at least precipitation, minimum and maximum temperature and wind speed. Furthermore, VIC provides minor programs handling the disaggregation of precipitation and temperature, and preparation of other model inputs (available at http://www.hydro.washington.edu/Lettenmaier/Models/VIC/index.shtml).

Simulation results

VIC is a research model which has been applied to several major river basins, as well as being applied globally in various forms (Chen et al., 2011; Nijssen et al., 2001). Hence, its main application is to simulate the hydrology of large river basins on a long term basis. The model results comprise fluxes (moisture and energy), snow for each time step, and discharge at each station (daily to yearly). Depending on the routines chosen to be applied for the model, more detailed results can be obtained. Modelling outcomes of the EU FP6 WATCH project are listed and available at *https://gateway.ceh.ac.uk/terraCatalog/Start.do* using the search term 'WATCH'.

4.3.8. WaSiM-ETH – Water balance Simulation Model - ETH

WaSiM (former WaSiM-ETH) is a (gridded) distributed, deterministic, mainly physically based hydrologic model (Schulla, 2013). It is a continuous type of model allowing for at least hourly simulation runs using internally flexible sub time steps if necessary. The model includes the simulation of snow accumulation and melt, dynamic glacier growth and runoff through melt, dynamic vegetation, evapotranspiration and interception, soil temperature and permafrost, groundwater flow, runoff generation and surface discharge routing including lakes and reservoirs (Schulla, 2013). Furthermore, WaSiM allows for coupling with other models (Schulla, 2013). There are two versions available: the TOPMODEL approach and the Richards approach version. However, only the Richards version will be extended and maintained.

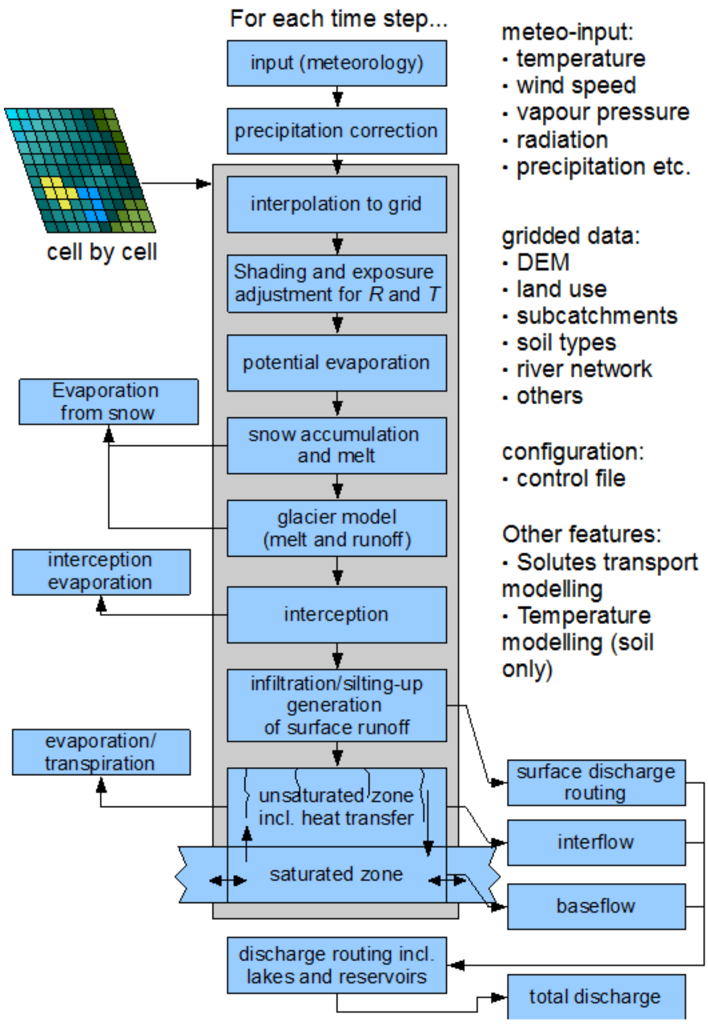

Figure 20: Model structure of WaSiM (Schulla, 2013)

Model structure and complexity

WaSiM has a modular structure comprising several sub models (Figure 20). Most of these sub models offer various methods including process based to physically based approaches in order to fit the available input data. Thus, the model complexity strongly depends on data availability. In addition, each sub model can be turned off to meet the desired modelling purpose. For each time step calculations are performed sequentially for each sub module for the entire model grid. Using the OpenMP standard WaSiM takes advantage of parallelized algorithms to improve the model processing speed (Schulla, 2013). Due to its mainly physically based methods and its demand on data input applying the entire model framework WaSiM can be classified as a 'White-Box' model.

Input data

For the meteorological data input the WaSiM requires at least time series of precipitation and temperature but also vapour pressure or relative air humidity as well as sunshine duration or radiation and wind speed are possible inputs. The spatial distribution of values from meteorological stations is accomplished by a selection of interpolation methods. Even several methods may be applied simultaneously. Spatial data requirements comprise the digital elevation model (DEM), the slope and aspect, a land use and soil type classification and the subbasins. Thus, these inputs have to be prepared in advance. WaSiM provides the tool TANALYS (Schulla (2013), available at www.wasim.ch) which derives the most important spatial data from the DEM. All the spatial inputs have to be converted to a binary format in order to run the model. Furthermore, WaSiM offers several default parameters for land use and soil type classes (applicable for alpine catchments). These parameters may be adapted and extended to meet the actual catchment properties.

Simulation results

WaSiM applications have a wide range including long term impact analyses (climate change (Kleinn et al., 2005), land use (Krause et al., 2007)), short term runoff forecast (Wagner et al., 2006), groundwater recharge (Wagner et al., 2006) or glacier runoff (Verbunt et al., 2003). Thus, the model outputs comprise a large number time series and spatial data. However, the main results for long term water balance analyses for each subbasin and the entire catchment are routed discharge, evapotranspiration components, runoff components, meteorological outputs and melt from snow and ice.

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