European
Commission

Technical Report - 2015 - 090

Guidance document on the application of water balances for supporting the implementation of the WFD

Final – Version 6.1 – 18/05/2015

Environment

Luxembourg: Office for Official Publications of the European Communities, 2015

ISBN 978-92-79-52021-1
doi: 10.2779/352735

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1.1. Context

The vital importance of water for supporting the functioning of ecosystems while contributing at the same time to economic development is widely recognized in all parts of Europe today. Historically, most attention has been given to water quality issues as illustrated by the early European Union (EU) water directives developed during the 1970s and the early 1980s that aimed at ensuring the good quality of waters used for different purposes (e.g. for drinking, water swimming, fishing, etc.).

With the increasing imbalance between water supply and water demand [1]in many parts of Europe, including also some in parts of Northern Europe [1], potentially exacerbated by changes in climate during the past few decades, water availability and water scarcity has progressively emerged as a key issue in national and EU water policy making and implementation, as illustrated in the policy objectives of different Directives and Communications (Table 1).

Table 1. Policy objectives related to water availability in different directives, working documents, communications and strategies.

EU Directive/Communication/ Strategy	Policy Objective
EU Water Framework Directive (WFD) 2000/60/EC, daughter directives (2000) [2], and guidance documents within the Common Implementation Strategy.	Ensure a good quantitative status of groundwater bodies; Achieve good ecological status of surface water bodies (including in terms of supporting environmental river flow requirements); Identify significant pressures from abstraction (Art. 5).
EC Communication "Addressing the challenge of water scarcity and drought in the European Union" (2007) [3]	Encourage Member States (MS) to identify river basins which face quasi-permanent or permanent water stress or scarcity; Improve drought risk management; Improve knowledge and data collection.
EC Communication "Blueprint to Safeguard Europe's Water" (2012) [4]	Put quantitative water management on a much more solid foundation (including identification of the ecological flow –i.e. the amount of water required for the aquatic ecosystem to continue to thrive and provide services) and address the issue of over-allocation at the river basin scale; Recognize that water quality and quantity are intimately related within the concept of good status; Develop water efficiency targets for river basins which are (or are projected to be) water stressed, on the basis of water stress indicators developed in the Common Implementation Strategy (CIS) process and applied at river basin level; Implement Water Accounts at river basin and sub-catchment level: they can tell water managers how much water flows in and out of a river basin and how much water can realistically be expected to be available before allocation takes place; Identify and reduce of illegal abstraction/impoundments.
EU Strategy on Adaptation to Climate Change [5]. **EC Communication "White Paper:**	Build a solid knowledge base on the impact and consequences of climate change for EU water resources as a basis for developing sound adaptation strategies for water. (Water resources are directly impacted by climate change, and the management of these resources affects the vulnerability of

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[1] 'Water demand' is used in the document according to the meaning reflected in sectoral EU policy and water resources management (i.e. water requirements of specific quality for different purposes), which may differ from its economic definitions. See Box 5.

EU Directive/Communication/ Strategy	Policy Objective
Adapting to climate change: Towards a European framework for action" (2009) [6].	ecosystems, socio-economic activities and human health. Water management is also expected to play an increasingly central role in adaptation. Climate change is projected to lead to major changes in water availability across Europe with increasing water scarcity and droughts mainly in Southern Europe and increasing risk of floods throughout most of Europe).
UN-Water: Water in the post-2015 development agenda (2014) [7]. **Sustainable Development Goals (SDGs) for water: core indicators related to Target B-water resources management (WRM).**	Target B: Improve by (x %) the sustainable use and development of water resources in all countries. Suggested action: - Bringing freshwater withdrawals into line with sustainably available water resources.
GEOSS Water Strategy **Integrated Global Water Cycle Observation (IGWCO)**	Develop widely available, sustained water cycle data sets and related information products, at both global and basin scales, tailored to the near- and long-term needs of stakeholders and end-users; Guide decisions on water cycle observations; Promote strategies for the acquisition, processing and distribution of data products needed for effective management of the world's water resources.

The system of Integrated Environmental and Economic Accounting (SEEA) of the United Nations Statistics Division was created in 1993 and modified on 2002. The main aim has been to integrate environmental and economic information in a common, comprehensive and coherent way to measure the contribution of the environment in the economy and the impact that economic activities may have on the environment. The system provides a number of methodological options, including the assessment of natural assets or methodologies for assessing natural and environmental services. It also establishes indicators and statistical methods to measure these interactions. What this system was not intended for was to establish the optimal use of the environment for economic uses, but to obtain through the combined use of different measures, a balance between human and environmental needs. Since there is no general consensus on how to incorporate environmental accounting in national accounts, the SEEA recommends the use of *satellite accounts* that integrate environmental aspects without changing deeply traditional accounting systems. These accounts can focus on different natural assets, as for instance water (i.e. water accounts).

Some MS have incorporated in recent decades *satellite water accounts* without overloading or distorting the central accounting system. These accounts provide expanded information on water issues which are considered to have a special social interest, using complementary concepts, expanding the information on their specific relationship to human activities, associate databases and identify potential gaps in them. This technical guidance document focuses on the development of physical water accounts or **water balances**, which constitutes the first step towards deeper economic accounting. These refer to category 3 of the "Asset Accounts" of the SEEAW as indicated in Box 1.

The development of water quantity assessment frameworks focusing on water balances or asset accounts (which use hydrological information), or incorporating additional elements and economic information related to water using concepts (physical supply and use accounts, hybrid and economic accounts), have been identified as a useful tool for guiding water policy and management at different decision making scales, in particular with regards to the quantitative management and efficient allocation of water resources[2].

At global scales, several initiatives aim at developing water resources assessments and water balances, such as the activities of the UNESCO-IHP programme (UNESCO's Intergovernmental Scientific Cooperative Programme in Hydrology and Water Resources). Under this programme, an Atlas of World Water Resources was developed already in the 1970s and guidelines for conducting water resources assessment developed [8]. A compilation of water balances has also been produced by FAO/AQUASTAT[3] and the Mediterranean initiative of BluePlan. The World Meteorological Organization (WMO) Commission for Hydrology (CHy) has also worked on hydrology and water resources assessment[4] . All of this material is the core of water balances thinking as we know it today.

At the EU scale, the European Environment Agency has worked in recent years on physical water balances at catchment scale [9], with specific efforts being put in developing an EU wide physical water assets account database and assessing the relevance of integrating the degradation of the natural capital in water (economic) accounts. Eurostat has also worked on collecting data (hydrological and economic information) to feed the development of water accounts under the SEEAW [10] framework at administrative levels (country, NUTSII).

Physical water balances can also help support the development of River Basin Management Plans by providing a coherent framework to cross-evaluate the information on drivers, pressures and impacts on water quantity (including the coherence between water abstraction and water recharge, water flows between water bodies/catchments, storage changes over time, etc.) and providing a sound basis to the quantitative management of water resources. Though they can be applied as such, water balances are usually linked to models for simulating different components of the balance and different water management scenarios in order to assess (*ex-ante*) their potential impact on water use, demand and availability, or to learn (*ex-post*) from the effectiveness of past efforts and applied measures to respond to drought and water scarcity.

Today, water balances are not systematically applied as an integrated component of sustainable water resources management in individual river basins and catchments facing imbalance conditions. Due to the importance of quantitative management of water resources on the imbalance between water availability and water demand and of water scarcity and drought, both in ecological, economic and financial terms, MS and the European Commission (EC) agreed to develop the current Guidance. This document focuses on the application of water balances (also known as Water Budgets) for supporting River Basin Management planning processes and the implementation of the WFD in the EU.

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[2] The OECD encourages policy makers to engage in a water allocation reform when competition for water uses is increasing. This entity has developed a "Health Check" for water resources allocation for a proper understanding and assessment of the availability of water resources (surface water, groundwater and alternative sources of supply). (OECD, 2015. Water Resources Allocation: Sharing Risks and Opportunities)

[3] See http://www.fao.org/nr/water/aquastat/main/index.stm

[4] http://www.wmo.int/pages/prog/hwrp/index_en.php

1.2. A guidance: what for?

The main objective of this guidance is to **support the development and use of water balances** at the river basin and/or catchment scales in the context of the EU Water Framework Directive (WFD) implementation, as pre-requisite to sound and sustainable quantitative management of water resources. A water balance is based on mass conservation. It reflects that the rate of change in water stored in a hydrological unit (e.g. catchment) is balanced by the rate at which water flows in and out of the unit. In the medium term, the application of water balances will support: integrated water resources management and decision-making at different scales; a critical review of current water allocation mechanisms between and within water use sectors; the definition of policy (water quantity) targets; and the drafting and adoption of measures that account for the (quantitative) sustainability of water resources. In the medium term, the initiative will contribute to the achievement of the environmental objectives of the WFD and will deliver wider socio-economic benefits.

Box 1. Water balance or water account?

'**Water Balance'** in this guidance is defined as the numerical calculation accounting for the inputs to, outputs from, and changes in the volume of water in the various components (e.g. reservoir, river, aquifer) of the hydrological cycle, within a specified hydrological unit (e.g. a river catchment or river basin) and during a specified time unit (e.g. during a month or a year), occurring both naturally and as a result of the human induced water abstractions and returns.

'**Water Accounting'** integrates physical (hydrological) and economic information related to water consumption and use, to achieve equitable and transparent water governance for all water users and a sustainable water balance between water availability, demand and supply. Standard water accounting frameworks have been developed by various organizations, such as the United Nations Statistics Division (UNSD), the Food and Agriculture Organisation (FAO), the International Water Management Institute (IWMI), the Australian Government, etc. The UNSD has proposed a conceptual water accounting framework called System of Environmental Economic Accounting for Water (SEEAW) [10] for the organization of physical and economic information related to water using concepts, definitions and classifications, describing the interaction between the economy and the environment. The SEEAW comprises the five categories of accounts: (1) physical supply and use and emission accounts (hydrological data on the volume of water used and discharged back into the environment by the economy, as well as the quantity of pollutants added to the water); (2) hybrid and economic accounts (linking the physical information recorded in the previous category with monetary supply and use information); (3) asset accounts (they measure stocks and their changes due to natural causes, such as precipitation, evapotranspiration, etc., and human activities, linking thus water abstraction and return to the availability of water in the environment); (4) quality accounts (stock of water in terms of its quality); (5) valuation of water resources.

In the context of this guidance document, **category 3 of the 'Asset Accounts' of the SEEAW are aligned with the concept and components of the 'Water Balance'**, although some discrepancies might exist in the definitions and in the scales of application of both frameworks (see Annex III for further information).

The guidance aims primarily at supporting **water and river basin managers** in EU MS in establishing and applying water balances as essential tools for the effective management of water resources. The guidance document and proposed mechanisms reflect flexibility in incorporating and taking into account local conditions and specificities. It should also raise awareness on the different inter-connected facets of the quantitative management of water resources for key stakeholders involved in, or contributing to, participatory planning processes at different management scales (in particular the catchment, river basin and river basin district scales). As water balances are more systematically applied at these management scales, they will further:

- **Enhance Europe-wide (comparable) knowledge** on the state and quantitative management of water resources (based on data held by the MS). This knowledge will in turn facilitate and contribute to on-going and future Pan-European initiatives such as: (1) the mapping of the Europe-wide state of water resources by DG Environment, as a contribution to the evaluation of the effectiveness of current water policies; (2) the development of water balances by the European Environment Agency (EEA) as an input to the State of the Environment report;

- **Facilitate MS WFD reporting** to the European Commission on the quantitative status of groundwater resources and on the abstraction pressures on surface and groundwater bodies. It will also facilitate the preparation of MS responses to the EEA (WISE-SoE#3[5]) and Eurostat (JQ on Inland Waters and REQ) water-related questionnaires on water resources availability, abstraction and use;

- **Support the *ex-ante* assessment of possible future water policy scenarios** by individual MS, or at the EU level in the context of the hydro-economic modelling platform currently developed by the DG Joint Research Centre (JRC) [11].

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[5] The new code for Water quantity reporting is WISE SoE#3 (http://rod.eionet.europa.eu/obligations/184). See also: http://forum.eionet.europa.eu/nrc-eionet-freshwater/library/wise-soe-reporting-2013/water-quantity-reporting-2013

Box 2. What are the benefits you, as water and river basin managers, can get from applying water balances?

By applying water balances, you will….

- Better understand whether your water resources are "**at quantitative risk" - or not**! and the gap to good status that need to be filled with measures.
- Support the identification of drought and water scarcity situations.
- Contribute to the development of a **common EU-wide knowledge** with coherent and comparable data, harmonized definitions and common understanding of the relevant assessments when applying water balances within the general proposed framework of this guidance document.
- Have a good overview of **the spatial and temporal variability of water resources**, under current and future (scenario building) conditions in order to design, identify or bridge the gaps of appropriate **allocation schemas.**
- Identify **"where best to target efforts"** (be it identifying areas where action is needed due to existing or future water stress, reducing abstraction from a given use, focusing on runoff, increase storage, develop reuse, etc.) when selecting measures for improving the quantitative state of water resources.
- Have a solid base for additional **water resources assessment and management at various scales**: runoff estimation, groundwater recharge potential, nitrates mass balance, water-energy nexus, e-flows and GES determination, input to real-time analysis, operation and forecasting.
- Provide a coherent framework for **combining and structuring hydrological and socioeconomic information** on climate, water resources in different compartments, water uses (abstraction, discharge…), etc.
- Facilitate the identification of priority water quantity priority data flows and identify possible **"data gaps".**
- Provide a **common platform for building a "shared understanding"** of issues between stakeholders and different water users, as all are represented by one or more components of the water balance.
- Facilitate **reporting** (EC, EEA, Eurostat), including a better structuring of the water-quantity related information for the WFD RBMPs in the next cycle.
- Provide sounder arguments as part of **communication and awareness raising.**

1.3. Guide to the reader

In addition to the present introductory chapter, the guidance is organised in 6 chapters:

- Chapter 2 - **Key components of water balances** presents the basic components of the standard hydrological cycle and the main equations that govern the hydrological cycle. It constitutes the basis of water balances.

- Chapter 3 - **Key issues in developing water balances** addresses the main methodological issues encountered when developing water balances. These include issues related to: time and spatial scales; data sources and availability, and related uncertainty; approaches for incorporating ecological needs; etc.

- Chapter 4 - **Applying water balances in practice** presents examples of current water balance applications in European MS, illustrating in particular available tools that are or have been mobilised for supporting the establishment of water balances.

- Chapter 5 - **Using water balances for supporting water management** illustrates how water balances can help addressing water management decisions at different stages of the river basin planning process. In particular: supporting the development of the Programme of measures (PoM); highlighting water resource allocation potentials and challenges; adapting proposed measures for addressing water quantity issues accounting for climate change or resource efficiency improvement.

- Chapter 6 - **Expanding the physical water balance for addressing complementary water management issues** suggests possible expansions of the basic water balance framework so other water management issues can be addressed. Specific attention is given to accounting for water quality issues, and to linking water balance information to basic socio-economic indicators characterising specific water use sectors.

- Chapter 7 - “**Recommendations**” summarizes the main lessons and recommendations that originate from the shared collective experience of water balance applications in Europe, highlighting how water balances can help supporting the implementation of the WFD and the achievement of its environmental objectives.

2. KEY COMPONENTS OF WATER BALANCES

Building water balances helps to combine and structure the key components of the natural hydrological cycle (without human pressures) and the relevant inputs and outputs due to human interventions (e.g. abstractions, returns, etc.) into a coherent framework. The following sections explain these different components, identifying the type of information that is required for describing each component and developing water balances. It combines general information on definitions and concepts, with illustrations presenting “how to do it” in practice. Specific attention is given to the choice of temporal and spatial scales, as these have direct implications on data requirements and the ease of developing water balances[6].

2.1. The key components of the hydrological cycle

The first step in developing water balances requires the assessment of the freshwater resources, accomplished through the quantification of the components of the hydrological cycle. The (natural) hydrological balance equation is based on the principles of conservation of mass in a closed system: any change in the water content of a given soil volume during a specified period must equal the difference between the amount of water added to the soil volume and the amount of water withdrawn from it. In its simplest form, the hydrological balance of a catchment is described by the equation:

$$\mathrm{IN} = OUT \pm \Delta S \qquad \textit{[Eq. 1]}$$

Where IN = inflow of water to the hydrological unit[7]; OUT = outflow from the hydrological unit and ΔS = change in storage within the selected hydrological unit (e.g. catchment). The components of [*Eq. 1*] are expressed in units of volume per time unit, i.e. hm^3/month, hm^3/year, etc. In a system with no external inflows from neighbouring catchments and territories, the water is entering the system via precipitation (P), converted into evaporation (E) and/or runoff (R) (surface, subsurface or groundwater) and associated storage (S) or change in storage ΔS during the time period investigated, as expressed in the following general equation:

$$P = R + E \pm \Delta S \qquad \textit{[Eq. 2]}$$

In more detail, looking at the functioning of the hydrological cycle and the dynamics of its different components (Figures 1-3.) during a given time period, (P) reaches the soil surface and the vegetation where water can be intercepted and evaporate directly (Ei) or stored (ΔS). Water can also infiltrate the soil or directly runoff (Rs) if the amount of rainfall exceeds the infiltration rate capacity (rainfall excess). The water infiltrating the soil goes to the unsaturated zone (ΔSu) and recharges the ground water (ΔSgw). Groundwater (Rgw) and unsaturated zone water (Rsub) can also contribute to river flows as subsurface runoff. The roots of vegetation absorb water that is transported to the stomata of the leaves, where it goes back to the atmosphere as transpiration (Et). Water can also evaporate directly from the soil or from the river (Es). Capillary rise brings water to the soil surface and then water evaporates.

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[6] Note also that the definition of the boundaries of the system which hydrological functioning will be captured in the different components of the water balance is crucial when developing water balances.

[7] The unit of analysis could also be a hydrogeological unit, since the boundaries of the catchments often do not coincide with the boundaries of the underlying groundwater bodies.

These elements and their inter-relations are illustrated in Figures 1 and 2, and lead to the following formulation of equation 2:

$$P = Rs + Rsub + Rgw + Es + Ei + Et \pm \Delta S \qquad [Eq.\ 3]$$

Where:

P: Precipitation [hm^3/ time unit]

R: Runoff (s: surface, sub: subsurface, gw: groundwater) [hm^3/ time unit]

E: Evaporation (s: surface, i: interception, t: transpiration)[hm^3/ time unit]

ΔS: Change in storage over time[hm^3/ time unit]

**Note: $1hm^3 = 1$ million m^3*

The runoff process contains three components [11] [12]: (a) the overland flow, (b) the interflow, and (c) the baseflow. The *overland flow* (also known as surface runoff *Rs* or Hortonian overland flow) occurs when the rate of precipitation (or snow melt) exceeds the interception requirements and the infiltration rate / capacity. The excess water then starts to accumulate in small surface depressions, and gradually forms an overland downslope flow, influenced along its course by tension and friction. Eventually, as rainfall continues, this overland flow culminates downstream in the river (or a topographic depression) through the main and secondary drainage network of the catchment, eventually contributing to the streamflow. The *interflow* (or subsurface runoff*Rsub*) is the portion of infiltrated rainfall that moves laterally through the upper soil layers until it reaches the stream channel. It depends on the physical characteristics of the catchments and the spatiotemporal characteristics of the rainfall (e.g. in thin soils overlaying impermeable layers interflow is prominent, whereas in permeable soils the downward infiltration dominates) [11].The *baseflow* (or groundwater runoff *Rgw*) is the portion of infiltrated rainfall that reaches the groundwater table and then discharges into streams. It responds much more slowly to rainfall and does not fluctuate rapidly. In areas with seasonal rainfall baseflow gradually builds-up, peaking towards the end of the wet season. In areas of limited outflow, the baseflow may be intermittent or seasonal [11].The overland flow together with the interflow are the two components of the Direct Runoff [11]. The Direct Runoff, combined with the Baseflow Runoff (resulting from groundwater runoff and/or delayed subsurface runoff) contributes to the Total Discharge (or streamflow) as illustrated in Figure 1.

Estimating the different storage capacities of a water system or catchment is key to understanding and analysing the overall hydrological process. Water storage can occur in soil, groundwater, lakes, rivers, snow and glaciers or vegetation. Storage in vegetation is relatively limited compared to the total volume stored, although it can have a significant impact in the short-term on vegetation water use. But other forms of water storage, such as in soils, lakes, glaciers, groundwater or snow (in particular in Nordic and mountainous conditions) are important to study, especially in a context of land use change. Climate change can impact any of the components of the water balance, in particular precipitation and storage. For long-term averages under assumptions of stationary conditions, it is often assumed that the change in storage for an annual time step is marginal and equal to zero, yet this is not applicable at the monthly scale.

The quantification of the components of *Eq. 3* at a given hydrological unit in a given time period requires information from monitoring stations. Hydrometeorological networks provide information on water flows into, and losses from, rivers, soils, lakes and aquifers, as well as on precipitation and evaporation, in selected sites, depending on the design and density of the network. However, some kind of inference is always needed since it is impossible to monitor every component at every place, so the water resources assessment of *Eq. 3* usually requires the use of rainfall-runoff models which are properly calibrated at the control monitoring sites.

In a natural system with external inflows from neighbouring catchments and territories, Eq. 3 can be further formulated as follows:

$$P + ExIn = Rs + Rsub + Rgw + Es + Ei + Et \pm \Delta S \qquad [Eq.\ 4]$$

Where:

P: Precipitation [hm^3/ time unit]

R: Runoff (s: surface, sub: subsurface, gw: groundwater) [hm^3/ time unit]

E: Evaporation (s: surface, i: interception, t: transpiration) [hm^3/ time unit]

ΔS: Change in storage over time [hm^3/ time unit]

ExIn: External Inflow is the total volume of actual flow of rivers and groundwater entering the hydrological unit of analysis from neighbouring territories/other units [hm^3/ time unit]

In some cases, there might be some amount of water that is lost from the hydrological unit due to naturally occurring groundwater outflow to neighbouring systems or to the sea (i.e. outflows from the groundwater bodies which do not contribute to the baseflow but feed neighbouring systems or discharge directly to the sea). This is common in karstic systems, coastal areas, islands, etc. This amount should be then incorporated in *Eq. 4* as a sink (External Outflow) and part of the right side of the hydrological balance equation, but it is usually difficult to estimate.

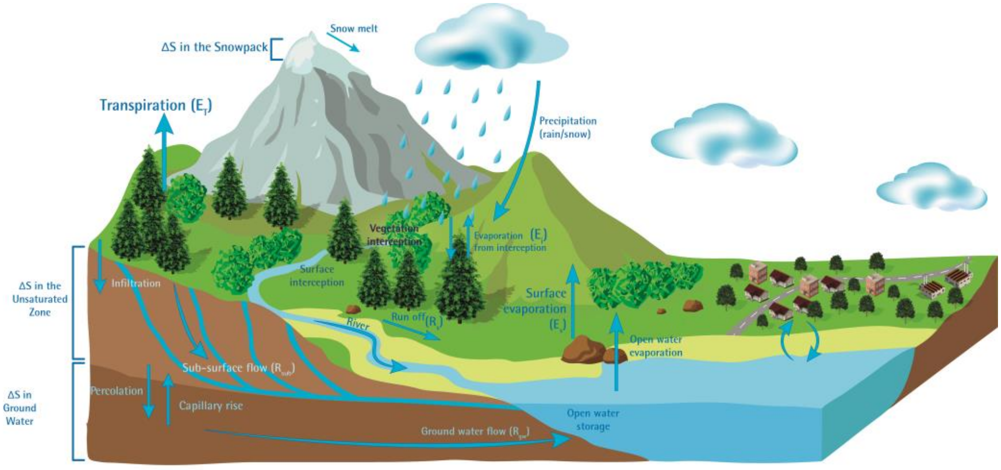

Figure 1. Capturing the key components of the hydrological cycle[8]

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[8] ACTeon, 2014

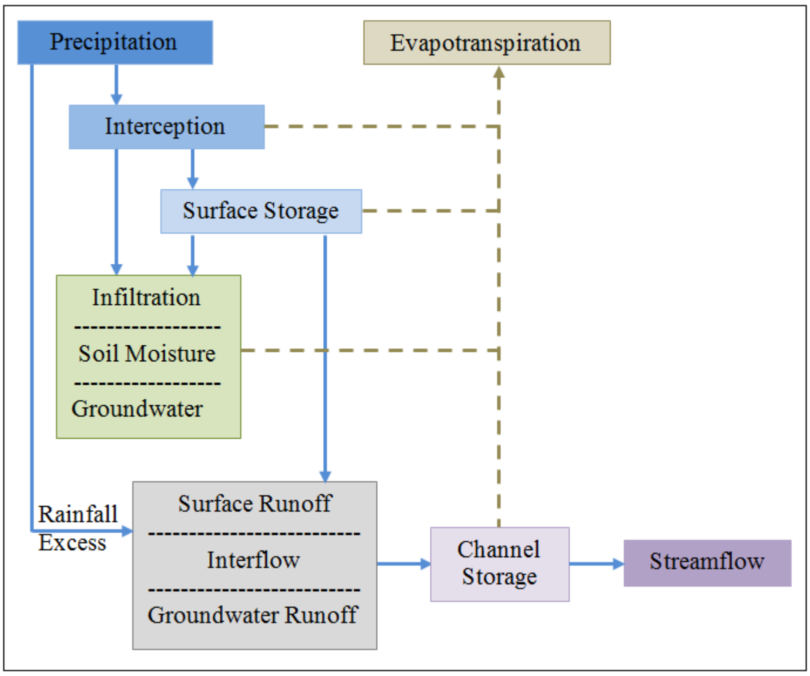

Figure 2. Schematic representation of the hydrological cycle [12]

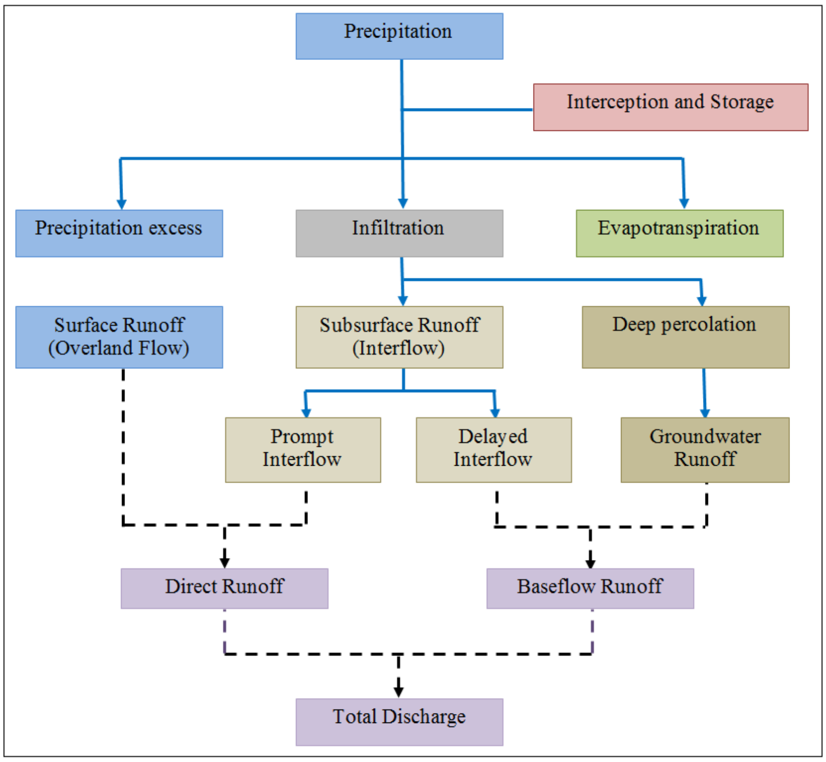

Figure 3. The runoff process components and their contribution to total discharges [12]

Box 3. Groundwater considerations

While groundwater balances could be done separately, these should ideally be done in an integrated way, i.e. for the whole natural hydrological cycle.

To better incorporate groundwater aspects, water balances should be accompanied by dynamic, numerical, distributed physical based, groundwater-surface water models (validated with measured water balance data). These models should be applied and used for the calculation of water balances in relation to catchment, groundwater aquifers and impacts from groundwater abstraction on ecosystems, or ecological flows in rivers among others. This type of model may be used to determine dynamic changes of the water balance and the complex changes in interactions between abstraction, groundwater level, drainage flow, groundwater discharges in space and time that groundwater abstraction will cause [13].

Box 4. Investigating the importance of the snowpack in water balances

Snowpack is an essential part of the water cycle in Northern Europe and in mountainous regions. In particular, the river flows of several large Central European rivers depend partly on the melting of the snowpack of the Alps. Snowpack can be considered a water reservoir that: (1) recharges and releases water without human control; (2) has typically a yearly pattern in variation which affects the entire water cycle; and (3) is not abstracted for human use and thus has a purely natural variability.

Accumulation of snowpack decreases runoff and recharge of other reservoirs during the winter months. On the other hand melting of snowpack increases runoff and recharge of reservoirs during spring. Lack of snowmelt can increase possibilities for drought during the spring and early summer. On the other hand, rapid snowmelt may cause floods. E.g. in Finland snowpack accumulation is between 10-30 % of yearly precipitation and snowmelt takes usually only one to two weeks during spring which often causes spring floods. The warming climate is predicted to increase variation in the snowpack, increasing the risks of floods and droughts, and to also affect the timing of the spring snowmelt, leading consequently to change of the time (month) of maximum spring runoff in some countries.

There are several methods for assessing the snowpack. In Finland, snowpack data are based on about 150 snow course measurements (a snow course is a 2 to 4 km long trail through various terrains typical for the area). Measurements are made once or twice a month. For days between measurements, daily values of the snowpack are calculated by a model which also assimilates data from satellite remote sensing. The Finnish Meteorological Institute develops and provides snow water equivalent (SWE) values for the whole Northern Hemisphere. The SWE data are based on passive microwave radiometer data combined with ground-based synoptic snow observations. These data are used e.g. to calculate Standardized Snowpack Index (SSPI) daily and nearly real-time (one day delay) for the whole Europe with 25 X 25 km grid (refer to the SSPI Indicator Fact Sheet [13]). The SSPI provides information of the relative volume of the snowpack in the catchment on a daily, monthly or yearly basis (compared to a given period of reference). The SSPI can be used as drought indicator, e.g. by the European Drought Observatory EDO.

2.2. From water balance to a detailed list of water quantity related parameters used to support policy making

Flows and storages described previously are due to natural phenomena. Human activities can influence components of the hydrological balance equation, by removing (abstractions for water supply or water transfers) or adding (returns from various users or water transfers) certain amounts of water at certain times, or by modifying storage capacity components. Land use changes induced by human activities, such as increase in imperviousness on urbanized areas or crop patterns in agricultural land, can also have significant influence in the processes of soils storage, infiltration and runoff. Water Balances capture the equilibrium in the physical system between inputs and outputs as modified by the human intervention[9]. In general, the

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[9] In terms of inputs and outputs induced by human interventions, only those that influence the equilibrium of the physical (natural) system are considered here, as opposed to the overall equilibrium of the water supply system, or the equilibrium between availability and demand. In other words, the total volume of desalination or imported water is not an input to the natural system since a part is consumed. Only the volume of these components that is returned to the physical system/environment is relevant in the Eq. of the Water Balance. The total volume of desalination, imports and water reuse is of course relevant for the water accounting since it is an input received from economic units to the water supply and management system. This is analysed in more detail in the following sections.

water balance is described by the following equation, building on the basic input-output components of the natural hydrological balance (*Eq. 1 and 2*):

$$INPUTS = OUTPUTS \pm \Delta S \qquad [Eq.\ 5]$$

Where: $INPUTS = P + ExIn + RET$

$OUTPUTS = Eta + Outflow + ABS$

P = Precipitation [hm^3/ time unit]

ExIn = External Inflow is the total volume of actual flow of rivers and groundwater entering the hydrological unit of analysis from neighbouring territories/ other units [hm^3/ time unit].External Inflow must not be confused with the inputs received from economic units (e.g. desalination, water reuse) or the imported water since those are directed for consumption and only a part of them is finally discharged to the rivers and groundwater via returns.

RET = Returned water is the volume of abstracted water, and/or water produced by economic units, and/or imported, that is discharged to the fresh water resources of the hydrological unit either before use (as losses) or after use (as treated or non-treated effluent). It includes water that was directly discharged from a user (e.g. domestic, industrial etc. including cooling water, mining), and water lost from the waste water collection system (as overflow or leakage). Internal transfers in the hydrological unit such as artificial groundwater recharge with source-water generated within (abstracted from) the hydrological unit, and/or recharges into rivers with source-water generated within (abstracted from) the hydrological unit can be considered under the returned water component for the current calculation purposes. Discharges to the sea are excluded [hm3/ time unit].

Note: We can further break down Returned water into 2 components: R1 is the amount that is released in-situ and returned in the system within the time unit and is practically a reduction in the abstraction part, while R2 is the volume that is returned in the system at a next time step or ex-situ (e.g. urban wastewater) and is practically an addition on the resources part. Cooling water can fall under R1 or R2 depending on the type of industry and case).

ETa = Actual Evapotranspiration[hm^3/ time unit].

Outflow = The total volume of actual outflow of rivers and groundwater into the sea plus actual outflow into neighbouring territories (outside the hydrological unit of analysis) [hm^3/ time unit]. Note: Environmental Flow-EF and other Water Requirements-WR as defined e.g. by treaties are a part of the Outflow).

ABS = The total volume abstracted from the system, from surface and groundwater resources, intended for any use (consumptive, non-consumptive, transfer etc.). Water abstracted for hydropower generation (in-situ use) should be excluded from the formulation of the water balance equation, while water abstracted for cooling should be included.

ΔS = Change in Storage (both in surface water and groundwater as a lumped sum).

**Water transfers, exported or imported water, are included in Eq. 5 as part of returns and abstractions respectively.*

Water generated from desalination is a "non-natural feature" and thus the full volume of the available desalinated water is not considered as an input to the freshwater resources. What is in fact considered an input in this case is the volume of water coming from desalination and discharged to the freshwater resources after use. This is incorporated in the Returned water. If all of the available desalinated water was considered an input, this would result in a biased water balance equation since part of this volume is in reality consumed and thus not available to the natural/physical system.

As with *Eq. 3* and *Eq.4* above, *Eq. 5* can be further refined reflecting the various components of the hydrological cycle for both the physical parameters (e.g. inflow can be surface or subsurface, evapotranspiration could be from surface or interception or transpiration, storage can be surface or subsurface, etc.) and the anthropogenic induced activities (abstraction can be separated to surface and groundwater, returned water before use[10] or after use[11], etc.). The

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[10] Water abstracted from any freshwater source and returned to a freshwater recipient *before use* refers to the volume of water lost during transport through leakage between a point of abstraction and a point of use, and/or between a water supplier/distributor. Discharges to the sea are excluded. Evapotranspiration losses, or water which occurs during mining or construction activities is not included (EEA – ETC/ICM, 2013.WISE-SoE Water Quantity, Data Manual, v3.1)

[11] Water abstracted from any freshwater source and returned to a freshwater recipient *after use* refers to the total volume of water discharged after use as treated effluent or as non-treated into freshwaters. Cooling water is included. Discharges to the sea are excluded. Treated effluent: effluent that has undergone treatment through UWWTP or other WWTP. Non-treated effluent: Effluent that has not undergone any wastewater treatment and

customization of *Eq. 5* depends on the objectives and on the scale of the analysis. It is unlike that all the refined parameters are needed or are of equal importance in all analyses (i.e. some are of low importance or even negligible), and this relates of course to the selected boundaries of the unit of analysis. Data availability is also a relevant issue here (i.e. monitoring networks are not designed to measure all sub-parameters of the hydrological balance but are usually designed according to specific situations taking into account the hydrological and geological background). For example, in a small well-defined catchment (where its boundaries also correspond to groundwater divisions), where surface outflow occurs via a main river outlet and groundwater feeds the river system, then outflow can simply be represented by the streamflow and baseflow (such ideal cases can of course be very rare). In other cases, groundwater discharge can be estimated as the groundwater recharge depending on the time step and the characteristics of the aquifer.

Water balances can be expanded and complemented with additional water quantity parameters which are relevant to water accounting, water management and policy, such as water use per economic sector, alternative water supplies (desalination, reuse), water demands, conveyance efficiency and losses, or economic information on the main water users (e.g. yields, income generated, etc.) as indicated in Table 2. The relevance of including or excluding specific water components will depend on the key water management questions that need to be addressed, on the importance of quantitative water management issues for a given country/area, and on the specificities of the river basin being assessed. Table 2 stresses in particular the importance of three different spatial scales (from small to large) which are relevant to reporting and/or monitoring: site-specific point data which are linked to a specific water body, main aquifers (the ones which collectively account for more than 85% of the MS's or River Basin District (RBD)'s groundwater abstractions), catchment/River Basins (or national part of the RB in transboundary rivers) of a size relevant to the desired analysis requirements. A fourth scale, administrative or statistical unit (such as the Nomenclature of Territorial Units for Statistics-NUTS or the River Basin District - RBD is suggested as a scale for aggregation and visualization (or reporting) purposes, as opposed to a primary calculation scale.

The different water quantity parameters are classified under four main categories related to the: hydrological cycle, water balance, water accounts, water management and policy. There is a clear rationale behind this escalating classification. The "hydrological cycle" group comprises the physical parameters that are necessary to fully describe the physical water volume of surface, soil, and groundwater resources. They span from parameters which are products of direct measurements (e.g. streamflow, groundwater level) and are essential in identifying status and trends of actual available resources and linking them to Good Ecological Status (GES), to parameters which are products of hydrological rainfall-runoff models (e.g. evapotranspiration or change in water storage) essential in evaluating the availability side of the balance equation or the dependency of a given territorial scale on external water inflows.

The "hydrological cycle" parameters can be expanded into "water balances" by including anthropogenic components which alter the physical balance (abstractions and returns, as shown in *Eq. 5*). These are key to the identification and quantification of the overall pressures, understanding over-exploitation or capturing the relative importance of illegal groundwater

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was returned to the water body. It includes water that was directly discharged from a user (e.g. domestic, industrial etc., including cooling water, mining), and water lost from the waste water collection system (as overflow or leakage) (EEA – ETC/ICM, 2013.WISE-SoE Water Quantity, Data Manual, v3.1).

water abstraction[12], but can also provide the information base for the identification of significant beneficial activities which could be affected if the water resource allocation policies were to be changed. Water exports are incorporated in the water balance as part of the abstractions (i.e. water can be abstracted for use within the territory or for export). The water balance aims to represent the balance of the natural system (focusing on the freshwater environment) and not that of the water supply system. Thus, water imports or alternative desalinated water, which are stored in the water supply system are not explicitly incorporated as sources/inputs, since a part of them is consumed. Only the volume (of imports and desalination) that is discharged to the fresh water resources is of interest here, and this is incorporated in the water balance through "returned water". The full volumes of imported or desalination generated water are of course relevant in water accounting and water supply management since they represent inputs received from economic units to the water supply and management system.

Regarding water reuse, it has a beneficial impact since in theory it reduces the volume of abstraction needed, but at the same time it reduces also the potential available volume of returned flow. It is seen here as an intermediate step in the process and hence not explicitly relevant to the water balance, yet relevant to water accounting and water management.

Returned water is an important component of the water balance, and includes the volume of water discharged to the fresh water resources of the hydrological unit either before use (as losses) or after use (as treated or non-treated effluent). This water might have originated from abstraction, imports, desalination or other economic units' production. It includes water that was directly discharged from a user (e.g. domestic, industrial etc. including cooling water, mining), and water lost from the waste water collection system (as overflow or leakage). In some cases there may be some "internal water transfers" from one water body to another, within the hydrological unit of analysis. Although in terms of overall equilibrium of the hydrological units these transfers may be evened out, they need however to be correctly represented since they might be significant for specific water bodies, and/or temporal and spatial scale of analysis. Such internal transfers include artificial groundwater recharge with source-water generated within (abstracted from) the hydrological unit, and/or recharges into rivers with source-water generated within (abstracted from) the hydrological unit. These cases, for the purposes of the water balance equation [Eq. 5] can be included under "abstraction" (for the loosing water body) and "returned water" (for the receiving water body). Caution is again needed here in how to correctly represent these special cases in the water balance (in order to avoid double-counting) and also how to make it transparent to water agents not to infer anything about the water use characteristics of those water users from the water balance equation. The calculation of returned water is challenging, and data on conveyance efficiency and losses (although not components of the water balance as such) are necessary for estimating the returns.

Further on, the "water accounts" framework introduces a human dimension (e.g. making water use per sector explicit, specifying water reuse or accounting for seawater desalination) that help identifying pressures on water resources as well as on the water supply, and possible mismatches between water availability and actual, potential or desired water use. This

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[12] Illegal abstractions are important in the water balance equation since, if not incorporated under the total volume of abstracted water, the equation can result in a misleading equilibrium. How to calculate them in practice is challenging (e.g. through past data on illegal water use, via satellite data on soil moisture, via proxies comparing existing registered abstractions to water demand, etc.), and this adds, of course, uncertainty to the water balance accuracy.

provides further grounds to supporting policy reforms. The “water accounts” category also includes purely economic information on the main users (e.g. agricultural yields, income generated, etc.) linking production values to availability and water use. This could help to link the protection of water resources to economic development, or to identify possible barriers imposed by existing water imbalances. Finally, the “water management and policy” category provides a wide and comprehensive view by complementing knowledge of the previous categories (hydrological cycle, water balance, water accounts) with additional information on conveyance efficiency, losses and water demand for the main users. It thus further supports the identification of water conservation potential and improvements in water efficiency, the identification of potential (and future) water stress (as a mismatch between availability and demand), the evaluation of water supply sustainability, or the evaluation of trends in water balance resulting from future (baseline) trends in water demand.

It has to be noted that this list of parameters relevant for water management and policy are not exhaustive, but are the most relevant to the water quantity/ water balance aspects. Many more parameters are relevant in view of an integrated water planning and management (including drought, climate change adaptation, etc.), but are beyond the focus of the current guidance document.

Table 2. Relevance of the water quantity related parameters to different spatial scales and key policy questions [12]

<table>
<tr><th colspan="5">Relevance of the parameters to different spatial scales and Key policy questions</th><th colspan="4">SPATIAL SCALES (smallest to larger)</th></tr>
<tr><th colspan="5">PARAMETERS</th><th>Site-specific (point data linked to water body)</th><th>Main Aquifers (the ones which collectively account for more than 85% of the MS's or RBD's groundwater abstractions)</th><th>Catchment / River Basin (or national part of the RB in transboundary rivers). Approximate size: variable - based on the physio-geographical characteristics</th><th>Administrative or statistical unit (RBD, NUTS) *product of aggregation (not reporting)</th></tr>
<tr><td rowspan="12">Water Management & Policy</td><td rowspan="2"></td><td rowspan="5"></td><td rowspan="9"></td><td>Water demand (for the main users)</td><td></td><td colspan="3">Identify water stress,evaluate sustainability of water supply, evaluate trends for future demand projections.</td></tr>
<tr><td>Conveyance efficiency and losses (for the main users)</td><td></td><td></td><td colspan="2">Identify the potential for water conservation and improvements in water efficiency.</td></tr>
<tr><td rowspan="8">Water Accounts</td><td>Economic Information on main users (e.g. yields, income generated, etc.)</td><td></td><td colspan="3">Linking production values to availability and water use, Identify barriers to sustainable economic growth due to its dependance on water-intensive sectors.</td></tr>
<tr><td>Additional water supplies (reuse, desalination)</td><td></td><td colspan="3">Identify dependency on alternative water resources, identify impacts of policy reforms.</td></tr>
<tr><td>Water use (per economic sector)</td><td></td><td></td><td colspan="2">Identify pressures and the responsible sectors and sustainability (availability vs. use), identify impacts of policy reforms.</td></tr>
<tr><td rowspan="7">Water Balance</td><td>Water transfers</td><td></td><td></td><td colspan="2">Identify dependency on external water resources.</td></tr>
<tr><td>Returned water</td><td colspan="4">Identify degree of alleviation of the abstraction pressure and the % contribution of returned water to the availability.</td></tr>
<tr><td>Reservoir inflow/outflow</td><td>Linking downstream conditions with GES, identify climate and/or water demand signals.</td><td></td><td></td><td></td></tr>
<tr><td>Abstractions</td><td colspan="4">Identify pressures and trends, identify over-exploitation, identify (implicitly) illegal groundwater water abstraction due to mismatch between availability and actual measurements.</td></tr>
<tr><td rowspan="3">Hydrological cycle</td><td>Total Availability (surface and groundwater, theoretical and actually exploitable)
Change in Storage (snow and ice)
Change in Storage (Surface and Groundwater)
Baseflow
Outflow (surface and groundwater)
External Inflow (surface and groundwater)
Actual Evapotranspiration
Precipitation</td><td></td><td></td><td>Identify trends in availability and water balance, evaluate water exploitation of both surface and groundwater resources, evaluate water stress, identify dependency on external water resources.</td><td>Provides the regional and/or national context.</td></tr>
<tr><td>Aquifer Change in Storage
Aquifer discharge
Aquifer recharge</td><td></td><td>Identify pressures and trends in groundwater availability, identify over-exploitation, identify (implicitly) illegal groundwater water abstraction due to mismatch between change in storage and reported abstractions.</td><td></td><td></td></tr>
<tr><td>Groundwater level
Sreamflow</td><td>Linking current quantitative status (observed) with quality and GES of Water Bodies, identify status and trends of "observed" available water.</td><td></td><td></td><td></td></tr>
</table>

The different components of the "hydrological cycle" and "water balance" convey information on the state of the inputs and outputs at reference times, and their changes between two different reference periods (generally at the start and at the end of an annual hydrological cycle). These components are dynamic (even within the hydrological year), subject to trends and influenced by the following natural and anthropogenic drivers:

- **Climate change**, which has direct consequences on precipitation (amount and timing) and on temperature. Temperature and air humidity rates influence evapotranspiration and the amount of precipitation impacting surface runoff (heavy rains leading to increase in surface runoff). Climate change can also impact water demands and the reference (natural) conditions of water bodies;

- **Water abstraction (linked to water demand)** from rivers, lakes or groundwater that impacts on water stored and on water flows with contiguous compartments. Agriculture, in particular when irrigated, also impacts evapotranspiration[13], interception and percolation. And while changes in domestic water use and industry might be more limited in terms of overall quantity "extracted" from the hydrological system in some regions, it can lead to shifting water between compartments of the water balance (e.g. abstracting groundwater for drinking water supply that is then returned via treated effluent discharges to rivers at potentially different locations);

- **Flow regulation induced when building storage infrastructure** for enhancing the reliability of water supply or producing electricity can also influence runoff and infiltration or increase ground water recharge, depending on the size of the storage built;

- **Land use change**, including urbanisation[14], leads to soil sealing, increasing surface runoff and decreasing infiltration and evapotranspiration, and affects groundwater recharge.

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[13] Actually any change of land-use that results in vegetation change has an evapotranspiration impact

[14] See for example E.g. http://ec.europa.eu/environment/archives/soil/pdf/sealing/Soil%20Sealing%20In-depth%20Report%20March%20version_final.pdf

Box 5. Glossary of the key terms & components of water balances[15]

** All the parameters' units are expressed in volume/time unit (e.g. hm^3/time unit)*

Alternative water supplies: Refers to reused water, desalinated water, etc.

Aquifer sustainability: The safe yield of a groundwater aquifer is the amount of groundwater which can be pumped from an aquifer without unacceptable negative impacts on groundwater level and water quality, compared to the pre-developmental, virgin situation (Source: Henriksen HJ and Refsgaard JC 2013. Sustainable groundwater abstraction. GEUS report 2013/30)

Available water resources: That part of water resources that is available for use. The concept is ambiguous, and depends on whether it refers to water available for immediate use or freshwater resources available for future development.

Average year: a year with average (normal) precipitation conditions.

Change in storage (ΔS): Changes in the stored amount of water (>0, if storage is increasing) during the given time period, including river bed, lakes, underground water (soil moisture and groundwater) as natural part of the storage (Snat) and in regulated lakes or artificial reservoirs (Sart). ΔS can be ignored for long-term averages if it is not feasible to evaluate them, but should be evaluated in annual calculations and to be considered in monthly calculations.

Conveyance efficiency: indicates the efficiency with which water is conveyed from source of supply to the field. It is expressed as a percentage or ratio.

Desalinated water: the total volume of water obtained from desalination processes.

Dry year: a year with lower than average precipitation conditions. The definition of what percentage of precipitation constitutes a dry year is not universal and depends on the characteristics of a region, river basin etc.

Ecological flows: Ecological flows are considered within the context of the WFD as "a hydrological regime consistent with the achievement of the environmental objectives of the WFD in natural surface water bodies as mentioned in Article 4(1)". Considering Article 4(1) of the WFD, the environmental objectives refer to: non deterioration of the existing status; achievement of good ecological status in natural surface water body; compliance with standards and objectives for protected areas, including the ones designated for the protection of habitats and species where the maintenance or improvement of the status of water is an important factor for their protection, including relevant Natura 2000 sites designated under the Birds and Habitats Directives (BHD) (Guidance Document No. 31. Ecological flows in the implementation of the Water Framework Directive. Technical Report 2015, EC)

Evaporation losses: Water abstracted from any freshwater source lost during transport through evaporation between a point of abstraction and a point of use, between a water supplier/distributor and a point of use or between points of use or reuse.

Evapotranspiration: Total volume of evaporation from the ground, wetlands and natural water bodies and transpiration of plants. According to the definition of this concept in hydrology, the evapotranspiration generated by all human interventions is excluded, except rainfed agriculture and forestry. The "actual evapotranspiration" is measured or calculated using different types of mathematical models, ranging from very simple algorithms (Turc, Penmann, Budyko, Turn Pyke, etc.) to corrections related to vegetal cover and season to schemes that capture the hydrological cycle in detail.

External Inflow: Total volume of actual flow of rivers and groundwater, coming from neighbouring territories outside the hydrological unit of analysis.

Freshwater abstraction (or freshwater withdrawal): Water removed from surface or groundwater resources, either permanently or temporarily, regardless of any input from water return or artificial recharge. Mine water and drainage water are included. Water abstracted for hydropower generation (in-situ use) should be excluded from the formulation of the water balance equation, while water abstracted for cooling should be included. Water abstractions from groundwater resources in any given time period are defined as total amount withdrawn from the aquifer.

Leakage losses: It refers to the volume of water lost during transport through leakage between points of use and reuse, after the treated effluent leaves the wastewater treatment plant and is transported to the recipients.

Outflow: Actual outflow of rivers and groundwater into the sea plus actual outflow into neighbouring territories (outside the hydrological unit of analysis).

Precipitation: Total volume of atmospheric wet precipitation (rain, snow, hail, etc.). Precipitation is usually measured by meteorological or hydrological institutes.

Returned water: Volume of abstracted water, and/or water produced by economic units, and/or imported, that is discharged to the fresh water resources of the hydrological unit either before use (as losses) or after use (as treated or non-treated effluent). It includes water that was directly discharged from a user (e.g. domestic, industrial etc. including cooling water, mining), and water lost from the waste water collection system (as overflow or leakage). Internal transfers in the hydrological

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[15] Extracted from the EEA-ETC/CIM WISE-SoE Water Quantity, Data Manual, v3.1 (2013) and are in line with the WEI+ Factsheet terminology.

unit such as artificial groundwater recharge with source-water generated within (abstracted from) the hydrological unit, and/or recharges into rivers with source-water generated within (abstracted from) the hydrological unit can be considered under the returned water component for the current calculation purposes. Discharges to the sea are excluded [hm3/ time unit].

Reused water: Water that has undergone wastewater treatment and is delivered to a user as reclaimed wastewater. This means the direct supply of treated effluent to the user. Excluded is wastewater discharged into a watercourse and used again downstream. Recycling is excluded.

Snowpack: Volume of snow accumulated stored over a period which can result (fully or partially) in snow melted water. It does not include glaciers, and it is measured at a reference time.

Surface runoff: Also known as overland flow, surface runoff occurs when the rate of precipitation (or snow melt) exceeds the interception requirements and the infiltration rate / capacity. The excess water starts then to accumulate into small surface depressions, and gradually forms an overland downslope flow, influenced along its course by tension and friction. Eventually, as rainfall continues, this overland flow culminates downstream in the river (or a topographic depression) through the main and secondary drainage network of the catchment, eventually contributing to the streamflow.

Water accounts: Water Accounting provides a conceptual framework for organizing the hydrological and economic information in a coherent and consistent manner. It is the systematic process of identifying, quantifying, reporting, assuring and publishing information about water in the form of an accounting book, considering inflows, outflows and changes in stocks.

Water balance: Numerical calculation accounting for the inputs to, outputs from, and changes in the volume of water in the various components of the hydrological cycle, within a specified hydrological unit and during a specified time unit, occurring both naturally and as a result of the human induced water abstractions and returns.

In either case, access to the water would have a cost (FAO Aquastat Glossary online, available from http://www.fao.org/nr/water/aquastat/data/glossary/search.html?lang=en).

Exploitable water resources: (or manageable resources) Part of the water resources which is considered to be available for development under specific technical, economic and environmental conditions (FAO Aquastat Glossary online, available from http://www.fao.org/nr/water/aquastat/data/glossary/search.html?lang=en).

Water asset (according to SEEA-W): Water resource assets are defined as water found in freshwater, brackish surface water and groundwater bodies within the national territory that provide direct use benefits, currently or in the future (option benefits), through the provision of raw material, and may be subject to quantitative depletion through human use. The SEEA-Water asset classification of water resources consists of the following categories: EA.13:Water resources (measured in cubic metres) EA.131: Surface water EA.1311: Artificial reservoirs EA.1312: Lakes EA.1313: Rivers and streams EA.1314: Glaciers, snow and ice EA.132: Groundwater EA.133: Soil water.

Water demand: Water requirements of specific quality for different purposes, such as drinking, irrigation, etc., assuming that water availability is not a limiting factor. Water demand is theoretical (calculated or estimated) and can correspond to current situation or to future socio-economic scenarios.

Water requirements: Volume of water which must be retained in the catchment (thus not actually available for abstraction) in order to meet different legal obligations (e.g. downstream navigation, environmental thresholds, as defined in transboundary treaties).

Water Transfer: Refers to imports or exports. Water that enters or exits the territory of reference through mains or other forms of infrastructure.

Water Use: In contrast to water supply (i.e. delivery of water to final users including abstraction for own final use), water use refers to water that is used (consumed) by the end users for a specific purpose, such as for domestic use, irrigation or industrial processing (usually the basis for paying fees.) Returned water (at the same place and in the same time period) and recycling is excluded.

Wet year: year with higher than average precipitation conditions. The definition of what percentage of precipitation constitutes a dry year is not universal and depends on the characteristics of a region, river basin etc.

3.1. Developing water balances…. at the right scale

There are many challenges linked to information availability and accuracy when developing water balances, depending on the spatial and temporal scales at which water balances are applied. While there is no pre-conceived rule for deciding on the “most appropriate” temporal and spatial scales at which to develop water balances, this choice will depend on the expected use of the water balance itself (how the information will be used, for which water management decision) and on the specific hydrological and water management context (in particular existing spatial and temporal variability).

In terms of the **time scale**, a water balance is generally established for a sufficiently long time period such as a year that corresponds to a specific cycle (hydrological year, calendar year, wet/dry season, multi/annual period etc.). The variability of the key variables of the water balance (ref. to *Eq. 5*), such as the evolution of water abstraction during a given year, or differences in rainfall patterns depending on seasons, can lead to choosing a smaller time scale such as the month or the week. Similarly, if groundwater resources are very significant in the basin's system, a water manager may use larger time scales for comparison (i.e. to reflect groundwater recharge flows that may take 10-20 years).

In some cases, rainfall variability during a single year and variability between years, but also variability in water demands from different sectors, can require different water balances being developed (in particular when the balance of surface water resources is at stake):

- For capturing the intra-annual variability of rainfall, in particular when surface water is the main water resource, two complementary water balances can be developed: a water balance capturing the overall water availability building on inter-annual averages; and a water balance with shorter time periods such as a week or even a day.

- For capturing the inter-annual variability, water balances building on inter-annual or multi-annual averages values can be complemented by a water balance for a dry year[16].

The time step selected for gaining a better understanding of the functioning of the hydrological cycle within a given year should be carefully selected based on the central water management issues to be investigated in the considered catchment. The influence that changes in the components of *Eq. 5* may have on water management decisions, and the potential solutions that might be eventually proposed. Apart from precipitation, water flows and stocks considered in water balances do not have the same time response. For example, the effect of reduced precipitations (dry period) is quickly reflected in soil moisture. But it needs more time to be translated into changes in river streamflows, and even more time to affect the groundwater balance. Figure 4. stresses the time scales relevant to different flow processes/components of the water balance. Even if all processes occur at the same time, responses in terms of changes in groundwater levels or balance for example are significantly

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[16] For example, in Spain, the irregularity of the hydrological regime and its impact on water supply and ecosystems is introduced in the Spanish legislation by the concept of “garantía” (level of service) meaning the maximum acceptable deficit in determined periods throughout a series of years.

slower (time lagged) and smoother (attenuated) than changes in water precipitation or water demand (two key inputs to the water balance).

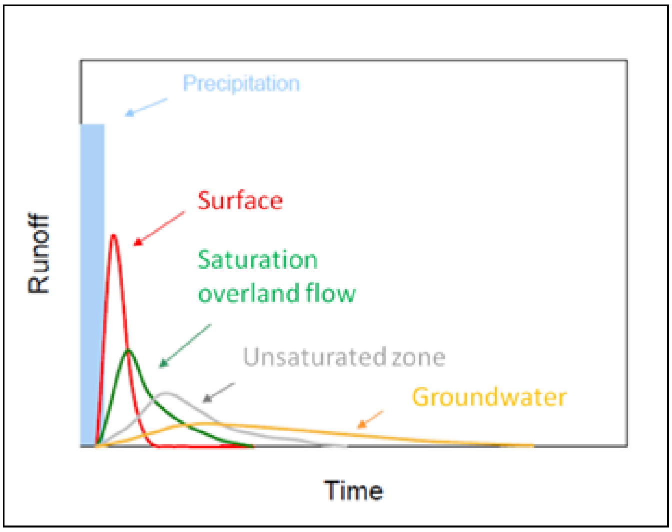

Figure 4. Relevance of timescales to different runoff processes (Source: http://ocw.tudelft.nl/courses/watermanagement/hydrology-of-catchments-rivers-and-deltas/lectures/6-flow-paths/

With regard to the **spatial scale**, all processes and flowpaths occur at different spatial scales. The wide range of spatial scales considered for these different processes, and the key processes that are addressed in priority when taking water management decisions, should help reflecting the choice of the most appropriate spatial scale for establishing a water balance. Building water balances for very large catchment areas can mask the variability of water resources and water demands within the study area, and ultimately hide crucial water management challenges. On the other hand, developing water balances for very small water units (e.g. a group of fields or a municipality area) will not help identifying water management challenges that could be addressed by changes in water management rules and strategies developed and applied at the water catchment, river basin or sometimes regional/national scales, and that are most relevant to the implementation of the WFD and the RBMP process (refer to Chapter 5).

Thus, defining the correct spatial and time scales at which water balances are established is a methodological challenge that needs to consider various elements, which should be supported by robust knowledge for supporting policy decisions. In particular, the requirements that water authorities might have with regards to the required accuracy of water balances must be taken into account in this process, so that end-products accommodate their specific needs.

3.2. Data sources (quality) and uncertainties

Data on water flows and storage evolution are necessary to evaluate the water balance of a catchment. Elements like rainfall are easily measurable, yet for other components of the hydrological cycle it is difficult to obtain direct and accurate measurements (e.g. evapotranspiration). Aggregation and/or extrapolation from point data to areal data (e.g. precipitation) can be challenging as well, and representativity issues can arise depending on the density of the point observations. Furthermore, the availability of time-series of an adequate length, and without gaps is not always guaranteed. Therefore, modelling or estimation is necessary. For example, storage evolutions and runoff are, most of the time evaluated, from measurable indicators or modelled. Estimation techniques can introduce further errors due to non-harmonised definitions, poor methodology or interpretation, or bias occurring in the aggregation of primary datasets from different sources and scales. Error can further propagate in simulation models used to represent the salient features of the water cycle or mimic the anthropogenic activities (i.e. water abstraction, land use change, etc.), due to the inherent difficulty in reproducing the behaviour of a dynamic physical system.

A key problem in any water balance assessment, as part of a conceptual model development, or as a result of inverse optimization of a physical based dynamic groundwater surface water model, is the estimation of potential evapotranspiration (PE). PE is not a measured variable but assessed from equations and formulas. At the catchment scale, several PE estimation methods may prove suitable. Simple methods involving only a few climatic variables may be preferred given restrictions in data availability (to more complex formulas e.g. Penman). Climatic variables generally used are: temperature, wind speed, solar radiation and relative air humidity. Several types of methods exist as for instance those based on temperature, those based on radiation or those that combine aerodynamic and energetic approaches.

In any case, reliable and frequent measurements are the base of a sounder (less uncertain) water balance. Furthermore, extreme events and climate change will require adaptation to drought and abnormal rain patterns and this requires the use of a large series of hydrologic data in order to make an adaptive management plans. Building a knowledge base and turning it into an effective tool requires an important work over large areas and many years. It also requires the development of working relations and data exchange between institutions representing either impacts on water resources or use of water resources. Thus, it is important that data collection personnel works in a co-ordinated way with those working on water resource assessment, so that data continue to be relevant to current problems, adequate for the assessments and users can rely on their quality.

In a recent DG Environment initiative under the “Preparatory Action on development of prevention activities to halt desertification in Europe”, water balances following the SEEAW methodology were developed in selected pilot river basins[17]. From 2011 onwards, 10 grants have been awarded for implementing activities in the following 12 pilot river basins: Tiber[18] (Italy), Mulde[18] (Germany), Ali-Efenti[18] (Greece), Vit[18] (Bulgaria), Guadiana[19],[20] (Spain), Jucar[21] (Spain), Segura[22] (Spain), Duero[23] (Spain/Portugal), Arno[24] (Italy), Guadalquivir[25] (Spain), Andalusian Mediterranean Basins[26] (Spain), Tagus[27] (Spain/Portugal). The exercise

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[17] Two calls were launched, in 2011 and 2012 (http://ec.europa.eu/environment/water/blueprint/balances.htm).

[18] Assessment of Water Balances and Optimization based Target setting across EU River Basins (ABOT), www.abot.it

[19] System of economic and environmental accounts for water in Guadiana River Basin (GuaSEEAW), http://iderm.imida.es/guaseeaw/

[20] New developments in Water Accounts Implementation in Guadiana river basin (GUASEEAW+)

[21] Halting Desertification in the Jucar River Basin (HALT-JUCAR-DES), http://www.emwis.org/initiatives/desert-jucar

[22] Accounting System for the Segura River and Transfers (ASSET), http://www.assetwater.eu/

[23] Duero River Basin: Water resources, water accounts and target sustainability indices (DURERO), http://138.100.137.130/durero_project_2014/

[24] Pilot Arno Water accounts (PAWA), http://pawa.emwis.net/

[25] System of Water Accounting in the Guadalquivir River Basin (SYWAG)

[26] Water accounting in a multi-catchment district (WAMCD)

stressed its usefulness as a knowledge-taking exercise that helps structuring all available (scattered) information and data into a coherent framework. It also highlighted key challenges with regards to the application of the SEEAW water-asset account tables, in particular with regard to [16]: the types of data required which in many cases cannot be simply obtained as products of existing water policy reporting, but that require the set-up of detailed hydrological/water resources management models (e.g. for estimating opening stocks in rivers or exchanges of flows between the different components of the hydrological cycle); the discrepancies in definitions and proxies of parameters related to water use in particular between water use, water needs, water demand, water consumptions; the attention required for transforming data available at different spatiotemporal scales into the spatiotemporal scale chosen for applying the water balance (mostly the monthly and water catchment scales); or the current data infrastructure which in many MS does not facilitate the (automatic) feeding of data into a water balances-like database. Despite these many challenges, the initiative showed that monthly water balances at the catchment scale present a clear added value for better water management and seems affordable and feasible. Some methodological lessons, along with the presentation of the different data used in part of DG ENV pilot projects and in other MS initiatives are presented in the Annexes of the present guidance document.

Uncertainty in estimates of the main water balance output indicators is inherent to the water balance development and calculations. Uncertainty is explained by a combination of factors such as the accuracy of input data and measurements used to estimate key parameters of the water balance, or the application of specific estimation techniques, building for example on model simulation, that cause uncertainty in the values of parameters estimated. While eliminating uncertainty would be impossible, understanding uncertainty becomes central to the correct interpretation of water balance calculations so results are adequately and cautiously used for supporting decision making.

Reliability of water balance estimates will depend on conceptual model development as well as performance of a site specific model. A good reference for model performance is to compare it with uncertainties of available field observations. If the model performance is within this uncertainty range we often characterize the model as 'good enough'. But usually it is not that simple. Therefore, the decision on what is 'good enough' generally must be taken in a socio-economic context. This implies that the performance criteria must be discussed and agreed between water manager and the modeller beforehand. Reliability of water balance estimates therefore is conditional to the amount of data and hydrological/hydrogeological knowledge available, the development of the hydrostrategraphic model, knowledge about initial and boundary conditions, maturity of process description, temporal and spatial discretization, and water balance input data for the modelling (precipitation, evapotranspiration, abstraction/irrigation etc.).

3.3. Correctly identifying water availability and accounting for ecological needs (links to e-flows)

Water resources availability as a term is used in very different ways, addressing separate or combined water volumes that are part of the water system. Notions and indicators such as

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[27] Water balances in the Tagus River Basin (PROTAGUS), http://evren.es/wp-content/uploads/2014/12/PROTAGUS_WEB_30122014_VINCULOS.pdf

‘natural resources’, ‘renewable water resources’, ‘exploitable water resources’ are often confused with no clear understanding of differences between these concepts[28].

In most cases, water resources are restricted to the actual volumes of water available for use since part of the water resources might be practically unrecoverable due to specific geological and morphological conditions (i.e. deep aquifers or direct discharges to the sea in coastal aquifers as illustrated in Figure 5.).

While these might be challenging to estimate, environmental and other water requirements that have a legal basis (e.g. specific water discharges defined at a frontier point as part of transnational water treaties) need to be considered when developing a water balance, as these can limit the water available for exploitation and use for consumptive purposes. It is recognized that the percentage of the mean annual river flow or baseflow that needs to be allocated to freshwater-dependent ecosystems to maintain them in good ecological status should consider the temporal variability of the environmental demand and the seasonal natural variations to account for the functioning of river ecosystems. It should also consider aquifer sustainability[29], e.g. impact on groundwater level and groundwater quality of related groundwater bodies. Excluding this volume from the available for exploitation water may result in changing the severity level of water quantity status.

Environmental water requirements for different large European basins or drainage regions are presented in some studies [15], as a percentage of the available water required to be maintained for environmental purposes. These percentages vary (e.g. 40% for Danube, 34% for Dnieper, 45% for Elbe, 47% for Oder, 44% for Rhine, 40% for Rhone, 35% for Seine) but generally they are around 40%. Of course, these are just some indicative numbers, since the percentage required highly depends on the spatial scale of analysis and cannot be generalised for all rivers (e.g. in the case of smaller rivers, precautionary assessment often assumes that only 10-20 % of low flow can be impacted by withdrawals). Returned water (into the same hydrological unit where abstraction occurs) can also affect the water resources availability of an area. Depending on the water quality and location where the return occurs (e.g. sufficiently upstream so it is exploitable by potential users downstream of the return flow point), this returned water volume can be an important addition to the hydrological cycle alleviating potential water imbalance problems downstream, stressing the potential role water reuse could play in some river basins for addressing current imbalances in water resources. These will need to be accounted for when calculating the overall balance between water availability and water needs) of a region or catchment to assess its current water stress conditions. It is of course recognized that return of untreated or poorly treated water can worsen the water quality and ecological status of a water body, and limit further abstraction for users requiring good quality water.

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[28] In the SEEAW 2012 indicators related to water resources availability are presented in detail in Annex III. (United Nations Statistics Division (UNSD). 2012. System of environmental-economic accounting for water, United Nations, New York, 2012).

[29] In Denmark a max 30% of total groundwater recharge to aquifers/bodies is allowed for abstraction. In practice, in many places only 50% can be removed without impacts on groundwater quality, when based on detailed investigations with analysis of monitoring data.

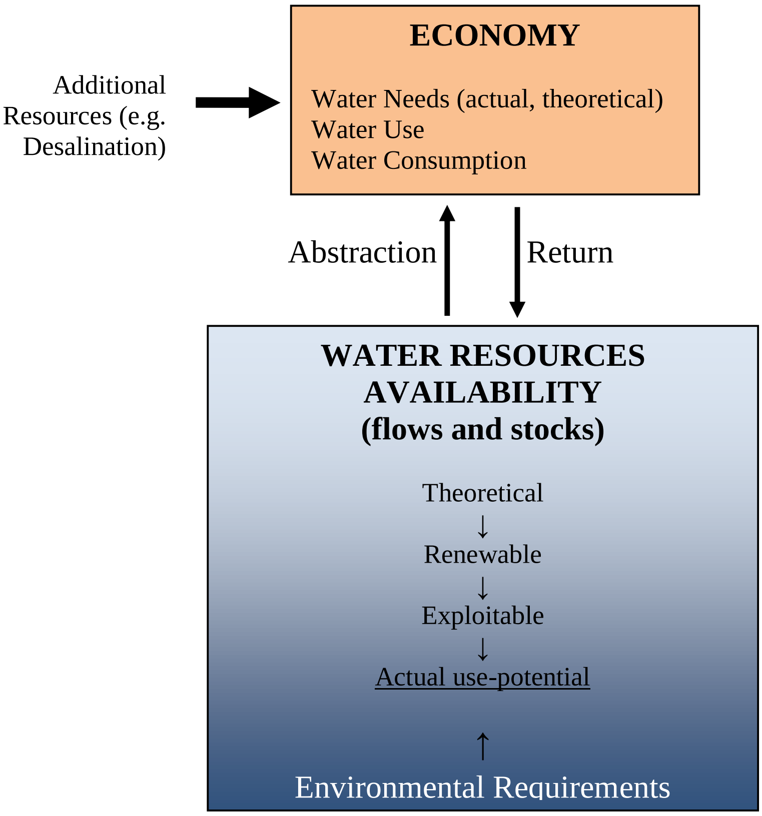

Figure 5. The flows of water between the environment and the economy along with relevant water scarcity parameters [1]

Box 6. Estimation of the Actual Available Water Resources in the Malta River Basin District[30]

In small islands and coastal river basins, natural subsurface discharge of groundwater can reach levels of around 50-60% of the mean annual recharge to groundwater and is thus an important factor in the water balance calculations. It is one of the main factors limiting groundwater availability and its non-consideration has the effect of artificially increasing the 'Available Renewable Water Resources' since freshwater lost by this natural process is not available for abstraction and subsequent use.

Additionally, one should note that the small distance to the coast and other topographical considerations limit the proportion of rainwater runoff which can be collected/harvested for eventual re-use. Due to their small size, the proportion of rainwater runoff generated in near coastal areas (and thus not recoverable) assumes higher significance compared to bigger continental river basins. Similarly to subsurface discharge, not taking this fact into consideration results in artificially increasing the 'Renewable Water Resources'. The main impact of these two factors, namely increasing the 'Renewable Water Resources' can result in artificially low indices of Water Exploitation for these river basins if not properly accounted for, which do not reflect the reality which these basins are facing. Considering data from Malta RBD as a case study, deducting the natural subsurface discharge and unrecoverable surface runoff from the ‘Renewable Water Resources’ (as these volumes cannot actually be recovered) results in a better estimation of the actual full use-potential. The resulting water exploitation (defined as the ratio of abstraction minus returned water over the actual full-use resources) is 69% for the long-term average and 99% for the year 2010, demonstrating conditions of heavy exploitation, as presented below. If these volumes had been considered as available for abstraction, the water exploitation ratio value would have been 40% and 55% respectively, illustrating a lower and unrealistic exploitation of the RBD.

Calculation of the Water Exploitation WEI+ for Malta RBD, taking into account the volume of water resources that cannot actually be recovered.

Parameter	**LTAA**	**2010**	**Comments**
Precipitation (P) (hm3)	174	162	
Actual Evapotranspiration (ETa) (hm3)	105	97	assumed at 60% of total precipitation in both cases
Renewable Water Resources (hm3) (RWR = P – ETa)	69	65	
Natural subsurface discharge (Qsub) (hm3)	23	23	
Unrecoverable surface runoff (Run) (hm3)	6	6	Estimated at 25% of total surface runoff generated (initial estimate)
Actual Available Water Resources (hm3) (AAWR = RWR – Qsub – Run)	40	36	
Total Abstraction (hm3)	37,5	43,7	
Returned water (hm3)	10	8	return from leakages - value is reducing due to leakage program
WEI+	69%	99%	

WEI+ here is defined as the ratio of Total Abstraction minus Returned water over the Actual Available Water Resources (WEI+ = (Abstraction-Returned water) / AAWR)

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[30] Source: Data provided by the EIONET NFP of Malta (Malta Resources Authority, Regulation Unit) during the EEA Consultation of the WEI+ in August 2012, in Kossida et. al., 2012

4. APPLYING WATER BALANCES IN PRACTICE

Water balances are not yet systematically developed and applied today in each and every catchment in Europe. Reasons that might explain this situation include: (1) the absence of water stress or water "imbalance" situation (i.e. not all exploitable water being used) in many catchments that does not justify developing a water balance; (2) the disaggregated efforts made to monitor the different components of the hydrological cycle, with no (institutional) mechanism for combining these into a common (water balance) framework that could help supporting policy making; (3) the lack of information available for estimating the main components of a water balance with sufficient accuracy at spatial and temporal scales that are relevant to water management decisions; (5) traditional water management based on local experience and water level information.

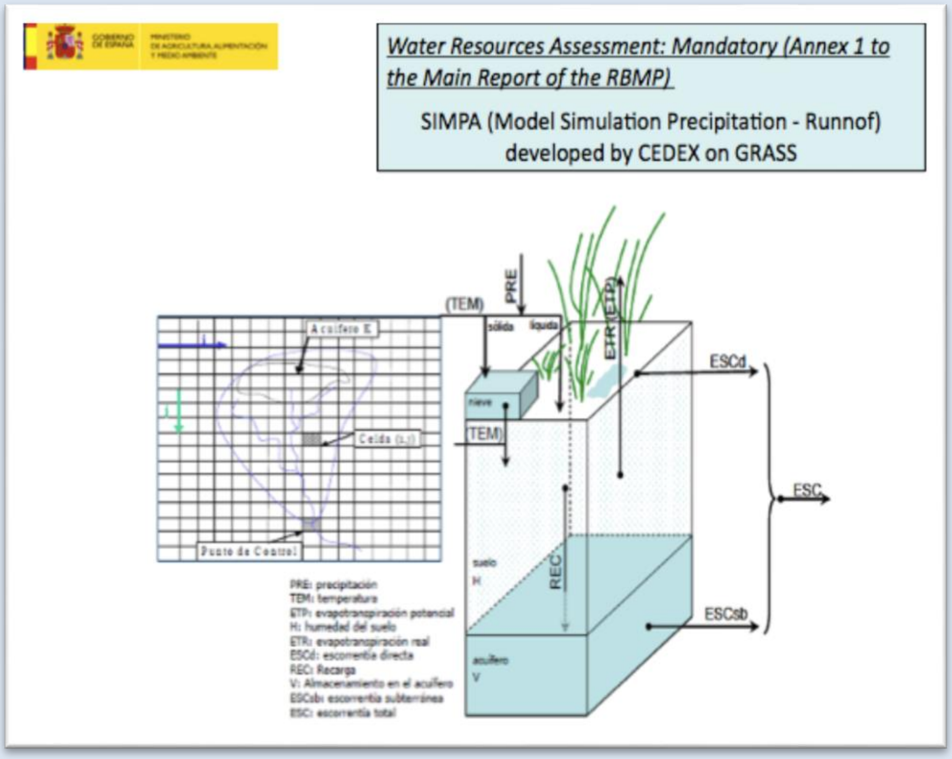
Still, many water authorities in different MS have experience with the application of (full or partial) water balances or with assessment frameworks that have similarities with water balances. Depending on the MS, water balances can be applied systematically (even if not fully developed) as part of the regular water management activities, as *ad-hoc* methods for justifying new investments that aim at enhancing water resources or balancing water needs to availability, or for supporting the development of new strategies. For example:

- In **Italy**, water balances are applied by the River Basin Authorities on their territory following Article 145 of the Legislative Decree 152/2006. Water balances are developed on the basis of the indications given by the Ministry of Environment Decree of 28th July 2004.

- In **Spain**, Royal Decree 907/2007 on Water Planning and the Ministerial Instruction ARM/2656/2008 for implementing the WFD in RBMPs requires the application of water balances in all basins shared with Portugal and by several autonomous regions. This regulation defines the scope of the basin water balance (resource studies, uses and demands, rules of management) but also the methods and tools that can be mobilized for developing water balances. The basic tools required by the existing regulation include the implementation of rainfall and runoff models for the characterization of water resources, combined with allocation models for water resources to assess ex-ante the potential impacts of measures proposed for RBMPs.

Box 7. From Water Resources Assessment to Water Balance in Spain

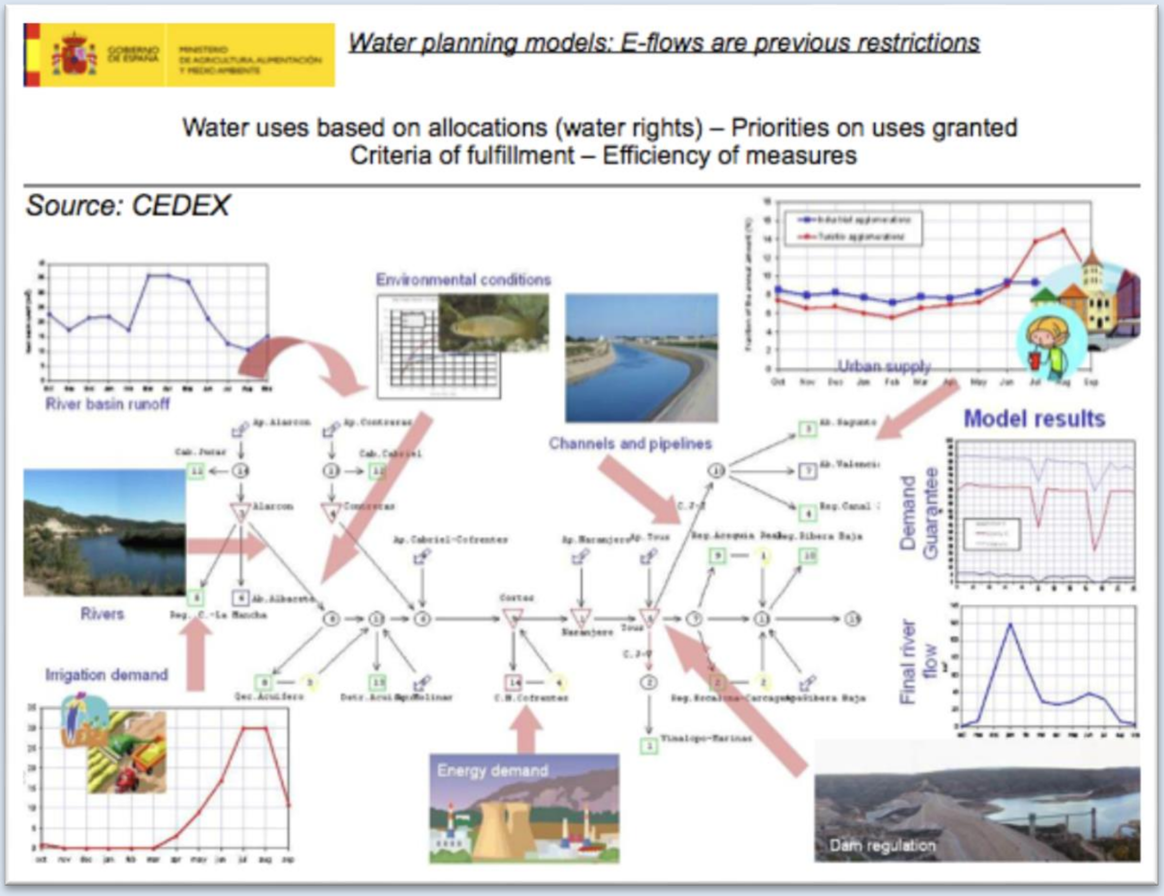
The water resources assessment is performed at RBD level for the whole national territory, with a spatial resolution of 500 m (for the most recent updating). Water balances are performed at the level of "water exploitation systems" (some 150 in total) in each RB, being e-flows as previous restrictions and simulating for calculation of water supply reliability for each water use (calculation time period is for a long register, and at least from 1980/81 – 2011/12) by means of the DSS AQUATOOL.



Water Resources Assessment: Mandatory (Annex 1 to the Main Report of the RBMP)

SIMPA (Model Simulation Precipitation - Runnof)
developed by CEDEX on GRASS

PRE: precipitación
TEM: temperatura
ETP: evapotranspiración potencial
H: humedad del suelo
ETR: evapotranspiración real
ESCd: escorrentía directa
REC: Recarga
V: Almacenamiento en el acuífero
ESCsb: escorrentía subterránea
ESC: escorrentía total



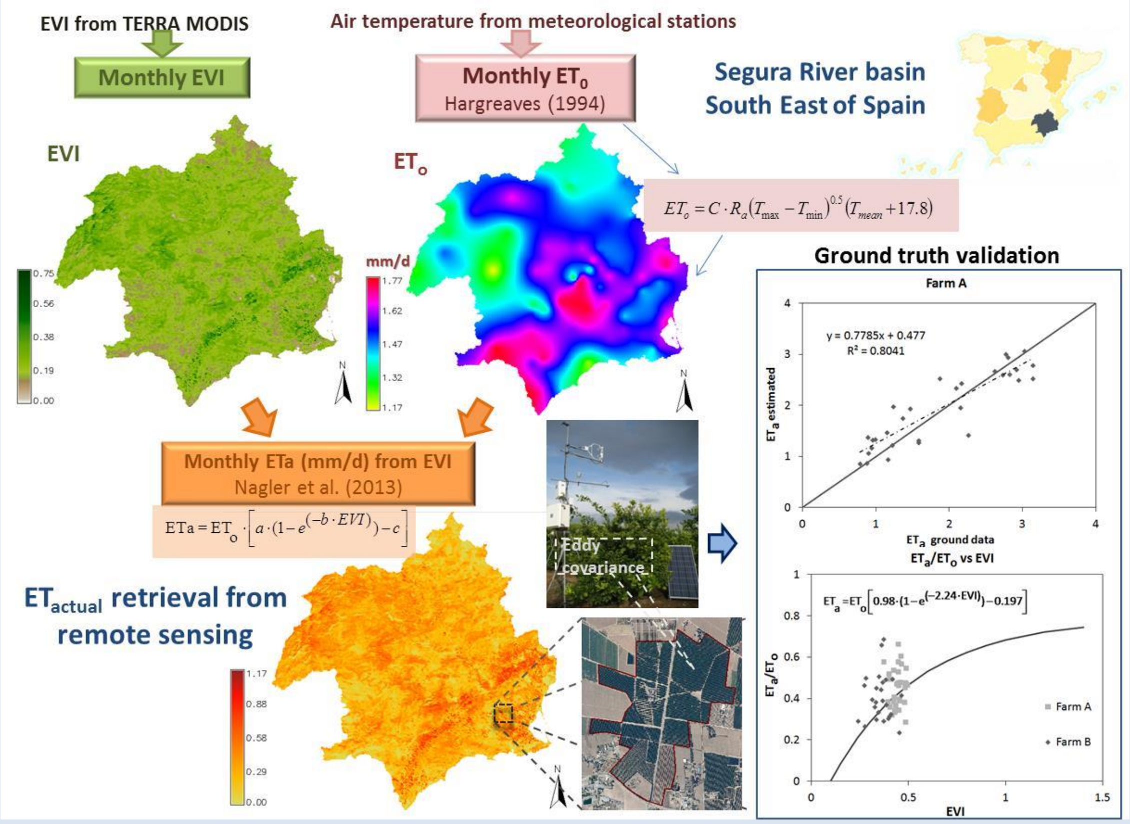
Water planning models: E-flows are previous restrictions

Water uses based on allocations (water rights) – Priorities on uses granted
Criteria of fulfillment – Efficiency of measures

Source: CEDEX

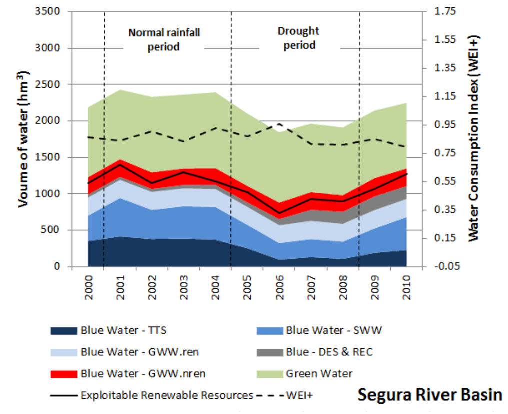
Box 8. Innovative methodology for generating input to water balances: Actual evapotranspiration retrieval from remote sensing

The actual evapotranspiration (ETa) is a key input to water balances, and sometimes a source of uncertainty. Assessing ETa from satellite images (MODIS data) provides spatial-temporal distributions. The ground truth validation with eddy covariance, demonstrates the reduction of uncertainties involved.



Box 9. Evolution of the total water usage by consumptive activities and the overall WEI+ in the Segura River Basin, South East of Spain.

The 2005-2008 drought period was triggered by extreme low rainfall amounts in 2005 and was followed by positive anomalies of annual precipitation. The satellite-based estimations of green water consumption in the 4-year period drought showed no large reductions, suggesting that this drought period was primary triggered by the reduction of the surface water inflows reaching the basin than by a local meteorological drought (Figure 3).



- Water resource balance is a tool that is regularly used in the **Slovak Republic** for the assessment of the real status of water use and water resources[31]. In surface water,

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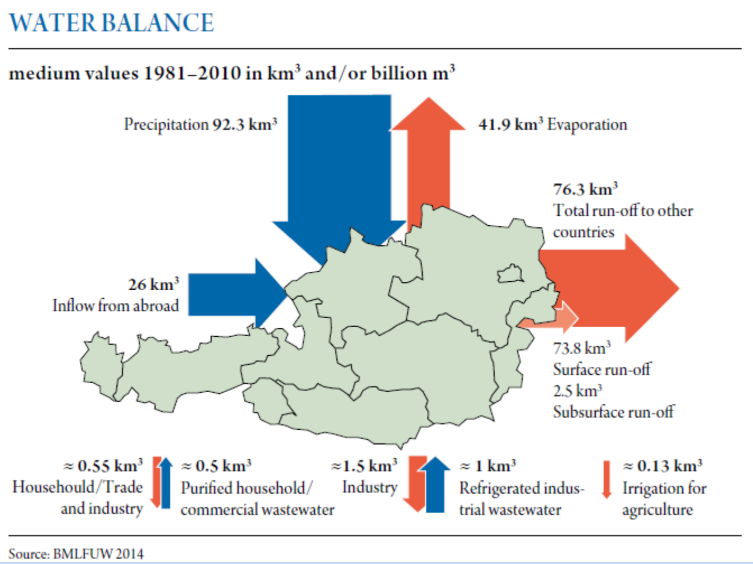
[31] The legislative background for regular assessment of Water resource balance in Slovak Republic can be found at:

quantitative water resource balance one of the key parameters is the minimum balance discharge (representing guaranteed flow, which could be considered as e-flow), which is considered on the side of water demands.

- Water balances in **Austria** are applied at high spatial and temporal aggregation levels, i.e. nationwide on the basis of long term annual averages (1981-2010) for precipitation, evapotranspiration, inflow, outflow (rivers and groundwater) and abstractions from industry, households and agriculture.

Box 10.Water balance application in Austria

Austria is abundant in water, only about 3% of the yearly available water resources are used by industry, agriculture and the private sector. Non consumptive water abstractions from (and returns to) rivers for hydropower production and cooling are not considered. However, hydropower as a renewable source is highly relevant (i.e. about 60%) for the Austrian electricity generation. Drinking water supply is 100% covered by groundwater and spring water. Because of an average precipitation of 1,100 mm per year (higher in the western alpine parts, lower in the eastern parts) only around 1% of the agricultural land is irrigated. Against this background, and after some adaptation measures to increase resilience and the security of water supply - taken due to experiences in the very dry reference year 2003, water scarcity is not a major issue in Austria.



Source: BMLFUW 2014

In the Austrian River Basin Management Plans 2009 and 2015 more detailed assessments for all groundwater bodies and groups of groundwater bodies were made looking closely at the sustainably available water resources, the ecological needs of dependent surface water ecosystems and the amounts of water abstracted. The assessment showed that 100% of all Austrian groundwater bodies and groups of groundwater bodies are in good quantitative status.

- In **Poland,** water resources per capita index get one of the lowest value in Europe, i.e. 1.8 ths. m^3.ca-1.year-1 (Central Statistical Office of Poland, 2014). Moreover, water resources are characterized by considerable temporal and spatial variation. Therefore, water balance calculations were introduced in Poland in the 1970s. Comprehensive methodology for water balances was developed in the 1990s, and was updated in 2008

- Act. 364/2004 Coll. - Water Act, § 6 Water balance - mentions two parts of water balance: hydrological balance and water resource balance. "Water resource balance compares the requirements for the abstractions from surface waters and groundwater and discharges of waste waters and special waters with the available amount of water and its quality and it assesses the impact of the discharging of waste waters and special waters on the quality of available amounts of water."
- Implementing regulation of Water Act. Regulation of Ministry of Agriculture, Environment and Regional Development of Slovak Republic No 418/2010 about execution of some provisions of Water Act, where in §19 Water resource balance – there is more detailed description of Water resource balance, its inputs and outputs, mentioning that it is being elaborated for the purposes of Water management plans of Slovakia, according to the approved time schedule using approved procedures.
- Act 201/2009 Coll., about state hydrological and state meteorological service. §4 - where Water balance is listed as one of the main tasks of the State hydrological service.

for the purpose of WFD implementation, development of RBMPs and PoMs. Water balances, defined as a comparison of water resources and demands of water users in terms of water quantity and quality, have been developed in Poland at several spatial scales: water regions, groundwater balance units and river catchments indicated in RBMPs as being at risk of not achieving good status. Water balances are calculated by simulating water allocation between various users. They take into account requirements of aquatic and water dependent ecosystems, relationships between surface and groundwater as well as impacts that hydro-technical structures have on surface water resources. Simulations are undertaken usually with a time step of 10-days for river catchments and for water regions they are performed on a monthly basis. Input data for such balances consist of multi-annual time series of river flows and demands of water users or ecological flow requirements. However, demands of agricultural users (fish ponds, which form an important part of water demands in Poland, and irrigation) are modelled simultaneously with water allocation simulations, as they depend on previous water supplies. Influence of groundwater abstractions on the base flow component is accounted for by appropriate corrections applied to river flows within a given balance cross-sections. Water allocation is based on the predefined priorities of water users, where basic environmental flow requirements are the most important in the hierarchy. The degree of implementation of water supply tasks is assessed in terms of time or volumetric reliability. Water balances are computed for several scenarios that consider different water demands, i.e. reflecting water license agreements and the level of current (or future) water use, more or less stringent requirements for aquatic and water dependent ecosystems, various operational regulations for existing (and planned) hydro-technical structures or alternative hierarchy in water use. Such analyses help to identify impacts that economic development may have on water resources, as well as allow assessment of the effects of proposed mitigation measures. They help to identify the best solutions and minimize potential conflicts. For water management policy, the most valuable outcomes from the water balance simulations are that they detect a mismatch between water resources and demands, i.e. they identify conflicts between environmental requirements and demands of water users or identify conflicts between different water users. Results of water balance calculations form a basis for defining priorities and restrictions for water use within river catchments, issuing of water licenses, formulating/updating operational regulations for hydro-technical facilities and drafting PoM.

- In **Denmark**, water balances are applied routinely as part of 3Da 3-Dimensional geological and hydrological mapping of groundwater aquifers to identify groundwater protection areas. A national hydrological model (DK model) is applied as part of WFD implementation and River Basin Management Planning, including inverse calibration, where water balance criteria are included in the optimization.

- In order to protect ecological river discharges and to avoid overuse of groundwater resources, quantitative water balances were introduced in **Hungary** in the 1960s. For surface and groundwater resources, separate water balance methodologies were developed with no attempt till the 1990s to connect and harmonize them. The WFD gave new impetus to methodological developments, especially to account for and quantify the surface-groundwater interactions, to incorporate groundwater dependent ecosystems (GDEs), and to better handle ecological discharges (see Box 10 below).

Box 11. Applying water balances in Hungary

Surface water

Due to topographic reasons, the reservoir storage capacity in Hungary is relatively low, the surface water resources available for withdrawal are mostly limited to the actual flow within the rivers. Water stress usually occurs in July and August when low-flow coincides with maximum irrigation water demands. Consequently, the water balance methodology was focusing on this summer low flow period and the concurrent water usage. For practical reasons, the time scale of the water balance was chosen to be 1 month and the critical surface water resources were identified as the 80% of August's daily flows (or the 80% of August's average flows). Water resources are determined every ten years, from daily discharge time series of the previous 30-years period, in compliance with WMO guidelines. Ecological discharges are either established by specific ecological and hydrological on-site analyses, or identified by 60% of the quantity of the critical surface water resource of the given river section.

From a hydrological point of view these low flows should be considered as part of the baseflow and as such, are mainly of subsurface origin. Two types of water balance are calculated:

- Surface water balance of the permitted water usage: long term water resources compared to permitted water withdrawals and discharges, providing information for water management policies and for the permitting procedures;
- Surface water balance of the actual water usage: water resources compared to actual water usage in a given year; informing water managers at the operational level. Currently, the actual balance is also based on the same long term water resource values, although there is a research project to be launched to estimate the actual runoff using hydrological models.

In both cases one of the purposes of the water balance that must be checked, is to ensure that water withdrawals do not exploit the ecological discharge.

Groundwater balance

Depending on the geographical scale groundwater balance calculations either rely upon small scale hydraulic modelling or on larger scale. In water accounting calculations are carried out on each of the groundwater bodies of a region. Groundwater resources were re-assessed for the 1st River Basin Management Plan in 2004-2008, based on observations of the 1991-2000 period, taking into account the interaction between different groundwater bodies, the interaction with the surface waters (primarily in the form of the baseflow component), and the constraints imposed by the preservation of the GDEs. For each (group of) groundwater body the exploitable amount was set, beyond which withdrawals might have severe environmental effects or damage to other groundwater uses.

The temporal scale of the groundwater balance is 1 year, and elements of the water household calculations (precipitation, evapotranspiration, in- and outflow, withdrawals, etc.) are expressed as volume for one year. National and regional scale water balance calculations are routinely carried out every year, in order to effectively manage resources. Re-validation of the withdrawal limits are generally carried out every ten years, and regional changes in groundwater heads are monitored continuously. Data on annual and monthly groundwater extractions are collected every year by the regional water directorates.

Also, many national- and EU-funded research projects addressing water scarcity in general, or sectoral (irrigation in particular) water use in water scarce regions, rely on the development of water balances (see Annexes for illustrations of applications of water balances in MS and within EU-funded pilot projects).

Many tools and methodologies exist to support the development and application of water balances. Existing hydrologic computer-simulation models that help understanding the hydrology of watersheds, rivers and aquifers are developed on water-balance principles for estimating responses of the water-balance to changes in internal (land surface) or external (rainfall) stressors. Depending on their level of complexity, these models provide an overall water balance for a (management) unit, or capture the processes that drive water within this unit. Their application at the watershed scale to support watershed management and planning helps predicting stream discharges at the mouth of a basin on the basis of rainfall, snowmelt, evapotranspiration, exchanges between groundwater and transfer of water within the river network.

Also practical stepwise implementation processes have been elaborated by different authorities in order to adopt flexible approaches that better account for water management challenges and available information. Box 12 presents a series of practical steps that can be followed for supporting the elaboration of water balances in different countries and river basins.

Box 12. A stepwise process for developing water balances

Step 1 – define the scope of your water balance (system boundaries, spatial and temporal scale …).

Step 2 – Identify the main components (constraints and pressures) of the water balance. For example, abstractions and discharges from different uses, downstream targets (different catchments, other countries when the balance is established for the national part of international river basins), level and flow water dependent ecosystems, quality of the water (and potential changes in water quality for example, saline intrusion), climate change, sea level rise etc.

Step 3 – Review existing tools (software, etc.) for developing water balances. Select an appropriate tool which fits your purpose and level of analysis. Consider expandability issues in your assessment of appropriate tools. Identify specific data format requirements that the tool might have that will influence the type and format of the basic data that need to be collected.

Step 4 – Collect all relevant data and information on key parameters available in your river basin.

Step 5 – Process data/information to estimate parameters at the right spatial and temporal scales. Make all assumptions transparent.

Step 6 – For parameters for which information is not available, propose innovative methods for assessing proxies (see example in the Annexes to the present guidance) or use estimates from the literature for similar conditions (of soil, water, ecosystems, water services…)

Step 7 – Develop the water balance using the selected tool(s). Calibrate and validate the output. Identify possible incoherence and inconsistencies in parameter estimates. Mobilize additional data and expertise, and perform a sensitivity analysis to refine parameter values and obtain a coherent water balance. Note: perform these steps for average, dry and wet conditions.

Step 8 - Identify gaps, priority parameters whose estimates need to be refined, and initiate studies for improving the knowledge base.

Step 9 – Start using the water balance for assessing: (a) current quantitative status and significant pressures; (b) historical trends and possible increases in pressures and deterioration; (c) future quantitative status and pressures under baseline scenario and/or climate change scenarios; (d) the impact (effectiveness) of individual potential measures proposed for the RBMP.

Step 10 – Update the water balance calculations regularly, as necessary.

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5. USING WATER BALANCES FOR SUPPORTING WATER MANAGEMENT

This chapter illustrates the application of water balances and their added value in supporting the implementation of the EU WFD and more efficient and optimal water management decisions. Whenever possible, practical illustrations of "water balances in practice" developed to support water management decisions are presented as a source of inspiration, building in particular on experiences of MS and studies carried out under European Commission grants. Additional examples of the application of water balances are provided in annexes to the present guidance.

5.1. Supporting the characterization of river basins and the identification of key water management issues

Water balances can be used at different steps in the WFD planning process, in particular for the characterisation of river basins and the implementation of the WFD Article 5. Water balances will help to characterise in a coherent manner the hydrological functioning of catchments or river basins. Depending on the spatial scale at which they are developed, they will help identifying catchments with significant quantitative water management challenges or water bodies at risk of failing the WFD environmental objectives, be it under current conditions or when accounting for changes in key drivers (population, agriculture, land use…) and (quantitative) pressures that are foreseen under a given baseline scenario. Thus, areas that might face situations such as over allocation, non-authorized abstraction and overexploitation can be detected.

5.2. Supporting the selection of measures for the WFD PoM

Water balances can help support the selection of measures for the Programme of Measures (PoM) proposed for each river basin district that will improve the quantitative state of water resources and achieve a set objective (e.g. the equilibrium between water demand and water supply, a set ecological river discharge or a set objective for replenishing aquifers). Potential measures that can be considered include: measures for reducing losses in water distribution networks (drinking water and irrigation water) [19]; measures for increase water use efficiency; Natural Water Retention Measures (NWRM) that aim at enhancing the retention capacity of soils and aquatic ecosystems [20]; water reuse and recycling; the development of desalination plants, etc.[32] Once potential measures are identified, and their direct unitary impact on water abstraction, runoff or recharge established (e.g. in mm or cubic meters of water saved), water balances can help translating a change in pressure into a change in the overall water resource balance. This may help quantify the impact of proposed measures for water resources, assess whether the set WFD (quantitative) objective is met and support the

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[32] If the impact of economic instruments such as water tariffs or abstraction charges on the water balance is to be investigated, additional information on water demand price elasticity (obtained from econometric or water-use behavioural models) is required. This information helps in translating changes in water tariffs into change in water demand (input into the water balance).

selection of the set of measures necessary to reach the WFD environmental objectives[33]. In establishing whether or not proposed measures are appropriate, it is necessary to perform a sensitivity analysis on key parameters to assess whether the assessed effects of the measures proposed remain sufficient for achieving set WFD objectives. Depending on the outcome of these assessments, it may be relevant to revise set objectives in the light of improved knowledge on the wider environmental, societal and economic consequences associated with the achievement of the original objective in accordance with conditions for WFD exemptions. It is important to stress that while these steps appear relatively straightforward on the paper, practical application remains challenging, in particular as evidence on the potential effect(s) of measures is often unknown or known with limited reliability (see Box 12 below).

Box 13. Sound and coherent water balances required [34]

The Dutch guidance document on cost-effectiveness analyses was tested in the eastern part of the country, where different pilot study areas were selected including the Eastern part of the Rhine river basin district. In this pilot study, water balances were developed using data from different provinces, regional water authorities, and municipalities. One of the lessons learned from that pilot study was that using information from various sources created problems, because different borders and surface areas had been used in different researches. Another problem was with the existing substances. The first balances of polluting substances that were also developed showed significant discrepancies that required recalculations in order to perform reliable analyses. In particular, the fact that not all internal loadings could be explained properly had significant consequences for the reliability of the results (without a proper substance balance, a cost-effectiveness analysis becomes a shot in the dark). This pilot study led to efforts to improve data and modelling on water and substance balances. This significantly increased reliability and usefulness of the various analyses, including of the cost-effectiveness analyses that were performed as part of the preparations for the PoM for the WFD and other policies.

As discussed further below, the information on the potential impact of potential measures on the quantitative state of water resources will contribute to the selection of measures, combined (as discussed in Chapter 6) with wider environmental and socio-economic consequences of such measures that can be combined into cost-effectiveness, cost-benefit or multi-criteria assessments.

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[33] In the WAMCD Pilot Project (see illustration in Annex II), two different and complementary approaches for analysing the effect of the Programme of Measures were proposed.

- A complete set of SEEAW tables has been calculated, taking into account the expected evolution of pressures from human activity and the effects of the actions included in the PoM.
- The building of a catalogue of Measures / Lines of Action in terms of their main incidence water account parameters. For each entry, the following data are included: name; response to; main incidences in physical accounts; main incidences in economic and hybrid accounts; supplier and user; metering; assessment; programme of measures (inclusion or not in the MBA PoM); additional information (including relevant regulatory or administrative tools supporting the measure).

[34] For more details: http://publicaties.minienm.nl/download-bijlage/16702/dutch-handbook-on-cost-effectivenes-analysis.pdf

5.3. Target setting and allocation

Water balances can help in evaluating the soundness of current water allocation between water uses. In particular, they can help identify where there is insufficient water to satisfy simultaneously all of the desired uses of water by economic sectors and provide the desired allocation to the environment as required to meet WFD objectives. The possible impact of changes in existing water abstraction permits and/or allocation rules among economic activities on the different components of the water balance can be assessed. Also, the water balance can help in establishing overall targets for water abstraction for each individual use so the sustainability of water resources is ensured – so the right balance between abstraction and recharge for groundwater/aquifers that support depending aquatic ecosystems and surface water bodies is achieved, or for ensuring sufficient quantities of water are left to river ecosystems. And this can lead to proposed adaptations in existing water permits/consents that account for the environmental needs of aquatic ecosystems.

While an annual or equilibrium water balance can often be sufficient for conceptual development and preliminary establishment of groundwater abstraction targets, finer time scales that can help in capturing part of the river water flow variability over shorter time periods are more relevant for supporting the definition of surface water abstraction targets and groundwater abstractions with seasonal variation (e.g. irrigation from shallow aquifers connected to rivers). And the definition of water abstraction permits can also consider series of water balance that capture average years and also for below average years and drought conditions. This can help in defining water abstraction permits that account for the variability and reliability of water supplies.

Box 14. Water balance calculations to define acceptable pumping rates in the Central Flemish Aquifer System, Belgium.

The Central Flemish Aquifer System is located in the north-west of Belgium. The northern part of this aquifer system consists of a sequence of sand and clay deposits, forming a phreatic aquifer system with up to three underlying confined groundwater bodies. The confined aquifers are heavily used by the (food) industry and by livestock farmers. Horticulture and other sectors with less stringent water quality demands often use phreatic groundwater.

The carrying capacity of the confined groundwater bodies is limited, amongst others because of the presence of brackish to saline water in the north. Water balance calculations were performed to assess the sustainability of the actually permitted pumping rates. These calculations were performed for equilibrium conditions, so that the long-term impact of an exploitation regime on the flows between different groundwater bodies and between ground- and surface water could be assessed. Equilibrium balances were calculated for several exploitation scenarios, including a scenario without groundwater abstractions and one where all wells extract the permitted rate.

The water balance calculations suggest that in natural, undisturbed conditions (no abstractions) the three confined groundwater bodies would receive an inflow from neighbouring non-saline water bodies and generate an outflow to neighbouring more saline water bodies. This would imply a steady freshening of the confined groundwater bodies of the Central Flemish Aquifer System. However, under the current permitted exploitation regime, the water balance calculations predict an inflow of water from the more saline regions for two of the three confined groundwater bodies that were studied. For the third (deepest) confined aquifer, a small reduction of the outflow towards the more saline region is expected, but no change in flow direction. This means that the actually permitted exploitation regime might at the long run lead to a water quality degradation of the upper two confined groundwater bodies. For the third one, there is no urgent risk.

Groundwater management in the Central Flemish Aquifer System aims at reducing the volume pumped from the confined groundwater bodies, eventually by allowing an increase in pumping rate from the phreatic system. Increased phreatic abstractions might affect the low flows of the rivers and the availability of surface water during droughts. The water balance calculations show that the actually permitted abstraction rates could reduce the outflow of groundwater to surface waters in the region by approximately 9% compared to natural base flows. This is well below the generally accepted thresholds for the impact of anthropogenic activities on river flows. A limited increase in phreatic pumping rates could thus be acceptable.

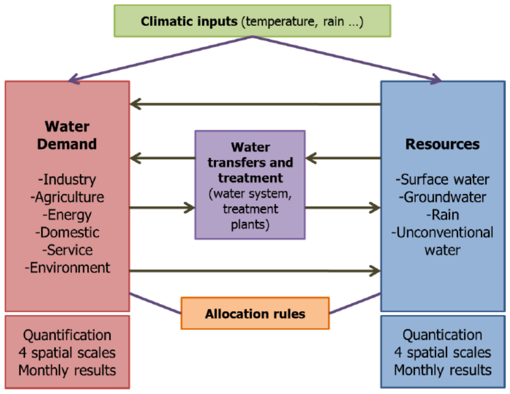
5.4. Adapting to climate change

Water balances can be used for identifying water deficit areas under climate change scenarios, or whether climate change will exacerbate or limit current water deficits. Indeed, as mentioned above, climate change impacts water balances directly via changes in rainfall and indirectly with temperature changes that affect evapotranspiration. In territories that are very dynamic from a socio-economic point of view, likely (potential) changes in water demands from different economic sectors and changes in land sealing (due to urbanization), obtained from prospective studies for example, can also be considered. And water balances for future situations that simultaneously integrate wider global changes that affect the hydrological cycle can then be developed (e.g. via participatory integrated assessments and scenario development) to identify actions that will enhance the resilience of aquatic systems.

In the context of WFD implementation, water balances can help performing the climate proofing of the measures proposed in the PoM. Water balances can first help assessing the potential impact of different climate change scenarios. They can also help performing sensitivity analyses on climate-related parameters to check whether measures proposed in the PoM remain relevant and (cost-)effective under future climate change scenarios.

Box 15. Using the STRATEAU model for supporting the development of climate change adaptation strategies for water[35]

Strateau is a water-balance decision-support tool that confronts water resources availability and water demand for different uses. It relies on a consistent database that combines structural characteristics of territory and observed data. Based on these data, Strateau helps assessing the impact of scenarios linked to changes in agriculture, climate, demography, industrial uses, or environmental demand. The results in terms of withdrawals, discharges, consumption, average river flows and aquifer (net) recharge are presented at the scale of administrative (region) and hydrologic scales (sub-river basin or river basin) units, using yearly and monthly time scales. The model includes two modules that interact thanks to well-defined allocation rules: a resource part integrating a ground water sub-model and a surface water model and a demand part combining an agricultural (CROPWAT-based) model and generic sub-models for other sectors relying on unitary demand, water demand determinant and exogenous parameters.



The model was used as part of the Explore 2070 project to assess the potential impact of different climate change adaptation scenarios on water – comparing the actual situation, a 2070 situation under climate change and other global (economic) changes and a situation with adaptation scenarios implemented. Measures investigated included changes in cropping patterns, changes in storage capacity, changes in priority allocation rules, etc.

5.5. Identifying room for improvement in resource efficiency

Water balances can be applied in searching solutions/options that respond to (water) resource efficiency objectives and for the optimisation of water use per unit of economic output. This optimisation can be part of the selection of the measures for the WFD PoM or as part of wider resource efficiency strategies developed at relevant decision making scales. When addressing

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[35] http://www.developpement-durable.gouv.fr/Evaluation-des-strategies-d.html

water use efficiency, it is important that efficiency targets are adequately set for the non-productive evaporation/loss water to avoid potential negative impacts for downstream waters once return flows are accounted for.

When addressing sustainability issues like resource efficiency, it is important to account for water and energy issues simultaneously (i.e. estimating energy required and related CO_2 emissions for different options of water use and allocation) so resource efficiency is assessed in its wider context.

Box 16. Water per unit of economic output and Thermal Power Plant Cooling Water System Choices

The choice of cooling system configuration is a fundamental aspect of the design of a thermal power plant. While air-cooling can be seen as highly favourable from an aquatic ecosystem perspective (with zero gross and net water demand) as compared to recirculating tower-cooling (abstraction limited as compared to net demand) or through cooling (an option that implies significant water abstraction and that can be considered only where water resource and receiving water sensitivity allows), such a plant will inevitably have a significantly lower thermal efficiency than an otherwise identical water-cooled plants. Reduced thermal efficiency implies more use of fuel per unit energy produced, greater emissions to air and greater production of waste or by-product per unit energy produced. It is evident that an option which may appear desirable from the perspective of the water environment or a water resource manager must also be considered from a much wider environmental and socio-economic perspective.

In some sectors, for example thermal power plant, apparent water use efficiency as measured by gross and net m^3/unit product can vary significantly between individual users whilst remaining consistent with the Best Available Technique. Care should be taken when considering the possible use of comparative data on water use efficiency between users to ensure comparative data are on the same reporting basis. For example, different literature sources use different vocabulary particularly in regard to ‘consumptive’ water use, storage, transfer and discharge/release. It is recommended that the water efficiency of a given user lying outside a reported range of peer group users should be regarded as a trigger to investigate the specific circumstances of that user, taking into account the wider environmental and socio-economic circumstances, rather than immediately making the inference that it is appropriate to set a more stringent water efficiency target for that user to bring it in line with the peer group. The investigation should be aimed at establishing whether or not the particular water use can be regarded as optimal in the light of the specific circumstances.

5.6. Contributing to informing and reporting on water policy implementation

The establishment of physical water balances can facilitate reporting to the EC on the implementation of the WFD. At the time of writing, guidance on reporting is being developed in the context of the CIS process (see the CIRCABC site for the latest CIS reporting guidance[36]), the objective being on providing concrete elements of information that help in understanding how the different WFD obligations have been addressed. Readers can take a look at CIRCABC for the most recent version of reporting sheets.

The establishment of physical water balances at the water catchment scale will also facilitate drawing an accurate pan-EU picture to inform EU water policy making and serve awareness purposes, as well as streamline reporting and help MS responding to reporting requirements.

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[36] https://circabc.europa.eu/w/browse/3eaafe7c-0857-47d4-a896-8022df48d3ba

Widely applied, it will help in identifying water catchments at quantitative risk – and thus provide the basis for estimating their relative importance at different spatial scales (e.g. river basin district scale, national scale).

6. EXPANDING THE PHYSICAL WATER BALANCE FOR ADDRESSING COMPLEMENTARY WATER MANAGEMENT ISSUES

Once set, physical water balances can be complemented with information linked to water quality or economics that can help support the implementation of the WFD and water management decision making at the catchment and river basin scales.

6.1. Expanding water balance to account for water quality

Integrating water quality[37] more specifically into physical water balances can help address water quantity and water quality issues simultaneously. Balances for the input of nutrients (e.g. N) can be developed using appropriate assumptions for the storage, use, runoff and leaching of nutrients in different soil and water compartments. This can help estimate nutrient leaching to the aquifers, and estimate nutrient concentrations in rivers accounting for average river flows at a given time scale (e.g. monthly). These concentrations can then be compared to target nutrient concentrations so first judgments can be made on pollution risks and on the risk of failing achieving the WFD objectives[38]. Also, water balances can help investigate issues of saline intrusion in coastal aquifers that result from the depletion of these aquifers.

Water balances can provide information for assessing the advective transport of substances. For some substances, reactive transport and/or diffusion might have a significant impact on the amount and concentration of the substance and thus on the pollution risk, certainly in groundwater.

6.2. Integrating the economic dimensions of water use and management

As indicated above, physical water balances can be linked to socio-economic information on the different economic activities that affect directly or indirectly the quantitative state of water resources. For example, economic information on the main water abstractors such as gross income, value added or employment collected as part of the WFD Article 5 assessment can be compared to the water abstraction/pressure imposed by each sector so an average productivity of water is estimated. This can provide an overall picture of the economic importance of water quantity for a water catchment or river basin. Methodologies to address cost-recovery issues in the context of Article 9, in particular the assessment and recovery of resource costs, could also be developed building on the establishment of water balances [21].

This integration can then support the identification of potential measures that might help address gaps in water status while accounting for the economic importance of water abstractors, including for assessing whether exemptions in the achievement of the WFD objectives might be considered and justified.

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[37] Experimental Water quality accounts are considered under the SEEA Water framework. They describe the quality of the stocks of water resources, and have a simpler structure than the assets accounts, as changes in quality are the result of non-linear relationships. It is however not possible to distinguish changes in quality due to human activities from changes in quality due to natural causes. One of the main problems in their application is the little standardization at the international level of concepts and definitions or aggregation methods for the definition and the measurement of water quality classes. [10]

[38] Clearly, as average nutrient loads and river flows for the water balance chosen time scale (usually the year or the month) are considered, this does not take account of the significant variability that might exist within the chosen time scales.

Additional efforts can be made to make the water-economic relationships more explicit by including water use per sector, water reuse or the importance of water desalination. Such information may be useful when considering options in cases where insufficient water is available to satisfy both the desired potential societal water use and the desired allocation of water to the environment.

Purely economic information on the main users (e.g. agricultural yields, income generated, etc.) can also be specified, linking production values to availability and water use, and providing the possibility to illustrate the effectiveness of policies aimed at a decoupling of economic growth and water use or (including emissions to water (see Box 14). By adding information on conveyance efficiency, water losses and water demand for the main users, the water balance leads to an overall water census that can support the:

- Identification of the potential for water conservation and improvements in water efficiency;
- The identification of water stress (as a temporal mismatch between availability and demand);
- The evaluation of the water supply reliability;
- The understanding of the impact (estimated) future water demand might have on the sustainability of water resources in a climate change context –information that is necessary for proactive water (but also land-use) planning.

Complemented with information on the unitary costs of potential measures (Investment and Operation and Maintenance Costs in € per ha or per water saving device), and expected water savings or additional water supply that would be expected from the implementation of these measures. For instance, water balances can support cost-effectiveness analysis and the prioritisation of measures when preparing the WFD RBMP and Programmes of Measures (PoM). In such assessments, effectiveness can be considered as (1) the contribution of individual measures to a given river discharge target/objective (e.g. in % of improvement as compared to the current discharge level, or in contribution to river discharge in m^3/s), (2) the restoration of a given groundwater level or (3) the contribution to balancing net aquifer recharge.

Cost-effectiveness ratios estimated for each individual (demand or supply) measure help ranking and prioritising measures because of their favourable cost-effectiveness ratio, including, whenever relevant, Natural Water Retention Measures (NWRM) [20].

When information on the marginal value of water (i.e. the expected unitary income loss that would result from the removal of, or addition of one cubic meter to, a given water abstractor) is available[39], the marginal values of water for different water uses can be compared. Marginal values of water can provide useful information for management of abstraction permits/consents. It might also help in revising current water abstraction permits/consents, or support the development of flexible mechanisms that allow for water reallocation between individual holders of water permits/consents that might support socio-economic development at no additional pressure on water resources.

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[39] Usually obtained from econometric models or from simulation using available hydro-economic models.

Box 17. NAMWA: Linking water accounts to economic data

Over the past decades, the demand for information about the economic value of water and the wider economic consequences of water policy and management has increased rapidly. Obviously, the introduction of the WFD has given this demand an important impulse. To meet this growing demand, the Dutch Ministry of Environment and Infrastructure and Statistics Netherlands have developed an integrated water economics information system called the National Accounting Matrix including Water Accounts (NAMWA). Following a pilot project in 1997 (De Haan, 1997), the Dutch system of environmental accounts (NAMEA) was extended in 2002 with the water accounts. NAMWA is a further specification of NAMEA for water, using the same accounting structure (Van der Veeren et al., 2004; Brouwer et al., 2005). The Dutch water accounts present information at the level of the four main river basin districts in the Netherlands: Meuse, Scheldt, Ems, Rhine-North, Rhine-West, Rhine-East and Rhine-Centre. The information of those water accounts are used as input for the Dutch economic analyses reports for the WFD.

The NAMWA-matrix consists of 10 monetary accounts and 4 physical accounts. The first two physical accounts for the emission of substances and water extraction and discharge represent the flows. The third physical account for water extraction and discharge describes changes in stocks, while the fourth physical account for emissions describes the contribution of various substances to ‘environmental themes’ such as eutrophication or the dispersion of heavy metals in water. By linking water and substance flows to economic flows and doing this systematically for a number of years, insight is gained into the (nature of the) relationship between our physical water systems and the economy. The integration of physical and economic information also allows the construction of integrated indicators. For instance, water use by various economic sectors can be related to the economic interests involved. By linking information about the physical pressures exerted on the water system by economic agents and the associated economic interests, NAMWA enables policy makers and water managers at national and river basin scale in a consistent way to assess the necessary measures to reduce these pressures and meet the environmental objectives in the WFD in an integrated way. NAMWA offers opportunities to analyse the trade-offs between environmental goals and the economic interests involved at the relevant level of analysis, i.e. river basins.

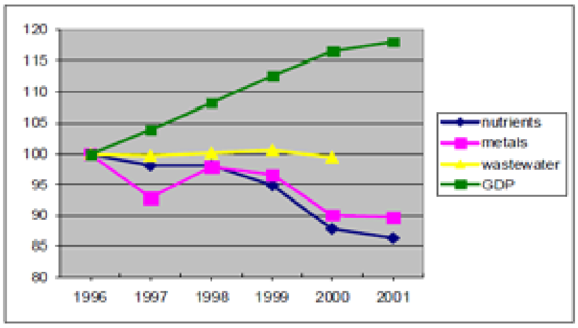


Figure 25: Economic growth, wastewater production, emission of nutrients and metals (excluding import) in the Netherlands over the period 1996-2001 (1996=100)

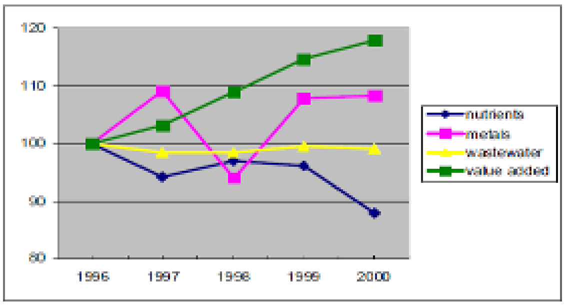


Figure 28: Economic growth, wastewater production, emission of nutrients and metals (excluding import) in the Meuse river basin over the period 1996-2000 (1996=100)

For more details, see http://www.helpdeskwater.nl/publish/pages/5396/anewintegratedriverbasininformationsystem.pdf & Brouwer, R. Schenau S.J. and van der Veeren, R. (2005), Integrated river basin accounting in the Netherlands and the European Water Framework Directive. UNECE Statistical Journal ECE 22, 111−131.

Box 18. Water productivity based upon SEEA water account tables

The SEEA-W methodology allows the management of information from standardised official databases, organising data in standard tables and using these to produce indicators that can serve for temporal or spatial comparisons. The tables for the Guadalquivir basin (2004-2012) have been used to follow the impact of meteorological droughts (years 2005 and 2012) and a hydrological drought (2005-2008). This was done by following the evolution of the ratio 'Gross Added Value (GAV)/water consumed', discriminating the role of irrigation water (blue) and soil water (green) according to SEEA-W definitions.

	2004	2005	2006	2007	2008	2009	2010	2011	2012	Average
GAV (Million EUR*)										
Livestock+Forest	616	484	459	573	598	600	650	688	630	589
Rain-fed	1.112	874	830	1.035	1.081	1.083	1.174	1.243	1.138	1.063
Irrigation	3.045	2.393	2.272	2.834	2.959	2.967	3.214	3.403	3.117	2.912
Water (mm)										
Forest Soil Water	495	277	460	488	458	448	504	491	336	440
Rainfed Soil (GW)	511	270	469	490	464	464	509	507	325	446
Irrigated land Soil Water	537	252	470	496	471	476	537	537	304	453
Irrigation (BW)	343	389	198	190	194	276	284	279	345	278
VAB/Water (EUR/m3)										
Total Consumed Water	0,15	0,20	0,13	0,15	0,17	0,16	0,16	0,17	0,23	0,17
Forest + LIvestockSoil GW	0,06	0,08	0,05	0,06	0,06	0,06	0,06	0,07	0,09	0,06
Total Irrigation (GW+BW)	0,48	0,45	0,41	0,49	0,53	0,46	0,46	0,48	0,55	0,48
Rainfed Soil GW	0,08	0,12	0,06	0,08	0,09	0,09	0,08	0,09	0,13	0,09
Irrigation (BW)	1,24	0,74	1,37	1,78	1,80	1,26	1,32	1,42	1,04	1,33
Irrigation residual BW	1,12	0,66	1,22	1,58	1,59	1,11	1,16	1,24	0,93	1,12
% Soil water IRR	61%	39%	70%	72%	71%	63%	65%	66%	47%	62%
% Blue Water IRR	39%	61%	30%	28%	29%	37%	35%	34%	53%	38%

(*) GAV constant prices 2012; GW= soil (green) water; BW=irrigation (Blue) water

Green (soil) water in irrigated land accounts for about 62% of water consumed by crops (increasing up to 70% during the hydrological drought from 2006 to 2008 when irrigation restrictions are applied). The ratio 'GAV/water consumed' shows that water apparent productivity for rain fed agriculture is 0.09 EUR/m^3 compared with 0.48 EUR/m^3 for irrigated land. When the denominator of irrigated land excludes soil water and includes only irrigation supply, the apparent productivity of irrigation water increases to 1.33 EUR/m^3. This type of information can help water managers understand the economic consequences of different options when allocating water to different uses and may support the evaluation of measures to prevent impact of climatic events (see Borrego-Marín, M.M., J.M. Perales, A. Posadillo, C. Gutiérrez-Martín y J. Berbel (2015 Analysis of Guadalquivir droughts 2004-2012 based on SEEA-W tables. International Conference Drought R&SPI 2015. Valencia).

Box 19. Estimating technical and economic indicators in the WAMCD project (see Annex II for more information)

In the SEEAW Guidance Document, four types of indicators are proposed to synthesize the massive amount of information compiled, each representing a potential aspect of water management and /or RBM planning under the IWRM approach. The WAMCD project team has selected a collection of relevant technical and economic indicators that can be obtained from SEEAW tables or auxiliary datasets and may facilitate handling information and extracting helpful conclusions. These indicators were calculated for three different scenarios: 2009 –baseline, corresponding to RBMP-09–, 2015 –current scenario of RBMP-15– and 2021 –future scenario after the first stage of implementation of the PoM.

	2009	2015	2021	Units
A) Water resource availability				
A1. Renewable resources	1,660.49	1,681.05	1,692.40	hm^3/year
A2. Per capita renewable resources	636.26	607.14	590.95	m^3/resident.year
A3: Consumption index	56.70%	56.63%	57.18%	dimensionless
A4: Exploitation Index	114.59%	113.97%	113.94%	dimensionless
A5: Use of renewable vs. non-renewable water resources	34.48%	34.04%	19.60%	dimensionless
B) Water use for human activities				
B1-a: Water use per unit produced. ISIC I-3	1.24	1.30	1.28	m^3/€
B1-b: Water use per unit produced. Rest of human activity	0.04	0.04	0.04	m^3/€
B2-a: Water Productivity Ratio. ISIC I-3	0.81	0.77	0.78	€/m^3
B2-b: Water Productivity Ratio. Rest of human activity	26.69	26.48	26.13	€/m^3
B3: Water pollution per person (only ISIC 37)	n.a.	53.371	54.692	Kg COD/resident.year
B5: Decontamination ratio (only ISIC 37)	n.a.	79.73%	83.76%	dimensionless

Box 20. Financial cost recovery estimation based upon SEEA

The Guadalquivir River is the longest river in southern Spain with a length of around 650 km. Its basin covers an area of 57,527 km2 and has a population of 4,107,598 inhabitants. Agriculture is the main user in the basin and it has implemented an intense investment in water saving measures. The philosophy of SEEA Water is based on time and resource saving efficiency in data gathering. It is crucial that data are based on officially published information avoiding 'ad hoc' estimations. Following this strategy, project SYWAG has estimated cost recovery rates in the SEEA Water tables. SEEA includes information for a) the capital and investment costs b) operational and maintenance costs of water services, c) Government account table for water-related collective consumption services d) Financing accounts. By combining information included in those tables, SYWAG obtained the following result

		Financial cost recovery index			
Service cost recovery (Estimation for 2012)		Urban	Agrarian	Industry	Total
		1	2	3	
Water supply: abstraction, storage and distribution, surface and groundwater	Upper level surface services	74%	64%	76%	66%
	Collective groundwater abstraction	100%			100%
	Water irrigation distribution		73%(*)		73%
	Urban cycle (distribution of drinking water)	97%			97%
	Self service (surface & GW)		100%	100%	100%
	Reuse		100%		100%
Collection and treatment of sewage water	Non connected collection	--	--	100%	100%
	Public network collection	93%			93%
		87%	75%	91%	78%

(*) Non recovered cost for water irrigation distribution are justified by the reduction in farmers' water rights (25% on average).

A detailed study of material and methods can be seen at Berbel, J., Borrego-Marín, M.M. y Gutiérrez-Martín, C. (2015). System of Water Accounting in Guadalquivir River Basin (SYWAG).Final Report. Universidad de Córdoba. Colección: DESPA. http://hdl.handle.net/10396/12557.

Box 21. Cost effectiveness analysis (CEA) applied to water-saving measures in the Guadalquivir basin

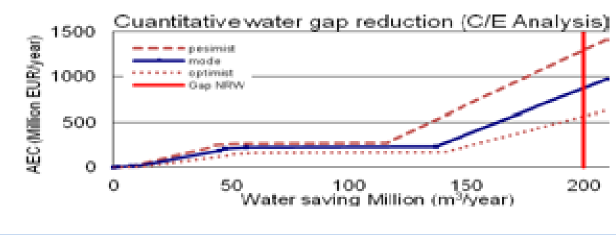
Average renewable resources in the Guadalquivir River Basin (GRB) amount to 7,230 Mm3/year, from which in an average year 3,850 Mm3 are used. Per capita water consumption in the GRB is 950 m3. Currently, the main water uses in the basin are agriculture (85%), domestic use (11%), industrial use (3%) and tourism. Cost effectiveness analysis (CEA) was applied to water-saving measures. CEA is a form of economic analysis that compares the costs and outcomes (effects) of two or more courses of action. Generally in water management, the objective of CEA is to bridge the gap between the total water supply and total projected consumption. In the context of the WFD, the objective is to achieve good status, and therefore the goal of the Programme of Measures (PoM) is to reach a sustainable rate of water consumption while maintaining minimum environmental stream flows and groundwater levels.

The term ‘measure’ is understood here as a specific intervention, which can include management programmes and/or techniques, aimed at saving water. Here the focus is on the measures discussed in the public participation process for the elaboration of the PoM for the Guadalquivir River Basin. An additional complexity in the case study of the Guadalquivir for water saving measures is that some of the defined “measures” by the PoM imply a combination of both technical and economic instruments. An example maybe the complex measure called ‘irrigation modernization” which is the improvement of irrigation networks that generally includes the substitution of open channel irrigation by pressurized systems, introduction of metering devices and volumetric billing leading to price increase. The next step in the model is the estimation of the effectiveness and the costs of the measures to calculate the CE ratio. The challenges here are: i) information availability; ii) avoiding double counting over the different measures; and iii) accurately measuring the impact of the measure.

Water-saving measures	Effectiveness		Annual Equivalent Cost (10^6€ per year)	CE pressure reduction (€/m^3)	CE impact reduction (€/m^3)
	Pressure reduction (Mm^3)	Impact reduction (Mm^3/year)			
Improvement of urban distribution networks	44.99	2.19	21.61	0.48	9.87
Modernisation of irrigation systems	259.51	35.26	172.18	0.66	4.88
Service cost recovery in urban sector	17.59	9.58	18.55	1.05	1.94
Service cost recovery in irrigation	22.46	2.20	2.41	0.11	1.10
Volumetric billing for irrigation	38.26	5.90	6.20	0.16	1.05
Extension services for irrigators	9.78	1.58	3.82	0.39	2.42
Subtotal	392.59	56.72	224.77	0.57	3.96
Strict groundwater abstraction control	323.11	80.38	5.50	0.02	0.07
Total	715.71	137.09	230.27	0.32	1.68

Source: Berbel, J., Martin-Ortega, J., & Mesa, P. (2011). A cost-effectiveness analysis of water-saving measures for the water framework directive: the case of the Guadalquivir River Basin in Southern Spain. Water Resources Management, 25(2), 623-640. DOI.10.1007/s11269-010-9717-6

The analysis of cost and effectiveness of measures is made at water mass level, and there are around 400 water masses in the Guadalquivir River Basin. The measures' impact analysis is made by aggregating them accordingly to account for spatial interactions between the different water bodies in the river basin, as some water-saving measures upstream will positively affect water bodies downstream. Because of the spatial interactions, the cost of reducing the pressure on a downstream water body will be significantly lower if water-saving measures are undertaken upstream. There are differences between CEA in the 'pressure reduction' ratio (defined as reduced water abstraction) and CEA defined as 'impact reduction' ratio when return flows are taken into account and real impact in water masses quantitative status is considered.



The Figure in this example illustrates data contained in the table, (central continuous line) defined as the 'most probable cost and effectiveness. Discontinuous line above and below the 'most probable' show the 'pessimistic' and 'optimistic' estimation of cost and effectiveness. This allows the integration of a measure of uncertainty assumed as a triangular distribution (pessimistic, most-likely, optimistic).

6.3. EEA and Eurostat related works

Estimation of Water Assets Accounts for Europe is the first step of this analysis towards obtaining information on the Water Exploitation Index (WEI). Based on the previous EEA experiences on Water Accounts and WEI three spatial scales (i.e. Sub basin, River Basin and Country) and three temporal resolutions (monthly, seasonal and annual) have been chosen to present the results. The UN SEEA–Water framework is the conceptual framework for the asset accounts. Therefore, the results of assets accounts introduced in the EEA's study are in line with standard water availability and the water use tables of that framework also provides information on water use by the economic sectors in the respective area and time period. The parameters are also in line with the Eurostat collection on water statistics.

The WEI+ results are calculated as derived results from the water balances arising from the European Water Assets Accounts. Water Exploitation Index (WEI+) is understood as an indicator for presenting water scarcity conditions across Europe. Formulas were developed and agreed by the “Expert network on water scarcity and droughts” and the “Working group on water accounts” under the CIS for the WFD. Two different formulas were endorsed by the Water Directors in implementing the Renewable Water Resources. The EEA presents the results from both formulas. Following this, the WEI also describes sectorial pressures over the renewable water resources. The tool (the EEA WA-infrastructure) is flexible enough to accommodate possible further adjustments of the formula.

The EEA Water Accounts infrastructure is not only producing results from Water Accounts, but also provides data and information to further assess water quality in different domains (such as the JRC work on water consumption and efficiency in the service sector).

The results suggest the following interpretation of the water resource situation across Europe (as the data sources and the details of the methodology are, at the time of writing, under consultation, these should be considered as preliminary):

- Assessment of WEI at sub basin scale on monthly/seasonal resolutions revealed that the freshwater systems are under pressure especially in Mediterranean countries due to high irrigation water demand in summer months, while the rest of Europe experiences lower water scarcity stress by other economic sectors as water collection treatment and supply, energy and industries.
- From the environmental perspective, high water demands overlap in lower available renewable water resources particularly in summer months, which create partly additional stress over the freshwater resources.
- As water availability is a site-specific phenomenon, spatial aggregation of water stress and scarcity for instance to the country scale is prone to hide the real conditions in the respective less aggregated areas. In this sense, the study also verifies the findings in the previous studies on regionalised WEI. Sectorial share of water abstraction and use is crucial information for the policy makers and stakeholders in assessing water resources efficiency and implementing the measures to tackle environmental concerns including the role of water resources as part of total natural capital.

Regarding Eurostat, the entity is organising collections of data from the members of the European Statistical System (ESS: EU+EFTA countries) by means of the OECD/Eurostat

Joint Questionnaire on Inland Waters (JQ-IW, national level) and the Eurostat Regional Environmental Questionnaire (REQ, for NUTS2 and RBD/SU aggregations). Both data collections include a table addressing water resources; these tables could be at least partially (pre-)filled with data from water balances exercises and pilot projects. Total water abstractions and returns are likewise elements of other central tables in the JQ-IW and REQ, so that these data can be complemented and counterchecked with statistical information available from the ESS. Complete recording of metadata including estimates of accuracy would vastly enhance the value and usability of the water balance data sets.

To support the implementation of the WFD, due consideration needs to be given to **water quantity issues** to better understand the balance between water supply and water demand and the current balance or imbalance of water resources, as a pre-condition for achieving the WFD environmental objectives (in particular: Good Ecological Status for Surface Water bodies, Good Quantitative Status for Groundwater bodies, no deterioration for both water body types). As summarised in the following table, water balances are tools that can **help support the sound implementation of the WFD** so its environmental objectives are achieved in a cost-effective manner[40].

Table 3. Potential applications of water balances for supporting the implementation of the WFD

WFD implementation step	Role of water balances	Possible expansion of water balances
Characterisation of river basins (Article 5)	Identification of areas with imbalance between water supply and water demand (today and under baseline scenario conditions) Identification of significant "quantitative" pressures on water status (significant water abstractors, pressures on water infiltrations, etc.)	Integration of socio-economic data (economic importance of water uses) to capture the role of water resources in the socio-economic development of river basins and for performing the assessment of cost-recovery (Article 9) Integration of water quality data to strengthen against the risk of failure to achieve good chemical status
Development of the RBMP and PoM (Article 11, Annex III & Annex VII)	Assessment of the effectiveness of individual measures (including adaptation in current water abstraction permits/consents) and selection of measures required for achieving good status (ecological flow, groundwater quantitative status, no deterioration) Climate proofing of measures	Assessment of costs of measures to perform cost-effectiveness analysis and prioritizing measures Integration of socio-economic information on the economic value of water to perform the assessments required if exemptions are considered

Water balances are tools that can help MS to carry out their **assessment of the potential risk of quantitative imbalance**, be it today or in the future if no preventive action is taken. They can be developed and applied when carrying out the WFD Article 5 analysis, helping to identify: (1) water bodies and/or catchments that are at quantitative risk and for which measures should be proposed for closing the water status gap; (2) significant pressures that explain current water imbalances; and (3) possible gaps in, and incoherence between, the existing knowledge base on the different components of the hydrological cycle and on the inventory of water abstractions.

Water balances should be built in a stepwise and tiered approach, with a preliminary analysis of current management challenges helping to define the key components of the water balance that require specific attention. In addition, managers should identify time and spatial scales at which it is relevant to develop the water balance so it can help supporting management

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[40] Developed with the right level of detail accounting for available data, available human/financial resources and the expected value added, water balances might deliver in supporting water management.

discussions and decisions. Water balances should explicitly consider the **environmental demand** of aquatic ecosystems in coherence with the definition of Eflows for surface waters.

Water balances can also be used to **select measures for the WFD PoM**. They can help: (1) assess the effectiveness of measures proposed for improving the quantitative balance of surface and groundwater resources; (2) review existing water abstraction permits; (3) assess the relevance of water efficiency measures or development of water reuse.

Complemented with information on the costs of measures, they can help prioritise potential measures based on their cost-effectiveness ratio and identify the combination of measures that can achieve a sustainable use of water resources at the lowest possible cost. In some cases, the technical, environmental and economic information provided, when linking water balances to socio-economic information, can help investigate the need for any WFD exemptions. Finally, water balances are critical to enable the comparison of the different management options including the development of new infrastructure (e.g. dams) that require an exemption under Article 4(7) of the WFD.

Accounting for future **climate change** scenarios and their impacts on rainfall, water balances can also provide useful information for climate-proofing of measures, and for selecting measures that enhance the resilience of aquatic ecosystems. In addition, they can be used as the basis for emergency plans in case of water shortages and of conflicting water uses.

Water balances are one of several approaches that can shed light on the issues linked to **the sustainability of water management, water availability and (efficient) water resource use**. Other approaches that have clear connections to the components and applications of water balances include, for example, life-cycle analysis or analysis of water footprints.

It is important that further efforts are made for these approaches to be applied more systematically in the context of environmental, water resource and resource efficiency strategies while accounting for future socio-economic development and climate change. In addition to supporting the implementation of the WFD, this will contribute to the identification of measures and solutions that best support the sustainable development of Europe.

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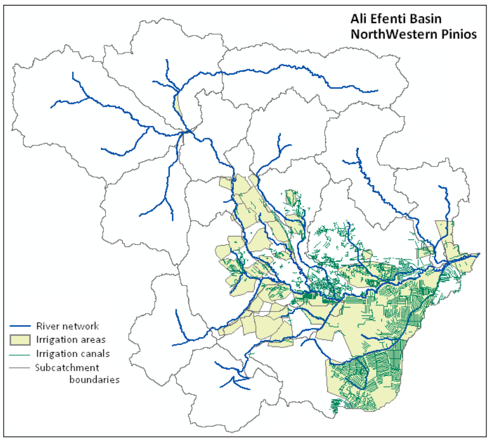
ANNEX I – ILLUSTRATING THE APPLICATION OF WATER BALANCES

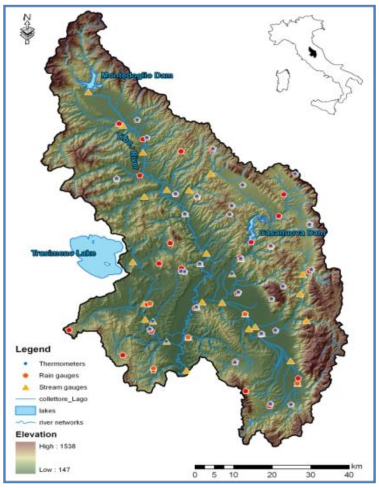
Case study #1: Ali-Efenti River Basin, Greece (ABOT project, DG ENV)

Study Area: ***Ali-Efenti River Basin, Greece***	The **Ali-Efenti River Basin** is located in the North-western part of the Pinios River in Thessaly RBD (GR08), in Greece. Two main urban centres (the cities of Trikala and Karditsa) are within the basin, while numerous significant peri-urban settlements are also present (Kalambaka, Mouzaki, Neoxori, etc.), all together with a total permanent population of 190,276 inhabitants. In terms of land use the area is dominated by agriculture and forests (about 33% each), followed by pasture (30%) and urban (2%). The long-term annual average precipitation in the basin has a high spatial variability, ranging from 1,000-1,300 mm in the west, to a lower precipitation of 460-600 mm in the east. 
Which are the main challenges with regard to water management in the study area?	This basin has extended irrigation areas (the main crop cultivated is cotton), while irrigation efficiency is low. Imbalance between demand and availability (water stress) is frequent, and the unmet demand is highly pronounced during the summer period. As a result over-abstraction has led to environmental impacts, such as the degradation of the groundwater resources and declining groundwater levels. Drought Management Plans or other policy instruments are lacking, and water quantity management is currently based on "crisis management" rather than on a pro-active and preparedness approach.
How did the development of Water Balances support local water management and help alleviate the problem?	The area has competing water uses, irrigation being the predominant one, thus socio-economic impacts of water stress are major. Establishing detailed water balances provided the necessary input for the development of a cost-effective **optimum water allocation schema** among the users, considering the spatial and temporal availability of water resources. By identifying the imbalances across the water quantity components and the related drivers and pressures (which can consequently also impact water quality) robust **targets were established**. Furthermore, the detailed water balances guided the development of a series of demand reduction **measures and interventions** which are based on a holistic assessment and can mitigate water stress in the short and long-term. Finally, projected water balances as calculated for 3 future climate and socio-economic

	scenarios were used to test the robustness of the selected measures, supporting thus **climate change adaptation**.
Key findings:	Detailed water balances have been developed for the Ali-Efenti basin in Pinios from 1980-2010, allowing the representation of the components of the hydrological cycle and catchment process along with the water demand and uses in the catchment. All water balance features have been calculated at monthly time step, for each of the 23 sub-catchments and 50 demand sites, allowing the identification of opening and closing stock, and exchange in flows, and have also been compared to a dry year (2007), a normal year (1997) and a wet year (2010). The balance between demand and availability is negative, resulting in unmet demand in all the 23 sub-catchments every year, mainly for irrigation purposes. Unmet demand for industrial and livestock activities has also been experienced during 2004-2008, but at a much lower level than in irrigation. **The total annual unmet demand in the Ali-Efenti ranges from as low as 5 mio m^3 (1995) to as high as 114 mio m^3 (2007), with an average value of 33 mio m^3 over the 16-year period**. This unmet demand is mainly attributed to irrigation, yet the industry and livestock sectors are also affected during some years. **The Reliability (R) of the system in supplying the requested demand** (i.e. the percentage of the time steps in which a demand site's demand was fully satisfied) varies among the uses. As domestic use is top priority, water allocation to this use has a reliability of 100%. Reliability in the provision of water to the livestock sector is a bit lower at around 98% and for industry around 95%.The reliability in irrigation water supply is highly variable and in some cases is as low as 70%: 52% of these users have R>95%, 26% have a high R (85-95%), 13% have a medium R (75-85%) and 9% have a low R (<75%). To reduce the unmet water demand a bundle of **demand management measures have been assessed within the urban and agricultural sectors** and an **optimization process has been applied to determine the most cost-effective options**. The urban water saving measures examined included dual flush toilets, low flow taps and showerheads, efficient washing machines, rainwater harvesting and greywater reuse. In the agricultural sector a mix of conveyance and irrigation methods that would lead to increased irrigation efficiency, as well as deficit irrigation and reform of cultivated crops (% of the existing ones to new crops) have been investigated. Optimisation of interventions in the urban sector indicates a water saving potential equal to 26% water saved per capita. However, above the water saving level of 7.5% water saved per capita, the applied measures are relatively expensive, and include rainwater harvesting, greywater reuse and efficient washing machines. In order to improve the combined efficiency of irrigation networks a high percentage of drip irrigation and precision agriculture is required. Optimization indicates 18% reduction of unmet demand with an investment cost (AEC) for increasing irrigation efficiency equal to 12 million euros per year. An investment above that level has insignificant impact on reduction of unmet demand. Where deficit irrigation is implemented unmet demand reduces dramatically (75% reduction of unmet with an investment cost equal to 11.5 million euros per year). The optimization analysis indicates a maximum decrease of agriculture unmet demand equal to 18% with an AEC of 12 million euros if only demand reduction interventions are taken into account. On the other hand 75% reduction of agricultural unmet demand is achievable if deficit irrigation practice is also taken into account – albeit with a cost to farmers' production and hence income. This result, although intuitive, suffers from the problem that, in practice, farmers that have access to groundwater would use that instead of conforming with deficit irrigation practices – hence tapping into non-renewable groundwater reserves.

	In order to derive suitable indicative targets for reducing the vulnerability of water resources in the Ali-Efenti, the robustness of the proposed interventions has been assessed against 3 future climate and socio-economic scenarios. The response measures seem to be suitable as in all scenarios a reduction of the unmet demand is observed. **On this basis, the proposed indicative targets are to increase the irrigation efficiency in the two main irrigation districts by 7-9% (thus reaching 82% and 86% respectively), as well as increase the urban water savings by 6%.** These interventions have a total cost in the range of 6.5 to 16 million euros AEC (at current prices). The investigated solutions will in fact render additional reduction of the unmet demand under a Markets-First socio-economic scenario which incorporates changing the crops to more profitable and less water demanding ones (i.e. 15% of cotton cultivation replaced by aloe vera; 5% of maize cultivation replaced by broccoli; 10% of maize cultivation replaced by kiwi). These crop changes will also lead to an increase in the farmers' income in the range of 25-30 million euros. Thus, the key to increase farmers' income and simultaneously reduce the unmet demand is the reform of cultivated land. Even without applying any of the above selected solutions, and **only by reforming the cultivated land a reduction of unmet demand of 67% can be achieved**.
Problems encountered related to the development of the Water Balances:	To calculate detailed water balance a distributed water resources management model is commonly required, at the appropriate temporal scale in order to reflect the variability of the water resources. In the case of the Ali-Efenti RB a model has been set up using the WEAP software, at monthly time steps for the period 1980-2010. In order to set up the node-based disaggregated WEAP model, a detailed analysis of the study area has been implemented to post-process all the data collected and create the necessary input data for the model. The model comprises of 23 sub-catchments, 8 groundwater bodies, 6 springs, 46 runoff/infiltration links (carrying runoff and infiltration from catchments to rivers and groundwater bodies), 57 demand sites, 6 WWTPs, 139 transmission links (transmitting water from a surface or groundwater withdrawal node to a user), 70 return flow links (directing the water that is not consumed in a demand side to a WWTP, surface or groundwater body). Setting up such a detailed model, able to represent all the salient features of the water cycle/balance can be a quite complex task, especially if the necessary data are not readily available. In the case of Ali-Efenti, the hydrological and socio-economic data were available at different spatial and temporal scales, thus aggregation techniques and proxies were necessary. Additionally, the model would have benefited if additional calibration points were available.

Case study #2: Tiber River Basin, Italy (ABOT project, DG ENV)

Study Area: ***Upper-Middle Tiber River Basin, Italy***	The Upper-Middle Tiber River basin (central Italy) has an area of about 5,300 km^2 with a main channel length of 141 km. The water resources in the basin consist of the main River and its tributaries, the Trasimeno lake, the groundwater, two large reservoirs and 5 smaller ones. The demand sites are represented by 16 irrigation schemes and 24 urban nodes. The study area is characterized by a complex topography with an elevation ranging from 147 to 1,538 m asl and a mean value equal to 478 m asl. The climate is typical Mediterranean with a mean annual rainfall of about 950 mm, and higher monthly rainfall values generally occurring during the autumn-winter period. 
Which are the main challenges with regard to water management in the study area?	The basin has extended irrigation and urban areas, while losses along the pipes are high (≅40%). For that, imbalance between demand and availability (water stress) is frequent, especially for the urban sites. Moreover, the decrease of precipitation observed in recent years resulted in a decrease of the average flows in the Tiber River and its tributaries. Specifically a possible declining trend of both precipitation and river flows has been observed and in 2000-2003 and 2007 severe water crises occurred within the basin. The need to meet domestic and irrigation demands has caused the overexploitation of ground water supply. As a consequence, many temporary wells were installed illegally and their number and locations, as well as the volumes of water abstracted, were mostly unknown, thus not allowing an assessment of the the contribution of the groundwater in drought mitigation.
How did the development of Water Balances support local water management and help alleviate the problem?	Most of the users of water resources within the Tiber River basin are urban municipalities and agriculture districts. To decrease the unmet demand, mainly observed for the urban sites, the implemented water balance allowed the development of a cost-effective optimum water allocation schema among the users. Based on that, different possible measures and interventions were suggested to the stakeholders in charge of the water resources management for the maximization of the unmet water demand reduction with the minimum possible investment. Their robustness was evaluated for three different future climate and socio-economic scenarios which were examined and compared with the baseline.
Key findings:	Detailed water balances were developed for the Tiber River basin for 2008-2011.

Based on observed data, these four years are considered to be representative. In particular, 2008 data are used for the water balance modelling calibration, and 2009-2011 data for validation purposes.

The target of the calibration was to adjust the model so that the simulated flow resembles the observed flow data as closely as possible. The procedure required adjustment of some parameters reflecting the real hydrological, climatic, water demand and consumption or anthropogenic conditions in the study area. All water balance features were calculated at a monthly time step and were compared with the dry year 2011, the average year 2009 and the wet year 2010.

The higher consumptions within the Tiber River basin are for domestic and agriculture use with a total water demand equal to 565.07 Mm^3 and 212.69 Mm^3, respectively (for the simulation period 2008-2011). In particular, **the 99.2% of the unmet demand derives from the urban domain and is equal to 28.48 Mm^3 for the entire simulation period**.

To reduce the unmet water demand, water saving measures were assessed within the urban and agricultural sectors through the development of cost-benefit curves.

Specifically, within the **urban sectors** two measures of monitoring and leakage repairs and replacement of old pipes were selected along with four water saving measures:
1. low flow taps;
2. dual flush toilets;
3. efficient washing-machines;
4. efficient dishwashers.

Within the **agricultural sector**, the selected analysed measures were:
1. monitoring and leakage repairs, pressure control;
2. replacement of irrigation plants (switch from sprinkler to drip irrigation).

For the **urban sector**, within the four water saving measures, e**fficient washing-machines and efficient dishwashers were found to be less convenient from the economic point of view** and, as a consequence, were discarded for arranging the cost-benefit curve. If **low flow taps and dual flush toilets are adopted as measures for water saving and assuming a population of 50% apply them, the water saving is, on average, 5% for both measures with a cost of 3M€ and 43M€,** respectively.

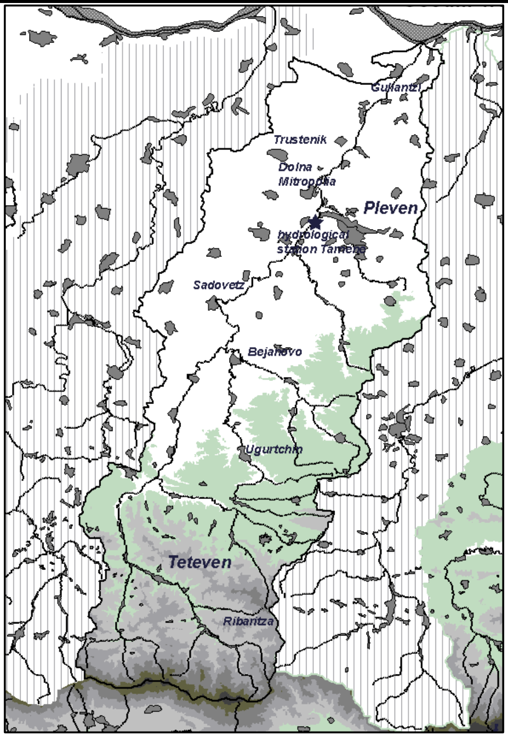
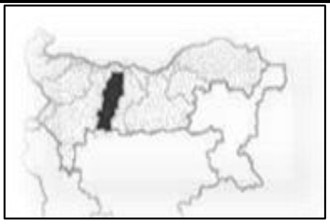
As regards the loss rate control parameter identified in the two measures of monitoring and leakage repairs and replacement of old pipes, it was found that for the first measure to further reduce the level of losses, i.e. to get a loss rate lower than 34.9%, which corresponds to a cost of about 8 M€, the cost increases considerably. Similarly for the second measure, i.e., the replacement of old pipes, **the maximum benefit was found by a network replacement of 10% with a cost of 49 M€.** For higher percentages, the costs are very high and replacement of pipes is no longer economically convenient.

For the **agricultural sector** the analysis showed that by applying measure 1 (monitoring and leakage repairs, pressure control) **the irrigation efficiency can be improved by increasing the irrigation fraction from 52.5% up to 59.3%, with a relative cost of about 1.5M€**. To get higher values of irrigation efficiency, the cost increases considerably. Similar conclusions can be drawn for measure 2. In this case**, the maximum benefit can be obtained by carrying out the replacement of 90% of the irrigation system network, with a cost of 4.1 M€.**

The robustness and the sensitivity of the water balance modelling for the Tiber

	River basin was evaluated for three different future scenarios which were examined and compared with the baseline scenario (referring to the simulation period: years 2008-2011). The scenarios include Climate Change (CC scenario), Socio-Economic change (SE scenario) and a combination of both (CC-SE scenario). All the investigated scenarios indicate that **in future years the unmet demand will increase due to modified climatic conditions and population growth**. The increase of the irrigated area, on the contrary, does not affect the agricultural unmet demand which is negligible for each scenario. The shape of the 'Pareto front' of optimisation calculated for the CC-SE scenario suggests that **the unmet demand, which is expected to increase in the future, could be reduced by about 14% with a relative low cost by applying the selected water saving measures**. To reduce the unmet demand further, the cost increases significantly.
Problems encountered related to the development of the Water Balances:	To calculate detailed water balance in the Tiber River basin a distributed water resources management model was required, at the appropriate temporal scale in order to reflect the variability of the water resources. The WEAP software was used at a monthly time step for the period 2008-2011. A scheme of the water consumers and their interconnection links was identified as a first step for the model development and a database with the information necessary for feeding WEAP platform was created. For the data retrieval, however, some problems were encountered, mainly due to the large number of water managers which are different from the ones who manage the supply. The gathered data (irrigation and domestic) had different formats (daily, monthly, or seasonal) according to the different water supply managers. Therefore, the main problem concerned the heterogeneity of the collected data, as well as the temporal resolution. Due to this heterogeneity, the simulation period (i.e. the period when all the data were available) was only four years.

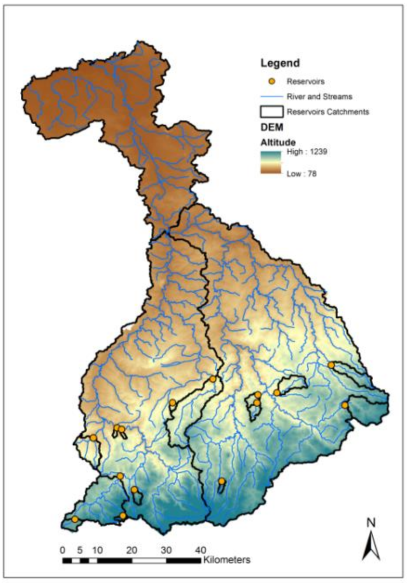
Case study #3: Vit River Basin, Bulgaria (ABOT project, DG ENV)

Study Area: ***Vit River Basin, Bulgaria***	  The Vit River basin is situated in central northern Bulgaria with watershed area covering 3,220 km2. The river starts from the Stara Planina mountain at an altitude of 2,030 m, flows through the central part of the Danube Valley and discharges into the Danube river. Within the catchment there are two administrative districts - Pleven and Lovech, including in total 11 Municipalities, 7 towns and 74 villages. The biggest town is Pleven - a district centre with a population of over 100,000; the population of other towns vary between 2,800 and 10,600; the population of the villages varies between 50 and 3,800 residents. The water supply system is operated by two companies and it is characterized by quite a high share of non-revenue water (50%), mostly due to significant physical leakages resulting from the outdated pipe network. There is a number of industrial water consumers concentrated mainly in two towns: Pleven and Dolna Mitropolia. The total water use within the Vit River Basin in 2009 was 134 million m3. The electricity and steam producing industries have the biggest share (63%), followed by agriculture (16%) and urban (10%). It should be noted however that the hydro power plants that belong to the former group are situated in a cascade thus the same amount of water is recorded several times.
Which are the main challenges with regard to water management in the study area?	The relationship between the different water sources and water users within Vit Basin is very complex. There are many existing technical connections (channels, pipes, boreholes) between the major water sources and the different water users. Due to the seasonal fluctuations of the river flow, water abstractions directly from the river are mainly used for feeding the reservoirs and for hydropower generation. The reservoirs are built in a cascade as the upper reservoirs feed the lower ones and thus the same amount of water is used several times. Industrial water supply and water for irrigation are mostly provided by the reservoirs. Groundwater is used for industrial and potable water needs. Since groundwater abstraction requires pumping, therefore costs for energy mean it is a costly option for water yield. That

	is why water imported from the neighbouring basin, transferred by gravity, is also used for drinking water, accounting for about 80% during recent years.
How did the development of Water Balances support local water management and help alleviate the problem?	The area has a complicated management scheme. Establishing detailed water balances provided the necessary input for the development of a cost-effective **water management**, considering the spatial and temporal availability of water resources. The balances guided the development of a series of demand reduction **measures and interventions** which are based on a holistic assessment and can mitigate water stress in the short and long-term. Finally, projected water balances as calculated for 3 future scenarios (climatic alteration, specific socio-economical alteration and combination of them) were used to test the robustness of the selected measures, supporting **climate change adaptation**.
Key findings:	For the purpose of developing the water balance in the Vit basin hydrological and socio-economic datasets for 2000-2009 were used. The WEAP model was calibrated for 2009, which represents an average year for water resources availability. The difference between the calibrated and simulated water volumes for three of the reservoirs vary between 0.45 and 6%. The observed and simulated monthly flows at the hydrometric station of Tarnene have an average annual difference of less than 3%. This goodness of fit metrics gives confidence that all the natural hydrological and anthropogenic factors were adequately modelled. The simulated monthly values by the WEAP model enable the detailed assessment of the water resources in the studied watershed. The water balance modelling allowed the determination of some parameters that are required in the SEEAW tables and which cannot be products of monitoring and reporting alone, such as: the potential evapotranspiration for the non-irrigated land, the effective precipitation and the percentage distribution between the surface and groundwater bodies of the non-effective precipitation run-off, the losses along the water distribution networks and the resulting flows to the groundwater and for evaporation; the water received from other economic units, the returns to groundwater and surface water, the amount of soil water. The optimization results for the Vit pilot river basin show that 14% of the abstracted water could be saved with low investment cost. The most effective measure is to reduce leakages in the municipal distribution network by applying active leakage control and installation of pressure reducing valves. The results indicate that if the water losses in the town of Pleven decrease by 25.25% then the unmet demand equals zero. The climatic scenario showed a threat of a decreased flow in the river system, which would lead to some deficit in water demand during the hot months. The combined climatic scenario and the most unfavourable socio-economic scenario leads to superposition of the two types of different negative impacts - climatic and increased water consumption as a result of significant growth in irrigation. This combination is the most severe among all studied scenarios with a big decrease of river flow, a big decrease of water volume in the reservoirs and a very significant unmet demand. A set of mitigating measures were investigated. Two measures with the highest impact were "increasing of the irrigation efficiency" and "rehabilitation of the irrigation system". The strong influence of water losses in the irrigation system is due to the fact that the irrigation network is also used for the transportation of water for hydropower production, which is the biggest user of water in the catchment.
Problems encountered related to the development of the Water Balances:	By studying the SEEAW tables, it was found that some elements/parameters of the tables are very difficult to fill based on observed and measured data (e.g. soil water, flows between the water resources from one water body to another). That is why the WEAP model was used to feed the SEEAW tables with these very challenging parameters. WEAP software was found to be a reliable tool that can easily support

	the production of water accounts under the SEEAW methodology. For complex systems like the presented case study, characterized with multiple reservoirs connected in cascade, the filling of SEEAW water supply and use tables is quite challenging, since the reservoirs are not identified as “economic” units most probably because they store water and this is not considered as a “production unit”. Within the SEEAW platform they belong to the general category “surface water”. The construction and operation of such reservoirs however demands huge investments and significant expenses for operation and maintenance. Therefore their consideration as an “economic unit” should not be neglected.

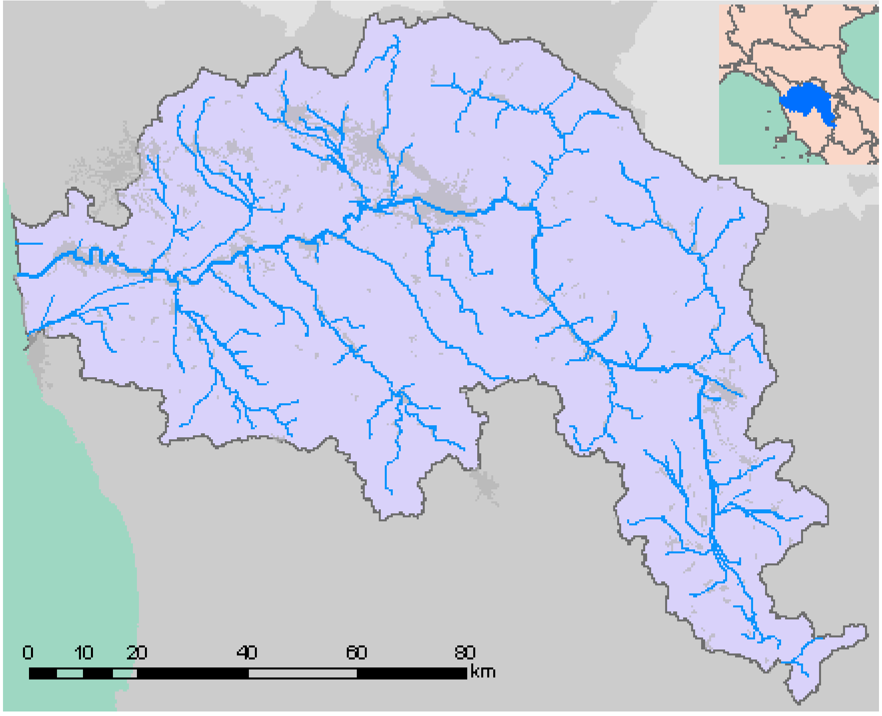
Case study #4: Mulde River Basin, Germany (ABOT project, DG ENV)

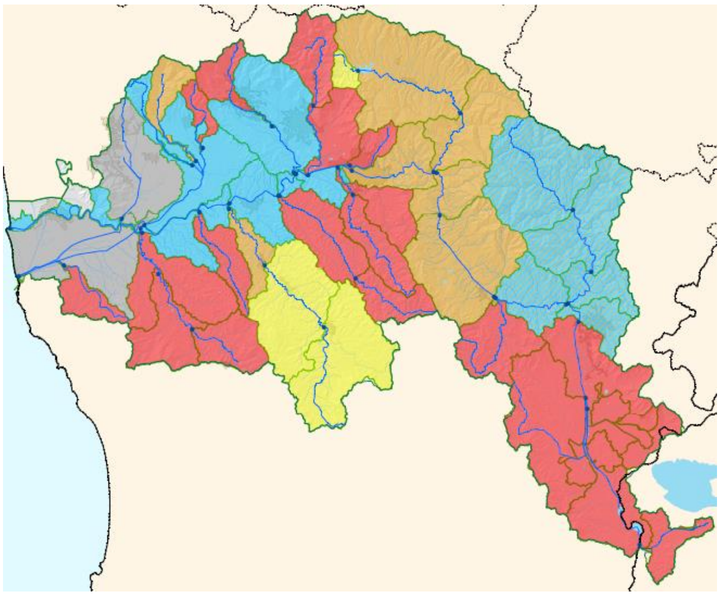
Study Area: ***Mulde River Basin*** ***Germany / Saxony***	The **Mulde River Basin** is located in Saxony in Central Germany and is one of the major tributaries of the Elbe. It covers an area of ca. 7,400km² and consists of 3 larger sub-basins. Besides several small and medium size cities (20k-80k inhabitants) the catchment is mainly rural and home to more than 1 Mio. people. The land use is dominated by farmland (60%) with high proportions of drainage-tiled areas, followed by forests (17%), urban areas (10%) and pasture (10%). The average annual precipitation is 770 mm while there is a strong variation between the ore mountains (1000-1200mm) and the lower parts with 550-600mm. 
Which are the main challenges with regard to water management in the study area?	There is no actual severe water availability issue in the Mulde catchment as the water supply system is highly managed, mainly by 15 reservoirs which are partly interconnected due to a remote water supply system. Nevertheless, climate change predictions suggest future heat waves and related drought risks which may force the dominantly rain fed agriculture towards irrigation systems. Since the Mulde catchment provides water supply to around 1.5 mio. people, an increasing water demand in agriculture may lead to water-related competitions and conflicts in the long term. Therefore farmers and policy makers should develop strategies to face future water shortage together with a potential supply priority plan.
How did the development of Water Balances support local water management and help alleviate the problem?	We showed that the water management in the Mulde catchment is well managed and prepared to face future challenges and thus might be a good example for other regions. Nevertheless the supply system is based on a difficult structure of administrative units and responsibilities. Together with numerous reservoirs this complicated the modelling with regards to model input data, management and policies. The development of water balances supported the understanding of the water supply structure and thus allowed us to establish a model that is capable i) to simulate the multi-scale impact of measures, ii) to highlight the spatial distribution of future risks (impact of climate change projections) and iii) to suggest corresponding adaptations. Furthermore, we were able to incorporate water balances in a comprehensive model structure as a powerful tool to link water demand and supply to socio-economic factors and investigate the systems cost efficiency.

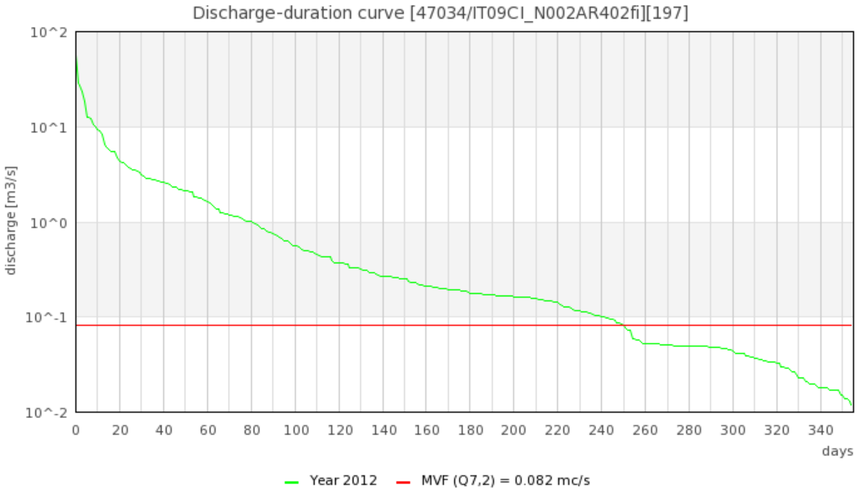
Key findings:	We developed the model (WEAP – Water Evaluation And Planning) representing the water balances for the Mulde catchment from 2000-2008 at monthly time steps. The model was calibrated from 2000-2006, including 3 representative years, one very dry, one very wet and one year with average conditions. The following years were used for validation purpose. Calibration and validation showed with .78 and .66 acceptable coefficients of determination. For a sound representation of the hydrological processes we applied 18 sub-catchments representing the main reservoir and river catchments. 27 demand sites, 13 supply catchments and three groundwater "buckets" were implemented. The water balance in the catchment is very positive. We could not find any unmet demand - not even for the "negative" change (socio-economic) –scenario and extreme climate change projections. The percentage of used water to available water did not exceed 5% at any stage. This is also highly influenced by the well operated remote water supply system (reservoirs) which accounts for <40-80% in the regions (65% on average) together with a sufficient local water supply by ground and river water. We found that water levels of some reservoirs might be vulnerable considering the change scenarios but since the reservoirs are mainly interconnected, the supply side may easily be adapted in such cases. The strongest impact was projected for the climate change scenario (WETTREG data based on IPCC A1B) on river stream flow showing a stronger periodicity and related variations in discharge (up to 12% +/- change in some month on average). The region faced major emigration in the past 2 decades (which resulted in severe difficulties in handling waste water due to deficient water use). It is forecasted that the population will continuously decrease by 8.7% until 2015. Based on that we developed population change scenarios considering the effect of population dynamics by plus and minus 8.7%. The effect on the water balance was similar as for the climate change impact - no risk on the supply side could be identified. We can show that the Mulde River Basin has a very advanced water resource management system which is able to completely meet both actual and potential future regional water demands. Therefore it turned out to be impractical to apply optimization procedures for selecting additional measures to decrease unmet demand – since such a demand was not identified in the simulations. Still, as the private sector was identified as the main water user followed by the public sector and finally the larger business, we investigated measures for the urban water management measures as those may provide additional benefits. Hence, we simulated the effect of rainwater harvesting considering the positive effect on urban flooding and low flow problems in wastewater systems. This could also reduce supply costs from the remote system by increasing the regional water supply share. We could show that such measures could lead to 55 and 10 litre water saving per Euro invested. This accounts for up to 30% of the total water demand in private households. The main issues for such systems in Germany are legal difficulties.
Problems encountered related to the development of the Water Balances:	The main issues which we faced were on data pre-processing. All input data was available on very different spatial and temporal scales and assigned to various administrative boundaries. Water demand and use data are often collected by different municipalities while environmental data are bound to natural borders and available on Federal or International levels. To synchronize that and setup a model able to represent such a complex structure is time consuming and demanding. Other data are difficult to get due to the data protection law. Reservoir management plans are such an example, since they are used for supply purpose as well as for flood regulation.

	There are also small scale effects on water supply/demand changes which might not be covered by the model. A good example is water use reduction in urban areas. If the urban water use falls below a certain minimum (often along with strong emigration dynamics in addition) the disease risk from waste water systems increases due to low flow conditions (especially in summer).

Case study #5: Arno River Basin, Italy (PAWA project, DG ENV)

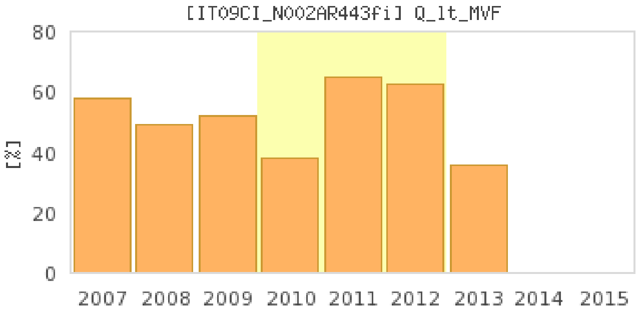
Study Area: ***Arno river basin, Italy***	The **Arno River Basin** is located in the Central-West part of the Italian peninsula, in the Northern Apennines River Basin District (ITC). The Arno river flows through two main cities: Florence and Pisa; many other urban centres are located within the basin. The total permanent population is 2,200,000. The Arno basin has a total area of approximately 8,000 sq. km and is bounded by the Apennine Range that forms an arc which extends from North to East and has an average elevation of 1,000 m above sea level, its highest peaks rising around 2,000 m above sea level. Water abstraction affects both surface water (approx. 360 Ml m^3/Year) and groundwater (approx. 260 Ml m^3/Year); public water supply is the main use (40-50%), followed by agricultural and industrial uses. 
Which are the main challenges with regard to water management in the study area?	**Water stress conditions** are often recorded in a wide range of sub-basins and aquifers recurrently prone to critical conditions due to the high variability of the precipitation regime (i.e., discharge below defined thresholds – Minimum Vital Flow; steady decreasing trend for aquifers). **Concurrent uses** (e.g. agricultural versus public water supply) are worsening the water stress conditions in sensitive areas particularly during the summer months. More than 60% of SWBs and 50% of GWBs are **below GES** (2013 update). According to the 3rd RBPM evaluation report, there is an urgent need for clear and specific **use of alternative objectives** and correct application of properly justified exemptions under art. 4.7. In general, a quantitative **Drought Management Plan** is needed (and is foreseen as one of the measures included in the updated PoM – 2nd cycle of RBMP). A quantitative evaluation of **climate change impacts**, according to the updated IPCC scenarios, is necessary in order to include in the above mentioned plan a specific appraisal of the sustainability and effectiveness of measures in the RBMP, 2nd cycle.

How did the development of Water Balances support local water management and help alleviate the problem?	Critical conditions are evaluated, in relation to a defined threshold for the number of days with discharge below MVF, by defining MVF and simulating high resolution discharge series in every reach of the river network; this is possible for each sub-basin/surface water body. The competent authority applies a different cost policy to abstraction licenses on the basis of the above described classification of the water stress prone areas. During recent drought events (e.g.in 2012), the availability of a calibrated model, both for SW and for GW, delivered an operative tool to support decision making for the different water management strategies (e.g. reservoirs' release programmes). Water balance derived parameters are currently used in a dedicated Executive Information System, to enhance the justification of exemptions and the correct application of WFD art 4.7.
Key findings:	Thanks to the spatial scale of the analysis, it was possible to define different conditions for every sub-basin/water body. The critical areas (Fig. 5) are concentrated in the Southern portion of the basin, which comprises the following left bank tributaries: Chiana, Ambra, Greve, Pesa, Egola, Era. This level is also critical for the upper Ombrone basin and for the entire Bisenzio basin.  *The spatial distribution of critical areas according to the defined threshold. In red, the drainage area of the most critical water bodies.* The results on the Arno basin as a whole and on a list of sub-basins were used, in the River Basin Management Plan, as the basis for the quantitative evaluation: the good MOBIDIC-WRM capabilities to simulate the major seasonal runoff characteristics and to represent temporal and spatial variability, together with the choice of a very detailed (daily) temporal scale, this allows a fine classification of water deficit status and a flexible application of government strategies.



Example of a modelled Duration-Discharge Curve with the comparison with the threshold value, in order to highlight the length of the critical period i.e. with discharges below MVF.

Water balance derived parameters (average discharge; average discharge during the summer months, number of days below MVF; distance from a reference – average – discharge duration curve) were fed into an Executive web-based Information System that gathers and connects all information and data extracted from the RBMP for each SWB: drivers, pressures and impact on the WB; monitored ecological and chemical status, operative actions related to the approved PoM. Thus single year monitoring results and water balance parameters are compared to verify the possible application of art. 4.7.



Example of the annual evaluation of the parameter "yearly percentage of days with discharge below MVF" for IT09CI_N002AR443fi SWB of the Northern Apennines District (T. Bure, natural river, 54 sq.km). The highlighted 3-year period is related to the most recent completed monitoring period (2010-2012)

The model outputs have been used in the Halt desertification project ("Pilot Arno Water Account", **PAWA** project: Arno River Basin Authority, ISPRA, SEMIDE/EMWIS) which aims at implementing the SEEA-W tables for three specific sub-basins. A preliminary discussion was carried out to include into the Arno Water Accounts scenario-generation options based on measures and climate change parameters.

Problems encountered related to the

Data collection. The choice of very detailed spatial and temporal scales *implies* effort in data gathering. Hydrological data are available for long time series (more than 20 years) at a very precise time scale and with a high spatial granularity. Water abstraction and return data are instead affected by a higher degree of

development of the Water Balances:	uncertainty and imply higher data collection costs since they require a long validation process. In many cases, especially for agricultural and industrial uses, a modelled estimation at a monthly scale is the only reliable available data. During the implementation of the PAWA project data, collected to build the water account tables, have been analysed and validated in order to identify gaps, alternatives and/or additional data sources. **Model calibration**. About 12 calibration gauges were used to perform an optimization of the model's parameters. Due to the limited time series with reliable discharge data, and to the uncertainty of flow measures for smaller basins during the dry (Summer) season. Therefore, the calibration of the model is still in progress. Consequently, data collection, validation, processing and evaluation of results require a continuous and accurate effort in order to achieve increasing confidence regarding the assessment of relevant water balance elements. **Support to EEA update on WA**. According to the recommendations expressed during the latest WG meeting, these processes will be carried out with the aim of supplying data to the EEA in the framework of their activity on WA at European level. Another relevant issue is the quantitative **evaluation of uncertainty**. The level of confidence of water abstraction and returns data is significantly lower than that of hydrological data: the impact of such a variable degree of reliability should be quantified and reported together with the estimated outputs.
Technical details	The Arno River Basin Authority has set up a modelling framework for the estimation of water balances using the distributed MOBIDIC package ("MOdello di BilancioIdrologicoDIstribuito e Continuo"). More specifically, the MOBIDIC-WRM (Water Resources Management) tool is a physically-based model that allows the estimation of the elements of the hydrological balance in: the sub-surface layer, the soil-vegetation system and surface water bodies. In the representation of physical processes, the main innovations with respect to existing models concern the coupling of the water balance in soil and vegetation with surface energy balance (to the benefit of evapotranspiration computation and use of remotely sensed maps of Land Surface Temperature for calibration and validation) and the detailed interaction between ground water and surface water bodies. Geographical input data, both in raster and vector, can be supplied to the model in most common GIS formats or as raw binary or ASCII data. Meteorological inputs and data on withdrawals, artificial releases and reservoir operations are fed into the model in DBF or text tables. A pre-processing step of the model (MOBIDIC-BUILDGIS) is devoted to consolidate the input of geographical and time-series data, and to establish the mutual spatial and topologic relationships between topography, river network, reservoirs and withdrawal /release points. The hydrological balance can, then, be run with MOBIDIC-WRM with the desired spatial and temporal resolution. The output of the simulation includes time series of modelled discharge of each branch of the hydrographic network and related statistics (e.g. flow duration curves) and maps of hydrological components (evapotranspiration, runoff, precipitation). The output of the hydrological balance can then be linked with information on environmental flow and water consumption, and the water balance can be computed for each branch of the hydrographic network.

During the application of the methodology to the Arno basin the hydrologic simulation has been performed on a daily time scale for the period 1993-2013 (21 years). The geomorphology of the basin and related hillslope processes have been modelled using a Digital Elevation Model with 10 m square cells. Information on land cover, geology and soil hydraulic properties has been retrieved from existing maps and remote sensing data. Both natural (where no withdrawals or artificial releases have been considered) and ‘anthropic’ scenarios have been simulated. The results include modelled discharge time series on nearly 20,000 river branches and more than 22,000 withdrawal sites, flow duration curves, and maps of hydrological components over the basin area (soil moisture, evapotranspiration, infiltration).

Meteorological input data were obtained from the regional hydro-meteorological monitoring network. Also, water level measurements for a set of stations with available stage-discharge relationships for at least few years in the study period were used for calibration and validation purposes.

The hydrologic simulation of the whole Arno basin at 200 m resolution represents the scientific basis on which multi-year strategies and water balance management actions are based. In this context, the hydrological model results support strategies and plans to control water status, in order to monitor the volume and level or rate of flow to an extent that is considered relevant to preserve ecological status and potential. This is the main goal of the Arno River Water Balance Plan, approved in April 2008.

The water balance plan was drafted dividing the river network into significant tracts and sub-basins. Out of these, 44 river sections were deemed to be representative and selected as underlying homogeneous basin portion in terms of hydrology and criticality.

Hence, the water balance was computed, for each river branch, in accordance with the requirements of the Decree of the Italian Ministry of Environment dated July 29, 2004, as natural discharge (Q) minus withdrawal (W) and Environmental Flow (EF):

$$WB = Q - EF - W$$

WB represents the “residual flow”, i.e. the flow actually available for further use, or, on the contrary the possible deficit.

The water balance was drafted, on the basis of the MOBIDIC-WRM results, as daily series focusing attention on the temporal intervals during which the most critical conditions can occur.

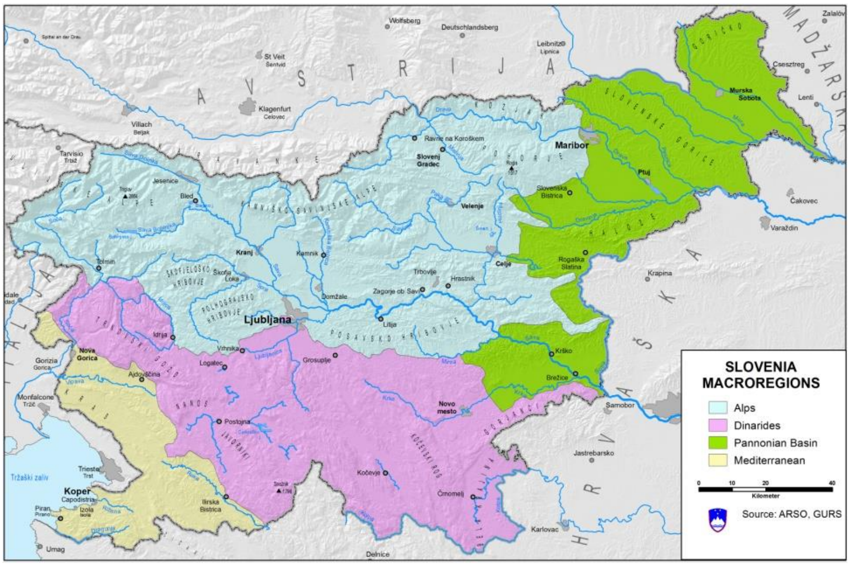
Due to the markedly torrential character of the water courses in the basin, that even concerns the reaches of major hierarchical rank, the investigated time interval coincides with the months: June, July, August, and September. The application of the above model produced discharge synthetic series for 1993-2006; the results are expressed, for each significant section, as a duration curve of the yearly period and similar duration curves for the dry season (June-September).

With the aim of establishing and quantifying the conditions of river reaches, in terms of maintenance of sustainable discharge values, the environmental flow was identified, with the use of hydrological criteria, as Q7,2, i.e. the minimum average flow over 7 days with a 2 years return time.

The component that represents water use (W) which includes all abstraction typologies is referred to the June-September time interval. Furthermore, it includes

	the concentrated returns from the waste water treatment plants. therefore the equation for average summer withdrawals is: $W = Q_{srf} + Q_{spr} + Q_{wll} - Q_{wst}$ where the first three terms on the right hand side are dissipative withdrawals from, respectively, surface water bodies, springs and dug wells, and the fourth term is wastewater returned to the river network. The resulting residual flow WB may be, in the significant river sections, either negative or positive values. The negative values show a condition of severe water deficit in the summer period, with flow lower than Minimum Flow Index for more than 60 days. The positive values represent the average flow available for further withdrawals. The Arno and its tributaries are characterized by a highly variable regime, closely linked to precipitation *patterns*. This shows that the most critical conditions are concentrated during the summer, when high temperatures increase evapo-transpiration losses. For these reasons and with the further consideration that river ecosystem stress is mostly due to prolonged persistence of lean values, the case study was focused on the results of simulations regarding the four summer months, during which all factors having an influence on water balance reach a critical phase correlation. To synthesize this into a single stress indicator, the analysis was finally focused on the number of days when the average daily flow rates falls below the site-specific EF value. This number of days is derived from simulated (modelled) flow duration curves. Critical values were aggregated into 4 classes , on which the earlier criticality map is also based.
References	Yang, J., Castelli, F., and Chen, Y.: Multiobjective sensitivity analysis and optimization of distributed hydrologic model MOBIDIC, Hydrol. Earth Syst. Sci., 18, 4101-4112, doi:10.5194/hess-18-4101-2014, 2014 F. Castelli, G. Menduni, B. Mazzanti. A distributed package for sustainable water management: A case study in the Arno basin. In: H. J. Liebscher, R. Clarke, J. Rodda, G. Schultz, A. Schumann, L. Ubertini, G. Young. The Role of Hydrology in Water Resources Management, pp. 52-61, Wallingford: IAHS, ISBN:9781901502947, 2009 Campo, L., Caparrini, F., and Castelli, F.: Use of multi-platform, multi-temporal remote-sensing data for calibration of a distributed hydrological model: an application in the Arno basin, Italy, Hydrol. Process., 20, 2693–2712, 2006

Case study #6: Slovenia

Study Area: ***Slovenian macro-regions***	The case study area is the whole territory of Slovenia. This poses quite a challenge in water balance modelling, since Slovenia is located at the intersection of four major European geographical regions: the Alps, Dinaric Alps, the Pannonian Basin and the Mediterranean. The four main macro-regions have very heterogeneous climatology, geographical, geological and ecological characteristics that create great spatial and temporal variability. 
Which are the main challenges with regards to water management in the study area?	Most of the water used for water supply systems in Slovenia is from groundwater resources. The WFD requires groundwater quantitative assessment which is done in Slovenia with the use of a regional water balance model as a key tool for groundwater recharge evaluation. The water management challenges depend on the water balance model as it is the basis for sustainable water management. The main challenges in the study area arise from: - big geographical variability in geology, relief, climate, vegetation, land use etc., - big intra- and inter-annual variability of water balance elements like seasonal variability of water balance elements, highlighted by increased incidence of droughts and floods in recent years, - large areas with complex karst hydrology and hydrogeology covering more than 40% of the territory.
How did the development of Water Balances support local water management and help alleviate the problem?	The first RBMP used long term water balance as a basis and in the process it has been found that the yearly or even monthly water balance will be needed in the next RBMP cycle in order to manage water resources sustainably. In the WFD there is also a request for groundwater quantitative status assessment and over the years annual water balance was made for the separation of total runoff into various components. It allowed us to quantify and evaluate the groundwater recharge and assess the groundwater quantitative status. The regional water balance model GROWA, developed at FZ Jülich, Germany, was adapted in bi-national cooperation with Slovenia. The GROWA model

outputs provided the necessary input to analyse water abstraction to water resource ratio.

The GROWA model was first used for long term water balance and later on for annual water balance calculations on a regional scale and by river basins.

The result of the model is spatial distribution of water balance elements over the whole territory of Slovenia. Spatial distribution allowed us to identify local areas with possible problems in water quantity. The water authority now has the data on water quantities that can be used for water management.

Key findings:

Spatial distributed calculation of water balance elements is a useful tool both for regional and local water management The water balance model allows water managers to improve water planning.

The model itself proved to be robust and flexible enough to encompass big spatial variability of water balance across the territory. It is of special interest that it proved reliable in karst areas with a scarce surface watercourse network and complex hydrogeology.

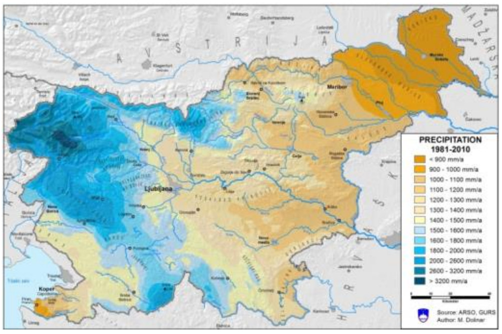
Water balance enables the identification of local areas with possible problems in water quantity.

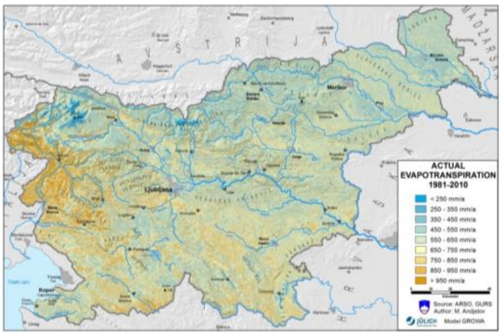
Water balance is also indispensable in the process of nutrient flow modelling which is now being analysed in Slovenia.

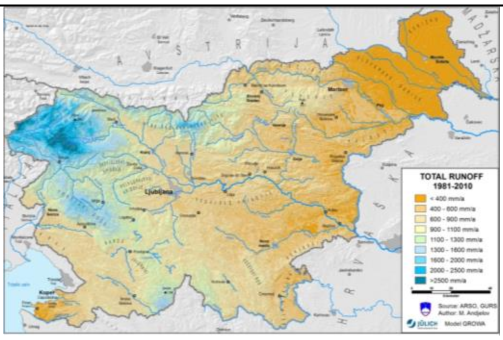
Water balance results are used on a regular basis for national reporting on the WFD implementation to the European Commission and for supplying data to the EEA.

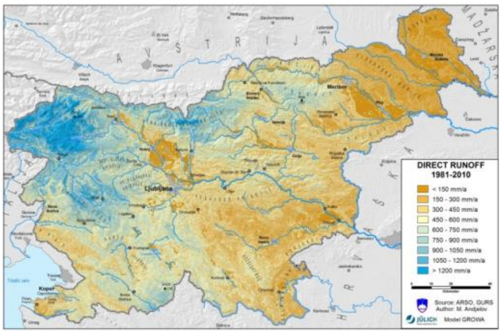
The model enables both calculation of numerical values of water balance components by river basins or any hydrological closed area, and spatial representation of the results in maps. So, it gives both useful graphical overview of the water balance and numerical data for practical solutions to water management problems.

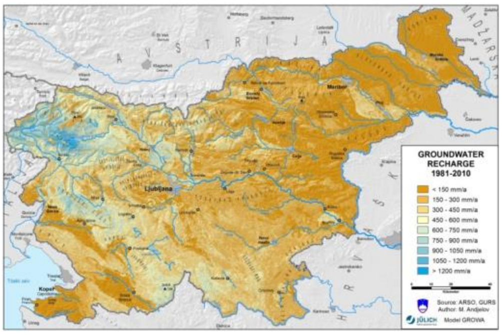
The maps showing spatial distribution of water balance components means for a long term period 1981 to 2010; precipitation, actual evapotranspiration, total runoff, direct runoff and groundwater runoff (groundwater recharge):





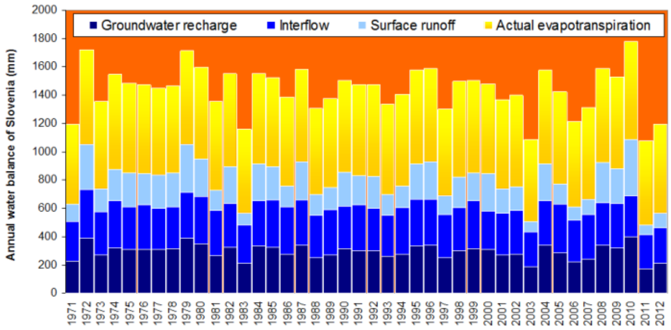
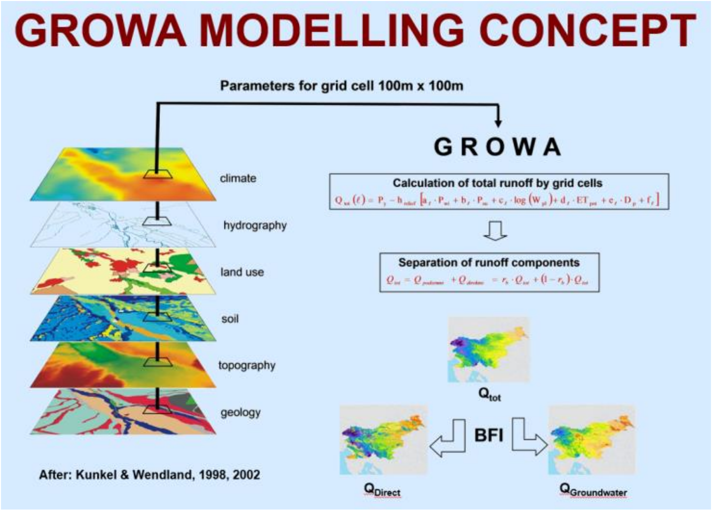






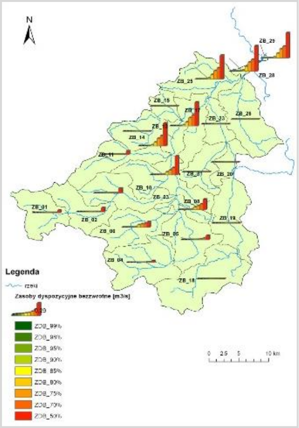
MEANS OF 1981 – 2010			
	mm/a	%	m3/s
Precipitation: P	1 431	100	
Evapotranspiration: ETR	641	45	
Total runoff: QT = P - ETR = QD + QGW	790	55	508
Direct runoff: QD	501	35	322
Groundwater recharge: QGW	289	20	186

Distribution of annual amounts of precipitation to water balance components actual evapotranspiration, surface runoff, interflow and groundwater recharge for 1971 to 2012, showing inter annual variability:

	 In recent years inter annual variability has been increasing.
Problems encountered related to the development of the Water Balances	It should be noted that the calculations of water balance for the hydrological year in the model used can vary from the calendar year. Also, the present RBMP suggests that the temporal scale of annual water balance model must be downscaled due to big intra-annual variations of water balance elements in Slovenia. The resolution should be downscaled to monthly or even daily level.
Technical details	GROWA – GROßräumiges WAsserhaushaltmodell (Regional Water Balance Model) developed at Forschungszentrum Jülich, is a grid based empirical regional model consisting of several modules, enabling separation of input precipitation into the main water balance components: actual evapotranspiration, total discharge, direct runoff and groundwater recharge. It calculates net water balance originating only from precipitation at the modelled area, for a hydrological year from November 1st to October 31st. Due to the modular architecture the model is flexible both in the calibration process, as well as for upgrading to modelling of nutrient transport and refining of temporal scale below a year. It has been adapted from the German setting for use in the complex setting of Slovenia. It has been calibrated with hydrological data measured in the 1971 to 2000 reference period.  The main features of the model are: • Scale of application: 100 – 500,000 km2 • Spatial resolution: Variable - dependent on input grid • Temporal resolution: Year (with a possibility to downscale to a finer temporal scale) • Units: mm of water column; runoff also m3/s • Input data type: Digital data - maps

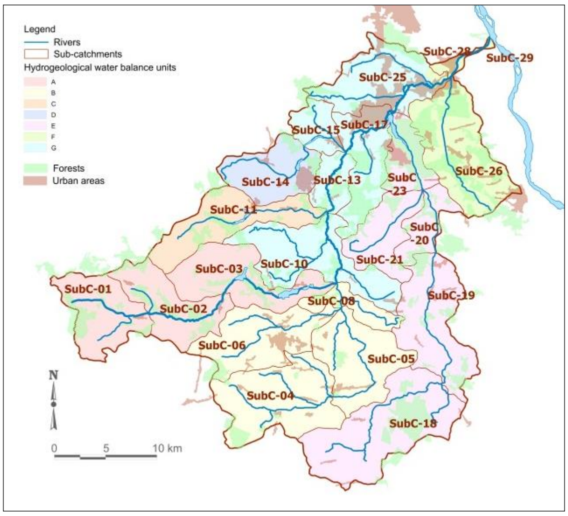
	• Potential evapotranspiration: Penmann – Monteith equation • Actual evapotranspiration: Renger - Wessolek equation • Runoff separation: Base flow indices – BFI • Results: Total runoff, direct runoff (overland flow + interflow + drainage flow), groundwater recharge • Validation: Runoff data from gauging stations (MQ, MoMNQ) • Implementation: C++, GIS – linkages to GRASS / ArcView
References	Andjelov, M., Wendland, F., Mikulič, Z., Tetzlaff, B., Uhan, J., and Dolinar, M., (2014). Regional Water Balance Modelling by GROWA in Slovenia. Proceedings of Danube Conference 2014, XXXVI Conference of the Danube Countries on Hydrological Forecasting and Hydrological Bases of Water Management, Deggendorf. Andjelov, M., Mikulič, Z., Tetzlaff, B., Uhan, J. and Wendland, F. (2015). Groundwater recharge in Slovenia. (In preparation), Schr. d. FZJ, Reihe Umwelt, Jülich. Frantar, P. (ed.) (2008): Vodna bilanca Slovenije 1971-2000 = Water Balance of Slovenia 1971-2000.: Ministrstvo za okolje in prostor, Agencija Republike Slovenije za okolje, 119 p., Ljubljana. Kunkel, R. & Wendland, F. (2002) : The GROWA98 model for water balance analysis in large river basins - the river Elbe case study.- Journal of Hydrology 259: 152-162.

Case study #7: The Jeziorka River Catchment, Poland

Study Area: ***Jeziorka River Catchment, Poland***	The **Jeziorka River** is a tributary of the Vistula River, located in the central part of its RBD, in Poland. The Jeziorka River Catchment is a rather small lowland catchment (989 km^2) with a long-term annual average precipitation of 530 mm. The area, which partially covers the suburbs of Warsaw, is quite densely populated (167 pers./km^2) with 4 major towns of 4 to 42 ths. inhabitants. The catchment is dominated by agricultural land use, about 76%, of which more than half is arable. Forests cover 17% of the catchment, and urban areas – located mainly in the downstream part of the catchment – 7%.  The following case is the description of the typical methodology applied in Poland.
Which are the main challenges with regard to water management in the study area?	Intensive use of groundwater resources for municipal supply and sprinkler irrigations of fruit and vegetables, together with surface water abstractions for fish ponds, have caused problems with meeting the environmental flow requirements and cause periodic water shortages. For these reasons, and also because of water quality issues, the Jeziorka River Catchment was indicated in the Vistula River Basin Management Plan as being at risk of not achieving the environmental objectives and thus requiring development of a water management policy document (named Conditions for the Water Use in the Catchment).
How did the development of Water Balances support local water management and help alleviate the problem?	The development of detailed water balances allowed identification of the causes of water stress, its spatial extent and severity. On the basis of balance results a water management policy document has been developed in which: i) priorities of water uses in the catchment have been set, ii) environmental flow requirements defined, and iii) restrictions for introducing new water users and issuing water permits have been stated. Moreover, water saving incentives and necessary measures for improving the accuracy of the demands and water use assessment have been formulated.
Key findings:	Water balances have been developed for the multi-annual period of 1988-2009. Firstly, groundwater balance has been calculated as a comparison of available resources (renewable groundwater resources minus part of a base flow which is needed for maintaining environmental flows during low flow conditions) and groundwater abstractions in hydrogeological - water-balance units. Two scenarios for groundwater balance have been analysed: i) for abstractions declared in the

system of water charges in 2010 (157 users in the catchment, 28.9 ths. m^3/d) and ii) for abstractions allowed by water permits (79.9 ths. m^3/d, 332 users, including 210 agricultural users which did not then incur water charges). Within these balances correcting factors for base flow discharges to the rivers representing the impact of groundwater use in analysed sub-catchments have been computed. The balance results are positive for the catchment as a whole, but local deficits occur in the downstream units, in which the majority of abstractions is situated, highly pronounced in the ‘water permit scenario’ (about 14.0 ths. m^3/d). Additional, scenarios are also analysed based on the expected economic development/growth and forecasted climate changes.

Surface water balance has been modelled as a simulation of water allocation in the catchment with a 10-day time step. In the area 29 sub-catchments (see map below) have been defined and 77 surface water users have been identified, including environmental flow requirements in each of analysed balance cross-sections, 1 industrial plant, 9 fish farms and 38 return flows from municipal groundwater abstractions.



Water resources have been described as time series of (naturalised) mean 10-days flows derived from water gauging stations. Water demands have been reflected by time series of flows or have been modelled during simulation – for the users as fish ponds, whose demands depend on the amount of water previously supplied and meteorological conditions. Various hierarchies of water users have been analysed during simulation thus allowing for analysis of different management options. However, in the applied hierarchy the environmental flow requirements have always had the highest priority.

Balance results for the ‘water permit scenario’ show that the time reliability (percentage of the time steps in which the demand – or flow requirement – was fully satisfied) for environmental flow requirements differ much within the catchment – from 51 to 100% with the lowest value in the Mała River sub-catchment of high groundwater abstractions. Low time reliability values have been noticed also in the upper reaches of the Jeziorka River and its tributaries, but volume reliabilities (ratio of total volumes of supplied water and water demands) have been much higher (96-99%), thus indicating frequent occurrence of small deficits in river flows. Time reliability for industrial demands has reached 94%, and volume reliabilities for fish farms have been rather high, 80-95%, with the lowest value in the Mała River sub-catchment. Available surface water reserves exceeding 0.1 m^3/s have been identified at rather low reliability, smaller than 80%, and only in the lower reaches of the main river.

	The balance results have formed a basis for development of the Conditions for the Water Use in the Jeziorka River Catchment. In this document the hierarchy of water uses have been defined, starting from the most important one: environmental flows and drinking water supply, industrial demands, fish farms, irrigation. The restrictions for allowing for new water uses in the sub-catchments with already existing conflicts between environmental requirements and other demands have been formulated too. Moreover, a review of water permits for groundwater use has been recommended, aiming at more realistic specification of a demand value in permits – for existing users it should be close to the mean values reported in the water charge system in recent years. Furthermore, metering of water abstractions for agricultural purposes, both sprinklers and fish farms, has been proposed, together with improvements in reporting procedures.
Problems encountered related to the development of the Water Balances:	To perform balance analysis in the Jeziorka River Catchment collection of a broad set of data on water demands, abstractions and water resources was required. Time series of river flows were available for two water gauging stations, and one of these gauges was monitored for a short period of time, hence assessment techniques were used for water resources description. Real values of water abstractions for agricultural purposes (sprinklers and fish farms) were lacking. Modelling water demands for these kinds of users was a reasonable solution and the selected time step of 10-days enabled reflection of temporal variability of such demands, but better assessment of balance components, such as evapotranspiration or filtration losses, would improve the accuracy of balance computations. Registering and reporting of water abstractions with appropriate time resolution is also necessary. The range of inaccuracy in water use assessment was clearly illustrated by comparison of volume of groundwater abstractions reported to water charges system and volume allowed by water permits, with the latter 2.8 times greater than the former.

Case study #8: Use of water resource balance as a tool for the assessment of the quantitative relationship between water requirements (including the minimum balance discharge) and water resources – example from Slovakia

General information

Member State(s): Slovak Republic
RBD(s): SK 40000/Danube; SK 30000/Vistula
Location: Slovakia
Time period (start/end): 2010 to 2012

1.1 Objective of the Case study

The study describes the assessment of water resources in Slovakia towards the water requirements, and what role in this balance the parameter „minimum balance discharge (MQ)", representing the ecological flow is playing.

1.2 Policy and management context

The Eflows implementation is being implemented following the conclusions of the CIS working groups. The national coordinator is the Ministry of Environment of Slovak Republic. Institutions participating in the preparation of River Basin Management Plans are sharing in the implementation of Eflows. Currently, Slovakia is re-evaluating the e-flow values and their implementation into the planning and decision-making processes.

2 DETAILED INFORMATION

2.1 Practical Tasks (in case of methods and/or procedures)

The Water Resource Balance (VHB) has been used in Slovakia to frame water planning since 1973; after the implementation of WFD into the national legislation the methodology of VHB was revised, as a basis for the quantitative assessment of the water resources. The updated methodology of VHB was elaborated by the Water Research Institute (in cooperation with the Slovak Hydrometeorological Institute) and approved by the Ministry of Environment in 1994. Legally, the VHB is supported in the Water Act (Act No. 364/2004 Coll. as later amended) and its implementing regulations. Under this Act there are reporting obligations for users with withdrawals or recharges of quantities higher than stated limits. The amounts of the withdrawals and recharges reported are one of the main inputs to VHB. E-flow is represented by the value of minimum balance discharge (MQ), which is considered to be one of the demand side inputs. According to the Water Act no. 364/2004 Coll., this flow represents a flow, which allows general use of surface water, provides the functions of the watercourse and provides protection of aquatic ecosystems in it (in short – a minimum residual flow)

2.2 Temporal and spatial scales

VHB is performed in a yearly cycle, by evaluation of the previous calendar year. The processing itself is made in a monthly time step. The whole territory of Slovakia is assessed, in the main sub-basins, using the data from a network of 137 balance profiles. The assessment by the sub-basins is necessary due to the complex hydrological balance of water resources as well as due to historical aspects (a long-term tradition of annual hydrological assessment by main sub-basins). The balance profiles have been selected so as to cover the areas with important influence by water uses (water reservoirs, water transfer, etc.) or which may be at the risk of water scarcity.

2.3 Type of analysis or tool

VHB is based on the assessment of the relationship between the water demands and water resources and its quality during the previous year. Water demand represents actual withdrawals from the surface waters and groundwater and the recharge of the waste waters and special waters. The aim is to make objective, factual and timely assessment and express the status and the possibilities for water resources utilization during the previous year and in this way to provide the binding basis for water management for the next period.

The VHB has been processed separately for surface waters and for groundwater, for quantity and quality of water. This study further focuses on the water resource balance of the surface water quantity only.

The water resource balance of surface water quantity of the past year is processed for 12 main sub-basins using the network of 137 water balance profiles, covering important locations for water use, influence of water reservoirs and water transfers and also the availability of the hydrological information with the maximum connection to the existing network of water-gauging stations.

The utilization in the past year is the reported amounts of used surface water and groundwater and recharge of the waste waters and special waters according to the Water Act. The limit values for the reporting of the withdrawals are 15,000 m^3 per year or 1,000 m^3 per month.

The water management measure assessed in VHB is the effect of water reservoirs and water transfers.

Water balance calculation:

At every balance profile the following characteristics are evaluated:

- **Effect of water utilization - change of discharge - X**
-

$$X = V - (PO + PZO)(1)$$

where: V - is the sum of recharges of waste water from the origin of the river down to the water balance profile, PO – is the sum of surface water withdrawals from the origin of the river down to the water balance profile, PZO – is the sum of groundwater withdrawals from the origin of the river down to water balance profile.

- **MQ – minimum balance discharge**

MQ is a discharge which represents conditions for sustainable biological activity in the river and its close surroundings. It guarantees the general usage of water which does not require a permission from water management bodies.

- **MPP – minimum needed discharge**

Minimum needed discharge is an indicator which includes the water demands from water users (represented by the change of discharge X) as well as the demands to guarantee a minimum balance discharge MQ.

$$MPP = MQ - X \tag{2}$$

- **E – influenced discharge –** is the discharge measured in a water balance profile or value derived from a discharge measured in a water-gauging station.

- **ENP – discharge influenced by reservoirs and water transfers**

This value of discharge is that one which would flow through the given profile, if there was no utilization of water but influenced by operation of water reservoirs or water transfers only.

$$ENP = E - X \ (3)$$

- **C – natural discharge (scavenging)**

Natural discharge is the discharge value adjusted for the water utilization as well as for the influence of water reservoirs and water transfers. That means, this would be the discharge flowing through the given profile in natural conditions.

Natural (scavenging) discharge is calculated as an influenced (measured) discharge minus the sum of withdrawals, recharges, influence of reservoirs and water transfer:

$$C = E - X - N - P \ (4)$$

where E – influenced discharge, N – water reservoir influence, P – water transfer influence, X – change of discharge

- **Balance status (BSC, BSENP)**

The balance status is a non-dimensional parameter which is calculated for following alternatives:

1. $BSC = C / MPP$,(5)

The balance status of natural discharges – evaluation of what the balance situation would be during the natural discharges taking account of actual abstractions and discharges of water in the evaluated year.

,

2. BSENP = ENP / MPP ,(6)

The balance status for the river influenced by reservoirs or water transfers; in balance profiles without the influence of water reservoir and water transfer BSC = BSENP.

The following classification is used:

BSC (BSENP) > 1, 1 - category A – active balance status

1, 1 > BSC > 0, 9 - category B – tense balance status

0, 9 > BSC > 0 - category C – passive balance status

If:

BSC < 0 – the following values have to be tested: MPP, C:

MPP < 0 - category A – active balance status

C< 0 - category C – passive balance status (in very special occasions only)

- **Water resource capacity - (KZC, KZENP)**

Water resource capacity represents the value of the discharge, which was in the water balance profile in a given time above the value of MPP. Where the water resource capacity has a negative value, the water demands or the MQ requirements were not covered.
Water resource capacity is a parameter which is calculated for following alternatives:

1. Natural water resource capacity – represents the natural discharge in the river taking account of actual abstractions and discharges of water in the evaluated year.

   KZC = C – MPP, (7)

2. Influenced water resource capacity – represents the discharge in the river influenced by water reservoirs or water transfers taking account of actual abstractions and discharges of water in the evaluated year.

   KZENP = ENP – MPP, (8)

The assessment of the past year has following table form (tab. 1):

Table 1. Example of VHB table output: water balance profile Ipeľ – river mouth, 2012)**:**

Item **(m^3/s)**	**Month**				**Year**
	1	**2**	**.....**	**12**	

Sum of withdrawals from surface waters	**PO**	0.087	0.113		0.081	0.104
Sum of withdrawals from groundwater	**PZO**	0.086	0.090		0.102	0.104
Sum of discharging	**V**	0.317	0.309		0.357	0.327
Change of discharge	**X**	0.144	0.106		0.174	0.119
Min. balance discharge	**MQ**	0.437	0.437		0.437	0.437
Min. needed discharge	**MPP**	0.293	0.331		0.263	0.318
Influenced discharge	**E**	5.982	6.593		7.091	4.799
Water reservoir influence	**N**	0.313	0.400		-0.208	-0.095
Water transfer influence	**P**	0.000	0.000		0.000	0.000
Discharge influenced by N+P	**ENP**	5.838	6.478		6.917	4.680
Natural discharge (scavenging)	**C**	5.526	6.087		7.125	4.775
Mean long-term monthly discharge	**D**	16.175	26.711		20.111	18.100
Water bearing coefficient	**KV**	0.342	0.228		0.354	0.264
Balance status of natural discharges	**BSC**	18.85 A	18.37 A		27.10 A	15.03 A
Balance status real	**BSENP**	19.91 A	19.58 A		26.31 A	14.73 A
Natural water resource capacity	**KZC**	5.232	5.756		6.862	4.457
Influenced water resource capacity	**KZENP**	5.545	6.156		6,654	4,362

Outputs:

- assessment of the water bearing of the year,
- assessment of the amount of the withdrawals from surface waters and groundwater,
- assessment of the amount of recharged waste water,
- assessment of the water reservoirs and water transfers,

- assessment of the balance status for natural discharges taking account of actual abstractions and discharges of water in the evaluated year,
- assessment of the balance status on the streams taking account of the effect of water reservoirs and water transfers and taking account of actual abstractions and discharges of water in the evaluated year.

Concrete example of the outputs of VHB:

Table 2 shows the number of water balance profiles (from all 137 evaluated profiles), which were in tense and passive status during 2010-2012. 2010 was extremely wet in Slovakia, followed by an extremely dry period 2011 - 2012.

Table 2 Tense and passive states in water balance profiles in Slovakia in 2011 and 2012

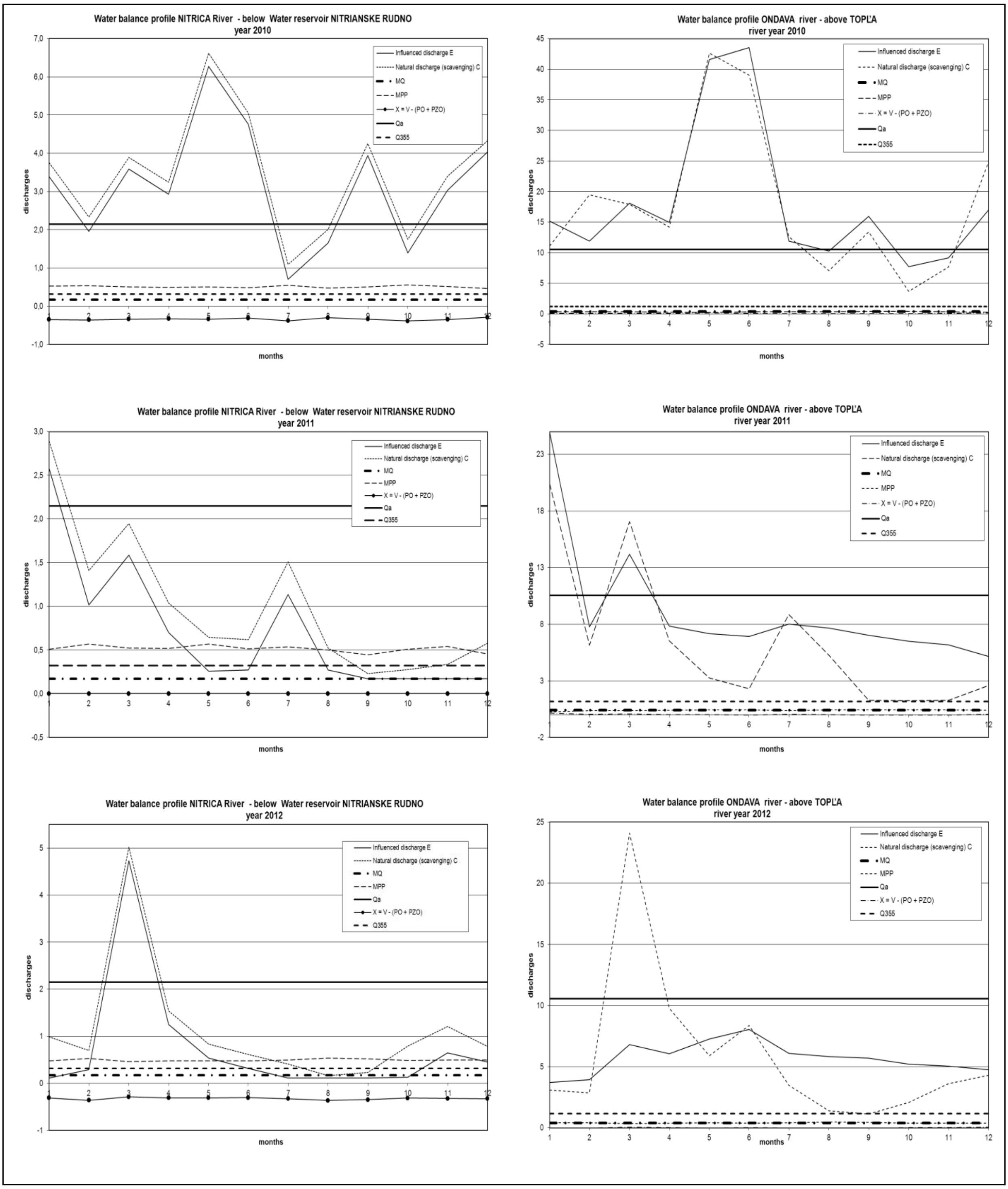
Year	Number of profiles with tense balance status		Number of profiles with passive balance status	
	BSC	BSENP	BSC	BSENP
2010	0	1	2	0
2011	7	5	5	0
2012	7	6	9	4

The examples of the courses of monthly values of natural discharge, influenced discharge, water demands – MQ and water utilization expressed by change of discharge X, as well as long-term values Q_a (mean long-term discharge) and Q_{355} (355-day discharge) are presented in Figure 1. The examples show the situation in 2010, 2011 and 2012 in two water balance profiles situated close under the water reservoirs Nitrica- NitrianskeRudno (on left side) and Ondava – above Topľa (on right side).

In the wet year 2010 - water resources can cover the demands without any problems. However in 2011 at the profile Nitrica – NitrianskeRudno, the last third of the year the influenced discharges are decreasing to the value of MQ, and in 2012 (which was an extremely dry year) the influenced discharge was even lower than the value of MQ. This is an extraordinary situation, which needs an extra permission for the water reservoir operation in the critical time, or after assessment of the past year it is subject for the revision of the measures.

The second profile in both dry years 2011 and 2012 shows the increasing discharge influence of the water reservoir during low flow period, when the natural discharge would be close to value Q_{355}, but the water reservoir operation is improving the discharge situation in the river channel under the dam.

Figure 1. Course of natural and influenced discharge, MQ, needed discharge MPP, change in discharge X – examples in 2 water balance profiles in 2010-2012



2.4 Information and data requirements

The necessary inputs into the VHB are the following:

A, Withdrawals of surface waters and groundwater- are provided by the users annually in a monthly time step if the withdrawal is more than 15,000 m^3/year or more than 1,250 m^3/month. Groundwater withdrawals are assigned to the river in the normal direction and they are calculated as a sum to the nearest downstream balance profile.

B, Recharge of waste water – reported if the amount is more than 10,000 m^3/year or 1,000 m^3/month.

C, Minimum balance discharge MQ – is a water balance value, where the preferred demand on water resource guarantees the protection of the environment. It represents the conservation of the conditions for the biological stability of the river and its close surroundings and guarantees the general usage of the water, which does not need the permission of water management bodies. The values of the minimum balance discharge for particular water balance profiles are determined according to the procedure approved by the Ministry of Environment of the Slovak Republic.

Determination of the minimum balance discharge MQ:

a) For the river reaches with regulated runoff:

- in the dam profiles MQ = Q_{355}, unless it is not stated otherwise by operative rules or by another reason,

- in other reaches the value of MQ is variable, the controlled increase of runoff by reservoir is declining steadily down to the point where the effect of the reservoir is undetectable, and in that case MQ is determined according to paragraph b.

b) Other river reaches:

- The minimum balance discharge (MQ) is determined as follows:

$$MQ = (Q_{min\ mes} + Q_{100.min.d})/2 \qquad (9)$$

where Q_{minmes} is the value adopted from a probability field of mean monthly discharges with a high level of guarantee, usually 98%.

$Q_{100.min.d}$ is the balanced value of the minimal mean daily discharge with the mean occurrence probability of once in a 100 years, determined by statistical methods.

The value resulted from the above equation should also meet the following condition:

$$\tfrac{1}{2}\, Q_{364} < MQ < Q_{355} \qquad (10)$$

For the profiles where the values of Q_{minmes} a $Q_{100.min.d}$ are not available MQ is determined according to the principles of hydrological analogy.

The optimum determination of the values of MQ is considered to be one of the fundamental and complex tasks of water management.

D, Monthly evaporation from reservoirs – is calculated on the basis of the monthly evaporation and the area of the flooded surface of the water reservoir.

E, Mean monthly influenced (measured) discharges in water balance profiles – the discharges measured in water balance profile or determined on the basis of hydrological analogy from the discharge values of water-gauging stations.

F, Mean long-term monthly unaffected (natural) discharges – representing the reference period 1961-2000 (used since 2006), serve for the supplementary assessment for particular months.

G, Mean monthly changes of water volumes in the reservoir – are determined on the basis of water volume change in the reservoir between the first day of the given month and first day of the next month.

The alternatives of the water reservoir activity are:

a, The volume of the water at the end of the month is larger than at the beginning of the month – accumulation of the volume of water reservoir – decreasing the discharges in the river,
b, The volume of the water at the end of the month is smaller than at the beginning of the month – discharging from the reservoir – increasing the discharges in the river,
c, The volume of the water at the end of the month is the same as at the beginning of the month – the reservoir did not influence the discharges in the river.

H, Mean monthly values of water transfer – occur in the water balance assessment in two ways:

a, in the water catchment the water is transferred from,
b, in the water catchment the water is transferred into.

2.5 Testing of results

The methodology is used for the annual assessment. Where there are problems, the input data are determined again, especially the data on monitored discharges and data on water utilization. The data on water utilization used for VHB are also used for payments. The balance status, evaluated permanently as passive or tense, is the signal to review the original measures or to set new ones.

2.6 Current application of the method/initiative

This methodology of the water resource balance assessment is supported by the Water Act. The values of the ecological flow (MQ) are being revised; according to the actual reference period and taking account of the ecological and economic consequences.

Beside this assessment in Slovakia, the perspective water resource balances are also elaborated. These, in principle, use the prognosis of water utilization on the demand side and discharge characteristics with high probability of exceedance (or guarantee, in case of water reservoirs) on the side of water resources, or even the simulation of the discharges using 50-year time series or more. Data series influenced by predicted climate change can be also used. The value of MQ can be also entered differently in the month step.

2.7 Learned lessons - Conclusions – Recommendations for application within the concept of Eflows

The Water Resource Balance makes the assessment of status after withdrawals from surface waters and groundwater and recharges of waste waters in previous (past) year. The data are obtained based on the legal duty of the users, who have to report data on water utilization once a year. The actual withdrawals (not permitted amounts) are charged. Not all data on withdrawals are taken into account in the VHB, because if the amount of withdrawal is less than the limit, the data are not reported and do not enter into the evaluation of water balances. This leads to some underestimation of the real demands for water.

VHB is a good tool for the monitoring of the functioning of the measures set in the previous period (operation of water reservoirs, water transfer, etc.). The disadvantage is that it is evaluated retrospectively for the previous period, as users report the withdrawals annually. It is therefore not possible to use this assessment for operational purposes. Following the evaluation, however, if a problem is identified, the cause is looked into – if the measure is set in a given area, and whether it is sufficient, or whether the problem arises because of another reason. Then for the next programming period the measures are reconsidered.

Contact information

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- Web page, where the VHB assessments for previous years are available (in Slovak language): http://www.shmu.sk/sk/?page=1571
- References:

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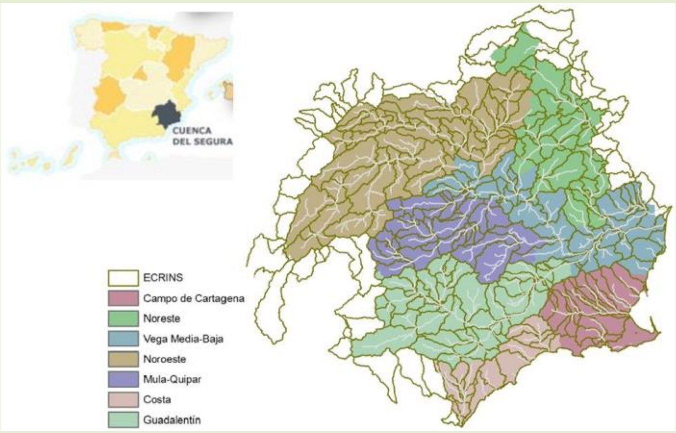
Name of the Pilot project	PAWA (Pilot Arno Water Accounts) project
Spatial scales • **Territory (catchment, other) covered by the pilot project** • **Basic unit at which the water balance has been set (water body, catchment, other)**	Three sub-basins of the Arno river basin, which covered spatial scales as follows: • Chiana valley (1,373 sq. km) • Bisenzio valley (320 sq. km) • Pisa area (407 sq. km) These sub-basins were identified using the following criteria: i) vulnerability to drought and water scarcity; ii) data availability; and iii) water governance structure. Nonetheless, data collection and modelling tools took the whole Arno river basin as a reference area.
Temporal scales • **Time unit at which the water balance is developed** • **Smallest time unit considered**	Temporal scales considered: • monthly; and • yearly. Due to the high seasonal variability of hydrological parameters and anthropic activities, it is only possible to highlight the most critical conditions for water availability at the monthly scale. Hydrological data are generally available at shorter time scales (daily), and they can be easily aggregated. Abstraction/restitution data are available at a monthly scale only in a few cases (e.g., for industrial use in the Bisenzio basin); they can often be reconstructed taking into consideration yearly values based on water monthly withdrawal models which are estimated for each water use.
Accounting for the environmental demand	The “environmental demand” has been accounted for using a threshold for the “WEI+” indicator within the optimization procedure carried out for selection of measures.
Accounting for potential desalination	Even if desalination is taken into consideration in the list of possible measures for the production of SEEA-W tables, local experience (based on stakeholders’ involvement and on the analysis of local water plans) reveals the limited affordability of this type of intervention.
Accounting for potential water transfers	Water transfers are not planned in the analysed areas and they have not been taken into account as a potential measure for the optimization process with SEEA-W tables.
Information mobilized	Hydro-meteorological data have been provided by the Region of Tuscany (Hydrological Service). Abstraction data have been provided by water utilities and Tuscany Provinces. Information on wastewater treatment plant (WWTP) production has been provided by water utilities. Socio-economic data have been downloaded from ISTAT (Italian National Institute for Statistics) data warehouse.

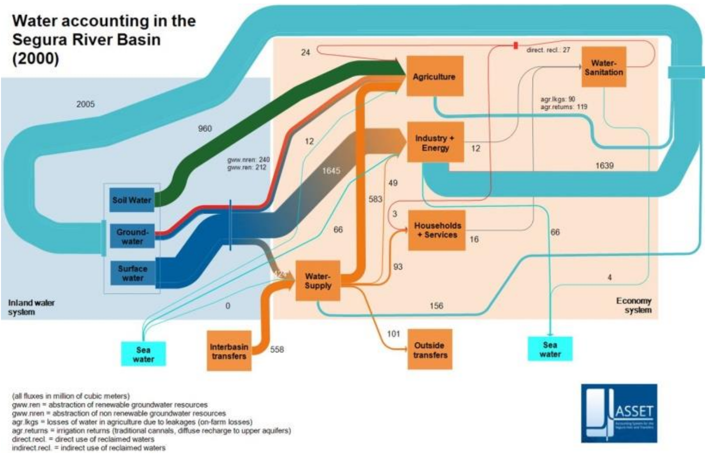
Main sources of uncertainty	The datasets with the highest degree of uncertainty are abstraction data for agricultural, industrial and household uses. In many cases, only estimates are available, based on permits or even more general evaluations (e.g., extent of irrigated areas). As a result, the total amount of irrigation groundwater losses and evapotranspiration also have a high level of uncertainty. In the industrial sector, some uncertainty is due to the exploitation of water for manufacturing without a clear distinction between production and sanitary uses. Mechanisms for uncertainty reduction are based on statistical analysis and use of simple models (e.g., linear regression) in order to verify and correct outliers and biased values.
	Key parameters that are particularly difficult to assess based on current data and information: • WWTP inflows/outflows; and • storm urban catchment flows from combined sewer overflows. In both cases, gathered data (from WWTP management) do not have an acceptable level of reliability; the total amount is often derived from simplified models based on precipitation over urban areas. Due to the non-linear process of discharge, a more specific analysis based on more detailed rainfall data and sewer network characteristics should be carried out in order to improve these estimates.
	The different datasets for hydro-meteorological variables referring to climate change scenarios are an "innovative source of information". Six different reconstructed time series, which were obtained by using three different global circulation models and two different socio-economic scenarios, have been used for simulating the impact of measures.
Link to modelling	A distributed hydrological model has been used in order to obtain physical water asset account values. The MOBIDIC-WRM (Water Resources Management) tool is a physically-based model that allows the estimation of the elements of the hydrological balance in the sub-surface layer, the soil-vegetation system and surface water bodies. A lumped groundwater model has been used to obtain monthly data of aquifer water quantity and exchanges. Both models delivered detailed information and consistent estimations of the physical quantities. A Visual Basic Application (VBA) tool for MS-Excel has been produced by the PAWA partners to automatically compile the SEEA-W Physical Use & Supply tables (PSUAT) and the Asset account tables. Thus, it is possible to perform the compilation of tables and the production of thematic graphs in a quick and reliable way directly using the data stored in the Geo-Database that has been developed and populated for the project activities.
Socio-economic indicators estimated	Due to their insufficient number and reliability (at the level of each sub-basin studied), detailed socio-economic indicators have not been integrated into the water balance framework.
Main management scenarios investigated	Many “management scenarios” have been analysed using the water balance, combining 16 different measures for general purposes or for specific uses (e.g., reducing leakages, awareness, reuse, water

	saving devices, green measures, tariffs).
Other specific challenges met when developing the water balance	For both the Chiana and the Bisenzio areas, the interaction between surface water and groundwater plays a role in the estimation of water availability and evaluation of the effectiveness of water saving measures. The possibility to improve groundwater modelling (for the Prato aquifer, connected to the Bisenzio river) allowed a better understanding of the relationship and highlighted the need of a similar application for every groundwater with strategic water storage and high abstraction pressures.
General comments	• Water accounting is a good supporting tool for water quantitative management with stakeholders. • It is well suited to generate scenarios to assess the impact of a combination of measures. • It also highlights the need to improve knowledge and data management between stakeholders.

Name of the Pilot project	ASSET (Accounting System for the SEgura river and Transfers)
Spatial scales - **Territory (catchment, other) covered by the pilot project** - **Basic unit at which the water balance has been set (water body, catchment, other)**	The study basin corresponds to Segura River Basin (SRB, Spain), with an area of 18,870 km^2, located in the south-eastern part of the Iberian Peninsula. The basic unit at which the water balance has been set corresponds to exploitation systems. Therefore the basin was discretized in seven representative elementary watershed management units considering aggregation of ECRINs units and sub-basins. This basin has the lowest percentage of renewable water resources of all Spanish basins and is highly regulated. The main water demand comes from agriculture, covering more than 43% of the basin surface, of which one-third is brought under irrigation (269,000 ha). It should be emphasized that agricultural water demand from irrigated areas of the SRB accounts for 85% of the total water demand in 2007 in the entire basin. Water scarcity is a major issue in the SRB. Available water resources per inhabitant in the SRB (only 442 m^3/inhabitant/year) are much lower than the national water scarcity threshold, which is set at 1,000 m^3/inhabitant/year, according to United Nations and the World Health Organization. The difference between water supply and demand is high. Consequently, two water transfers together with desalinization are considered the most attractive options to increase water availability in the basin. The problems of water scarcity and droughts are persistent in the basin, affecting the economy of the region and generating water conflicts between the final users (irrigation communities, etc.).  Location of SRB and spatial disaggregation
Temporal scales - **Time unit at which the water balance is developed** - **Smallest time unit considered**	The time discretization was set up at the monthly scale. The time period corresponds to 2000-2010.
Accounting for the environmental demand	The environmental demand was considered according to the water planning of the basin (SRB water planning). The water agency (CHS) provided these data, and the methodology applied is described in the water plan of the basin.
Information mobilised	The main data source was the Confederación Hidrográfica del Segura (water agency). This water agency provided data from meteorological and hydrological networks, such as the automatic SAIH system (Automatic System of Hydrological Information), manual networks of rain gauges and stream gauges (ROEA), and other additional information. Digital information below a GIS was also provided, such as SRB limits, channel network, groundwater bodies, reservoirs, wetlands & protected areas, aggregated demand units, and so on. Satellite images were analysed for the estimation of actual evapotranspiration, and results from a rainfall-runoff model (SIMPA) were collected.

Main sources of uncertainty	The principal uncertain physical water balance components are: groundwater recharge and soil moisture. The actual evapotranspiration (AET) cannot be based on direct measurements, but need to be modelled. A combination of remote sensing information and hydro-meteorological networks are needed to quantify physical water balances for adequate decision making. Appropriately calibrated hydrological models could be a valuable tool. These methods allow an objective assessment of water demand and water consumptive use and the impact of measures, to support an economically and environmentally sustainable future of Mediterranean agricultural basins.
Link to modelling	Remote sensing AET retrieval algorithms were applied for assessing the corresponding inputs to the tables. The model applied is based on vegetation indices estimated from MODIS satellite images. In first instance, the SIMPA rainfall-runoff model was considered for estimation of inputs to the ASSET table, such as AET and soil moisture. The comparison between the time evolution of AET estimated from remote sensing and that simulated by the model, demonstrates a bad performance of the model in the estimation of this variable. Therefore, the model outputs were not considered as input to the tables. One way for strengthening the robustness of the water balance developed considering a rainfall-runoff model, is to modify the structure of the model. Spatial calibration of the model on the basis of AET estimated from remote sensing is a way. Another possibility is considering remote sensing AET retrieval as input to the model (instead of potential evapotranspiration). In that case, on the one hand the uncertainties will be reduced and on the other hand the accuracy in the results will be higher.
Socio-economic indicators estimated	Economic information is partly available for administrative regions that are away from river basin territory. Data quality could be improved if statistical economic information can be adapted to the river basin activities. The nature of economic data (yearly information) cannot be transformed to monthly or daily data without introducing bias. Therefore, the economic outputs from the ASSET project will be at an annual scale and for the whole basin. Economic indicators suggested by the SEEAW methodology will be assessed for the Segura River Basin. At the basin scale, some indicators have been estimated: one related with Water Productivity (WPe), and others related with the cost of supplying water, Implicit water price (IWP) and Implicit wastewater treatment price (IWTP), the Average water supply cost (AWSC) and the Average wastewater treatment cost (AWTC). Also, by industry, others indicators have been estimated in order to show the differences among water users sectors. Thus, additional information is collected by the indicators: Water Productiviy (WPi) Average water supply cost (AWSCi) and the Average wastewater treatment cost (AWTCi). Finally, the Added Values by unit of water used have been estimated (AVWUi).
Main management scenarios investigated	In order to extract indicative target levels of water availability and usage, and potentials for water saving and increase in the resilience of the Segura River Basin (SRB) against future water shortages, three critical issues are addressed: - The calculation of a set of use-to-availability indicators at the sub-basin scale from the SEEAW tables. - The analysis of the effects of a 4-year drought period on the use-to availability patterns observed at the basin, and - The impact evaluation of various water management measures on water shortage taking into account climate change and population growth.
Other specific challenges met when developing the water balance	In many Mediterranean basins, the agricultural sector is the main water user, and provides a significant role in the local economy. Basin-level physical water balances are often well studied in these regions given their importance and the recurring drought events. But to target measures that support sustainable agricultural water use in agriculture, it is necessary to understand the water balance at a finer scale than the basin scale.
General comments	The project is not yet concluded. Therefore, more specific information about these topics will be included at the end of the project. The following figure (Sankey scheme) represents a summary of water accounting in the SRB in

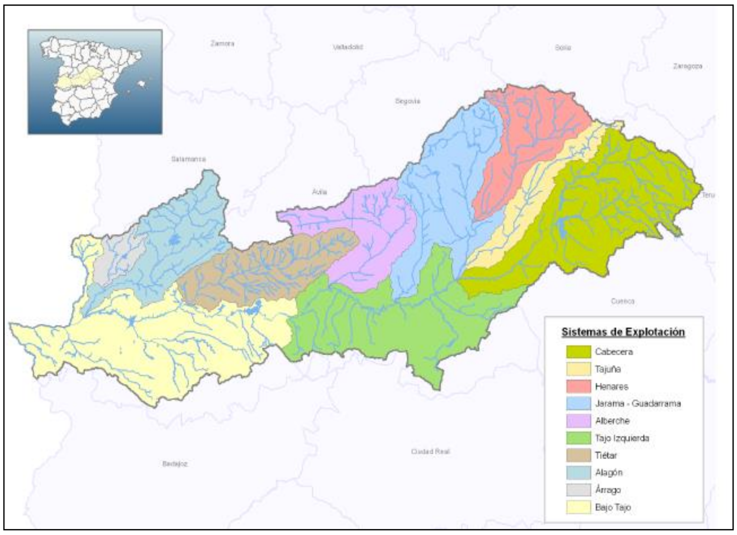
2000.



(all fluxes in million of cubic meters)
gww.ren = abstraction of renewable groundwater resources
gww.nren = abstraction of non renewable groundwater resources
agr.lkgs = losses of water in agriculture due to leakages (on-farm losses)
agr.returns = irrigation returns (traditional cannals, diffuse recharge to upper aquifers)
direct.recl. = direct use of reclaimed waters
indirect.recl. = indirect use of reclaimed waters

Name of the project	**SYWAG: Guadalquivir River, Spain**	
Spatial scales - **Territory (catchment, other) covered by the pilot project** - **Basic unit at which the water balance has been set (water body, catchment, other)**	The Guadalquivir is the longest river in Southern Spain, with a length of around 650 km. The basin drains 57,527 km² with a population of 4.2 million, flowing south-west into the Gulf of Cadiz (Atlantic Ocean). The total length of the river and its tributaries are around 10,700 km. Its middle reaches flow through a populous fertile region at the foot of the Sierra Morena, where its water is used mostly for irrigation. The lower course of the Guadalquivir river passes through extensive marshlands (Las Marismas) that are used for rice cultivation. The Guadalquivir river is tidal up to Seville, corresponding to 80 km upstream capable of navigation for ocean-going vessels. The basin is heavily regulated (volume of reservoirs is 8.6 Km^3, and average renewable resources is 5.7 Km^3). The resources have been managed centrally by the Water Authority since 1920's. Therefore, the management scale is the basin itself.	
Temporal scales - **Time unit at which the water balance is developed** - **Smallest time unit considered**	The spatial scale considered for the SEEA tables has been the whole basin. For building the water balance tables, the spatial scale has been units of 1km$^{2.}$ The time unit for hydrological variables analysis is a month. Tables have aggregated data on a yearly basis for presentation of balances and economic data.	
Accounting for the environmental demand	The "environmental demand" has not been specifically accounted for as it is already a constraint set in the hydrological plan and Spanish law makes compulsory requirements at the time scale in L/sec and spatial scale of water mass, so that SEEA tables are not practical at this scale. The water balance at a monthly level gives enough water resources to fulfil the environmental constraint with enough margin (monthly resources)	
Information mobilised	Variable	Data source
	Population (municipal)	INE
	Industrial activity by ISIC/location	INE/MAGRAMA
	Metropolitan area MAGRAMA	MAGRAMAEDAR
	Agricultural production by branch	MAGRAMA (province)
	Evaporation rate from reservoirs	Evaporation stations
	Agricultural surface evolution	CHG
	Volume in reservoirs	CHG
	Rainfall	SIMPA monthly
	Rainfall	REDIAM
	Infiltration	SIMPA monthly
	Potential evaporation ETP	SIMPA monthly
	ETR	SIMPA monthly
	Groundwater runoff	SIMPA monthly
	Irrigation efficiency by units (1)	Inventario regadíos (CHG)
	Irrigation efficiency by units (2)	CHG
	Irrigation use (water doses)	Inventario regadíos
	Surface runoff	SIMPA monthly
	Temperature (1)	SIMPA monthly
	Gauging stations	SAIH/Gauge monitoring network
		Groundwater resources, aquifer characterization
	Volume of dam/regulation capacity	CHG
	Water demand	CHG
	River flow	SAIH
	Returns	CHG
	Aquifer level (piezometric)	Piezometric monitoring network
	Agg ECRINS	CIRCA
	ANyECRINS	CIRCA
	FEC ECRINS	CIRCA

	GAZ ECRINS CIRCA River ECRINS CIRCA TR ECRINS CIRCA CORINE CIRCA Urban water water treatment CIRCA Urban runoff DBO5 concentration USEPA Urban runoff volume Own elaboration Census Discharges CHG Red ICA/DMA (water quality) CHG Abstraction SIMPA, Own calculations Use PHC, Survey water services, Own calculations Returns Own calculations based on IPH Consumption Own calculations based on CHG Intermediate consumption I/O Tables regional Gross Value Added Regional Accounts Gross fixed capital formation Regional Accounts, WB investment series Clossing stocks of fixed assets Water tariff, Admin.budget (2004-2008) Water self-service production cost: Groundwater, Ministry Report Water self-service production cost: Surface Water tariff Water self-sanitation Survey water services Government account table Administration budget (2004-2008), WB investment series Specific transfers Admin. budget (2004-2008), WB investment series
Main sources of uncertainty	SYWAG has developed tables for 2004-2012 at a monthly scale and aggregated at a yearly scale. The evaluation of hydrological data is based upon the SIMPA model and ETP is based upon evaporation measures in the basin. The uncertainties are reasonable regarding the nature of hydrological models.
Link to modelling	It is based upon SIMPA (official Ministry model for water resources evaluation) and complemented SIMPA for agricultural land water consumption (irrigated and rain fed agriculture). Some specific models have been developed for urban water runoff.
Socio-economic indicators estimated	Socioeconomic indicators have been included, specifically: gross added value per sector, intermediate consumption, financial issues and specifically a methodology for cost recovery indicators have been developed based upon the SEEA tables.
Main management scenarios investigated	SEEA tables have been developed for 2004-2012 including a severe hydrological and climatic drought (2005-2008) and two climatic droughts (years 2009 and 2001) that have been managed by the use of reservoirs and groundwater. Simultaneously the impact of 'modernization' (water saving investment) has been observed in the period
Other specific challenges met when developing the water balance	There is a close relationship with the Water Agency that has included SEEA Tables in the Basin Hydrological Plan. Two workshops with the Segura Basin project have been held. Information is available in the University of Cordoba Library services (Helvia): http://hdl.handle.net/10396/12557
General comments	SEEA tables are a good instrument for standard presentation and analysis of economic information included in the WFD and required for reporting. It can be used for Basin Characterization (Art 5 WFD) and for Cost recovery analysis (Art 9 WFD). It can be used also for scenario building. The level of analysis of SEEA tables is adequate for basin /sub-basin analysis but (in our opinion) it cannot be used for water mass and environmental flow analysis because the level of scale is not adequate to the SEEA methodology.

Name of the Pilot project	Pilot project on water balances in the Tagus river basin, PROTAGUS
Spatial scales	The transboundary basin of the Tagus, with a surface area of 81,447 km^2 (55,781 km^2 in Spain and 25,666 km^2 in Portugal). The total population in the Spanish basin is 7,833,089 and in the Portuguese part is 3,485,816.
	Data collection has been set at Water Management System (WMS) level because the data are available at this scale. However, the water balances has been set at river basin scale (separated for Spain and Portugal) because the relationship between groundwater and surface water and the economic data are not well adapted at WMS. Water Management System in the Spanish part are: 1. Cabecera (surface area: 9,400.94 km^2) 2. Tajuña (surface area: 2,593.27 km^2) 3. Henares (surface area: 4,134.96 km^2) 4. Jarama-Guadarrama (surface area: 6,510.55 km^2) 5. Alberche (surface area: 4,103.64 km^2) 6. Tajo izquierda (surface area: 8,321.64 km^2) 7. Tiétar (surface area: 4,459.24 km^2) 8. Alagón (surface area: 4,409.08 km^2) 9. Árrago (surface area: 1,021.13 km^2) 10. Bajo Tajo (surface area: 10,826.35 km^2) 
Temporal scales	The period of study has been 2001-2010 (accounting year). The hydrological data have been collected at a monthly scale, but the balance has been set at an annual scale because the economic data and behaviour of groundwater (lag time and inertia) are best suited to adapt at the annual scale.
Accounting for the environmental demand	The “environmental demand” has not been accounted for in the water balance.
Information mobilised	See Annex 1
Main sources of uncertainty	– Data robustness depending on source and no recorded data for some parameters needed to develop water accounts. The proposed solution is to manage the most reliable data (in agreement with the Tagus River Basin Authorities). In addition, and when needed, the team will take into account aggregated data or models (e.g. simulation model for natural regime). – For the development of water accounts, data uncertainty should be considered and even calculated for practical reasons. When data are not systematically measured (lack of instruments or economic resources), hydrological models and estimations are necessary (e.g. for urban abstractions indirect estimations are made based on

	population and well measured consumption volumes, for agricultural demand estimations are made based on remote sensing). In addition, there is some danger of accumulating errors if these are present in different variables. – Source data (heterogeneous database): multiple sources, many formats and raw data, diverse units of measurement, different spatial and temporal scales. Data are arranged, organized and transformed (Standardized data). – The same parameters were sometimes monitored from different entities and sometimes with different tools (several series exist). The approach has been to cross-check the series, determining if there were large discrepancies. ➢ Lack of standardized method for initial stock estimations (river resource analysis). Further analysis of the advantages and disadvantages of the methods for ordering river networks, the geomorphological identification required to define the geometry, and the necessary measurements to estimate current flow levels. Meanwhile, a certain level of uncertainty affects River initial stocks in SEEAW. ➢ Available renewable resources in aquifers lack detail (groundwater resources analysis). The piezometry relative evolution is used. ➢ Soil water resources: a large component of resources but with high uncertainty. ➢ Difficult definition of interaction flows along continental-transition boundaries. ➢ International watersheds: closer cooperation in the common definition of climatic and hydrological datasets. Foster WISE assumption as a common framework for international basin's data. ➢ Losses in distribution: have been estimated based on previous supplier's studies. ➢ Economic data: no direct sources of data for filling hybrid accounts. Downscaling statistics (NUTS level 3 in Europe). Regular measurement of GVA to identify trends and compare basins /territories. Serious obstacles when analysing past series. Risk of applying own calculations, unless statistics institutes conduct retropolation for past series. ➢ Investment records, infrastructure inventory: complex distribution of funds between government agents and lack of unified records presents some risks of double accounting. Requires common commitment to integrate budgets in WISE framework.
Link to modelling	**SIMPA**: The support of hydrological models facilitates the process of computing each component of the water cycle from the atmospheric level to the core ones of hydrology (surface runoff, infiltration, groundwater runoff…), especially on the case of the distributed Spanish model SIMPA, in contrast with the aggregated simple Témez in Portugal, which does not allow flexible GIS treatment. **AQUATOOL**: The existence of a Decision Support System (DSS) model like the Spanish AQUATOOL, DMA provides a user-friendly base to geographically compile and integrate hydrological variables with use and supply units. In this way, detailed geographical compilation of uses/demands enable the interpretation of Water assets in smaller scales than the basin (like the WMS or Hydro-Enviro Regions proposed).
Socio-economic indicators estimated	Socio-economic indicators have been integrated into the water balance framework. GVA has been taken as the main basis for the socio-economic characterization of the basin.
Main management scenarios investigated	The study was made on the 2001-2010 series, so that the simulation has been made on real measured data and not on future scenarios. It has studied management in wet years and dry years.
Other specific challenges met when developing the water balance	The PROTAGUS project has provided an opportunity to test and check the feasibility of applying the SEEA-W to produce water accounts in the Tagus River Basin District. The results obtained have helped to assess, in a retrospective way, water availability, abstractions for economic uses, storage capacity of specific elements within the system (reservoirs, lakes, groundwater bodies) and determine how pertinent water management practices have been during the studied period (2001-2010). By assessing a whole decade, the relevant phenomena and general trends could be easily discerned. A summary of the analysis conducted is included below: – The relationship between groundwater and river (GW-River interaction). – The importance of soil water resource for the rainfed agriculture and forestry.

	– Analysis of dry episodes. – Anthropogenic pressure on water resources (abstractions, water quality) – The importance of hydropower cannot be shown with SEEA-W system unless the lack of definition on economic statistics for hydropower by INE is solved. – The difficulty to make the study in a transboundary river basin. There were serious obstacles within Portuguese RBD territory caused not only by the lack of data due to the crisis, but also, and more importantly, due to the lack of coherence between Portuguese and Spanish datasets in several fields (climatic: temperatures, rainfall, ETP…) as well as with the hydrological variables. As each country tends to use its own traditional units system, criteria to determine the WMS or use of hydrological models to characterize the basin, at least some effort to synchronize the results of its own basin analysis should be addressed under the Wise and Inspire European frameworks. – No direct sources of data for filling hybrid accounts: Economic data gathering and systematic collection still need large improvements. In many cases, the data gathering process at different scales (for instance at regional level by the National Statistics Institute) poses great difficulties for obtaining reliable numbers at the basin level. ➢ Lack of economic data available and in different scales. ➢ Lack of investment records and infrastructure inventory. Complex distribution of funds between government agents and lack of unified records presents some risks of double counting. – Water balances results can be useful in the application of agreed indicators (WEI & WEI+) or for Eflows calculations.
General comments	The overall assessment of the PROTAGUS project is very positive. The performance and achievement of outputs turned out to be very close to what was initially expected. Some of the obtained benefits are summarised below: – A closer collaborative relationship was established between EVREN and CHT. This project allowed for even closer collaborative work among the teams' members, exchange of ideas and fruitful discussions. This is extendible to EC officials: the project allowed for frequent communications, meetings and exchange of ideas with representatives from the DG Environment, which led to information sharing to improve work, to review the EEA's exercise, and discuss future collaborations. – The partners gained further knowledge on the status of the Tagus RBD, environmental accounting and water balances development as the project allowed for hands-on experience of these issues and practical application (direct use of UN tables). – PROTAGUS has been working in depth on the economic issues, which has allowed EVREN to obtain an exhaustive knowledge about the gaps and inconsistencies in the economic datasets from the hydrological datasets, as well as to perform an assessment of the economic activities involved in the Integral Water Cycle. – The partners had a chance to broaden their experience in water accounting, to show their expertise in information sharing and dissemination practices and gained visibility from networking and participation in events. With the participation of EVREN in the "2nd Mediterranean Water Forum", the lessons learnt on this practical case will also be valuable for other river basins around the Mediterranean for developing national and regional water information systems that could deliver the data required to fill-in the water accounts. The project consolidated its role as a main tool of exchanging water know-how in the Euro-Mediterranean region. – As for benefits for each specific party: ➢ EVREN had extensive previous experience in participating and leading international contracts and projects. In addition, it is the second time that the team was in charge of a grant from the EC. The team improved skills in public data scrutiny processes, hydrological models and data representation, using the new approach of SEEA-water. ➢ In this project, there have been a better contacts and information exchanges with other similar funded projects, particularly with regards to the SYWAG project of the University of Cordoba. For EVREN's team, the experience can be described as very enriching, especially on the assessment of

economic issues, due to the fact that the SIWAG team has experts on this. Their input and support to our project have been very fruitful.

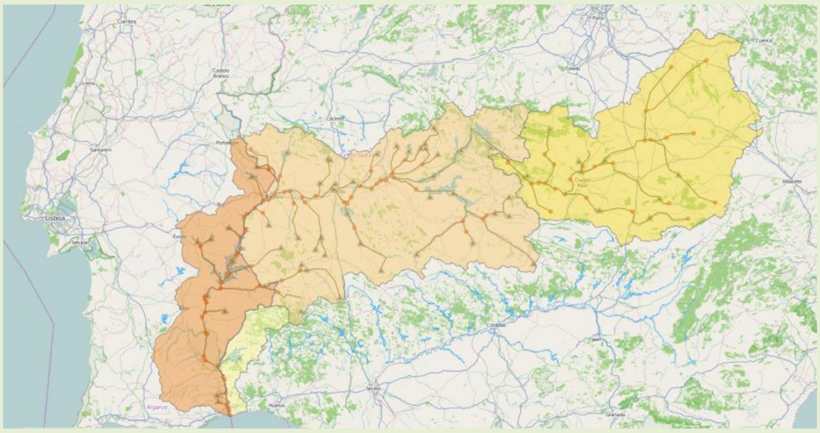
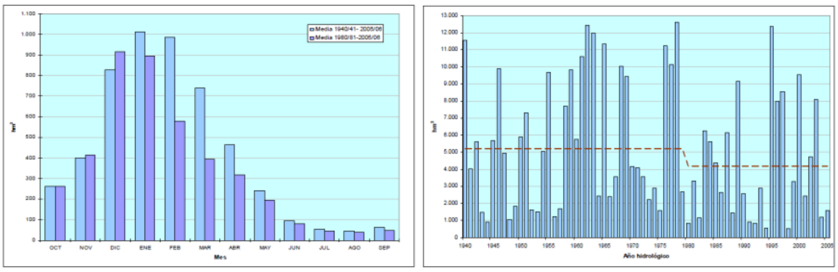
- For the Tagus River Basin authorities the compilation of data required to produce water balances, allowed the team to homogenize information coming from different sources and databases, and progress toward their integration in the Hydrological Information System. In addition, this project confirmed the need for integration of the economic issues into the hydrological balances, as well as having direct measurements of the water uses taking place in the basin. Regarding the final results, the CHT now has a validated methodology and the corresponding tools to develop and produce water accounts which could be integrated in hydrological planning.

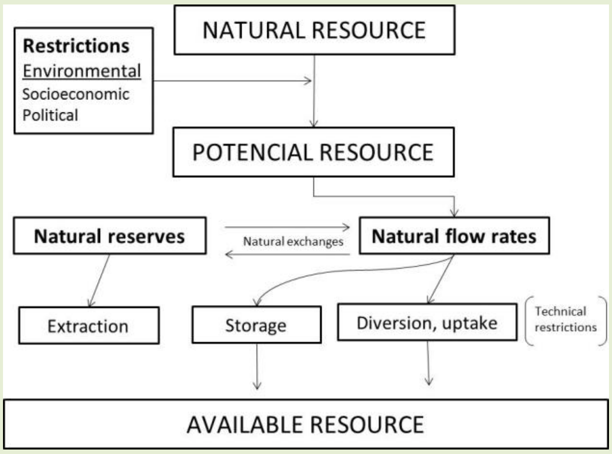
The results of the SEEAW accounting system of the Tagus River Basin District, might for instance, help in assessing measures of the River Basin Management Plan and the existing Drought Management Plan, improve demand estimations and facilitate any adjustments for environmental protection, management and control, demand and supply, or management of non-conventional sources (e.g. from waste water reuse). In addition, they provide a standardised representation of data, which could facilitate auditing, and comparison with other SEEAW-studied basins and with the next editions of the accounts.

In river basins, such as the Spanish RBD studied, where there are robust hydrological models and a long tradition of collecting management related data, it will be possible to achieve this type of analysis. However, in those with less reliable information, the difficulty in developing water accounts can be high, and may lead to imprecise results. Therefore, there is a need to obtain a consistent and reliable set of both hydrological and economic data at the river basin or sub-basin level on sectoral demands, and progress towards a long-term application to increase their effectiveness.

Any progress towards obtaining and applying reliant hydrological models and data collection related to water accounts implementation in those basins that currently lack appropriate tools, will involve economic investments which should be considered and assessed by policy evaluators. Most of the hydrological information can be supplied by global models, but that will not be the case for data on abstractions, returns, flows in altered regimes, and the relationships between the various elements with groundwater –which require a detailed and local knowledge.

Additional future steps to be taken that would enrich the exercise and provide additional inputs to water managers, statisticians, and economists include working towards the production of specific water quality tables and valuation of water resources as presented in the second part of the SEEAW manual. That would provide a better understanding of the socioeconomic impact of pollution and the weight of water use in goods, as well as the blue and green footprints of activities or the environmental services of water ecosystems.

Name of the Pilot project	New developments in Water Accounts implementation in Guadiana River Basin GuaSEEAW+
Spatial scales • **Territory (catchment, other) covered by the pilot project** • **Basic unit at which the water balance has been set (water body, catchment, other)**	The Guadiana River Basin (GRB) is one of the larger river basins in the Iberian Peninsula, being 67,147 km2, shared by Spain and Portugal (55,527 km2 (83%) and 11,620 km2 (17%) respectively). GRB has been covered in full in GuaSEEAW+ project. GRB has been separated, according Guadiana water managers' needs, in the following four subareas: i. Upper Guadiana: including the Oriental Exploitation System, which includes the Upper Subsystem, the Bullaque Subsystem and the Tirteafuera Subsystem. ii. Middle Guadiana: including the Central System and the Ardila System. iii. Lower Guadiana: including the South System. iv. Portugal: including the Portuguese part of the basin.  Guadiana River Basin
Temporal scales • **Time unit at which the water balance is developed** • **Smallest time unit considered**	Among the hydrological restrictions of the Guadiana River Basin, the seasonal irregularity and the hydrological diversity are the most remarkable elements (see figure). As a result, water management is closely connected to spatial and temporal considerations. To access climatic variability it is necessary to deal with relatively large time series up to 40 years long, that ensure adequate cover of the inter annual variability. Moreover, the seasonal variability needs a sufficiently smooth discretization in order to identify local and seasonal issues of lack of water availability. Following the Spanish legislation, a monthly discretization was established. This temporal subdivision is adequate for planning, to identify local and temporal issues of water availability.  Monthly distribution of the average water input and series of average annual water inputs of Guadiana's river basin for the 1940-2005 period (Guadiana Hydrological Plan 2009-2015)

Accounting for the environmental demand	Water accounts in SEEAW describe the economic activities and sectors as driving forces related to the water system. These driving forces exert different types of pressures such as water extraction and emissions to environment. As a result, SEEAW does not consider specifically the environmental water demand. However, the water balance in the GuaSEEAW Project + (following the Spanish methodology for the development of RBMP-River Basin Management Plan) has taken into account the environmental demands of the basin. The environmental demands are considered as a restriction pertaining to the natural resource, external to the water use system, and have a prior and superior character. In this sense, the methodology applied clearly identifies the concepts of natural resource, potential resource and available resource (see figure). These restrictions limit the real water use: one can consider supply or availability of resources, only after having complied with these environmental constraints. In addition to these environmental constraints that determine the potential resource, there are others of a technical character that may limit water use (depending on transport and storage infrastructure, etc.) and determine the amount of resources actually available for productive use. A conceptual scheme of mobilization of natural resources and their transformation into available resources (White Paper on Water in Spain, MAGRAMA 2000) is given below.  The determination of the amount of environmental demand is a complex issue which has recently been addressed in the EC Guidance document on Ecological flows in the Implementation of the Water Framework Directive (EC 2015). In the work of the RBMP of Spanish part of the Guadiana this is resolved by habitat models (Instream Flow Incremental Methodology) and habitat-hydraulic models. After estimating, these Eflows are introduced in the model basin management (AQUATOOL) through appropriate operating rules for environmental flows met in strategic surfaces water bodies. In the case of groundwater bodies, the IPH sets the environmental constraint as the average annual rate of flow required to achieve the objectives of ecological quality in associated surface water bodies. Currently, given the great difficulty to make a reliable technical approach, it has been considered, as a first approximation, an environmental demand as 20% of the natural resource of each groundwater body. This volume of water does not enter the calculation of resource available for productive purposes.
Accounting for potential desalination	In the Guadiana demarcation there is no plan to install any desalination facility, so this kind of actions have not been considered in the project.
Accounting for potential water transfers	Water transfers from other basins have been included in the Hydrological Plan to increase available resources and meet existing demands on those management systems

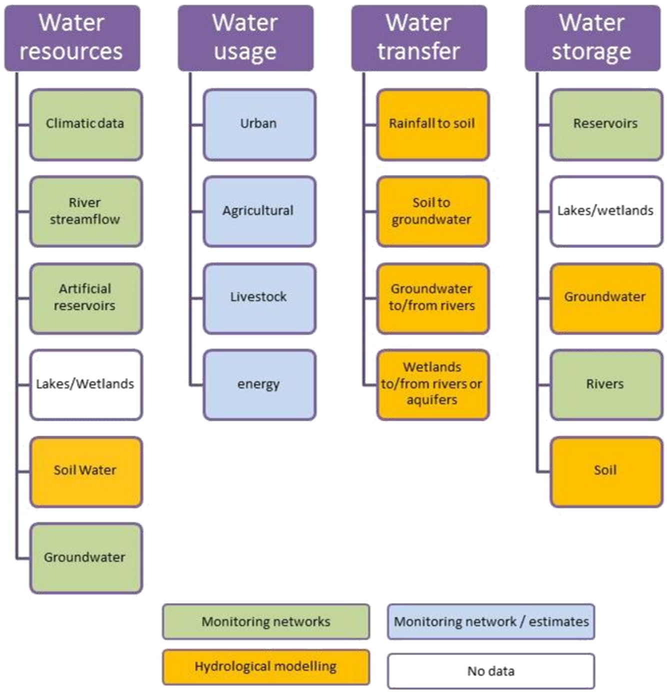
that, exclusively with resources of internal origin, are unable to meet this objective. For this aim it is planned to import 71 Mm3/year from other river basins, which would mean 1.5% of the available resources in the Guadiana, mostly from the Tagus.

To carry out these transfers it is planned to use transport infrastructures, i.e. the Tajo-Segura transfer.

These infrastructures are considered in the Hydrological Plan in modelling future scenarios of balances. However, in the model developed for the Guaseeaw+ project update exercise was carried out on real data as of 2011, so they were not taken into account as infrastructures for subsequent planning scenarios.

Information mobilised

All data used to develop water balances are obtained from the RBMP of the international Guadiana river basin. The origin of the data and acquisition strategies are summarized in the following figure.



Most of the information on water resources comes from monitoring networks: climate data, rivers flow rate, reservoirs water volumes, groundwater levels in aquifers.

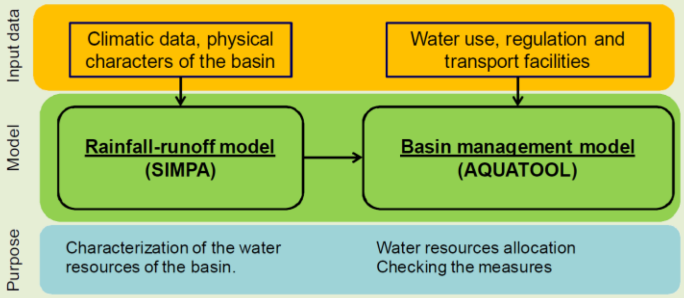
Data on water use comes from monitoring networks (flowmeters or gauging stations in irrigation channels) on the main water users of the basin, supplemented by indirect estimates when no direct data are available. The non-consumptive, hydroelectric power water use is one of the most important in relation to water volume used. The information on the volume of turbinated water is supplied by the users. In the case of consumptive uses, returns are calculated from coefficients that have been evaluated for each unit of demand depending on their specific features (or, if available, with real data from flowmeters or gauging stations for urban or industrial).

Other variables are complex to estimate, especially those having to do with exchange rates between different components of the water cycle: evapotranspiration, groundwater recharge, or transfers between rivers and aquifers or between wetlands and aquifers. To estimate these variables, hydrological modelling tools have been used.

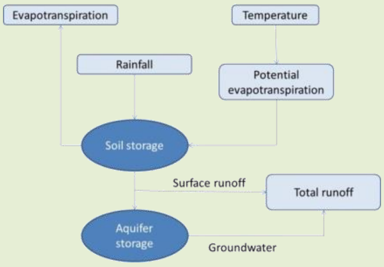
All this information has been prepared and verified under the RBMP, so homogenized series are arranged on a monthly basis and for a time series of 1980/81 - 2011/12.

Main sources of uncertainty

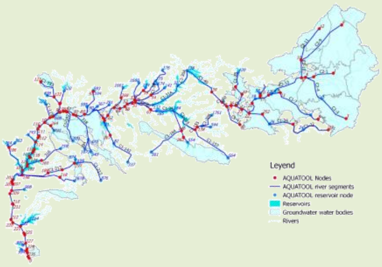
SEEAW water balances involve several resources of several magnitudes that require different gathering strategies, which can cause a problem when closing the water balance for the control period. For instance, while the total water extraction from the basin accounts for about 3,000 cubic Mm/year, the evapotranspiration reaches values

	greater than 14,000 cubic Mm/year. Such magnitudes exceed in amount the closing stocks of the water account, to which they transmit an error that almost for sure exceeds the value of key aspects such as water abstraction. The uncertainty of data such as river flows, or water abstraction is relatively small and known, since most of them are gathered from direct measuring using devices such as gauging stations or flow meters. Nevertheless, evapotranspiration or soil humidity (among others) are variables of difficult estimation that required to be modelled. It is hard to calculate the uncertainty of such variables statistically. There can be an approximation through complex sensitivity analysis of the model, but technically it is very hard to determine its contribution to the aggregated error in the closing balance.
	With the available information it is possible to have a quantitative valuation of the groundwater transferences between rivers and aquifers. However, the assessment of deep groundwater reserves has a great associated uncertainty. This is mainly due to the complexity of getting information on the deep aquifers geometry and their hydrodynamic properties. The balances in lakes and wetlands in the basin also have great uncertainty due mainly to the lack of gauging data from the official control networks. However, this is a very small volume considering the global basin water balance. Besides, the most relevant wetlands of the basin are subject to environmental protection measures, and are not considered as available water resources to be exploited. In relation to the demands, the most important of the basin are controlled by metering and gauging devices in channels, so that there is adequate approximation to the actual consumption of the basin. However, there are illegal withdrawals, mainly from groundwater in the middle and upper reaches of the watershed that are outside of this type of direct control. Actual consumption in this case cannot be estimated only by direct measurements. In these areas the estimation of actual areas of irrigation and water consumed by remote sensing has proved to be an efficient tool.
Link to modelling	The Guadiana basin forms a complex water resource system, with several water reservoirs, piping, superficial and groundwater extractions to supply agricultural, urban and industrial demands, flood control systems, hydroelectric production, etc. Thus, the main rivers of the watershed show a hydric regime very modified when compared to their natural flow regime. This, added to its sharp seasonal variability and its remarkable spatial diversity, results in a very complex hydrological behaviour of the basin. To analyse this complexity, Spanish authorities have used, in the scope of RBMP, hydrological modelling tools to address hydrological balances, detailed on a monthly basis and by river segment (coherent with the water bodies division considered in the WFD). This modelling strategy was established at the national level through the Hydrological Planning Instruction (ORDEN ARM/2656/2008, 10th September) for all the basin plans shared by several Autonomous Communities.  Schematic diagram of hydrological modelling implemented in the Guadiana Water Management Plan

Water balance components in SIMPA



Hydraulic diagram of the basin used in AQUATOOL



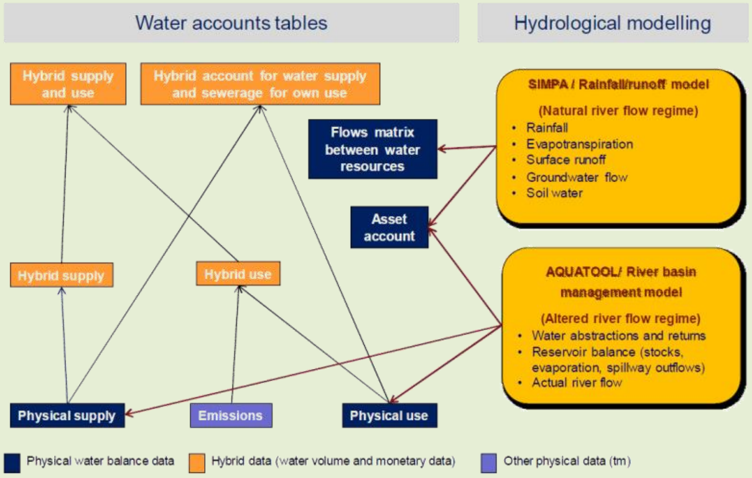
This includes a first step in which a rainfall/runoff model (SIMPA) was run, which allowed assessment of the water resources of the basin in natural flow regime. After that, the results of SIMPA model were implemented in a river basin management model (AQUATOOL). The model includes water demands for different activities and their returns to the rivers, the facilities for water storage and transport and the rules of operation of reservoirs. This modelling simulates the actual hydrological conditions of the basin and allows the evaluation of different stress scenarios (changes in demand, rules operations, etc.). It also runs on a monthly basis.

From this modelling strategy it is possible to get a monthly water balance for series of up to 40 years. Most of the data required by the SEEAW for water balance can be obtained from this modelling scheme.

The SEEAW tables containing information on water balances are essentially the physical use and supply tables, the asset account table and the matrix of flows between water resources. Part of the physical information of these tables feeds the hybrid tables, along with other physical and monetary information.

Information on use and physical supply - abstractions and returns - comes from the modelling of river basin management with AQUATOOL. Data about the water balance in reservoirs (stocks, evaporation, and releases spillway outflows) and river flows, as required in the table of asset accounts, have been taken from management modelling with AQUATOOL. This information is quite consistent and heavily relies on direct observation and studies of characterization of water use and produces a picture about water exploitation of the basin pretty close to reality.

The natural flow regime modelling (SIMPA) provides data on precipitation, evapotranspiration, surface and groundwater runoff and soil moisture. Fundamentally this information nourishes the matrix of flows between water resources. It also covers part of the required data in the table of asset accounts.



Socio-economic indicators estimated	Economic information has been implemented into GuaSEEAW+, following the implementation of SEEAW tables. Standard tables: – Physical supply and use of water. – Hybrid supply and use of water. – Hybrid account for supply and use of water. – Government accounts. – National expenditure accounts. – Asset accounts. Supplementary tables: – Matrix of flows between water resources. These tables have been incorporated into the GuaSEEAW+ Data Model so they become dynamic tables that can be easily updated, improving their utility for water managers and facilitating the calculation of results at different spatial and temporal resolutions and the implementation of indicators supporting policies and decision making processes: www.seeawater.eu
Main management scenarios investigated	The scope of the project has been implementing SEEAW tables on the water balance and the hybrid tables with real data (updated 2011). In this sense, it only has taken into account the current management scenario as it is implemented in the RBMP. No other scenarios have been simulated.
Other specific challenges met when developing the water balance	Considering the most relevant tables in the water balance, the use and physical offer, is possible to get a suitable outcome from the available information. The results are consistent with the physical reality of the basin since they are largely based on direct observed real data. Besides, these balances generated by the responsible authorities are consistent with the official figures used in the RBMP for the allocation of water resources and in the measures of the Plan. The assets tables and matrix of flows between water resources complement the water balance vision in SEEAW. There are some minor gaps in these tables, especially related to water stored in lakes and wetlands, for which there is almost no information coming from control networks. However, this is a very small volume considering the global basin water balance. Besides, the most relevant wetlands of the basin are subject to environmental protection measures, and are not considered as available water resources to be exploited. The basin deep groundwater reserves are another source of uncertainty. With the available information is possible to have an objective quantitative valuation of the groundwater transferences towards/from the rivers. However, the assessment of the deep groundwater reserves has a great associated uncertainty.
General comments	The Spanish Water authority has shown a great interest by the applicability of statistical SEEAW methodology for water planning in Spain. The Spanish water authorities already have a well-established background in the field of water balances necessary to address recurrent episodes of scarcity in many of the Spanish basins. RBMP in Spain are demanding consistent water balances, since from it depends the significant investment in water infrastructure to be undertaken by the authorities in Spain through the programmes of measures in the respective management

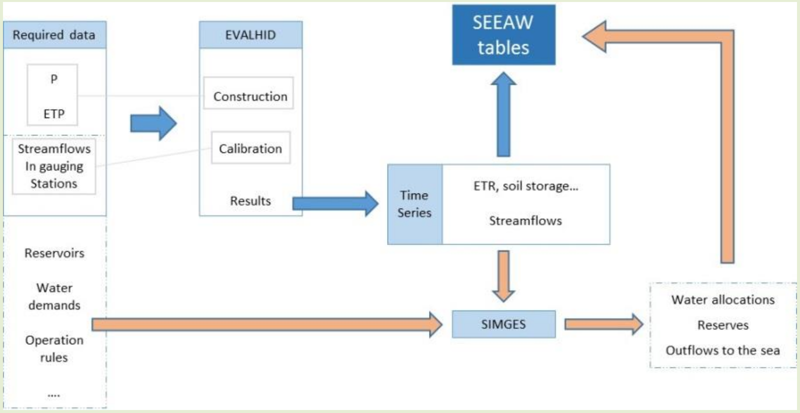
plans.

Therefore, and in line with the guidelines of cost recovery policy, one of the main concerns of the authorities is the need to establish relationships between water and economy at the administrative level in order to define, promote and discuss important decisions. It seems that SEEAW tables will help to achieve it. Its mandatory disaggregation between economic sectors, dry and irrigated agriculture, (between blue and green water, as stated in water footprint terms), types of industries and taking into account tourism is quite important. They consider mandatory to know the correct price of water in order to better define a proper recovery cost policy.

Presently it is remarkably difficult to establish relationships between hydrologic and economic data, as they are compiled by different authorities with different spatial and temporal aggregation levels, standards and objectives.

Name of the Pilot project	Water Accounting in a Multi Catchment District (WAMCD)
Spatial scales • Territory (catchment, other) covered by the pilot project • Basic unit at which the water balance has been set (water body, catchment, other)	The methodological approach is focused on filling the SEEAW tables for the Mediterranean Basins of Andalucía River Basin District [MBA RBD]. The total surface area is 17,762.32 km^2. The RBD includes 16 subsystems, ranging from 145.8 km^2 to 3,481.02 km^2.  Water balances have been set at subsystem level (assets account) or RBD level (physical supply and use), but rely on subsystem datasets. The choice is justified by the wide range of climatic conditions and management differences among subsystems. The Project was intending to provide a benchmark for the application of water accounts to heterogeneous environments and climates, but with similar datasets and criteria.
Temporal scales • Time unit at which the water balance is developed • Smallest time unit considered	As far as water balances are concerned (SEEAW water assets tables), the time unit has been the month. The main hydrological datasets are available on a monthly basis and a variety of modelling tools (integrated in AQUATOOL DSS) have been applied working at this scale (see below). The monthly scale better reflects the seasonal irregularity of water regimes in the RBD. Another important issue is the reference period. There are two basic options when calculating water balances: using one specific (hydrological) reference year (e.g. 2005/06) or using some statistical value representing a series of years. According to the Spanish Technical Regulation, balance between resources and demands must be representative of normal supply conditions. This criterion has been reproduced by using the 50th percentile of the monthly components of the water assets. The analysis of the irregularity of the hydrological regime has been introduced through a complementary assessment to determine asset accounts for the driest phase of the reference period, namely the triennium from 1992/93 to 1994/95.
Accounting for the environmental demand	A specific tool for environmental allocation assessment (CAUDECO) has been tested. E-flow regimes, determined in the framework of the River Basin Management Plan [RBMP], have also been considered when simulating the exploitation of systems depending on reservoirs. Nevertheless, SEEAW does not explicitly consider environmental demands.
Accounting for potential desalination	Both "transfers from and to the rest of the world" and "desalinated water" (two expressions from the SEEAW tables) are specifically accounted for in the Table III.3 of SEEAW (*Detailed physical supply and use tables*). In the Table VI.1 (*Asset accounts*) the inflows from both desalination and external transfers have been allocated, for practical reasons, under the concept *Transfers from upstream territories*.
Accounting for potential water transfers	In addition, internal transfers within the RBD have been considered when filling the tables.

Information mobilised	Potential data sources have been identified and available data have been collected, mainly from: • ”Mediterranean Basins of Andalusia River Basin Management Plan 2009" [RBMP-09] and the “Draft Proposal of Mediterranean Basins of Andalusia River Basin Management Plan 2015" [RBMP-15] • SIMPA model (hydrological datasets) • Institute of Statistics and Cartography of Andalusia • Spanish Statistical Office The information collected has been put into relation with the data included in the RBMPs and with the grouping of ISIC activities required by SEEAW.
Main sources of uncertainty	The combination of information from different sources causes certain problems for closing water assets balances. Ideally, the use of consistent rainfall-runoff models integrated with management simulation models should end up in completely coherent water assets. This approach has been explored in the WAMCD Project and should be implemented in the framework of the next WFD management cycle. In the meantime, the component *Other changes in volume* of Table V-1 that has been calculated as a residual, gives a relative magnitude of the maladjustments caused by mixing different sources. This way, it is relevant to focus future efforts on those subsystems were major problems have been identified.
	Direct measurement (or fine assessment) of stocks of groundwater and soil water are not feasible at reasonable costs for the whole RBD. EVALHID and CAUDECO modules from AQUATOOL DSS have been tested and a specific tool for data transfer from this model to the SEEAW tables has been applied in the case study of the Velez River Basin, where both rainfall-runoff and simulation management models were available.

Link to modelling	EVALHID in combination with SIMGES has proven to be an effective tool for organizing the required information since: • It allows choice among different rainfall-runoff models (Témez, HBV, Sacramento and others), to be selected depending on the available data, the complexity of the basin and the user's experience. • It provides spatially distributed information on the hydrological parameters needed for a comprehensive assessment: temperature, precipitation, potential actual evapotranspiration, infiltration, surface runoff, groundwater runoff, soil storage. • Streamflow series may be introduced in management simulation models (such as SIMGES), so it is possible to obtain other relevant data regarding water allocation: development of storage in reservoirs, supply deficits, environmental flows, water transfers, outflows to the sea...Moreover, the results of SIMGES reflecting the altered flow regime may feedback into the calibration of the rainfall-runoff model.  We understand that these kind of models are fundamental for supporting management decisions for a variety of reasons: • They introduce seasonal and inter-annual variability, which are key aspects when hydrological variability and water scarcity are relevant issues. • They allow simulation of different management alternatives/solutions, both at detailed or strategic planning level. • They enable a better assessment of scenarios linked to expected changes in pressures or climate induced ones: on the one hand, by translating temperature and precipitation variations into effects in the other components of the water cycle (streamflow, infiltration…); on the other hand, helping to evaluate their impacts on water allocation to human activity and the environment.
Socio-economic indicators estimated	On the one hand, SEEAW includes a set of hybrid accounting tables to integrate physical and economic datasets with water use accounts. On the other hand, to synthesize the massive amount of information compiled, a collection of thirty-five relevant indicators has been calculated on the basis of the SEEAW tables (and with the occasional support of intermediate/auxiliary tables). Indicators refer to water resource availability, water use for human activities, opportunities to increase effective water supply, water cost, pricing and incentives for conservation and other supplementary indicators. Additionally, comprehensive WEI+ estimates have been made.

Main management scenarios investigated	The whole work has been closely linked to the RBM planning process and is intended to be consistent with RBMP-15 and, at the same time, provide valuable inputs to the planning process. Three scenarios have been characterized by the SEEAW set of tables: 2009 (baseline, corresponding to RBMP-09), 2015 (current scenario of RBMP-15) and 2021 (future scenario after the implementation of the PoM). All the measures included in the MBA PoM and others suggested by the Project Team have being structured and classified. Moreover, the resulting group of measures/lines of action (along with the main drivers) have been characterized in terms of their main effects on the water accounts, and summarized in a catalogue. For each entry, the following data are included: name of the measure; response to; main effects on physical accounts; main effects on economic and hybrid accounts; supplier and user; metering; assessment; PoM (inclusion or not in the MBA PoM); additional information (including relevant regulatory or administrative tools supporting the measure).
Other specific challenges met when developing the water balance	The main challenges identified were (some have been mentioned before): • Complex calculation of physical tables when mixing data from different information sources, eroding internal consistency of water assets. • Lack of data on volume, quality and destination of water returns to the environment after use. • Lack of direct measurement of groundwater reserves, soil water and scarce data on the snowpack. • Different alternatives for the calculation period for water assets. • Consideration of hydrological irregularity. • Environmental water allocation not properly considered in SEEAW. • SEEAW provides a great deal of data, difficult to handle and to extract conclusions. • Scale of available economic information corresponds to the administrative units, not water catchments. • Aggregation of ISIC activity sectors, relevant for SEEAW in the Input/Output Tables and other macroeconomic datasets. Different solutions have been adopted to overcome these problems, as reflected in the upcoming Final Technical Report.

General comments	Regarding potential use: • The SEEAW provides a useful standard for the building of water balances and a conceptual framework to integrate economic data, describing the interaction of economic activity, water resources and water use. • If sustained over time, the SEEAW can be a useful tool for monitoring the evolution and impacts of policies related to water. • The SEEAW is compatible (and may be complementary) with the traditional water balances established in the Spanish RBMPs for the allocation and reserve of water resources. • The calculation of the cost recovery rate, as required by the Water Framework Directive, may be enhanced with the support of the SEEAW, since interchanges among activities related to the provision and use of water are further clarified. • The SEEAW may be a support tool to analyse the effects of strategic options affecting the water cycle and water use. Regarding limitations: • It is difficult to ensure internal consistency of water assets when direct data and model (and/or other kind of) estimates are used, which is the usual case. Direct measurement (or fine assessment) of stocks of groundwater and soil water are not feasible at reasonable costs for the whole RBDs. • The SEEAW is very demanding in terms of information requirements and, frequently, no direct data are available to fill many of the boxes. In Spain, this is particularly true in the case of economic statistics, forcing the use of additional criteria and proxies. The lack of information hinders practical applicability of the SEEAW and questions the uniformity and comparability of results, eroding, to some extent, its positive role as a common standard. • Though SEEAW provides useful information on the pressure exerted by human activity on water ecosystems, environmental water allocation is not integrated into SEEAW and additional analyses and indicators have to be developed and carried out. • The SEEAW cannot substitute DSS tools (AQUATOOL or similar) to build significant water balances, if water scarcity and hydrological irregularity are a major issue. Similarly, it is not the appropriate tool to analyse specific investment options where environmental and socio-economic impacts and benefits must be carefully assessed.

ANNEX III –COMPARISON BETWEEN THE “SEEAW ASSET ACCOUNTS” AND THE “WATER BALANCE” COMPONENTS

The System of Environmental-Economic Accounting for Water (SEEAW) was developed by the United Nations Statistics Division (UNSD) in collaboration with the London Group on Environmental Accounting and contributions from the Eurostat Task Force on Water Accounts, with the objective of standardizing concepts and methods in water accounting. The SEEAW purpose is to encourage countries to launch an integrated water resources management (IWRM) approach through the establishment of an operational framework that integrates economic and hydrological information. Following the original Handbook of National Accounting “Integrated Environmental and Economic Accounting -2003[41]” (commonly referred to as SEEA-2003) which provided the opportunity to develop methodologies for water accounts, the UN Committee of Experts on Environmental-Economic Accounting (UNCEEA) was established in 2005 with an aim to raise the system of environmental accounts to an international statistical standard and to advance the implementation of SEEA in all countries. The final draft of the SEEAW was established in 2007 to conform to the content and style of an international statistical standard, while a fictitious dataset was developed to populate the standard tables (UNSD, 2007[42]), and was further updated in 2012 [9]. The main argument for implementing the SEEAW is that it provides the much-needed conceptual framework for organizing hydrological and economic information in support of Integrated Water Resource Management (IWRM), permitting a consistent analysis of the contribution of water to the economy and the impact of the economy on water resources, and should be thus adopted as the international standard for water statistics. The SEEAW-2012 accounting framework considers the stocks, flows and exchange of flows between the environment (i.e. water resources and the different components of the hydrological cycle) and the economy (i.e. water abstraction, use and return from/to the different NACE economic activities), and includes, as part of its standard presentation, information on the following [9]:

- Stocks and flows of water resources within the environment;
- Pressures imposed on the environment by the economy from water abstraction and emissions added to wastewater and released into the environment or removed from wastewater;
- The supply of water and its use as an input in production processes and by households;
- The reuse of water within the economy;
- The costs of collection, purification, distribution and treatment of water, as well as the service charges paid by its users;
- The financing of these costs, that is, who is to pay for the water supply and sanitation services;

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[41] United Nations Statistics Division (UNSD). 2003. Handbook of National Accounting: Integrated Environmental and Economic Accounting: An Operational Manual, Series F, No. 78, Rev.1 (United Nations publication, Sales No. E.00. XVII.17).

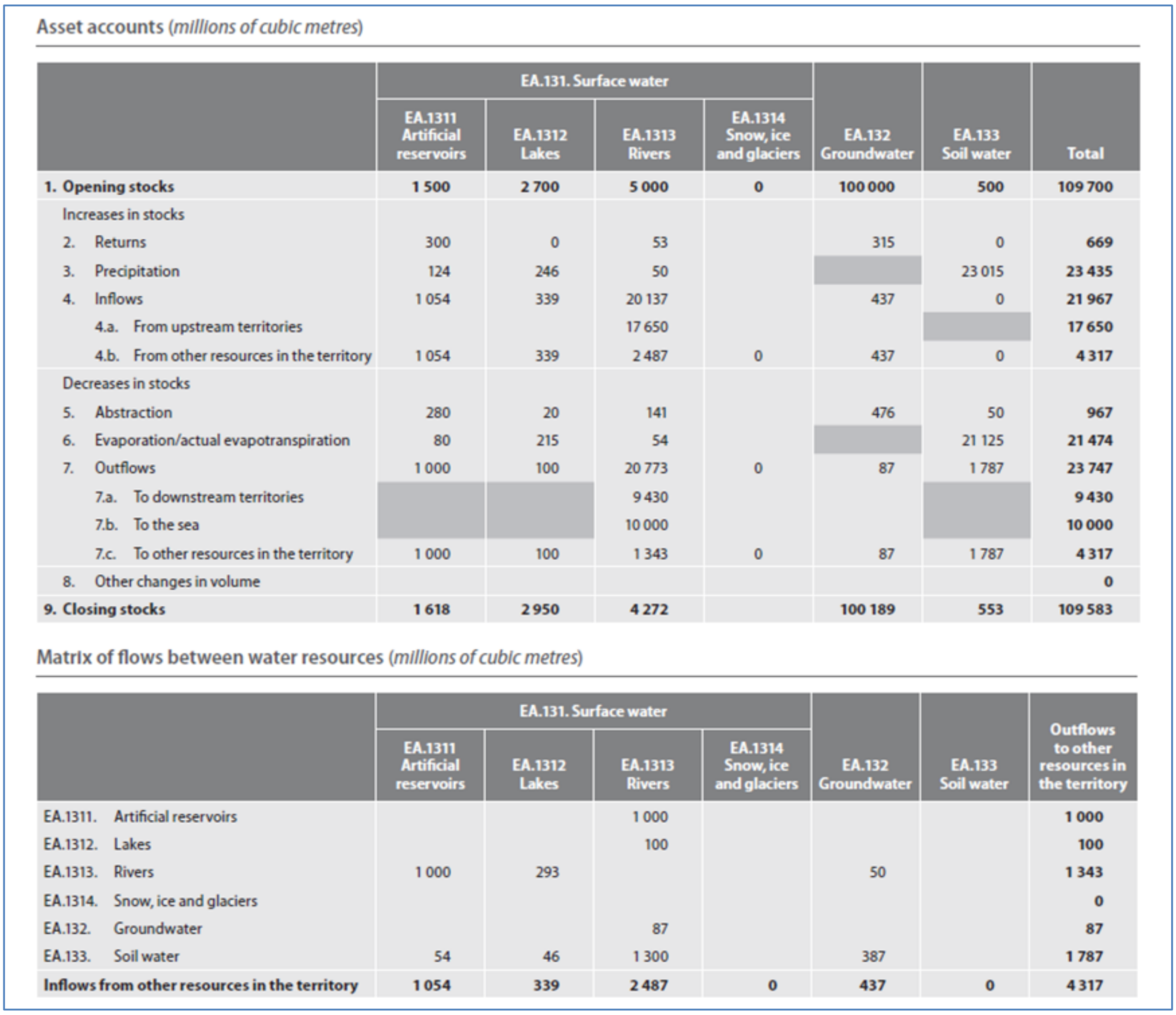
[42] United Nations Statistics Division (UNSD). 2007. System of Environmental-Economic Accounting for Water. Final Draft, March 2007.

- The payment of permits for access to abstract water or to discharge wastewater;
- The hydraulic stock in place, as well as investments in hydraulic infrastructure made during the accounting period.

SEEAW also presents water quality accounts (yet at an experimental level) and proposes a set of indicators which can be derived from the accounting systems (rather than from individual sets of water statistics) and are useful to the policy makers.

The five main categories of water accounts are described below [9]:

1. Physical supply and use tables and emission accounts: the physical supply and use tables collect information on the volumes of water exchanged between the environment and the economy (abstractions and returns) and within the economy (supply and use within the economy). The emission tables collect information on the quantity of pollutants which have been added to or removed from the water (by treatment processes) during its use by economic activities and households.
2. Hybrid and economic accounts: these accounts combine the physical information of the water supply and use tables with monetary information (e.g. costs associated with water use and supply, such as water abstraction, purification, distribution, wastewater treatment, etc.). They also provide information on financing, i.e. the amount that users pay for the services of wastewater treatment, etc.
3. Asset accounts: these tables provide information on the water resources in physical terms (opening and closing stocks, changes in stocks due to precipitation, evapotranspiration, inflows, outflows, abstractions and returns) and link water availability to abstractions, thus facilitating the identification of pressures on the environment. The additional supplementary tables convey information on the flows between the compartments of the hydrological cycle.
4. Quality accounts: these tables provide information on the quality of the stock of the water resources. They are still at an experimental level.
5. Valuation of water resources: these tables provide information on the valuation of water and water resources. In the case of water quality these are still at an experimental level.



Asset accounts (*millions of cubic metres*)

	EA.131. Surface water						
	EA.1311 Artificial reservoirs	EA.1312 Lakes	EA.1313 Rivers	EA.1314 Snow, ice and glaciers	EA.132 Groundwater	EA.133 Soil water	Total
1. Opening stocks	**1 500**	**2 700**	**5 000**	**0**	**100 000**	**500**	**109 700**
Increases in stocks							
2. Returns	300	0	53		315	0	**669**
3. Precipitation	124	246	50			23 015	**23 435**
4. Inflows	1 054	339	20 137		437	0	**21 967**
4.a. From upstream territories			17 650				**17 650**
4.b. From other resources in the territory	1 054	339	2 487	0	437	0	**4 317**
Decreases in stocks							
5. Abstraction	280	20	141		476	50	**967**
6. Evaporation/actual evapotranspiration	80	215	54			21 125	**21 474**
7. Outflows	1 000	100	20 773	0	87	1 787	**23 747**
7.a. To downstream territories			9 430				**9 430**
7.b. To the sea			10 000				**10 000**
7.c. To other resources in the territory	1 000	100	1 343	0	87	1 787	**4 317**
8. Other changes in volume							**0**
9. Closing stocks	**1 618**	**2 950**	**4 272**		**100 189**	**553**	**109 583**

Matrix of flows between water resources (*millions of cubic metres*)

	EA.131. Surface water						
	EA.1311 Artificial reservoirs	EA.1312 Lakes	EA.1313 Rivers	EA.1314 Snow, ice and glaciers	EA.132 Groundwater	EA.133 Soil water	Outflows to other resources in the territory
EA.1311. Artificial reservoirs			1 000				**1 000**
EA.1312. Lakes			100				**100**
EA.1313. Rivers	1 000	293			50		**1 343**
EA.1314. Snow, ice and glaciers							**0**
EA.132. Groundwater			87				**87**
EA.133. Soil water	54	46	1 300		387		**1 787**
Inflows from other resources in the territory	**1 054**	**339**	**2 487**	**0**	**437**	**0**	**4 317**

Figure 1: SEEAW “Asset Accounts main” and supplementary tables.

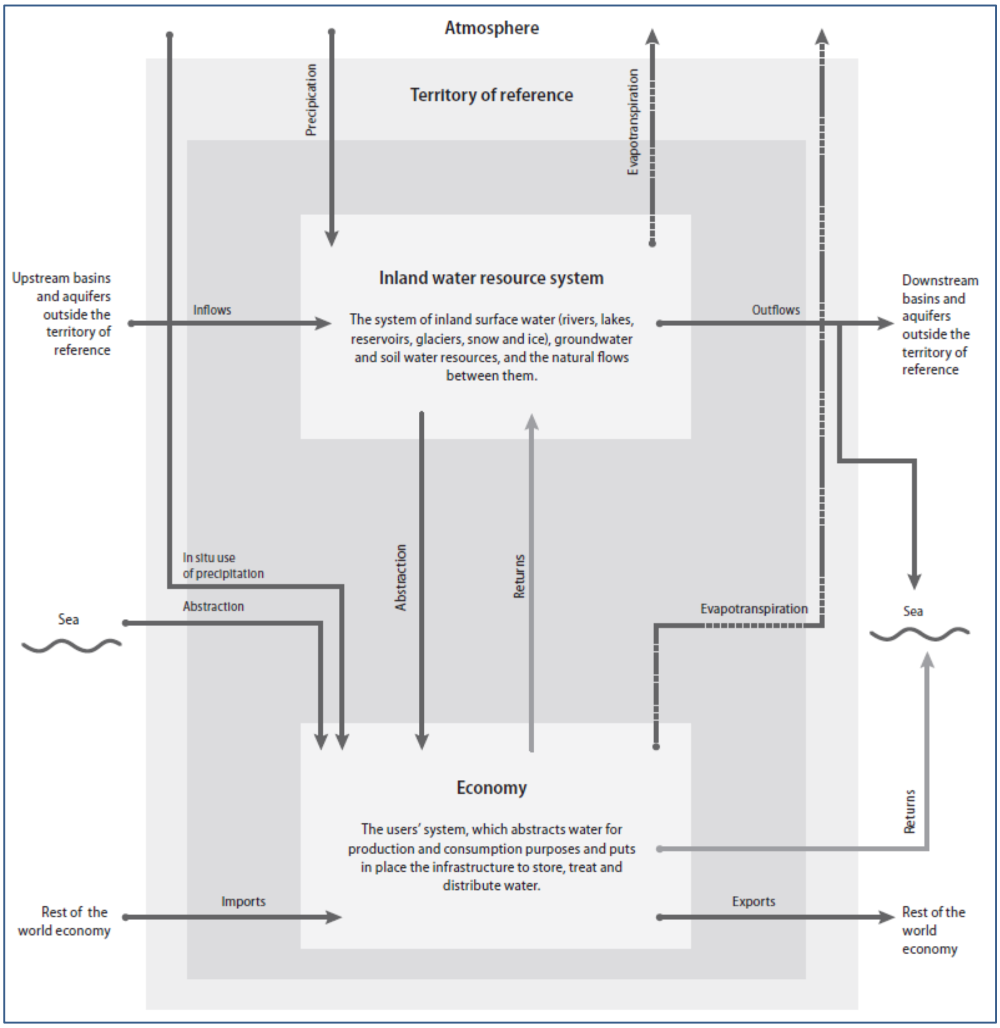


Figure 2: Main water flows between the inland water resource system and the economy captured by the SEEAW. Source: UNSD, 2012

Table 1. Comparison between SEEAW Asset Accounts and Water Balances parameters and definitions

	SEEAW Parameter	SEEAW Definition	WB Parameter	WB Definition
INPUTS	Precipitation (in artificial reservoirs, lakes, rivers, snow/ice/glaciers, soil water)	The total volume of atmospheric wet precipitation, such as rain, snow and hail, on a territory in a given period of time.	Precipitation (areal, in the hydrological unit of analysis)	Total volume of atmospheric wet precipitation (rain, snow, hail, etc.). Precipitation is usually measured by meteorological or hydrological institutes.
	Inflows from upstream territories (in artificial reservoirs, lakes, rivers, snow/ice/glaciers, groundwater)	Inflows: Water that flows into a stream, lake, reservoir, container, basin, aquifer system, etc. It includes inflows from other territories/ countries and inflows from other resources within the territory.	External Inflow (to surface water, groundwater)	Total volume of actual flow of rivers and groundwater entering the hydrological unit of analysis from neighbouring territories/ other units [hm3/ time unit]. External Inflow must not be confused with the inputs received from economic units (e.g. desalination, water reuse) or the imported water since those are directed for consumption and only a part of them is finally discharged to the rivers and groundwater via returns.
	Inflows from other resources in the territory (in artificial reservoirs, lakes, rivers, snow/ice/glaciers, groundwater, soil water)		Incorporated in Returned water	Internal transfers in the hydrological unit such as artificial groundwater recharge with source-water generated within (abstracted from) the hydrological unit, and/or recharges into rivers with source-water generated within (abstracted from) the hydrological unit can be considered under the returned water component for the current Water Balance calculation purposes. Discharges to the sea are excluded.
	Returns (to artificial reservoirs, lakes, rivers, snow/ice/glaciers, groundwater, soil water)	Water that is returned into the environment by an economic unit during a given period of time **after use.** Returns can be classified according to the receiving media (water resources and sea water) and to the type of water, such as treated water and cooling water).	Returned water	Volume of abstracted water, and/or water produced by economic units, and/or imported, that is discharged to the fresh water resources of the hydrological unit **either before use (as losses) or after use (as treated or non-treated effluent).** It includes water that was directly discharged from a user (e.g. domestic, industrial etc. including cooling water, mining), and water lost from the waste water collection system (as overflow or leakage). * Internal transfers in the hydrological unit such as artificial groundwater recharge with source-water generated within (abstracted from) the hydrological unit, and/or recharges into rivers with source-water generated within (abstracted from) the hydrological unit can be considered under the returned water component for the current WB calculation purposes. Discharges to the sea are excluded.

OUTPUTS	Evaporation/ Actual Evapotranspiration (from artificial reservoirs, lakes, rivers, snow/ice/glaciers, soil water)	Evaporation: The quantity of water transferred from the soil to the atmosphere by evaporation and plant transpiration. Actual Evapotranspiration: The amount of water that evaporates from the land surface and is transpired by the existing vegetation/plants when the ground is at its natural level of moisture content, which is determined by precipitation.	Actual Evapotranspiration (s: surface, i: interception, t: transpiration)	Total volume of evaporation from the ground, wetlands and natural water bodies and transpiration of plants. According to the definition of this concept in hydrology, the evapotranspiration generated by all human interventions is excluded, except rainfed agriculture and forestry. The “actual evapotranspiration” is measured or calculated using different types of mathematical models, ranging from very simple algorithms (Turc, Penmann, Budyko, Turn Pyke, etc.) and corrections related to vegetal cover and season to schemes that capture the hydrological cycle in detail.
	Outflows to downstream territories (from rivers, snow/ice/glaciers, groundwater)	Flow of water out of a stream, lake, reservoir, container, basin, aquifer system, etc. It includes outflows to other territories/countries, to the sea and to other resources within the territory.	Outflow (from surface waters, from groundwater)	The total volume of actual outflow of rivers and groundwater into the sea plus actual outflow into neighbouring territories (outside the hydrological unit of analysis). Note: Environmental Flow-EF and other Water Requirements-WR as defined e.g. by treaties are a part of the Outflow.
	Outflows to the sea (from rivers, snow/ice/glaciers, groundwater)			
	Outflows to other resources in the territory (from rivers, snow/ice/glaciers, groundwater)		*Incorporated in Abstraction*	Internal transfers in the hydrological unit such as artificial groundwater recharge with source-water generated within (abstracted from) the hydrological unit, and/or recharges into rivers with source-water generated within (abstracted from) the hydrological unit can be considered under the returned water component for the current calculation purposes. Discharges to the sea are excluded.
	Abstraction (from artificial reservoirs, lakes, rivers, snow/ice/glaciers, groundwater, soil water)	The amount of water that is removed from any source, either permanently or temporarily, in a given period of time for final consumption and production activities. Water used for hydroelectric power generation is also considered to be abstraction. Total water abstraction can be broken down according to the type of source, such as water resources and other sources, and the type of use.	Abstraction (from surface water, groundwater)	Water removed from surface or groundwater resources, either permanently or temporarily, regardless of any input from water return or artificial recharge. Mine water and drainage water are included. Water abstracted for hydropower generation (in-situ use) should be excluded from the formulation of the water balance equation, while water abstracted for cooling should be included. Water abstractions from groundwater resources in any given time period are defined as total amount withdrawn from the aquifer.
CHANGE	Opening Stocks (in artificial reservoirs, lakes, rivers, snow/ice/glaciers, groundwater,	Stocks at the beginning of the accounting period.		

	soil water)			
	Other changes in volume (in artificial reservoirs, lakes, rivers, snow/ice/glaciers, groundwater, soil water)		Change in Storage - Natural ΔSnat: in lakes, rivers, soil, groundwater, snow and glaciers - Artificial ΔSart: in regulated lakes, artificial reservoirs	Changes in the stored amount of water (>0, if storage is increasing) during the given time period, including river bed, lakes, underground water (soil moisture and groundwater) as natural part of the storage (Snat) and in regulated lakes or artificial reservoirs (Sart). ΔS can be ignored for long-term averages if it is not feasible to evaluate them, but should be evaluated in annual calculations and be considered in monthly calculations.
	Closing stocks (in artificial reservoirs, lakes, rivers, snow/ice/glaciers, groundwater, soil water)	Stocks at the end of the accounting period		

KH-01-15-728-EN-N

Publications Office