Final report on the implementation of water balances in the EU

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Implementation of water balances in the EU

Final report

European Commission, DG Environment

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1. Executive Summary

A water balance is – in simplified terms - a calculation of the water quantity available during a specific time period (such as a month or a year) in a river basin, considering water abstraction, use and consumption. This calculation can be used to maintain sufficient water levels in water bodies, to ensure their good status/potential, to allocate water to the different users, to avoid overexploitation of natural water resources, and to build resilience against climate change.

In some EU Member States, water balances have been in place for a long time, whilst for others this is a new field of water management. To support their development and use, an EU guidance document was adopted in 2015[1]; however, there are still major challenges for their implementation. The analysis for this report has grouped these challenges (including on the basis of Member State self-assessments) in four blocks:

- **Data availability:** Though most EU Member States implement water balances, usually at the river basin level, water quantity measurements that can help determine consumptive uses across sectors are often either not available or not undertaken systematically.
- **Data reliability** remains a challenge for many Member States, in particular regarding the metering or estimation of water use and consumption[2], especially in irrigation agriculture. A key gap is the estimation of illegal water uses, which in some locations are very significant: these are usually not considered in water balances. Avoiding double accounting for reused water and groundwater-surface water interactions is a challenge in several Member States.
- **Usability** of water balances for river basin management is a further issue. Often the water balances are developed only by water managers without involving relevant researchers and other interested parties and do not necessarily reflect indicators such as sustainability thresholds which can directly be incorporated into the RBMPs and management decisions.
- **Harmonisation** of water balances across borders remains a major challenge, often due to a lack of mutually accepted data, common definitions and procedures for preparing water balances.

This report presents, for many (but not all) of these challenges, illustrative examples that have been collected from volunteering Member States. These examples could guide others that are still in the process of setting up water balances or struggling with implementation challenges.

Water scarcity and droughts have struck many regions in Europe over the past years, illustrating the need for urgent and transformative action to adapt to climate change – and for the implementation and use of effective water balances. In consequence, the following **recommendations** are made for improving water balances as the knowledge basis for water allocation decision-making:

- Calculations of water use (abstraction, consumption, return) should move further from estimations to real data (metering), especially for large consumers.
- Illegal water use should be estimated and accounted for in calculations of the water balance, especially for irrigation agriculture.
- Transboundary cooperation should be improved, by exploring opportunities to share monitoring, databases and modelling tools, as well as joint assessments of the water balance results.
- Water balances should be updated regularly, to reflect changes due to climate change, such as projected increases in variability of temperatures and precipitation.
- In areas with significant water scarcity, impacts on water quality and the effects of water prices should be explored in water balances to improve the understanding of the system, its values and its risks.

2. Context

In 2022 and 2023, the ad-hoc technical group on water scarcity and drought under the Common Implementation Strategy (CIS) for the Water Framework Directive (WFD) has addressed several

[1] European Commission, Directorate-General for Environment (2015): Guidance document on the application of water balances for supporting the implementation of the WFD: final: version 6.1 – 18/05/2015, Publications Office, 2015, https://data.europa.eu/doi/10.2779/352735

[2] The part of the used water which is not returned to the water system e.g., downstream.

related topics. In particular, three interrelated background documents have been prepared to review and foster the implementation of key tools to better manage water scarcity and drought: (1) water balances (this report), (2) water allocation mechanisms and (3) ecological flows.

Water balances take stock of the available water resources and water use and conclude with a review statement of water supply feasibility and/or overexploitation. They constitute a proper knowledge basis for the establishment and implementation of water allocation mechanisms, which allow water use in a certain area or time. Water allocation mechanisms are also key for ensuring that ecological flows are implemented, ensuring the achievement of good ecological status/potential under the Water Framework Directive and broader biodiversity and sustainability goals.

This report was produced as an input to the ATG WSD's work but does not represent in itself an output of that WG, contrary to CIS Guidance Documents. The contents draw largely from consultants' research as well as input received from ATG WSD members during surveys, meetings and discussions (see below, section 4.2). This report strives to add value to the 2015 CIS Guidance which already covered the following topics, providing guidance for developing water balances:

- Key components of water balances
- Key issues in developing water balances
- Applying water balances in practice
- Using water balances for supporting water management
- Expanding the physical water balance for addressing
- Complementary water management issues
- Recommendations and conclusions

However, the Commission's 5th WFD Implementation report (EC, 2019) pointed out insufficient implementation of ecological flow and water balances, despite their significant potential to contribute to solving water scarcity problems. Therefore, a contractor was requested to develop a stock-taking exercise for defining actions in support of enhanced implementation of water balances, particularly focusing on their contribution to achieving WFD objectives and supporting sustainable and climate resilient water management.

This report revisits the implementation of water balances across the EU and builds on a Member States self-assessment of the main challenges facing for developing such water balances, as well as illustrating examples to visualise the progress towards good practice in the implementation of water balances. It aims specifically at how the main challenges faced can be addressed, and is therefore not replacing the 2015 guidance but providing complementary insights on how to progress towards good practices.

3. INTRODUCTION: WATER BALANCES

'Water balances' are mentioned explicitly in the Water Framework Directive. Annex II (Identification of Pressures) requires Member States to "collect and maintain information on the type and magnitude of the significant anthropogenic pressures to which the surface water bodies in each river basin district are liable to be subject, in particular the following: … Estimation and identification of the impact of significant water flow regulation, including water transfer and diversion, on overall flow characteristics and water balances". There is however no WFD obligation in place for developing such balances, if related significant pressures are not existing or can be identified by different means.

In addition, WFD Art.4(1) requests Member States to "protect, enhance and restore all bodies of groundwater, ensure a balance between abstraction and recharge of groundwater."

This report focuses on the balances referred to in WFD Annex II to understand the 'bigger picture' at the basin or sub-basin level; however, it includes also references and illustrative examples on balances established for groundwater bodies.

A 'Water Balance' is defined in the 2015 Guidance document (EC, 2015) as the numerical calculation of 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 period (e.g. during a month or a year). These inputs and outputs can occur both naturally and as a result of the human-induced water abstractions and returns. As explained in the guidance, the terminology 'water balance' and 'water accounts' are often used indistinctively, though the accounting part usually refers to the physical (hydrological) and economic information supporting the balance.

In many water-stressed basins, water balances have been developed over decades to allocate water or to identify areas for developing new storage, including natural water retention measures. The 2012 Blueprint for Water identified additional actions that could greatly improve quantitative water management in Europe. According to the Blueprint, water accounts (or balances) "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. Water accounts fill a gap by bringing together knowledge that so far was only available in a scattered and piecemeal manner. If widely implemented, they could go a long way towards helping to solve water scarcity problems, e.g. by better analysing structural and episodic categories of water stress and providing better insights for water resource indicators. Water accounts are closely linked to the identification of ecological flow as they should ensure that the needs of nature are respected and that water balances within a river basin stay within sustainable limits." (EC, 2012)

As a follow-up of the Blueprint, in the framework of previous WFD CIS work programmes, the establishment and improvement of water balances was fostered, for example by a set of pilot grants to explore the applicability and limits of the UN System for Environmental-Economic Accounting for Water (SEEA-W) framework to the European Union. As a follow-up action, in 2015, a Guidance document on the application of water balances for supporting the implementation of the WFD (EC, 2015) was adopted by the EU Water Directors and published.

Since then, water balances have been referred to in several reports and studies (e.g. EEA's 2021 Water resources across Europe — confronting water stress: an updated assessment), but not analysed at a comprehensive pan-European level, nor considered in the European Commission's WFD Implementation reports. The most explicit statement can be found in the Integrated Assessment of the Second River Basin Management Plans (EC, 2019b): "in the 2nd RBMPs, the majority of MSs and RBDs have conducted assessments of water balances, sometimes supported by modelling studies. However, there is no evidence that water accounting frameworks (e.g. UN System for Environmental-Economic Accounting for Water) when put in place are used by water administrations to organise information in a harmonised way and take decisions."

4. Aim of this report

4.1. Scope and purpose of report

The purpose of this report is to elaborate good practices in implementing water balances and to define actions in support of enhanced implementation of water balances, particularly focusing on their contribution to achieving WFD objectives and supporting sustainable and climate resilient water management.

4.2. Methodology

This report has been developed in a stepwise process, driven by the consultants, steered by the European Commission and engaging the members of the ad-hoc technical group on water scarcity and droughts of the Water Policy Common Implementation Strategy (CIS). The main steps of the process have been:

- Analysis of literature, including scientific publications, planning documents, evaluation reports and other sources by the consultants to identify challenges in the implementation of water balances.
- Development of good practice options for each of the challenges identified
- Consultation of the ad-hoc technical group at its autumn 2022 meeting on previous steps
- Development and responses from 20 Member States (AT, BE-FL, BE-WL, CY, CZ, DE, DK, EL, ES, FI, HU, IE, IT, LT, LU, MT, NL, PL, PT, SE, SK) on a self-assessment questionnaire aiming at identifying the situation of challenges and good practice across the EU
- Integration of responses and discussion with the group at the spring 2023 meeting on preliminary findings and priorities set for the further work
- Development and responses by ATG WSD members on a template for collecting illustrative examples in progressing towards good practice

- Validation of the examples and identification of recommendations at the autumn 2023 ATG meeting
- Finalisation of the technical report

5. Key challenges for implementing water balances

The following general constraints and detailed challenges for the implementation of water balances have been identified.

5.1. *Data availability*

Lack of data can impede the setting-up of water balances. The following specific challenges have been found:

- Water quantity measurements that can help determine consumptive uses across sectors are often either not available or not undertaken systematically or comprehensively enough. This can be due to a 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, but also more broadly because of the absence of a water stress or water "imbalance" situation (i.e. not all exploitable water being used) in many catchments; so water managers consider the effort of developing a water balance not justified, instead relying on traditional water management based on local experience and more rudimentary water level information.
- Geographical differences in data collection (e.g. between data collection at the river basin scale and municipal/regional scale) increase the level of uncertainty. This might be due to 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 support policy making.
- Similar data (for instance on water quality) is collected by different agencies with no coordination and feedback mechanism and sometimes different/contradictory results.

No explicit mention has been found or made regarding the costs associated with gathering the data.

5.2. *Reliability*

The lack of reliability can lead to uncertainties about the result of water balances and their non-acceptance by water managers and other stakeholders. This can be caused by the following factors.

- Changes in rainfall, runoff and recharge (e.g. due to climate change) are not well measured or modelled at the regional/local scale; e.g. groundwater recharge patterns might change due to the increased intensity of rainfalls, and no longer correspond to the historical relationship as established by the proportion of rainfall to recharge[3].
- Datasets are old (e.g. not updated in accordance with a water efficiency improvement or crop changes), estimated (not metered, but reflecting e.g. crop consumption standards established by FAO[4] - which might not respond to real water consumption) or discrepancies in definitions and proxies (e.g. only referring to abstractions and ignoring storage or losses (exports, consumption and/or return flows).
- Illegal water abstractions are not considered, though existing[5].
- Some water resources (e.g. recycling, rainwater harvesting, wastewater reuse, flows between groundwater bodies or basins, managed aquifer recharge) are accounted for twice (e.g. when urban wastewater is being reused, a new water resource volume is accounted

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[3] See the review of groundwater recharge changes in the Spanish Doñana area published by Kohfahl, et al., 2019. Monitoring and current research of groundwater resources and recharge in the Doñana Natural area (SE Spain). Boletín Geológico y Minero, 130 (4): 661-690. ISSN: 0366-0176. DOI: 10.21701/bolgeomin.130.4.005

[4] FAO (2023) at https://www.fao.org/land-water/land/land-governance/land-resources-planning-toolbox/category/details/en/c/1026559/

[5] E.g. European Court of Auditors (2021): Special Report 20/2021: Sustainable water use in agriculture: CAP funds are more likely to promote greater rather than more efficient water use. Available at: https://www.eca.europa.eu/Lists/ECADocuments/SR21_20/SR_CAP-and-water_EN.pdf

for as "reused water", but no change/reduction is made to the return flows from urban water users)[6].

- Groundwater and surface water interactions are unknown and/or their role in water balances is not properly assessed.
- Data, information, calculations, assumptions and results of water balances are not published or validated by external scientific peers/panels, but rather kept internally or only publishing the summary results.
- Water balances do not include ecological flows (to achieve good ecological status or potential), broader environmental flow requirements or the flows as agreed under international treaties.

As a result of these issues, the reliability of a water balance may not be sufficient for water management.

5.3. *Usability*

Establishing a water balance can require an effort which is not compensated by the subsequent use of the knowledge and results gained. This can happen in the following circumstances.

- Water balances are developed on an ad-hoc and one-time basis or intermittently.
- The time scale of useful water balances is unclear or it does not match the needs (e.g. for water allocation mechanisms)
- Water balances are only implemented in a few/insufficient RBDs and/or at an inappropriate scale to contribute to water management decisions.
- Water balances are only developed by a few staff members or a small technical team, without engaging interested parties.
- Water balances do not properly reflect sustainability thresholds of water consumption are surpassed, e.g., the 20/40% thresholds indicated by the EEA for the WEI+, and thus cannot provide alerts when these are approached or surpassed.
- The complexity of integrating water balance data in modelling tools (e.g. Colorado, Aquatool) used for river basin management planning can hinder their application.
- Water balances are often independent tools, not used for computing indicators which can help identify critical variables that need to be altered for improving river basin management. Ideally, water balances can help support the selection of measures for the Programme of Measures (PoM) of 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, an established ecological river discharge or an objective for replenishing aquifers).
- Water balances only refer to water quantity and do not reflect water quality or water pricing (e.g. addressing the complexity of cost recovery when using different water sources) aspects. The quality of water can have an impact of how much you can actually use. If water is so polluted that you cannot even treat and use it, this should be reflected in the water balance.
- The water price also can have significant impact on the water demand, especially by those water users who make a low added economic value out of the water used, and with increased water prices might shift to other products or production systems. As stated by the United Nations water accounting system, regarding the valuation of water and water resources, the price charged for the product contains an element of rent, which implicitly reflects the value of the natural resource. Establishing this implicit element is at the heart of valuing the stock of the resource. In the case of water, however, which is often an open access resource, this implicit element is often zero. Increasingly, water is being treated as an economic good. Therefore, it is expected that in the future the resource rent for water would be positive and thus the value of the water stocks would be included in the balance sheets of a country. (UN DESA, 2012) However, it should be noted that both aspects are so

[6] E.g. as happening in the Guadalquivir 3rd cycle RBMP when compared with the water balance of the 2nd cycle RBMP. Whilst in the new plan annually 20 million m3 urban wastewater are foreseen to be reused in agriculture in the upper river basin, the urban water return flow estimation has been kep at 80% of abstractions, resulting a double accounting of the same water resources in the overall water balance.

far only experimentally established in the System of Environmental-Economic Accounts for Water (SEEA-Water).

- Water balances only deal with average figures and are not relevant for (extreme) droughts.

5.4. *Harmonisation needs*

Water balances are often inconsistent across regional boundaries or river basin districts within a country as well as across national boundaries. Key factors include a lack of mutually accepted definitions and standards for collecting data on water balances and and procedures for preparing water balances, e.g. no agreement on the simulation models (where data is not available) that can give mutually accepted results. Consequently, there can be disagreements on water management.

6. Identifying good practices

In order to be able to actively promote the exchange of good practices in the implementation of water balances and to go beyond the information incorporated in the 2015 EU guidance document on the topic, a detailed set of challenges and corresponding good practices was prepared, aiming to crystallise specific issues.

6.1. *What could good practice look like for each implementation challenge?*

For each of the 21 detailed challenges, options for good practice have been defined, including a justification, as shown in the below table.

Table 1: Challenges and good practice options for the implementation of water balances

	Implementation constraints	Challenges	Good practice options for further assessment in MS	Justification
B1	Data availability	Data are not available	A system of automatized real-time water quantity and quality data is available (online)	To enable the control of environmental flows and basin balance adaptation to real-time events
B2	Data availability	Geographical differences in data collection	Institutional agreements are in place to monitor the different components of the hydrological cycle, and for combining these into a common (water balance) framework	To ensure consistent datasets and completeness
B3	Data availability	Similar data collected by different agencies and potentially different or contradictory results, with different qualities	Institutional agreements are in place to monitor the different components of the hydrological cycle, and for combining these into a common (water balance) framework, using the best available data	To ensure consistent datasets and completeness
B4	Reliability	Water availability datasets are old, estimated or conceptually incomplete. Changes in rainfall, evaporation, runoff and recharge (due to climate change and land use changes) are not well depicted	Water balances are using updated water availability datasets, including metering and modelling of rainfall, runoff and recharge, accounting for climate change impacts	To ensure changes in water availability are properly reflected, including increased evaporation or decreases in average recharge due to a larger number of high-intensity rainfalls

	Implementation constraints	Challenges	Good practice options for further assessment in MS	Justification
B5	Reliability	Water use datasets are old, estimated or conceptually incomplete	Water balances use reliable datasets, including updated metered data on water abstractions, storage, consumption and return flows by all water uses, especially of those with the largest use, as well as of cumulative minor abstractions (which might not require permitting)	To ensure water balances reflect the reality of water use in the area, and to reduce the influence of less-reliable datasets (e.g. modelling, extrapolation, surveys)
B6	Reliability	Illegal water abstractions are not considered, though existing	Water balances do consider explicitly illegal water abstraction/consumption	To ensure water balances reflect the reality of water use in the area
B7	Reliability	Some water resources are accounted for twice	Water balances avoid double-counting water resources (e.g. caused by recycling, rainwater harvesting, wastewater reuse, flows between groundwater bodies or basins, managed aquifer recharge; rainwater reported as (non-specified) part of wastewater)	To avoid that some water resources are accounted for twice, e.g. if a certain amount of treated urban wastewater is accounted as reused water for irrigation, it shall be deducted from the urban return flows to downstream rivers
B8	Reliability	Groundwater and surface water interactions are unknown and/or their role in water balances is not properly assessed	Water balances properly account for groundwater-surface water interaction, based on proper studies/modelling	To avoid that groundwater contribution to water balance is calculated as differences in inputs and outputs resulting that GW is just a mistake in the water balance calculation
B9	Reliability	Water balances do not include ecological or broader environmental flow requirements, and/or flows as agreed under international treaties	Water balances explicitly consider the environmental demand of aquatic ecosystems (environmental flows) and international commitments (where relevant)	To ensure that the ecological/ GEP or broader environmental flow requirements and thus the achievement of WFD objectives are appropriately depicted, as well as fostering transboundary cooperation
B10	Reliability	Information, calculations, assumptions and results of water balances are not published	Water balances, their underlying data, criteria and assumptions are publicly accessible	To ensure transparency and accountability, as well as trust by water users
B11	Reliability	Reliability of water balance is insufficient for water management	Water balance performance criteria are discussed and agreed upon between the water manager and the modeller beforehand[7], involving stakeholders	

[7] Guidance Document No 34, page 27: "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.)."

	Implementation constraints	Challenges	Good practice options for further assessment in MS	Justification
B12	Usability	Water balances are developed randomly, on an ad-hoc and one-time basis or intermittently	Water balances are built in a stepwise and tiered approach, e.g. targeting first (sub)basins with the highest water exploitation values and/or the risk of surpassing the sustainability thresholds	To help define the key components of the water balance that require specific attention
B13	Usability	The time scale of useful water balances is unclear or it does not match the needs (e.g. for water allocation mechanisms)	Water balances are generally established for a sufficiently long period such as a year-specific cycle (hydrological, calendar, wet/dry season, multi/annual period etc.), depending on their primary use (e.g. supporting water allocation mechanisms for drought and water scarcity)	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)
B14	Usability	Water balances are only implemented in a few/insufficient RBDs	Water balances are established for all relevant river basin districts or areas, at the proper water allocation scale[8]	To ensure a broad and relevant application of water balances
B15	Usability	Water balances are developed by a few staff members or a small technical team, without engaging interested parties	Participation of scientists, users and stakeholders is fostered for the development of water balances, including their criteria and assumptions. Capacity development for developing and implementing the water balance concept at the river basin scale	To ensure water balances reflect know-how, societal priorities and user needs
B16	Usability	Water balances do not properly reflect or alert when sustainability thresholds of water consumption are surpassed	Water balances explicitly consider and reflect the thresholds of water stress and sustainable water consumption (e.g. 20%-40%, according to EEA/WEI+, potentially also others) of the available water resources, and alert when they are surpassed	To support sustainable water management by the application of the precautionary principle (e.g. given the remaining uncertainty about the effectiveness of established ecological flows), e.g. the EEA threshold for sustainable water management shall be reflected
B17	Usability	Complexity of integrating water balance data in modelling tools	The water accounting tool and the modelling tool(s) are developed in an interconnected and automated way	To ensure water balances are used for planning purposes
B18	Usability	Water balances are independent tools, not used for computing relevant indicators and/or	Water balances are built into River Basin Management Plans and inform (e.g. via indicators) the Programmes of Measures, e.g. supporting quantitative (gap) analysis and its climate-	To underpin the achievement of RBMP objectives, supporting quantitative (gap) analysis

[8] E.g. monthly water balances at the catchment scale, according to the experience of the pilot within the "Preparatory Action on development of prevention activities to halt desertification in Europe", as referred to in the Guidance Document No 34.

	Implementation constraints	Challenges	Good practice options for further assessment in MS	Justification
		for river basin management	proofing. Once potential measures are identified, and their direct unitary impact on water abstraction, runoff or recharge is established (e.g. in mm or cubic meters of water saved), water balances help translate a change in pressure into a change in the overall water resource balance.	
B19	Usability	Water balances only refer to water quantity and do not reflect water quality or water pricing aspects	Water balances incorporate other water use elements such as water quality or water pricing aspects	To improve the reliability of water balances within complex systems
B20	Usability	Not relevant for (extreme) droughts	Water balances are (also) made/used for (extreme) drought years	To support water quantity management also during critical extreme events
B21	Harmonisation	Water balances are inconsistent across boundaries	Joint water balances are established for transboundary river basin districts, based on compatible and mutually accepted/agreed definitions, data and procedures, e.g. simulation models	To foster transboundary cooperation

On the basis of this review, the following 21 criteria are defined for good practices in the implementation of water balances:

1. A system of automatized real-time water quantity and quality data is available (online)
2. (and also 3) Institutional agreements are in place to monitor the different components of the hydrological cycle, and for combining these into a common (water balance) framework, using the best available data
4. Water balances are using updated water availability datasets, including metering and modelling of rainfall, runoff and recharge, accounting for climate change impacts
5. Water balances use reliable datasets, including updated metered data on water abstractions, storage, consumption and return flows by all water uses, especially of those with the largest use, as well as of cumulative minor abstractions (which might not require permitting)
6. Water balances do consider explicitly illegal water abstraction/consumption
7. Water balances avoid double-counting water resources (e.g. caused by recycling, rainwater harvesting, wastewater reuse, flows between groundwater bodies or basins, managed aquifer recharge; rainwater reported as (non-specified) part of wastewater)
8. Water balances properly account for groundwater-surface water interaction, based on proper studies/modelling
9. Water balances explicitly consider the environmental demand of aquatic ecosystems (environmental flows) and international commitments (where relevant)
10. Water balances, their underlying data, criteria and assumptions are publicly accessible
11. Water balance performance criteria are discussed and agreed upon between the water manager and the modeller beforehand, involving stakeholders

12. Water balances are built in a stepwise and tiered approach, e.g. targeting first (sub)basins with the highest water exploitation values and/or the risk of surpassing the sustainability thresholds
13. Water balances are generally established for a sufficiently long period such as a year-specific cycle (hydrological, calendar, wet/dry season, multi/annual period etc.), depending on their primary use (e.g. supporting water allocation mechanisms for drought and water scarcity)
14. Water balances are established for all relevant river basin districts or areas, at the proper water allocation scale
15. Participation of scientists, users and stakeholders is fostered for the development of water balances, including their criteria and assumptions. Capacity development for developing and implementing the water balance concept at the river basin scale
16. Water balances explicitly consider and reflect the thresholds of water stress and sustainable water consumption (e.g. 20%-40%, according to EEA/WEI+, potentially also others) of the available water resources, and alert when they are surpassed
17. The water accounting tool and the modelling tool(s) are developed in an interconnected and automated way
18. Water balances are built into River Basin Management Plans and inform (e.g. via indicators) the Programmes of Measures, e.g. supporting quantitative (gap) analysis and its climate-proofing. Once potential measures are identified, and their direct unitary impact on water abstraction, runoff or recharge is established (e.g. in mm or cubic meters of water saved), water balances help translate a change in pressure into a change in the overall water resource balance.
19. Water balances incorporate other water use elements such as water quality or water pricing aspects
20. Water balances are (also) made/used for (extreme) drought years
21. Joint water balances are established for transboundary river basin districts, based on compatible and mutually accepted/agreed definitions, data and procedures, e.g. simulation models

6.2. *Progress of MS in tackling challenges and developing good practice*

A questionnaire was sent to all EU Member States, to identify the relevance of the challenges and the existence of good practices which could be shared. They were asked to indicate whether in their country the specific topic is considered rather a (major or operational) challenge or if good practice is in progress or established in the whole country or some areas. In addition, Member States were asked to indicate the level of application of water balances and the tools used for them. The responses received from 20 Member States have been summarised in the following main findings:

6.2.1. *Level of application*

In most EU Member States, water balances are in place, though the level of application varies significantly from the local/water body to the national level. Most Member States carry out the assessments for the whole of the country, though in some countries the practice is limited only to some areas/regions. Water balances are:

- Developed in the whole Member State: AT, BEFL, BEWL, CY, CZ, DK, EL, ES, FI, HU, IT, LT, LU, MT, NL, PL, PT, SK.
- Developed in some areas: DE, HU, IE, SE
- Under investigation: AT (options for higher resolution (time and space))

The implementation examples provided by MS and included in the Annex illustrate the work undertaken to develop water balances at different levels:

- Hungary provided a detailed description of the national approach for building longitudinal water balances along a river stretch, which is being implemented stepwise in the country.

- Poland carried out a pilot in the catchments of the Pilica and Wkra rivers, to estimate the natural water retention capacity, using analysis, modelling and identification of areas where to implement activities.
- Sweden, where the national hydrological model has been run in pilots to estimate GW abstractions from other available/modelled data from the model.

6.2.2. *MODELLING TOOLS*

The European Commission JRC provides an open access, comprehensive hydrological and water resources model (LISFLOOD) that is extensively applied for EU-scale assessments, and can be used for the development of river basin-scale water balances also at regional scale on regions of a few hundred squared kilometers or more (see further below).

Furthermore, different modelling tools are being used for water balances. Though some Member States use globally available tools, such as the United Nation's System of Environmental-Economic Accounts for Water (SEEA-Water), the Water Evaluation And Planning System (WEAP) or the MIKE HYDRO Basin. Sometimes, these models are only used for research activities, as marked below indicated by brackets. Most of the EU Member States rely on a set of models which have been developed at the national level. The models used across the EU are:

- SEEA-Water: DE, (ES), (FI), HU, (IT), LT
- Other global models: WEAP, MIKE BASIN, WDI (Water Depletion Index) – (FI)
- National models: CZ, DK (DK-model), EL, ES (SIMPA, AquaTool), FI (Watershed simulation and forecasting system (WSFS)), IE, IT (BIGBANG), LU (LARSIM, WEAP, LAWA), MT, NL (Nationaal Water Model - Helpdesk water), PL, PT (Temez, MIKE BASIN), (SE), SK
- Regional models: BEFL, (BEWL), DE, NL

The implementation examples provided by MS and included in the Annex illustrate the work undertaken to use and combine different modelling tools for the establishment of water balances:

- Spain implements since 1995 a model (SIMPA) to calculate natural streamflows and uses another model (Aquatool) for calculating water balances; the two models and their results are described in detail.
- Finland: The Finnish hydrological watershed model system could calculate water balances, and be easily connected with the supply database (VEETI) for incorporating water abstraction data.

6.2.3. *STATUS OF IMPLEMENTATION OF WATER BALANCES*

The following overview tables provide a summary of the status of implementation of water balances, and in particular, challenges faced, progress towards good practice and ambitions for improvement according to the self-assessment of Member States participating actively in the exercise. The responses have not been validated or double-checked with other stakeholders. The overviews only display the acronyms of those Member States which can provide good practice examples.

Overall, there are more EU Member States that self-assess their situation as having progressed towards good practice, either across the whole country, some areas or currently in progress, than those that face challenges, especially for the following aspects (marked with green font in the table 2):

- Automatized real-time data
- Institutional agreements in place to monitor and common frameworks
- Water balances are using updated water availability datasets
- Balances, data, criteria and assumptions are publicly accessible
- Built-in a stepwise and tiered approach
- Sufficiently long periods for water allocation & droughts
- Established for all relevant areas, at the proper water allocation scale
- Built into River Basin Management Plans and inform PoM

However, there are several topics, where a large number of Member States face challenges (marked with red font) and have not yet developed good practice:

- Water use datasets are old or incomplete
- Illegal water abstractions
- Some water resources are accounted for twice
- GW-SW interactions are unknown
- Not include e-flow and international treaties
- Only refer to water quantity
- Not relevant for (extreme) droughts
- Inconsistent across boundaries

Out of this second list, there are some topics for which at least 8 Member States state that they are facing either:

- Major implementation challenges (e.g. institutional, governance, regulation, data) to develop this good practice, or
- Operational implementation challenges (of methodologies, tools, resources, capacity, rules or regulation) to develop this good practice.

It was discussed and agreed in the technical ad-hoc group that this report shall focus on those challenges which affect a larger number of Member States, and where several Member States plan to progress during the coming one to three years. These include (marked in Table 2 in red and bold text):

- B5: Water use datasets are old or incomplete
- B6: Illegal water abstractions are not accounted for
- B8: Groundwater – surface water interactions are unknown
- B19: Water balances only refer to water quantity
- B21: Water balances are inconsistent across boundaries

The following table provides an overview of the results (number of EU Member States) of the self-assessment in the way from challenges to good practice.

Table 2: Overview of the number of Member States addressing water balances implementation challenges and developing good practices

		Not applicable	From Challenges…		… to good practices being implemented			
	Challenges faced	1	2	3	4	5	6	Good practices in place
			Major challenges	Operational challenges	In process	In place in some MS areas	In place in the whole MS	
B1	Data are not available	0	0	1	4	7	10	Automatized real-time data
B2	Differences in data collection	2	0	2	3	4	10	Institutional agreements in place to monitor and common frameworks
B3	Similar data collected by different agencies	3	1	0	2	5	10	
B4	Water availability data old or incomplete	1	2	0	4	4	10	Water balances are using updated water availability datasets
B5	**Water use datasets are old or incomplete**	1	**2**	**7**	2	4	5	Updated metered data on abstractions, storage, consumption and return
B6	**Illegal water abstractions**	**5**	**7**	**3**	3	1	**2**	Consider explicitly illegal water abstraction/consumption
B7	Some water resources are accounted for twice	2	**3**	**3**	3	2	8	No double-counting e.g. recycling, reuse, managed aquifer recharge…
B8	**GW-SW interactions are unknown**	1	**1**	**7**	3	3	6	Groundwater-surface water interaction studies/modelling
B9	Not include e-flow and international treaties	1	2	2	5	5	6	Explicitly consider e-flow and international treaties
B10	Not published	1	2	2	2	4	10	Balances, data, criteria and assumptions are publicly accessible
B11	Reliability insufficient for water management	3	0	3	2	6	7	Performance criteria agreed upon by the water manager, modeller and stakeholders
B12	Randomly, ad-hoc and one-time basis	2	0	3	1	4	12	Built-in a stepwise and tiered approach
B13	The time scale is unclear	2	2	0	3	3	12	Sufficiently long periods for water allocation & droughts
B14	Only implemented in a few/insufficient RBDs	2	1	2	1	5	11	Established for all relevant areas, at the proper water allocation scale
B15	Developed without interested parties	2	**3**	**2**	3	3	8	Participation of scientists, users & stakeholders fostered, capacity built
B16	Reflect sustainability thresholds	3	**2**	**5**	3	2	6	Reflect thresholds of water stress and sustainable water consumption
B17	Difficult integrating with modelling tools	2	**1**	**6**	5	3	**3**	Water accounting and modelling tool(s) are interconnected and automated
B18	Not used for indicators and RBMPs	3	**2**	**4**	1	2	9	Built into River Basin Management Plans and inform PoM
B19	**Only refer to water quantity**	3	**7**	**2**	3	1	5	Incorporate water quality or water pricing aspects
B20	Not relevant for (extreme) droughts	2	**2**	**5**	3	2	7	Water balances are (also) made/used for (extreme) drought years
B21	**Inconsistent across boundaries**	**5**	**2**	**8**	1	3	**2**	Compatible and agreed definitions, data and procedures

Note on Table 2: Challenges relevant for a larger number of MS (>7) have been marked in red and in bold; good practices achieved by a larger number of MS (>8) in green. Columns indicate 1. Not applicable, 2. Major implementation challenges (e.g. institutional, governance, regulation, data) to develop such good practice, 3. In the MS, there are operational implementation challenges (of methodologies, tools, resources, capacity, rules or regulation) to develop such good practice, 4. In the whole MS or some areas, such specific good practice is in the process of being implemented, 5. In some MS areas (e.g. RBDs, regions or pilots), such specific good practice is in place, 6. In the whole MS, such specific good practice is in place.

Furthermore, Table 3 (below) adds information on the EU Member States which have developed good practices and could share such specific examples which are either in progress or in place in some areas or the whole country with interested parties. It also includes the previously mentioned information about how many Member States are planning to address such specific challenges within the next 1-3 years.

Table 3: Simplified overview of Member States that are implementing and improving good practices for water balances implementation

	From Challenges….	Nr of MS foreseeing action	4	5	6	… to good practice
B1	Data are not available	2	BEFL, EL, HU, LU	CY, DE, ES, NL, IT, PL, PT	AT, BEWL, CZ, DK, FI, IE, IT, LT, MT, (SK)	Automatized real-time data
B2	Differences in data collection	1	BEFL, PT, SE	BEWL, DE, ES, NL	AT, CY, CZ, DK, FI, IT, LT, LU, MT, SK	Institutional agreements in place to monitor and common frameworks
B3	Similar data collected by different agencies	2	BEFL, SE	BEWL, DE, ES, PT, SK	AT, CZ, DK, FI, HU, IT, LT, LU, NL, MT	
B4	Water availability data old or incomplete	3	CZ, DE, LU, PL	BEFL, BEWL, CY, NL	AT, DK, EL, ES, FI, IT, LT, MT, PT, SE	Water balances are using updated water availability datasets
B5	**Water use datasets are old or incomplete**	**5**	EL, PL	BEWL, CY, MT, NL	CZ, DK, ES, LT, PT	Updated metered data on abstractions, storage, consumption and return
B6	**Illegal water abstractions**	4	CZ, MT, SE	ES	CY, PT	Consider explicitly illegal water abstraction/consumption
B7	Some water resources are accounted for twice	2	EL, IT, MT	PL, PT	BEFL, CY, CZ, DK, ES, LT, NL, SE	No double-counting e.g. recycling, reuse, managed aquifer recharge…
B8	**GW-SW interactions are unknown**	**4**	CZ, EL, MT	DE, PL, SE	CY, DK, ES, LT, (NL), PT	Groundwater-surface water interaction studies/modelling
B9	Not include e-flow and international treaties	**4**	BEFL, DE, MT, PT, SE	CY, DK, EL, FI, PL	CZ, ES, HU, IT, LT, NL	Explicitly consider e-flow and international treaties
B10	Not published	2	FI, MT	DE, NL, PL, SE	AT, CY, CZ, DK, EL, ES, IT, LT, PT, SK	Balances, data, criteria and assumptions are publicly accessible
B11	Reliability insufficient for water management	2	LU, PL	BEWL, DE, EL, FI, NL, SE	CZ, DK, ES, IT, LT, MT, PT	Performance criteria agreed upon by the water manager, modeller and stakeholders
B12	Randomly, ad-hoc and one-time basis	2	BEFL	BEWL, DE, FI, IT	AT, CY, CZ, EL, ES, IT, LT, MT, NL, PL, PT, SK	Built-in a stepwise and tiered approach
B13	The time scale is unclear	1	BEFL, DE, HU	BEWL, IT, SE	CY, CZ, DK, EL, ES, IT, LT, MT, NL, PL, PT, SK	Sufficiently long periods for water allocation & droughts
B14	Only implemented in a few/insufficient RBDs	3	BEFL	DE, HU, IT, MT, SE	CY, CZ, DK, EL, ES, IT, LT, NL, PL, PT, SK	Established for all relevant areas, at the proper water allocation scale
B15	Developed without interested parties	2	BEFL, MT, PT	BEWL, DE, SE	CY, CZ, DK, EL, ES, IT, NL, PL	Participation of scientists, users & stakeholders fostered, capacity built
B16	Reflect sustainability thresholds	1	BEFL, MT, SK	BEWL, DE	CY, CZ, DK, ES, IT, PT	Reflect thresholds of water stress and sustainable water consumption
B17	Difficult integrating in modelling tools	1	BEFL, CY, CZ, DE, FI	NL, IT, SE	DK, ES, PT	Water accounting and modelling tool(s) are interconnected and automated
B18	Not used for indicators and RBMPs	2	EL	NL, SE	CY, CZ, ES, IT, LT, MT, (PL), PT, SK	Built into River Basin Management Plans and inform PoM
B19	**Only refer to water quantity**	1	MT, SE	NL	CY, CZ, ES, PT, (SK)	Incorporate water quality or water pricing aspects
B20	Not relevant for (extreme) droughts	3	BEFL, CZ, HU	EL, LT	CY, DK, ES, MT, NL, PT, SK	Water balances are (also) made/used for (extreme) drought years
B21	**Inconsistent across boundaries**	**4**	BEFL	BEWL, CZ, SK	DK, FI	Compatible and agreed definitions, data and procedures

Note on Table 3: Column ACT indicates the number of MS aiming to improve this area in the next 1-3 years. Columns indicate 1. Not applicable, 2. Major implementation challenges (e.g. institutional, governance, regulation, data) to develop this good practice, 3. In the MS, there are operational implementation challenges (of methodologies, tools, resources, capacity, rules or regulation) to develop this good practice, 4. In the whole MS or some areas, such specific good practice is in the process of being implemented, 5. In some MS areas (e.g. RBDs, regions or pilots), such specific good practice is in place, 6. In the whole MS, such specific good practice is in place.

6.3. *Opportunities for the harmonization of water balances in an EU perspective*

The European Commission Joint Research Centre (JRC) has developed a comprehensive water resources model, LISFLOOD[9], which is an essential component of the European Flood Awareness System (EFAS)[10] and the European Drought Observatory (EDO)[11]; it has been applied for policy support exercises both at the European scale and on specific regions[12, 13, 14, 15, 16, 17, 18].

LISFLOOD is a model that simulates the full water cycle from rainfall to water in rivers, lakes and groundwater. The model simulates large areas such as river basins, continents or the entire globe. The model simulates the combined effects of weather and climate changes, land use, socioeconomic changes on water demand, as well as policy measures for water savings or flood control. The model is used for water and climate studies, as well as flood and drought forecasting. More information on LISFLOOD is available as a technical factsheet (EC, 2022).

The model and the essential input datasets[19] are open source and freely accessible. While most applications of the model at European scale used a 5 km resolution setup, a new version of the model setup has been recently developed at a resolution of 1 arc minute (approximately 1.4 km). This caters for detailed assessments appropriate at the scale of single river basins or regions with an area of a few hundred square kilometres or more. The key limitation in applying the model is appropriate information on weather forcing (particularly rainfall) and the distribution of water uses. The datasets used for European scale calculations provide a first approximation, but should be ideally complemented with locally gathered information in order to improve accuracy. The JRC is committed to incorporate information from local, regional and national sources as soon as it becomes accessible, in order to produce new versions of the input datasets expected to be increasingly accurate and relevant at the local scale. If a Member State or a region in the EU needs to develop a water balance model, the open source LISFLOOD model with the existing input data can be used as a starting point, and inputs can be further refined with better local knowledge. The LISFLOOD model may contribute to overcome the key challenges outlined above, particularly by:

- improving data accessibility at the onset;
- ensuring the reliability of the model on the basis of extensive verification at the European scale and in other regional settings;
- enhancing usability as the model users are connected to a community of other users;
- securing harmonization as the model already includes a representation of transboundary hydrological flows and state variables.

6.4. *Examples of water balance implementation for priority key challenges*

The priorities identified in the section above indicate the most urgent needs for accessing good practice of implementation to overcome existing challenges across the EU. Member States with available good practice examples on these priority challenges have been requested to share information on their good practice in this report. Examples of the implementation of water balances

[9] A description of the model is given at: https://ec-jrc.github.io/lisflood-model/
[10] https://www.efas.eu/en
[11] https://edo.jrc.ec.europa.eu/edov2/php/index.php?id=1000
[12] https://publications.jrc.ec.europa.eu/repository/handle/JRC75938
[13] https://publications.jrc.ec.europa.eu/repository/handle/JRC130025
[14] https://publications.jrc.ec.europa.eu/repository/handle/JRC120388
[15] https://publications.jrc.ec.europa.eu/repository/handle/JRC118586
[16] https://publications.jrc.ec.europa.eu/repository/handle/JRC110927
[17] https://publications.jrc.ec.europa.eu/repository/handle/JRC111817
[18] https://publications.jrc.ec.europa.eu/repository/handle/JRC99886
[19] LISFLOOD static and parameters maps for Europe are available on the JRC Data Catalogue: https://data.jrc.ec.europa.eu/dataset/f572c443-7466-4adf-87aa-c0847a169f23. Weather forcing variables at 5 km and 1 arc minute resolution are available at https://data.europa.eu/data/datasets/0bd84be4-cec8-4180-97a6-8b3adaac4d26?locale=en

have been collected in the summer of 2023 using a template, including information about the case study location, the implementation time and duration, the objectives and main actions taken, the current situation, lessons learned in the process and contact information for gathering further details.

For the implementation of water balances, Member States provided ten useful examples of current practice. An overview is given in the table below.

Table 4: Summary of examples that can be used to improve water balance implementation

Implementation challenge	Implementation example from MS
B1: Data are not available	**Sweden**: As a consequence of higher public demand for information during the 2016-2018 droughts, chemical and quantitative data from national and regional groundwater monitoring are published online, including maps. This is very relevant for the groundwater body balance.
B4: Water availability datasets are old, estimated or conceptually incomplete. Changes in rainfall, evaporation, runoff and recharge (due to climate change and land use changes) are not well depicted	**Portugal** has implemented recently a modelling tool in MIKE that allows to obtain water balances, with updating input data, to help with efficient and sustainable water management based on the allocation of water volumes to abstraction permits; though not all water uses are metered.
B5: Water use datasets are old, estimated or conceptually incomplete	**Denmark** has integrated comprehensive national databases for geologic borehole data, groundwater-related geophysical data, geologic models, as well as a national groundwater-surface water model (DK-model) to support water management. This makes it possible to facilitate the examination of the quantitative status of groundwater resources by e.g., estimating the effect of ground water abstraction on ground water level and stream flow. It has been possibly to identify areas with water scarcity as well as effects from climate changes. The same system is applicable to transboundary groundwater management.
	Czechia: Large water users are obliged to report data in excess of a certain amount to the river basin authorities (River Boards, state enterprises). Water users report data via an on-line system. The data processing is carried out by River Boards, state enterprises (water management balance), the Czech Hydrological Institute (hydrological balance) and the TGM Water Research Institute (aggregated water balance of the main river basins of the Czech Republic). Validation of the data can be done for only large water users (using flow meters).
B6: Illegal water abstractions are not considered, though existing	**None**
B8: Groundwater and surface water interactions are unknown and/or their role in water balances is not properly assessed	**Poland** carried out a pilot in the catchments of the Pilica and Wkra rivers, to estimate the natural water retention capacity, using analysis, modelling and identification of areas where to implement activities.
	Sweden: The Swedish national hydrological model has run some pilots to estimate GW abstractions based on other available/modelled data.
B8: Groundwater and surface water interactions are unknown and/or their role in water balances is not properly assessed B17: Complexity of integrating water balance data in modelling tools.	**Spain** implements since 1995 a model (SIMPA) to calculate natural streamflows and uses another model (Aquatool) for calculating water balances; the two models and their results are described in detail. In addition, Spain informs of an action plan adopted in 2023 which will improve information and knowledge on the existing gaps regarding groundwater-surface water interactions.
B11: Reliability of water balance is insufficient for water management	**Hungary** provides a detailed description of the national approach for building longitudinal water balances along a river stretch, which is being implemented stepwise in the country.

B12: Water balances are developed randomly, on an ad-hoc and one-time basis or intermittently	
B17: Complexity of integrating water balance data in modelling tools.	**Finland**: The Finnish hydrological watershed model system could calculate water balances and be easily connected with the supply database (VEETI) for incorporating water abstraction data.
	Czechia: Ensuring good data recording practice in water management takes place in several steps: the applicant applies for a permit (for abstraction or discharge), the Water Authority issues a decision (issuing a permit), and the Central Register of Water Rights (CRVE) registers the permit. This process is described in detail.
B19: Water balances only refer to water quantity and do not reflect water quality or water pricing aspects	**None**
B21: Water balances are inconsistent across boundaries	**Denmark**: see under B5
	Czechia: Cross-border cooperation with other member states of the Czech Republic (Germany, Poland) focused on the collection and exchange of hydrological and climate data.

While the table highlights useful examples, this compilation has also shown:

- A lack of examples to be shared regarding (B6) accounting for illegal water use and developing water balances that also (B19) address water quality and water pricing elements, such as is recommended by the United Nations (SEEA-Water). No MS has volunteered to illustrate such aspects. This is especially a concern regarding the estimation and accounting for **illegal water uses**, which can lead to significant deviations in water balances. Only the Swedish illustration on modelling groundwater resources shows how modelling can be used to estimate illegal water use. However and despite not being illustrated by an example in this report, some progress has also been made in using remote sensing techniques for detecting and quantifying illegal water use (see Bea-Martinez, 2021 for WWF Spain and Garrido-Rubio et al., 2020)
- Some of the practices shared have been in place for several decades. For those MS addressing such topics now and with time pressure, the shared examples might be of limited added value. A few practices illustrate action taken post-2015 (adoption of the EU guidance document) or as a consequence of the recent droughts in Europe.
- Whilst some examples illustrate comprehensive addressing of the good practice options outlined previously, not all examples address all specific and relevant aspects.

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8. Annex: Examples of water balances implementation

8.1. Sweden: Public presentation of groundwater information

8.1.1. General information

Member State(s)	Sweden
RBD(s)	National
Location	National
Time period (start - end)	1984, but updated with current information since 2020
Good practice example promoter	Geological Survey of Sweden

8.1.2. Challenge(s) faced

Code of the challenge(s):

- B1: Data availability - Data are not available

Description of the challenge:

It is important to provide current information on groundwater, both quality and quantity. Especially quantity is important to communicate to the public, municipalities, and decision-makers in order to be able to take measures to prevent water shortages during drought situations, as well as in situations with high water levels.

8.1.3. Good practice(s) developed

Code of the good practice(s):

- B1: System of automatized real-time water quantity and quality data is available (online)

Table 5: Synthetic overview of the actions taken

	Type of actions	Characteristics
	Regulatory	
✓	Technical	Develop websites, interactive maps, and charting tools that can present data in a suitable way.
	Economic	
✓	Research	Modelling tools to translate current measured groundwater levels in monitoring stations into national maps that show current water levels and to what degree the aquifers are filled with water. Also, future forecasts under different weather conditions are calculated and presented.
	Governance	
	Others	

Description of the good practice:

Chemical and quantitative data from national and regional groundwater monitoring are published on the SGU website. For information on the chemistry of groundwater, maps with sampling locations are published. For each sampling location, it is possible to obtain information on tested parameters in a diagram or an Excel file. Multiple parameters can also be shown in a single diagram. The data is updated and supplemented with new data at least once a year.

For quantitative status, there are also maps with national and regional results of groundwater level monitoring. For the monitoring stations with automatic loggers (currently approximately half of all), the maps are continuously updated, while others are updated at least once a year.

On the SGU website, national maps are presented with current water level and filling levels once a week, for both small and large aquifers. The presentation also includes a forecast for the development up to 180 days ahead, divided into different weather conditions. The national monitoring of groundwater levels is used as the basis for the maps, where the results are modelled to cover the entire country.

Maps with water levels and filling levels are often used in agriculture and forestry to predict the water needs of crops. They are also used by municipalities and other decision-makers to anticipate water shortages and take action before the situation becomes too serious. Even owners of private wells benefit from being able to understand and predict the groundwater situation.

Reasons for initiating action(s):

There is a need to be able to show current groundwater situations and create an understanding that action needs to be taken in good time to prevent water scarcity. During the drought years of 2016 and 2018, the information became particularly important.

Selection of the action(s):

The drought years of 2016 and 2018 meant that even the general public began to use the maps showing groundwater levels and the forecasts for future groundwater situations.

Description of the action(s):

For more information and maps see below websites.

Effort of the action(s):

Except for the monitoring and the management of the data, the maps and publishing of results of water qualitative and quantitative takes 1 person month a year.

For the maps showing current groundwater levels and prognoses, the development and updating of the model technique need quite a lot of actions. The publishing of the maps once a week takes approximately 3-4 h.

Result(s) achieved so far:

Maps with water levels and filling levels are often used in agriculture and forestry to predict the water needs of crops. They are also used by municipalities and other decision-makers to anticipate water shortages and take action before the situation becomes too serious. Even owners of private wells benefit from being able to understand and predict the groundwater situation.

Difficulties faced:

Evaluate the models to prognose

Remaining constraint(s):

None at the moment, but the tools will surely be updated in the future.

Planned next step(s):

None at the moment, but the tools will surely be updated in the future.

Transferability:

none

8.1.4. FURTHER INFORMATION

Websites:

- Map displays and charts for environmental monitoring of groundwater chemistry Kartvisare och diagram för miljöövervakning av grundvattenkemi (sgu.se)
- Map displays and charts for estimated levels Kartvisare och diagram för beräknade nivåer (sgu.se)
- Current groundwater levels Aktuella grundvattennivåer (sgu.se)
- Future groundwater levels Framtida grundvattennivåer (sgu.se)

Other publications/documents:

- Calculation of current groundwater levels Så beräknar SGU aktuella grundvattennivåer
- Calculation of future groundwater levels Så beräknar SGU framtida grundvattennivåer
- What is meant by filling level and groundwater situation? Det menas med fyllnadsgrad och grundvattensituation (sgu.se)

Contact:

- Geological Survey of Sweden

  SGU@sgu.se

8.2. POLAND: ANALYSIS OF NATURAL WATER RETENTION AREAS

8.2.1. GENERAL INFORMATION

Member State(s)	Poland
RBD(s)	Vistula River Basin District, Water Region of the Central Vistula
Location	The catchment area of the Pilica river and Wkra river
Time period (start - end)	2017-2019
Good practice example promoter	State Water Holding Polish Waters

8.2.2. CHALLENGE(S) FACED

Code of the challenge(s):

- B8: Groundwater and surface water interactions are unknown and/or their role in water balances is not properly assessed

Description of the challenge:

The obligation to develop this analysis stems from the Flood Risk Management Plan (FRMP) for the Vistula river basin district and the development of a plan to counteract the effects of drought Water Region of the Central Vistula (PPSS), requesting further analysis of natural water retention areas. The PPSS analyzed the current state of retention in the balance catchments and the resulting water resources - the number of reservoirs, location of reservoirs, capacity, functions performed. Farm ponds were excluded from the analysis due to their nature - they do not retain water for drought mitigation. The sum of disposable resources in natural and not-natural reservoirs was also determined. The deficit of water resources was then determined. After comparing the amount of water resources with the water deficit for the balance areas, areas that require more detailed analysis (taking into account surface water resources and groundwater resources) were determined. Among these areas were the catchments of the Pilica River and Wkra River. Analysis, modelling and identification of areas where to implement activities in the field of counteracting and minimising the effects of drought. Such an analysis will enable rational design activities in a given catchment area taking into account natural and economic conditions. It will contribute to proper water management and water resources management water resources in river basins and river basin districts. The catchments of the Wkra River and the Pilica River were selected as pilotage catchments.

8.2.3. GOOD PRACTICE(S) DEVELOPED

Code of the good practice(s):

- B8: Water balances properly account for groundwater-surface water interaction, based on proper studies/modelling

Table 6 : Synthetic overview of the actions taken

	Type of actions	Characteristics
✓	Regulatory	The obligation to develop this analysis stems from the planning document, the plan flood risk management plan (FRMP) for the Vistula river basin district. The study identifies measures to increase water retention. These activities will contribute to reducing flood risk and mitigating the effects of drought
✓	Technical	Developing a hydrological model and running the modelling using MIKE SHE. As part of the analysis of the results of retention in the Pilica River catchment and Wkra River catchment, the water balance was developed for all identified balance sub-catchments and for the whole catchment area. 4 action options have been developed where a range of measures have been mapped to increase catchment retention to counteract flooding and drought effects. All options were modelled and presented by means of simulation.

	Economic	not applicable
✓	Research	A hydrological model was developed as part of the study. The MIKE SHE program was used to evaluate the existing retention in the Pilica and Wkra catchments, as well as to analyze the possibility of increasing it. This program is based on a mathematical description of all relevant physical processes of the water cycle. A full hydrological cycle was mapped in the MIKE SHE model for the Pilica River catchment.
	Governance	not applicable
	Others	not applicable

Description of the good practice:

As part of the works carried out, a number of analyzes were carried out for the purpose of developing, above all: the hydrological model of the catchment, assessment of catchment retention, a program of measures to increase retention, multi-criteria analysis, cost-benefit analysis. The results of the project were also presented in the form of a geoportal and made available to all interested parties.

Reasons for initiating action(s):

The obligation to develop this analysis stems from the planning document, the Flood Risk Management Plan (FRMP) for the Vistula river basin district and the development of a plan to counteract the effects of drought Water Region of the Central Vistula (PPSS). The FRMP for the Vistula river basin district identifies more than a dozen analogous retention analyses in catchments for which technical solutions have not been planned, due to the lack of comprehensive knowledge of existing risks and retention potential in the Vistula river basin. Action is included in the Plan to counteract the effects of drought in the Middle Vistula water region. Execution of an expert opinion is aimed at identifying measures to increase water retention using an analysis of the characteristics of the Pilica and Wkra catchments and modeling of their processes hydrological processes.

Other than procedural reasons for undertaking this project were issues of climate change and adaptation to these changes.

Selection of the action(s):

A hydrological model was developed to evaluate existing retention in the catchment and analyze the possibility of increasing it using the MIKE SHE program based on a mathematical description of all relevant physical processes of the water cycle (topography, climate (precipitation, evapotranspiration, snow melting modulus), land use, surface water, surface runoff, aeration zone, saturation zone. The software used made it possible to assess the relationships between the various elements of the water cycle. The compatibility of the model was assessed using data from aquifers (surface water) and groundwater measurement points.

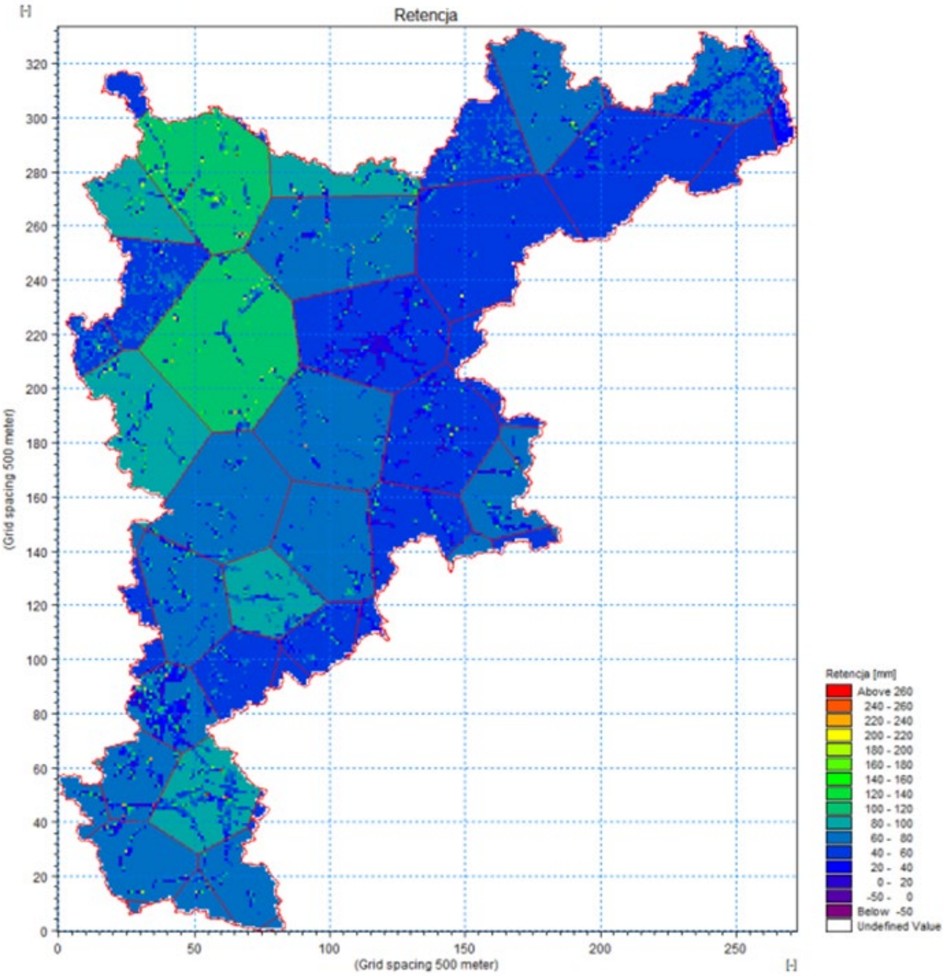

Figure 1: Calculation results: map of 1-day retention totals in the Pilica catchment area

Analysing the spatial distribution of the retention index, it was observed that extreme retention values generally occur along surface watercourses. In areas where the mapping of drainage systems is included in the model, the retention index takes on the lowest values (below 50%), while in river valleys in places of local depressions, retention is very high (retention index exceeds 99%). Such high values of the index are due to the fact that the changes in retention calculated in the model in individual modules illustrate the total amount of water retained in the catchment over a longer period of time, and not just the proportion of precipitation on the day of maximum retention. The amount of retention is influenced by the precipitation over a longer preceding period, but also by temperature, groundwater levels, among others. The analysis of existing retention in the Pilica catchment was also carried out for the designated 61 balance sub-catchments and 12 urban areas. In addition to the average 1-day retention in the sub-basin/urban area, 2-day retention and retention indices were calculated.

In order to analyse the amount of water run-off from each sub-catchment, the maximum run-off rate, the run-off rate on the day of maximum rainfall occurrence during the calculation period and the average run-off rate for the 2010-2016 multi-year period were calculated.

This allowed the identification of problematic catchments/urban areas with low retention.

The final classification of areas in the catchment, representing the average value of the classification for the two indicators analysed, indicated the problem areas in the catchment (problem areas responsible for increasing the rapidity of floods and droughts), showing the lowest retention.

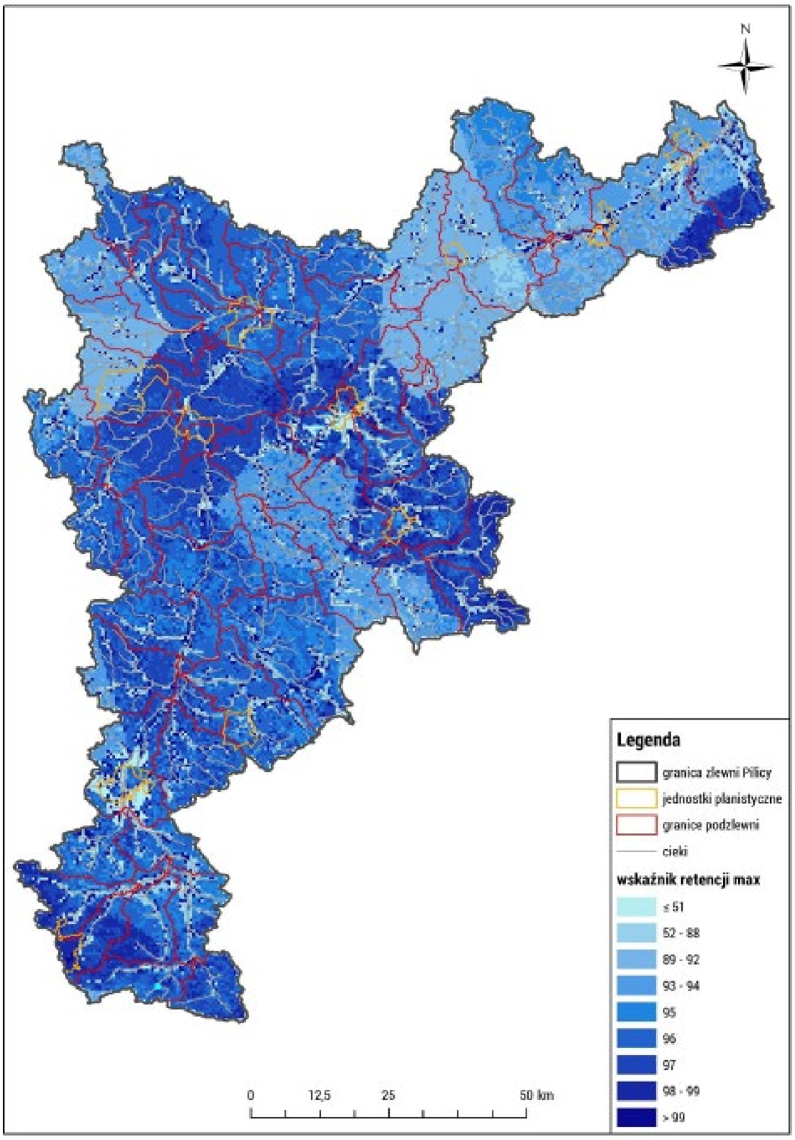

Figure 2: Retention capacity of areas in the Pilica catchment area on the basis of the maximum retention index.

Subsequently, 4 action variants were developed, with variants 1, 2 and 3 mapping a number of measures to increase the catchment's retention capacity to counteract flooding and drought effects, while variant 4 additionally tested a measure to change part of the catchment's drainage systems from drainage to drainage/irrigation. It was decided to separate this measure into a separate option due to the results obtained during the simulations.

An integrated hydrological model of the Pilica catchment made it possible to quantitatively analyse the effects of measures for flood prevention and drought mitigation.

Analysis of the results indicates that:

- the construction of small retention reservoirs has a local impact, at the scale of the balance sub-basins the effect of such measures is small,
- non-technical measures, especially when applied over large areas, have a noticeable effect on increasing retention at the catchment scale,
- the proposed non-technical measures have the greatest impact on small flood flows, with maximum flows of less than 10% probability of occurrence,
- in order to reduce larger surges, the construction of reservoirs on watercourses, with an adequate flood reserve and properly controlled, is necessary.

A range of action options have also been developed, illustrating the impact of different sets of activities of varying nature on retention in the catchment - the planned options for action have been implemented in the developed integrated model. On the basis of various analyses, the most favourable measures for increasing the retention capacity of the catchment have been selected.

On the basis of, among other things, a retention assessment, an economic analysis of the action programme, an analysis of the compatibility of the measures with legal and environmental requirements, and an analysis of formal obstacles, the most favourable variant of tasks to increase the retention capacity of the catchment area was selected.

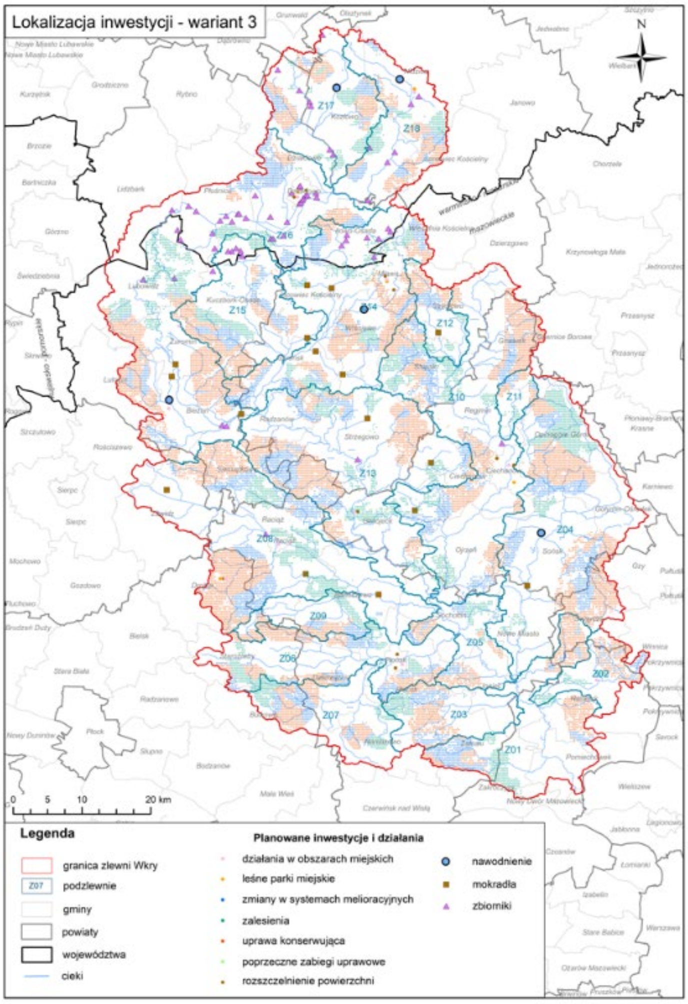

Figure 3: Location of activities and tasks from variant 3 increasing retention for the Wkra catchment area.

In addition, the project has developed a Good Practice Catalogue describing the actions recommended for implementation in the catchment area, together with an indication of how to implement them. These measures are aimed at increasing retention in the catchment, but their implementation will also result in other positive effects, such as the protection of water-dependent habitats and species, increased biodiversity, reduced pollutant loads entering waters from the catchment.

The catalogue includes the following information for each good practice described:

- description of the measure,
- conditions of use,
- benefits of application
- examples of application.

The catalogue provides universal material for use in other areas of the country as well, developed in an accessible manner, even for audiences not familiar with water management.

As part of the study, "commune fiches" were created - information material for the municipalities, containing a range of information characterising the area of the municipality in terms of the issues analysed, i.e. the risks involved, the results of the model analyses carried out, the actions indicated to be implemented in the area of the municipality within the framework of the action programme developed, and proposals for provisions allowing the planned actions to be implemented in planning documents with a map representation for each municipality showing the location within the municipality of the planned activities and other information relevant to the project being developed.

The project also provided theoretical training with a practical part on the use of the hydrological model developed as part of the project.

As part of the implementation of the project, a series of information and consultation meetings were held to present the results of the project so far and to discuss with participants and representatives of local authorities and municipalities the additional information that should be taken into account during the development and modelling of the catchment programme of action.

The analysis made it possible to determine the pattern of water circulation in the catchment area (surface water and groundwater) and, based on this, to determine what are the water resources in the catchment area and to identify measures to increase retention.

Description of the action(s):

To date, the activities contained in the documents Analysis of opportunities to increase retention in forest, agricultural areas and urbanized areas in the area of the Pilica River catchment within the framework of maintaining and increasing the existing retention capacity in the Middle Vistula Water Region and Analysis of the possibility of increasing retention in forest, agricultural and urbanized areas in the area of the Wkra River catchment within the framework of maintaining and increasing the existing retention capacity in the Middle Vistula Water Region have not been implemented.

Effort of the action(s):

Preparation of each document took about 2 years and cost about 2 million PLN equivalent to 450,000 Euro.

Result(s) achieved so far:

not applicable

Difficulties faced:

Problems at the level of implementation of the document: Difficulties in financing investment activities. The costs of implementing the measures will be borne by both public and private sector entities. Due to the potential possibility of cofinancing/financing the measures from various sources and, on the other hand, the lack of confirmed sources of funding, it is not possible to precisely allocate all the costs of implementing the measures to specific sources, e.g. the state budget, local authority or other entities. For many units, priority is given to other tasks that do not fit into the objectives of the planning documents, resulting in a lack of funding for flood and drought protection. A key technical obstacle is the issue of the technical condition of water facilities in the pilot areas.

Remaining constraint(s):

not applicable

Planned next step(s):

The development of analogous documents is included in the drought effects counteracting plan (adopted in 2021). It is planned to develop a nationwide methodology for preparing an analysis of the possibility of increasing water resources in the basin.

Transferability:

not applicable

8.2.4. Further information

- Websites: http://retencjawisla.pl/
- Contact:

  State Water Holding Polish Waters
  National Water Management Authority
  Żelazna 59a
  00-848 Warsaw
  Poland

8.3. Sweden: Model-calculated values for water flow (S-HYPE) provide an opportunity to estimate water abstractions

8.3.1. General information

Member State(s)	Sweden
RBD(s)	National
Location	National
Time period (start - end)	2008 - ongoing
Good practice example promoter	Swedish Meteorological and Hydrological Institute

8.3.2. Challenge(s) faced

Code of the challenge(s):

- B8: Groundwater and surface water interactions are unknown and/or their role in water balances is not properly assessed.

Description of the challenge:

There is a lack of data on water abstraction in many places in Sweden and a better knowledge of the size of the water abstraction is needed to be able to calculate relevant water balances.

8.3.3. Good practice(s) developed

Code of the good practice(s):

- B8: Water balances properly account for groundwater-surface water interaction, based on proper studies/modelling.

Table 7: Synthetic overview of the actions taken

	Type of actions	Characteristics
	Regulatory	
✓	Technical	Estimate the size of water abstraction from the difference between modelled discharge and observed discharge.
	Economic	
	Research	
	Governance	
	Others	

Description of the good practice:

The national hydrological model is used to describe, among other things, snow, water flows, soil moisture and water quality. The model describes the landscape based on what affects the water's path. These are things like lakes, waterways, soil, land use and if there is human influence, for example regulations and water abstractions. The water that is missing in real measurements compared to modelled data is assumed to disappear based on water abstractions in the catchment area.

Reasons for initiating action(s):

There is a lack of knowledge about the size of water abstraction in many places in Sweden. There is also abstraction that are not known because they do not have a permit. A better knowledge of the size of the water abstraction is needed for a better estimation for the water balance within the catchment area.

Selection of the action(s):

The Swedish Meteorological and Hydrological Institute (SMHI) is responsible for describing and monitoring Sweden's hydrology. This is done both with the help of observations and models. Today there are around 300 observations that aim to measure both high and low, see how much water flows to the sea from Sweden's land areas and to see how the water supply has varied over time.

Description of the action(s):

At times of low water discharge, it is possible to estimate the size of water abstraction calculated as the difference between the modelled discharge and the observed discharge. SMHI calculates water flow with a good resolution (about 10 km2 catchments) for the entire country. There are also observations for water discharge in many places. At times of low water discharge, it is possible to examine how these differ. If the measured discharge is systematically lower than the modelled discharge, it is likely that there are water abstractions in the area. The size of the abstraction can be estimated by calculating the difference between the modelled and measured discharge. The result is an overview of the size of the water abstractions which can be used to calculate the water balance for the area. It can also be a help to find areas with large water abstractions where the work of collecting water abstraction data can be prioritized.

Effort of the action(s):

Calculating this is relatively easy, a few working months to get an overview for Sweden.

Result(s) achieved so far:

These calculations have so far been carried out for a few catchments.

Difficulties faced:

It is important to be aware of uncertainties in order to use the data correctly. When observational data is used, it may be useful to know that SMHI's monitoring of water flow around the country takes place by continuously measuring the water level at the institute's hydrological stations.

Remaining constraint(s):

The result is just an estimation because there are uncertainties in the models.

Planned next step(s):

The modelling results can eventually be consulted by interested parties in the near future. This can cover replication in other areas, finetuning of the methodology applied, development of related indicators, etc.

Transferability:

The methodology can be used with results from the S-HYPE model throughout Sweden. It could also be used with data from any other detailed hydrological model and observations in other countries.

8.3.4. Further information

Websites:

- Water discharge - station network | SMHI: Vattenföring - stationsnät | SMHI

  Vattenföring | SMHI
- Models for calculating water discharge | SMHI : Modeller för att beräkna vattenföring | SMHI
- The HYPE model for the entire Sweden: S-HYPE: HYPE-modell för hela Sverige | SMHI and HYPE: Our Hydrological Model | SMHI

Scientific articles: see websites

Other publications/documents: see websites

Contact:

- Swedish Meteorological and Hydrological Institute
  kundtjanst@smhi.se

8.4. FINLAND: WATER ACCOUNTING AND MODELLING TOOLS ARE INTERCONNECTED AND AUTOMATED

8.4.1. GENERAL INFORMATION

Member State(s)	Finland
RBD(s)	Whole country
Location	Whole country
Time period (start - end)	ongoing
Good practice example promoter	Finnish Environment Institute

8.4.2. CHALLENGE(S) FACED

Code of the challenge(s):

- B17: Difficult integrating in modelling tools

Description of the challenge:

Not enough information about hydrological cycle and its components, available renewable water resources and water abstractions. The Finnish watershed and forecasting system is used for drought monitoring and forecasting purposes, but it is not used to assess water scarcity, since that is not an issue in Finland due to abundant water resources.

8.4.3. GOOD PRACTICE(S) DEVELOPED

Code of the good practice(s):

- B17: Water accounting and modelling tool(s) are interconnected and automated

Table 8: Synthetic overview of the actions taken

	Type of actions	Characteristics
	Regulatory	
✓	Technical	A national hydrological watershed model has been established covering the entire land phase of Finland. In addition, a database for water abstractions (and water supply in general) was established in 2015.
	Economic	
	Research	
	Governance	
	Others	

The Finnish Environment Institute has a hydrological watershed model system (WSFS). WSFS is used for flood forecasting, real-time monitoring, nutrient load simulation and climate change research. Hydrological water balance maps are created in real time. Forecasts are made daily for over 500 discharge and water level observation points. Forecasts are used for lake regulation planning, flood damage prevention and as information for the public and authorities.

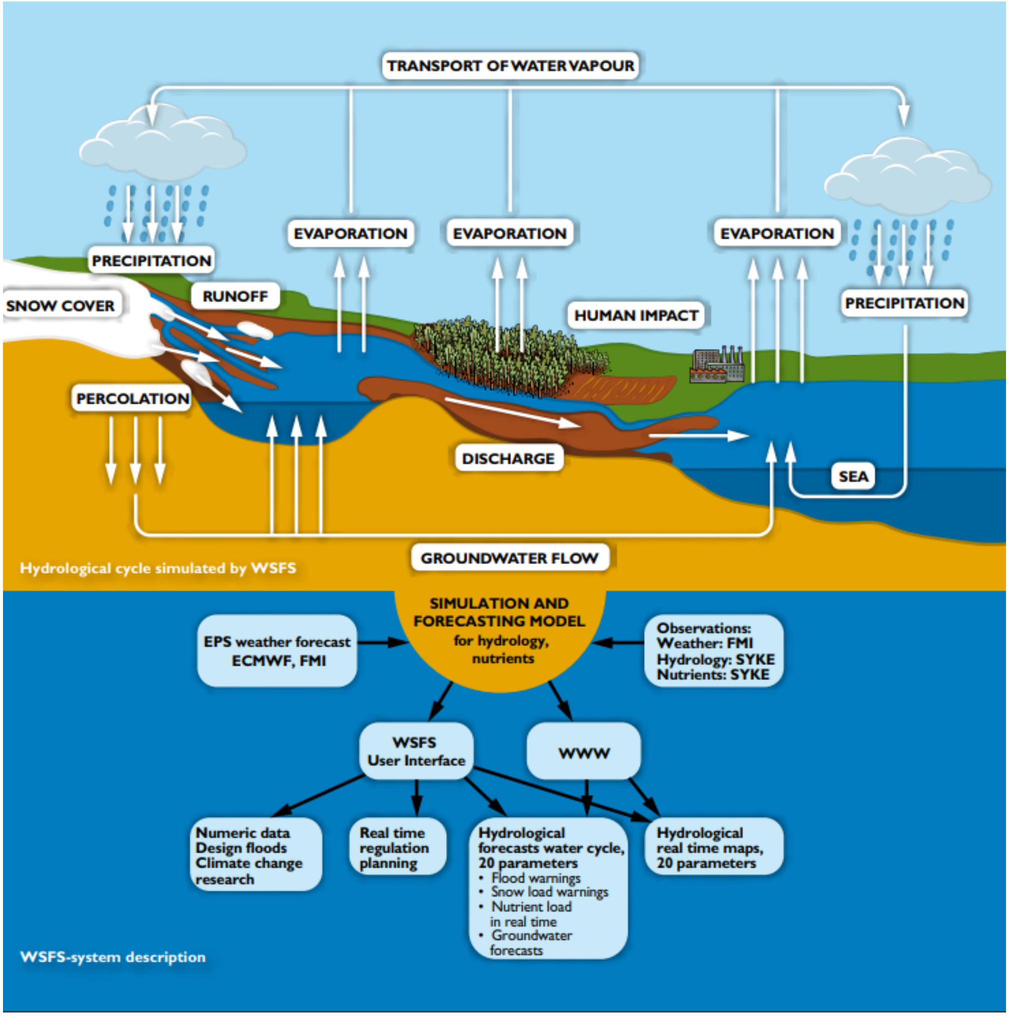

Figure 4: Watershed and forecasting system description

Although water abstractions are not included in the WSFS, the information is available via water supply database (VEETI). It combines information on water abstractions and sewage systems since 2015. The Water Services Act (119/2001) obliges water suppliers to provide this information.

Remaining constraint(s):

Data and models to calculate water balances is readily available, but actual water balance calculations are lacking. Minor or illegal water abstractions are not reported to the national database.

Planned next step(s):

The model could be used to calculate water balances. There is on-going development to better monitor and model Finland's groundwater resources.

8.4.4. *Further information*

Websites:

- Watershed simulation and forecasting system – Brochure (PDF) https://www.syke.fi/download/noname/%7B46044A4B-F779-43E5-8B80-E2501DF98A45%7D/91524
- Watershed simulation and forecasting system – Youtube video: https://www.youtube.com/watch?v=aWl3UamQXpY

Scientific articles:

- Vehviläinen, Bertel, and Markus Huttunen. "Hydrological forecasting and real time monitoring in Finland: The watershed simulation and forecasting system (WSFS)." (2001).

Contact:

- Finnish Environment Institute, Latokartanonkaari 11, 00790 Helsinki

  Noora Veijalainen, noora.veijalainen@syke.fi

8.5. CZECH REPUBLIC: GOOD PRACTICE OF INTERNATIONAL COOPERATION IN GROUNDWATER AND SURFACE WATER DATA COLLECTION, EXCHANGE AND SUMMARIZATION

8.5.1. GENERAL INFORMATION

Member State(s)	Czech Republic
RBD(s)	Oder, Elbe
Location	Silesia-Poland border (RBD Oder); Lusatian Mountains, Bohemian Switzerland and Děčínský Sněžník area (RBD Elbe)
Time period (start - end)	Silesian-Poland border since 1979 – present; Lusatian Mountains and Bohemian Switzerland since 2011 - present
Good practice example promoter	Ministry of the Environment of the Czech Republic, T.G. Masaryk Water Research Institute

8.5.2. CHALLENGE(S) FACED

Code of the challenge(s):

- **B21:** *Joint water balances are established for transboundary river basin districts, based on compatible and mutually accepted/agreed definitions, data and procedures, e.g. simulation models*

Description of the challenge:

Cross-border cooperation with other member states of the Czech Republic (Germany, Poland) focused on the collection and exchange of hydrological and climate data.

8.5.3. GOOD PRACTICE(S) DEVELOPED

Code of the good practice(s):

- **B21:** *Joint water balances are established for transboundary river basin districts, based on compatible and mutually accepted/agreed definitions, data and procedures, e.g. simulation models*

This type of good practice cannot be evaluated using Table 9. It is mainly about monitoring. It is not a technical device (equipment, technology, etc.).

Table 9: Synthetic overview of the actions taken

✓	Type of actions	Characteristics
	Regulatory	
	Technical	
	Economic	
	Research	
✓	Governance	Joint evaluation of groundwater abstraction pressures, agreement on hydrological and climatological data sets
	Others	

Description of the good practice:

The impetus for international cooperation on border waters in the region of the Intra-Sudete basin was the realization of the "Regional hydrological survey of the Polish Cretaceous basin" carried out in 1972-1975. This survey was financed from the funds of the water management and the direct investor was *Water Management Development and Construction* (Prague). Surveys were financed on Polish territory mainly from the state resources of the ministries. From the beginning to the present, there have been no problems with financing or setting the methodology on both sides of the member states. Measurement and evaluation of the state of ground and surface water have been taking place for several decades on the Czech-Polish border waters in the area of the water-economically important intra-Sudete and Polish basins. The Czech side works under the leadership of the Ministry of the Environment. Every year, joint measurements of the levels (or pressures) of underground water and the conditions and flows of surface water are carried out. As a tool for balancing and long-term development, a transboundary mathematical model of groundwater flow was compiled. The annual joint evaluation serves both to assess the impact of significant groundwater withdrawals on both sides of the state border, as well as to assess natural effects, especially climate change. In 2023, both sides (CZ and PL) shared and agreed upon hydrological and climatological data sets, including groundwater withdrawal data for the 2022 hydrological year. The data sets with which we work, especially the daily conditions (and the surface water flows derived from them) and the height of the groundwater levels in the observation wells, are comparable. Twice a year, they are jointly measured by experts from both sides, and the conformity of the measurements is regularly evaluated. Once a year, there is a meeting where evaluations (precipitation, surface and underground water conditions, sampling, etc.) are presented and mutual information is also provided about any changes to the basic and additional network of measured objects.

Similarly, significant problems with the long-term drop in groundwater levels on the Czech-Saxon border were solved by two joint tasks (GRACE and ResiBil) with the contribution of funds from the EU funds for cross-border cooperation. the GRACE project was financed from EU Ziel3/Cíl3 funds, co-participation in the amount of 10% was paid by the Czech Ministry of the Interior. The ResiBil project was co-financed by the European Regional Development Fund (ERDF) in the cross-border cooperation program INTERREG.

Individual mathematical flow models were compiled for the border areas of the Lusatian Mountains, Bohemian Switzerland and the Děčínský Sněžník area. The areas are home to significant sources of groundwater that are used for human consumption on both sides of the border. Joint evaluations made it possible to uncover the impact of climate change and the effects of groundwater withdrawals on the condition and balance of groundwater. Within the framework of the mathematical flow models, the issue of groundwater decline in the context of future climate change was also addressed.

Project GRACE: Protection of water resources and clarification of the causes of decline groundwater levels in the defined cross-border areas of Hřensko/Křinice-Kirnitsch and Petrovice-Lückendorf-Jonsdorf-Oybin. The results of the project are intended to contribute to the sustainable use of underground water resources and the improvement of their protection, they will further improve the ecological awareness of the public, complement professional knowledge and help create joint strategies for the protection of underground water in these areas.

Project ResiBil: The goal of this project is to carry out a balance sheet and evaluate the possibility of long-term use of underground water reserves in the Czech-Saxon border region, depending on the expected impacts of climate change. On the basis of previous experience and the knowledge gained in the research on climate change and its impact on the environment, it is possible to count on a long-term decrease in the formation of new groundwater. Since the formation of new groundwater is a decisive factor for the volume of groundwater, as a result, it is necessary to consider the reduction of groundwater reserves. Therefore, it is important to analyse and assess the impacts of possible future climate changes on usable groundwater resources, which includes assessing the vulnerability and resilience of the monitored system, including water supply, in terms of climate and weather conditions.

Two aspects are essential to achieve the project goal:

- Balancing both static and dynamic groundwater reserves using groundwater flow models based on well-founded knowledge from the field of geology and hydrogeology as a basis for the accumulation and movement of groundwater.

- Analysis and evaluation of climate data, including climate modelling using scenarios and projections.

The processing of these findings in the framework of soil water balancing models is important for the quantitative interception of the creation of new groundwater via natural recharge and the creation of forecasts for the creation of new groundwater. In accordance with the goal of this project, by connecting the above-mentioned model tools, it is possible to carry out a methodologically comprehensive evaluation of the knowledge gained. Analysis and assessment of the stability of water resources and the ecosystem against changes in climate and weather conditions will take place in the pilot areas. The project will thus make a decisive contribution to answering common questions in the field of water management planning and to institutional cooperation in this region.

Result(s) achieved so far:

Continuous action (data collection and evaluation).

Difficulties faced:

Reluctance to cooperate, weak financial support from states.

Remaining constraint(s):

Cannot be applied to this example of good practice.

Planned next step(s):

Continuous collaboration, data collection and exchange. Suggestions for future action.

Transferability:

Poor cooperation with neighbouring states. Many other cross-border areas are still pending to undertake similar action.

8.5.4. Further information

Websites:

- https://www.vtei.cz/wp-content/uploads/2015/08/vtei_2008_1.pdf
- https://heis.vuv.cz/data/webmap/datovesady/projekty/grace2011/default.asp?lang=cs&tab=7
- https://www.resibil.sachsen.de/cs/

Scientific articles:

- https://www.vuv.cz/resibil/publikace-resibil/

Other publications/documents:

- https://www.vtei.cz/wp-content/uploads/2020/10/6271-casopis-VTEI-5-20.pdf
- https://heis.vuv.cz/data/webmap/datovesady/projekty/grace2011/docstazeni/prameny_kl.pdf
- https://www.resibil.sachsen.de/cs/ergebnisse-4918.html

Contact:

- T.G. Masaryk Water Research Institute (https://www.vuv.cz/en/)

8.6. CZECH REPUBLIC: IMPROVED WATER ABSTRACTION METERING

8.6.1. GENERAL INFORMATION

Member State(s)	Czech Republic
RBD(s)	Elbe (CZ_5000), Danube (CZ_1000), Odra (CZ_6000)
Location	Without specification, everywhere in the Czech Republic
Time period (start - end)	regularly
Good practice example promoter	Ministry of Agriculture of the Czech Republic, Ministry of Environment of the Czech Republic and The T. G. Masaryk Water Research Institute

8.6.2. CHALLENGE(S) FACED

Code of the challenge(s):

- B5: Water balances are using reliable datasets, including updated metered data on water abstractions, storage, consumption and return flows by all water uses, especially of those with the largest use, as well as of cumulative minor abstractions (which might not require permitting)

Description of the challenge:

One of the bases for decision-making in water management, whether for surface water or groundwater, is the water balance. The water balance is established by law. It is compiled annually.

8.6.3. GOOD PRACTICE(S) DEVELOPED

Code of the good practice(s):

- B5: Water balances are using reliable datasets, including updated metered data on water abstractions, storage, consumption and return flows by all water uses, especially of those with the largest use, as well as of cumulative minor abstractions (which might not require permitting)

Table 10: Synthetic overview of the actions taken

	Type of actions	Characteristics
	Regulatory	
	Technical	
	Economic	
	Research	
✓	Governance	The Water Act: legal obligation. Monitoring data on groundwater and surface water abstractions and discharges.
	Others	

Description of the good practice:

The processing of the water balance is one of the basic activities in the field of identification and assessment of surface and groundwater status. The water balance assessment consists of the hydrological balance and water-management balance. The hydrological balance identifies changes in the level of inflow and outflow of water and changes in the level of water storage in a river basin, area or water body within a given time interval. The water management balance compares the requirements for surface water and groundwater abstraction and waste water discharge with the available water resources taking into account water quantity and quality and its ecological status. The data is obtained through a legal obligation.

Large water users are obliged to report data in excess of a certain amount to the river basin authorities (River Boards, state enterprises). Water users report data via an on-line system. The data processing is carried out by River Boards, state enterprises (water management balance), the Czech Hydrological Institute (hydrological balance) and the TGM Water Research Institute (aggregated water balance of the main river basins of the Czech Republic). Validation of the data can be done for only large water users (using flow meters).

The outputs of the water balance are used by water authorities as well as by state administration authorities in their decision-making. The water balance also serves as a basis for river basin management plans.

Effort of the action(s):

Research activities are part of the work activities of individual entities (River Boards, state enterprises and Czech Hydrometeorological Institute). Individual costs cannot be quantified.

Result(s) achieved so far:

The results of the water balance serve as a basis for decision-making in the field of water management, it is not a measure.

Difficulties faced:

Unknown.

Remaining constraint(s):

Unknown.

Planned next step(s):

Possible improvements for the future could be an update of the methodological guideline, development of the software used to share and control the online storage of data in all databases, all in cooperation with other River Boards and other research entities.

Transferability:

Water balance is certainly usable (transferable) anywhere/anywhere, in any region, country, etc. It is just a matter of having the necessary database and data required for its compilation. Furthermore, the property and legislative aspects must not be forgotten.

8.6.4. Further information

Websites:

- https://portal.mze.cz/ssl/web/file/716505/Vodni_hospodarstvi_2021_ENG_web.pdf

Contact:

- T.G. Masaryk Water Research Institute (https://www.vuv.cz/en/)
  River Boards, state enterprises
  Czech Hydrometeorological Institute

8.7. *CZECH REPUBLIC: GOOD PRACTICE OF THE WATER ACCOUNTING TOOL AND THE MODELLING TOOL(S)*

8.7.1. *GENERAL INFORMATION*

Member State(s)	Czech Republic
RBD(s)	Elbe (CZ_5000), Danube (CZ_1000), Odra (CZ_6000)
Location	Without specification, Everywhere in the Czech Republic
Time period (start - end)	regularly
Good practice example promoter	Ministry of Agriculture, Ministry of Environment of the Czech Republic

8.7.2. *CHALLENGE(S) FACED*

Code of the challenge(s):

- B17: The water accounting tool and the modelling tool(s) are developed in an interconnected and automated way

Description of the challenge:

The Water Act in the Czech Republic lays down obligations (e.g. measurement of water quantity). Data from these obligations are recorded in various systems (e.g. ISPOP, ISVS-WATER).

8.7.3. *GOOD PRACTICE(S) DEVELOPED*

Code of the good practice(s):

- B17: The water accounting tool and the modelling tool(s) are developed in an interconnected and automated way

Table 11: Synthetic overview of the actions taken

	Type of actions	Characteristics
	Regulatory	
	Technical	
	Economic	
	Research	
✓	Governance	The Water Act: legal obligation.
	Others	

Description of the good practice:

Three pillars are necessary to ensure good practice of data recording in water management, and these are legislation (e.g., the Water Act), organisations that are dedicated to data collection, recording, evaluation and publication (e.g., Ministry of Environment, Ministry of Agriculture, Water Management Authorities (regions), River Boards, state enterprises, Czech Hydrometeorological Institute, TGM Water Research Institute) and Information systems in which the data are stored (e.g., Information systems - public - GeoPortal INSPIRE, ISVS-Water, CRVE, WRI HEIS, Information systems - professional - IS of regions, ISyPo, Arrow, HAMR (drought), POVIS (floods), ISPOP (CENIA)).

Ensuring good data recording practice in water management takes place in several steps: the applicant applies for a permit (for abstraction or discharge), the Water Authority issues a decision (issuing a permit), and the Central Register of Water Rights (CRVE) registers the permit.

After the permit for water management, the applicant becomes a Mandatory Notifier, who reports (data on actual water management, abstraction or discharge) to the Integrated System for fulfilling national reporting obligations (called ISPOP) - the CENIA system registers and checks the data, the data from ISPOP is then verified by the Basin Manager (River Boards, s.e) and used for the design and implementation of measures in the basin, for the assessment of the status of water bodies, etc. The use of permits is controlled by water authorities (permit overruns). Data on water management are provided to public information systems, e.g. ISVS - Water, WRI HEIS, where the data are processed and published. The data are then used by the public or by expert institutions (organisations) to obtain feedback on the published data based on their comments.

Recording of data in water management in databases and information systems enables decision-making by water authorities (especially for determining the amount of water to be abstracted or the permissible pollution of discharged water), planning in the field of water and other activities under the Water Act, use of data for reporting to the EEA, summary assessment of water status and reporting on water status.

The advantages of publishing data in public are:

- To present information on water management in one place in a comprehensive and unified manner, regardless of the division of competencies between ministries.
- Provision of state-guaranteed data useful for decision-making by state and local government bodies, academic purposes and, last but not least, for improving public awareness.
- Uniform and clear processing of metadata.
- Transfer of data within and outside the system by web services (WMS).
- Use for WFD implementation (impacts on status evaluation, measures).

The interoperability between the different systems is ensured by a common data interface and data services are based on OpenGIS Consortium (OGC) standards. The models used in the data evaluation are:

- Simulation model of the storage function of the water management systems
- Water balance models (water source, water use and ecological flows)
- Hydrological model

Effort of the action(s):

Not applicable to this example of good practice.

Result(s) achieved so far:

Ongoing activity.

Difficulties faced:

Unknown

Remaining constraint(s):

Unknown

Planned next step(s):

None

Transferability:

Unknown

8.7.4. Further information

Contact:

- T.G. Masaryk Water Research Institute (https://www.vuv.cz/en/)

8.8. Hungary: Use of Longitudinal Water Balance Profiles for Water Permits

8.8.1. General information

Member State(s)	Hungary
RBD(s)	Danube
Location	Hungary, country wide
Time period (start - end)	since 1970
Good practice example promoter	General Directorate of Water Management, Budapest, Hungary

8.8.2. Challenge(s) faced

Code of the challenge(s):

- B11: Water balances are developed randomly, on an ad-hoc and one-time basis or intermittently.
- B12: Water balances are only implemented in a few/insufficient RBDs

Description of the challenge:

Establishing a sufficiently reliable water balance for a hierarchical (generally of first to third order) river system with many water uses needs a systematic approach that

- is able to calculate the water balance for any section of the river
- can be replicated on any watercourse within a river system
- is able to describe the continuity of flow along a complex hierarchical river system, and
- is robust enough to provide sufficiently accurate information for the legal procedures of water permitting on a variety of different catchments.

In general, water balances are supposed to be updated at least once in every 10 years, when the new discharge statistics are recalculated for the past 3 decades (30 years). The water balance of a particular river is updated on an ad-hoc basis, e.g. when the permit of a major abstraction is issued or modified. At present, a detailed water balance for all surface water bodies of the country is calculated for the River Basin Management Plans, i.e. in every 6 years.

8.8.3. Good practice(s) developed

Code of the good practice(s):

- B11: Water balances are built in a stepwise and tiered approach.
- B12: Water balances are established for all relevant river basin districts or areas, at the proper water allocation scale.

Table 12: Synthetic overview of the actions taken

	Type of actions	Characteristics
✓	Regulatory	Drafting of supporting guidance and education material
✓	Technical	Promoting a unified procedure to calculate water balance profiles, development of GIS based program systems, and water resource and water use data bases that implement the calculations on the river systems of the country
	Economic	

✓	Research	Research and Development project to extend water balance calculations to different seasons (months) and assessment of reliability criteria
	Governance	In the past thirty years water governance and especially water resources management was subject to several organizational and legal changes, reflecting the varying importance and value attributed to water resources, water ecosystems and sustainable water management in general. Recently, as climate change induced severe droughts are becoming more frequent, there is an increasing demand for water that on the long run can only be satisfied by sustainable water management methods, e.g. without over-exploiting groundwater resources thus diminishing low flows (base-flow) in rivers. The longitudinal water balance profile is a useful technical tool, but is of limited significance without good water governance and those legal instruments that need to be in place, such as well organized permitting procedures and enforcement; adequate monitoring of water resources, ecological status, and water uses; and the information of the public on important water resource issues.
	Others	In development of water balances priority is to be given to catchments with high and/or significant water use, including those with reservoirs.

Description of the good practice:

Reasons for initiating action(s):

By the mid-1960s, irrigation became widespread and by its volume the largest water use in Hungary. Its rapid growth caused a risk of over utilization on several catchments and rivers, therefore more accurate methods for water permitting were needed. As a consequence, water resources management became a separate branch within the water management organization, the concept of surface water resources was defined and water resources assessment got started. The use of longitudinal water balance profiles was also adopted at that time, as a means of storing and visualizing information on available water resources.

Recently, river basin management planning and the importance of the good quantitative status of surface water bodies added a new significance to the method.

Selection of the action(s):

Depending on its spatial conceptualization, there are two types of water balance methodologies: (i) the catchment balance, which is based on catchment totals of input quantities and provides water balance totals for the outflow section of the catchment; (ii) the longitudinal balance that calculates a continuous water balance along a river section. Both have their advantages and drawbacks. The catchment balance is usually simple to calculate and gives a better overview of complex river networks, but ignores local water deficits as long as the overall balance is positive. The longitudinal balance is more accurate, therefore gives enough local detail for decisions on individual water uses, while being more work-intensive to construct and maintain its hydrological database.

Description of the action(s):

Water balance-related terms used in the following section are in conformity with Figure 5. describing the main components of the longitudinal water balance profile. If it was possible, they were taken from the following sources:

- European Commission (2015) Guidance document on the application of water balances for supporting the implementation of the WFD; Technical Report – 2015 090; p.22-23. available at: *https://circabc.europa.eu/sd/a/820ec306-62a7-475c-8a98-699e70734223/Guidance%20No%2034%20-%20Water%20Balances%20Guidance%20%28final%20version%29.pdf*
- AQUASTAT Glossary, FAO, 2019: *https://www.fao.org/aquastat/en/databases/glossary/*

Actual water resource: Water resources observed in reality, accounting for human influence. (Does not necessarily include effects of climate change.)

Natural water resource, Q_d: Water resource metrics of which effects of human influences are removed.

Manageable water resource, *K*: is considered to be available for actual use or future development, taking into consideration the following factors: natural or actual water resource, reservoir yield and retention, water transfers between catchments, extracted groundwater discharged into surface waters, and minimum flow requirements.

Minimum flow requirement, $Q_m(x)$: That part of the water resource that has to be maintained along the river, in order to fulfil priority goals such as ecological flow, navigation, water resource allocated to downstream users and/or downstream countries, etc. The minimum flow requirement at any given point *x* along the river is the maximum of all priority requirements relevant at that point:

$$Q_m(x) = \max (Q_e(x); Q_n(x); Q_a(x))$$

where $Q_e(x)$, $Q_n(x)$, and $Q_a(x)$ are the ecological flow, the navigation flow requirement, and the flow allocated to downstream users or countries, respectively, and x denotes the distance measured from the downstream end of the river.

Although some of the priority goals can only be attributed to x_0, the downstream end of the river (e.g. resource allocated to downstream uses), care has to be taken to fulfil that constraint by limiting upstream uses or water consumption.

Ecological flow, environmental flow $Q_e(x)$: The quantity and timing of freshwater flows required to sustain ecosystems, and the human livelihoods and well-being that depend on them. In the Water Framework Directive context, ecological flow is considered a hydrological regime consistent with the achievement of the environmental objectives of the WFD in natural surface water bodies. HMWBs are supposed to met the same ecological flow or water balance conditions as other SWBs. Artificial water bodies are subject to specific rules, depending on the ecosystems they maintain.

Available water resource, F^+: That part of the manageable water resource that is available in the river for future use.

Deficit, F^-: That part of the existing water uses (water abstractions, consumption, reservoir retention, or diversion) that cannot be served by the manageable water resource.

Water use: The withdrawal of water for domestic, industrial and agricultural (including irrigation and fish culture) purposes, power production, transportation and recreation. Part of the water withdrawn is usually returned to surface waters after being used.

The longitudinal water balance profile is a graph or a table depicting or numerically representing the main components of the water balance along a watercourse or section of a watercourse (e.g. a river water body). These main components are (i) natural and (ii) manageable water resources; (iii) ecological flow; (iv) artificial modifications of the natural flow by reservoirs and water transfers (diversions); (v) water abstractions (withdrawals) from and returns (discharges) into the watercourse by water uses; (vi) available water resource and (vii) deficit, these latter two being the result of the water balance. All components are expressed as discharges [m^3/s or l/s] and are a function of x, the distance [river km] from the downstream endpoint of the river in question. The steps of constructing the profile are shown in Figure 5. and are explained in detail in the following text.

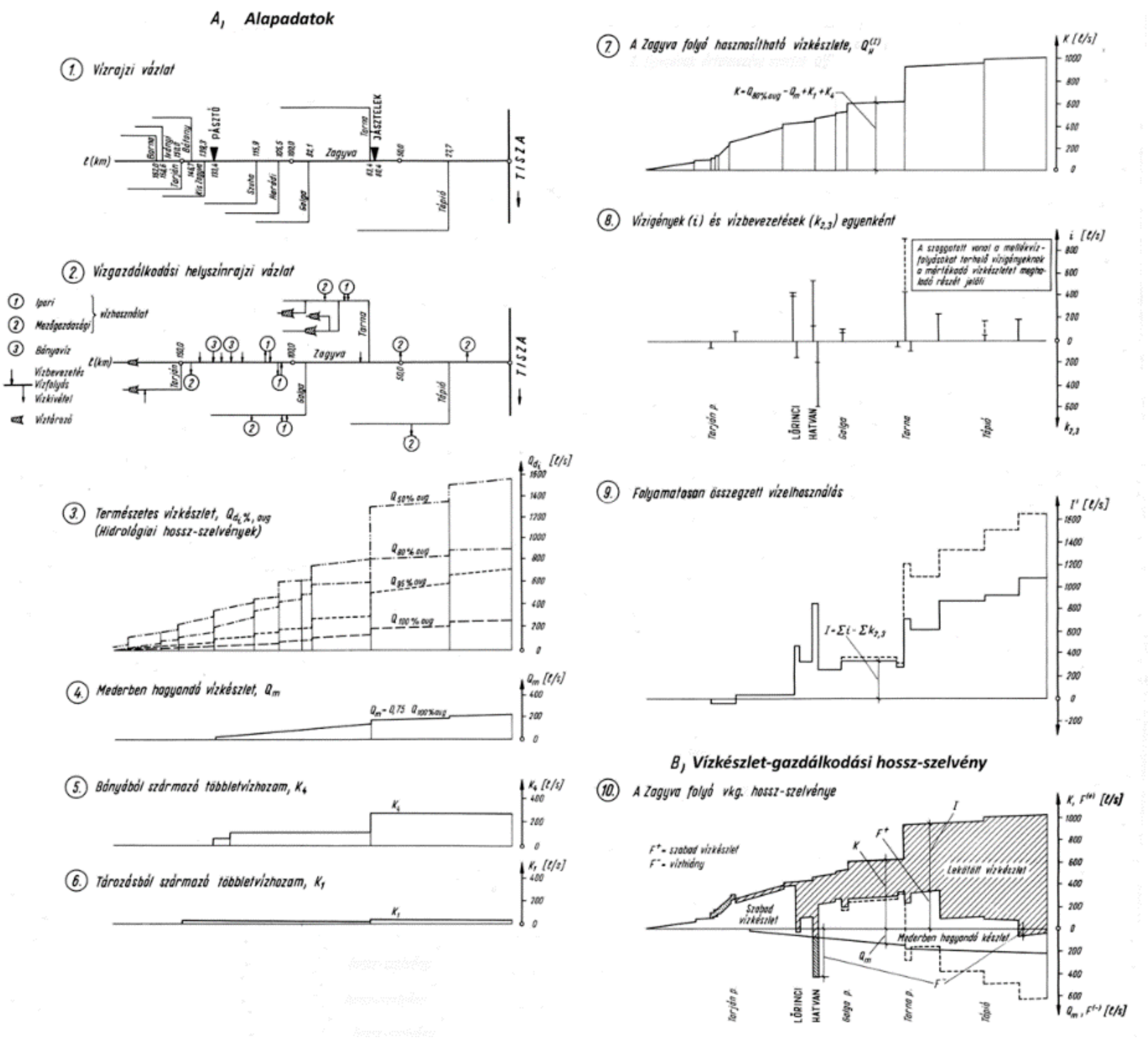

Figure 5: Step-by-step explanation of the longitudinal water balance profile plot *(based on: Bözsöny Dénes - Domokos Miklós: Gyakorlati vízkészletgazdálkodás (Tankönyvkiadó, Budapest, 1975)*

The following points describe the main steps of constructing the water balance profile – these points correspond to the 10 graphs in Figure 5. Although the graphs might be helpful to understand how the water balance is built up, in practice there is no need to actually plot all of the graphs shown in the figure, they are there mainly to visualize the procedure.

1. Set up the schematic ***river network***, and locate tributaries along the selected watercourse.

2. Chart ***water uses along the river network***, including reservoirs, diversions, water extractions, and returned discharges.

3. Calculate the integral curve of the catchment area, then estimate the ***Q_d natural runoff*** values using different statistics (duration values) of measured flows or modelled runoff time series. For unmeasured catchments, use specific runoff values derived by methods of hydrological analogy. Measured flow values should be corrected against the effect of water uses. (In Hungary, surface water resources are defined as the 80% duration value of the August daily flows.)

4. Define the longitudinal profile of the ***Q_m ecological flow*** along the watercourse as required by ecological specifications, if exist any, or e.g. as a given percentage of Q_d.

5. Plot the integral curve of ***K_4 return flows originating from groundwater extractions*** (e.g. communal wastewater or discharges from mine dewatering). These discharges are considered external resources with regard to surface waters. (If a groundwater extraction has a direct effect on surface runoff –for example, bank filtered wells have – it should be proportionally accounted among the surface water uses.)

6. Plot the integral curve of ***K_1 reservoir releases*** (+) ***or retentions*** (-) and ***K_5 water diversions*** into (+) or from (-) the watercourse.

7. Calculate and plot the ***K manageable water resource integral curve*** by summarising the integral curves of steps (3), (5) and (6), and substracting (4), the Q_m ecological flow.

8. Plot the values of the existing ***i water abstractions*** (upward bars, positive quantities) and ***$k_{1,3}$ returns*** (downward bars, negative quantities) along the watercourse. Those on the tributaries should be represented by the algebraic sum of all abstractions and returns; moreover, calculate the water balance of the tributary using the following equation:

$$Fj = Kj - \Sigma ij + \Sigma kj$$

where Fj is the water balance result of the jth tributary, Kj the manageable water resource, Σij and Σkj the sum of all extractions and returns on the same tributary, respectively.

If the F_j balance is negative – i.e. water consumption exceeds manageable water resources of the tributary – then denote the deficit part of the abstraction bar with a dashed line. In that way, continuous lines would denote only that part of the abstractions that could be legally realised (without violating the minimum flow requirement – or could be realised at all, if there was enough flow available).

9. Plot the cumulative ***I(x) curve of the existing water abstractions (+) and returns (–)***. Take into account also those on the tributaries, first including only the realised part of the abstractions. Following that, superimpose the cumulative tributary deficits upon the realised abstractions I(x) curve. In that way we may have two curves in the graph, the I′(x) expected total cumulative water consumption (the upper curve) and the I(x) realised (or legally realised) consumption (the lower curve). Normally, if water permits were issued prudently, there is no deficit and I(x) and I′(x) – realised and expected – curves coincide.

10. Construct the ***longitudinal water balance profile curves*** from the following components:

Manageable water resources integral curve: $K(x) = Q_n(x) - Q_m(x) + K_1(x) + K_4(x) + K_5(x)$

Minimum flow requirement: $Q_m(x)$ plotted as a negative quantity.

Water balance curve: $F(x) = K(x) - I(x)$

Available water resource and Deficit: along those parts of the river where $F(x) > 0$, there we have a positive $F^+(x)$ balance, i.e. there is water resource available for additional uses, while along those parts of the river where $F(x) \leq 0$, no additional uses can be served, and an $F^-(x)$ deficit might be present.

We now have all the necessary information to calculate the total deficit of the whole river catchment in question, simply by adding up the deficits on the tributaries and the maximum deficit along the F(x) curve.

Water balance deficits are a sign of a malfunction from the water resources management point of view. The situation might be repaired by either reducing the volume of water abstraction or increasing the manageable water resources by reservoirs or through water import from other catchments.

A longitudinal water balance profile is to be set up for all watercourses where there are several or significant water uses. When connected to a river network geodatabase, a water use and water resource database, water balance profiles can be algorithmically constructed, interconnected and continuously updated. GIS-based applications can accelerate decisions on permitting new water uses.

In practice, water balance profiles can be integrated into more comprehensive, larger catchment-based water balance calculations, where watercourse level details give way to a regional or national level overview of the water resource management status and for the evaluation of strategy options.

Effort of the action:

Construction of the longitudinal water balance profile of a watercourse takes – depending on river size and network complexity – about 0,5 to 2 days for an experienced hydrologist. Work can be made more efficient using Excel templates that store input data as well as formulae for the calculations and graphic templates for any or all of the 10 profiles mentioned in the previous section. In Hungary there are cca. 600 watercourses where longitudinal profiles were constructed in the past or might be worth to construct in the future as its water resource could be utilised.

Result(s) achieved so far:

An ArcGIS-based application has been developed for the calculation of water balance profiles, potentially at least on 6000 watercourses.

Difficulties faced:

The accuracy of the method is depending on the availability of hydrological observations: (i) time series observed at gauge stations on representative catchments/rivers, and (ii) a one-time discharge measurement series during a low flow period along the river, especially above and below tributaries, to establish the pattern of low flow accumulation. In the last 10 years, these patterns are changing as the intermittency of runoff is increasing.

Remaining constraint(s):

Longitudinal water balance profiles are primarily for natural river systems, where the hydrological processes are definitive in the availability and amount of the water resource.
In artificial and heavily controlled channel systems (e.g. irrigation systems) water resource availability is rather dependent on the operation rules and on the capacities of channel sections and hydraulic structures. Although water balances and longitudinal profiles can be constructed on any watercourse, in these cases the method is less informative and water resource managers are better served by hydraulic models.

Planned next step(s):

Calibration and validation of the GIS-based application for all natural river systems in Hungary.

Transferability:

The method can be useful in any catchment, region or river, where there is a risk of overexploitation of water resources.

8.9. *SPAIN: WATER BALANCES AND MODELLING TECHNIQUES FOR WATER PLANNING IN SPAIN*

8.9.1. *GENERAL INFORMATION*

Member State(s)	Spain
RBD(s)	Inter-regional river basin districts (ES010 - Minho-Sil, ES017 - Eastern Cantabrian, ES018 - Western Cantabrian, ES020 - Douro, ES030 - Tagus, ES040 - Guadiana, ES050 - Guadalquivir, ES070 - Segura, ES080 - Jucar, ES091 - Ebro)[20]
Location	Inter-regional river basin districts (listed above)
Time period (start - end)	2000 to date (on-going)
Good practice example promoter	Spanish Ministry for the Ecological Transition and Demographic Challenge - Directorate General for Water (DGA) - River Basin Authorities (RBAs)

8.9.2. *CHALLENGE(S) FACED*

Code and description of the challenge(s):

[20] The modelling tool described in this good practice example for water resources assessment (SIMPA) is available for all Spanish RBDs including Canary and Balearic Islands and Portugal, while the modeling tool for simulating water exploitation systems and obtain water balances (SIMGES module of the AQUATOOL tool) is used by all Spanish 3rd RBMPs except for 2 of the 4 exploitation systems in the River Basin District of Catalonia (ES100).

- B8: Groundwater and surface water interactions are unknown and/or their role in water balances is not properly assessed.

The water discharges under natural regime in the Spanish peninsular basins are estimated at 99,096 hm^3/year (1980/81 - 2011/12 series). On the other hand, the available groundwater resources have been estimated at 27,138 hm^3/year. Finally, the utilization of unconventional resources amounts to 793.35 hm^3/year[21]. Having reliable data and a proper consideration of the integrity of the hydrological cycle are fundamental to avoid risks of double accounting or overallocation.

- B17: Complexity of integrating water balance data in modelling tools used for river basin management planning.

Overall, this complexity lies in collecting comprehensive and representative data of water resources, calibrating models accurately, accounting for uncertainties, and capturing the intricate dynamics of water availability and demand within a river basin. Furthermore, the planning process requires integrating climate change forecasts, variations land use patterns, and water demand dynamics, in addition to the effects of the planned measures themselves.

Water balances and modelling tools are also crucial for facing eflows and water allocation challenges. To facilitate understanding of the constraints and consequences of implementing ecological flows under altered regimes, their inclusion in exploitation simulation models establishes the basis for an appropriate allocation of water to uses and environmental needs. This integration considers the constraints of availability and their intra- and inter-annual variations, as well as the complex interactions between water resources, effective management possibilities, and distribution to various uses within the basin.

8.9.3. Good practice(s) developed

Code of the good practice(s):

- B8: Water balances properly account for groundwater-surface water interaction, based on proper studies/modelling.
- B17: The water accounting tool and the modelling tool(s) are developed in an interconnected and automated way.

Table 13: Synthetic overview of the actions taken

	Type of actions	Characteristics
✓	Regulatory[22]	Water Act Hydrological Planning Regulation (RPH) Hydrological Planning Instruction (IPH) Regulatory documents of the RBMPs
✓	Technical[23]	SIMPA distributed rainfall-runoff model, developed by the Centre for Hydrographic Studies of the CEDEX[24] AQUATOOL - Decision Support System, developed by the Research Institute of Water and Environmental Engineering of the Polytechnic University of Valencia[25]. The metering of water flows and water abstractions are customary tasks of RBAs, needed to properly feed and calibrate the models.

[21] Data from DGA - CEDEX 2019.
[22] Detailed references and weblinks in section 8.9.4.
[23] The case study focuses on these two modeling tools because of their application to all intercommunity RBDs. Other rainfall-runoff models are also used, such as PATRICAL in the Jucar RBD or TETIS in the Eastern Cantabrian RBD, or specific groundwater modeling tools (MODFLOW, RENATA, VISUAL BALAN, APLIS).
[24] Centre for Public Works Studies and Experimentation. (Centro de Estudios y Experimentación de Obras Públicas). https://www.cedex.es/.
[25] https://aquatool.webs.upv.es/aqt/en/home/

	Type of actions	Characteristics
✓	Economic	Works for improving groundwater balances and updating of SIMPA are made by IGME[26] and CEDEX under DGA commissioning. The updating of water resources, demands and balances (using AQUATOOL), including the assessment of the impact of climate change, will be carried out as part of the technical assistance for the drafting of the RBMPs (approximate cost for the 4th cycle for each inter-community RBD: 200,000 euros). PERTE for digitization of the water cycle plans to mobilize 3.06 billion € in public & private investments to promote new information technologies[27].
✓	Research	SIMPA hydrological model is in continuous evolution, particularly for the improvement of surface-groundwater interaction. Further AQUATOOL R&D practical applications are being generated by research projects and activities on operating rules by coupling genetic algorithms and network optimization; water quality modelling; water resources management risks analysis; calculating of biological indicators in river sections; integration of rainfall-runoff models; analysis and stochastic generation of streamflow series. The Groundwater Action Plan 2023-2030 includes, among other lines of action, measures to improve knowledge (including general hydrogeological studies and numerical modelling), the promotion of monitoring programmes and the digitalisation and control of uses (supported by PERTE and a specific groundwater documentation system).
✓	Governance	Following RPH and IPH, water resources inventories (surface, groundwater, reclaimed and desalinated) and water balances are established in the RBMPs. These provisions are decisive for the concession regime (e.g. whether or not to allocate new concessions).
	Others	

Description of the good practice:

Water balances is a compulsory content of Spanish RBMPs, as stated in the Water Law and in the Hydrological Planning Regulation. They are the result of an iterative process based on the systematic uses of modelling tools – mainly, SIMPA and AQUATOOL- where the best knowledge on water resources and water demand is combined and calibrated with metering data. This requires the development of protocols for interconnection and automation of modelling processes (B17).

Firstly, natural water resources assessment is carried out at national and basin scale using the distributed rainfall-runoff model SIMPA, that quantifies the interactions between the different components of the hydrological cycle (B8). Secondly, a simulation of water management is applied jointly considering the water resources spatial and temporal distribution as determined by SIMPA, water demands and available or programmed hydraulic infrastructure, environmental restrictions (B19) and internationally agreed transboundary flows (B21). The guarantee of supply of demands is assessed in a multi-annual perspective based on historical series of natural runoff and considering the foreseeable impacts of climate change on the hydrological cycle. The model used for this purpose is the AQUATOOL (SIMGES module).

Reasons for initiating action(s):

The «White Paper Book on Waters in Spain» (MIMAM, 2000) - addressed the need for compiling national basic water data, which were scattered across numerous administrative and private entities. Its purpose was to discuss Spain's water-related problems, by establishing the foundations for describing the current situation, estimating the foreseeable evolution, and establishing options

[26] Spanish Geological Survey (Instituto Geológico y Minero de España). https://www.igme.es/
[27] This includes assistance for administrations and competent entities in the urban water cycle, industry, irrigation communities, and groundwater user associations. It also involves the installation of water meters at water intakes and irrigation plots (including soil moisture and conductivity monitoring) and the digitization of Automatic Hydrological Information Systems.

and priorities in water use. The analysis of the RBMPs in force at that time revealed the use of different procedures and analytical methodologies, with varying interpretations of certain concepts and inconsistent levels of precision in the assessment of water resources and demands. Moreover, the need for an integrated consideration of the various components of the hydrological cycle was widely discussed (section 3.1), and an analytical modelling of the water allocation system was advised (section 3.5).

Selection of the action(s):

For the preparation of «Water in Spain» it was decided to produce hydrological series up to 1995/96 using a homogeneous methodology for all the Iberian basins, by means of a massive modelling of the basic components of the hydrological cycle. For that purpose, the quasi-distributed and conceptual rainfall-runoff model **SIMPA** (Sistema Integrado de Modelización Precipitación-Aportación)[28] was developed, including detailed accounting of groundwater-surface water interaction. Distributed models advantage aggregated ones for handling large basins at the planning scale, integrating the spatial variability of hydrological data and parameters (Cabezas Calvo-Rubio et al. 1999). Additional information on the model is provided below.

Furthermore, and considering the complexity of the hydraulic schemes in most of the Spanish basins, a realistic assessment of the availability of water resources required the use of analytical tools capable of simulating and optimising the distribution of water under different infrastructure alternatives and management scenarios including inter-basin transfers. Thus, the construction of a unified national exploitation system was undertaken. The **AQUATOOL** model by the Polytechnic University of Valencia (Andreu et al., 1991) was selected for this purpose[29]. It should be noted that, at that time, there was already a first generation of Spanish hydrological plans that had undertaken modelling work and consequently developed water balances.

Since then, both tools have been used for drafting RBMPs, meeting the specific requirements of Spanish legislation, which combines the objectives established by the Water Framework Directive with others of its own, literally:

> *meeting water demands, balancing and harmonising regional and sectoral development, increasing the availability of the resource, protecting its quality, economising its use and rationalising its uses in harmony with the environment and other natural resources.*

Description of the action(s):

The management of water resources in Spain has historically been conditioned by the pressure for water use typical of Mediterranean countries. Giving the magnitude of the water demand (31,126.39 hm^3/year in 2021) and its significant effect on river flows, it is also critical for assessing the impact of abstraction on compliance with environmental objectives in water bodies. For this reason, the mandatory contents of the Spanish RBMPs (art.42 TRLA) include:

- The building of an **inventory of natural water resources** that must include quantitative estimates and qualitative descriptions of the water resources, their temporal distribution, as well as an assessment of the possible effect of climate change. It is explicitly stated that the Ministry for Ecological Transition and Demographic Challenge (MITECO), with the support of CEDEX, will be responsible for maintaining an updated inventory to be made available to RBAs and the public.
- The **allocation and reserve of water resources** to meet the water needs of current and future uses (art. 21 of RPH) by establishing the water balances at exploitation system level. The current balance is established for normal supply conditions (but accounting for climate variability) and legal allocation priorities, where eflows are considered a general restriction to water, which is set at a level which is conducive to the achievement of good ecological status or potential (B19). Balances must also be established for future horizons (6 and 12 years after the reference date), including the effects of climate change.

[28] SIMPA was developed from a formulation of the Temez water resources model (1977) and the implementation of a tank model in collaboration with the University of Valencia (Estrela et al. 1996a, 1996b and 1999; García-Bravo et al. 2022). It took advantage of the advances made at the time, such as the first publication of a comprehensive characterisation of the Spanish aquifers (Ministry of Industry and Energy, Ministry of Public Works, Transport and Environment 1995), which in turn benefited from the enormous work carried out by the IGME in the groundwater survey and by the RBAs in the preparation of the first generation of RBMPs in 1998).

[29] AQUATOOL was first applied in 1993-94 to the hydraulic system of the Guadalquivir River to assess the guarantees of supply for agricultural uses.

The objective of the IPH, by developing the provisions of TRLA, is to provide a comprehensive and sufficiently detailed methodological guide to approach the planning tasks in a homogeneous and systematic manner. This is made by leveraging the accumulated experience from previous work and ensuring that optimal technological tools for organizing and processing information are made available for the drafting of RBMPs. The processes are highly demanding in terms of compiling meteorological and hydrological data, soil properties and land use, technical and operational characteristics of infrastructure, spatial distribution of water demands and uses, seasonal modulation, efficiency parameters… Models help to build a dynamic picture of current water availability and use based on this information, which facilitates the understanding of problems and the evaluation of strategies under different scenarios.

- The **inventory**, as stated in section 2.4.2 of IPH, should include hydrological time series of, at least, the following variables: precipitation, potential evapotranspiration, actual evapotranspiration, groundwater recharge, surface runoff, subsurface runoff, and total runoff or discharge. The variables should be coherent with each other, obtained through hydrological simulation processes that reproduce the main interactions among them.

  The inventories have been obtained from the application and successive updates of the **SIMPA model** (Estrela and Quintas, 1996a and 1996b; Estrela et al., 1999; Álvarez et al., 2005). SIMPA is a conceptual and quasi-distributed rainfall-runoff model that simulates the process of transformation of precipitation into runoff, considering the dynamics of water storage in soils and aquifers. This model simulates the hydrological processes on a monthly scale, in natural regime and in each of the cells in which the territory is reticulated.

  The balance is carried out based on the incoming precipitation flow, which is distributed among a series of outflows (real evapotranspiration, surface contribution and contribution from subway sources), another series of intermediate flows (infiltration) and a final series of intermediate storage (soil moisture and volume stored in the aquifer)[30] (Figure 6).

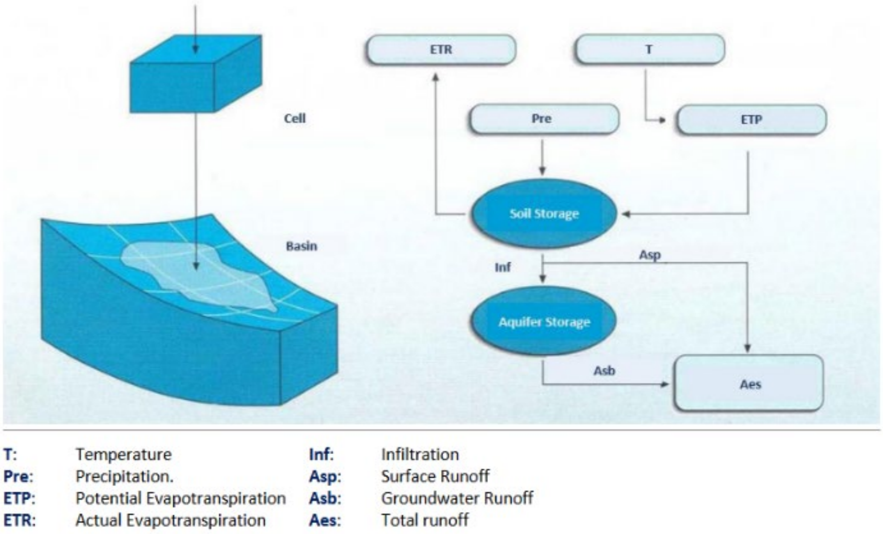

Figure 6: Flow chart of the distributed model SIMPA (Source: WAMCD Project, 2015)

The results are a set of monthly, annual, and average maps of the long-term series (since 1940/41) and short-term series (since 1980/81) of the different hydrological variables.

- The SIMGES module from the **AQUATOOL Decision Support System** (DSS) is used to address the simulation of the exploitation systems in accordance with IPH, section 3.5.1.2. SIMGES ensures the consistent integration of the data requirements, namely:
  - Water resources represented by inflow series in natural regime obtained by SIMPA that are incorporated on significant points of the fluvial network. They are estimated considering direct runoff over the surface as well as groundwater discharges from aquifer.

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[30] In areas where snow is a characteristic phenomenon, information about this variable will be added.

- Groundwater resources management can be modelled by different AQUATOOL conceptual schemes depending on aquifer characteristics and relationship with surface waters.
- water demand units, characterized by type of uses, level of priority for allocation purposes, abstraction point, annual volume, monthly distribution coefficients, and return coefficients
- eflows and water requirements of lakes and wetlands
- transboundary minimum flows as specified in the Albufeira Convention, where applicable
- reservoirs, characterized by the relation between flooded surface area and stored volume, monthly evaporation rates, minimum and maximum monthly volumes and operational rules.
- main conveyance infrastructure and other relevant facilities such as wastewater treatment plants, desalination plants or pumping stations

The model allows for any configuration within limits imposed solely by hardware capabilities, making it usable for any hydraulic resource scheme (Figure 7), taking also into account the relationships between surface water and groundwater. The simulation is performed monthly and replicates, with the desired spatial detail set by the user, the flow of water through the system.

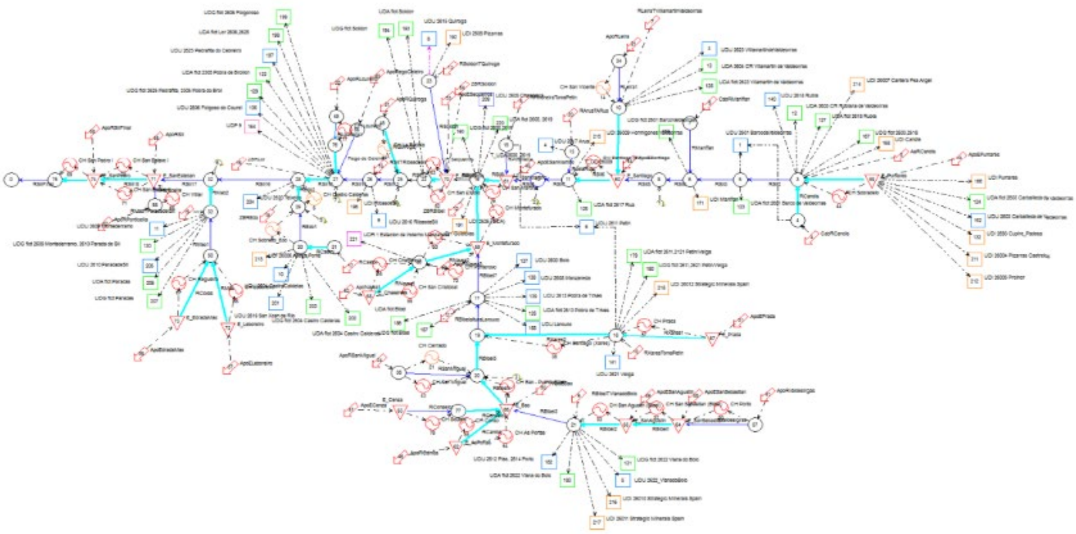

Figure 7: Detail of the optimisation diagram for the Lower Sil River System (Source: Minho-Sil RBMP 2022-2027. Annex 4[31])

The combination of SIMPA and AQUATOOL provides results in accordance with the requirements of the IPH. Specifically, it is assessed whether the levels of guarantee for meeting water demands (which vary depending on the type of use) are met and whether minimum ecological flow regimes are complied with, both in the current situation and in future scenarios, while evaluating the contribution of planned measures. Furthermore, the compliance or non-compliance with these levels helps to gauge whether there are water scarcity situations qualified as "structural" (long-term overexploitation).

Water scarcity is considered temporary when it arises from drought situations (or other transitory anomalies) and does not prevent compliance with the levels of guarantee. Its management is framed within Drought Management Plans (DMP)[32] and is based on systems of indicators and thresholds that trigger - among other administrative, organizational, and management measures – stepwise reductions in water allocation and mobilization of extraordinary resources. The strategies for overcoming temporary episodes defined in the plans become part of the operating rules of the SIMGES models.

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[31] https://www.chminosil.es/images/planificacion/proyecto-ph-2022-2027/VMITERD/001.PHC/04._ANEJO_IV---.pdf

[32] DMPs in force are available at https://www.miteco.gob.es/es/agua/temas/observatorio-nacional-de-la-sequia/planificacion-gestion-sequias/.

Effort of the action(s):

The SIMPA model is operated by the CEDEX Centre for Hydrographic Studies under a recurring commission from the DGA. In each planning cycle, the model is recalibrated with new data and its parameters are reviewed, with particular attention to improving the interaction between rivers and aquifers[33]. Additionally, SIMPA serves as a basis for evaluating the effects of climate change in water resources (Álvarez et al. 2016, CEDEX 2017). The last evaluation exercise uses 12 climate projections derived from the 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) and is complemented by an analysis of extreme events (maximum rainfall and droughts) based on statistical models. The results of this body of work are provided to the RBAs to support their planning work.

The drafting of the RBMPs is undertaken following the compliance schedule of the Water Framework Directive (WFD) and involves, in addition to technical officials from the RBA, the hiring of external consulting companies. A fundamental component of these contracts is the compilation, updating, and reassessment of water demands and environmental needs, the integration of changes in the hydraulic system and the programming, where needed, the interventions to address quantitative management issues, including expected impacts of climate change. Specialized consulting firms have expert teams to cover these tasks and carry out the necessary modelling exercises to establish water balances, allocation, and reserves. The indicative cost of these tasks for the 4th cycle in each inter-community RBMP can be estimated at 200-250 thousand Euros[34].

Moreover, to feed, update and improve SIMPA and AQUATOOL, it is necessary to maintain monitoring and recording systems for the meteorological datasets, reservoirs' management (inflows, stored volumes, and releases), flowing water discharges in the river network (including compliance with ecological flow regimes), diverted flows in conveyance infrastructure, piezometric evolution, irrigated surfaces and crops, volume contributed from desalination plants or wastewater regeneration facilities, supply data to users, changes in concessions and water rights, and more.

Result(s) achieved so far:

These modelling tools have been successfully applied to generate the inventory of water resources and the balances (allocation and reserves) in the three cycles of hydrological planning developed to date. These results are widely applied in technical studies and research papers.

It is particularly noteworthy the contribution of these RBMP components to some crucial functions developed by RBAs to implement the Spanish water resources management system:

- the establishment of exploitation potential in groundwater bodies and surface water systems, serving as a justifying framework for granting or denying new rights
- the analysis of the effectiveness of water management measures, considering the expected impact of climate change and water demand dynamics
- the determination and adaptive monitoring of ecological flow regimes and environmental needs of lakes and wetlands, and the calibration of their impact on water uses
- the analysis of the effects of other policies (irrigation, urban development), facilitating the positioning (prescriptive reports of the RBAs)

In each hydrological cycle, the SIMPA data series are updated and revised to incorporate changes resulting from improved hydrogeological knowledge, such analysis of interrelationships between groundwater, rivers, springs, wetlands and other relevant natural ecosystems or new inventories of groundwater resources. As a result of this work, there is a remarkable understanding of how surface water and groundwater interact. However, there is still room for improvement.

Furthermore, AQUATOOL has become a tool known and understood by stakeholders, which enables its use in the public participation of RBMPs and, in general, for technical discussion with users.

Difficulties faced and remaining constraints:

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[33] Improvements for the third cycle have included increased spatial discretization, analysis of the quality of river flow metering data series, climatological series, and their interpolation, as well as enhancements in snow treatment. This development has been carried out in collaboration with the RBAs, IGME, and the State Meteorological Agency (AEMET). The scope of work has been expanded to neighboring areas of Portugal and France to simulate water flows into Spanish territory in those regions.

[34] In any case, it should be noted that the initial assembly cost of the AQUATOOL models for the first cycle was significantly higher (around 600-700 thousand Euros per RBD).

The application experience in the first three cycles has built a solid working architecture and a good information base. That said, certain limitations can still be noted:

- The main difficulties still come from data capture and their integration into the model. The combination of measured, estimated, and simulated data hampers the full consistency of the water balances.
- When implementing hydrological models as SIMPA, scale problems and associated uncertainties should be considered. Models are developed for a defined scale, but water uses, and derived hydrological processes may depend on higher scales.
- AQUATOOL works with fixed water demand values but must reproduce the variability of supply that depends on the situation of the hydraulic system and the management practices applied.
- Moreover, the historical variation of water demands and return coefficients must be considered for the validation of the results.
- When irregular uses have a significant weight, they introduce indeterminacy for the purposes of calibration and interpretation of the results.
- No functionality is available for coupling demand functions in water demand nodes; nor is there a mechanism for optimizing drought management strategies based on the magnitude of expected impacts.

Planned next step(s):

In addition to the completion and series of meteorological and hydrological variables (for processing in SIMPA), and the updating of the characterization of infrastructures and water demands, with each planning cycle the weaknesses of the balances are identified, and work is planned to respond to them (e.g., integration of new groundwater models).

Currently, the revision of the DMPs is being finalized with the corresponding redefinition of indicators, thresholds, and programs of management measures to mitigate impacts.

The Groundwater Action Plan (MITECO, 2023) includes multiple activities for the enhancement of groundwater knowledge, management, and governance. It is planned to continue to work on improving the treatment of the groundwater component of the water cycle in the SIMPA model for the inventory of water resources at the national level.

Finally, it should be noted that both models are under continuous development, addressing process improvements and new functionalities. Suggestions from RBAs and the large community of practitioners are considered when designing the evolution of the tool.

Transferability:

The main limitation arises from the need to compile, organize, and process a large amount of data. Additionally, besides modelling specialists (rainfall-runoff and simulation of water resource management), it is also necessary to have expert personnel to lead implementation in each water resource system, with a notable understanding of the hydrological cycle, its interactions with uses, and the legal framework for water resource allocation.

One possibility is to implement it step by step, starting with a general assessment of the situation and valid scenarios at a strategic level, to progress towards increasingly detailed models that are useful for characterizing balances and allocation at the level of the hydraulic system, demand unit, or water body.

The SIMPA model was developed by CEDEX and has been implemented in Spain as well as in Central and South American territories. AQUATOOL licence is free for public institutions if used for nonprofit-making purposes. Price for engineering & consulting firms is 12.000 €.

8.9.4. Further information

Websites:

- AEMET official website: www.aemet.es (State Meteorological Agency)
- Albufeira Convention website: http://www.cadc-albufeira.eu/es/

- AQUATOOL (https://aquatool.webs.upv.es/aqt/). Official website of the Decision Support Systems (DSS) development environment for planning and management of river basin or water resource systems.
- CEDEX website dedicated to the Integrated Model of Basin Management (https://www.cedex.es/index.php/centros-laboratorios/centro-estudios-hidrograficos-ceh/proyectos/modelo-integrado-gestion-cuencas) Information on the ongoing project consisting of an integrated basin management, national simulation with data from the 2nd RBMPs (2015 - 2021).
- PERTE plan for the Digitization of the Water Cycle (https://www.prtr.miteco.gob.es/es/perte/perte-digitalizacion-ciclo-agua.html). Access to information and documents on the Strategic Plan for Economic Recovery and Transformation (PERTE) framed within Spain's Recovery and Resilience Plan.
- River Basin Management Plans in force section on the Ministry for Ecological Transition and Demographic Challenge (MITECO) website (https://www.miteco.gob.es/es/agua/temas/planificacion-hidrologica/planificacion-hidrologica/planes-cuenca/default.aspx). Regulation of RBMPs is available via this web page.
- SIMPA Model (https://www.miteco.gob.es/es/agua/temas/evaluacion-de-los-recursos-hidricos/evaluacion-recursos-hidricos-regimen-natural/). Description of the model and results.
- Spanish Office for Climate Change section in the MITECO website: https://www.miteco.gob.es/es/cambio-climatico/temas/organismos-e-instituciones-implicados-en-la-lucha-contra-el-cambio-climatico-a-nivel-nacional/oficina-espanola-en-cambio-climatico/

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- AQUATOOL user manual Version 1.0, September 2015 (in Spanish) (https://aquatool.webs.upv.es/files/manuales/aquatool/ManualAquaToolPlus.pdf)

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8.10. *Denmark: water balance development*

8.10.1. *General information*

Member State(s)	Denmark
RBD(s)	DK1 Jutland and Funen DK2 Zealand DK3 Bornholm DK4 International (Vidå-Kruså)
Location	Denmark
Time period (start - end)	2003 - ongoing
Good practice example promoter	Ministry of Environment of Denmark, Environmental Protection Agency

8.10.2. *Challenge(s) faced*

Code of the challenge(s):

- B5: Water balances are using updated water availability datasets, including metering and modelling of rainfall, runoff and recharge, accounting for climate change impacts.

Description of the challenge:

The challenge has been to develop a national water resources model for the entire hydrological cycle covering the entire 43.000 km^2 of Denmark to support the national water management and the groundwater characterisation, risk assessment, status assessment and measures.

In addition, the ongoing climate change has shown the importance of valid hydrological models.

8.10.3. Good practice(s) developed

Code of the good practice(s):

- B5: Water balances are using updated water availability datasets, including metering and modelling of rainfall, runoff and recharge, accounting for climate change impacts using the Danish national water resources model (DK-model).

  This is illustrated by the development in Denmark, where comprehensive national databases for geologic borehole data, groundwater-related geophysical data, geologic models, as well as a national groundwater-surface water model (DK-model) have been established and integrated to support water management. This makes it possible to facilitate the examination of the quantitative status of groundwater resources by e.g. estimating the effect of ground water abstraction on ground water level and stream flow. It has been possibly to identify areas with water scarcity as well as effects from climate changes.

Table 14: Synthetic overview of the actions taken

	Type of actions	Characteristics
	Regulatory	
✓	Technical	Establishing a national water resources model for the entire hydrological cycle covering the entire 43.000 km² of Denmark.
	Economic	
✓	Research	Modelling the interaction between ground water and surface water. Modelling the effect from climate changes on the hydrological cycles.
✓	Governance	Improved coordination of dataflows between different competent authorities.
	Others	

Description of the good practice:

It is generally acknowledged that water management must be based on an integrated approach, considering the entire hydrological cycle. This has in particularly been endorsed by Water Framework Directive (WFD) imposing integrated management considering all waters.

An example is the growing need for immediate information on the entire water cycle, with quantitative assessments of critical hydrological variables and flow interactions between different domains, e.g. atmosphere, plant-soil, surface water, groundwater and the sea, as they take place. To ensure the possibility to evaluate climate changes on the hydrological cycle increasing resources has been invested to develop the national water model (DK-model).

To meet the challenge, there is established a national water resources model (DK-model) for the entire hydrological cycle covering the entire 43.000 km² of Denmark.

The DK-model is established in the MIKE SHE/MIKE HYDRO model system, which is a deterministic and physically based fully distributed model system that describes the most important flow processes in the land phase of the hydrological cycle.

MIKE SHE is used to describe evaporation from the soil surface and the root zone, the surface runoff (2D), flow in the unsaturated (1D) and saturated (3D) part of the groundwater system including drainage water runoff (2D). MIKE SHE is connected to MIKE HYDRO, where the runoff in streams is calculated (1D). The model system is implemented in MIKE ZERO. For computational reasons, it is necessary to divide DK models into several regional sub-models (DK1–DK7), delimited according to parts of the country and groundwater table.

Reasons for initiating action(s):

In Denmark, drinking water comes entirely from groundwater, and only a limited part of the water consumption is produced from surface waters. Knowledge of groundwater flow paths and water balances available are therefore essential for the water management. As the WFD calls for proper assessment of the influence on groundwater quantity and quality of surface water ecology has to be met.

Selection of the action(s):

Since 1996 the Geological Survey of Denmark and Greenland has been developing the Danish national water resource model (DK-model). The model has been regularly updated as new knowledge and data becomes available which has resulted in a continuous development of the model set up. The implementation of the WFD and the RBMPs has increased the use of the model as well the needs for development. Especially the ground water-surface water interaction has received increasing focus and needs for development. Throughout the past decades, climate change has received increasing attention and the changes in the hydrological cycle.

Description of the action(s):

The development of the DK model has taken place continuously since its establishment in 1996, with the most significant updates in 2004–2009 and 2013–2015. Throughout the past decades, climate change has received increasing attention and the changes in the hydrological cycle.

<u>1996-2009</u>

From the start in 1996, the National Water Resource Model had three main activities: creating a nationwide overview of the usable drinking water resource, which in Denmark is almost 100 percent groundwater-based, reorganization of the national monitoring station network and further development of the model system. There was thus a desire for a tool for calculating and overall assessment of Denmark's total available freshwater resource in terms of quantity, quality and protection. With input in the form of rainfall and land use, the aim was to be able to carry out a more precise quantification and monitoring of the development of the groundwater resource's current size and regional distribution now and in the future. Integration with the existing monitoring of groundwater quality was planned from the start. The aim was a significantly improved basis for assessing Denmark's total available freshwater resource in terms of quantity, quality and protection as a function of pollution sources, rainfall, climate, land use, etc.

The first version of the DK model was established in the period 1996–2003.

During the period 2005-2009 the DK-model was updated among other things with

- the module for calculating the net precipitation has been replaced, where the previously used "stand-alone" root zone module has been replaced with the "two-layer" module, which is an integrated water balance module in MIKE SHE.
- In addition to the transition to two-layer, there has been a detailed description of the soil physical parameters for the root zone as well as the development of the root depth, which controls the amount of evaporation and its spatial distribution.
- Climate data is refined from 40 x 40 km climate grid to 10 x 10 km climate grid for precipitation and 20 x 20 km for temperature and potential evaporation (however 40 x 40 km climate grid until 1998).
- The horizontal discretization is reduced from 1 x 1 km to 500 x 500 m grids.

The model was built so that it could be included as an important tool in connection with the work with the design of the river basin management plans and Natura 2000 management plans, as well as in connection with Denmark's obligations in connection with reporting to the EU's Water Framework Directive.

<u>2010-2015</u>

The next significant upgrade of the DK model took place in the period 2010–2015, when the model's watercourse network, waste water discharges etc. was further detailed and data processing was further standardized. Multi-objective calibration was significantly expanded during this period, and the first nationwide simulations of climate effects on groundwater level and runoff were carried out as part of research in climate adaptation and published on the klimatilpasning.dk portal.

At the same time, the model's application was extended to also include calculations for unmeasured catchments for use in University of Aarhus’s (DCE) monitoring of the marine load with nutrients. Work was also done during this period on an update of good practice in hydrological modelling, just as challenges with the water balance (precipitation correction) were identified. The model was further developed as the basic tool used in the second cycle of the River basin management plans, as a revised delimitation of groundwater bodies was carried out and, on the basis of data from the Danish national well database - JUPITER and the model, a chemical and quantitative condition assessment of all groundwater bodies was carried out with the implementation of degree of utilization and ecological flow criteria for fish and small animals.

2016-2022

In the fourth development period, 2016–2022, the operationalization and exhibition of the DK model's results has primarily focused on making the model more accessible to a wider group of users in municipalities and regions. Several initiatives have been in play. Partly there was VandWeb, which contained an exhibition of selected water extraction scenarios from the DK-model for use in screening watercourse impact in relation to zero extraction, current extraction and permitted extraction with calculation of changes in ecological quality elements cf. DCE – Danish Centre for environment and energy's established empirical formulas.

In the fourth period, there was an increased focus on ground water close to the ground and floods from ground water and streams. In this connection, GEUS developed a more detailed model version, hydrological information and prediction (DK-model HIP, i.a. in 100 m resolution). The new calculations were subsequently displayed on the HIP portal (hipdata.dk) of the Danish Agency for Data Supply and Infrastructure (SDFI) and on klimatilpasning.dk with a view to more detailed data base for climate adaptation planning The number of watercourses was expanded from 19,000 km to 22,500 km, drainages were distributed in 7 categories, land uses were expanded from 24 to 28 types, and soil types were expanded from 3 to 9 soil types, but the DK model development was continued every time a new version was established, so that updates in the geological model from the mapping were continued in the HIP model, etc. Also in connection with the latest River basin management plans (2015-21) the delineation of the groundwater bodies has been updated, just as the model has once again been able to support the basic analysis and condition assessment in relation to the various tests included in the respective chemical and quantitative condition assessment.

Alongside the development of the DK-model, the model has been part of a number of research projects from the very beginning, which have contributed to the development. In the first period 1996-2003, it was about research around large-scale physically based hydrological modeling (up-scaling) and assessment of sustainable water extraction. In the second period (2004–2009) it dealt with stakeholder involvement in the modeling process, quality assurance and good practice in hydrological modeling as well as inverse calibration using PEST (Parameter ESTimation code), climate effects on groundwater and integrated modeling and monitoring. In the third phase (2010–2015), precipitation correction and integration with satellite data were in focus, as well as dynamic coupling of the climate model and DK model. The first tests of a real-time model for the whole country were also made and research into data assimilation was carried out during that period. Finally, in the fourth development phase (2016–2022), as part of the Space project, research was conducted into spatial patterns in the evaluation of a hydrological model against satellite data.

In the latest development phase, hybrid modeling has been simultaneously researched and developed, whereby a number of downscaling products were developed using a combination of machine learning and the physically based DK-model (e.g. in C2C CC context of the depth to near-terrain groundwater for Central Jutland, followed by high-resolution machine learning-based nationwide 10 m HIP model for the depth to near-terrain base, and some random forest downscaling from 500 m to 100 m of climate effects on the groundwater level).

Another important step in the water balance is to have reliable data for water abstractions by all water users. In this work, it has been important to ensure an easier dataflow by increasing use of digital reporting, and a clear division of labor between water supplies, municipalities and Ministry of Environment.

In the period from 2005-2010 the dataflow changed from largely been on paper to only digital. The setup is based on the Danish national well database – JUPITER, and the reporting takes place by using special software or using a web interface. In the work, there has been a user group with participation from e.g. municipalities supporting the process. At the same time, the Ministry of Environment and the Geological Survey of Denmark and Greenland, who drives and develops the JUPITER-database, has made detailed guide documents to support the municipalities, water supplies and well drillers.

Besides, the division of labor are based on a clear legislation and agreements between the KL - Local Government Denmark (the municipalities' interest organization) and the state (Ministry of Environment). In Denmark, the state compensates municipalities for municipal expenditure changes because of, among other things, new legislation. This is done by the total state subsidy being increased or reduced when the municipalities are assigned or deprived of tasks.

Effort of the action(s):

The work with building up the DK-model has lasted over 25 years. It is not possible to estimate how many resources have been used. This must also be seen in the light of the fact that development of the DK model has had a multidisciplinary aim and is not only limited to work with the River basin management plans.

Result(s) achieved so far:

With the DK-model it is possible on a regional level to estimate the effect of ground water abstraction on ground water level and stream flow using reliable datasets, including updated metered data on water abstractions. The dataflow from the national well database – Jupiter, and other data area is automatized.

Difficulties faced:

The scale of the DK-model has been a barrier to evaluate the link between ground water and surface water. Originally, the scale was in 2x2 km. cells, later refined to 500x500 m. cells. Now the model is developed to 100 x 100 m. cells, whereby it is possible to calculate ground water abstractions effects on e.g. areas of 10 acres in size and watercourses with the length of larger than 100 meters.

Remaining constraint(s):

The scale of the model is still a remaining constraint, especially to evaluate the link between ground water and surface water. At the same time, the calibration of the model, especially when evaluations are to be made on both deep and subterranean groundwater bodies and their connection to surface waters.

Planned next step(s):

In the coming years, in the fifth development phase, 2022-2025, the aim is to continue to develop the model tool in such a way that the improvements that are developed in connection with different model versions are taken on board in the development of the DK model. There are several ongoing projects: partly a project where the DK model is updated dynamically (HIP real-time), i.e. with daily updated calculations with the DK model in 100 m in real time, incl. forecasts 5-10 days ahead. Another project involves developing a warning model for 500 m.

Besides, further development of the Jupiter-database will take place in the coming years, which will result in the database becoming more user-friendly and more easy to facilitate data access. The process will be supported by the end users i.e. municipalities, water supplies and well drillers.

Transferability:

In Denmark, there is a long tradition to collect hydrogeological data in central public databases in an easy accessible fixed structure.

8.10.4. Further information

Websites:

- **https://vandmodel.dk/**

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8.11. PORTUGAL: EVALUATION OF WATER AVAILABILITY BY RIVER BASIN AND APPLICATION OF THE SCARCITY INDEX WEI+

8.11.1. GENERAL INFORMATION

Member State(s)	Portugal
RBD(s)	PTRH1 - MINHO AND LIMA PTRH2 - CAVADO, AVE AND LECA PTRH3 - DOURO PTRH4A - VOUGA, MONDEGO AND LIS PTRH5A - TAGUS AND WEST RIVERS PTRH6 - SADO AND MIRA PTRH7 - GUADIANA PTRH8 - ALGARVE RIVERS
Location	Portugal mainland
Time period (start - end)	2021 - ongoing
Good practice example promoter	Portuguese Environmental Agency

8.11.2. CHALLENGE(S) FACED

Code of the challenge(s):

- **B4:** Need for having a tool for modelling the assessment of water availability and water use in the various sectors in order to quantify the WEI+ scarcity index

Description of the challenge:

Considering the changes precipitation, air temperature and consequently the flow regime in the last twenty years is was vital to adapt the modelling tool to this new reality in order to obtain water balance results between water availability, maintenance of e-flows and the volumes abstracted from all sectors, by updating data. This information must be used in licencing and even for the revision of existing permits for guarantee a sustainable volume allocation.

8.11.3. GOOD PRACTICE(S) DEVELOPED

Code of the good practice(s):

- **B1:** Implementation of a modelling tool in MIKE that allows to obtain water balances, with updating input data, to help with efficient and sustainable water management based on the allocation of water volumes to abstraction permits.

Table 15: Synthetic overview of the actions taken

	Type of actions	Characteristics
✓	Regulatory	Law Nº. 58/2005 of December 29th – Approves the Water Law, transposing Directive 2000/60/EC into the national legal order and establishes the bases and institutional framework for sustainable water management.

	Type of actions	Characteristics
		Decree-Law nº. 226-A/2007, of May 31th - Establishes the regime for the use of water resources. National Water Plan (Decree-Law n.º 76/2016, 9 November) Regulatory documents of the River Basin Management Plans (RBMP)
✓	Technical	Acquisition of specialized services for the development of the modelling tool in MIKE software
✓	Economic	It has been included in the contractual obligations that allow them to use water resources. Also the results will be used to define the scarcity coefficient apply to Water Resources Fee.
✓	Research	Use of new technologies in the identification of irrigated crops that allow for greater accuracy in estimating water needs for agriculture. Identifying the origins of the water supply for irrigation was one of the most difficult steps in this calculation process, and should therefore be studied in greater depth in future revisions of this work.
✓	Governance	Increased water abstraction control by allocation the right abstracted volumes or each abstraction permit.
	Others	

Description of the good practice:

The sustainable use of water, especially in its quantitative aspects, constitutes a real challenge for the management of water resources, taking into account current and future uses and their combination with climate change scenarios.

To respond to this situation, in addition to more efficient management of existing storage capacity, measures must be taken in the field of water use efficiency, enhancing reuse, guaranteeing ecological and environmental flows, leading to a reduction in global consumption in areas of greatest water scarcity.

In the context of climate change, the worsening of extreme phenomena further highlights the need to define a clear strategy for understanding availability and adapting needs in a sustainable way.

It was therefore necessary for the National Water Authority to develop a study that brought together the best available information and made an assessment of existing and future availability as well as determining the scarcity index per basin and sub-basin in a way to effectively be able to have a reference for licensing and to serve as a basis for planning water-dependent sectors.

The study carried out, in conjunction with the scientific community (and with the participation of the best national experts BlueFocus, Nemus and Hydromod, 2021), used the best available information, coordinating with different entities and guaranteeing the connection to other studies, which are also being carried out by National Water Authority, like the National Roadmap for Adaptation 2100.

The study carried out developed important modelling tools that allows a continuous work to calculate and update:

- Annual and monthly assessment of surface water availability under natural conditions in wet, medium and dry years;
- Assessment of water availability for various climate scenarios;
- Assessment of water use by sectors;
- Annual and monthly assessment of surface and underground water availability in a modified regime in wet, medium and dry years;
- Determination of the WEI+ scarcity index;
- Licensing guidelines.

Reasons for initiating action(s):

Changes in precipitation patterns, combined with the increase in average temperatures, are already significantly aggravate existing pressures on water bodies, in terms of quality and availability of water resources, a situation that will predictably be exacerbated in a not too distant future.

The geographical position of mainland Portugal is conducive to the occurrence of drought situations. In fact, there has been an increase in the frequency and intensity of drought situations, especially in the last two decades of the 20th century and the first decades of the 21st century.

Of the 30 hottest years in mainland Portugal in the period from 1931 to 2020, 21 occurred after 1990 and 13 since 2000. The year 1997 was the hottest followed by the year 2017. The increase in temperature and the decrease in the number of wet years in the last two decades has caused:

- Less replenishment of water volumes stored both in reservoirs and in groundwater;
- Difficulties in achieving good status of water bodies;
- Increased temperature and intensification of activities have resulted in an increase in consumption.

For Portugal, according to the most severe climate scenarios (RCP 8.5, IPCC AR5), the temperature increase could reach +5°C in 2100 (applicable to minimum, average and maximum temperatures), particularly during summer and inland Portugal. High temperatures are related to the substantial increase in very hot days (Tmax ≥ 35°C), especially in the southern interior, the increase in the number of tropical nights (Tmin ≥ 20°C) and longer heat waves, especially in the northeast interior. In the least severe scenario (RCP 4.5), average temperature increases could vary between 2°C and 3°C.

Precipitation patterns are also expected to face changes, with a significant reduction in annual values across the entire territory, despite the increase in precipitation in December/January (particularly for the period 2041-2070). Therefore, it is expected that the dry season will extend from summer to spring and autumn. Even so, this reduction in precipitation is not greater than the positive deviations in inter-annual variability, meaning that despite this trend there will be years with more precipitation than the 1971-2000 climate normal.

Therefore, it is urgent to promote the maintenance of water availability and quality of service, through interannual management of water availability, the adoption of water efficiency measures in all economic sectors and increasing the resilience of water availability in the regions. For that the developments of modelling tools for define available water and the allocation is crucial.

Description of the action(s):

The assessment of surface water availability in the natural regime was carried out using hydrological modelling to produce monthly runoff series from the precipitation and potential evapotranspiration series. A matrix distributed hydrological model was adopted with a spatial resolution of 1 km x 1 km and a monthly time scale that implements a water balance model, known as the Temez model. The model's data are the monthly precipitation and monthly average temperature surfaces, from which the monthly potential evapotranspiration, actual evapotranspiration, aquifer recharge and total runoff surfaces are calculated.

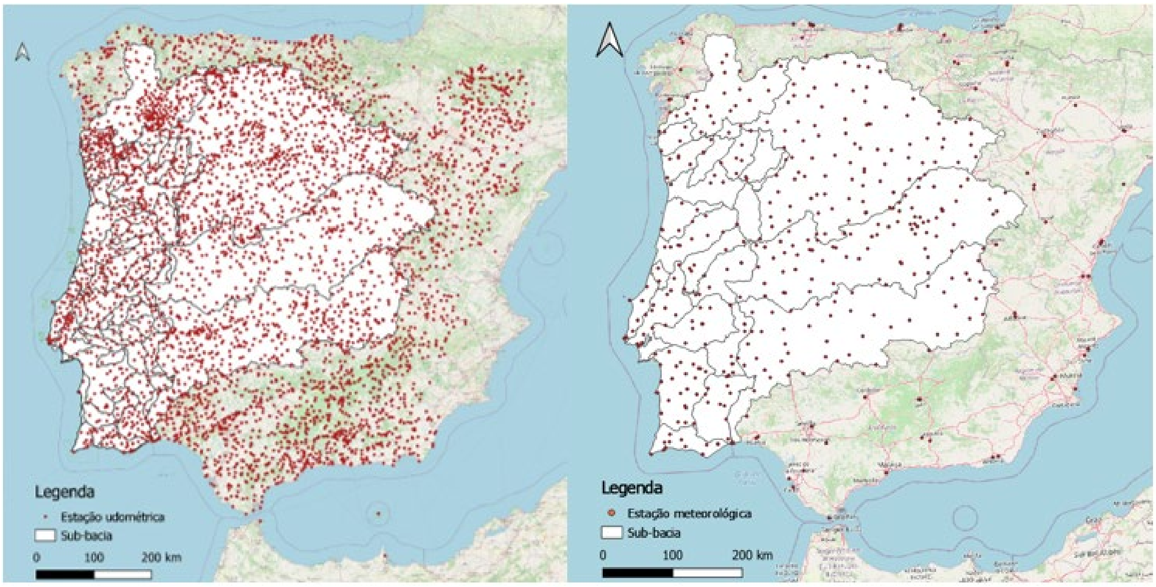


Figure 8: Precipitation and air temperature monitoring stations used for the period 1930-2015 (BLUEFOCUS, NEMUS and HIDROMOD, 2021)

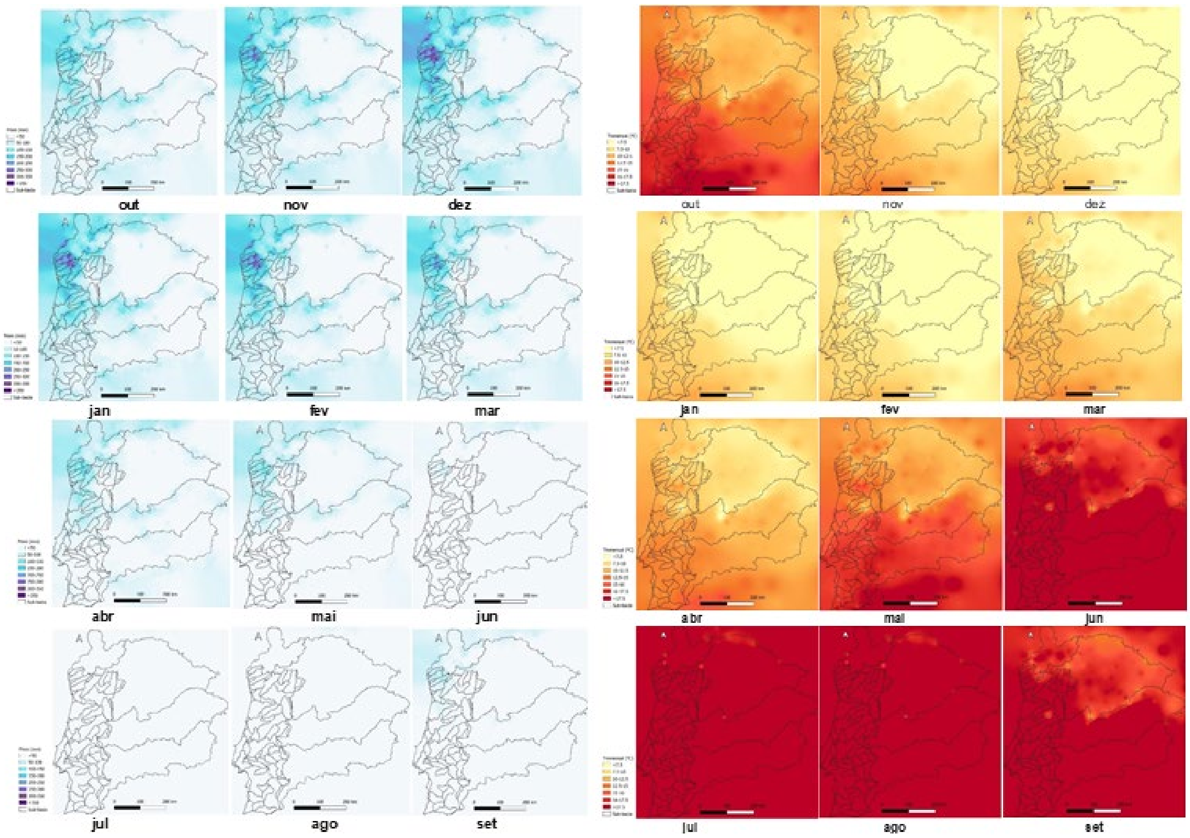


Figure 9: Spatial distribution of precipitation and monthly average air temperature (BLUEFOCUS, NEMUS and HIDROMOD, 2021)

Potential water availability under the modified regime was estimated using a simple model that takes into account the storage capacity installed upstream of each section. This model aggregates all the storage capacity installed upstream of the section of interest into a single reservoir and considers that all the water inflows generated under the natural regime in that river basin flow into that reservoir. For modelling purposes, the inflows downstream of each section are considered, from which the volumes abstracted in the upstream section have already been removed, thus obtaining the water availability actually available in each modelled section.

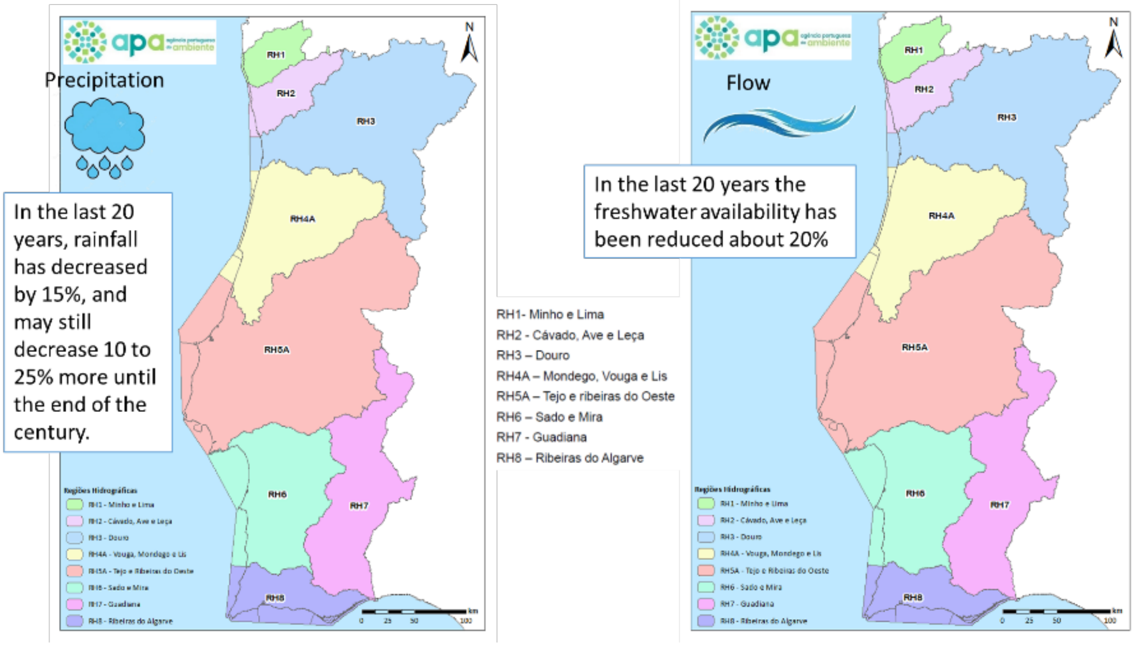


Figure 10: Modelling results shows an importance decrease (BLUEFOCUS, NEMUS and HIDROMOD, 2021)

To determine the volume of water abstracted for the different sectors, with the exception of tourism - golf courses, agriculture and livestock, whose values were the result of estimates (explained below), information was used from the permits database (SiLIAmb) and the data from water resources fee (TRH).

The need to assess water use for irrigation within the scope of the project is justified by the low representativeness and reliability of water consumption data from the water use permits associated with the agricultural sector and the lack of estimates using indirect methods that cover the entire national territory and include private and state-initiated hydro-agricultural schemes.

In the methodology used, it was necessary to ensure that the data required by the methodology was available and properly organised, and that it covered, with the appropriate spatial resolution, the entire continental territory, including private and state-initiated hydro-agricultural developments. The estimates of water use to be calculated should also cover surface and groundwater use. The possibility of automating the calculation was also a criterion taken into account. The elements needed for this methodology were:

- Area irrigated by type of crop and irrigation method provided by Agricultural Census 2019 (RA2019) carried out by the National Statistics Institute;
- Boundaries of public hydro-agricultural schemes provided by Directorate General for Agriculture and Rural Development;
- Location of areas in classes 2 (Agriculture), 3 (Pastures) and 4 (Agroforestry areas) provided by Land Use Map (COS) 2018 carried out by Directorate-General for Territory;
- Table of irrigation allocations by crops provided by reference allocations for irrigation in mainland Portugal carried out by Directorate General for Agriculture and Rural Development;
- water transport and distribution efficiency at the irrigation system;
- Irrigation efficiency;
- Monthly distribution of volumes abstracted.

From a spatial point of view, the mainland was divided into more than 50,000 polygons, with a maximum area of 273 km2, which resulted from cross-referencing the boundaries of parishes, hydro-agricultural schemes and the classes on the land use map (COS). The aim of this cross-referencing was to distribute the irrigated area figures per parish and per crop, provided in the RA2019, to smaller areas that respect the boundaries of the hydro-agricultural schemes and, if possible, the land use classes of the COS2018 (GIS information related with land use).

The irrigated area provided by administrative area and by crop in the RA2019 (agricultural census 2019) was distributed according to the following rules. For each crop class, an attempt was made to associate the total irrigated area in the administrative area, according to RA2019, with the part of the administrative area that falls within the irrigation perimeter and which, according to the COS2018, has that crop class. The remaining value, if any, was associated with the area outside the irrigation polygon that the COS2018 indicates as having that crop class. In a small number of cases, there was still an area to distribute after this process. It should be remembered that COS2018 has no information on whether the crop is grown under irrigation or rainfed.

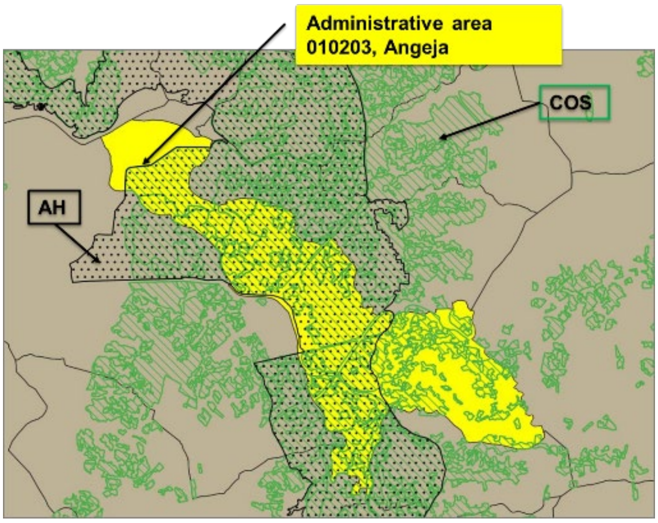


Figure 11: Methodology used to defined irrigated areas using several sources of information (BLUEFOCUS, NEMUS and HIDROMOD, 2021)

As there is no relationship between the taxonomies adopted in RA2019 and COS2018 and the fact that the latter covers both rainfed and irrigated crops, it was necessary to associate the crops identified in the former, with one or more classes in the latter, in order to apply the rules.

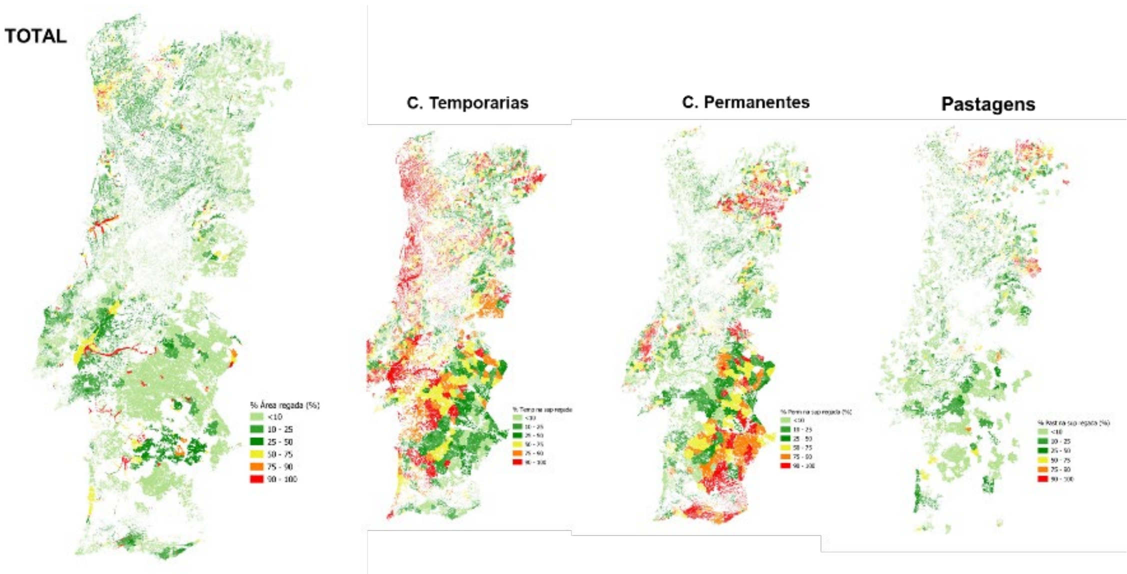


Figure 12: Irrigated areas identified (BLUEFOCUS, NEMUS and HIDROMOD, 2021)

The volume of water consumed in each polygon for the irrigation of each crop was calculated by multiplying the irrigated area of the crop by the crop allocation taking into account the irrigation method adopted in the region where the polygon is located.

For the subsequent calculations, the volumes of water consumed in each polygon to irrigate each crop were aggregated into the classes. One of the results of the project is a shapefile with more than 50,000 polygons, with a maximum area of 27,300 ha. Each polygon is characterised by the following set of attributes:

- Polygon area (km2);
- Percentage of the polygon area that corresponds to irrigated areas of each of the following crop classes: rice and other temporary crops, shelter crops, olive groves, vineyards, orchards, and permanent pastures (six attributes);
- Irrigated area of each crop class (km2), corresponding to the product of the percentage of irrigated area by the total area of the polygon (six attributes);
- Specific consumption (m3/ha) resulting from the ratio between the sum of the consumptions and the sum of the irrigated areas per crop in the parish;
- Water consumption of each of the above crops (m3), resulting from multiplying the specific consumption by the irrigated area (six attributes).

To calculate the volumes abstracted, each of the calculation polygons was associated with one of the 1809 surface water bodies and 93 groundwater bodies. This association was made on the basis of knowledge about the origin of water from hydro-agricultural schemes, the location of surface water abstractions and the location of groundwater abstractions. In practice, an attempt was made to identify all surface abstractions, assuming that the volume not satisfied by surface sources had an underground origin in the vicinity of the consumption calculation polygons. Occasionally, the monitoring records of groundwater bodies were evaluated to confirm the reasonableness of the estimates of the volumes abstracted there. Identifying the origins of the water supply for irrigation was one of the most difficult steps in this calculation process, and should therefore be studied in greater depth in future revisions of this work.

When calculating the volumes abstracted from each body of water, the volumes of water consumed were affected by a supply and distribution efficiency that takes into account water losses in the irrigation channels between the abstraction site and the irrigation application equipment. It should be noted that the irrigation application efficiency is reflected in the irrigation allocation values adopted, which take into account the various irrigation methods. In cases where irrigation is supplied by groundwater, a 100 per cent supply and distribution efficiency was assumed, assuming that in these cases the catchment is close to where the irrigation is applied, so there are no supply and distribution systems.

Finally, the monthly distribution of the volumes abstracted was carried out considering different distributions for each region, according to the data available in the annual reports of the collective agricultural hydraulic infrastructures or in the concession contracts.

The quantities of water consumed by livestock were estimated based on information, for the year 2019, on the number of livestock per farm and respective location, including the number of birds, cattle, goats, sheep and pigs. Although the amount of water that animals need is conditioned by several factors, namely the state of growth, gestation, lactation, activity, diet and intake levels, as well as environmental temperature, average capitations were used to each species under study, which considers these factors intrinsic to the animals, the type of farm, and also environmental factors.

In the case of cattle, a non-uniform monthly distribution of the quantities of water consumed was considered, which took into account the distribution of the average monthly temperature of each river basin district.

The quantities of water collected for livestock farming include drinking water, but also the service water used to wash the animals' housing. The values used to calculate the quantities of washing water used in livestock activities that drain the reception tanks are based on the information provided in the Code of Good Agricultural Practices.

Taking into account the assumption that livestock farms use their own supply systems originating from private abstractions (mostly groundwater), where the point of consumption is very close to the extraction site and losses in the water transport process were not considered.

The quantities of water consumed by the golf sector were estimated based on the methodology developed by the United States Golf Association (USGA) (Gross & Hartwiger, 2016). This method considers a calculation involving the area of the golf course, as well as climatic and environmental variables, such as evapotranspiration, precipitation or crop coefficient, to estimate the annual irrigation needs of a golf course.

It was also considered that the effective precipitation corresponds to the real precipitation affected by a runoff coefficient of 50%, as described by Gross and Hartwiger (2016). In the same way, a crop coefficient of 0.8 was also used. Cross-referencing this methodology with information on existing golf courses (areas and number of holes allowed the estimation of water needs for irrigation of golf courses.

As in the golf sector the irrigation method generally used is sprinkler, an application efficiency of 85% was adopted. Golf courses use their own supply systems originating from private abstractions (mostly groundwater), where the consumption/irrigation point is very close to the extraction site, meaning losses in the water transport process were not considered.

By using the methodology previously presented, the following graphs summarize the volumes annually abstracted by the different sectors and their distribution in terms of use of surface and groundwater.

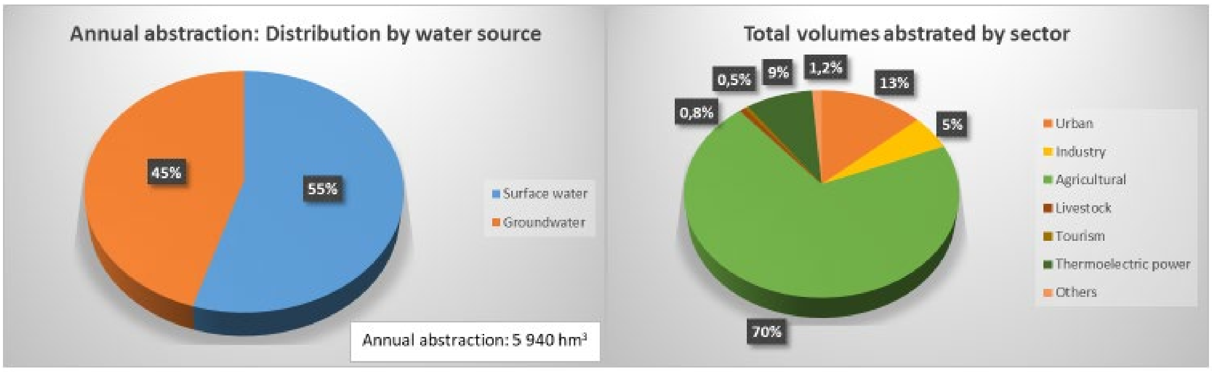


Figure 13: volumes annually abstracted by the different sectors

Result(s) achieved so far:

The study provides the following tools:

- Evaluates water availability and needs (in various sectors) and includes modelling of water allocation and use and the calculation of the WEI+ scarcity index;
- It will strengthen decision support - in the planning and licensing processes;
- Improves knowledge, namely uses of the agricultural sector (agricultural census RA2019 with COS2018 and crossing public and private irrigated areas);
- It will provide more information for sectors to make decisions at national level, knowing what they are counting on, particularly in scenarios of drought and scarcity;
- Trends illustrate that we have to start changing before the last drop falls.

Production of maps showing the percentage of the territory in which each crop class is irrigated.

Data from estimated monthly water volume abstracted in agriculture (Figure 14) and annual water availability on average and dry year per RBD in the periods 1930-2015 and 1989-2015 (Figure 15 and 16). Determination of the WEI+ scarcity index - use of the MIKE Model: The model results include volume series stored in reservoirs and groundwater bodies, as well as the modified runoff flowing in each watercourse and the volumes of water supplied to each water use. From these results it was possible to determine performance indicators that assess the system's ability to meet water needs, namely the guarantee of supply or the average deficit, in case of non-compliance with supply objectives. Calculation of the scarcity index based on water availability and water consumption (WEI+) is represented in Figure 17.

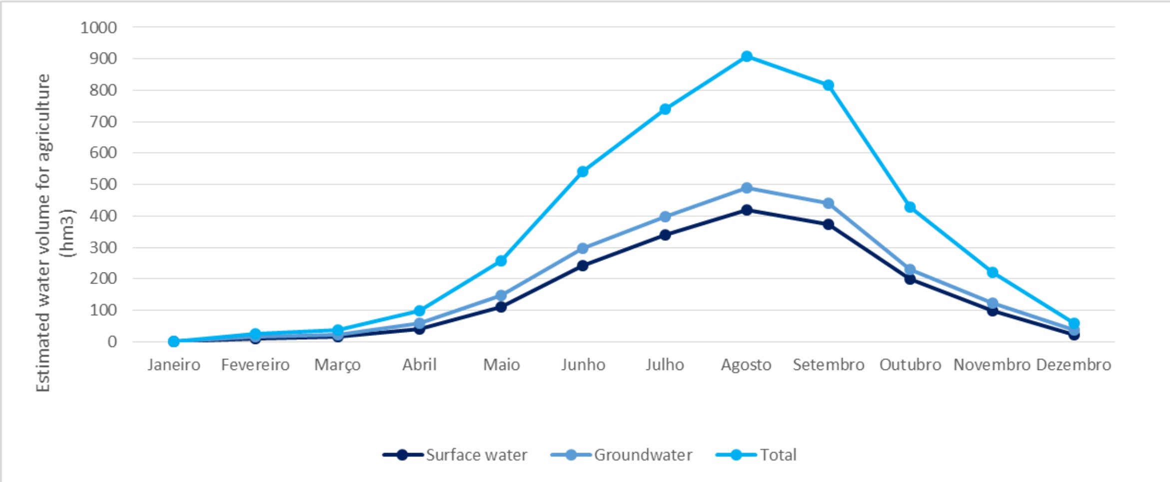
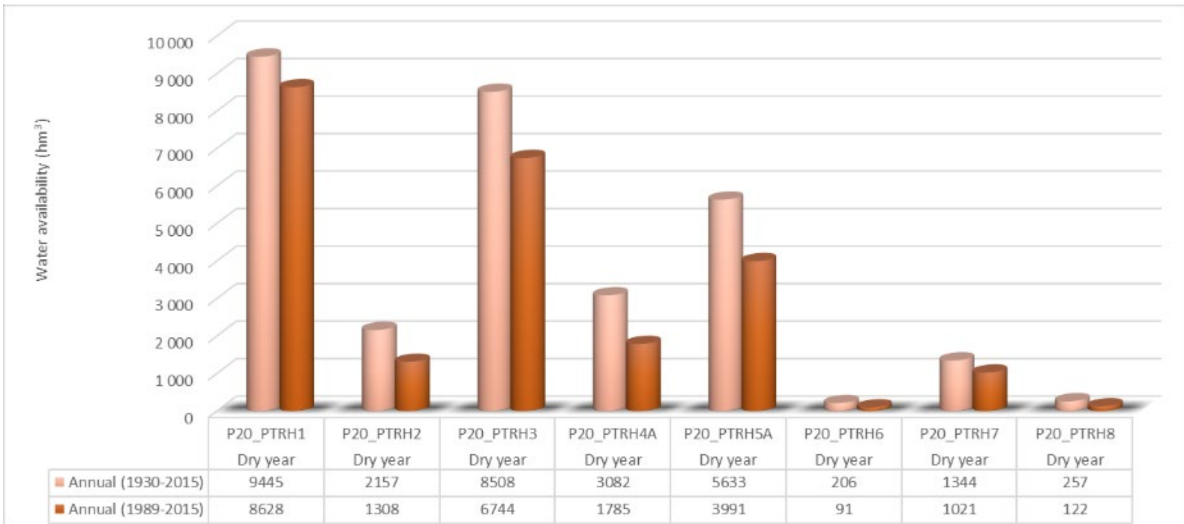
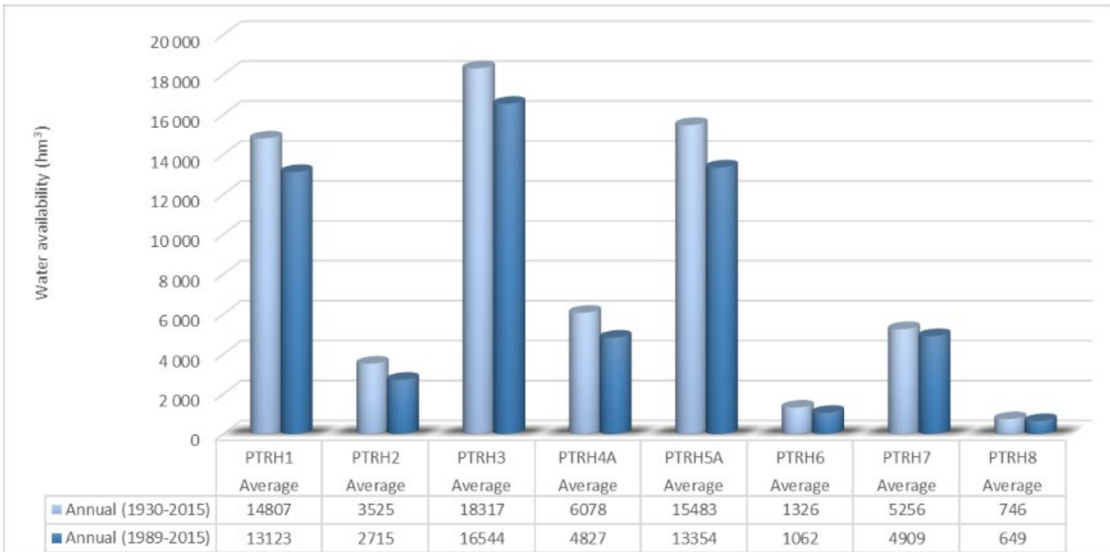


Figure 14: Estimated monthly water volume abstracted in agriculture



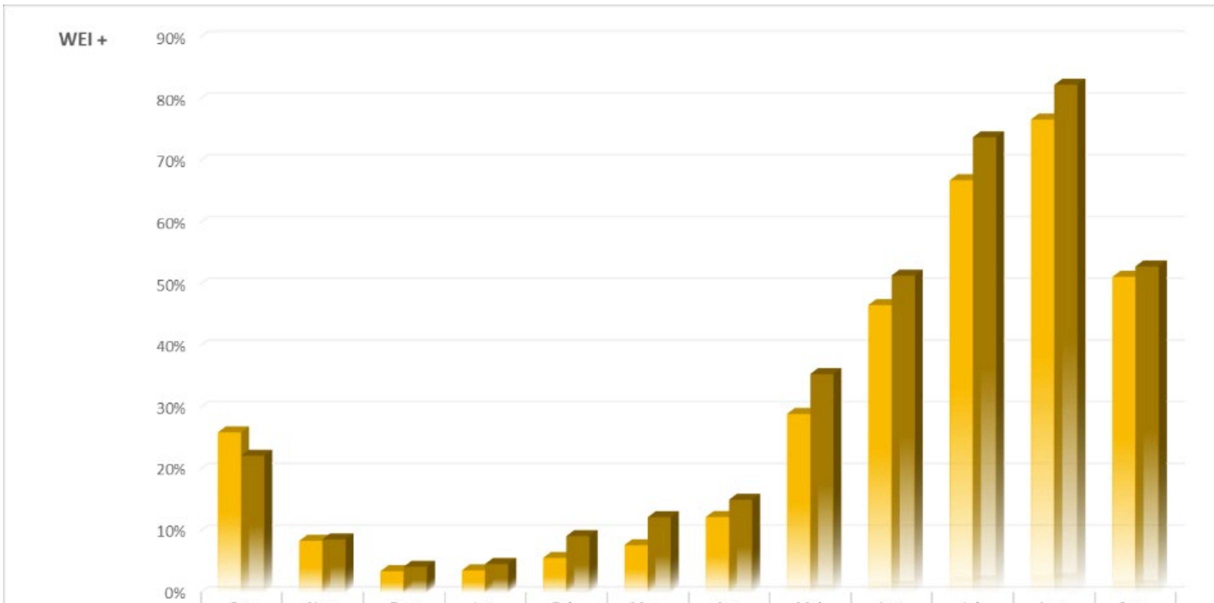
	P20_PTRH1 Dry year	P20_PTRH2 Dry year	P20_PTRH3 Dry year	P20_PTRH4A Dry year	P20_PTRH5A Dry year	P20_PTRH6 Dry year	P20_PTRH7 Dry year	P20_PTRH8 Dry year
Annual (1930-2015)	9445	2157	8508	3082	5633	206	1344	257
Annual (1989-2015)	8628	1308	6744	1785	3991	91	1021	122

Figure 15: Annual water availability on dry year per RBD in the periods 1930-2015 and 1989-2015



	PTRH1 Average	PTRH2 Average	PTRH3 Average	PTRH4A Average	PTRH5A Average	PTRH6 Average	PTRH7 Average	PTRH8 Average
Annual (1930-2015)	14807	3525	18317	6078	15483	1326	5256	746
Annual (1989-2015)	13123	2715	16544	4827	13354	1062	4909	649

Figure 16: Annual water availability on average year per RBD in the periods 1930-2015 and 1989-2015



	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Mai.	Jun.	Jul.	Aug.	Sept.
PTCONT 1930-2015	26%	8%	4%	4%	6%	8%	12%	29%	47%	67%	77%	51%
PTCONT 1989-2015	22%	9%	4%	5%	9%	12%	15%	35%	51%	74%	82%	53%

Figure 17: Mainland WEI+ per month in the periods 1930-2015 and 1989-2015

Main collusions:

- In recent decades, precipitation in Portugal and Spain has decreased by around 15%, and is expected to decrease by between 10% and 25% by the end of the century.
- There is not the same water available in this century as there was in the middle of the last century, with a reduction of around 20%, so the projects to be implemented must be reviewed in light of this new information.
- The volumes captured on average in Portugal are around 6000 hm3, of which 70% by agriculture.
- The scarcity index worsened in all basins, compared to what had been calculated for the 2nd planning cycle, as a result of the decrease in availability but also the increase in consumption, reaching very high values (severe shortage) in some river basin districts, namely RH6, RH7 and RH8.
- The continuous maintenance of the monitoring networks are essential to better support the hydrological models developed.
- Improving the monitoring of volumes captured and losses by different sectors, making them available to the administration, namely agriculture, is an essential requirement for a more real knowledge of water needs.
- Compatibility of sectoral needs with existing water availability is a double challenge in water management. This double challenge involves ensuring optimised supply management and encouraging efficiency in demand.
- Seasonal and interannual climate variability translates into great variability in water availability, across the territory and over time, which will be worsen with climate change.
- Water management on the demand side involves increasing water efficiency and reducing losses and consumption, both in use and in water management by entities, with the aim of reducing water resources captured, often in contexts of scarcity.
- Water management on the supply side involves ensuring sustainable use of water, particularly in areas of scarcity, and water quality compatible with uses.
- The adaptation measures to be implemented must be evaluated a priori with a cost-benefit analysis for each solution.

Difficulties faced:

Collection of sufficient data for calibration and validation of the MIKE model in different areas of the country.

Remaining constraint(s):

Obtain data on abstracted volumes at a monthly level for all sectors in a reliable manner and through measurements and not estimates.

Planned next step(s):

Continuous improvement of this tool with the introduction of more data, both to improve the calibration of the model and to have results for the recent years that will give the validation more reliable of current events.

Based on water availability on a monthly basis, in dry and average years (the type of years that have been the most frequent since 2000), and after discounting the ecological flows in surface waters and the environmental flows in groundwater, the scarcity index illustrates water stress in basins. This will be the basis for evaluating new abstracting requests or for reviewing those already allocated that are not sustainable. The models developed at Mike Basin for each RBD are available at national water authority as an important tool to carry out simulations that may become relevant in the future.

Transferability:

This tool can easily be used in any country as long as there is data and all model connections are installed in MIKE to characterize the modified flow regime.

8.11.4. FURTHER INFORMATION

Other publications/documents:

- https://www.rederural.gov.pt/images/Noticias/2021/Estudo_Avalia%C3%A7%C3%A3o_das_disponibilidades_h%C3%ADdricas_atuais_e_futuras_e_aplica%C3%A7%C3%A3o_do_%C3%8Dndice_de_escassez_WEI.pdf
- https://apambiente.pt/sites/default/files/_A_APA/Comunicacao/Media/NotasOCS2021/Nota_ComSocial_82-2021_EstudoDisponibilidadesAgua.pdf

Contact:

- Portuguese Environment Agency (https://apambiente.pt/)

  drh.geral@apambiente.pt

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