B-WaterSmart

Deliverable 3.5

The water cycle modelling and assessment solutions toolkit – Final release

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 869171. The publication reflects only the authors' views and the European Union is not liable for any use that may be made of the information contained therein.

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Summary

WP3 aims at developing and deploying a series of water-smart applications, to be demonstrated at six Living Labs (LLs). The different solutions developed and demonstrated in T3.2-T3.7 are conceptually assembled into 2 coherent toolkits, a) the monitoring, negotiation and decision support solutions toolkit and b) the water cycle modelling and assessment solutions toolkit. The current report documents the final release of the water cycle modelling and assessment solutions toolkit, which is comprised of the following eight tools: UWOT #22, regional demand-supply matching GIS tool #23, reclaimed water distribution network water quality model #24, water-energy-phosphorous balance planning module #25, QMRA+ #26, risk assessment for urban water reuse module #27, short-term demand forecasting tool #28 and SuTRa #31 and complements the other toolkit. The final release of the toolkit aims at updating the readers about the latest developments on tools focusing on tool description, attributes and information around unique selling points, added value and innovation, how each tool addresses water related challenges, CE limitations and supports water smartness, pre-existing background, developments and advancements within the project, interoperability options offered, and how to access each tool and test data. D3.5 dives deeper in the application of tools to the LLs by introducing initially the water-smartness challenges and ambition of the LLs, presents the selected technologies and products and explains the integrative use, conceptual links, data flows and pilot interactions. Further, it presents the results and the initial lessons learned from tools' application to the LLs. Building on results from the cases, the toolkit attempts to provide a more holistic and complementary picture of how water-smartness can be enhanced while highlighting contribution towards strategic objects, complementarity and replicability aspects of tools.

Deliverable number	Work package
D3.5	WP3
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Planned delivery date	Actual delivery date
31/08/2023	31/08/2023 05/01/2024 (post review version)
Dissemination level	**PU = Public**

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History of Changes

Version	Date	Changes and Comments	Section of implemented changes
1.0	31/08/21	Submission in time.	-
2.0	05/01/24	History of changes was added to the document.	History of changes.
		The summary has been revised to better reflect changes in the report.	Summary
		The executive summary has been revised in order to be more specific, concise and concrete on the key achievements and outcomes.	Executive summary.
		Introduction was revised to be more concise and to reflect the changes made in the report.	Section 1.
		Chapter 2 and 3 were revised according to the suggestions given to D3.2. In order to avoid duplicating contents of the other deliverables of WP3 (D3.2 to D3.5), the most important information was kept, and cross-references were established with D3.4.	Section 2 and Section 3.
		Tables of tools' attributes and description from sections 5.1.1, 5.2.1, 5.3.1, 5.4.1, 5.5.1, 5.6.1, 5.7.1, 5.8.1 moved to newly created Annex A named "Overview tables of tools' attributes and descriptions". For the tools with no figure in the above sections, one was introduced based on the content of the overview tables (for tools #24, #25, #26, #27, #28, #31).	Sections 5.1.1, 5.2.1, 5.3.1, 5.4.1, 5.5.1, 5.6.1, 5.7.1, 5.8.1. Annex A (sections 12.1.1 – 12.1.8)
		Added new sub-sections named "Unique selling points / Added Value / Innovation" to provide clear information on the unique selling points of the tool, added value and innovation. Also updated the content of the table with tools attributes and descriptions that have been moved to Annex A to reflect the above-added information.	Sections 5.1.2, 5.2.2, 5.3.2, 5.4.2, 5.5.2, 5.6.2, 5.7.2, 5.8.2. Annex A (sections 12.1.1 – 12.1.8).
		A new section was added named "Addressing water challenges, limitation and contributing to water-smartness" to describe how each tool contributes to water related challenges and CE barriers, links with strategic objectives of water-	Sections 5.1.3, 5.2.3, 5.3.3, 5.4.3, 5.5.3, 5.6.3, 5.7.3, 5.8.3.

		smartness and links with quantifiable indicators that can be used to assess tools' impact.	
		The content of initial sections 5.1.6, 5.2.6, 5.3.6, 5.4.6, 5.5.6, 5.6.6, 5.7.6, 5.8.6 called "Indicative applications and synergistic benefits" has been reviewed in detail and updated when necessary. When available, the related material has been transferred to Annex C, while the necessary cross-references have been made. Justification has also been provided in the related Annex C to explain the purpose of this content, which is to give the overall potential of each tool.	Annex C (sections 14.1 - 14.2).
		Information on QCRA was added compared to QMRA (following a comment received by one of the reviewers during the review meeting).	Section 5.5.1.
		New information was added in SuTRa description on how the tool considers different soil and groundwater conditions such as temperature, aquifer type and conditions, soil properties, etc. The plan on when the database is going to be extended to other viruses was noted. In order to keep contents between D3.3 and D3.5 aligned; the revisions were incorporated in D3.5 too.	Section 5.8.1.
		The content of the report has been reviewed and synthesized when possible. Content of the below sections was also moved to Annexes:	
		1. Tables for tool's attributes and descriptions from section 5.1.1, 5.2.1, 5.3.1, 5.4.1, 5.5.1, 5.6.1, 5.7.1, 5.8.1 moved to Annex A.	1. Annex A (sections 12.1.1–12.1.8).
		2. Highly technical and long/detailed sections of "Navigation and primary functionalities" (former sections 5.1.4, 5.2.4, 5.3.4, 5.4.4, 5.5.4, 5.6.4, 5.7.4, 5.8.4) was moved to Annex B under each tool.	2. Annex B (sections 13.1.1, 13.2.1, 13.3.1, 13.4.1, 13.5.2, 13.6.1, 13.7.1, 13.8.2).
		3. Content of sections "Developments and advancements within the project" (former sections 5.1.3, 5.2.3, 5.3.3, 5.4.3, 5.5.3, 5.6.3, 5.7.3, 5.8.3) was reviewed and for some two tools (#26, #31) detailed information was transferred to Annex B.	3. Annex B (sections 13.5.1, 13.8.1).

		4. Content of "Indicative application and synergistic benefits" (former sections 5.1.6, 5.2.6, 5.3.6, 5.4.6, 5.5.6, 5.6.6, 5.7.6, 5.8.6) was reviewed and revised and has been moved to Annex C for 2 tools (UWOT, SuTRa) whereas for the rest, provided information was moved to the sections 5.3.1, 5.4.1, 5.5.1, 5.6.1, 5.7.1 because of relevance (i.e., reporting on synergistic effects with technologies/tools of the project).	4. Annex C (sections 14.1, 14.2), sections 5.3.1, 5.4.1, 5.5.1, 5.6.1, 5.7.1.
		5. Content of LL section referring to “Pre-processing stage and input data” (former sections 6.2.3, 7.2.3, 8.2.3) and “Setup process and application” (former sections 6.2.4, 7.2.4 and 8.2.4) was moved to Annex D. For Flanders and East Frisia case, the detailed results (former sections 6.2.5.1, 6.2.5.2 and 7.2.5.1) were moved to Annex D too and brief and concise results were included under the LL sections (section 6.2.3.1, 6.2.3.2 and 7.2.3.1).	5. Annex D (sections 15.1, 15.2, 15.3), section 6.2.3.1, 6.2.3.2, 7.2.3.1.
		6. The summary tables of the LL (former sections 6.4, 7.4 and 8.4) were moved to Annex E.	6. Annex E (sections 16.1–16.3).
		For each LL, the section “Lessons extracted” was split into “Overview” part on tools application in general and on the “Data” part. The first part was revised and enriched in order to cover aspects with regards to how relevant the initial conclusions based on the tools, were for the operators involved, to what extent the tools provided new (relevant) knowledge to address the challenges presented in the introduction, how tools improved water smartness and the strength and limitations of the tools. The new sub-section called “Data” was also added that discusses the data issue and how they impacted the deployment of the solutions, how were handled and the lessons learned on that matter.	Sections 6.3, 7.3, 8.3.
		The "Lessons extracted" section of Lisbon case was revised to better highlight the pros to derive the USPs/added value for tools as suggested and to expand on the challenge related to “promoting climate adaptation in buildings”.	Sections 8.3.1.

		The Conclusions chapter was restructured (distinguishing three sub-sections) and revised to a) underline whether the testing of the tools improved the “water smartness” of the region/city (as presented in the introduction in the report, especially referring to the strategic objectives leading to water-smart societies), b) to report how tools help mitigate/adapt to climate change and c) to highlight key elements to be considered for initiating/boosting transferability and replicability.	Section 9.
		References have been updated and placed in alphabetical order.	Section 10.
		General typos have been corrected across the document.	
		Added the units for pathogens concentrations and monitoring for the QMRA tool, as suggested in D3.3.	Section 13.5.1.
		Better described the Water-energy-Phosphorus Balance Tool #25 (purpose and relevance of combining these 3 elements), as suggested in D3.3.	Section 5.4.1 and 12.1.4.
		The part describing the Unique selling points /Added Value/Innovation of tool # 24 was revised in order to provide additional information and clearly describe each aspect of it, as suggested in D3.3.	Section 5.3.2 and 12.1.3.

List of Acronyms and Abbreviations

AI	Artificial Intelligence
AOP	Advanced Oxidation Processes
API	Application Programming Interface
ARPAV	Agenzia regionale per la protezione ambientale Veneto
ASR	Aquifer Storage and Recovery
BOD	Biological Oxygen Demand
BOHB	Bayesian optimization with Hyperband
BS	Baseline Scenario
BSD	Berkeley Source Distribution
BWS	B-WaterSmart
CAPEX	Capital Expenditures
CARD	Controlled Agricultural Recharge and Drainage
CCRO	Closed Circuit Reverse Osmosis
CDF	Cumulative Distribution Function
CE	Circular Economy
CLC	CORINE Land Cover
CML	Camara Municipal de Lisboa
CO	Confidential
CoP	Community of Practice
CPU	Central Processing Unit
CRC	Climate Ready Certificate
CSS	Cascading Style Sheets
CSV	Comma-separated values
DALY	Disability Adjusted Life Years
DAP	Data Application Products
DBMS	Database Management System
DCAT	Data Catalog Vocabulary
DE	Digital Enabler
DPR	Direct Potable Reuse
DSS	Decision Support System
DW	Distilled Water
DWD	Deutscher Wetterdienst
DWTP	Drinking Water Treatment Plant
Dx.x	Deliverable
EC-JRC	European Commission - Joint Research Centre
EEA	European Environment Agency
EEC	European Economic Community
EEPA	European Enterprise Promotion Awards
EI	Expected Impact
EU	European Union

FAO	Food and Agriculture Organization
FAQ	Frequently Asked Questions
FIWARE GE	FIWARE Generic Enabler
FTP	File Transfer Protocol
GDPR	General data protection regulation
GHG	Greenhouse gases
GIS	Geographical Information System
GPU	Graphics processing unit
GUI	Graphical User Interface
GW	Greywater
GWR	Greywater Recycling
HD	Hard Drive
HTML	Hypertext Markup Language
HTTP	Hypertext Transfer Protocol
ICT	Information and Communications Technology
IdM	Identity Management
IEC	International Electrotechnical Commission
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
IT	Information Technology
IWA	International Water Association
JRC	Joint Research Centre.
JSON	JavaScript Object Notation
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
LL(s)	Living Lab(s)
LNEC	Laboratorio Nacional de Engenharia Civil
MAR	Managed Aquifer Recharge
MIT	Massachusetts Institute of Technology
MQTT	Message Queuing Telemetry Transport
MS	Milestone
MSL	Machine Learning
NA	Not Available / Not applicable
NGO	Non-governmental organization
NGSI-LD	Next Generation Service Interfaces – Linked Data
NTUA	National Technical University of Athens
O3/RO	Ozone/reverse osmosis
OOWV	Oldenburgisch-Ostfriesischer Wasserverband
OPC	Open Platform Communications
OPEX	Operating Expenses
OS	Operating System

PC	Personal Computer
PDF	Portable Document Format
PET	Potential Evapotranspiration
PIF	Progetto Integrato Fusina
PLC	Programmable logic controller
PO	Project Officer
PU	Public
QCRA	Quantitative Cost Risk Analysis
QMRA	Quantitative Microbial Risk Assessment
R&D	Research and Development
RAM	Random-Access Memory
RDSMG	Regional demand-supply matching GIS tool
REST	Representational State Transfer
RO	Reverse osmosis
RR	Resource Recovery
RW	Rainwater
RWDS	Reclaimed water distribution system
RWH	Rainwater Harvesting
SDFT	Short-term demand forecasting tool
SDM	System Dynamic Modelling
SM	Sewer Mining
SO	Strategic Objective
SSD	Solid-State Drive
SuTRa	Subsurface Transport and Removal
tbd	To Be Decided
TP	Technology Product
TRL	Technology Readiness Level
Tx.x	Task
UI	User's Interface
URL	Uniform Resource Locator
URN	Uniform Resource Name
UWC	Urban Water Cycle
UWOT	Urban Water Optioneering Tool
WC	Water closet
WE	Water Europe
WEM	Water Europe Marketplace
WEP	Water-Energy-Phosphorus
WFD	Water Framework Directive
WHG	Wasserhaushaltsgesetz
WiCE	Water in the Circular Economy
WM	Washing Machine
WP	Work Package

WPC	Water Production Centre
WPx	Work Package
WQ	Water quality
WRRF	Water resource recovery facility
WS	Water Smart
WSGI	Web Server Gateway Interface
WW	Wastewater
WWTP	Wastewater Treatment Plant
XML	Extensible markup language

Executive summary

The BWS project aims to accelerate the transformation to water-smart economies and societies in coastal Europe and beyond. To achieve this, WP3 “Water-Smart applications and data” through T3.8 delivers a series of smart data applications for more efficient and safe allocation and use of resources (water, energy, nutrients). The smart data applications are demonstrated at the six Living Labs (LLs) of the BWS project, namely Alicante (ES), Bodø (NO), Flanders (BE), Lisbon (PT), East Frisia (DE) and Venice (IT), where research partners and innovative solution providers worked with the LLs representatives, i.e., the problem owners participating in the project, having high ambitions to address water-related challenges and opportunities.

The applications have been organized in two complementary toolkits, as described in Section 4:

- **The monitoring, negotiation and decision support solutions toolkit**, addressed by D3.4, which aims at improving water smartness by supporting some high-level steps that include raising awareness of stakeholders, supporting decision making, managing and monitoring operations.
- **The water cycle modelling and assessment solutions toolkit**, addressed by this deliverable (D3.5), which is focused on advanced analytics for providing detailed evidence in support of decision-making. This is achieved by providing the tools to conduct simulations, predictions, demand/supply match-making and other quantitative analyses.

The two toolkits (D3.4, D3.5) have been prepared in parallel in order to ensure the alignment of work, present information in a consistent way and to highlight the complementarity of both toolkits by proposing synergistic ways in which the tools could be used to provide a more holistic and complementary picture of water-smartness at the water cycle scale. Table 1 below reports the corresponding sets of tools.

Table 1: The two BWS ICT solutions toolkits and the tools that assemble them. The name of the city that follows corresponds to relevant Living Labs, where the tool is applied.

The monitoring, negotiation, and decision support solutions toolkit	The water cycle modelling and assessment solutions toolkit
1. Water-reuse strategic platform (#16) – Venice	1. UWOT (#22) – Flanders & East Frisia
2. Sludge management platform (#19) – Venice	2. Regional demand-supply matching GIS tool (#23) – East Frisia
3. Digital Enabler (#32) – Venice	3. Short-term demand forecasting tool (#28) – East Frisia
4. Re-Actor (#18) – Alicante	4. QMRA+ for water reuse and agriculture (#26) – Flanders
5. Environment for decision support and alternative course selection - BASEFORM (#17) – Lisbon	5. SuTRa (#31)[1] – Flanders
6. UWC observatory (#20) – Lisbon	6. Reclaimed water distribution network water quality model - BASEFORM (#24) – Lisbon
7. Climate-readiness certification tool (#33) – Lisbon	7. Water-energy-phosphorous balance planning module - BASEFORM (#25) – Lisbon

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[1] SuTRa tool was originally called "ASR pro” tool. The name of the tool has been changed to ‘SuTRa’ to better reflect the broader application potential.

8. Stormwater reuse management system (#21) – Flanders	8. Risk Assessment for urban water reuse module - BASEFORM (#27) – Lisbon
9. Nessie System (#29) – Bodø	
10. Environmental Dashboard (#30) – Bodø	

This deliverable (D3.5) aims at introducing the readers to the eight tools of the water cycle modelling and assessment solutions toolkit as well as to the actual application of those tools to the three LLs:

- Flanders: #22, #26, #31 (#21 reported in D3.4)
- East Frisia: #22, #23, #28
- Lisbon: #24, #25, #27 (#17, 20, 33 reported in D3.4)

The report is structured in 4 main parts. The first part which is consisted of Chapter 1 to 4 set the base for readers by introducing them to water challenges and limitations that are related to the urban water cycle and water sector, while it provides a cohesive view on the two toolkits by contextualizing the different tools in a high-level process that drives their use for supporting water smartness. The second part (Chapter 5) summarizes information about each tool of the toolkit, including description of tools and their attributes, unique selling points, added value, innovation, explains how each tool addresses water challenges, CE limitation and contributing to water-smartness, it gives the pre-existing background of tools and the developments done in the project, while it covers interoperability options offered by the tools including FIWARE and provides information on how somebody could access the tool or its test data. The third part (Chapter 6 to 8) reports the application of tools to the case studies of Flanders, East Frisia and Lisbon. For each LL information about the integrative use of tools is provided, pilot interaction and data flows, results and initial lessons extracted at the LL level on applied tools and data needs. Finally, the fourth part (Chapter 9) reports conclusions about the tools, their replicability and the preliminary results in improving water smartness of the regions/cities of the LLs.

As summarized below, the developed tools address specific challenges and issues of the corresponding LLs and enable some preliminary results and impacts with respect to the strategic objectives (SO)[2] leading to water-smart societies.

At the **Flanders** case the limitations in freshwater availability, decrease of groundwater level and deterioration of surface water quality during dry summers were the motivation of applying smart solutions for the use of alternative circular water sources for drinking water and agriculture. The application of UWOT contributes to several strategic objectives by assisting in identifying resource efficient water allocations (SOA) and new, untapped circular water supply options (SO B). It has also provided insights on the impact different water-smart measures (such as wastewater reuse, CCRO and urban rainwater harvesting) can have for regional water resources management (SOC and SOD). SuTRa has been linked to SOA by contributing to MAR technologies by giving the potential to increase availability of water in dry periods via the storage of water in periods with excess water. Similar to SuTRa, QMRA+ impacts SOA since it was used to evaluate various treatment schemes for

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[2] The Strategic Objectives as defined in the BWS water-smartness assessment framework are: SO A - Ensuring water for all relevant uses; SO B - Safeguarding ecosystems and their services to society; SO C - Boosting value creation around water; SO D - Promoting adaptive change towards resilient infrastructure; SO E – Engaging citizens and actors across sectors in continuous co-learning and innovation.

microbial safety of the produced water for the intended use. It also contributed to SOE by providing a common basis for the stakeholders in the LL to discuss water safety and identify key choices in this aspect and offers the mean to communicate the safety of the water to citizens. Overall QMRA+ tool contributed to the design of a smart water reuse system by allowing to balance water safety against other aspects such as costs, resources and environmental impact.

East Frisia is confronted with climate change (hot and dry summer periods with increasing water demand in various sectors), increasing pressure on groundwater resources and emissions from agriculture which affect the usability of water resources for drinking water purposes. The Regional Demand-Supply Matching GIS tool (#23) in combination with UWOT (#22) contribute to overcoming the key issues in water and resources management at LL East Frisia in the way that an efficient fit-for-purpose allocation of resources to all sectors is enabled (SOA) by analysing alternative water supply opportunities and supporting the users in the decision-making process, thus, reducing the pressure and conflicts with regards to the local groundwater resources. Further, by identifying untapped and new circular water supply options, tools #22 and #23 help to reduce the pressure on available groundwater resources in the region (SOB). The Short-term demand forecasting tool (#28) addresses the rising issues of peak loads within the water supply network of OOWV which results are also used for raising awareness for the district specific water consumption, thus contributing to SOE. Tool #22 is also linked with SOB and SOC since it produces results that are useful for the implementation of greywater recycling technologies and the potential reuse of treated greywater at household level (e.g. toilet flush) and the fact that supports simulation of different intervention under different climatic scenarios which help the design process and planning towards more resilient infrastructures.

At the **Lisbon LL**, the key challenge faced are (i) a growing resident population and economy, dependent on distant freshwater resources, (ii) climate challenges (e.g., droughts and floods) and (iii) need to increase urban green areas. Those challenges are tackled by tools: Reclaimed water distribution network water quality model (#24), the Water-energy-phosphorous balance planning module (#25) and the Risk assessment for urban water reuse module (#27) in conjunction with the rest of the tools (#17, #20, #33) (which are reported in D3.4) by improving the water supply / demand management and the city's water-energy-phosphorus (WEP) footprint while increasing the green areas and promoting the safe use of reclaimed water as an alternative water source. The testing of the Lisbon tools improved the "water smartness" of the city because it was possible to move towards a fit-for-purpose water allocation (SOs A & B and tools #17, #24, #25 & #27), an increased water efficiency (SO E and tools #17, #20, #25 & #33) and safe water reuse (SOs C & D and tools #24 & #27). With regard to tools impacts, it is expected to reach a decrease in use of freshwater by 5% for 2024 which is mainly related to the water reuse for irrigation of municipal green areas instead of using drinking water (abstracted from distant freshwater resources) and groundwater (from local boreholes) (tools #17, #24, #25 & #27). Improved water use efficiency is expected to be achieved in the mid-term (a 16% reduction in 2040) with an improved management of water losses in irrigation networks in result of the analysis of water supply/demand alternatives (tools #17 & #25) and the focus on citizen engagement (via tools #20 and #33). Expected values for water reuse for 2024 is estimated to reach 4% (treated ww used/water supplied) and 18% (treated ww used/total ww produced) with the promotion of water reuse as appropriate water source for non-potable uses (# 17, #25, #33) and support to a safe water reuse (#24 & #27). Reduction in water-related energy use at mid-term is estimated about 20% (in 2040) due to improved and sustainable water supply/demand management (tools #17, #24, #25 & #27) and, also, from an increased citizen engagement (tools #20 & #33). Water reuse in irrigation is expected to allow recovery of 4% of phosphorus for 2024 (tools #17, #24, #25 & #27).

Replicability of the digital solutions in other cities/regions is ensured by different actions and results that T3.8 pursued while interacting with the rest of the project. The developed BWS FIWARE approach with its interoperability guidelines (implementation guidelines, FIWARE and interoperability maturity levels) developed in T3.1 helped developers to conceive and realize tools that are easily integrated with third party systems using open and standard APIs, thus boosting replicability. Synergies with other WPs, i.e. WP2, WP1, WP7 also support replicability of solutions. Other key points to promote the use of tools are further testing in different regions and in the context of other research projects, systematically consider water reuse for fit-for-purpose water allocation, promote water use efficiency and keep developing the tools in a modular way and updating them towards state of the art.

In conclusion, D3.5 encapsulates the key information about the tools developed for the water cycle modelling and assessment solutions toolkit, highlighting the main preliminary results achieved towards the LL challenges and strategic objectives of water smartness. Final results will be made available via the WEM on M45 as part of MS32.

1 Introduction

This report, along with D3.4, is the final release of deliverables which document the work done within the tasks T3.2 – T3.7 under which the development, deployment and demonstration of a series of water-smart applications are foreseen in the six Living Labs (LLs), according to the Grant Agreement (GA). Task 3.8, building on the afore-mentioned work attempts to conceptually assemble the different solutions developed and eventually demonstrated in T3.2 to T3.7 into two coherent toolkits that provide added value with respect to the water related challenges of the case studies, serving at the same time as an umbrella to orchestrate and align the LLs around the deployment of tools. Under the lead of T3.8, tool owners in collaboration with the problem owners initially contributed to MS20 "Final input received from T3.2-T3.7 for D3.4 and D3.5" by delivering 6 individual input reports at M34 (end of June), one for each task, which served as the starting point for the development of the final release of both toolkits. The same approach was followed at an earlier stage of the project when draft input reports were received for MS17 (M23) and used to deliver the early release of the toolkits (D3.2/D3.3) in M25. At that point, the focus was on the documentation of the early developments of tools, whereas MS20 and the final release of toolkits aim at providing details on the latest developments of tools and their applications to the 6 LLs.

For the development of D3.2/D3.3/D3.4/D3.5, the leading teams, namely ENG, ICCS and KWR worked in parallel and in close cooperation, in order to ensure that information and results are aligned and presented in a consistent way. The ultimate purpose of T3.8 is to highlight the complementarity of both toolkits and propose synergistic ways in which the tools developed could be used to provide a holistic picture of water-smartness at the water cycle scale. With that as a goal, the D3.5 report is structured as follows.

Chapter 2 and chapter 3 set the base around the water challenges and limitations encountered in water management and Circular Economy (CE) by briefly mentioning them, while more detailed descriptions are provided in D3.4. Chapter 4, which is similar in D3.4/D3.5 explains how both toolkits complement each other, contribute to a more holistic assessment, and support the increase of water-smartness. Chapter 5 of this report documents in a consistent way the features of the 8 tools that form the water cycle modelling and assessment solutions toolkit. Chapters 6 to 8 have been allocated to the Flanders, East Frisia and Lisbon LL respectively and document the actual application and use of tools in the different case studies. With regard to the LL sections (Chapters 6 to 8), those set the basis of the LL work by briefly describing the case studies, the key water-smartness challenges and ambitions and listing the selected tools and technologies applied in their pilots. The integrative use of tools is also included in those sections, while making any necessary connection with the WP2 technologies (when relevant). The sections that follow provide information on key results and lessons extracted from tools' application but also with regard to data issues. Chapter 9 concentrates and highlights conclusions at the toolkit level while summarising key information for the 8 tools that form the water cycle modelling and assessment solution toolkit. References used in this report are concentrated in Chapters 10 and 11. Regarding the appendixes, Annex A (Section 12) concentrates overview tables of tools' attributes and their descriptions. Annex B (Section 13) collects more technical information on tools with regard to navigation and primary functionalities but also more technical details on the developments made within the project for some tools. Content of Annex C (Section 14) presents how some tools have been used in other applications outside of BWS in order to highlight aspect of tools' full potential and explain how they can be used in combination with other tools or technologies. Annex D (Section 15) provides details on the pre-processing stage and input data, the set-up process followed for the application of tools and detailed results when available. Annex E (Section 16) concentrates summary tables where concise information is provided at LL level from the application of the different solutions while making references to WP2 technologies, when relevant. Annex F (Section 17) explains the Technology Readiness Level, as considered in the current deliverable, and used in Chapter 5 for defining TRL of each tool, whereas Annex G (Section18) presents the template tables that were used to collect structured information for the tools and their applications to the case studies. Finally, Annex H (Section 19) provides a summary table of the different tools described in deliverables D3.4/D3.5. This is done for facilitating the readers to easily associate tool numbers to the appropriate name and basic information.

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2 Water challenges and limitations

A diverse set of conditions and water-related challenges is faced by different stakeholders and communities related to a) water availability, b) water quality and c) water related hazards. Population and economic growth, agriculture, water scarcity, regional imbalance in water availability and climate change put pressure on water resources availability. Water quality, on the other hand, can be attributed to microbial and toxic pollution, sedimentation, salinization and eutrophication, among others. Lastly, droughts and floods are the most known water related hazards. IPCC's 2022 report highlight that all components of the global water cycle have been modified due to climate change in recent decades (Douville et al., 2021) with impacts on current hydrological cycle, water related risks and on different sectors (e.g., agriculture, urban and peri-urban sections, energy, industrial water use, etc).

The above water related challenges place pressure on natural resources, which make the need of shifting from the traditional linear model (take-use-dispose) to a circular economy of vital importance (Govindan and Hasanagic, 2018). Nevertheless, there are barriers in applying technologies as part of a circular economy. Such barriers are related to:

a) high upfront costs, also due to expensive technologies e.g., on monitoring infrastructure and water attributes,
b) the need to solve technological challenges in the products development in order to enable products to be designed with environmentally friendly technology,
c) requirement of a high-level of IT readiness and capability for handling big data,
d) little experience of circular economy in large-scale implementations,
e) preference of centralised infrastructure rather than complete decentralised systems,
f) outdated legislation and the lack of governmental laws and policies which could support the shift towards a circular economy,
g) the people's low awareness of the principles of circular economy,
h) general distrust towards the use of reclaimed water, low social acceptance and strong psychological effect in society against direct waste recycling (also due to health and safety risks),
i) fluctuating fertilizer quality that cannot always be guaranteed with varying concentrations in wastewater which in turn hampers market acceptance.

By considering these limitations in CE and in water infrastructure, smart water solutions and tools seem to lead the way towards new water management approaches that will help to increase the efficiency of all elements in the water network (Lee et al., 2015) while supporting the adoption of circular economy technologies. Benefits that come along with this shift towards circularity, while utilizing digitalisation, include reduction of energy, unnecessary water loses and resources exploitation, better monitoring and reporting in quality, quantity and reuse of water, better preparation for water hazards, significant support in decision making and rise of stakeholders' and citizens engagement and awareness towards more sustainable behaviours which value and embrace circular economy opportunities (Mandy Mbavarira and Grimm, 2021). More detailed information on water challenges and limitations can be found in Chapter 2 of D3.4 “The monitoring, negotiation and decision support solutions toolkit – Final release”.

3 The urban water cycle and the cycle of technology implementation

The hydrologic water cycle i.e., how water moves between the land, ocean, rivers and atmosphere is affected by both climatic and non-climatic factors (Douville et al., 2021). Humann interventions, originating from the need to provide water services to the urban population, i.e., water supply, stormwater drainage and wastewater collection and management/disposal (Marsalek et al., 2014), has changed how water flows through the environment with substantial impact, reflected in the urban water cycle (UWC). Human actions are subjected to changes too, as part of societal response to climate variability (IPCC, 2022). The engineered methods alter the urban water cycle within which the water "travels" from source and eventually is discharged back to the environment, e.g., while extracting water from the different sources (e.g., groundwater withdrawal, surface water, seawater or brackish groundwater), treating it (including interventions such as managed aquifer recharge, river bank filtration, etc.), distributing or storing it, while allocating it to the different uses (e.g. irrigation, WaSH, industrial use, etc.), when collecting it again (e.g., via stormwater network) and treating it (via centralised or decentralised technologies) before its final discharge. Within those steps, the water practitioners need to be equipped with state-of-the-art technologies and tools to design systems in a robust way to meet water related challenges.

There is growing need to re-evaluate the conventional water management systems that produce (potable) water, use it and dispose is as quickly as possible (Bouziotas et al., 2020) i.e., the approach of considering separately the infrastructure that deliverables potable water from the one that disposes wastewater or the drainage of stormwater. On the contrary, there is a undoubted need to shift towards circular water systems and models that prioritise reduction of wastewater, removal of pollutants from water and waste water, reuse of waste water, recycling of water, recovery of resources as nutrients and energy and rethinking of water and wastewater to save and conserve water and to optimise water use, in all the relevant sectors (Morseletto et al., 2022; Smol et al., 2020). But this needs systemic innovation through a combination of new hardware technology, concepts and software solutions for the whole cycle of technology implementation: from optimal planning, what-if scenarios modelling, negotiations and decision making to monitoring, control and long-term performance assessment. In order to work towards delivering sustainable, robust and adaptive systems, new advanced software solutions coupled with CE technologies and concepts across a diverse set of conditions and under water challenges need to be exploited by the different stakeholders and decision makers within all steps of the technology implementation route. For further details, please refer to Chapter 3 of D3.4 "The monitoring, negotiation and decision support solutions toolkit – Final release".

4 The B-Water Smart ICT solutions toolkits

Challenges related to water described in sections 2 and 3 call for continuous and substantial innovations to avoid wasting such a precious resource due to inefficient management of its lifecycle. It is thus fundamental to improve decision-making and action planning by leveraging the large amount of data available, despite the fact that such data is actually scattered, non-standardized and generally of low quality.

The water sector is undergoing a gradual digital transformation that is affecting the entire water lifecycle, from water sourcing and storage, to distribution, use, treatment and reuse. The level of maturity that the digitalization process has reached throughout the water lifecycle varies from case to case, from simply incorporating sensors into operational procedures to capture relevant data, visualize trends and raise alerts about anomalous trends or events, to sophisticated and data-science-based approaches, data analyses that leverage state-of-the-art Artificial Intelligence (AI) techniques, producing predictions/simulations, and supporting automated and optimized operations on the field.

When thinking about digital maturity, it is important to highlight that data-based tools alone can only add a layer of technology that allows for better data collection and increased monitoring. It is their combined and structured use that enables a process of transformation towards the vision of water smartness, where more resilient and sustainable water services are deployed and information is turned from Information technology (IT) applications into data-driven decisions, that help optimize resources (through circularity), minimize climate impacts, and enhance health and safety.

The aim of the monitoring, negotiation and decision support solutions toolkit (in combination with the water cycle modelling and assessment solutions toolkit) is to provide a set of complementary tools for enabling and enhancing efficiency for the fundamental steps that have to be followed by subjects that aim to improve their water smartness.

The complementarity of the tools is defined using a high-level process, which is a reference procedural framework for using the toolkits (see Figure 1). The following description defines the reference process that somebody may follow to improve water smartness through the use of digital tools. As a general note, the process is represented as a cycle because water smartness is not a goal (with a finish line), but a trend that has to be improved iteratively.

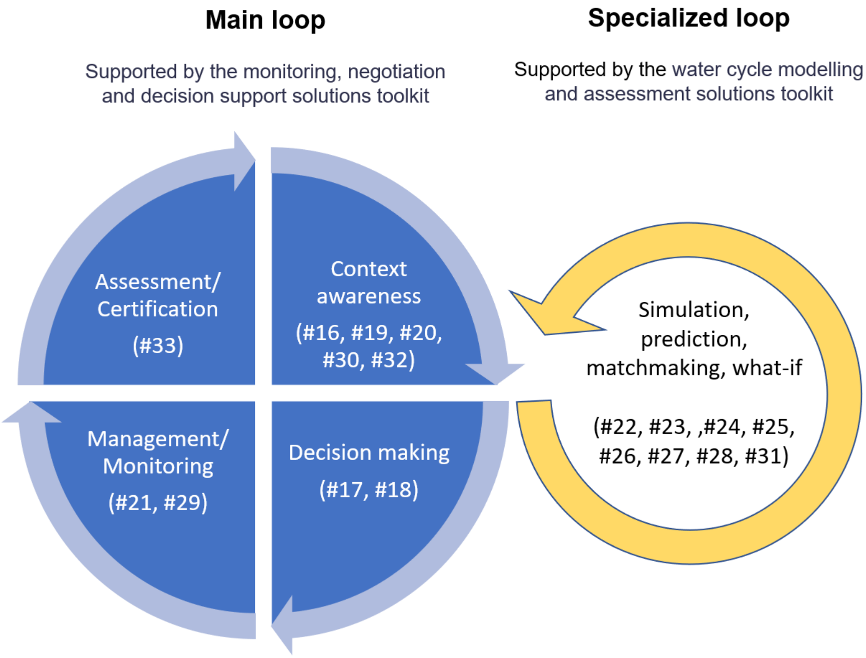


Figure 1: High-level process for iteratively improving water smartness through digital tools.

The process is composed of two main loops. The main loop includes the fundamental steps that have to be followed to improve water smartness:

- **Context awareness**: the first, strategic step for planning any kind of change process is understanding the state of the system using data-based evidence. Data and information have to be shared among relevant stakeholders as much as possible in order to highlight threats and opportunities, good practices and critical situations. This is the step where the current "as-is" situation is depicted in order to allow decision makers to share a common view of the system and be able to recognize the gaps and the priorities of actions.
- **Decision making**: this step builds on the information collected in the previous one for delivering actual strategic decisions on what to do for improving water smartness. This includes decisions on new investments in technologies or infrastructures, new regulations for fostering CE and Resource Recovery (RR), risk-aware alternative comparisons, etc.
- **Management/monitoring**: implemented actions have to be managed at operational level and their impacts have to be monitored on a regular basis to ensure that decisions are leading to the expected results in terms of water smartness.
- **Certification**: in some cases, the achievements of the change process can be certified with respect to some reference standard. This step is optional but represents a key added value for those subjects that have a structured and well-defined management plan for their water smartness, ensuring great visibility and credibility of their efforts.

The second loop is focused on advanced analytics for providing detailed evidence in support of the decision-making step. This is a separate loop (nested in the main one) because it may require several iterations, refinements and data exploitations to achieve the necessary results in terms of predictions, simulations, demand/supply match-making and other analysis.

The main loop is supported by **the monitoring, negotiation and decision support solutions toolkit**, whereas the specialized loop for advanced analysis is supported by **the water cycle modelling and assessment solutions toolkit.**

Aspects such as management changes or other horizontal matters not strictly related to water smartness are not considered in the reference process.

Table 2 below maps the role of different tools in both toolkits within the steps of the process and provides a brief description of their supporting functionalities.

Table 2: The impact of tools from both toolkits on the steps for improving water smartness.

Step	Tool	Description (how the tool supports this step)
Context awareness	Water reuse strategic platform (#16), enabled by Digital Enabler (#32)	Both platforms can be used for collecting and making available to the relevant stakeholders the heterogeneous information that is scattered across the territory about treated water and sludge and about their potential reuse. This includes any data available in a structured or unstructured format such as: quality and quantity of the product (sludge or water), producers, treatment plants and destinations; characteristics of the territory related to climate, urbanization, industrial plants, cultivated lands, state of soil, regulations at different levels, with information about barriers and drivers. Contextual information is presented through integrated visualizations in a coherent way in order to enable a more effective and data-driven decision process, allowing users to better understand the state of the territory in terms of issues and opportunities for reusing and valorising the available product.
	Sludge management platform (#19), enabled by Digital Enabler (#32)	
	UWC observatory (#20)	The Urban Water Cycle Observatory of Lisbon has the aim to systematise, collect and facilitate access to data on the city water cycle. The system provides access to context data through two different channels: i) open data about urban water and wastewater (main water flows, consumption disaggregation, amount of treated wastewater and reused water production) is provided to citizens and city stakeholders through publicly accessible infographics; ii) entities that have in place a remote water metering can access visualisations about aggregated consumptions and costs per typology of water use, water consumption evolution and individual consumption analysis, leading to an insightful water management, supported by data analytics and automatic performance reports.
	Environmental dashboard (#30)	The Environmental dashboard aims at presenting aggregated data sources (water meters, demographic data sets) in maps and graphs for providing a picture of water consumption in the different districts of a city.

Step	Tool	Description (how the tool supports this step)
Advanced analysis	UWOT (#22)	UWOT allows users (water planners, developers and relevant consultants) to compare different water management technologies (including water saving, recycling, treatment and drainage) at different scales. The tool simulates the urban water cycle by modelling individual water uses and technologies and aggregating their combined effects at development scale. UWOT provides a range of technology combinations, which are ranked according to user-based criteria. This allows the user to determine which combination of technologies will be most appropriate or beneficial for their new development.
	Regional demand-supply matching GIS tool (#23)	This is a GIS tool designed for visualizing and processing open-source information on natural water availability and sectorial consumption. Information can be used to identify i) possible consumption hotspots and areas of water shortage, ii) alternative water resources or areas with available water sources and iii) water drain from one region to another region. Based on the analysis, the impacts of alternative water availability scenarios on water demand can be displayed.
	Short-term demand forecasting tool (#28)	The tool is intended to generate water demand forecasts for the next 24 hours. The user can interact with the graphical user interface to train machine learning models and use them to generate and visualize demand forecasts. Furthermore, the user is able to aggregate forecasts for multiple smart meters to achieve the desired spatial resolution.
	QMRA+ for water reuse and agriculture (#26)	Quantitative Microbial Risk Assessment (QMRA) is a methodology that can be applied to assess risks of water (re)use and thus support decisions. The QMRA+ tool enables users to estimate the microbial health risk of using various water sources, including reuse of wastewater. A treatment system can be designed by selecting treatment steps from a wide array of possible treatment technologies, resulting in a product water quality. The application can assess the exposure of humans to this product water and the pathogens it may contain.
	SuTra (#31)	SuTRa calculates the subsurface removal of microbial organisms over a distance and with time using an analytical approach. The aim is to allow for a quick assessment of subsurface removal of microbial organisms after subsurface storage.
	Water-energy- phosphorous balance planning module (#25)	This tool is a matchmaking environment where sources and demand points are combined. The supply and demand alternative combinations are assessed through a range of user-selected metrics (e.g., volume availability, cost, energy content, carbon footprint, nutrient content) over a targeted period.
	Reclaimed water distribution network water quality model (#24)	This tool provides a simulation model for mapping and quantifying risk in reclaimed water distribution networks.
	Risk Assessment for urban water reuse module (#27)	This tool is a human and environmental risk framework dedicated to water demand planners and decision-makers in urban management, municipal and water utility contexts. The tool assesses supply/demand combinations, based on a range of current risk standards and regulations. It

Step	Tool	Description (how the tool supports this step)
		works as a risk-related gatekeeper that must be cleared for any supply/demand combination to be considered for assessment in tool #17.
Decision making	Environment for decision support and alternative course selection (#17)	This tool supports water demand planners and decision-makers in urban management to select the best water source combinations to satisfy specific non-potable uses and to prioritize planning options in the governance of water sources and water uses in an urban setting. The tool provides the means to compare supply/demand matchmaking alternatives produced by tool #25 and potentially qualified by tools #24 and #27.
	Re-Actor (#18)	The RE-ACTOR tool aims at supporting water utilities, planners, and decision makers in the evaluation of new investments and actions related to water reuse and water treatment. The tool allows to simulate alternative scenarios in a territory to explore potential impacts related different actuations, such as new processes in a WWTP, installation of renewable technologies or new reclaimed water distribution infrastructure to supply new users with reclaimed water.
Management/ monitoring	Stormwater reuse management system (#21)	The stormwater reuse management system will allow the combination of operational management of a stormwater tank and a connected subirrigation system for groundwater recharge and direct irrigation with the overall objective of reducing water scarcity in spaces or close to urbanised areas. The system includes innovative control concepts to actively manage existing rainwater infrastructures to unlock new applications for otherwise lost rainwater (e.g., agriculture, watering local parks and lawns, industry).
	Nessie system (#29)	The Nessie platform is an information system, able to acquire, process and store, and in general to manage, high-resolution data from IoT agents, such as sensors and smart meters, coupled with analytics and visualisation capabilities to present the information to the end-users. Beyond simple monitoring, possible advanced capabilities for the management of water consumption that could be built upon the tool are: i) the detection of leakages and bursts, ii) the comparison with past consumption data of the household, iii) the comparison with the water consumption of other households with similar socio-demographic characteristics, iv) the analysis of total consumption per appliance, v) the forecast of future consumptions and bills.
Certification	Climate-readiness certification tool (#33)	The climate-readiness certification tool is conceived to support householders, urban planners, the building industry, municipalities, urban planners and Climate Ready Certificates auditors in calculating and emitting the Climate-Ready Certificate (CRC, merging in one certificate the water efficiency, the water-energy nexus performance and the climate adaptation evaluation of households, buildings and neighbourhoods.

The water cycle modelling and assessment solutions toolkit, which is documented in the current report, is comprised of eight tools, which are listed in Table 3 below, along with the LL in which they are applied. Detailed information on each tool is provided in section 5 that follows.

Table 3: Tools of the water cycle modelling and assessment solutions toolkit.

#No.	WP3 Tool (leading partners)	Living Lab using the tool
22	UWOT (ICCS/KWR)	Flanders/East Frisia
23	Regional Demand-Supply Matching GIS tool (IWW)	East Frisia
24	Reclaimed water distribution network water quality model (BASEFORM)	Lisbon
25	Water-energy-P balance planning module (BASEFORM)	Lisbon
26	QMRA+ (KWR)	Flanders
27	RA-Reuse (BASEFORM)	Lisbon
28	Short-Term Demand Forecasting Tool (IWW)	East Frisia
31	SuTRa (KWR) (former ASR-pro tool)	Flanders

5 The water cycle modelling and assessment solutions toolkit

5.1 Urban Water Optioneering Tool (#22) and water system analysis

5.1.1 Tool description and attributes

The Urban Water Optioneering Tool (UWOT) is a simulation-based Decision Support System (DSS), of the metabolism modelling type, able to simulate the complete urban water cycle by modelling individual water uses and technologies/options (including water saving, recycling, treatment and drainage) for managing them, aggregating them and assessing their combined effects at multiple scales, starting from the household level and progressing up until the neighbourhood, regional and entire city level (Makropoulos, 2017). It provides a range of technology combinations, which are ranked according to user-based criteria. This allows the user to determine which combination of technologies will be most appropriate or beneficial for their new development. UWOT follows a bottom-up, signal-based systems analysis approach that starts from individual components (i.e., in-house appliances, units that use water and generate wastewater or runoff) and proceeds to the generation, transmission, aggregation and transformation of water demand signals that start from the household level and propagate towards the source of water demands, i.e., the central drinking water network (Rozos and Makropoulos, 2013). This demand-oriented conceptualization (see also Figure 2) places household and neighbourhood demand as the starting point of every study and enables UWOT to simulate the whole urban water system from tap to source (Rozos and Makropoulos, 2013). UWOT is able to simulate both standard urban water flows, i.e. potable water, wastewater and runoff, modelled as signals, as well as integrated interventions at household and neighbourhood level, which target these flows in order to create feedback loops that cover household demand; other types of flows that can be modelled through appropriate components are green roofs, blue-green urban areas (Rozos et al., 2013), peri-urban areas, irrigated zones, generic pervious or impervious areas etc.

The detailed page of the tool can be accessed via the following URL: https://mp.watereurope.eu/d/Product/25.

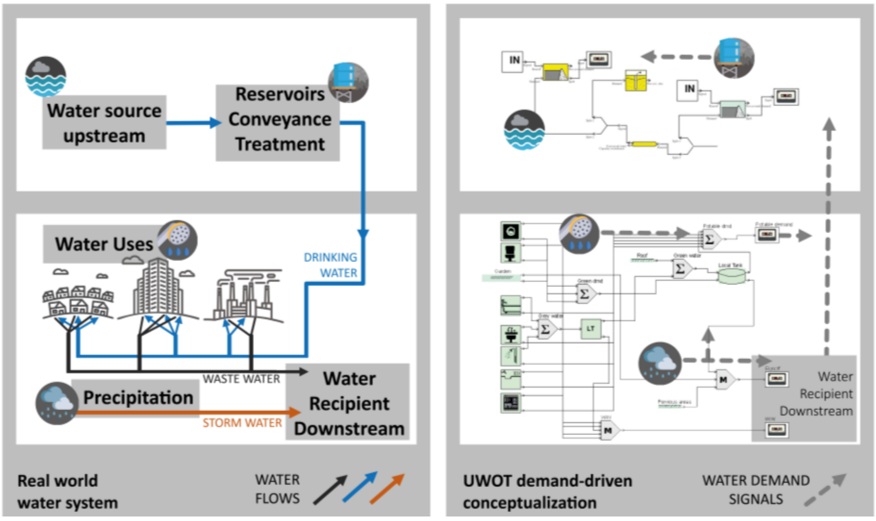


Figure 2: Modelling the urban water cycle from tap to source using UWOT (Bouziotas et al., 2019)

An overview table of the tool with its attributes and descriptions can be found under Annex A (section 12.1.1) whereas information on its primary functionalities and navigation via tool's user interface is available in Annex B (section 13.1.1). A notable application of high synergistic benefit (outside of BWS project) includes the use of UWOT for the ex-ante assessment or upscaling impact of a Sewer Mining installation (CE pilot) for urban water recycling at the local scale. Additional information is available in Annex C (14.1).

Within the water system, everything is connected. Interventions within the water system, such as the ones investigated within this project, can affect and be affected by other system components. Water systems analysis can provide information on the interaction between the intervention and the water system and may even aid in decisions regarding that technology.

Specifically for the case of Flanders, two methods that supplement each other are used for the water system analysis. Firstly, UWOT is applied to support pilots in Flanders, with further developments within BWS, followed by a regional water systems analysis that provides broader context at the provincial/catchment scale. The urban water cycle model UWOT is applied in the case of Flanders to support the generalisation and upscaling of the regional pilots and specifically on the regional (local) scale in support of two cases: (a) exploring aspects of the storage basin and water production system in the city of Woumen, (b) modelling an upscaling of the stormwater retention pond in the area of Mechelen.

Besides the UWOT application, the analysis is expanded by a regional water system analysis (from now on: Regional Analysis) using system dynamics modelling (SDM). This analysis method is under development in a parallel project within the 'Water in the Circular Economy' (WiCE) research program of the Dutch and Flemish drinking water utilities. SDM is used by KWR to analyse regional water flows and to assess the (interacting) effects of interventions and changing circumstances (such as climate change). For this purpose, a generic SDM model is developed and applied to several case studies.

As the tool is still under development and part of an ongoing project, it is not yet publicly available or extensively documented. The models are developed, however, within the publicly available SDM software Vensim (http://www.vensim.com), which is free to use for academic and educational purposes. The purpose of the Regional Analysis tool is to assist in the exploration of interactions within regional water systems. Within BWS, it was applied for regional flow analysis, in which interventions (storage, transport and treatment of water) were implemented. Basic understanding of SDM is required to properly use the tool; the proposed end-users are thus experts in the field of water resources management. The Regional Analysis with SDM was complementary to the UWOT study and was assisted by the UWOT data output and findings.

For the East Frisia LL, UWOT tool (#22) is used to simulate the water flows (water demand and supply points) for a test area and to investigate alternative scenarios based on different climatic and demand change conditions or with the implementation of partially decentralised technologies in the area of interest. The outcomes of UWOT tool is then incorporated into the Regional Demand-Supply Matching Tool.

5.1.2 Unique selling points / Added Value / Innovation

Unique selling points: UWOT tool is a bottom-up, component based urban water circle model. It includes multiple components and technologies (drinking water, wastewater/greywater, rainwater/runoff) and can simulate flows on a different temporal scale, in scenarios that span from years to decades.

Added value: UWOT enables the end-user to simulate different future water demand/supply scenarios in a quick and straightforward manner. It allows to construct scenarios based on socio-economic assumptions and supports different temporal and spatial scales.

Innovation: The tool is able to assist smartness in water, by modelling a range of decentralized, distributed interventions: rainwater harvesting, greywater recycling, blue-green areas, smart appliances and estimate water quantity and quality.

5.1.3 Addressing water challenges, CE limitation and contributing to water-smartness

UWOT mainly addresses water availability challenges. More specifically, it can examine regional scenarios related to the use of different sources, worsening climate conditions, population growth, changes on urban or agricultural demand, water scarcity issues (as presented in Chapter 2 challenges). Moreover, it can simulate possible solutions to handle them (including water saving, recycling, treatment and drainage management technologies) at different scales and the impact of climate change (changes on rainfall or temperature) on regional water demand. It includes a wide variety of components that have been designed to simulate CE technologies (taking into account the barriers of cost, legislation etc.) and offers the opportunity to users to construct different scenarios and investigate alternative water management policies. For example, it includes components to simulate the implementation of decentralized technologies (including greywater recycling or rainwater harvesting) at different scales. Thus, contributing to the implementation of technologies at more local scales with lower upfront cost. The results of such scenarios can be compared to the baseline scenario in order to calculate the amount of water saving. Moreover, other barriers related to outdated legislation and the lack of governmental laws and policies (as mentioned in Chapter 2), is tackled by using components that include information related to current regulations (for example, regarding the wastewater management process) in order to allow stakeholders have a clear picture of related barriers/drivers. It can also raise people’s awareness about principles of circular economy and tackle general distrust towards the use of reclaimed water, by investigating evidence-based and cost-benefit scenarios and highlighting the potential opportunities of CE in regional water management strategies.

For Flanders, UWOT allows the exploration of different policy schemes, e.g. different allowed wastewater (WW) reuse quantities, thus assisting stakeholder discussion and decision-making on how much WW can be reused regionally. The tool also helps to upscale CE implementation to larger scales. In combination with the Regional Analysis tool, it is used to compare the impact of different water supply security solutions for Woumen (e.g., WW reuse, CCRO), and to explore the operation and upscaling of a rainwater harvesting unit paired with subirrigation in Mechelen.

For the East Frisia case, UWOT with the Regional Demand-Supply Matching GIS tool (#23) contribute to overcoming the key issues in water and resources management in the way that an efficient fit-for-purpose allocation of resources to all sectors will be enabled by analysing alternative water supply opportunities and supporting the users in the decision-making process, thus, reducing the pressure and conflicts with regards to the local groundwater resources.

UWOT (#22) is linked to expected impacts EI_1 (decrease in use of freshwater resources), EI_2 (improved water use efficiency), EI_3, and EI_4 related to water reuse (as defined in GA, Table 7, part B, p. 40):

- EI 1 (freshwater abstracted / water supplied): by helping to reduce the use of freshwater resources by replacing freshwater usage by other resources, such as reclaimed water, rainwater, or other untapped water resources.
- EI 2 (water supplied / population served): water use efficiency is increased by UWOT in the way that a fit-for-purpose water allocation is enabled.
- EI_3 (treated wastewater used / water supplied): UWOT, through the simulation process, it provides knowledge about the current state and future opportunities of wastewater reuse in an area. UWOT and the Regional demand-supply matching GIS tool can promote the use of treated wastewater by highlighting its benefits for the regional water cycle.
- EI 4 (treated wastewater used/ total wastewater produced): same as EI 3.

The tool is also linked with the strategic objectives that can increase the water smartness. Those are:

- SO A – Ensuring water for all relevant uses: by assisting in identifying resource efficient water allocations.
- SO B - Safeguarding ecosystems and their services to society: by identifying (with the Regional Demand-Supply Matching GIS tool) untapped and new circular water supply options, thus, helping to reduce the pressure on available groundwater resources in the region.
- SO C – Boosting value creation around water: by producing useful results for the implementation of greywater recycling technology and the potential reuse of treated greywater at household level (e.g. toilet flush).
- SO D – Promoting adaptive change towards resilient infrastructure: by supporting simulation of different intervention under different climatic scenarios. Hence, supporting the design process and planning towards more resilient infrastructures.

5.1.4 Pre-existing background

UWOT has been previously developed and tested in water cycle modelling applications on different spatial scales for a diverse range of cases and demonstrated water management technologies. The range of applications includes neighbourhood-scale blue-green area design (Rozos et al., 2013), whole city cycle modelling (Rozos and Makropoulos, 2013), resilience studies (C. Makropoulos, Nikolopoulos, et al., 2018) and consultancy for circular water neighbourhood (re-)designs (Bouziotas et al., 2019). Indicative application of combined use of UWOT with sewer mining technology is presented in section 14.1.

Regarding the regional (SDM) part of the systems analysis, which was applied in the Flanders' case, the tool has been developed for regional analysis of water systems, building on recent analysis and methods (Pronk et al., 2021).

5.1.5 Developments and advancements within the project

For the purpose of BWS, UWOT is expanded to accommodate the case studies of Flanders and East Frisia in terms of components, extra demand needs, local data assimilation etc. More specifically for Flanders, UWOT topology customizations is investigated for complex processes such as supply through river intake under variable salinity conditions, regional stormwater retention, and demand coverage through subirrigation.

Regarding the regional (SDM) part of the systems analysis, the tool is being developed for application in typical Dutch landscapes. The tool's equations are adapted for the Flemish cases, as the hydrological characteristics of the Belgian landscapes are not the same as the Dutch ones. Furthermore, the model was applied to explore the interaction between proposed water-smart technologies and the water system, in which sensitivity analyses can provide information on effects under varying circumstances.

For the case study of East Frisia, UWOT components are used to simulate the baseline conditions in a test case and to investigate alternative scenarios. UWOT's outputs (i.e., water demand scenarios outputs) can be used by the Regional Demand-Supply Matching Tool for future-oriented scenarios.

5.1.6 Interoperability

UWOT requires standard, headerless CSV files of input, as well as manual input from the user through the GUI. The CSV data required are daily timeseries of water demands, supplied water, rainfall, occupancy, and/or temperature, depending on the components used. Manual input through the GUI is used to set initial conditions (such as initial water levels), as well as other parameters such as treatment rates and capacity, distribution of water across different sources, etc. Moreover, user interaction with the GUI is needed to view component and system results, in terms of timeseries, in both graphical and tabular format. UWOT saves the topology files as XML files, and exports time series as CSV files, as well as by Windows clipboard copy-pasting (e.g., in MS Excel spreadsheets). No further interoperability with regards to FIWARE is considered. As a tool using third-party data formats (XML/CSV/clipboard and MS Excel) for input and output, the corresponding interoperability maturity level as per D3.1 (section 2.3, Figure 6, p. 25.), is Level 1.

With regards to the regional (SDM) analysis applied in Flanders LL, as the methodology is currently under development and meant for scientific use, interoperability is currently not considered. The user interacts with the SDM through the use of relevant third-party software (Vensim) and saves projects as relevant files.

5.1.7 Accessing tool and test data

Test data and sample tutorials are available in the executable versions of UWOT. Software is available from the Watershare network (https://www.watershare.eu/) for research purposes free of charge upon request on a time limited license. For commercial purposes, there are commercial agreement options. Additional information and material can be found in the Water Europe Marketplace (https://mp.watereurope.eu/d/Product/25) and the website of the Urban Water Management and Hydroinformatic group (https://uwmh.civil.ntua.gr/products/86-uwot.html). Further details on accessing the tool can be provided by Dimitrios Bouziotas (bouziot@mail.ntua.gr).

The BWS training material and the demo time series for the UWOT tool are available at the following link https://mp.watereurope.eu/d/Product/25 (under the WE Marketplace) and includes:

- An overview presentation of UWOT model introducing the users to its content and role, explaining the way it works and providing results of its application to case studies and insights from past projects,
- A UWOT short guide and FAQ on installation and usage along with the most typical issues and their solutions,
- A UWOT hands-on training presentation and video serving as a step-by-step guide to create a topology and run a simulation using the UWOT model,
- Demo time series of UWOT model in order to perform the hands-on training,
- Video - UWOT hands-on training.

The overview presentation and video are also available via the project's website under the link: https://b-watersmart.eu/the-urban-water-optioneering-tool/.

For the regional analysis, the provision of test data and training material is not applicable; the software can be accessed through Vensim software (https://vensim.com/).

5.2 Regional demand-supply matching GIS tool (#23)

5.2.1 Tool description and attributes

The Regional Demand-Supply GIS tool (RDSMG) processes open-source information on natural water availability and sectorial consumption. A GIS program (open-source program: QGIS) is used for visualization and processing. In this way, information is bundled and placed in a higher-level context to identify i) possible consumption hotspots and areas with water shortage, ii) alternative water resources or areas with available water sources and iii) water drain from one region to another region. Therefore, different scales and depths of information can be analysed (Figure 3).

In the beginning, we had planned to use the FREEWAT software for its ability to handle large data sets. This is a composite plug-in for the GIS open-source desktop software QGIS (http://qgis.org) and was developed in the EU HORIZON2020 project FREEWAT. Since the end of the project, it has become deprecated, and the last stable version is not compatible with current versions of QGIS. Therefore, we decided to set up the tool directly in QGIS as a plug-in. For this reason, the RDSMG tool will stay functional for the foreseeable future (minor version update in QGIS). In addition, by setting it up directly as a plug-in in QGIS, the possibility of interoperability with other QGIS plug-ins is maintained.

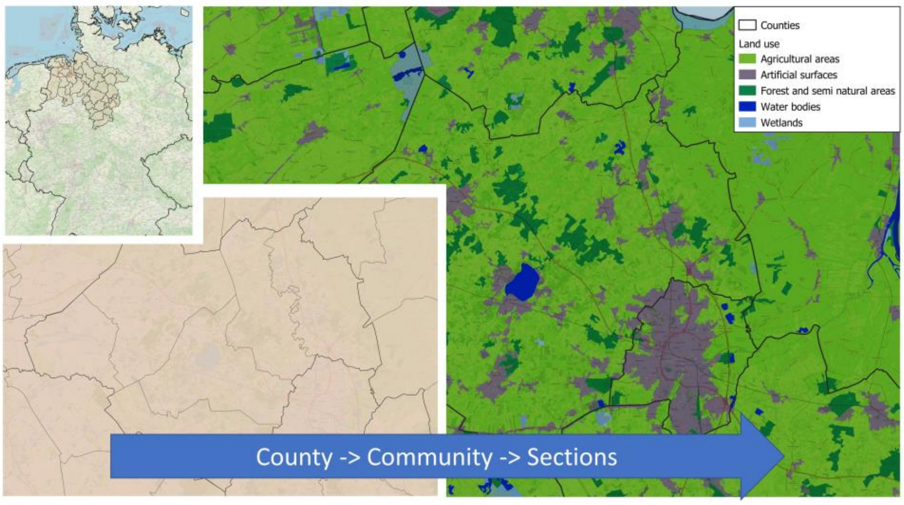


Figure 3: Different scales of information.

On the one hand, the tool can help to create awareness regarding the regional limitations of water availability in quantity and quality. In this context, projections show available water sources and water demands for all relevant sectors (domestic, industrial/commercial, agricultural) and the implications of inter-sectorial competition for water in these sectors.

On the other hand, through the targeted integration of all possible water sources, it promotes the use of alternative water resources for processes that do not require drinking water quality.

For this purpose, the sources are described in terms of quantity and quality. More specifically, the user can see all available water sources including details on their proximity, by querying the location in GIS. Based on this analysis, the impacts of alternative water availability scenarios on water demand can be displayed.

An overview table of the tool with its attributes and descriptions can be found under Annex A (section 12.1.2) whereas information on its primary functionalities is available in Annex B (section 13.2.1). The detailed page of the tool available in the WEM can be accessed via the following URL: https://mp.watereurope.eu/d/Product/35.

5.2.2 Unique selling points / Added Value / Innovation

Unique selling points: Improved decision making based on an enriched data base for East Frisia.

Added value: Structured GIS-based presentation of available information, enabling “cross-data” analyses.

Innovation: Combining information from different (public) and personal data bases.

5.2.3 Addressing water challenges, CE limitation and contributing to water-smartness

The Regional Demand-Supply Matching GIS tool (#23) in combination with UWOT (#22) contribute to overcoming the key issues in water and resources management at LL East Frisia in the way that an efficient fit-for-purpose allocation of resources to all sectors will be enabled by analysing alternative water supply opportunities and supporting the users in the decision-making process. Hence, reducing the pressure and conflicts with regards to the local groundwater resources. With regard to the barriers encountered, the Regional Demand-Supply Matching GIS tool (#23) increases the decision maker´s knowledge on tapped and untapped water resources, thereby enabling improved strategic decision making to foster water reuse projects and the closing of local water cycles. The barriers to adopting CE technologies mentioned in Chapter 2 are relevant for this tool. It not only includes information on the quantities of available water resources but also information on water qualities, thus, reducing upfront costs of implementations with regards to the monitoring of water attributes. Besides, it enables decision makers to manage enormous amounts of data and to present it in a user-friendly format.

As far to the expected impacts that can be achieved while using the tool, those are EI_1, EI_2, EI_3, and EI_4 (as mentioned in GA, Table 7, part B, p. 40). The link justification is the following:

- EI 1 (freshwater abstracted / water supplied): by helping to reduce the use of freshwater resources and by replacing freshwater usage by other resources, such as reclaimed water, rainwater, or other untapped water resources.
- EI 2 (water supplied / population served): water use efficiency is increased by the tool in the way that a fit-for-purpose water allocation is enabled.

- EI_3 (treated wastewater used / water supplied): it can promote the use of treated wastewater by highlighting its benefits for the regional water cycle.
- EI 4 (treated wastewater used/ total wastewater produced) – same as EI 3.

Regarding the strategic objectives towards water smartness, the tool is linked to:

- SO A – Ensuring water for all relevant uses: by assisting in identifying resource efficient water allocations.
- SO B - Safeguarding ecosystems and their services to society: by identifying (with UWOT) untapped and new circular water supply options, thus, helping to reduce the pressure on available groundwater resources in the region.
- SO E - Engaging citizens and actors across sectors in continuous co-learning and innovation: by assisting strategic planning including various stakeholders in the region.

5.2.4 Pre-existing background

As the tool was developed from scratch within the scope of the BWS project, there is no pre-existing background to the RDSMG tool.

The data used originates from open-source databases. In this context, data are based on different scales, may differ in availability for different regions or simply may lack GIS references. The most comprehensive data set for German case studies is available for districts (Statistisches Bundesamt) including information about e.g., population, population growth prognosis, per capita consumption, and industrial and agricultural water demand, public and non-public water supply. Information on water resources is given by state offices and may differ in scale as well as depth of information for each state (e.g., numis.niedersachsen.de). For instance, information about groundwater quality is provided for defined groundwater bodies and surface water quality is widely available. Available groundwater quality follows the classification of the European Water Framework Directive (WFD, e.g., umweltkarten-niedersachsen.de). In addition, other nationally available data are used (e.g., CORINE land cover, Census 2011). Grid-based information is available for precipitation (e.g., Deutscher Wetterdienst - DWD).

5.2.5 Developments and advancements within the project

Open-source data has been gathered for the pilot region of Lower Saxony and the association area of OOWV. Data has been – where needed - downscaled and assigned to GIS elements. A systematic scheme has been developed to visualize water demand and sources and identifies areas of high stress. A process has been developed to identify local water resources for a certain water demand in a certain region defined by the user. The actual RDSMG was implemented in QGIS via a plug-in. It allows the user to select input data, query points and other criteria via a graphical interface.

5.2.6 Interoperability

Input and output files used for the data are CSV-files. For a convenient query on numerous points of interest, point shape layers are used. For geospatial information shapefiles have been used. The RDSMG tool can optionally process UWOT output data (CSV data). No further interoperability with regards to FIWARE is considered.

5.2.7 Accessing tool and test data

The RDSMG tool as well as the example data (collected data) are accessible via the Water Europe Marketplace (https://mp.watereurope.eu/d/Product/35) or can be provided by Katharina Gimbel (k.gimbel@iww-online.de).

5.3 Reclaimed water distribution network water quality model (#24)

5.3.1 Tool description and attributes

Tool #24 – *Reclaimed water distribution network water quality model* – is a complete hydraulic and water quality extended-period simulation model for pressure flow networks, designed to simulate the advection, mixing and transformation of waterborne parameters in reused water. It aims primarily at mapping and quantifying risk in reclaimed water distribution networks (Figure 4).

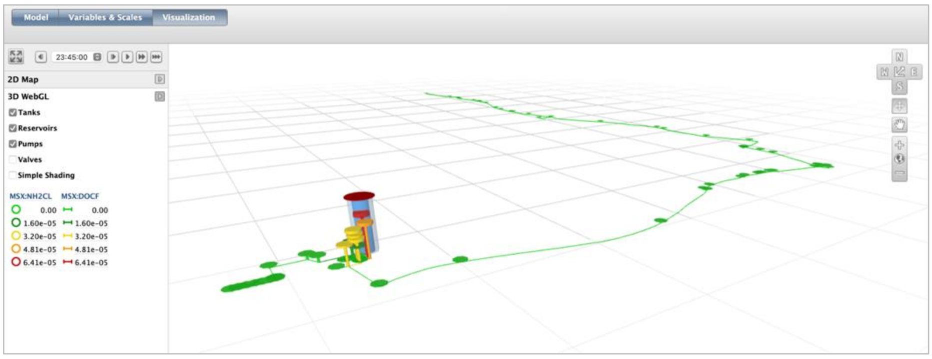
This tool complements Tool #25 in assessing the additional cost, risk and performance changes that may be required in case the supply/demand combinations chosen need to make use of an existing or new distribution network (see overall schematic in Figure 39).

The targeted end users of Tool #24 are hydraulic engineering experts in urban management, municipal and water utility contexts.

The model is deployable at the spatial scale of an urban water distribution network or bulk water network.

This cloud-based tool is developed by BASEFORM using its own proprietary Java-based, web-centric software platform designed for networked infrastructures.

It had a TRL of 3 at the outset of the project and an expected TRL of 7 at the end of the project.



☑ Tanks
☑ Reservoirs
☑ Pumps
☐ Valves
☐ Simple Shading

MSX:NH2CL	MSX:DOCF
○ 0.00	0.00
○ 1.60e-05	1.60e-05
○ 3.20e-05	3.20e-05
○ 4.81e-05	4.81e-05
○ 6.41e-05	6.41e-05

Figure 4: 3D representation of simulated reused water quality values (BASEFORM)

This model is self-contained and, as such, may be used on its own to fulfil its primary purpose. However, in the context of the project, it is intended to be used in conjunction with Tool #25 to qualify the supply/demand alternatives developed there. It aims to assess the risks incurred in transport and distribution of the combination of reused water.

An overview table of the tool with its attributes and descriptions can be found under Annex A (section 12.1.3) whereas information on its navigation and primary functionalities is available in Annex B (section 13.3.1). The detailed page of the tool as in the WEM can be accessed via the following URL: https://mp.watereurope.eu/d/Product/51

5.3.2 Unique selling points / Added Value / Innovation

Unique selling points: This specialized reclaimed water quality model is a new, dedicated solution to the problem of analysing and assessing the environmental and public health risks posed by using pipe networks for transporting and distributing reclaimed water. It benefits from the BASEFORM software's data compatibility features, capable of handling water supply system data in GIS or hydraulic model formats.

Added value: The tool is part of a sequence of four apps that jointly provide a complete ability to match water supply to demand, while managing water volume, cost, energy, nutrients and risk, with full GIS-compatible georeferenced capabilities. The apps are made available within the market tested BASEFORM water analytics package, which is used by utilities around the world servicing over 25 million people. This tool adds full reclaimed water quality modelling capabilities to the BASEFORM software universe.

Innovation: This tool implements a new, innovative algorithm for modelling chlorine decay, as a function of key water quality parameters, as the reclaimed water travels in distribution networks, on top of a standard hydraulic model. The tool works in conjunction with tool #25 by assessing transport and distribution risk of reclaimed water in candidate supply/demand combinations. The reclaimed water quality modelling algorithm has also been published as a result of the project.

5.3.3 Addressing water challenges, CE limitation and contributing to water-smartness

The reclaimed water distribution network water quality model is contributing to the Lisbon and water related challenges (please refer to Chapter 2 and section 8.1) by improving the water supply and demand management and promoting the safe use of reclaimed water as an alternative water source. It also assists in overcoming barriers (Chapter 2) that concern an incipient experience on water reuse projects, namely, design, licensing, and long-term planning needed to support the required investments in municipal infrastructures. Technical feasibility within decision process is specifically supported by the tool by mapping and quantifying risk in reclaimed water distribution networks (tool #24). During tool's development, barriers to adopting circular economy technologies were considered. Therefore, provision of a complete hydraulic and water quality model was delivered for reclaimed water distribution networks, including residual chlorine decay and disinfection which is a key barrier within human health risk management.

By applying the tool, the Lisbon LL is a step closer to achieve the expected impacts with regard to water reuse (EI 3 and 4, as defined in GA, Table 7, part B, p. 40) by enabling a safe water reuse in non-potable uses. Therefore, quantifiable indicators that can be used to assess tool's impact (in collaboration with other tools and technologies) are the treated wastewater used compared to the water supplied (EI 3) or the treated wastewater used compared to total wastewater produced (E4).

The tool is also linked with the strategic objectives that can increase the water smartness. Those are:

- SO A – Ensuring water for all relevant uses
- SO C – Boosting value creation around water
- SO D – Promoting adaptive change towards resilient infrastructure

by promoting safe water reuse and increasing the resilience of reclaimed water distribution networks.

5.3.4 Pre-existing background

BASEFORM software as described in https://baseform.com/np4/product/.

5.3.5 Developments and advancements within the project

The model uses previously existing formulations for hydraulics and basic advection, mixing and transformation of parameters in pressurized water distribution networks. The tool implements a new, specific water quality model formulation for reused water, designed within the project. It has been optimised through algorithmic and programming developments for the specific implementation and it uses BASEFORM's geo-based environment and hydraulic simulation framework. The underlying hydraulic and water quality model is based on a complete, specific Java-based implementation that is fully compatible with the EPANET .inp and MSX file formats.

5.3.6 Interoperability

Compatibility with FIWARE is available at read/write level only (through API and/or webservices), as mentioned above on Table 9.

5.3.7 Accessing tool and test data

The tool is part of the set of four tools developed by BASEFORM (#17, #24, #25, #27) for application in the Lisbon Living Lab, where it has been undergoing testing and application to the specific cases being explored in this LL. Sets of test data are available with the software. Real case application data pertaining to the Lisbon Living Lab are available from LNEC.

Accredited users may access the tool at the URL below:

https://bwatersmart.baseform.com

For the duration of the project, user credentials should be requested directly from BASEFORM through the following contact point: diogo.vitorino@baseform.com.

5.4 Water-energy-phosphorous balance planning module (#25)

5.4.1 Tool description and attributes

Tool #25 – *Water-energy-phosphorous balance planning* – is a matchmaking environment conceived and designed entirely for BWS, where sources and demand points are combined with a particular focus on matching and balancing water availability, energy consumption and carbon footprint, as well as nutrient content to enable the design of supply solutions to a set of potential users of reused water.

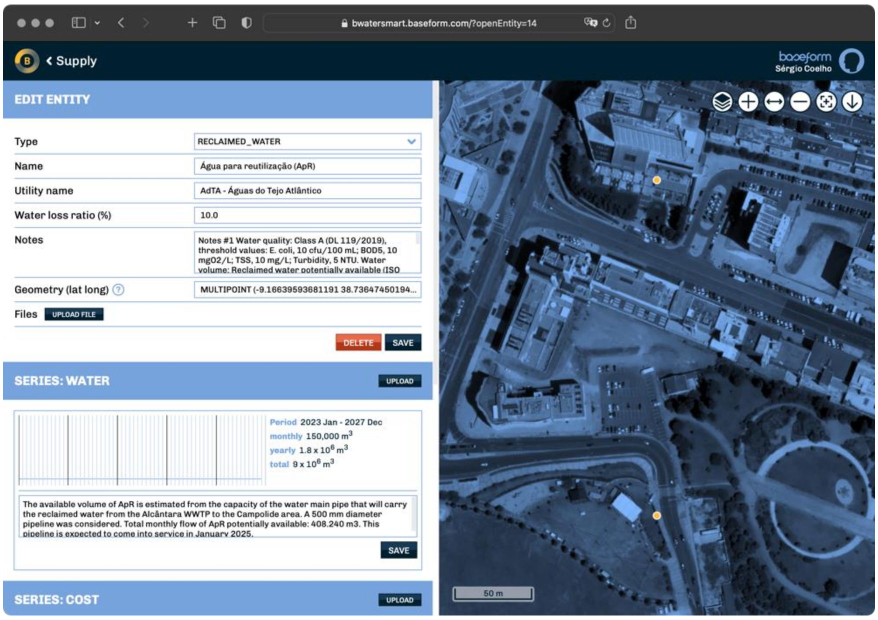
The supply and demand alternative combinations are assessed and matched through a range of user-selected metrics that cover not only those three key vectors but allow for cost tracking cost and other variables of interest over a targeted period. The alternative combinations produced are further made available to Tools #24, #27 and #17 as depicted in Figure 39.

The integrated use of tools #25 and #17 enables the decision-makers to define and prioritize combinations of two or more supplies, including reclaimed water, in satisfying non-potable water demands in urban or regional contexts, based on factual evidence. It is important to align the bottom-up (i.e., demand-driven) decisions with strategic and tactical planning at city level. This alignment is provided by specifically designed assessment variables such as volume availability, cost, energy, carbon footprint or nutrient content. These variables are used in or contribute for the calculation of metrics of the BWS assessment framework – strategic planning (tool #34). It is also important to have in mind the contribution of water supply-demand management to specific goals, such as energy neutrality and climate action.

The combined deployment of tools #25 and #17, together with tools #24 and #27 (in case of water reuse), goes beyond the state-of-the-art because it provides the ability to match water supply to demand, while managing water volume, cost, energy, nutrients and risk, with full GIS-compatible georeferenced capabilities. The result is a streamlined, simple-to-use analysis of supply and demand matchmaking that can be operated by decision-makers without deep technical knowledge, as well as by experts with full depth analysis.

As reclaimed water is a sustainable source, largely independent of climate uncertainty, it can contribute to reducing pressure on strategic freshwater resources and to allow resources' recovery, such as phosphorus. The matchmaking environment is driven by the demand(s) to be satisfied, translated as time series of required monthly volumes over a pre-specified period of time. The user is asked to register potential sources, with corresponding times series of available volumes taking place in the same time window, though not necessarily spanning its entirety.

The user is then asked to combine the available sources to make up the required monthly volumes, while ensuring the energy and nutrient content align with their needs. Such combinations are called 'alternatives' and are characterized by the degree to which they satisfy the required volumes over time, as well as by their energy consumption, nutrients contents and cost. One or more alternatives will be designed to solve the demand problem at stake. Figure 39 depicts the logical sequence that ensues after one or more alternatives have been developed, namely the risk assessment stages, before they reach the decision-making environment at Tool #17. Figure 5 depicts the tool's UI while specifying a reused water demand point in the matchmaking environment.



Type	RECLAIMED_WATER
Name	Água para reutilização (ApR)
Utility name	AdTA - Águas do Tejo Atlântico
Water loss ratio (%)	10.0
Notes	Notes #1 Water quality: Class A (DL 119/2019), threshold values: E. coli, 10 cfu/100 mL; BOD5, 10 mgO2/L; TSS, 10 mg/L; Turbidity, 5 NTU. Water volume: Reclaimed water potentially available (ISO
Geometry (lat long)	MULTIPOINT (-9.16639593681191 38.73647450194...
Files	

Period 2023 Jan - 2027 Dec
monthly 150,000 m^3
yearly 1.8 x 10^6 m^3
total 9 x 10^6 m^3

The available volume of ApR is estimated from the capacity of the water main pipe that will carry the reclaimed water from the Alcântara WWTP to the Campolide area. A 500 mm diameter pipeline was considered. Total monthly flow of ApR potentially available: 408.240 m3. This pipeline is expected to come into service in January 2025.

Figure 5: Specifying a reused water demand point in the matchmaking environment (BASEFORM).

Tool #25's key development period took place between months M18 and M24, with initial Lisbon LL testing release delivered at M26 and the initial project release in M30 as scheduled.

The tool's targeted end users are planners and decision-makers in urban management, municipal and water utility contexts. It is deployable at any spatial scale as it applies to any supply/demand context, but indicative scales are city facility (e.g., public park), neighbourhood, city, region. The software allows for full geographic representation of the sources and demands (screenshots below in Table 10).

The tool is developed by BASEFORM using its own proprietary Java-based, web-centric software platform designed for networked infrastructures. It has a TRL of 3 at the outset of the project and an expected TRL of 7 at the end of the project.

As mentioned above, Tool #25 is autonomous and may be deployed on its own, or in conjunction with the remaining tools (#17, #24, #27) as per the schematic in Figure 39. The primary goal is described in 5.4.1. Conceivably, the tool is applicable to any demand-driven matchmaking problem without requiring modification.

An overview table of the tool with its attributes and descriptions can be found under Annex A (section 12.1.4) whereas information on its navigation and primary functionalities is available in Annex B (section 13.4.1). The detailed page of the tool as in the WEM can be accessed via the following URL: https://mp.watereurope.eu/d/Product/55

5.4.2 Unique selling points / Added Value / Innovation

Unique selling points: This tool allows for a streamlined, simple-to-use analysis of supply and demand matchmaking that can be operated by decision-makers without deep technical knowledge, as well as by experts with full-depth analysis. It can be used with what-if or simplified supply and demand data for sensitivity gain, as well as with fully automated data from any available source. It benefits from the BASEFORM software's data compatibility capabilities as well as its georeferenced interface.

Added value: The tool is part of a sequence of four apps that jointly provide a complete ability to match water supply to demand, while managing water volume, cost, energy, nutrients and risk, with full GIS-compatible georeferenced capabilities. The apps are made available within the market-tested BASEFORM water analytics package, which is used by utilities around the world servicing over 25 million people. This tool adds supply/demand management capabilities to the BASEFORM software universe.

Innovation: This tool implements a novel matchmaking framework for formulating and assessing candidate combinations of two or more supplies, including reclaimed water, in satisfying non-potable water demands in urban or regional contexts, to enable prioritizing strategic and tactical planning options. The framework allows for essential assessment variables such as volume availability, cost, energy, carbon footprint or nutrient content to be factored in. It allows for analysis over projected periods of time, with full time-series representation as well as explicit mapping using a georeferenced mapping interface in the BASEFORM environment. It produces sets of candidate supply/demand solutions to be further assessed for risk in tools #24 and #27 (in case of water reuse), before being compared for prioritization and final decision in tool #17.

5.4.3 Addressing water challenges, CE limitation and contributing to water-smartness

The water-energy-phosphorous balance planning module is one more tool which attempts to address the Lisbon challenges described in section 8.1. Specifically, tool #25 contributes to the need to increase urban green areas by targeting to improve the water supply, demand management and the city's water-energy-phosphorus (WEP) footprint while increasing those areas. The tool also contributes to overcome the barriers which are related to the incipient experience on water reuse projects, namely, design, licensing, and long-term planning needed to support the required investments in municipal infrastructures, This is achieved by contributing on the technical feasibility by prioritizing strategic and tactical planning options on water management and the economic feasibility by providing information for cost-benefit analysis of reclaimed water use, including P and energy (while combined with #17). During the development phase, barriers to adopt circular economy technologies were considered which guided the way towards delivering a tool which provides an overview of current and planned water supply/demand alternatives in the city to enable prioritizing strategic and tactical planning options (in parallel with #17).

The tool is linked with several KPIs defined in Table 7 (in GA, Part B, p.40) which can be used in order to measure its impact. It is directly linked (along with other tools) to:

- EI 1- decrease in use of freshwater resources (freshwater abstracted /water supplied) by the matchmaking of water supply/demand enabling the use of reclaimed water as an alternative to the drinking water and groundwater currently in use,
- EI 3 & EI 4 – water reuse (treated ww used/water supplied & treated ww used/total ww produced respectively) by targeting water reduction.
- EI 5 – reduction in water-related energy use (of present use) by enabling the assessment (i.e., metrics) of energy consumption related with water uses (while used with #17).
- E7 – nutrient recovery (of total potential in case) via the assessment (i.e., metrics) of P-fertilizer production avoided through water reuse in irrigation,

and indirectly to EI 2 – improved water use efficiency (water supplied/population served) by contributing to the reduction of water consumption.

Linkage of tool#25 with the B-WaterSmart Framework assessing water-smartness and Lisbon LL Strategic Agenda is also ensured by embedding in the tool metrics that correspond as much as possible to metrics integrated in the BWS Assessment Framework (tool #34) or else contribute to their calculation. Thus, the tool supports all five specific objectives:

- SO A– Ensuring water for all relevant uses via the promotion of water use efficiency (indirectly)
- SO B – Safeguarding ecosystems and their services to society via the promotion of the use of reclaimed water in non-potable urban uses and, thus, reducing the pressure on strategic drinking water resources
- SO C – Boosting value creation around water via the promotion of reclaimed water use for irrigation urban green areas, including phosphorus valorisation
- SO D – Promoting adaptive change towards resilient infrastructure via the promotion of adaptive changes towards circularity (indirectly)
- SO E – Engaging citizens and actors across sectors in continuous co-learning and innovation by aligning decisions for water management in tactical and strategic planning (indirectly).

5.4.4 Pre-existing background

BASEFORM software as described in https://baseform.com/np4/product/.

5.4.5 Developments and advancements within the project

The tool is conceived and developed from scratch by BASEFORM within the project, based on the concept created by the LNEC team in task T2.4, and developed jointly with BASEFORM for implementation. It builds upon and benefits from BASEFORM's pre-existing online client-server environment, input/output capabilities, file system and geo-referenced environment for water infrastructures, as well as its graphical user interface.

The tool constitutes a new autonomous module within the BASEFORM environment, which may be deployed on its own as a stand-alone app or in conjunction with the remaining tools (#17, #24, #27) as per the schematic in Figure 39.

5.4.6 Interoperability

Compatibility with FIWARE is available at read/write level only (through API and/or webservices), as mentioned above in Table 10.

5.4.7 Accessing tool and test data

The tool is part of the set of four tools developed by BASEFORM (#17, #24, #25, #27) for application in the Lisbon Living Lab, where it has been undergoing testing and application to the specific cases being explored in this LL. Sets of test data are available with the software. Real case application data pertaining to the Lisbon Living Lab are available from LNEC and CML.

Accredited users may access the tool at the URL below:

https://bwatersmart.baseform.com

For the duration of the project, user credentials should be requested directly from BASEFORM through the following contact point: diogo.vitorino@baseform.com.

5.5 QMRA+ for water reuse and agriculture (#26)

5.5.1 Tool description and attributes

Quantitative Microbial Risk Assessment (QMRA) is a methodology that can be applied to assess risks of water (re)use and thus support decisions. The QMRA tool enables users to estimate the microbial health risk of using various water sources, including reuse of wastewater. A treatment system can be designed by selecting treatment steps from a wide array of possible treatment technologies. These treatment trains result in a product water quality for which the application can be selected to assess the exposure of humans to this product water and the pathogens it may contain. Besides microbial risks, effluent will also contain a range of chemicals that can be adverse to health. For many of these chemicals, health-based targets for drinking water quality have been developed using quantitative chemical risk assessment (QCRA) to avoid potential health risks. A key difference between microbial and chemical water quality is that chemicals can be analysed at low concentration levels to demonstrate they comply with these health-based targets, whereas microbial contaminants cannot be detected with sufficient sensitivity to verify compliance. Therefore, QMRA is applied to specific systems and case studies to demonstrate that treatment is sufficient to meet health-based targets given the concentration of pathogens in source water that can be detected with analytical methods. For potable water reuse this often demonstrates the need for ten or more orders of magnitude of pathogen removal. On the contrary, meeting chemical water quality targets often only requires one to two orders of magnitude removal of these substances, which can easily be verified by monitoring the treated water quality. Therefore, a QCRA is typically only used indirectly for specific water reuse schemes as it forms the basis for the water quality targets. In B-WaterSmart the chemical challenges were addressed in the design of treatment scheme alternatives. These alternatives were then evaluated for microbial safety by QMRA.

A calculation performed according to the QMRA approach involves the estimation of infection risk per person per year and the DALYs (disability-adjusted life years) per person and year for bacteria (*Campylobacter jejuni*), viruses (rotavirus) and protozoa (*Cryptosporidium*). Most other QMRA tools, e.g. QMRAspot (https://www.rivm.nl/en/who-collaborating-centre-risk-assessment-of-pathogens-in-food-and-water/tools/qmraspot), require users to enter microbial monitoring data from the source and treatment system or data that users need to obtain from literature (DPRisk, https://cawaterdatadive.shinyapps.io/DPRisk/). These tools also require some training to adequately use the tools. The QMRA+ tool has an easy-to-use web interface with explanations of the required input and how the tool operates and does not require data from the user as data on source water quality and water treatment efficacy from literature is incorporated in the tool. Therefore, the user can start a basic risk assessment using these default values. If the user has more specific data for their system, they can adapt these default values to make the tool more site-specific and accurate.

The tool was designed for users with no or limited experience and knowledge of QMRA, but also provides an effective tool for QMRA experts. It can be used for screening level QMRA to compare different scenarios or water system designs. The tool can also be used for education and training purposes since it's very user friendly and provides help and background information when used. With the basic functionality, generic reference values are provided for all inputs. The outcome should therefore be considered a first estimate of risk but cannot be interpreted as actual compliance to a risk target of a specific system. Since contamination of sources and performance of individual water treatment systems can vary, location specific data is required to reach a realistic risk estimate for a specific system. Users with sufficient QMRA knowledge can use the more advanced features of the tool to adapt the generic input data to locally relevant data on pathogens in water sources, treatment efficacy and exposure through various uses.

The tool was initially developed in the H2020 AquaNES project by KWR and KWB, based on previous work and QMRA tools. The goal was to make QMRA more easily accessible. Within BWS the tool was improved, and new features were added. Technical improvement included alteration of the risk calculation and bug fixing to increase the stability of the tool. Added features include additional water treatment processes and advanced options to adapt input parameters based on user data.

The target audience for the tool are risk managers of water systems and their stakeholders. The tool can provide a common basis for all stakeholders involved in system selection and design as it allows both experienced and inexperienced users to explore various scenarios and options. It provides a mean to introduce, educate and train QMRA principles to students, operators, engineers and regulators.

The tool is targeted at professional water supply systems. The input data is based on professionally designed and operated systems, ranging from small to large systems. Application to neighbourhood or household scale needs careful consideration since the performance, monitoring and management of such small-scale systems can deviate from those of large systems. A user with sufficient knowledge may adapt the standard input values accordingly.

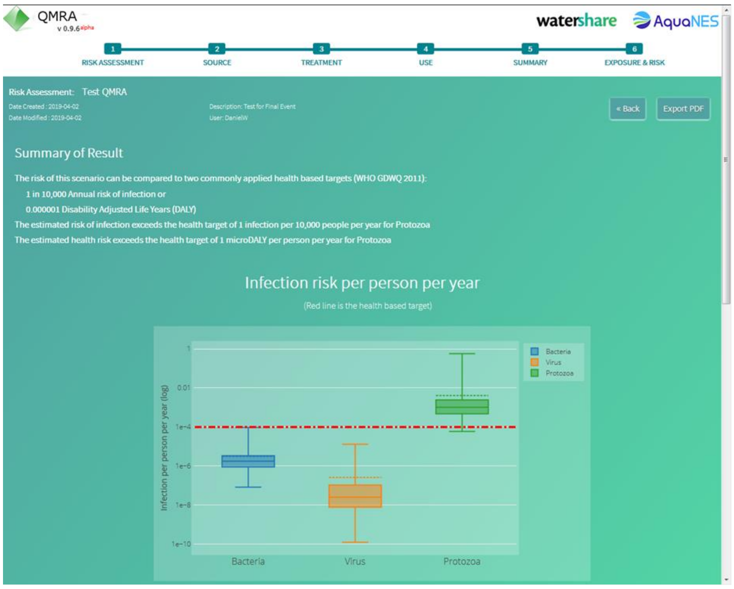
The tool is aimed at water uses that result in direct ingestion of various water uses, including unintended use. Examples are drinking water, irrigation, toilet flushing etc. Specific uses may require adaptation of the frequency and amount of ingestion based on user data.

The initial calculation software was developed by KWB in the DEMOWARE project. The initial user interface was developed by KWR within the AquaNES project. Both institutes worked together to develop the final tool. The QMRA+ version was developed by KWR in the BWS project.

The tool is web-based. It can be used through popular internet browsers without the need for any downloading of software. The original calculation was developed in R. Functions were programmed in R and integrated in the open-source R-package kwb.qmra (v0.2.0) accessible through GitHub (https://github.com/kwb-r/kwb.qmra) under the permissive MIT li-cense (https://github.com/KWB-R/kwb.qmra/blob/master/LICENSE) and documented under the following link: https://kwb-r.github.io/kwb.qmra/. The webtool and GUI were developed in Java on the server side. JavaScript, HTML, CSS are used on the client side.

The webtool is publicly available with the disclaimer that the developers are not responsible for any consequences arising from its use. The original R-code for the tool is accessible through GitHub (https://github.com/kwb-r/kwb.qmra) under the permissive MIT license. The R-code doesn’t include all functionality of the webtool.

The tool can be found here: https://tinyurl.com/QMRAplus. Users can login to the tool and store system designs for future sessions. A screenshot of the tool risk calculation results is available in Figure 6.



Risk Assessment: Test QMRA
Date Created : 2019-04-02
Date Modified : 2019-04-02
Description: Test for Final Event
User: DanielW

Summary of Result

The risk of this scenario can be compared to two commonly applied health based targets (WHO GDWQ 2011):
1 in 10,000 Annual risk of infection or
0.000001 Disability Adjusted Life Years (DALY)
The estimated risk of infection exceeds the health target of 1 infection per 10,000 people per year for Protozoa
The estimated health risk exceeds the health target of 1 microDALY per person per year for Protozoa

Figure 6: Screenshot of the QMRA+ tool risk calculation results.

The tool has been used within BWS to evaluate various design and treatment options for the Flanders drinking water case. Variables were the point of entry of the (upgraded) sewage treatment effluent and various water treatment options for the effluent and/or adaptation of the existing drinking water treatment system. The tool provided a good means to introduce the QMRA methodology to the various project participants. Participants could use the tool to explore other alternatives themselves, thus demonstrating the impact of various design options on health risk.

The tool has also been used in education to introduce MSc students at Utrecht University to the QMRA methodology.

An overview table of the tool with its attributes and descriptions can be found under Annex A (section 12.1.5) whereas information on its navigation and primary functionalities is available in Annex B (section 13.5.2). Technical details on new developments and advancements made within the project are available also in Annex B (section 13.5.1). The detailed page of the tool as in the WEM can be accessed via the following URL: https://mp.watereurope.eu/d/Product/56 .

5.5.2 Unique selling points / Added Value / Innovation

Unique selling points: The QMRA+ tool is extremely user friendly and can be used without training or previous knowledge. The QMRA+ tool is unique in the sense that all available knowledge to perform QMRA is already incorporated in the tool. The user doesn't need knowledge on QMRA or data to start using the tool and apply it on their cases. In addition, more experienced users can introduce their own data or knowledge to adapt default values in the tool, making the risk assessment more site specific and the outcomes more accurate for the situation at hand.

Added value: New water supply concepts are only feasible if they are safe. Unsafe practices could quickly lead to outbreaks of disease under their users or the people exposed (e.g.

through irrigation water spray). This would lead to discarding the innovative water supply solutions. The tool provides scientific substantiation of the safety of the innovative water concept that can be used to convince regulators, inspectorates and the public that water is safe and thus enhance acceptability of alternative water systems. It can be used to assess vulnerability e.g., due to failure and prepare monitoring and response plans for these situations.

Innovation: This tool combines various aspects of QMRA to provide an easy to use and scientifically sound tool to evaluate the safety of alternative water resources and uses. Before QMRA+ risk assessment tools required extensive data input from users, which is often not available. Using those tools required expertise in the field of QMRA and often training on how to use the tools as they were not user friendly. Uniquely QMRA+ provides the current scientific knowledge about relevant aspects such as source water quality, the effect of water treatment processes and the exposure through various uses. This allows users that encounter QMRA for the first time to quickly understand the principles and key concepts. The tool also allows them to quickly compare various options or scenarios for new water supply concepts and compare their risks to current internationally applied standards. Where other tools mostly provide a point estimate of risk, the QMRA+ tool incorporates uncertainty and variability in the risk assessment, providing a range for the assessed risk level. Incorporating uncertainty is essential for decision taking, and to define follow-up actions such as collecting the most relevant data to reduce this uncertainty. The tool works intuitively since the end user wat put centrally when developing the tool. It was developed from the point of end user needs rather than providing only scientific outcomes and approaches. More experienced users can introduce their own data to replace default values, thus making the risk assessment more site specific and accurate. Since the tool is provided as an online application, the latest scientific knowledge and insights can be, and are, incorporated in the tool over time.

5.5.3 Addressing water challenges, CE limitation and contributing to water-smartness

The QMRA+ tool doesn’t address water resources management directly, but it can be used to evaluate alternative water source for the aspect of health and safety. Microbial water safety is a key requirement for implementation of water reuse as part of a CE (Chapter 2) and the tool can be used to assess the safety of a treatment concept and demonstrate that treatment is sufficient. Additionally, QMRA+ allows for optimization of treatment, thus preventing over-design of treatment, thus preventing waste of resources including costs. Hence, the tool addresses barriers in applying technologies as part of CE (Chapter 2 and 3) which are related to a) high upfront costs, b) the need to solve technological challenges in the products development, c) little experience of circular economy in large-scale implementations, d) outdated legislation and the lack of governmental laws and policies and e) general distrust towards the use of reclaimed water, low social acceptance and strong psychological effect in society against direct waste recycling (also due to health and safety risks). The tool strongly focuses on health and safety of a CE, which generally is a barrier when using waste streams for new exposure. Although it is limited to microbial water safety, it does include a wide range of alternative water sources and diverse water use scenarios which were implemented while considering the barriers to adopting circular economy technologies.

Water reuse which can be quantified via EI 3 (Treated ww used / water supplied) and EI 4 (Treated ww used / total ww produced), as defined in GA, Table 7, Part B, p.40, is affected by QMRA+ deployment. Assessment of water reuse safety is a requirement for implementation. QMRA+ provides a prediction of microbial water safety by reuse technologies. Performing a QMRA is essential when implementing water reuse to assure that the water is sufficiently safe for the intended purpose. QMRA+ provides an easy-to-use tool for an initial assessment of alternative treatment schemes. Note that QMRA is also needed when the installation is in operation to determine whether the potential safety is actually achieved in practice.

QMRA+ can also be linked with strategic objectives leading to water-smart societies. Those are the following:

- SO A – Ensuring water for all relevant uses: The QMRA+ tool can be used to evaluate various treatment schemes for microbial safety of the produced water for the intended use.
- SO E - Engaging citizens and actors across sectors in continuous co-learning and innovation: The QMRA+ tool provides a common basis for the stakeholders in the LL to discuss water safety and identify key choices in this aspect. Outcomes can also be used to communicate the safety of the water to citizens.

5.5.4 Pre-existing background

The initial calculation software was developed by KWB in the DEMOWARE project. The initial user interface was developed by KWR within the AquaNES project. Both institutes worked together to develop the final tool. The QMRA+ version was developed by KWR in the BWS project.

5.5.5 Developments and advancements within the project

Within BWS the tool was improved, and new features were added. Technical improvements included alteration of the risk calculation and bug fixing to increase the stability of the tool. Added features include additional water treatment processes and advanced options to adapt input parameters based on user data. More technical details regarding the added features can be found in section 13.5.1 of Annex B.

5.5.6 Interoperability

The tool is not interoperable with other tools in the project and is therefore at FIWARE maturity level 0, (see D3.1 for definitions of maturity levels, section 2.3, Figure 6, p. 25). However, this maturity level follows from the goal of the tool and the characteristics of the user input. The data is included in the tool and the user only needs to make selections. As the tool is designed to explore and compare various water(re)use scenarios, there is no data input needed by the user. The tool doesn’t need real time data input for the risk calculation. Location specific monitoring data is generally scarce since monitoring programs for micro-organisms are very costly, especially for pathogens. Depending on the methods and the approach used, the data needs expert interpretation before it can be summarized for the tool. Since this will vary case by case a standard approach could not be developed within the tool.

5.5.7 Accessing tool and test data

The tool is accessible at: https://tinyurl.com/QMRAplus. No test data is available since data selections are made within the tool. The tool has been tested for the available input data.

5.6 Risk Assessment for urban water reuse module (#27)

5.6.1 Tool description and attributes

Tool #27 – *Risk Assessment for urban water reuse* – is a risk assessment framework that evaluates human and environmental risks incurred by the supply/demand combinations developed in Tool #25. These evaluations are based on a range of current risk standards and regulations including:

- ISO 16075 Guidelines for treated wastewater use for irrigation projects (2020, 2021),
- ISO 20426:2018 Guidelines for health risk assessment and management for non-potable water reuse,
- ISO 20761:2018 Guidelines for water reuse safety evaluation,
- EU Regulation 2020/741 on minimum requirements for water reuse.

The tool works in combination with Tool #25 following the workflow presented in Figure 39 and the description included in the introduction to Tool #17[3] documented in D3.4. It works as a risk-based gatekeeper that must be cleared for any supply/demand combination to be considered for assessment in Tool #17. Each alternative tested for human risk and for environmental risk undergoes a sequence of steps to translate the aforementioned standards and receives a risk grade. Depending on the targeted risk level, the alternative will either be rejected (and potentially returned to tool #25 for redesign) or approved and forwarded to Tool #17. The tool is functionally linked to Tool #25, which is aware of the alternative's risk score, if available (see e.g., Figure 59).

The targeted end users of Tool #27 are water demand planners and decision-makers in urban management, municipal and water utility contexts. Tool #27 is deployable at any spatial scale as it applies to any supply/demand context, but indicative scales are city facility (e.g., public park), neighbourhood, city and region. It has been developed by BASEFORM using its own proprietary Java-based, web-centric software platform designed for networked infrastructures. The TRL level of the tool was 2 at the outset of the project, whereas the ending TRL level is 7.

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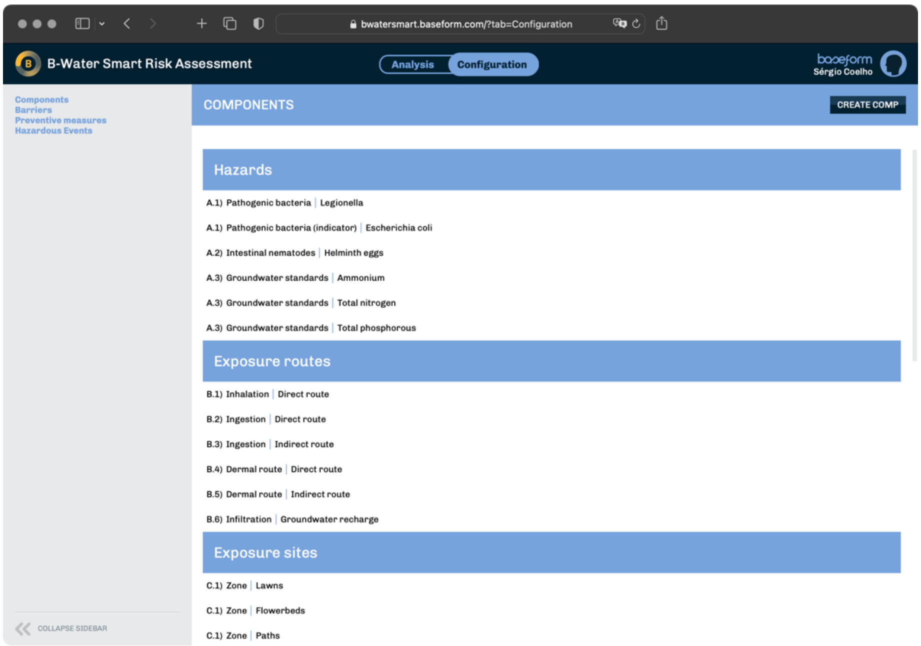
[3] Tool #17 – *Environment for decision support and alternative course selection* – is a multi-criteria decision framework designed to enable direct assessment, comparison and prioritization of decisional alternatives. Detailed descriptions about the tool are available in D3.4.

As mentioned above, Tool #27 is autonomous and may be deployed on its own, or in conjunction with the remaining tools (#17, #24, #25) as per Figure 39. Figure 7 display a configuration tab for the risk components as available in the UI of the tool.



Hazards

A.1) Pathogenic bacteria | Legionella
A.1) Pathogenic bacteria (indicator) | Escherichia coli
A.2) Intestinal nematodes | Helminth eggs
A.3) Groundwater standards | Ammonium
A.3) Groundwater standards | Total nitrogen
A.3) Groundwater standards | Total phosphorous

Exposure routes

B.1) Inhalation | Direct route
B.2) Ingestion | Direct route
B.3) Ingestion | Indirect route
B.4) Dermal route | Direct route
B.5) Dermal route | Indirect route
B.6) Infiltration | Groundwater recharge

Exposure sites

C.1) Zone | Lawns
C.1) Zone | Flowerbeds
C.1) Zone | Paths

Figure 7: Configuration tab displaying the risk components (hazards, exposure routes, exposure sites, activities, population at risk) (BASEFORM).

An overview table of the tool with its attributes and descriptions can be found under Annex A (section 12.1.6) whereas information on its navigation and primary functionalities is available in Annex B (section 13.6.1). The detailed page of the tool as in the WEM can be accessed via the following URL:https://mp.watereurope.eu/d/Product/67

5.6.2 Unique selling points / Added Value / Innovation

Unique selling points: This tool makes expert-knowledge available for risk managers and stakeholders responsible for non-potable water uses, guiding the user through the inherently complex context of public health and environmental risk guidelines and ensuring compatibility with the latest concepts in ISO standardization and EU regulation.

Added value: The tool is part of a sequence of four apps that jointly provide a complete ability to match water supply to demand, while managing water volume, cost, energy, nutrients and risk, with full GIS-compatible georeferenced capabilities. The apps are made available within the market-tested BASEFORM water analytics package, which is used by utilities around the world servicing over 25 million people. This tool adds full risk-assessment capabilities for water reuse management to the BASEFORM software universe.

Innovation: This tool implements a user-friendly risk assessment framework based on the latest ISO standards and EU Regulation, for water reuse in non-potable uses. It has been designed specifically to evaluate the candidate supply/demand combinations produced by tool #25, with which it works in tandem; it can also work as a stand-alone app.

5.6.3 Addressing water challenges, CE limitation and contributing to water-smartness

The tool contributes to address the key issues in water and resources management in Lisbon (described in section 8.1) by improving the water supply / demand management and promoting the safe use of reclaimed water as an alternative water source. Additionally, it assists in overcoming barriers related to CE practice increase by guiding risk managers and stakeholders responsible for non-potable water uses in the decision steps and by providing an easy to understand and communicate risk assessment method. While considering the barriers in adopting circular economy, tool #27 was developed to provide a user-friendly solution for carrying out the risk assessment, based on relevant ISO standards and EU Regulation, for water reuse in non-potable uses.

Relevant project's KPIs are increased water reuse (EI 3: treated ww used/water supplied and EI 4: treated ww used/total ww produced respectively) by enabling a safe water reuse in non-potable uses. With regard to specific objectives under water-smartness, tool #27 contributes in

- SO A - Ensuring water for all relevant uses by promoting safe water reuse,
- SO C - Boosting value creation around water (indirectly) via the promotion of reclaimed water use for irrigation urban green areas, including phosphorus valorisation.

5.6.4 Pre-existing background

BASEFORM software as described in https://baseform.com/np4/product/.

5.6.5 Developments and advancements within the project

The tool has been conceived and developed from scratch within the project. It builds upon and benefits from BASEFORM's pre-existing online client-server environment, input/output capabilities, file system and geo-referenced environment for water infrastructures, as well as its graphical user interface. The tool constitutes a new autonomous app within the BASEFORM environment, which may be deployed on its own as a stand-alone tool, or more likely in conjunction with tools #25 and #17 as per Figure 39.

5.6.6 Interoperability

Compatibility with FIWARE is available at read/write level only (through API and/or webservices), as mentioned above in Table 12.

5.6.7 Accessing tool and test data

The tool is part of the set of four tools developed by BASEFORM (#17, #24, #25, #27) for application in the Lisbon Living Lab, where it has been undergoing testing and application to the specific cases being explored in this LL. Sets of test data are available with the software. Real case application data pertaining to the Lisbon Living Lab are available from LNEC and CML.

Accredited users may access the tool at the URL below:

https://bwatersmart.baseform.com

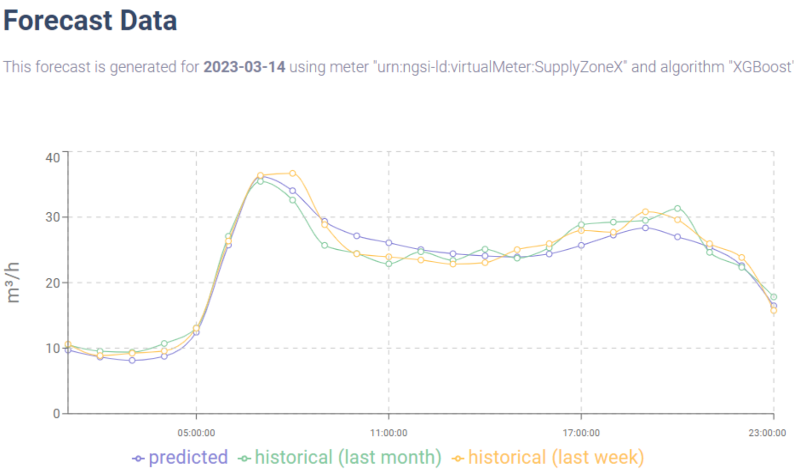
For the duration of the project, user credentials should be requested directly from BASEFORM through the following contact point: diogo.vitorino@baseform.com.

5.7 Short-term demand forecasting tool (#28)

5.7.1 Tool description and attributes

The tool generates water demand forecasts for the next (or current) day, which can be used to identify high peak loads in certain regions that require actions by the water utility. Figure 8 presents an example of forecast generation for a specific day, using the already trained model. This is particularly useful during times of drought when water availability is limited, and water distribution must be optimized. A good understanding of the amount of water needed in different districts helps to ensure security of supply, so that each region receives enough but not excessive water supply. The user can interact with the GUI to train machine learning models and use them to generate and visualize demand forecasts. Furthermore, the user can aggregate forecasts for multiple smart meters to achieve the desired spatial resolution. Furthermore, forecasts can be generated via a RESTful API which helps automate further data processing. The API also allows to integrate the tool in already existing platforms that use their own GUI.

Since the tool is driven by smart meter data, it has natural synergistic effects with smart meter technologies. In addition, services that provide historical or forecasted weather data can increase the quality of the results of the tool significantly.



Forecast Data

This forecast is generated for **2023-03-14** using meter "urn:ngsi-ld:virtualMeter:SupplyZoneX" and algorithm "XGBoost".

Figure 8: Forecast generation for a specific day, using the already trained model.

An overview table of the tool with its attributes and descriptions can be found under Annex A (section 12.1.7) whereas information on its navigation and primary functionalities is available in Annex B (section 13.7.1). The detailed page of the tool as in the WEM can be accessed via the following URL:

https://mp.watereurope.eu/d/Product/58 .

5.7.2 Unique selling points / Added Value / Innovation

Unique selling points: advanced forecasting on a high time resolution with an elevated level of accuracy.

Added value: short-term demand forecasts based on smart meter data.

Innovation: machine learning based forecasting, usable based on smart meter data or virtual meter data.

5.7.3 Addressing water challenges, CE limitation and contributing to water-smartness

With regard to key issues in water and resources management in the LL site, the Short-term demand forecasting tool (#28) addresses the rising issues of peak loads within the water supply network of OOWV. The impact of the tool related to the barriers to an improved CE and increase of water reuse practices is only implicit in the way the tool can help to increase the public awareness for CE approaches as necessary measures to tackle the issues of increasing household water demands.

The expected impacts that can provide insights regarding tool’s application are related to decrease in use of freshwater resources and improved water use efficiency. Specifically:

- EI 1 (freshwater abstracted / water supplied): by helping to reduce the use of freshwater resources by replacing freshwater usage by other resources, such as reclaimed water, rainwater, or other untapped water resources.
- EI 2 (water supplied / population served): by helping to lower household water demands by raising awareness on potential inefficiencies in water usage.

As for the strategic objectives towards water smartness, the tool targets to SO E (Engaging citizens and actors across sectors in continuous co-learning and innovation), the results of which are also used in the communication with the public in the city of Lohne.

5.7.4 Pre-existing background

There is no pre-existing background, the tool was developed within the scope of the BWS project.

5.7.5 Developments and advancements within the project

A backend component was developed as a microservice to create models and generate 24h-forecasts. It assumes the availability of pre-processed, hourly smart meter data inside a MongoDB database within the same network. If smart meter data is lacking, users can make use of data sets that were collected for training of the models.

The microservice’s RESTful API was documented with OpenAPI and designed to integrate easily with i) the frontend that is used by the water utility and ii) the Orion context broker that provides an interface to external applications. The frontend was developed based on user stories associated with the different REST endpoints. Similarly, the interaction with the FIWARE context broker was finalized and documented.

A concept was developed that enables the creation of models / forecasts for arbitrary spatial resolutions. Smart meters that are installed in the real world and measure water consumption are referred to as "physical meter". Additionally, the idea of a "virtual meter" was introduced to group meters together (e.g., a supply zone) in a hierarchical manner, as shown in the picture below (Figure 9). The user can create virtual meters for any area according to their specific needs and treat them identically to physical meters, i.e., train models for them and create forecasts.

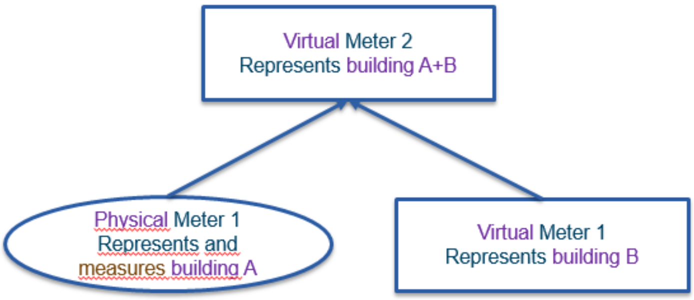


Figure 9: Data models that are needed to represent and work with virtual meters are iteratively refined to fulfil the requirements that become clearer with growing maturity of the tool.

Suitable algorithms from different backgrounds were selected for the tool, the implementations of which are provided by the open-source library Darts. The water utility might prefer statistical approaches that are easy to understand and thus perceived as more trustworthy. Specifically, the Prophet algorithm is very suitable for data with strong seasonality and very fast to train. XGBoost is a tree-based approach that resembles more classical machine learning and is able to learn very complex patterns from relatively small datasets while doing so with low training times. On the other hand, the provided deep learning-based approaches require much more training time, although their potential is generally higher when more training data is available. Depending on the specific context, the water utility may prefer one approach over the others, although XGBoost is considered to be a good default.

A hyperparameter optimization algorithm "Bayesian optimization with Hyperband" (BOHB) was integrated, using the open-source Ray library to automatically select suitable parameters and reduce the amount of machine learning expertise required by the user.

A weather agent interface was created that allows the water utility to provide data that should be used for training and forecast creation. This additional data would typically constitute weather data, although the interface is general enough to allow for any information that could possibly improve the predictions.

A synthetic dataset was created as part of the documentation that shows the form of the expected data and can be used to test the tool straight away, without connecting the water utility's own data streams right away.

5.7.6 Interoperability

The tool currently aims at interoperability maturity level 3 (refer to D3.1 "BWS, FIWARE based interoperability framework", section 2.3, Figure 6, p. 25.), as it uses NGSI compatible data models. Where possible, existing smart data models are used, e.g., for machine learning models. The solution is FIWARE-ready, as the tool can communicate with the Orion context broker and make parts of the functionality available through it to external apps. If desired, these external apps can read already generated forecasts, but cannot define virtual meters or train models or generate forecasts themselves. This is important for ensuring data consistency and to avoid large computational demands on the water utility's servers because of external services.

Beyond that, we recommend the use of a FIWARE IoT agent like Draco to store the smart meter data in the database so that it can be used by the tool. However, the choice to use such components has to be made and implemented by the water utility.

5.7.7 Accessing tool and test data

Users may access the backend and frontend of the tool via the GitHub repository by following the links:

https://github.com/iwwtech/bws-short-term-forecasting

https://github.com/iwwtech/bws-short-term-forecasting-ui

Further support and guidance can be provided by Marcel Juschak (ma.juschak@iww-online.de).

5.8 SuTRa (#31)

5.8.1 Tool description and attributes

SuTRa, which is developed by KWR Water Research Institute, is a Python package that calculates the advective removal of microbial organisms (also called 'pathogens') from source to endpoint. Figure 10 presents an example of the removal of pathogens from groundwater following infiltration from the ground surface during transport to a well.

Its main features are the following:

- Includes database of removal parameters for microbial organisms,
- Calculates the removal and concentration of the microbial organism over distance and with time.

SuTRa calculates the subsurface removal of microbial organisms over a distance and with time using an analytical approach. The aim is to allow for a quick assessment of subsurface removal of microbial organisms for a growing selection of species. A database was added, starting with plant pathogens 'solani' (*Dickeya solani*), 'carotovorum' (*Pectobacterium* *carotovorum*), and ‘solanacearum’ (*Ralstonia solanacearum*). Additional species will be added once more data become available.

Temperature is considered in the computation of the Boltzmann diffusion coefficient (DBM) (please refer to section 13.8.1. Aquifer types considered are oxic and anoxic aquifers. This main redox zonation is known to have influence on the inactivation and filtration of micro-organisms. Therefore, the user can select inactivation and filtration parameters for both oxic and anoxic conditions. Aquifer conditions considered is the flow velocity (v) (see equation in section 13.8.1). The soil property considered is the grains size. The median grain size is included in the computation of katt as d_c’ (section 13.8.1). Other soil properties that might also have an influence on (such as clay fraction) are ignored since there is no agreed mathematical method to incorporate these into a transport model of pathogens.

The extension of the database to other viruses is anticipated in 2024.

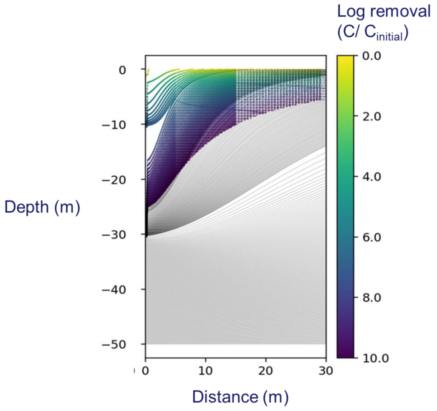


Figure 10: Example of the removal of pathogens from groundwater following infiltration from the ground surface during transport to a well on the left side of the image. Note that concentration reduction is depicted on a 10log scale.

An overview table of the tool with its attributes and descriptions can be found under Annex A (section12.1.8) whereas information on its navigation and primary functionalities is available in Annex B (section 13.8.2). Additional technical information on the developments and advancements made within the project are available in Annex B (section 13.8.1). Information on the potential of using SuTRa outside of the project is presented in Annex C (14.2). The detailed page of the tool as in the WEM can be accessed via the following URL:

https://mp.watereurope.eu/d/Product/59 .

5.8.2 Unique selling points / Added Value / Innovation

Unique selling points: The USP of the tool is to provide a simple method to estimate microbial risks of Managed Aquifer Recharge (MAR) systems.

Added value: The added value lies in that it thereby provides the user with the ability to optimize the design of the MAR system with respect to hygiene (human health) aspects.

5.8.3 Addressing water challenges, CE limitation and contributing to water-smartness

The SuTRa tool builds on microbial risk assessment to specifically model (plant) pathogen removal during subsurface passage of managed aquifer recharge and infiltration schemes. Therefore, the direct aim of the tool is to overcome water quality challenges related to microbial pollution. An indirect aim is to enable Managed Aquifer Recharge, thus overcoming water availability challenges in agriculture. Managed Aquifer Recharge (MAR) is a very circular technology, aimed at reuse of water. One of the barriers to MAR in agriculture that is usually highlighted by the farmers, is perceived risks caused by pathogens in infiltrated water. The tool aims to overcome these barriers.

Tools impact can be estimated via EI 1 - Decrease in use of water resources (freshwater abstracted / water supplied) by stimulating the application of MAR. Application of MAR replenishes the aquifer and can thus contribute to a net decrease of water abstraction. The influence on the abstraction of water depends on the reference situation. In case there is already irrigation taking place with abstracted natural groundwater, then the application of MAR will directly influence the KPI EI 1. In case there is no abstraction of groundwater, and the water use is “new” and facilitated by MAR, then there may be zero net effect. SuTRa tool is also linked with water reuse indicators i.e., EI 3 (treated ww used/water supplied) and EI 4 (treated ww used/total ww produced respectively) since it can be deployed to design use of treated wastewater for irrigation. The respective KPIs are influenced in the event that MAR is implemented with treated wastewater.

Since tool #31 contributes in MAR implementation which is a technology that increases availability of water in dry periods (by storage of water in periods with excess water), it contributes to SO A - Ensuring water for all relevant uses.

5.8.4 Pre-existing background

The code is based on the equations given in chapter 6.7 of BTO 2012.015 “*Gezondheidsrisico’s van fecale verontreiniging*” [in Dutch], pp 71-74. The tool has been developed within the BWS project and it is also co-financed by the BTO Joint Research Programme of the Dutch and Flemish Water Utilities.

The computations that the tool makes are incidentally performed on a project-by-project basis mainly based on information on transport and removal of human pathogens.

5.8.5 Developments and advancements within the project

The advancements made within the project with regard to the tool are:

- Collection of scientific data on plant pathogens.
- Derivation of typical transport and removal pathogens from these data.
- Development of a pipeline (Python tool) to facilitate fast and efficient computations of plant pathogen concentration in MAR systems.

Additional technical details on the developments made in within the project are provided in section 13.8.1

5.8.6 Interoperability

The input and output data, as well as the interoperability options offered by the tool are listed in the below table (Table 4).

Table 4: Input data, output data and interoperability of SuTRa

Input data
• Transport properties: Travel distance, Travel time, • Aquifer properties: Redox zone, grain size (d50), • Pathogen type: name (we will start with a limited number of indicator organisms), • Input concentration
Output data
• Pathogen properties: size, stickiness, etc. • Output concentration
Interoperability options
• Open-source python package allows for coupling with existing tools (e.g., UWOT). • The Python package can be downloaded to a PC from "https://pypi.org/project/sutra/" or installed directly using the package installer for Python pip. • The database of pathogen properties is part of the package and is therefore also downloaded during installation. Consequently, once installed, there is no need for an external connection to import the pathogen database. • SuTRa is compatible with any operating system that uses Python 3.6 or higher. • Input data are provided in either numeric ("float") or textual ("string") format, which are used as arguments in Python functions, as described in the online manual https://sutra.readthedocs.io/en/latest/tutorial.html. • Output is generated by functions and also consists of numeric ("float") and texts ("string") depending on what function the user enters. The user can either retrieve (echo) the input data to check it or analyse the results, such as the output concentration. • A list of the input-requirements (data format) and functions can be found in the manual at https://sutra.readthedocs.io/en/latest/tutorial.html.

5.8.7 Accessing tool and test data

The tool is accessible through the following URL where users may find instructions on the installation process: https://pypi.org/project/sutra/.

Documentation and additional information may be found at https://sutra.readthedocs.io/en/latest/ or/and provided by Martin van der Schans (Martin.van.der.schans@kwrwater.nl).

6 Tools and Methods for LL Flanders

6.1 Key WS challenges, ambition and case study description

Flanders is a region with high water demand due to high population density and high industrial and agricultural activity. The region faces increasing limitations in freshwater availability and decreasing groundwater levels. The deterioration of surface water quality during dry summers has negative consequences for drinking water production. At the Water Production Centre (WPC) De Blankaart water intake is limited during the dry summer months as the water quality of the river is too low to be suitable for treatment in the current facility. Next to freshwater limitation, there is also an increasing risk of flooding during high intensity precipitation events, especially in urban areas. These issues are expected to increase in frequency and duration under climate change.

Currently, there are strong initiatives in Flanders to improve the robustness of the water system with the aim of taking significant steps towards implementation and upscaling of circular solutions for developing a smart and sustainable water system within the next 3-5 years. The development of a stronger water management and optimal use of the available water resources is encouraged and supported by the current Flemish government for example through the Blue Deal programme. The water-smart opportunities in the Flanders LL are to establish regional circularity in the water system by using alternative water resources for drinking water supply, and to secure irrigation by interaction with the urban reuse cycle.

In BWS, smart solutions are developed for alternative circular water sources for drinking water and agriculture. The main challenges we are addressing in this project are firstly, the need for technologies for water reuse and practical testing of their operation at demonstration sites to gain a better understanding of purification needs and the efficiency of these approaches. Secondly, better understanding is needed on microbial risk assessment methods to help determine the design requirements of purification and subsurface passage systems. Furthermore, we aim to develop better connections between wastewater utilities, drinking water utilities, municipalities, and farmers to help identify potential circularities. Within the water system, everything is connected. Interventions in the water system, such as the ones investigated within this project, can affect and be affected by other system components. An understanding is needed of the potential contribution and impact of local circular solutions on the water system at a more regional level to better understand and identify potential trade-offs and benefits and to help decision makers make choices and develop strategies.

6.2 Application of tools and methods

6.2.1 Selected tools and technologies of pilots

There are two parts to the technology development in BWS LL Flanders. The first aims to improve the robustness of the drinking water supply by expanding drinking water treatment capacity with an advanced Closed Circuit Reverse Osmosis (CCRO) system that will allow the WPC to take in low-quality surface water (aquifer storage recovery - technology #2). In parallel, the potential for effluent reuse for drinking water is explored as an alternative or supplementing water source (effluent reuse for drinking water production - technology #3). The aim of this demonstration is to compare these solutions and analyse what their relative benefits and trade-offs are or how they could enhance each other. In the second demonstration, a system is developed for stormwater reuse for agriculture (urban stormwater reuse for agriculture - technology #5). A stormwater retention basin is built by the city of Mechelen to prevent flooding of urban areas. Within BWS a system is developed to make the water from the basin available for subirrigation at nearby fields. The Stormwater Reuse Management system (tool #21) is used to control the outflow from the basin and the water distribution for irrigation to optimize the functioning of the basin for flood prevention and availability of water for irrigation during dry periods.

There is a need to place these technological demonstrations in a broader context to assess how they can contribute to a more robust and smarter water system at a regional level. The regional analysis and UWOT (tool #22) were used to assess the demonstrations in their regional context with regard to their impact on water availability and resilience of the water system. Next to that, the potential to include alternative water sources while minimizing negative impact on local nature and environment in order to design a sustainable water supply for the future was analysed. The regional analysis was used to identify regional effects of changes in water supply and demand. The results can be used to start collaborations and can help communication between stakeholders in the region.

A critical success factor for water reuse is the assessment and control of microbial safety risks. The QMRA+ (tool #26) is developed to support the design and assess the required treatment needed for water reuse. QMRA+ is a valuable tool for quantitative microbial risk assessment that can be used to assess existing purification systems and to help determine the design requirements of purification systems for e.g., alternative water sources with regards to microbial safety requirements. Within the Woumen case, QMRA+ was used to help design the effluent reuse demonstration system by comparing the safety of various treatment options and point suppletion of the existing drinking water system. The SuTRa tool builds on microbial risk assessment to specifically model (plant) pathogen removal during subsurface passage of managed aquifer recharge and infiltration schemes. In the Mechelen case this helped to determine the minimum design parameters and residence time required for pathogen removal. The outputs from SuTRa may support the regional analysis or similar studies in related projects by providing input parameters on subsurface passage if these are included in the conceptual design.

The LL Flanders technologies and tools and their link to the living lab challenge and strategic objectives are presented in Figure 11. The high-level interactions among tools and the pilots are depicted in Figure 12. In Annex E, a summary table of the LL is provided (Section 16.1).

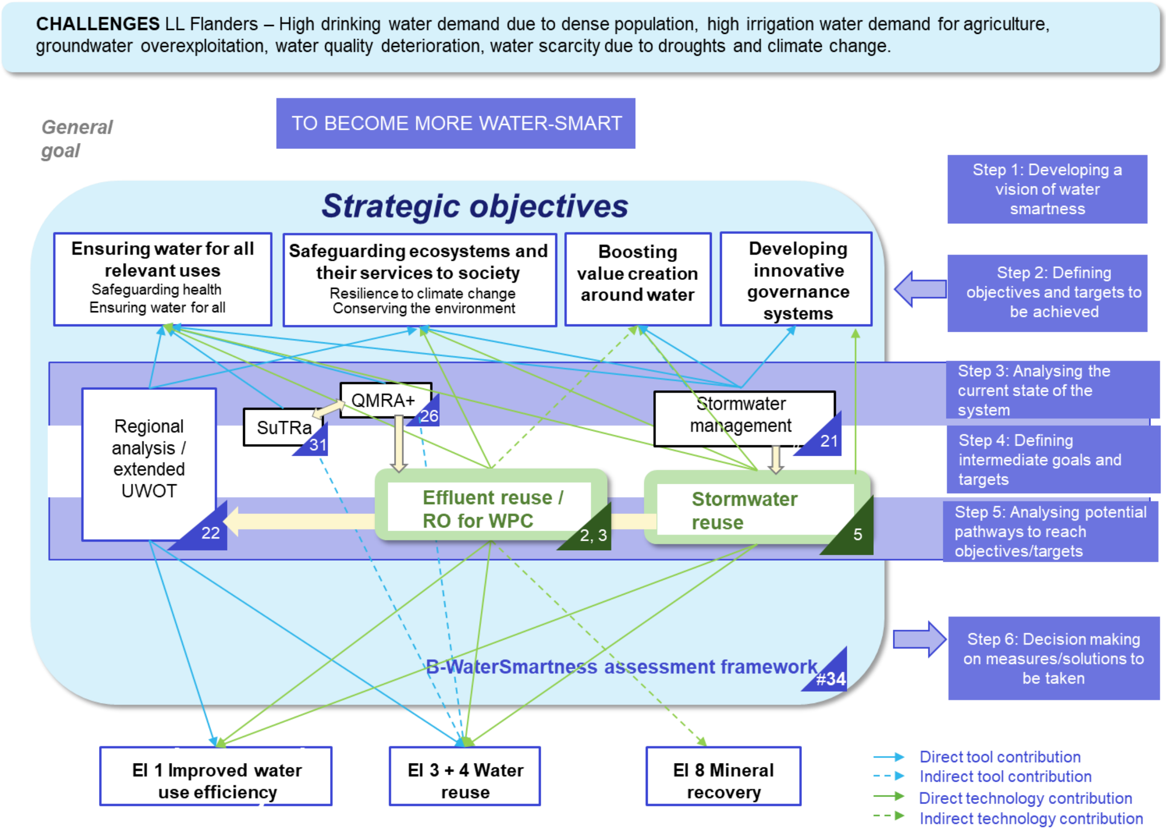


Figure 11: The LL Flanders technologies and tools and their link to the living lab challenge and strategic objectives.

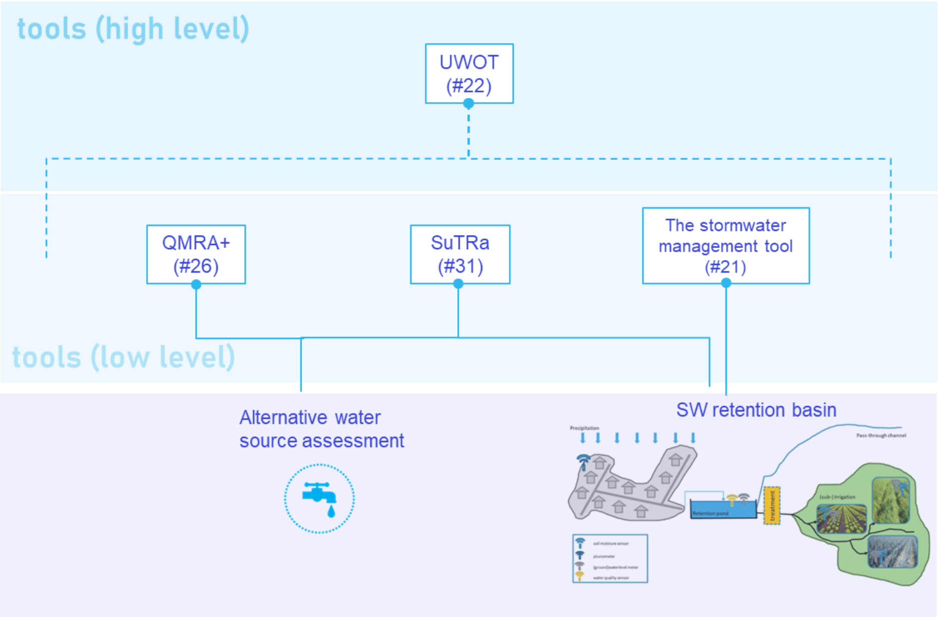


Figure 12: Tool and pilot high-level interaction.

6.2.2 Integrative use of tools, pilot interaction and data flows

With regard to UWOT and the Regional Analysis, both methods involve water systems analysis and proceed by designing model architectures with multiple interacting components at a regional level. For the tools to be used in an integrated fashion, thus, it makes sense to pool resources and steps in the (a) conceptualisation of regional modelling cases within the Flanders LL, and (b) the data inventorisation, collection and preparation process. Both stages are done in collaboration with the Flanders LL regional stakeholders, as (i) their input and concerns are valuable in identifying regional issues and design smart water applications with practical interest, and (ii) regional data is needed which is only accessible at the utility or municipal level and can be requested from selected stakeholders. Figure 13 below depicts the conceptualization process chain (incl. data flows) for the UWOT and Regional Analysis models.

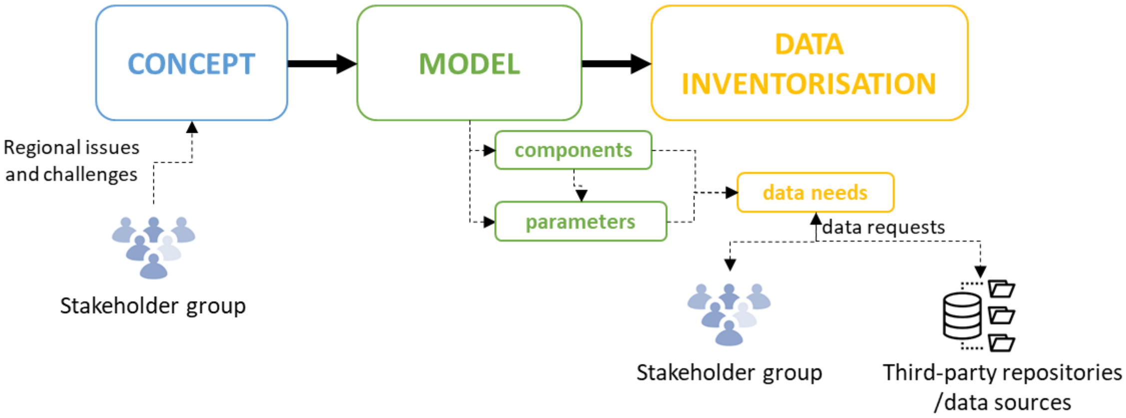
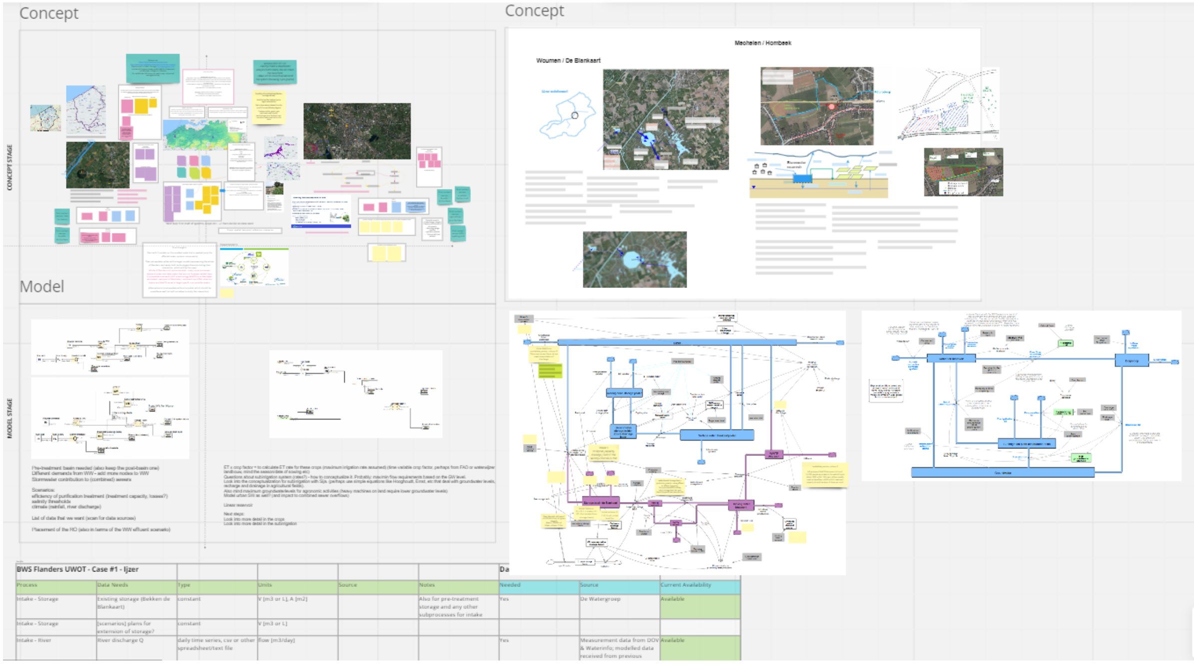


Figure 13: Conceptualization process chain (incl. data flows) for the UWOT and Regional Analysis models.

To align workflows, the creation of both UWOT and Regional Analysis models was based on a common conceptualization process chain that was performed online using “miro” (Figure 14), a visual collaboration platform for cross-functional teamwork (https://miro.com/app/dashboard/). The process chain included the following stages:

1. The concept stage, where, following a series of group meetings with regional Flanders stakeholders, the main problems of the area were discussed, and regional applications were outlined. This creative process resulted in multiple ideas on regional issues, which were then evaluated against model characteristics and capabilities. The goal was to decide which regional applications have high interest and are feasible within the modelling domain of UWOT and the regional analysis.
2. The model stage, where initial model topologies were created from selected ideas in stage (1). This led to model files for UWOT and the Regional Analysis, where parameters were outlined, and data requirements to run the models were determined.
3. The data inventorisation and request stage, where data needs that follow from stage (2) were inventorised and tabulated. Moreover, meetings with selected regional stakeholders that can be data providers were held in order to identify potential data sources and the overall data availability. At this stage, possible open-access data sources were also discussed (e.g., regional hydrometeorological databases, data repositories, census data etc.).



Pre-treatment basin needed (also keep the post-basin one)
Different demands from WW - add more nodes to WW
Stormwater contribution to (combined) sewers

Scenarios:
efficiency of purification treatment (treatment capacity, losses?)
salinity thresholds
climate (rainfall, river discharge)

List of data that we want (scan for data sources)

Placement of the RO (also in terms of the WW effluent scenario)

Linear reservoir

Next steps:
Look into more detail in the crops
Look into more detail in the subirrigation

BWS Flanders UWOT - Case #1 - Ijzer						Da		
Process	Data Needs	Type	Units	Source	Notes	Needed	Source	Current Availability
Intake - Storage	Existing storage (Bekken de Blankaart)	constant	V [m3 or L], A [m2]		Also for pre-treatment storage and any other subprocesses for intake	Yes	De Watergroep	Available
Intake - Storage	[scenarios] plans for extension of storage?	constant	V [m3 or L]					
Intake - River	River discharge Q	daily time series, csv or other spreadsheet/text file	flow [m3/day]			Yes	Measurement data from DOV & Waterinfo; modelled data received from previous	Available

Figure 14: Snapshot of the miro working environment (canvas) for the conceptualisation and data flows of the UWOT/Regional Analysis tools.

QMRA+ was used to assess the microbial safety using quantitative microbial risk assessment. It was used in BWS LL Flanders in relation to the technology development (Task 2.3.1) on potential effluent reuse for drinking water. The tool was used to help determine the minimum design requirements of the purification system with regards to microbial safety by comparing various treatment schemes. Next to supporting the design of the technical solutions, QMRA+ and SuTRa can also help inform the water system modelling done with UWOT and the Regional Analysis tool as they can give an indication of the microbial water quality. UWOT and the Regional Analysis tool can only model water quantities.

However, considering water quality and safety requirements is essential for successful implementation of water reuse. SuTRa can be used to help determine the minimum transport time and/or distance for subsurface infiltration and storage solutions required to remove pathogens. These design parameters inform the boundary conditions for water system modelling.

The Stormwater Reuse Management System (tool #21) which is reported in D3.4, is integrated with the technology development of the stormwater management system (Task 2.3.2). The tool is intended to be used to control the basin inlet and outlet and distribute irrigation water to fields based on water availability and demand. The tool is based on the specific design parameters and local situation of the stormwater management system and has a local scale. The output from the tool can be used to inform and calibrate the modelling in UWOT and the Regional Analysis Tool with regards to the stormwater reuse case. As these tools are strongly integrated in the smart-technology development, the discussion below is focused on UWOT and the regional analysis model.

More detailed information on the preprocessing stage and setup process of tools is provided in Annex D (Section 15.1).

6.2.3 Results

6.2.3.1UWOT results

Woumen

For the case of Woumen, UWOT is used as a stress-testing platform to explore if the current system implementation can satisfy present-day demands. Moreover, stress-testing is extended to predict how vulnerable the current system is towards changes in factors such as the river intake salinity and regional demand, as well as to explore if water-smart technologies can alleviate these (potential) vulnerabilities. To do this, UWOT requires a water supply strategy (defined by the drinking water production rules seen in Table 20), as well as an assumption on the regional demands that are served in the Woumen area. As demand data are not available from any source (third-party sources or stakeholder groups), the following alternative (i.e., mutually exclusive) assumptions are made on the demand side to generate the corresponding demand time series which are required as UWOT input:

- A **variable demand** assumption, which assumes that a similar variable quantity to the observed - and available, as input - WWTP effluent is requested from clients.
- A **constant demand** assumption, which assumes that a set daily quantity D_s of water (in m^3/day) is requested by regional clients.

Both assumptions (variable and constant) are employed in the stress-testing analysis. Stress-testing is based on using UWOT to perform simulations at the daily timescale in the system and its components, thus measuring how each component behaves in terms of flow variability, overflows, time points with low or empty storage levels etc. With a time window from 2006 to the end of 2020, a total of 5479 daily timesteps are used per simulation, with UWOT returning time series of flows and water storage for each simulation. Once these time series are returned by the model, the output data is post-processed to assess the percentage of time the intake basin was under stress (i.e., meaning the volume of available drinking water being alarmingly low) or completely empty (i.e., meaning no availability of drinking water to satisfy demands), creating results in the form of ‘stress curves’, visually depicting the % of simulated time that the system becomes increasingly empty, i.e., failing to provide service. The results (Figure 15) demonstrate that the basin continues to operate well under demands in the range of 10000-25000 m^3/day, but begins to experience significantly more stress and, eventually, failure for larger values. The effects of increased salinity in the river Ijzer source are also explored for the baseline; the results (Figure 15) demonstrate that, while for low water demand values, the drinking water system can mitigate a worsening salinity future without significant loss of reliability or failure rates, if water demand requests become significant, then any worsening salinity future will translate to significant stress levels and failure rates (>10% for significant (>50%) salinity increase). This means that the drinking water system is particularly prone to the combination of worsening salinity levels paired with increased demand needs.

Besides highlighting the vulnerabilities of the current state of the drinking water production system, the stress-testing analysis assesses the efficiency of two water-smart technologies for Woumen: (a) the reuse of wastewater (WW) effluent from the Woumen WW treatment plant (WWTP), assuming a steady reuse rate Qr (in m3/day), (b) the installation of a Closed-Circuit Reverse Osmosis (CCRO) unit that results in an increased salinity threshold S_{thr} compared to the baseline (reference) case. The results (Figure 15) show that the introduction of WW reuse improves the reliability of the DW production unit considerably, particularly for the medium and heavy demand cases of 25000 m^3/day and 35000 m^3/day. Concerning the measure of CCRO, the introduction of added treatment with the CCRO system improves the reliability of the drinking water production system under regular regional demands (15000 – 25000 m3/day) but becomes less efficient under high demand scenarios. Moreover, higher threshold scenarios prove to be less efficient, meaning that an added investment in large CCRO capacities has to be significant (i.e., raising S_{thr} considerably higher than the 280-480 mg/L zone) to be translated to improved reliability to the system.

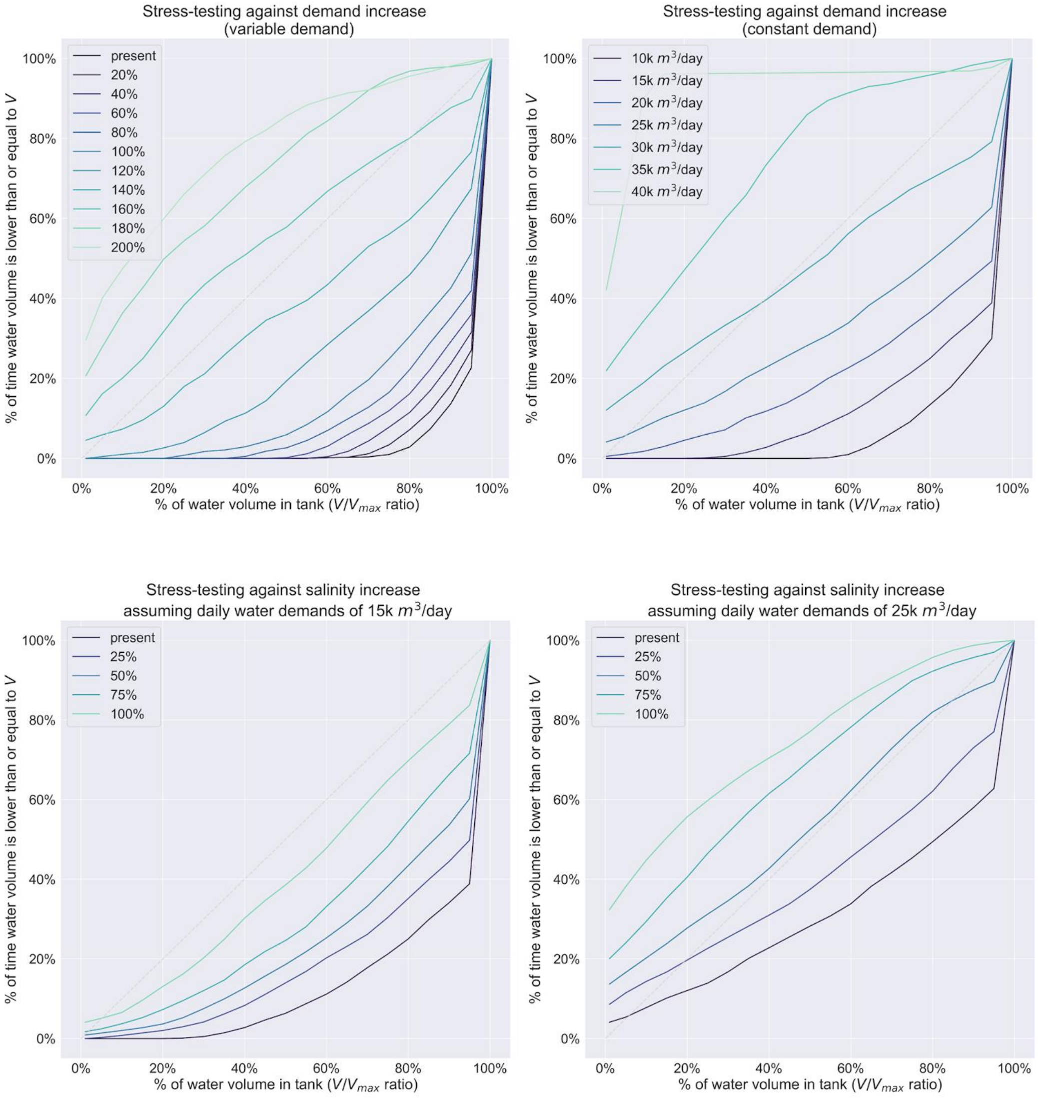


Figure 15: UWOT stress-testing of Woumen against % increase in regional water demands (upper graphs), as well as river salinity (lower graphs).

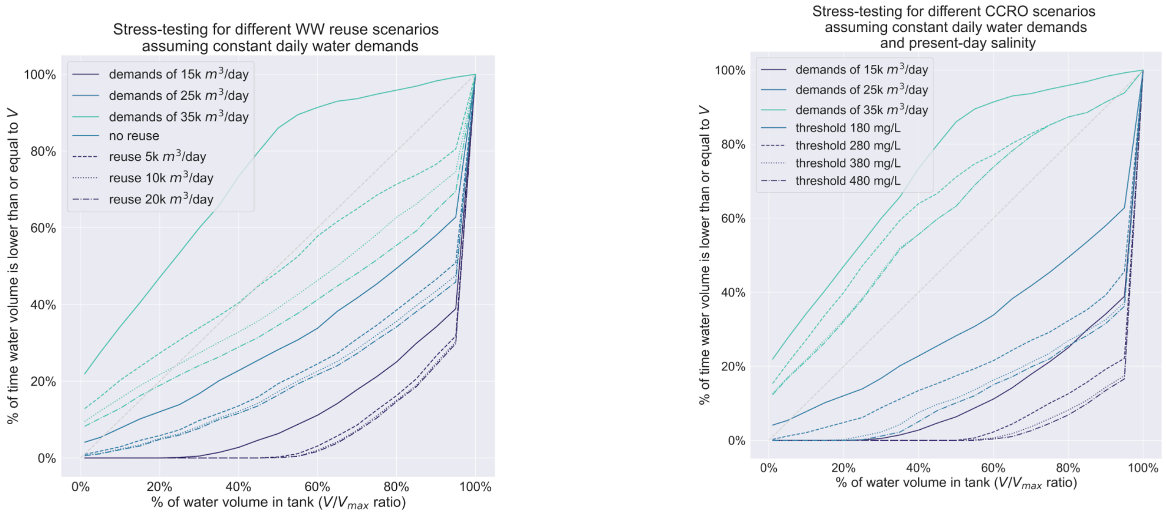


Figure 16: UWOT stress-testing of Woumen for different WW reuse scenarios (left panel) and for different CCRO scenarios (right panel).

Mechelen

UWOT is used to simulate the daily response of the retention basin for 14 years. The results (shown in detail in the Appendix) demonstrate that the retention basin has periods of both full and empty storage, which appears to be seasonal and is affected by (a) the variability in crop evapotranspiration demands, which are higher during summer, warm months, and (b) the availability of incoming water in terms of runoff, indicating that operational rules are needed to maximize the efficiency of the basin. Additionally, the effect of introducing larger urban areas upstream is explored in Figure 17. In this analysis, the retention basin keeps the same design but the serviced urban area upstream (i.e., the area whose discharge is led to the retention basin) grows by 20%, 40% and 60% respectively. The ratio of pervious and impervious areas remains the same, as the household types in the area are uniform. Along with this increase, the pretreatment discharge capacity to the area is increased from 500 m3/day to 600, 800 and 1000 m3/day, respectively, to accommodate larger runoff influxes. The results show that the introduction of larger inflows has a beneficial effect on crop demands, leading to lower deficits; however, it comes with a trade-off to the flood-proofing capacity of the retention basin, as the basin remains fuller across multiple months and has a loss in its runoff reduction capacity (around 2%-25%, depending on the month).

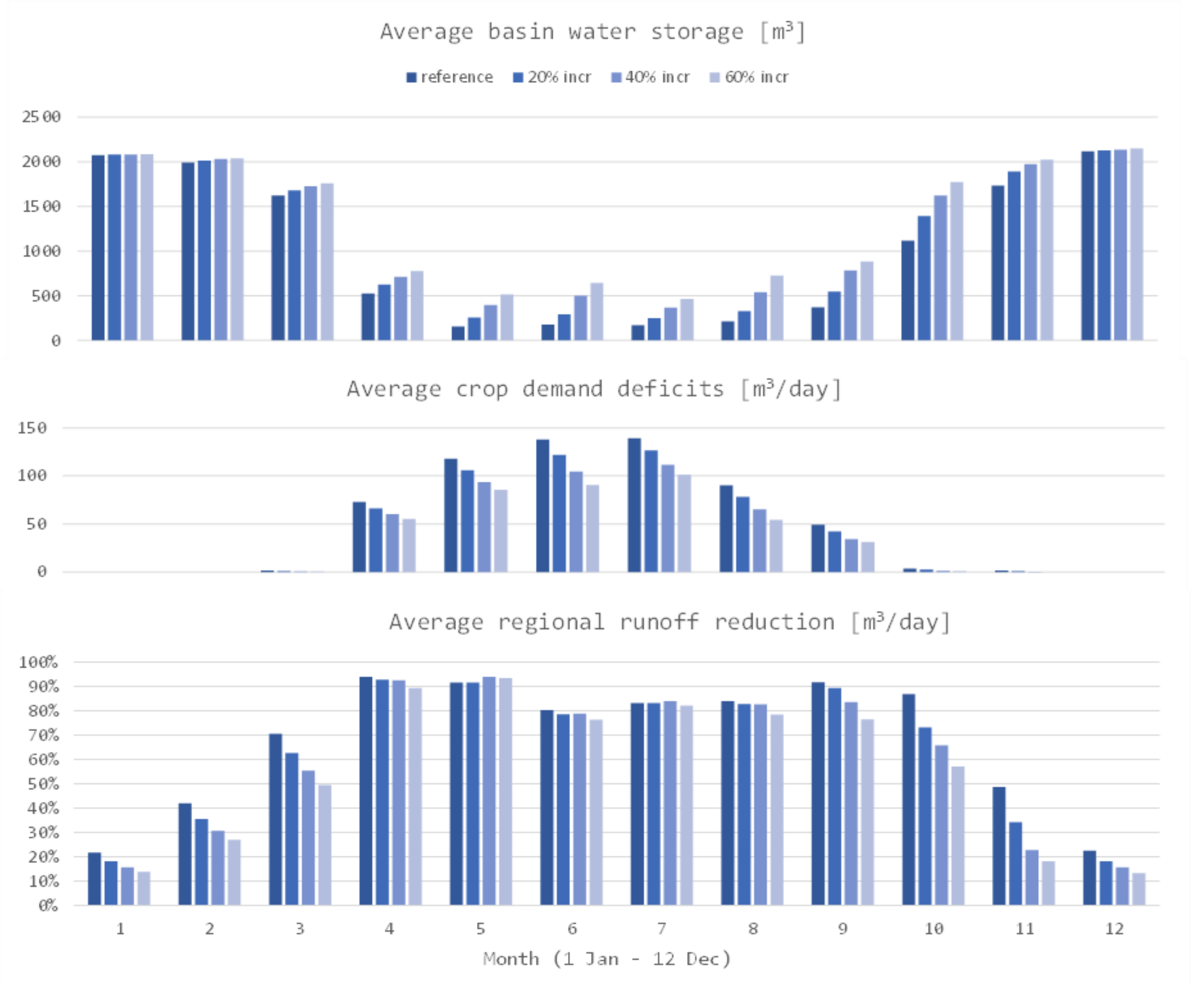


Figure 17: Results in monthly variability in the Mechelen retention basin with the introduction of larger harvesting areas (20% - 60% increase in serviced urban areas).

Detailed presentation of results from the application of UWOT is provided in Annex D (section 15.1.3).

6.2.3.2Regional analysis results

Woumen

The proposed measures to make the drinking water production more robust lead to varying beneficial effects. In all scenarios, the total amount of drinking water produced increased when compared to the reference situation (Figure 18). However, actual production was still lower than the desired production (fraction production lower than 1) in many summers during the time period. In total over the entire time period, the desired drinking water production was reached 70.4% of the time in the reference period, for scenario 1, 2 and 3 this percentage increased to respectively 72.3%, 77.4% and 79.1%. Figure 19, showing the total water intake per year for the reference and for all different technology implementation scenarios, demonstrates that the largest increase in drinking water production is found when both measures are implemented (scenario 3), while reuse of effluent only (scenario 1) has the lowest increase in production. Installation of the CCRO system only (scenario 2) led to higher drinking water production compared to the reference situation and scenario 1, but less production compared to scenario 3. When both measures are implemented (scenario 3), the total drinking water production originates from three different water sources: effluent, water treated in the existing treatment system, water treated with the CCRO system; this option leads to the highest system robustness.

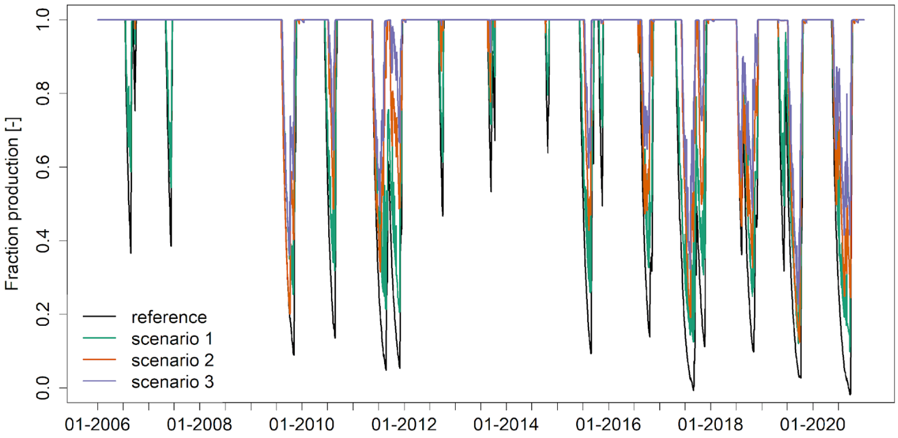


Figure 18: Fraction of the desired drinking water production for the reference situation and different scenarios for complete time series.

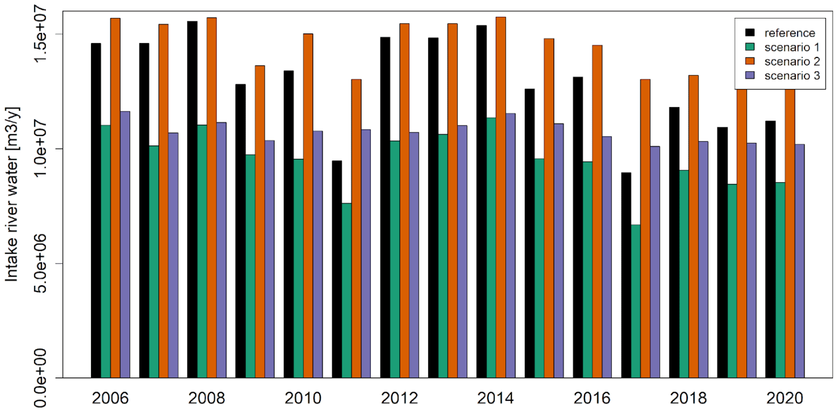


Figure 19: Total water intake per year from the IJzer for the reference and the different scenarios.

Mechelen

The implementation of a stormwater basin leads to a strong reduction in runoff to the Oude Tantelaerloop, especially when combined with subirrigation (scenario 2, see also Figure 20). For the complete period the average runoff to the stream was 71 582 m^3/y for the situation without retention basin, 57 888 m^3/y for scenario 1 and 5 632 m^3/y for scenario 2. Peaks in daily runoff were also reduced in the scenarios: for scenario 1, we observe a marginal decrease in peak runoff (by ~1%), as the basin was filled to capacity most of the time due to the lack of management rules in the regional analysis. For scenario 2, peak runoff decrease is more significant (22.2%), as more storage became available in the basin due to subirrigation. This indicates that proper management of the retention basin and/or use of the stored water is needed to prevent flooding. Meanwhile, the increase in groundwater levels had a positive effect on the crops. Subirrigation led to a higher actual evapotranspiration (an index of the effect of crops, as more evapotranspiration indicates better crop growth and thus higher yields) during the entire period (Figure 21). The average yearly evapotranspiration increased from 351 mm/y in scenario 1 to 406 mm/y in scenario 2. In both scenarios, the average potential evapotranspiration of 496 mm/y was not reached due to water limitations. A clear difference in the effect of subirrigation between the year can be also observed, indicating significant annual variability.

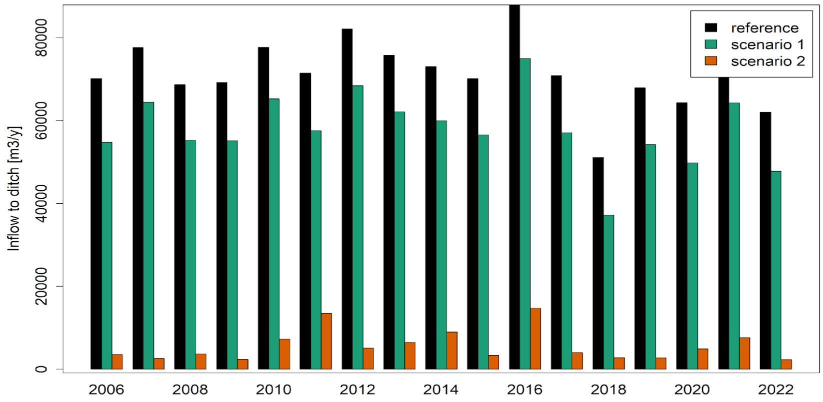


Figure 20: Runoff from precipitation to the Oude Tantelaerloop for the reference situation and after implementation of the retention basin (scenario 1 and 2).

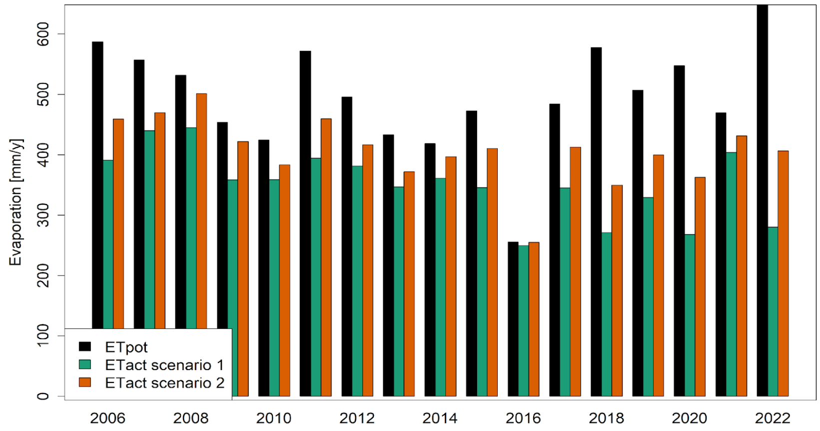


Figure 21: Yearly potential evapotranspiration based on observations (input) and yearly actual evapotranspiration for the different scenarios (scenario 1 is equal to reference situation).

6.2.3.3QMRA+ results

The QMRA+ tool was used to assess the safety various options for combinations of treatment processes shown in Table 5. Results from the application of QMRA+ tool showed that the current source, the IJzer river, contains significant fecal contamination. Therefore, the post-treatment of effluent for supply to the raw water reservoir can be relatively limited. This wouldn't affect the current contamination level in the reservoir. In most cases the post-treated effluent contained fewer pathogens than the current source. One example of QMRA+ output is shown in Figure 22. The boxplots indicate the variability and uncertainty about the annual risk of infection from treated effluent. This demonstrates that the predicted risk is several orders of magnitude below the health target of 1 infection per 10,000 persons per year as indicated by the red line.

Although chemical risk assessment wasn't part of the study, a typical post treatment system for effluent was evaluated for the effect on microbial drinking water quality. Such an extensive post-treatment would (in theory) be sufficient to directly produce safe drinking water, according to the QMRA+ tool. This demonstrates that integrating microbial and chemical risk assessments is needed to find safe and efficient solutions for effluent reuse.

Limitations of the study were mostly due to the lack of site-specific data on actual pathogen concentrations in the various sources (current river IJzer or effluent) and data on actual treatment performance for pathogen removal and inactivation in the current drinking water system. Obtaining this data would require a long-term monitoring program for pathogens which is costly and therefore not feasible within the constraints of the project. Pilot research to assess the efficacy of post-treatment options for effluent would provide more adequate, site-specific, data for the risk assessment.

Table 5: Studied treatment and supplement options and the assessed risk according to the QMRA+ tool expressed as log of infection per person per year. Values not meeting the Dutch guideline value of 4 are highlighted in red.

	Scenario	**UF**	**RO**	**RO50%**	**NF**	**UV**	**GAC**	**CONV**	**iCl2**	**RSF**	**GAC**	**Cl2**	**DAF**	**DRSF**	**AOP**	**UV**	**RO**	**Infectie**		**4**	**DALY**		**6**
																		B	V	P	B	V	P
1	Effluent huidig- Drinkwater huidig							X	X	X	X	X						2,6	0,7	0,1	5,4	2,8	2,9
2	Effluent optie1-Drinkwater huidig	X	X			X	X	X	X	X	X	X						19	14	14	22	16	17
2h	Effluent optie UF-UV - Drinkwater huidig	X	0			X	X	X	X	X	X	X						10	6,8	7	13	8,9	9,9
3h	Effluent optie UV - Drinkwater huidig	O		0		X	X	X	X	X	X	X						7,1	4,8	3	10	7	5,9
16	IJzer-Blankaart-Drinkwater huidig							X	X	X	X	X						4,1	1,3	3,2	7	3,4	6,2
17	IJzer-Blankaart-Drinkwater nieuw										2X	X	X	X	X	X		6,4	5,4	4,8	9,3	7,5	7,7
18	Effluent-RSF- Drinkwater nieuw			RSF							2X	X	X	X	X	X		7,2	5,2	3,5	10	7,4	6,5
19	Effluent-NF-Drinkwater nieuw				X						2X	X	X	X	X	X		12	11	8,3	14	12	11

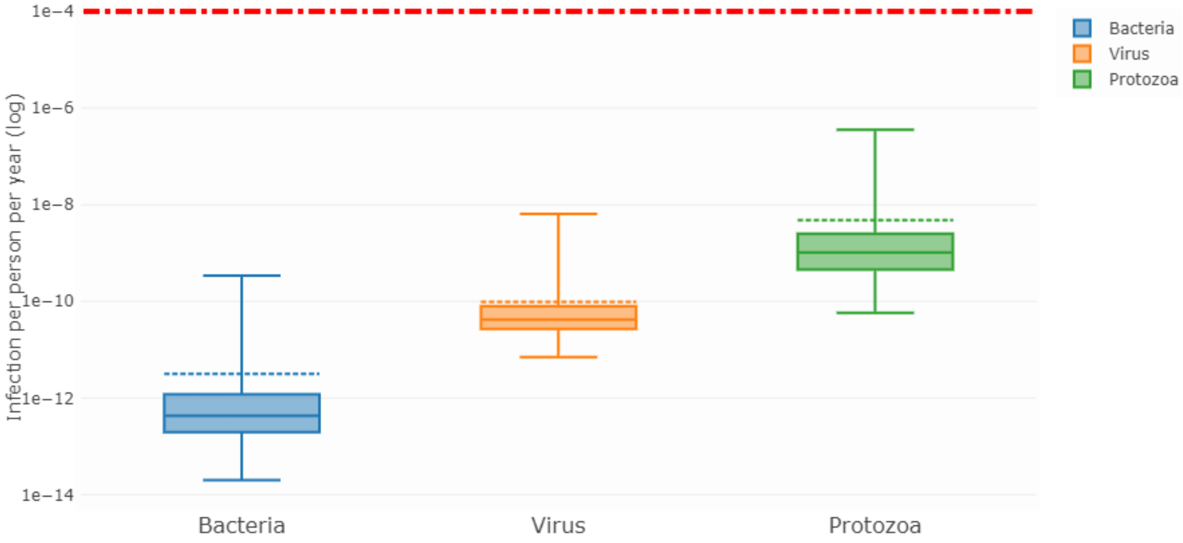


Figure 22: Output of the QMRA+ tool for scenario 19, effluent post treatment with nanofiltration and the upgraded drinking water treatment. Red line indicates the Dutch guideline value of 1 infection per 10,000 persons per year.

6.3 Lessons extracted

6.3.1 Lessons from the UWOT analysis

For the application in Flanders, the combined application of UWOT with the Regional Analysis tools **have provided insights** on the impact different water-smart measures (such as wastewater reuse, CCRO and urban rainwater harvesting) can have for regional water resources management. The detailed modeling results from both tools are available both for Woumen and Mechelen, providing quantitative insights on how the proposed solutions **contribute towards water-smarted management regionally**. Aggregate results (in terms of stress curves, seasonal charts, etc.) **give LL owners and operators** the chance to readily review and evaluate whether a proposed solution can be of use for improved water management in the context of their needs. As end users/LL owners have been actively contributing, through joint meetings, to the setup and data requirements of the models, there is increased visibility on the models' potential, outcomes, and limitations. Through tools application, they have provided insights on how various proposed solutions can increase regional robustness in water supply. As these solutions had been quantitatively untested before, both models offer the added value of an ex ante assessment that can be used to guide preliminary decisions before any of these water-smart solutions can be applied. Moreover, the stakeholders have insights on how these solutions fare against future uncertainty, for instance in urban demands or river boundary conditions. The lessons learned specifically for each pilot area are described below.

Woumen

- The present-day drinking water production system in Woumen appears to be under stress and is particularly susceptible to deteriorating changes in both salinity (e.g., due to lower discharge in Ijzer) and demands (e.g., due to the addition of clients, regional immigration or added industry needs). The system can presently cover daily average demands of 30000 m^3/day without having a significant failure and emptying rate. The maximum theoretical capacity of 40000 m^3/day cannot be met with equal demands without the basin emptying.

- In the case of worsening salinity, the basin will be able to operate without disturbance only for low demand requests (10000-15000 m^3/day). A combination of high regional demands with worsening salinity rates will quickly render the drinking water production system, with significant failure rates (>10%).
- Both measures (WW reuse and CCRO) improve the water security of Woumen assuming demands remain at reasonable levels. However, the effectiveness of the measures is limited when regional demands become high (>30000 m^3/day). The measure of WW reuse appears to be more efficient when regional demands increase, given the considered measure design ranges.
- The results indicate that the most efficient way to secure the system against future stresses is to combine both measures (i.e., WW reuse from the local WWTP and CCRO), without (over)relying on one solution, especially if high demand scenarios are considered.
- The model is limited by the lack of data, particularly on the demand side, as well as the CCRO implementation specifics. More information on these datasets would make the stress-testing analysis more accurate, particularly with regard to the actual, operational stress of the DW system. However, this limitation is mitigated by assuming multiple demand scenarios and exploring how the Woumen DW basin behaves under increasing urban water demands.

Mechelen

- The retention basin in Mechelen appears to fulfil the goal of flood-proofing the area, as it leads to runoff reduction rates that range from 22%-94% (depending on the month of reference). The values that are mentioned refer to the retention basin implementation without any operational rules; they can thus be further improved with the introduction of operational rules, e.g., emptying the basin during winter months and when anticipating flood events. The stormwater management tool (tool #22) was developed to implement these operational rules and ensure optimal use of the basin and collected stormwater.
- The design of the retention basin can accommodate an expansion in the serviced urban areas upstream, but with a compromise of its runoff reduction capacity of 30-40% for certain months. This will have a beneficial effect on subirrigation and may accommodate larger irrigated surfaces as well, but the trade-off with flood-proofing has to be taken into account, especially during autumn and winter.
- With regards to subirrigation, the basin appears to cover the majority of crop demands but comes with shortages in demand coverage in the summer months. This might lead to lower crop yields than the ones optimally planned for the given area; however, the crop demands could be covered by additional surface or groundwater sources.
- Considering the modelling of subirrigation, UWOT is limited with regard to predicting groundwater levels due to the lack of modelling vadose zone dynamics. The effects of subirrigation on groundwater are thus explored and discussed as part of the supplementary regional analysis.

As for the **strength of the tool**, it has user friendly interface, it is bottom-up, component based urban water circle model, it has multiple components/ technologies (drinking water, wastewater/greywater, rainwater/runoff including rainwater harvesting, greywater recycling blue-green areas, smart appliances, etc.), it is able to simulate flows on a daily/hourly time step, in scenarios that span years to decades, is able to assimilate (time-series, parameter) data from multiple sources, constructs scenarios based on socio-economic assumptions and supports spatial scales from appliance level and up, house/neighbourhood/city. Its weakness is that it is highly related to the data used, therefore it can be limited by the lack of data or the assumptions that are used. This **limitation** can be constrained by actively involving stakeholders during the data setup process (like the case of LL Flanders) or by ideally ensuring data-richer applications.

6.3.2 Lessons from the regional analysis and the stormwater reuse management system

Woumen

- Implementation of the measures increases the total drinking water production and combining the two measures results in the highest production. In all scenarios, however, desired drinking water production could not be reached during dry periods, because not enough water is available in the IJzer and through effluent.
- Reuse of the WWTP effluent led to less water intake from the IJzer, however, this also means the water is not available in other places anymore. The contribution of the WWTP effluent to environmental flows in the larger region is not clear, so this would need to be investigated further.
- Installation of the CCRO system on the other hand led to increased water intake from the IJzer, which means less water will be available downstream especially during drier periods. This extra water abstraction during a period when water quality is already deteriorating, might lead to more saltwater intrusion upstream. It was not possible to include this effect in the regional analysis, because a more detailed surface water model is needed.

Mechelen

- The stormwater retention basin was able to reduce the total runoff and peak runoff in the Oude Tantelaersloop, especially when the water was used for subirrigation. When the operational rules of the basin are optimized, peak values can be reduced even more.
- Water supplied through subirrigation to the agricultural fields led to higher groundwater levels and higher evapotranspiration values. Crop yields were increased.
- Excess water from the subirrigation partly left the system through drainage to surface water. However, this water left the system towards the Dorpsloop and therefore did not increase the risk of flooding in the urban areas near the Oude Tantelaersloop. When implementing the system in a different area, the extra drainage caused by higher groundwater levels should be considered to make sure the risk of flooding is not impacted.

With regard to the **strengths** of the regional analysis tool, it has large degree of abstraction in processes and multiple inter-connected processes can be included. But its **weaknesses** are related to the high data requirements and the multiple parameters needed to fine-tune an application.

Specifically, for the stormwater reuse management system (tool #21)[4] which is part of D3.4, the lessons learned are the following:

- Identifying and disconnecting existing pollution sources from the storm water system can be tedious, but it is paramount to ensuring system performance and allowance.
- Further purification of the stormwater may not be required by law but can provide an additional advantage for further flexibilization of re-use scenarios. In addition to the legal perspective, the water quality should be judged from a risk assessment point of view.
- PLC providers are currently designing and commercializing inexpensive hardware while still complying with industrial safety standards, hardware delivery times and software support may still form bottlenecks, especially with regard to short-term implementation.

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[4] The stormwater reuse management system (tool #21) is part of D3.4. Nevertheless, the preprocessing work and lessons learned are being documented in D3.5 as part of the LL work in order to provide a complete picture of the Flanders case since it is related with other tools.

- Fully edge-computing-based implementation of local control remains a desirable but currently unrealistic goal. This leads to hybrid solutions, here a combination of Python as an edge-computing language and the configuration of I/O based on conventional PLC-setup-packages. The setup of simple edge-based OPC-servers may form a solution to this drawback if it remains unaddressed by the hardware providers.
- The incorporation of external rainfall forecast data may prove challenging, especially when anticipating multiple data providers: available data formats, subscription models and service level agreements may vary considerably.
- Depending on the cloud service provider, the cost for design and hosting online the data transformation and control service (here: Python-based Azure-Databricks notebooks running as scheduled batch workflows on a dedicated compute cluster) as well as data storage and querying may be considerable. Simple on-premises hosting could form a solution if the forecast data volume allows. This may require a technology change, especially for data storage formats and workflow organization (replacing Databricks by either local or self-hosted Jupyter-Notebooks, or pure Python).
- The required real-time data exchange between project partners and external parties (e.g., for weather forecasts) requires sound preparatory communication. Typically handled data formats may vary considerably. Emerging concepts, such as dataspaces, may provide an apt solution to this challenge in the future.

With regard to **water smartness**, by engaging citizens and other local actors such as farmers during on site events, the water smartness of the region was elevated (SO E – engaging citizens and actors across sectors in continuous co-learning and innovation). Once the tool is operational, we expect to strengthen this created water smartness through fulfilling SO A – Ensuring water for all relevant uses. Links of the tool with the water-strategic objectives are also available in D3.4 (under the tool section).

The work on the tool led to an **increased awareness** of water management with the local farmers and will ultimately result in an additional water source for them. The development of the tool for this case led to significant progress in the control algorithm optimizing the retention of stormwater that can be directly applied in the design and operation of other urban water infrastructure. Hence, **tools application strongly provided further information** useful to the end-users and LL owners' side. Additionally, it provided **new knowledge** with regard to challenges, since interactions with the local stakeholders led to the identification of the main concerns with local farmers in participating in this type of management system (i.e., lack of control on their own fields, water quality). This knowledge can help in further communication and promotion of managed stormwater systems. Regarding tools' **weaknesses**, fields need to lie in the immediate vicinity of a buffer basin or a location with the need i.e., this situation only occurs on the interface between city (or greenhouse horticulture) and agriculture. **Strengths** are related to the fact that buffer infrastructure is extended by a novel functionality in that the designed control system will enable it to serve as source of water in reuse concepts while maintaining its buffer capacity. Up to now, in Flanders no control systems are available to manage stormwater retention and release based on rainfall predictions. Implementing this control algorithm provides an extra source of water to farmers, who directly can use this water in periods of drought and benefit from the extra available water. This will decrease their irrigation demand and the pressure on freshwater resources. The use of a subirrigation system makes use of the subsoil as a water buffer to ensure maximal reuse of the retained stormwater, either for plant uptake or for groundwater recharge.

6.3.3 Lessons from SuTRa and QMRA+

SuTRa tool was used to compute the microbial risks of Drinking Water Wells in a natural area. Firstly, the residence time between the source of contaminations and the groundwater well was computed as was the travel time. This required an update of the transport parameters, based on recent field investigations. The advantage of using the SuTRa tool over existing tools that are usually used to compute residence time (such as regional groundwater models) is that SuTRa allows for an explicit schematization of the well construction. Thus, high vertical flow velocities in the annulus of the well are taken into account more accurately. Figure 23 below depicts an example of the removal of pathogens from groundwater following infiltration from the surface during transport to a well.

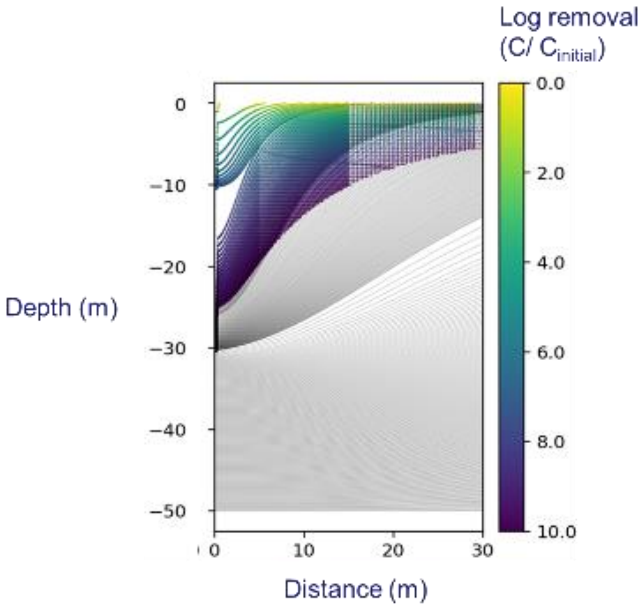

Figure 23: Example of the removal of pathogens from groundwater following infiltration from the surface during transport to a well on the left side of the image. Note that concentration reduction is depicted on a 10log scale.

With regard to each link with QMRA+, SuTRa is a process-based model that provides insight into the removal of pathogens during soil passage. Soil passage is one of the many treatment steps that can be considered by QMRA+. SuTRa can thus provide more detailed insight into the removal efficiency of one of the treatment steps that is simulated by QMRA+. QMRA+ allows for site specific pathogen removal based on the outcomes of the SuTRa tool, making the risk estimate more specific to the studied situation.

Regarding **water-smartness’** objectives mentioned in section 5.8.3, SuTRa tool has potential to meet those strategic objectives and criteria via the infiltration and re-use of water at a MAR-site and/or the provision of irrigation water that meets hygiene standards (for human health risks). The QMRA+ tool allowed to balance water safety against other aspects such as costs, resources and environmental impact. This it contributed to the design of a smart water reuse system and is related to SO A defined in section 5.5.3.

The knowledge gained from QMRA+ application was useful to the end-users since it provided quick, hands-on introduction into microbial risk assessment, also for stakeholders that were not familiar with the concepts of quantitative risk assessment and microbiology. Thus, it can also be seen as an educational tool. Feedback from the users gave the opportunity to improve the tool further and better connect to the daily practice of the intended users. The tool also **provided new (relevant) knowledge** to address the challenges, since most stakeholders were not familiar with QMRA. By using the tool and comparing the needs for chemical water safety it became clear that chemical water safety requirements were generally stricter. Any of the suggested schemes for chemical safety also turned out to be sufficient for microbial safety. The application of the tools also proved its **strengths and limitations**. Specifically, its strength is the ease of use even for users with limited knowledge about microbial water safety aspects. Furthermore, the tool includes default values for all aspects, where other QMRA tools generally require data. This allows for quick introduction into the topic and fast comparison between alternatives. A weakness of the tool is that it’s a theoretical risk assessment, since no actual data from the specific system is available. Therefore, it assesses the potential safety of a system. However, if the system is poorly built or operated, this potential won’t be met. As the tool includes generic data on the various elements of the risk assessment, the uncertainty range of the risk assessment is quite large.

With regard to SuTRa, it didn’t provide any new knowledge. On the contrary, its aim was to make existing knowledge and models better available. As far as its **strength and limitations**, the first lies to the fact that it is relatively easy in terms of parameterisation and computations. A weakness of SuTRa is that in practice the removal and transport parameters of bacteria are highly site specific. Therefore, it only provides a first estimate of the microbial risks if site specific data aren’t available. Additional measurements need to be conducted on site or collected for similar sites (from literature) to acquire a more robust estimate of the microbial transport and removal parameters.

6.3.4 Data

Data availability and quality play a significant role in tools’ application and deployment as with UWOT which is quite data intense at least for first-time application. In order to handle data issues in Flanders case, a methodological framework to discuss and define parameters in collaboration with the LL stakeholders was utilized, where the LL group was aware of parameter needs and was discussing their estimates. This, in combination with an extensive literature review, allows a clearer definition of input data. For the regional analysis tool, the same as UWOT applies. The data management framework was shared between models to maximize clarity in parameter definitions across stakeholders and modelling groups. The lessons learned on data issues was that visibility across stakeholder groups is very important, but it has to be scaled to groups that already know the context and can assist in locating the right data sources. Otherwise, in case of large non-expert groups, the co-creation exercise might be too complex and might lead to vague estimates.

QMRA+ (#26) on the other hand, doesn’t need data to be used, only a scheme of the system (source, treatment and use). However, if data is available, the risk assessment can be refined based on that data within the tool. Therefore, there were no lessons learned on data issues with regard to this tool.

SuTRa (#31) computes the removal of pathogens (micro-organisms) based on the residence time and flow rate of groundwater. Both these parameters are typically computed based on a groundwater model of water balance. If they are not estimated correctly, then this also impacts the accuracy of the predicted removal. The removal rates for pathogens are based on literature values. They may vary from location to location, based on local conditions. The tool only provides a small number of default parameters. These are stored as a dictionary inside the tool (python library). Storing also default parameters is not considered a difficult part. Therefore, no issues were encountered, and no lessons were extracted.

For the stormwater management system (#21) good rain predictions are essential to ensure proper coordination between the subirrigation part of the tool and the basin part of the tool. For the subirrigation part of the tool, recent data is needed. If there is not sufficiently recent data available, the subirrigation part will not be able to send water to the agricultural fields in order to prevent too high groundwater levels. In developing the tool, there was no real-life data available. Dummy data, either from historic measurements or a temporary test set-up or even pure synthetic data, were used. Maintenance of the sensors should prevent further data issues once the tool is up and running.

7 Tools and Methods for LL East Frisia

7.1 Key WS challenges, ambition and case study description

The OOWV (Lower Saxony, Germany) is one of the largest water suppliers in Germany with an area of 7.550 km², providing drinking water from groundwater resources to private, industrial, and agricultural customers (and treating wastewater in ~50% of the area). It is confronted with climate change, which causes hot and dry summer periods with increasing water demand in various sectors (households, industry, and agriculture) and increasing pressure on groundwater resources. Furthermore, emissions from agriculture affect the usability of water resources for drinking water purposes. The goal of OOWV is to identify unused water resources and increase the reuse of process water and treated wastewater in water-intensive sectors. For this purpose, OOWV is striving to increase the capacity of the water supply by i) identification of alternative resources, ii) intelligent protection strategies for groundwater bodies, and iii) improving the treatment of process water for reuse e.g., in the dairy industry. In the long term, integrated water resource management for the OOWV supply area is to be established using water reuse and alternative supply concepts. The methods and instruments developed in BWS as well as the technical know-how gained in the field of water reuse technologies are an important element in this.

7.2 Application of tools and methods

7.2.1 Selected tools and technologies of pilots

The East Frisian LL aims to identify untapped water resources and increase reuse of process water and treated wastewater in water-demanding key industries to reduce pressure on groundwater resources. Within the BWS project, a pilot plant is operated to test improved treatment of process water (vapour condensate and whey permeate) for reuse in the water-intensive sector of dairy production (technology #6). Besides, options for new digital solutions (e.g., machine learning) for monitoring were evaluated. A GIS-based spatial multi-criteria approach (tool #23) was developed to identify municipal and industrial water requirements and match these with regionally available water resources. The extended UWOT model (tool #22) was used to simulate alternative water demand and supply options under different climatic and demand change scenarios for a test case. A data driven tool (#28) for short-time water demand forecasting was developed, based on time series from smart meters and advanced stochastic demand modelling techniques.

The LL East Frisia technologies and tools and their link to the living lab challenge and strategic objectives are presented in Figure 24. In Annex E, a summary table of the LL is provided (Section 16.2).

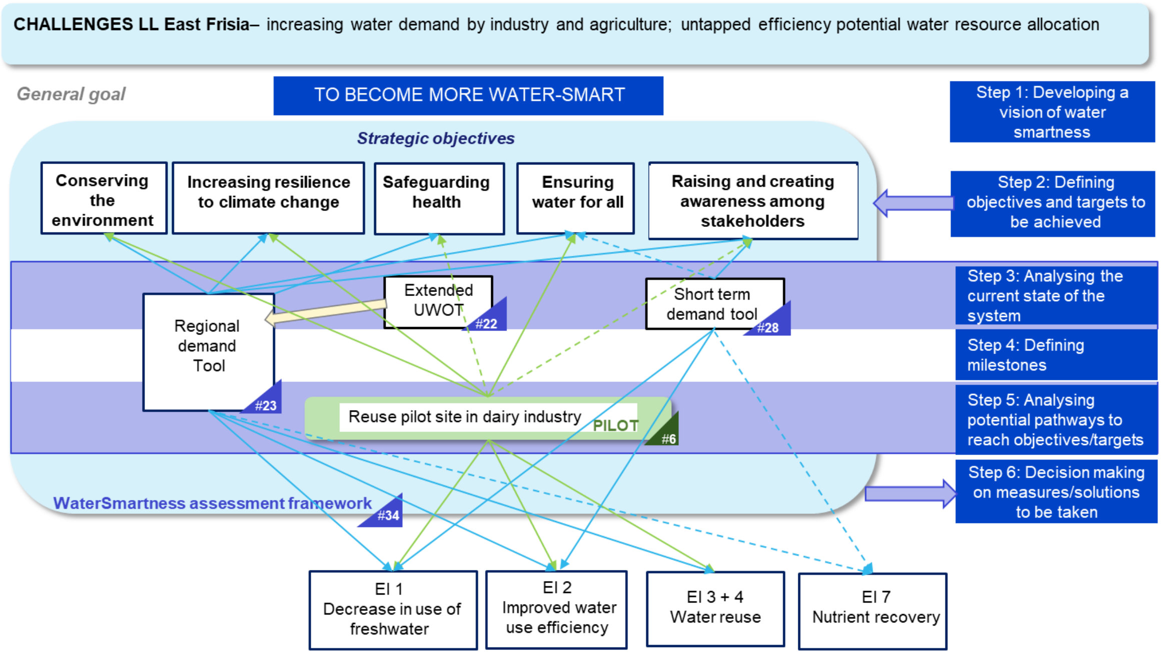

Figure 24: Systemic solution of LL East Frisia

7.2.2 Integrative use of tools, pilot interaction and data flows

Pilot activities and the development of digital tools in LL East Frisia are interlinked to a limited extent only. Pilot plant data will be embedded in the water demand-supply tool in the same way that increased industrial reuse by recirculation strategies will be included as a potential future water saving potential in large scale water management and upscaled to regional water saving potentials for industrial water demands. However, the technology that is piloted within the BWS project represents only one of various technological solutions for industrial reuse.

The three digital tools within LL East Frisia are interlinked as well. However, the regional demand supply matching is operating on a different scale compared to the other tools. UWOT and the Short-term demand forecasting tool are based on a small-scale analysis, while the regional demand supply matching tool is used for large scale analyses. The data flow between the tools can therefore be described in the way that UWOT and SDFT are producing water demand scenarios that can be included in the RDSMG for future-oriented scenarios. Conceptual data flow, integrative use of tools as well as pilot interaction are summarized in Figure 25 below.

Within the BWS project, an interface to the UWOT tool is implemented via the exchange of files in the CSV data format. Small-scale water saving scenarios can be calculated with the UWOT tool, which can then be visualized using the GIS tool.

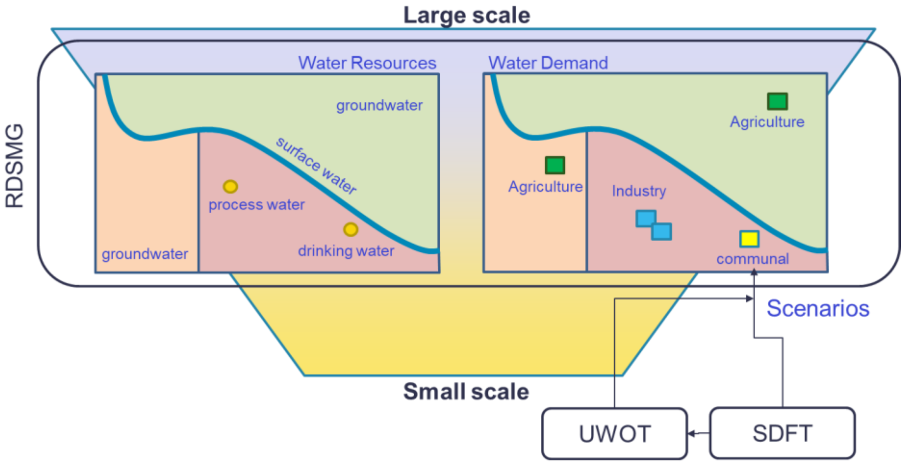

Figure 25: Tool and pilot data flow within LL East Frisia

More detailed information on the preprocessing stage and setup process of tools is provided in Annex D (Section 15.2).

7.2.3 Results

7.2.3.1 UWOT (#22)

Based on the data and the assumptions described in detail in Annex D (section 15.2.1.1 and 15.2.1.2), the selected time period for the simulation of the baseline scenario was 01/01/2017-31/12/2021 (5 years in total), using daily timestep. To avoid the large amount of time series produced, the main results are aggregated and presented in a monthly timestep.

At the household level, the pattern of water demand derived from the use of domestic appliances, the greywater production and the ‘total water demand’[5] is shown in the Figure 26. The decline noted in months 6-8 (June-August) is mainly following holiday patterns in the test case residents. The other category of water demand in the test case is for agricultural purposes and it is presented in the same figure. The increased water demand shown for the years 2018 and 2019 is a result of low precipitation combined with high temperatures during the summer-autumn period.

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[5] The term “total water demand” refers to the households’, industry’s and livestock’s water demands, that are covered by groundwater and tapped springs and doesn’t include the agricultural water needs, which are covered by farmers’ wells.

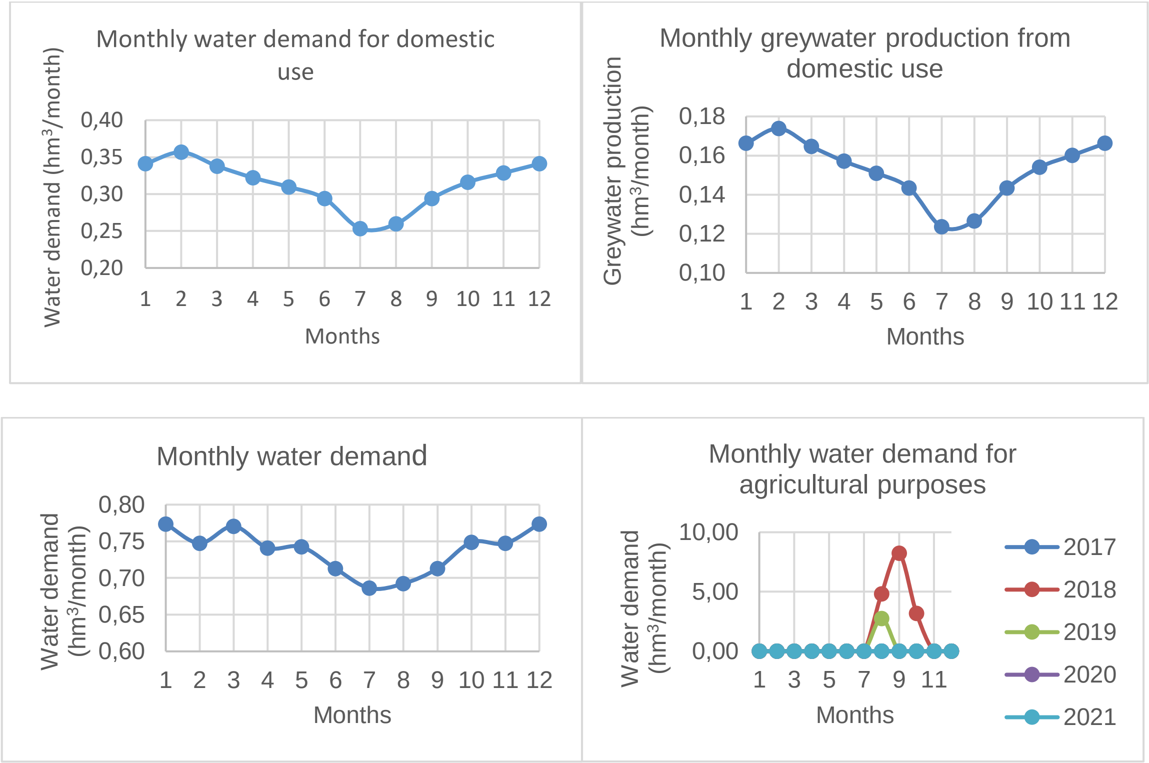


Figure 26: Baseline scenario results

The next step in this process is the comparison between the results from the baseline model and the different categories of scenarios (regarding the next five-year period) that are described in detail in sub-section 15.2.1.2 . In short, the five categories and their corresponding results are the following:

First category: 1% and 2% increase in the number of households.

A 1% and 2% increase in the current number of households can raise the total annual water demand by about 0.45% and 0.8% respectively, as it is shown in the Table 27 (section 15.2.1.3).

Second category: 0.5%, 2% and 4% decrease in industrial water demand.

A 0.5%, 2% and 4% decrease in the industrial water demand can decrease the annual water demand by about 0.23%, 0.9% and 0.8% respectively, as shown in Table 28 (section 15.2.1.3).

Third category: Changes in livestock by decreasing animals' population between 1 and 2%

A 1% and 2% decrease in the animals' population can decrease the annual water demand by about 0.23% and 0.34% respectively, as shown in Table 29 (section 15.2.1.3).

Considering that the term “total water demand” refers to the summary of water needs derived from the three examined categories (households, industry and livestock) which cover their needs from groundwater and tapped springs, it was examined the impact that a 2% (in absolute term) change (increase/decrease) in each category can have on the total amount of water demand. The results are presented in Figure 27.

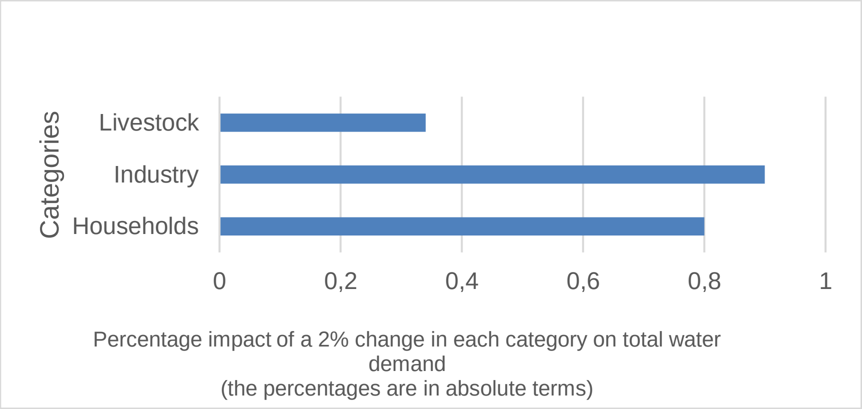


Figure 27: Percentage impact of a 2% change of each category on total water demand

The diagram shows that the total water demand is more sensitive to changes that are related to industry than households and less so than livestock.

Fourth category: Climate change related scenarios.

The examined climate change scenarios that are examined to investigate their impact on the agricultural sector and their results are presented in section 15.2.1.3 (Annex D):

The greater difference among the scenarios examined can be found between the Scenarios 1 and 2 (also compared to the baseline) which indicates the impact of temperature and rainfall on agricultural water demand whereas a 0.5 - 1% change on agricultural areas does not seem to play crucial role on the results.

Fifth category: Implementation of decentralized technologies for water management.

The results regarding the domestic water demand (and the total water demand respectively) before and after the implementation of greywater treatment plant (decentralized technology) are presented in detail in Annex D (section 15.2.1.3).

The results show that greywater recycling technology has a significant impact on potable water demand and can play a major role in attempts to reduce potable water needs in the household level. Compared the greywater quantities at both scenarios (baseline and GWR), it is obvious that the second approach significantly reduces the amount of greywater finally produced, as it is recycled inside the household (Figure 28).

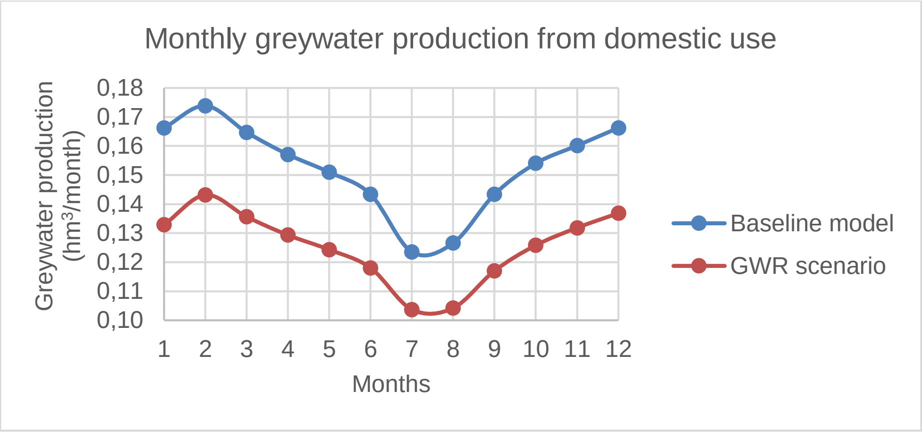


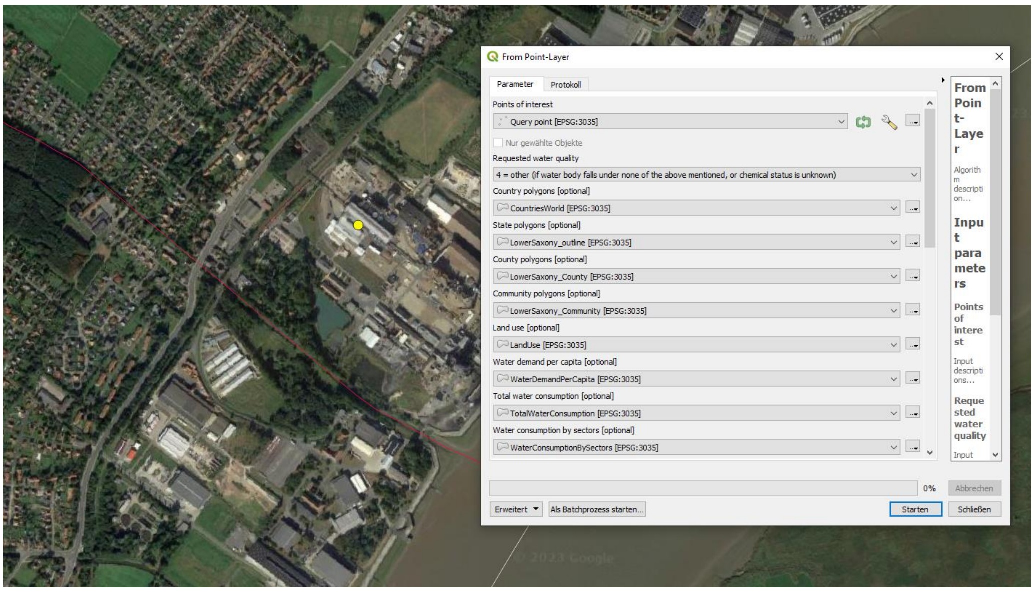
Figure 28: Greywater production in the baseline and GWR scenarios

Detailed presentation of results from the application of UWOT is provided in Annex D (section 15.2.1.3).

7.2.3.2 Regional demand-supply matching GIS tool (#23)

The results of the tool are the collection of publicly available data resources and the tool itself (QGIS plug-in). To illustrate the functioning of the tool, a sample scenario is presented below. A consideration of alternative water use in the Nordenham industrial area, district of Wesermarsch, was chosen as a fictitious application example. The chosen scenario envisages that part of the water required for production should be obtained from alternative sources, as it is assumed in the scenario, that no special demands are made on chemical and biological quality for the planned use. To get an overview of the resources available at the sample site, the RDSMG tool is used.

For this example, the site of interest was selected via a point layer, and the corresponding input data was selected via the dropdown menu (Figure 29).



Points of interest: Query point [EPSG:3035]

☐ Nur gewählte Objekte

Requested water quality: 4 = other (if water body falls under none of the above mentioned, or chemical status is unknown)

Country polygons [optional]: CountriesWorld [EPSG:3035]

State polygons [optional]: LowerSaxony_outline [EPSG:3035]

County polygons [optional]: LowerSaxony_County [EPSG:3035]

Community polygons [optional]: LowerSaxony_Community [EPSG:3035]

Land use [optional]: LandUse [EPSG:3035]

Water demand per capita [optional]: WaterDemandPerCapita [EPSG:3035]

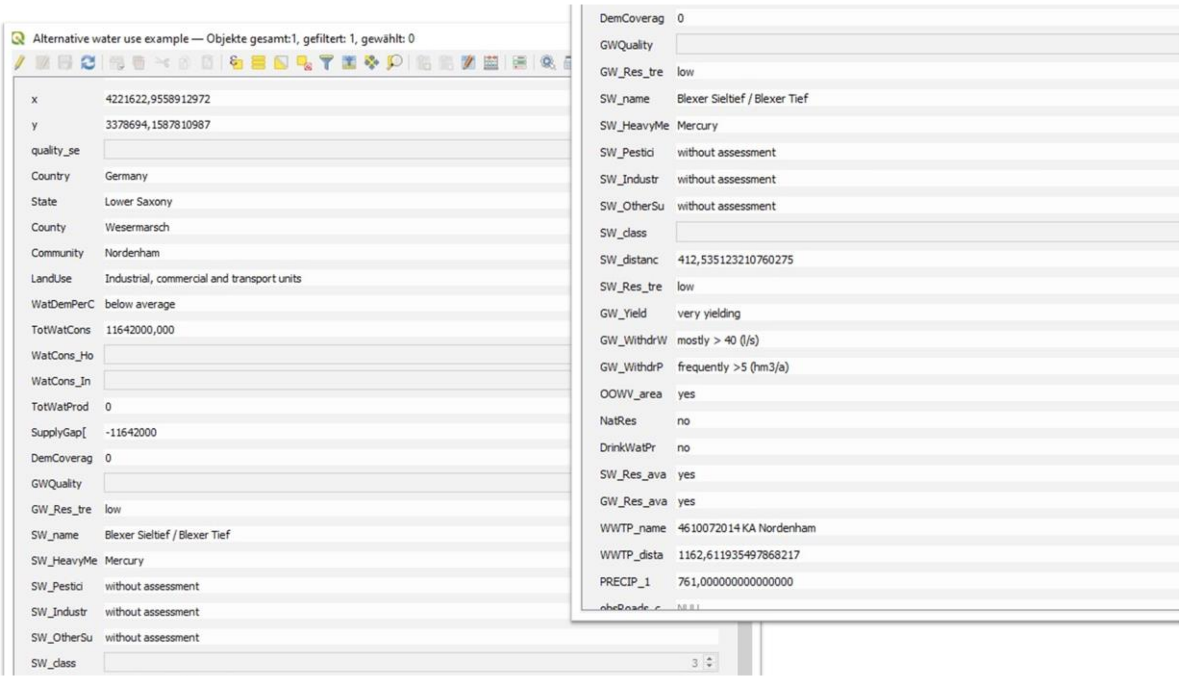
Total water consumption [optional]: TotalWaterConsumption [EPSG:3035]

Water consumption by sectors [optional]: WaterConsumptionBySectors [EPSG:3035]

Figure 29: Screenshot data selection regional demand-supply matching tool (#23)

If available for the selected point, the tool provides the following data: administrative information, land use information, information on drinking water - water consumption and water extraction, information on groundwater and surface water bodies, as well as alternative resources and, if available, optional user-defined data (examples in Figure 30). The query indicates groundwater of sufficient quality and a yield of > 40 l/s for the selected point (Figure 30). In this simulation, however, the focus is to be on the water resources that can be used alternatively to groundwater or water from drinking water supply.

The tool shows three possible alternative resources: firstly, the surface water of Blexer Sieltief/Blexer Tief is only 415 m away and could possibly be used. The second alternative resource is the Nordenham sewage treatment plant, which is about 1.2 km away. Both resources would be linked to construction investments, as the corresponding pipelines would have to be built over these distances. It would also have to be clarified whether these waters meet the process requirements or would have to be treated accordingly and whether the available quantities are sufficient for the demand. Treatment would involve further costs that should be taken into account. A third option is the use of rainwater. The tool determines a mean annual precipitation of 761 mm for the query point. This means that a roof area of only 100 m² has the potential to recover 76 100 l/a. Since a hall roof is many times larger, the amount of water potentially available is many times greater. If, in addition, the water volumes of the other sealed surfaces are also used instead of being discharged into the sewerage system or land drainage, the water volume available is many times greater. For use as process water, rainwater would have the advantage of low mineralisation.



Alternative water use example — Objekte gesamt:1, gefiltert: 1, gewählt: 0

x	4221622,9558912972
y	3378694,1587810987
quality_se	
Country	Germany
State	Lower Saxony
County	Wesermarsch
Community	Nordenham
LandUse	Industrial, commercial and transport units
WatDemPerC	below average
TotWatCons	11642000,000
WatCons_Ho	
WatCons_In	
TotWatProd	0
SupplyGap[	-11642000
DemCoverag	0
GWQuality	
GW_Res_tre	low
SW_name	Blexer Sieltief / Blexer Tief
SW_HeavyMe	Mercury
SW_Pestici	without assessment
SW_Industr	without assessment
SW_OtherSu	without assessment
SW_class	3

DemCoverag	0
GWQuality	
GW_Res_tre	low
SW_name	Blexer Sieltief / Blexer Tief
SW_HeavyMe	Mercury
SW_Pestici	without assessment
SW_Industr	without assessment
SW_OtherSu	without assessment
SW_class	
SW_distanc	412,535123210760275
SW_Res_tre	low
GW_Yield	very yielding
GW_WithdrW	mostly > 40 (l/s)
GW_WithdrP	frequently >5 (hm3/a)
OOWV_area	yes
NatRes	no
DrinkWatPr	no
SW_Res_ava	yes
GW_Res_ava	yes
WWTP_name	4610072014 KA Nordenham
WWTP_dista	1162,611935497868217
PRECIP_1	761,000000000000000

Figure 30: Screenshots query output (without map) example case regional demand-supply matching tool (#23)

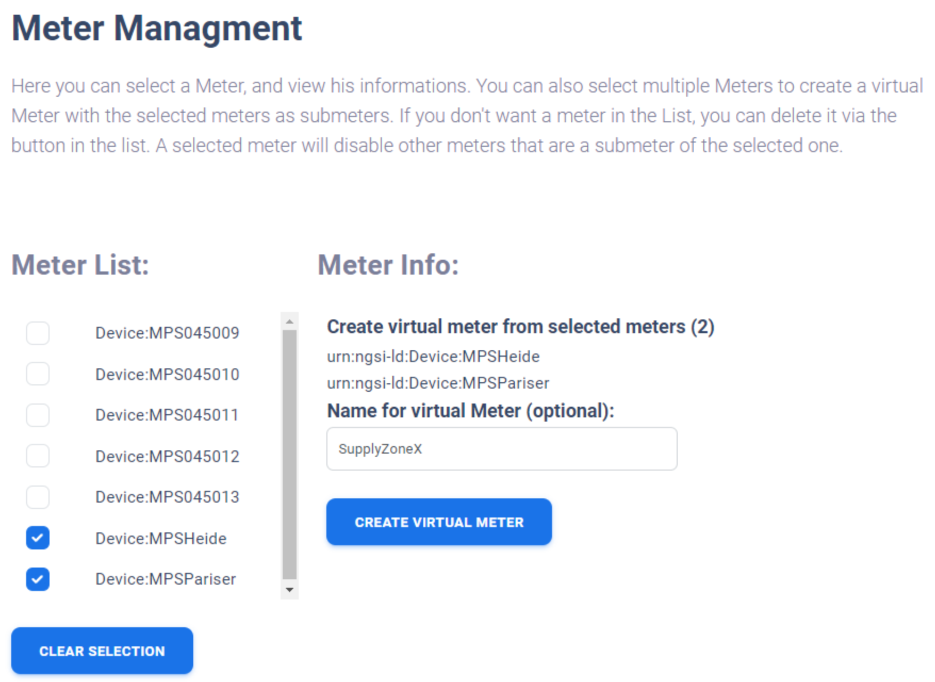
In this selected example, this information could serve as a starting point for further, targeted investigations and feasibility studies on the use of one or more of the alternative resources. The RDSMG tool can be used not only for estimating alternative water resources, but also for strategic planning of e.g., sites for new developments, especially with regard to aim of building with alternative, more environmentally friendly standards in terms of water conservation.

7.2.3.3Short-term demand forecasting tool (#28)

The results consist of the headless core tool and the optional frontend, which can both be used to train machine learning models on smart meter data to create 24-hour forecasts on different spatial scales. In the following, a typical workflow is shown. In Figure 31, the user starts by aggregating existing smart meters to a “virtual meter” that represents a larger zone for which he/she wants to create forecasts. In Figure 32, the user then chooses this virtual meter and one of the implemented algorithms to train a model. As they usually do not know which hyperparameters to choose for the algorithm, the users select to perform an automatic hyperparameter search (using Bayesian optimization with Hyperband) to find the best set of hyperparameters according to 15 trial runs. In Figure 33, the user examines the performance of the model with reference common error metrics and by contrasting predicted versus actual consumption on a holdout dataset (note that the final model is trained on this data, too). Finally, the user can generate forecasts using this model for dates in the future, as seen in Figure 34. By comparing the predicted load curve against historical values of the same day of the last week and last month, the user can quickly check the prediction for plausibility. The same workflow can be done without any UI and thus be automated with additional organization-specific computations that make use of the predictions. For example, an alert can be sent in case the predicted water demand exceeds a threshold.

The tool provides algorithms that use very different approaches (statistical, tree-based, deep-learning) that each may be more appropriate for different datasets. The user has to empirically determine the best approach for his specific context. For the smart meters used in the LL, the XGBoost algorithm proved to produce good results (see Figure 33) while keeping the computational load low (few minutes) as compared to the deep-learning approaches which can take up to hours to train. On the other hand, statistical approaches were found to be lacking in performance even though they are very fast to train. In general, performance depends on two major factors. Firstly, the amount of randomness in the historical water demand by definition heavily affects predictability and can vary a lot across different scenarios like a house of retired people or a young family. Secondly, low data quality can render prediction models useless. In the LL, a problem was that some sensors would, from some point forward, regularly drop measurements which led to data gaps in most days' measurements.

In conclusion, the tool allows the user to aggregate smart meters and train and query machine learning models for short-term demand forecasts through either a UI or a restful API. Both good and bad results could be achieved for smart meters used in the LL, depending on the nature of the measured area and sensor malfunctions.



Meter Managment

Here you can select a Meter, and view his informations. You can also select multiple Meters to create a virtual Meter with the selected meters as submeters. If you don't want a meter in the List, you can delete it via the button in the list. A selected meter will disable other meters that are a submeter of the selected one.

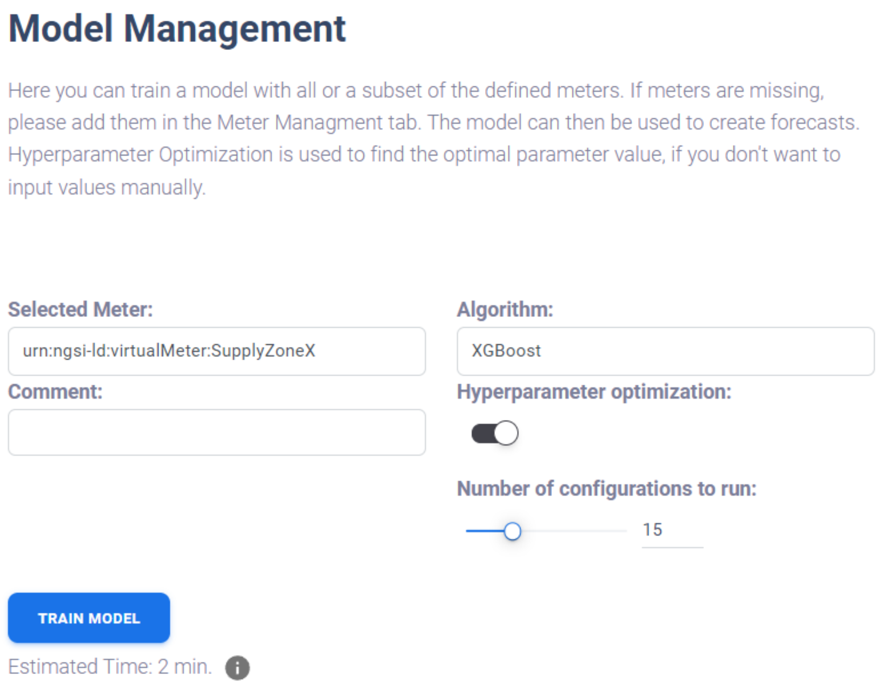
Meter List:

☐ Device:MPS045009
☐ Device:MPS045010
☐ Device:MPS045011
☐ Device:MPS045012
☐ Device:MPS045013
☑ Device:MPSHeide
☑ Device:MPSPariser

Meter Info:

Create virtual meter from selected meters (2)
urn:ngsi-ld:Device:MPSHeide
urn:ngsi-ld:Device:MPSPariser
Name for virtual Meter (optional): SupplyZoneX

Figure 31: Aggregating smart meters to a virtual meter to train and query models with.



Model Management

Here you can train a model with all or a subset of the defined meters. If meters are missing, please add them in the Meter Managment tab. The model can then be used to create forecasts. Hyperparameter Optimization is used to find the optimal parameter value, if you don't want to input values manually.

Selected Meter: urn:ngsi-ld:virtualMeter:SupplyZoneX

Algorithm: XGBoost

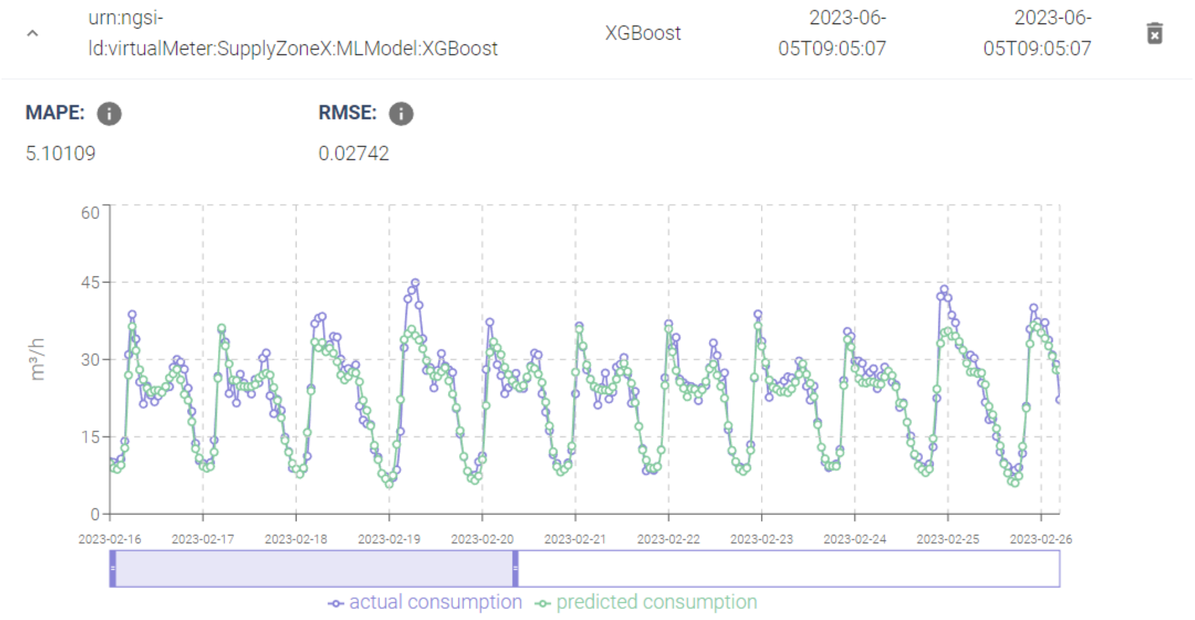
Comment:

Hyperparameter optimization: ●

Number of configurations to run: 15

Estimated Time: 2 min.

Figure 32: Model training with hyperparameter optimization.

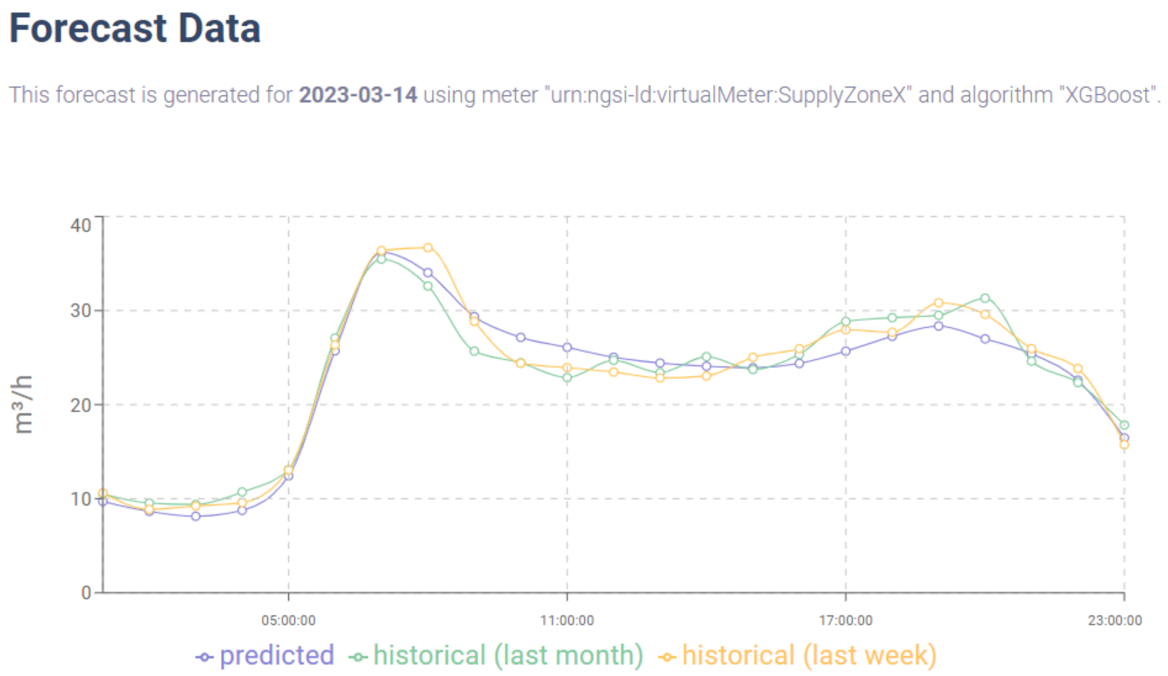


urn:ngsi-ld:virtualMeter:SupplyZoneX:MLModel:XGBoost	XGBoost	2023-06-05T09:05:07	2023-06-05T09:05:07

MAPE: 5.10109

RMSE: 0.02742

Figure 33: Evaluation results of model training in terms of performance on hold-out dataset.



Forecast Data

This forecast is generated for **2023-03-14** using meter "urn:ngsi-ld:virtualMeter:SupplyZoneX" and algorithm "XGBoost".

Figure 34: Short-term demand forecast with historical reference values for plausibility checking.

7.3 Lessons extracted

7.3.1 Overview

Being designed as decision support tools, the objective UWOT and the Regional Demand-Supply Matching GIS tool is to pursue the implementation of circular economy projects seeking and **increase water smartness in LL East Frisia**. The Short-term demand forecasting can, furthermore, enable a smarter water usage on household level in the city of Lohne by raising awareness for the district specific water consumption. **Regarding the usefulness of tools**, working on the Regional Demand-Supply Matching GIS tool, provided OOWV with in-depth insights in available water-related data and provided them with a structured approach for data management. Using UWOT was useful for OOWV to be able to simulate different future water use scenarios for the region. The Short-term demand forecasting tool enabled OOWV to visualize the newly gained smart meter information for the city of Lohne. Besides, it enables OOWV to prepare day-to-day forecasts so that water distribution can be optimized with regards resource efficiency and energy efficiency.

With regard to the new knowledge provided, UWOT and the Regional Demand-Supply Matching GIS tool built on existing knowledge (information on supply system, (public) data bases, literature values, etc.). New knowledge is generated in the Regional Demand-Supply

Matching GIS tool by combining all available information in one place to enabled informed decision making. Before applying the Short-term demand forecasting tool smart meters were installed in some districts in the city of Lohne. These measurements provided new insights into the intraday water usage on household level. Applying the tool based on this information, short-term demand forecasts can be produced, being added information to the users as well.

As for the **expected impacts**, the tools developed within LL East Frisia cannot alter project KPIs on water reuse (EI_3 and EI_4) but UWOT and the Regional Demand-Supply Matching GIS Tool can help to assess the implications of an increase in both KPIs. The estimated values for EI_1 and EI_2 are based on the assumption that several measures in the region will be implemented. However, it is impossible to estimate the impacts generated by the application of the three tools with regards to the EIs since the tools are only designed for decision making not for direct process control or optimization. However, based on the knowledge of actions planned and consequently implemented in the next years, it can be stated that the numbers provided in the GA will be achieved.

Specifically for each tool, the implementation of UWOT tool gave a good impression for the water use in the different sectors. It could have multiple benefits for water management strategy in case more data becomes available regarding the different water users and sources. Additionally, it could be useful to know the policy and measures related to water management to further investigate possible future scenarios based on real data and not assumptions. Some main conclusions produced from the examined scenarios' results are the following:

- The water system was found to be more sensitive to changes that are related to the industry in comparison with the households and the livestock.
- The impact of climate change (regarding meteorological conditions, mainly temperature and rainfall) on agricultural water demand is crucial whereas small changes on agricultural areas don't seem to significantly affect the water needs.
- The greywater recycling (GWR) technology has a significant impact on potable water demand and can play a major role on attempts for reducing potable water needs in the household level. It has the potential to reduce the annual domestic water demand by 8.50% and the annual total water demand (including households, industry, and livestock) by 3.60% in the test case.

The model can be adjusted to account for changes in any scenario parameters (e.g., population increase, livestock changes, industry changes, climate-driven scenarios etc.).

As for the **strength of the tool**, it has user friendly interface, it is bottom-up, component based urban water circle model, it has multiple components/ technologies (drinking water, wastewater/greywater, rainwater/runoff including rainwater harvesting, greywater recycling blue-green areas, smart appliances, etc.), it is able to simulate flows on a daily/hourly time step, in scenarios that span years to decades, is able to assimilate (time-series, parameter) data from multiple sources, constructs scenarios based on socio-economic assumptions and supports spatial scales from appliance level and up, house/neighbourhood/city. Its weakness is that it is highly related to the data used, therefore it can be limited by the lack of data or the assumptions that are used. **This limitation** can be constrained by actively involving stakeholders during the data setup process (like the case of LL Flanders) or by ideally ensuring data-richer applications.

The RDSMG tool was implemented in the LL and has great potential to become a key monitoring and decision-making tool for sustainable water resources and water demand management in the region. However, its acceptance and usefulness very much depend on the input data available. For this first-time implementation the main ambition was to make the most use of publicly available information from national, regional, and local databases. With this information on water resources usage and water demands, it was possible to derive important insights on regions with surplus and exceeding water demands as presented in section 7.2.3.2. However, publicly available data shows some gaps with regards to industrial uses and only limited data is available on water extractions by self-supply systems. This limits the user´s benefit with regards to investigating potentials for industrial reuse and future predictions on agricultural water demand in the region. The highest benefits from the tool can be derived if data sets are regularly updated and enriched by new information collected from stakeholders.

The **strength** of the tool proved to be the high potential for replicability, whereas its **limitations** are related to the large amount of data required and lack of data for some regions.

The SDFT was successfully implemented in the city of Lohne. The results of the case study application prove the **usefulness** of the tool for predicting future load profiles of municipal water demand in the districts under investigation. Nevertheless, the accuracy of the prognosis depends very much on the positioning of smart meters in the network and the demographic information available in this section of the supply network. For future studies, a large-scale implementation of smart meters would be desirable instead of summarized measurements of small city districts in order to enhance the prognoses´ quality. For this tool, the user-friendly interface and the fact that it is easy to use are the considered as **strengths**. On the other side, the requirement of smart metering data is considered as its **limitations**.

7.3.2 Data

All three tools are highly affected by data availability and quality. Especially the short-term demand forecasting tool is requiring smart meter data as input. UWOT and the Regional demand-supply matching GIS tool are both quite data intense at least for first-time application. The data issues encountered were handled differently for each tool. For UWOT, expert guess was needed to fill data gaps and use of logical assumptions was made based on relevant papers (references) for the case study. For the Regional Demand-Supply Matching GIS tool, incorporating also incomplete GIS layer was not avoided. The distribution of an additional survey among households in the respective city districts of Lohne was the action implemented to address the data issues for the Short-term demand forecasting tool. The lessons learned overall on data issues is that it is unavoidable to work with expert guesses for decision-making (required at some points) since complete data will be probably never available in any case study context.

8 Tools and Methods for LL Lisbon[6]

8.1 Key WS challenges, ambition and case study description

Lisbon has a smart management strategy for all key areas of urban development. The city aims at providing high quality of life for an increasing population and growing economy, whilst tackling climate change challenges based on a green-blue problem-solving infrastructure. As such, the key smart-water **challenges** of the Lisbon Living Lab (Lisbon LL) targeted in BWS are (i) a growing resident population and economy, dependent on distant freshwater resources (up to 100 km), (ii) climate challenges (e.g., droughts and floods) and (iii) need to increase urban green areas. Actions to address these challenges include (i) improving the water supply / demand management and ultimately the city's water-energy-phosphorus (WEP) footprint while increasing the green areas, (ii) promoting the safe use of alternative sources (e.g., reclaimed water), and (iii) promoting climate-ready (water-energy efficient, climate-change proof) housing. Figure 35 presents the **Lisbon LL ambition**.

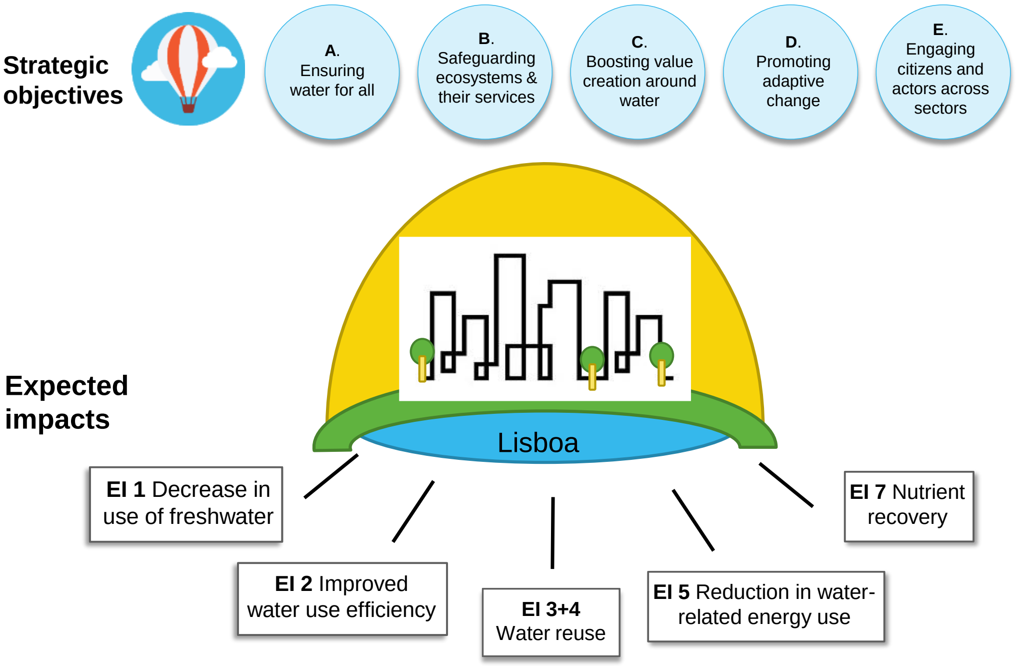


Figure 35: The Lisbon LL ambition.

The Lisbon LL gathers six partners working for these goals:

- **CML** (Lisbon Municipality) is the Lisbon case-study problem owner; as such, CML makes the city's data and resources available as a living lab in the project, promotes the Lisbon Community of Practice (CoP), participates in the BWS Innovation Alliance, tests the Lisbon LL

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[6] This section has been included in both deliverables (D3.4/D3.5) since it provides information on the integrative use of tools that are applied in Lisbon case. Six tools have been developed as part of this LL work, which have been split and documented in the 2 toolkit reports.

solutions developed within the project and plays a key role in disseminating and promoting the adoption of these solutions among its extensive networking platforms. CML also develops the urban water cycle observatory, through a linked third-party – LEN (Lisboa E-Nova).

- **LNEC** (Laboratório Nacional de Engenharia Civil) is the mentor and R&I partner for the Lisbon LL, responsible, among others, for the development of the knowledge, methodologies and analytics behind the tools of (health and environment) risk assessment, reclaimed water quality modelling in the distribution network, WEP balance, and decision support of alternative courses of action based on performance-cost-risk indicators. LNEC also participates in the development of the water reclamation protocol for potable water reuse in beverage industry for artisanal craft beer production.
- **ADTA** (Águas do Tejo Atântico) is the water utility enabler of Lisbon LL, providing real data (on wastewater treatment and water reclamation) for several tools and is responsible for conducting the pilot tests needed to develop the water reclamation protocol for potable water reuse in craft beer production.
- **ADENE** (Agência para a Energia) is a solution provider responsible for developing the knowledge and tools for climate-readiness certification.
- **BASEFORM** is a solution provider responsible for developing the software for the risk assessment, reclaimed water quality modelling in the distribution network, WEP balance and decision-support tools.
- **ICS-UL** (Instituto de Ciências Sociais da Universidade de Lisboa) is a cross-cutting R&I partner integrating the social sciences and humanities and is the Lisbon CoP moderator.

Case study description

Lisbon LL aims (i) to demonstrate the potential for safe potable water reuse in the beverage industry in the **mid to long run**, and (ii) in the **short term**, to promote water (and related energy and phosphorus) efficiency, water smart allocation (fit-for-purpose quality), circular economy, and safe non-potable urban water reuse, work that is to be developed within the following tasks:

- Task 2.4.1 Protocol for water production from wastewater,
- Task 2.4.2 Water matrix and concepts behind water observatory,
- Task 2.4.3a Urban WEP balance,
- Task 2.4.3b Risk management - health component,
- Task 2.4.3c Risk management - groundwater component,
- Task 2.4.3d Reclaimed water quality modelling in the distribution system,
- Task 2.4.4 Water-smart for climate ready certificates.

8.2 Application of tools and methods

8.2.1 Selected tools and technologies of pilots

Lisbon LL developed methods, algorithms and software for a smart allocation of the water quality (fit-for-purpose) and quantity (water efficiency) in the city (Figure 36), delivering the following Data Application Products (DAPs)[7]:

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[7] Tools #17, #20, #33 are described in D3.4 ”The monitoring, negotiation and decision support solutions toolkit – Final release”.

- **Tool #20 - Urban Water Cycle Observatory**, to systematise, collect and facilitate access to data at city the level and at the single users/consumers level (DAP 2).
- **Tool #24** – **Reclaimed water quality in the distribution network**, for modelling reclaimed water quality in the distribution network (DAP 2).
- **Tool #25** - **Water-Energy-Phosphorus balance planning**, a module for the quantification of the city water cycle components and assessment of water-energy-phosphorus balance for non-potable uses (DAP 2).
- **Tool #27** - **Risk assessment for urban water reuse**, a module for the implementation of alternative water sources (DAP 6).
- **Tool #17 - Environment for decision support and selection of alternative courses of action**, a decision support tool for WEP sustainable management based on performance-cost-risk assessment (DAP 2), which integrates the above three tools (#24, #25, #27)
- **Tool #33 – Climate readiness certification**, with climate-readiness index and the subsequent auditing/certification mechanism for Climate Readiness of households, buildings and neighbourhoods (DAP 10).

Furthermore, a protocol for food-grade water production from treated wastewater by ozone/reverse osmosis for craft beer production is being demonstrated for communicating and disseminating (C&D) safe water reuse and thus building trust in this resilient, rainfall-independent water source. The development of this **Technology Product** (TP), TP1, does not involve software production, and consequently there is no link to T3.5 in this case.

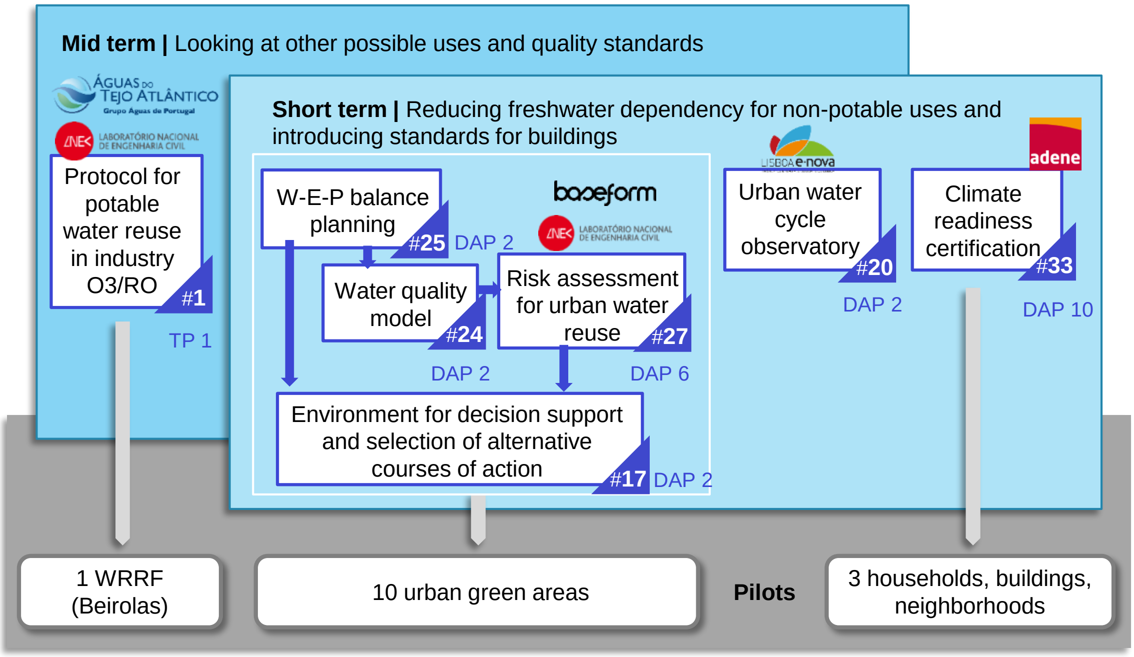

Figure 36: The LL Lisbon tools.

The links with Lisbon LL **pilots** (WP2, tasks 2.4) are the following (Figure 37):

- TP#1 / task 2.4.1: 1 ozone oxidation/reverse osmosis (O3/RO) pilot installed at Beirolas water resource recovery facility (WRRF) for demonstration of water reuse in the food industry, namely, in artisanal craft beer production (direct potable reuse, DPR).
- Tool #25, Tool #27, and Tool#17 (and at city level, Tool #20) / task 2.4.3 (and task 2.4.2): 10 green urban areas for WEP sustainable management based on performance-cost-risk assessment, comprising 2 non-potable water uses (irrigation and landscape lakes) and 4 potential water sources, two currently used (drinking water and groundwater) and two new, i.e., reclaimed water and spring water from the Águas Livres aqueduct.
- Tool#24 / task 2.4.3: 3 reclaimed water distribution systems (RWDSs) for water quality modelling (1 rooftop-garden's irrigation circuit, 1 reclaimed water distribution network in the city (near "Frente Ribeirinha"), 1 park's irrigation circuit), to support the residual chlorine management for a safe water supply.
- Tool #33 / task 2.4.4: 9 pilots for water-smart climate-readiness certification (3 households, 3 buildings, 3 neighbourhoods).

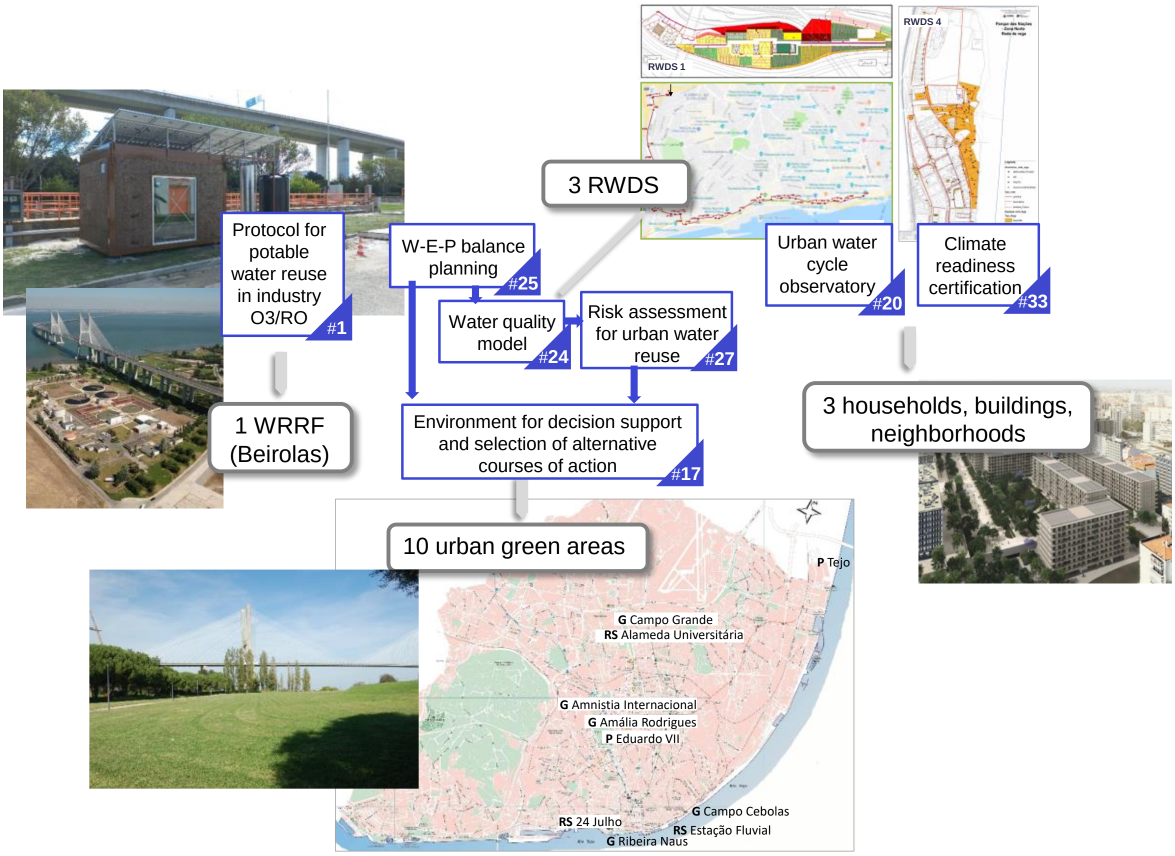

Figure 37: The LL Lisbon pilots.

In Annex E, a summary table of the LL is provided (Section 16.3).

8.2.2 Integrative use of tools, pilot interaction and data flows

Making Lisbon a water-smarter city implies the involvement of different stakeholders in the provision and use of water. Thus, the Lisbon LL is focused on the development of software tools to facilitate safe water reuse and improve water-energy-phosphorous efficiency in non-potable uses, improving Lisbon's climate resilience to water scarcity. The following approaches were considered for the desired transformation into a water-smarter society:

- To increase the citizens' awareness about the local context regarding the water use in the city via the provision of appellative information on water consumption, wastewater treatment, and fit-for-purpose water use, particularly, safe water reuse.
- To inform individual entities (public or private major water consumers) about their water consumption, in case of smart water metering, and increase their awareness on wastewater treatment and fit-for-purpose water use, particularly, safe water reuse.
- To support the decision-making process of water demand planners and managers in urban, municipal and water utility contexts, by delivering an overview of the current water supply and water demand in the city to enable prioritizing strategic and tactical planning options.
- To guide or assess the promotion of climate adaptation in housing via a certification process used by housing owners and planners.

The level of integration between these tools naturally depends on the purpose for which they are used, which in turn is associated with the target user. Thus, the software applications developed at the Lisbon LL were designed to work as follows:

- Use of the **tool #20** alone with two distinct objectives in mind:
  - To increase the citizens' awareness of the urban water cycle by providing yearly-based, easy-to-read information on the city's water cycle (public access, top-down approach).
  - To promote an easier, faster, and more flexible way to access the detailed water consumption data on water facilities (usually, large consumers) and to provide a repository of information (private access, bottom-up approach).
- Integrated use of **tools #17, #24, #25, and #27** with the following objective:
  - To support urban management authorities and water utilities in making smart and climate-resilient water decisions for an efficient water-energy-nutrient balance in the city including safe water reuse, by enabling direct comparison of alternatives for matching water supply and water demand to satisfy specific non-potable uses.
- Use of the **tool #33** alone with two distinct objectives in mind:
  - To guide the design and assessment of the climate readiness potential of existing households, buildings or neighbourhoods.

Although they were not designed for integrated use in a single decision-making process, there are links between tools #20 and #33 and between these and the #17, #24, #25 and #27 tool group:

- From tool #20 to tool #25 - detailed information on water consumption locations, e.g., municipal green areas, when using the private access mode.

- From tool #17 to tool #20 or to tool #33 – general information on water management planning broken down by alternative water sources, as well as information on water related energy and phosphorus content.

Tools #17, #24, #25, and #27 were designed for **integrated use**, with each tool representing a step in the decision-making process (Figure 38), namely:

- Step 1 (tool #25) – Matchmaking of water sources (potential supplies) and water demands to enable the design of supply chain solutions (the shorter and more circular the better) to a set of potential users of non-potable water, namely, reclaimed water and other water sources alternative to those currently in use (e.g., groundwater). The supply/demand alternative combinations (matches) over a target period are assessed through a range of performance and cost metrics, for supporting strategic and tactical (aligned) planning (e.g., volume availability, cost, energy content, carbon footprint, nutrient content). This step produces the alternative combinations targeted for decision-making in step 4.
- Step 2 (tool #24) – In case of reclaimed water use, it is convenient to map and quantify risk in the water distribution network. This tool is a complete hydraulic and water quality extended-period simulation model for pressure flow networks. It complements Tool #25 in assessing the additional cost, risk and performance changes that may be required for the supply/demand combinations chosen to make use of existing or new distribution networks.
- Step 3 (tool #27) – In case of reclaimed water use, it is necessary to assess human health and environmental risk considering the applicable legislation (e.g., the Portuguese Decree-Law 119/2019) and the best practice as presented, for example, in relevant ISO standards (series ISO 16075 Guidelines for treated wastewater use for irrigation projects (2020, 2021), ISO 20426:2018 Guidelines for health risk assessment and management for non-potable water reuse and ISO 20761:2018 Guidelines for water reuse safety evaluation), based on which the EU Regulation 2020/741[8] on minimum requirements for water reuse in agricultural irrigation was developed. Tool #27 works as a risk-based gatekeeper that must be cleared for any supply/demand combination to be considered for assessment in Tool #17. Depending on the risk level targeted for completion, it will be rejected (eventually go back to tool #25 for redesign), or otherwise cleared and move on to Tool #17.
- Step 4 (tool #17) – For all matchmaking alternatives, a final prioritization between the supply/demand combinations developed in Tool #25 and qualified by Tools #24 and #27 support the decision on the course of action for a water-smarter city, for the specific case studied or others within comparable contexts. This tool is designed to enable users to select the best water source combinations to satisfy specific non-potable uses, and to align with strategic and tactical planning options on the governance of water sources and water uses in an urban setting. As previously referred, the supply/demand alternative combinations are assessed and prioritized through a subset of standardized, user-selected key performance/cost/risk metrics, extracted from those employed to qualify the initial selection in Tool #25 (e.g., volume availability, cost, energy content, carbon footprint, nutrient content) and to further qualify the risk assessment in Tool #27, as well as in Tool #24, if applicable, e.g., in case a network to distribute very-high quality reclaimed water for unrestricted urban uses

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[8] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32020R0741

(class A, according to 119/2019[9] and EU reg 2020/741)) is needed, as in Lisbon city (Lisbon LL).

Figure 39 illustrates the data flows among tools #17, #24, #25, and #27 and the pilots.

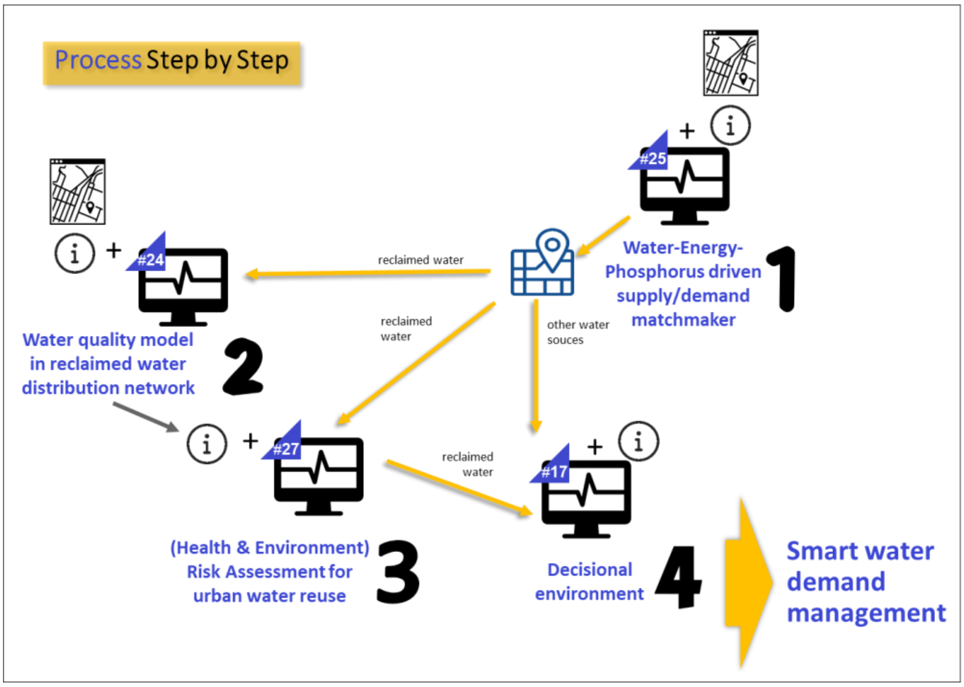

Figure 38: The LL Lisbon tools for a smarter water demand management and pilot interaction (step-by-step process).

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[9] https://diariodarepublica.pt/dr/detalhe/decreto-lei/119-2019-124097549

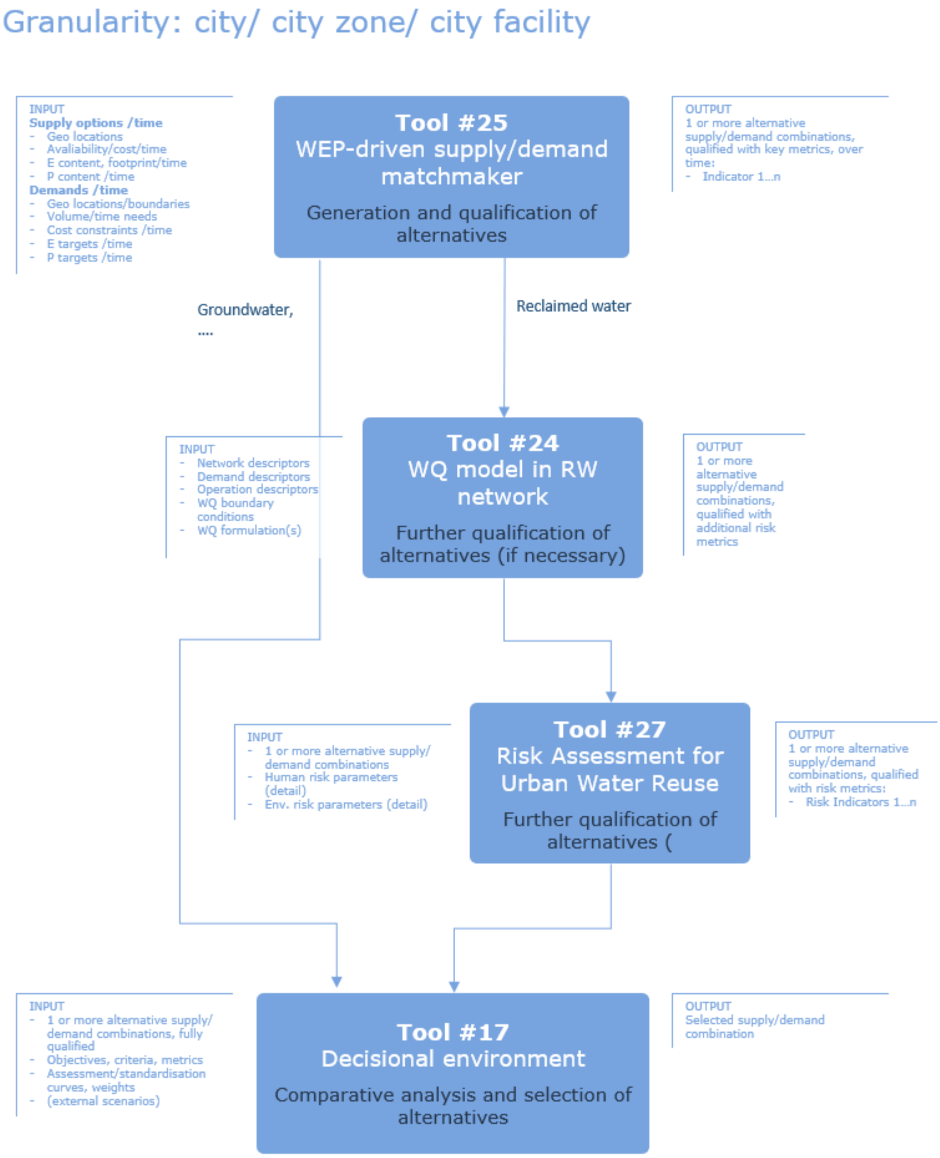


Figure 39: The LL Lisbon tools for a smarter water demand management and its data flows (start from top, tool #25).

More detailed information on the preprocessing stage and setup process of tools is provided in Annex D (Section 15.3).

8.2.3 Results

Having in mind the **Lisbon LL ambition** (section 8.1), the following results can be drawn at this moment for tools #25, #24, #27, and #17 (coherently with the outputs illustrated in Figure 39) and for tools #20 and #33:

1. Improving water supply-demand management

- **Tool #25 W-E-P balance planning** was successfully developed and as planned, is a matchmaking environment that enables the design of supply solutions driven by the demand(s) to be satisfied and translated as time series of required monthly volumes over a pre-specified period – “alternatives”. An “alternative” consists of the combination of the available water sources to make up the required monthly volumes in a predefined group of water demand points (e.g., green areas), while complying with the energy and nutrient contents as desired. Such combinations are characterized by the degree to which they satisfy the required volumes over time, as well as by their energy consumption, nutrient content, and cost. By facilitating the linking of water consumption locations (geographic representation) with various information related to those water demand points, tool #25 can function as a design planning tool since it allows the testing of different water management solutions, which are easily translated by the alternatives.
- **Tool #25** was designed to function both as an information repository and as a communication channel between different stakeholders – critical issues during planning and developing water-smart projects. The information to be provided to the software consists of a time series of required monthly values of water volumes, water price or P consumption over a pre-specified period, and unit values with the estimation of some variables. The full geographic representation of the sources and demands helps planners and decision-makers in urban management, municipal, and water utility contexts define water supply solutions. Finally, the software allows the introduction of text to justify the information as well as the design of alternatives. It is considered that this aspect (i.e., introduction of text) is of great use, both in a revisitation of the planning exercise, and in its consultation and discussion by different decision makers.
- The energy consumption associated with each alternative results from two factors: the energy consumption associated with water production (which naturally depends on the origin of the water), and the energy consumption associated with water distribution, i.e., placing the water at that point of consumption. This information, which results from the planner’s concrete knowledge of the locations of water consumption and available sources, is introduced in **Tool #25** through the description menu of each alternative. Tool #25 also includes information on water losses and carbon footprint related to each water source. In this way, it is possible to identify the contribution of the improved water supply-demand management to strategies implemented at the municipal level, through a water losses management plan or a climate action plan.
- **Tool #17 Environment for decision support and selection** of **alternative courses of action is** completed and enables users to select the best water source combinations to satisfy specific non-potable uses and enables prioritizing strategic and tactical planning options on the management of water sources and water uses in an urban setting. The supply/demand alternative combinations are assessed through a range of standardized, user-selected performance, risk, and cost metrics, complementing those employed to qualify the initial selection in Tool #25 (e.g., volume availability, cost, energy content, carbon footprint, nutrient content). To ensure the alignment of decisions for improving water supply/demand management with the Lisbon LL Strategic Agenda, the metrics correspond as much as possible to metrics integrated in the BWS Evaluation Framework (Tool #34) or else contribute to their calculation.

- **Tool #20 Urban Water Cycle Observatory** was upgraded as foreseen. Its public access component provides visually appealing information on the urban water cycle (including the consumption of drinking water, the treatment of wastewater and the production and use of reclaimed water) as a means of increasing citizens' water literacy, hoping to make them more willing to be active agents in managing water demand in the city. In 2022, there were 8500 visits to the website and until 22/06/2022, 7200 visits were registered. Its private access component can help those responsible for large water consumption (municipalities and private institutions of public interest) to be more efficient in managing water use in those facilities. Processing raw data from smart meters by type of use provides useful information.

2. Testing the use of alternative water sources – the case of water reuse

- **Tool #27 Risk assessment for urban water reuse** was successfully developed. It provides a user-friendly solution for carrying out human health and environmental risk assessments, requiring a basic knowledge of risk management and of the legislation applicable to water reuse. For this purpose, a methodology for hazard exposure scenario building was developed from scratch and a process for human health and environmental risk assessment based on ISO standards and the EU Regulation 2020/741 on minimum requirements for water reuse was defined (Ribeiro and Rosa, 2022).

- **Tool #24 Reclaimed water quality model in the distribution network** is completed and tested in three pilots (distribution networks). It simulates the advection, mixing, and transformation of waterborne parameters in reclaimed water (Costa et al., 2021). It aims primarily at mapping and quantifying risk in reclaimed water distribution networks. In the case of Lisbon, where the strategy for water reuse is being decided, Tool #24 has significant potential for supporting the design and monitoring of a public reclaimed water distribution network.

- **Tool #25 W-E-P balance planning** allows the integration of phosphorus circularity in a more comprehensive decision-making process regarding the management of water supply/demand in municipal (and other) green areas. It conducts a phosphorus balance in water consumption sites (gardens and other green areas) by comparing the P fertilisation needs throughout the year with what can be supplied through reclaimed water. The assessment of the fertilisation potential from the reclaimed water use is aligned with the need to improve resource efficiency and support the circularity of phosphorus – phosphate rock and specific form of P4 are currently on the EU Critical Raw Material List.

3. Promoting climate adaptation in buildings

- “3” is the number to consider for the promotion of climate ready housing, as there are three aspects to consider: the evaluated dimensions (water efficiency, water-energy nexus and climate adaptation), the scale of analysis (household, building and neighbourhood) and the moment of certification (design phase, in construction and in use). This was the basis for the development of the **Tool #33 Climate readiness certification**, which has been tested at the abovementioned scales of analysis.

This section will be completed with final results and reported through Milestone 32 at month 45 (which is suggested to be added).

8.3 Lessons extracted

8.3.1 Overview

Having in mind the **Lisbon LL ambition**, the following lessons can be drawn at this moment:

1. Improving water supply-demand management

Pros

- The integrated use of tools #25 and #17 enables the decision-makers to define and prioritize combinations of two or more supplies, including reclaimed water, in satisfying non-potable water demands in urban or regional contexts, based on factual evidence. It is important to align the bottom-up (*i.e.*, demand-driven) decisions with strategic and tactical planning at city level. This alignment is provided by specifically designed assessment variables such as volume availability, cost, energy, carbon footprint or nutrient content. These variables are used in or contribute for the calculation of metrics of the BWS assessment framework – strategic planning (tool #34). It is also important to have in mind the contribution of water supply-demand management to specific goals, such as energy neutrality and climate action.
- The integrated use of tools #25 and #17, together with tools #24 and #27 (in case of water reuse), goes beyond the state-of-the-art because it provides the ability to match water supply to demand, while managing water volume, cost, energy, nutrients and risk, with full GIS-compatible georeferenced capabilities. The result is a streamlined, simple-to-use analysis of supply and demand matchmaking that can be operated by decision-makers without deep technical knowledge, as well as by experts with full depth analysis.
- Social acceptability for an improved water supply-demand management can be achieved by increasing the citizens' awareness about the local context regarding the water use in the city and informing individual entities about their water consumption (tool #20)

Challenges

- Compiling information about water demand for non-potable uses in the city and available water sources can be difficult. Applying tools that function as data repository (e.g., tools #25, #20) catalyses proper data management.
- Exploiting the full potential of a smart-water allocation in Lisbon requires the existence of a public reclaimed water distribution network (nowadays available only in some areas), with sound asset management.

2. Testing the use of alternative water sources – the case of water reuse

Pros

- Tool #27 implements a novel, user-friendly risk assessment framework for water reuse in non-potable uses. Thus, it makes expert-knowledge available for risk managers and stakeholders responsible for non-potable water uses, guiding the user through the inherently complex context of public health and environmental risk guidelines and ensuring compatibility with the concepts in Regulation (EU) 2020/741 and relevant ISO standards (including ISO 20426 and ISO 16075).

- The new, innovative algorithm for modelling chlorine decay, as a function of key water quality parameters, implemented in tool #24 allows to analyse the public health risks posed by using pipe networks for transporting and distributing reclaimed water. This simulation supports the assessment of the need for disinfection and chlorine residual supply in the design of distribution networks or, in the case of already constructed networks, to evaluate the efficiency of the disinfection process to introduce adjustments if necessary.

Challenges

- The simulation of the evolution of reclaimed water quality in distribution networks, namely in irrigation networks, requires a temporal and spatial granularity of the base data that may be difficult to achieve. The state of conservation of the water distribution network can affect its hydraulic performance. These two aspects constrain the calibration of mathematical models, thus affecting the quality of simulation results.
- The results naturally depend on the quantity and quality of the information available for the calibration and use of the hydraulic and water quality models (as in tool #24). The effort required to obtain this information is largely compensated by the benefits that the control of the disinfection process of reclaimed water has on the risk management associated to water reuse, as well as on the investment and operational cost of the reuse system.
- The decision on at what point of a WWTP the treated wastewater should be subject to further treatment depends on the evolution of European regulations, particularly, the Directive 91/271/EEC concerning urban waste-water treatment, and it is important to recognise this uncertainty when planning on a strategic level. For example, for phosphorus, the likely more stringent limit values in effluent discharge to receiving waters may be avoided by promoting phosphorus circularity via water reuse for irrigation. This challenge on water discharge can turn into an opportunity for water reuse.

3. Promoting climate adaptation in buildings

Pros

- Tool #33 assesses in one certificate three dimensions: water efficiency, water-energy nexus, and climate adaptation, providing a transversal performance analysis that allows for the consideration and adoption of water efficiency and climate adaption measures in different stages of the building: design phase, new construction, or in operation. It can be applied to residential, small service or commercial buildings, as well as to “neighbourhoods” considering both buildings and outdoor areas.
- The climate adaptation dimension assesses the local policies and strategy implemented in the project area, it assesses the climate risks of the project’s implementation region, and according to the identified climate risks of the region (water scarcity, droughts, floods, heat waves), it assesses the project response to be adapted to those risks.
- Different stakeholders, from policymakers to urban planners, building developers and property owners, are aware of the building's performance and its adaptation to the local and regional climate, benefiting from a robust decision support tool in the different phases of the project development.
- It expands the already established AQUA+®, which promoted more than 300 audits of the residential sector carried out in mainland Portugal between 2020 and 2023 were analysed and

it was concluded that AQUA+ identified a potential use of water from alternative sources of around 20 per cent of water consumption, around 27 m3/year per property for non-potable purposes, in a country with frequent regional episodes of severe water scarcity.

Challenges

- Difficulties often found in the existing buildings certification projects due to the lack of infrastructure documentation of in-use buildings.
- CRC are voluntary and dependent on the perception of values that citizens give to water (which due to externalities doesn't often have its actual cost), but this situation can change and in the future CRC could be evaluated as a complement to the mandatory energy efficiency audits and be adopted in new buildings in the becoming years.

Having in mind the Lisbon LL ambition, the development of the tools and their application (overall) were **useful** to the Lisbon Municipality (LL owner) through the following aspects:

- Improving water supply-demand management – tools #20 & #25 function as coherent information repositories, enhancing a common understanding about water supply-demand management requirements in green areas (tool #25), alignment of decisions taken at tactical and strategic levels (tool #17), improving the knowledge about water use efficiency in municipal housing (tool #33);
- Testing the use of alternative water sources (water reuse) – improving the knowledge about the chlorine decay in irrigation networks (tool #24), guiding the risk assessment for water reuse in the irrigation of the 38-ha park used within the World Youth Day (tool #27);
- Promoting climate adaptation in buildings – using the Climate Readiness Certification within the municipal affordable house-renting program (tool #33).

These tools are to be adopted by the Lisbon Municipality within the framework of the WOLLL (Water-Oriented Living Lab of Lisbon).

Regarding Lisbon's tools, their **strengths and limitations** are the following.

Strengths:

- decision-making oriented (tools #17, #20 & #25);
- water-demand driven analysis (tool #25);
- user-friendly provision of expert-knowledge on risk (tool #27);
- specialized reclaimed water quality model in distribution networks (tool #24);
- transversal analysis of water, energy and climate adaptation measures (tool #33);
- citizen engagement (tools #20 & #33).

Limitations identified in the application of the tools:

- compiling information with temporal and spatial granularity for tools #24 and #25 may be difficult and time consuming, but once collected the tools work as repositories;
- water smart metering data may be difficult to obtain (tool #20);
- the lack of technical documentation from buildings is a certification bottleneck (tool #33).

Lisbon tools also provided **new (relevant) knowledge to address the faced challenges** which was incorporated in the tools:

- Improving water supply-demand management – tailoring a decisional framework based on performance-cost-risk KPIs to assess water supply-demand management alternatives (tool #17), innovative matchmaking approach for combining water sources and demand sites (tool #25), new KPIs to promote efficient water use (tool #20, private access);
- Testing the use of alternative water sources (water reuse) – identification and modelling the chlorine (bulk and wall) decay mechanisms in reclaimed water containing ammonia (tool #24), innovative approach for building hazard exposure scenarios in water reuse risk assessment (tool #27);
- Promoting climate adaptation in buildings – definition of metrics to assess the water-energy nexus and climate adaptation dimensions (tool #33).

Regarding the defined **impacts** which were mentioned in tools' section (5.3.3, 5.4.3 and 5.6.3) and in the respective parts of D3.4, the Lisbon tools contributed as follows:

- Decrease in the use of freshwater (EI1) – The expected reduction of 5% for 2024 is mainly related with the water reuse for irrigation of municipal green areas instead of drinking water (abstracted from distant freshwater resources) and groundwater (from local boreholes) (tools #17, #24, #25 & #27).
- Improved water use efficiency (EI2) – The results are expected to be achieved at mid-term (a 16% reduction in 2040) are mainly related with an improved management of water losses in irrigation networks in result of the analysis of water supply/demand alternatives (tools #17 & #25) and the focus on citizen engagement via the Water Cycle Observatory and the certification of water use efficiency in buildings (tools #20 & #33).
- Increased water reuse (EIs 3 & 4) – The expected values for 2024 (increase of 4% and 18%, respectively) are mainly related with the promotion of water reuse as appropriate water source for non-potable uses (tools # 17, #25 & #33) and the support to a safe water reuse (tools #24 & #27).
- Reduction in water-related energy use – The results are expected to be achieved at mid-term (a 20% reduction in 2040) and are mainly related with an improved and sustainable water supply/demand management (tools #17, #24, #25 & #27) and, also, from an increased citizen engagement (tools #20 & #33).
- Nutrient recovery – The expected recovery of 4% of phosphorus for 2024 is related with water reuse in irrigation (tools #17, #24, #25 & #27).

The testing of the Lisbon LL tools improved the **"water smartness"** of the city and the related strategic objective mentioned under each tool (5.3.3, 5.4.3 and 5.6.3 and in the respective parts of D3.4) because it was possible to move towards a fit-for-purpose water allocation (SOs A & B and tools #17, #24, #25 & #27), an increased water efficiency (SO E and tools #17, #20, #25 & #33) and safe water reuse (SOs C & D and tools #24 & #27).

8.3.2 Data

The extent to which the tools' functionalities are affected by the data availability naturally depends on the data spatial and temporal required granularity, as follows:

- Tool #24 uses complete descriptors for network assets, demands, operational constraints and rules, and state variables describing hydraulics, travel time, and transformation of water quality parameters, referring to specific distribution networks;
- Tool #20 (private access) requires smart metering data from enrolled water consumers;

- Tools #17 & #25 involve the use of calculated metrics and, in #25, previously processed data presented in time series (monthly values), referring to the city and to specific water use locations (e.g., gardens);
- Tools #27 & #33 consist in close questions, which are answered after a visit to the evaluated sites.

Naturally, it is important to ensure adequate quality of the data.

The data issues encountered in the Lisbon LL were handled as follows:

- Conducting tailored monitoring campaigns (tool #24),
- Promoting the use of the tools as a data repository system to improve data management (tools #25 & #20),
- Engaging potential users in working sessions (tool #17),
- Providing guides for data collection (tools #27 & #33).

The key lessons learned regarding data issues are the following:

- It is crucial the early involvement of the different data providers and water users in the decision-making process (tools #17, #24, #25 & #27);
- It is important to present accessible, comprehensive and clear data in a way users feel informed (tool #20);
- The provision of expert-knowledge can be achieved via a user-friendly framework (tool #27);
- The provision of technical documentation from buildings is important for the certification (tool #33).

9 Conclusions

The aim of BWS is to accelerate the transformation to water-smart economies and societies in coastal Europe and beyond. Among other results that the project delivers to achieve this objective, different smart data applications have been released to support more efficient and safe allocation and use of resources.

D3.5 reports the final release of 8 such applications (developed in tasks T3.2 – T3.7 in collaboration with the Living Labs) as part of the water cycle modelling and assessment solutions toolkit. The 8 tools have been applied and tested in 3 LLs. Those are Flanders, East Frisia and Lisbon. Summary and concluding remarks on the 8 tools of D3.5 are provided below. These are considered to be preliminary conclusions, as the tools will continuously be applied (and optimised where necessary) throughout the project duration.

9.1 Improving water smartness and helping mitigation/adaptation to climate change

The application of tools in the 6 LLs targeted towards the **increase of water smartness by contributing to the 5 defined strategic objectives**: SO A - Ensuring water for all relevant uses, SO B - Safeguarding ecosystems and their services to society, SO C - Boosting value creation around water, SO D - Promoting adaptive change towards resilient infrastructure and SO E – Engaging citizens and actors across sectors in continuous co-learning and innovation.

For the Flandres case, the application of UWOT contributed to several strategic objectives by assisting in identifying resource efficient water allocations (SOA) and new, untapped circular water supply options (SO B). It has also provided insights on the impact different water-smart measures (such as wastewater reuse, CCRO and urban rainwater harvesting) can have for regional water resources management (SOC and SOD). SuTRa has been linked to SOA by contributing to MAR technologies by giving the potential to increase availability of water in dry periods via the storage of water in periods with excess water. Similar to SuTRa, QMRA+ impacts SOA since it was used to evaluate various treatment schemes for microbial safety of the produced water for the intended use. It also contributed to SOE by providing a common basis for the stakeholders in the LL to discuss water safety and identify key choices in this aspect and offers the mean to communicate the safety of the water to citizens. Overall QMRA+ tool contributed to the design of a smart water reuse system by allowing to balance water safety against other aspects such as costs, resources and environmental impact.

For East Frisia, the Regional Demand-Supply Matching GIS tool (#23) in combination with UWOT (#22) contribute to overcoming the key issues in water and resources management at LL East Frisia in the way that an efficient fit-for-purpose allocation of resources to all sectors is enabled (SOA) by analysing alternative water supply opportunities and supporting the users in the decision-making process, thus, reducing the pressure and conflicts with regards to the local groundwater resources. Further, by identifying untapped and new circular water supply options, tools #22 and #23 help to reduce the pressure on available groundwater resources in the region (SOB). The Short-term demand forecasting tool (#28) addresses the rising issues of peak loads within the water supply network of OOWV which results are also used for raising awareness for the district specific water consumption, thus contributing to SOE. Tool #22 is also linked with SOB and SOC since it produces results that are useful for the implementation of greywater recycling technology and the potential reuse of treated greywater at household level (e.g. toilet flush) and the fact that supports simulation of different intervention under different climatic scenarios which help the design process and planning towards more resilient infrastructures.

For Lisbon, the application of tools improved the “water smartness” of the city because it was possible to move towards a fit-for-purpose water allocation (SOs A & B and tools #17, #24, #25 & #27), an increased water efficiency (SO E and tools #17, #20, #25 & #33) and safe water reuse (SOs C & D and tools #24 & #27). With regard to tools impacts, it is expected to reach a decrease in use of freshwater by 5% for 2024 which is mainly related to the water reuse for irrigation of municipal green areas instead of using drinking water (abstracted from distant freshwater resources) and groundwater (from local boreholes) (tools #17, #24, #25 & #27). Improved water use efficiency is expected to be achieved in the mid-term (a 16% reduction in 2040) with an improved management of water losses in irrigation networks in result of the analysis of water supply/demand alternatives (tools #17 & #25) and the focus on citizen engagement (via tools #20 and #33). Expected values for water reuse for 2024 is estimated to reach 4% (treated ww used/water supplied) and 18% (treated ww used/total ww produced) with the promotion of water reuse as appropriate water source for non-potable uses (# 17, #25, #33) and support to a safe water reuse (#24 & #27). Reduction in water-related energy use at mid-term is estimated about 20% (in 2040) due to improved and sustainable water supply/demand management (tools #17, #24, #25 & #27) and, also, from an increased citizen engagement (tools #20 & #33). Water reuse in irrigation is expected to allow recovery of 4% of phosphorus for 2024 (tools #17, #24, #25 & #27).

The B-WaterSmart tools also support **mitigation and adaption to climate change**. For the Lisbon LL, the green-blue infrastructure is applied for tackling climate change challenges related to droughts, floods and heat waves. As reclaimed water is a sustainable source, largely independent of climate uncertainty, it can contribute to reducing pressure on strategic freshwater resources and to allow resources’ recovery, such as phosphorus. The Lisbon LL solutions help to mitigate the city’s water scarcity through a fit-for-purpose water allocation (tools #17, #25 & #33), water efficiency (tools #17, #20, #25 & #33) and safe water reuse (tools #24 & #27). A greener Lisbon is a more adapted city to climate change. With regard to Flanders’s tools, the QMRA+ tool allows to determine the safety of alternative water sources and treatments. Thus, systems that help mitigate or adapt to climate change could be compared to alternatives with respect to their safety. SuTRa is directly linked to MAR which is a technique that helps to mitigate climate change by storing excess water for use in dry periods. This tool aims to help to take away certain barriers (pathogen risk) to adaptation of MAR in agriculture. The stormwater management system aims to mitigate effects of increased heavy precipitation events and longer periods of droughts due to climate change through buffering run off during precipitation effects and make this water available to agriculture. For the application in Flanders, as part of the analysis, water-smart solutions have been stress-tested within UWOT model against multiple future unknowns (such as water demands and salinity levels), thus highlighting how robust they can be against an uncertain future. The future unknowns that are considered, such as the increase in river salinity, are direct effects of climate change. Moreover, combined effects with other unknowns, such as an increase in population and thus water demands, have been explored. In East Frisia, increased peak load demands, increasing water demands in general, as well as increasing pressure on local groundwater resources are direct impacts of climate change. By addressing these key challenges in the region, the three tools provide a direct contribution to mitigate and adapt to climate change. Additionally, the UWOT model investigates different water demand options under different climatic and demand change scenarios (changes on rainfall or temperature) to help decision-makers to adjust their water management strategies and make the infrastructures more adaptive to climate change. Along with the Regional Demand-Supply Matching GIS tool can help to promote the adoption of technologies for water reuse in order to decrease freshwater resources thus adapting to water scarcity due to climate change.

9.2 Concluding overview on the tools

UWOT (tool #22) is a tool which can be used for the simulation of the urban water cycle by modelling individual water uses and technologies and aggregating their combined effects at any scale e.g., regional. With regard to the Flanders case, the primary goal of its application was to assess the demonstrations in their regional context with regard to their impact on water availability and resilience of the water system in support of the two cases (a) exploring aspects of the storage basin and water production system in the city of Woumen, (b) modelling an upscaling of the stormwater retention pond in the area of Mechelen. UWOT has also been applied in the East Frisia LL where the goal was to simulate the water flows (water demand and supply points) in a test case and to investigate alternative scenarios based on different climatic and demand change conditions or with the implementation of partially decentralised technologies. One of the primary lessons learned from the tool's application in both cases was that the tool can be used to model the expected effectiveness of measures with regards to water quantity under different scenarios. However, results can be limited by data availability, and results should be validated together with stakeholders.

The regional demand-supply matching GIS tool (tool #23), as tested in the East Frisia case, is a QGIS plugin for data visualization and processing with the scope to match demand-supply at a regional level e.g., the user can see all available water sources with an emphasis on the distance by querying the location in GIS. Within BWS, it has been used to identify i) possible consumption hotspots and areas of water shortage, ii) alternative water resources or areas with available water sources and iii) water drain from one region to another region. Thus, it assists in creating awareness regarding the regional limitations of water availability in quantity and quality. From its application, it was proven that it has the potential to become a key monitoring and decision-making tool for sustainable water resources and water demand management in the region. However, its acceptance and usefulness very much depend on the input data available. The highest benefits from the tool can be derived if data sets are regularly updated and enriched by new information collected from stakeholders.

The short-term demand forecasting tool (tool #28) is another tool applied in the East Frisia LL. It is a tool which generates water demand forecasts for the next (or current) day, which can be used a) to identify high peak loads in certain regions that require actions by the water utility, b) to train machine learning models and use them to generate and visualize demand forecasts and c) to enable aggregations of forecasts for multiple smart meters to achieve the desired spatial resolution. The results of the case study application prove the usefulness of the tool for predicting future load profiles of municipal water demand in the districts under investigation. Nevertheless, it was realised that the accuracy of the prognosis very much depends on the positioning of smart meters in the network and the demographic information available on this section of the supply network. For future studies, a large-scale implementation of smart meters would be desirable instead of summarized measurements of small city districts in order to enhance the prognoses´ quality.

For the case of East Frisia, UWOT and the Short-term demand forecasting tool are based on a small-scale analysis, while the regional demand supply matching tool is used for large scale analyses. The data flow between the tools can therefore be described in the same way that UWOT and STDFT are producing water demand scenarios that can be included in the RDSMG for future-oriented scenarios.

QMRA+ (tool #26), applied and tested in the Flanders case, is a tool that helps users estimate the microbial health risk of using various water sources, including reuse of wastewater, to assess the exposure of humans to this product water and the pathogens it may contain after being treated. The tool has been used within BWS to evaluate various design and treatment options for the Flanders drinking water case regarding the microbial safety risks. In the Woumen case, QMRA+ was used to help design the effluent reuse demonstration system by comparing the safety of various treatment options and enhancing certain points of the existing drinking water system. Its application to the case study revealed that QMRA is a new and complex topic for most water professionals and other stakeholders. The QMRA+ tool proved to be very accessible, and users quickly learned the principles of QMRA through the tool and were at the same time able to apply these principles to the project. It also provided a common ground for discussions, thus avoiding discussions about the safety of various scenarios. A point of attention for interpreting the tool results is a lack of expert knowledge by the user. Insufficient understanding can lead to misinterpretation of results. The tool provides the best estimate of water safety based on typical systems elsewhere. However, all input variables show large differences between individual systems. Therefore, it rather assesses the potential of a system. Verification of local water quality and treatment performance is essential to draw conclusions about safety of the actual system. Therefore, in most cases it is recommended to use the tool with consultancy support. Note that the tool only focuses on microbial risks and does not consider costs, chemical parameters etc. Therefore, it is not suitable for complete optimization of e.g., a wastewater reuse plant.

SuTRa (tool #31) is a Python package to calculate the advective removal of microbial organisms (also called ‘pathogens’) from source to endpoint and it calculates the subsurface removal and concentration of the microbial organism over distance and with time. For the Flanders case, the SuTRa tool builds on the microbial risk assessment of QMRA+ to specifically model (plant) pathogen removal during subsurface passage of managed aquifer recharge and infiltration schemes. This helps determine the minimum design parameters and residence time required for pathogen removal. The outputs from SuTRa may support the regional analysis or similar studies in related projects by providing input parameters on subsurface passage if these are included in the conceptual design. From its application it was proven that the tool can be used to help determine the minimum transport time and/or distance for subsurface infiltration and storage solutions required to remove pathogens.

Flanders’ work and outcomes suggested that the applied tools can be used in a synergistic way. QMRA+ and Sutra can also help inform the water system modelling done with UWOT and the Regional Analysis tool as they can give an indication of the microbial water quality. UWOT and the Regional Analysis tool can only model water quantities. However, considering water quality and safety requirements is essential for the successful implementation of water reuse. SuTRa can be used to help determine the minimum transport time and/or distance for subsurface infiltration and storage solutions required to remove pathogens. These design parameters inform the boundary conditions for water system modelling.

The stormwater reuse management system (tool #21) which is documented in D3.4, is a management tool to control water level in the basin and optimize distribution to the irrigation system based on water level, water demand, and weather prediction of precipitation/storm events (for flood protection too). The tool is used in the Flanders case to control the outflow from the basin and the water distribution for irrigation to optimize the functioning of the basin for flood prevention and availability of water for irrigation during dry periods. The tool is intended to be used to control the basin inlet and outlet and distribute irrigation water to fields based on water availability and demand. Tool #21 is based on the specific design parameters and local situation of the stormwater management system and has a local scale. Nevertheless, the interplay of these two objectives (flood volume retention vis-à-vis coverage of agriculture needs) can be explored using water systems modelling.

The **reclaimed water distribution network water quality model (tool #24)** is one of the tools applied in the Lisbon LL and is suggested to be used integrally with tools #17, #25, and #27 (with tool #17 being reported in D3.4). It is a complete hydraulic and water quality extended-period simulation model for pressure flow networks, designed to simulate the advection, mixing and transformation of waterborne parameters in reused water. Within the project, it aims at being used in conjunction with tool #25 to qualify the supply/demand alternatives developed from the viewpoint of assessing the risks incurred in transport and distribution of the reclaimed water, in Lisbon LL case, for non-potable, unrestricted urban reuse. It complements Tool #25 in assessing the additional cost, risk and performance changes that may be required for the supply/demand combinations chosen to make use of existing or new distribution networks. From the application to the Lisbon case, where the strategy for water reuse is being decided, tool #24 has significant potential for supporting the design and monitoring of a public reclaimed water distribution network.

The **water-energy-phosphorous balance planning module (tool #25)**, which is one more tool of the interconnected ones in the Lisbon LL, is a matchmaking environment where sources and demand points are combined to enable the design of supply solutions for a set of potential users of reused water. The supply and demand alternative combinations are assessed and matched through a range of user-selected metrics (e.g., volume availability, cost, energy content, carbon footprint, nutrient content) over a targeted period. For the Lisbon case it has been used for the matchmaking of water sources (potential supplies) and water demands to enable the design of supply chain solutions (the shorter and more circular the better) for a set of potential users of non-potable water, namely, reclaimed water and other water sources alternative to those currently in use (e.g., groundwater). The supply/demand alternative combinations (matches) over a target period are assessed through a range of performance and cost metrics, for supporting strategic and tactical (aligned) planning (e.g., volume availability, cost, energy content, carbon footprint, nutrient content). Tool #25 is autonomous and may be deployed on its own or in conjunction with tools #17 and #27. It is applicable to any demand-driven matchmaking problem without requiring modification. Further, it conducts a phosphorus balance in water consumption sites (gardens and other green areas) by comparing the P fertilisation needs throughout the year with what can be supplied through reclaimed water. The application of the tool to the Lisbon LL proved that it facilitates the linking of water consumption locations (geographic representation) with various information related to those water demand points. Thus, it can function as a design planning tool that allows to test different water management solutions, which are easily translated by the alternatives (i.e., combination of the available water sources to make up the required monthly volumes in a predefined group of water demand points (e.g., green areas), while complying on the energy and nutrients contents as desired). Tool #25 was designed to function both as an information repository and as a communication channel between different stakeholders – critical issues during planning and water-smart projects. It also allows the integration of phosphorus circularity in a more comprehensive decision-making process regarding the management of water supply/demand in municipal (and other) green areas.

The **risk assessment for urban water reuse module (tool #27)** is a risk assessment framework that evaluates human and environmental risks incurred by the supply/demand combinations developed in Tool #25, based on a range of current risk standards and regulations. It is a module which is considered essential for the implementation of alternative water sources, especially in case of reclaimed water use (in irrigation and other non-potable urban uses) since it assists in the assessment of alternatives that are aligned with principles established in European and Portuguese legislation. Tool #27 works as a risk-based gatekeeper that must be cleared for any supply/demand combination to be considered for assessment in Tool #17. Depending on the risk level targeted for completion, the alternative examined will be rejected (eventually go back to tool #25 for redesign), or otherwise cleared and move on to Tool #17. The strength of this tool is that it can provide a user-friendly solution for carrying out human health and environmental risk assessments, requiring a basic knowledge of risk management and of the legislation applicable to water reuse.

As noted, tools #17, #24, #25, and #27 can be used separately. Nevertheless, the integrated use can support urban management authorities and water utilities in making smart and climate-resilient water decisions for an efficient water-energy-nutrient balance in the city including safe water reuse, by enabling direct comparison of alternatives for matching water supply and water demand to satisfy specific non-potable uses.

Further to the above tools documented in detail in D3.5, 10 more software solutions are reported in D3.4, as part of the final release of the monitoring, negotiation and decision support solutions toolkit. The two deliverables have been prepared in parallel to ensure alignment and consistency among the approaches and contents and in order to highlight the toolkits' complementarity. Such complementarity is defined by a high-level process described in detail in Chapter 4 and summarized in Table 6, which is a reference procedural framework for using the toolkits through the fundamental steps that have to be followed by people who aim at improving the water smartness of their systems. While the monitoring, negotiation and decision support solutions toolkit aims at improving water smartness by supporting the steps of context awareness, decision making, management and monitoring and certification, the toolkit presented in this deliverable (D3.5) is focused on advanced analytics for providing detailed evidence in support of the decision-making step. This is achieved by providing the tools to conduct simulations, predictions, demand/supply match-making and other analyses (Table 6). Additionally, the two toolkits aim at providing solutions to assist in coping with the water related challenges (Figure 40) and to support each step of the urban water cycle while complementing each other, as depicted in Figure 41 and Figure 42.

Table 6: Overview of toolkits' solutions and apps used in the LLs.

	Alicante (Spain)	Bodø (Norway)	East Frisia (Germany)	Flanders (Belgium)	Lisbon (Portugal)	Venice (Italy)
Context awareness		(#30) Environmental Dashboard[1]			(#20) UWC observatory[1]	(#16) Water reuse strategic platform, enabled by Digital Enabler (#32)[1] (#19) Sludge management platform), enabled by Digital Enabler (#32)[1]
Advanced analysis			(#22) UWOT[2]	(#22) UWOT[2]	(#25) Water-energy-phosphorous balance planning module[2]	
			(#23) Regional demand supply matching GIS tool[2]	(#26) QMRA+ for water reuse and agriculture[2]	(#24) Reclaimed water distribution network water quality model[2]	
			(#28) Short-term demand forecasting tool[2]	(#31) SuTRa[2]	(#27) Risk assessment for urban water reuse module[2]	
Decision making	(#18) Re-Actor[1]				(#17) Environment for decision support and alternative course selection[1]	
Management/ monitoring		(#29) Nessie system[1]		(# 21) Stormwater reuse management system[1]		
Certification					(#33) Climate-readiness certification toolkit[1]	

*1. ***The monitoring, negotiation and decision support solutions toolkit***

*2. ***The water cycle modelling and assessment solutions toolkit***

Figure 40: 18 solutions of the 2 toolkits related to the urban water challenges.

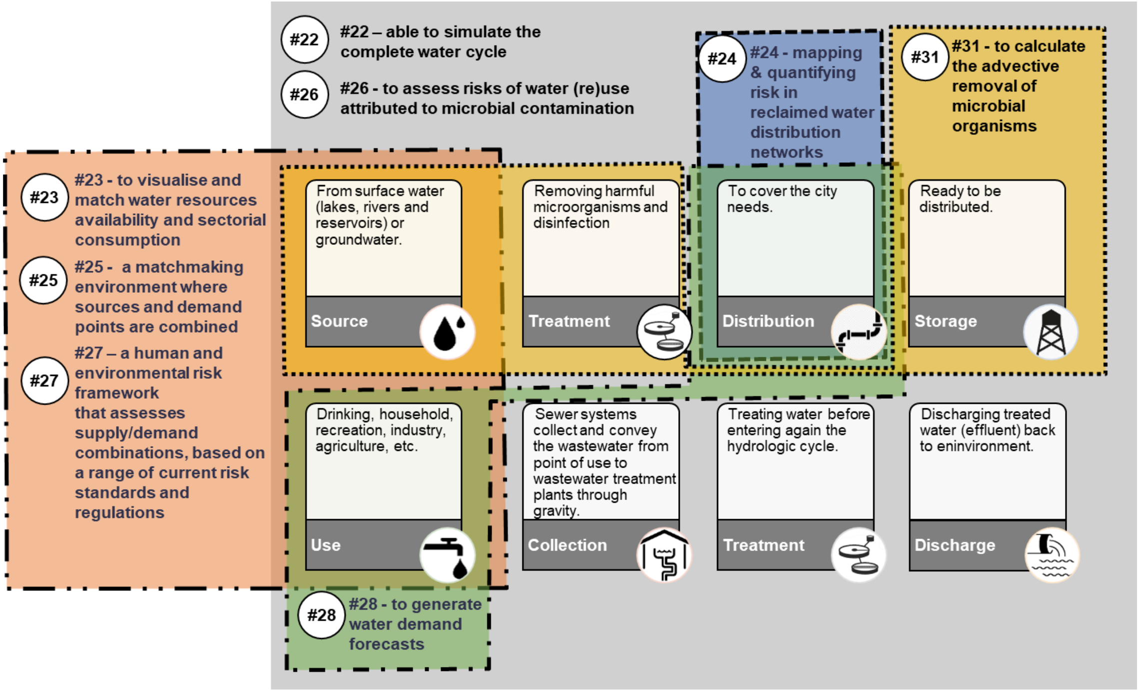
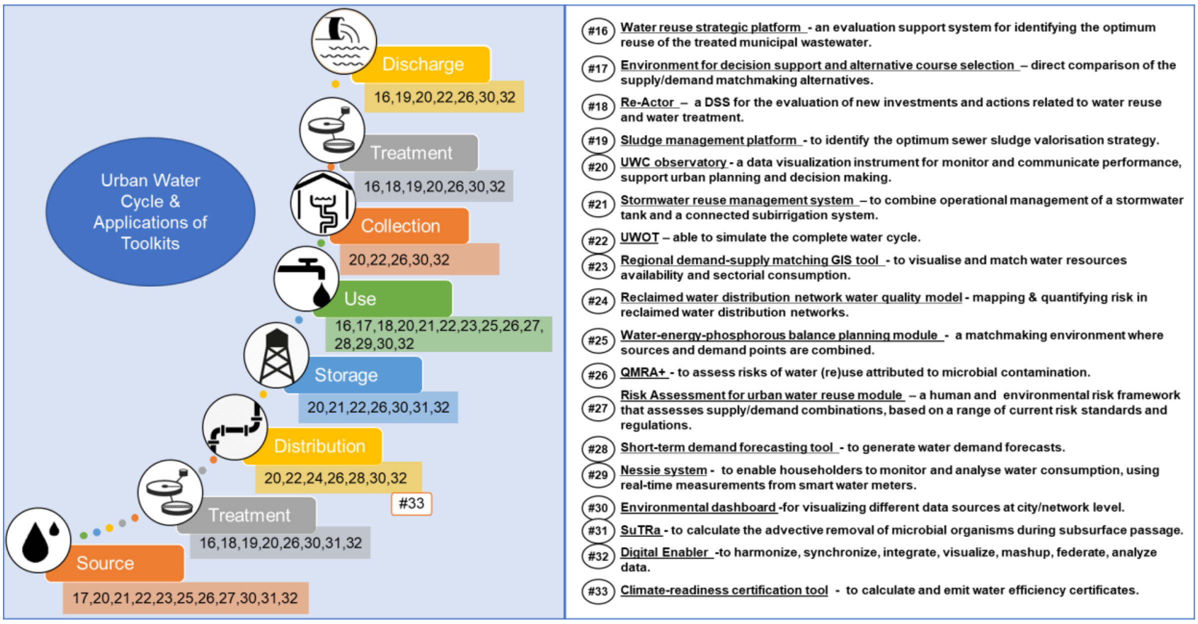


Figure 41: Tools of the water cycle modelling and assessment solutions toolkit supporting each step of the urban water cycle.



(#16) Water reuse strategic platform - an evaluation support system for identifying the optimum reuse of the treated municipal wastewater.

(#17) Environment for decision support and alternative course selection – direct comparison of the supply/demand matchmaking alternatives.

(#18) Re-Actor – a DSS for the evaluation of new investments and actions related to water reuse and water treatment.

(#19) Sludge management platform - to identify the optimum sewer sludge valorisation strategy.

(#20) UWC observatory - a data visualization instrument for monitor and communicate performance, support urban planning and decision making.

(#21) Stormwater reuse management system – to combine operational management of a stormwater tank and a connected subirrigation system.

(#22) UWOT – able to simulate the complete water cycle.

(#23) Regional demand-supply matching GIS tool - to visualise and match water resources availability and sectorial consumption.

(#24) Reclaimed water distribution network water quality model - mapping & quantifying risk in reclaimed water distribution networks.

(#25) Water-energy-phosphorous balance planning module - a matchmaking environment where sources and demand points are combined.

(#26) QMRA+ - to assess risks of water (re)use attributed to microbial contamination.

(#27) Risk Assessment for urban water reuse module – a human and environmental risk framework that assesses supply/demand combinations, based on a range of current risk standards and regulations.

(#28) Short-term demand forecasting tool - to generate water demand forecasts.

(#29) Nessie system - to enable householders to monitor and analyse water consumption, using real-time measurements from smart water meters.

(#30) Environmental dashboard -for visualizing different data sources at city/network level.

(#31) SuTRa - to calculate the advective removal of microbial organisms during subsurface passage.

(#32) Digital Enabler -to harmonize, synchronize, integrate, visualize, mashup, federate, analyze data.

(#33) Climate-readiness certification tool - to calculate and emit water efficiency certificates.

Figure 42: 18 solutions of the 2 toolkits related to the urban water cycle steps.

9.3 Replicability

Regarding the **future use and replicability of solutions**, **Lisbon LL** consider as key points to promote the use of tools (#17, #24, #25 & #27) in the context of other research projects (e.g., in UP2030); test the tools in other locations/countries (tool #33) and share experience in cities' networks (tool #20). Key elements for initiating/boosting transferability and replicability include: systematically consider water reuse for fit-for-purpose water allocation in the context of the recast Directive 91/271/EEC concerning urban waste-water treatment (tools #17, #24, #25 & #27); promote water use efficiency and water reuse in buildings in the context of national regulations and European standardization (tool #33); apply innovative citizen engagement measures (tool #20). For **Flanders**' tools and specifically QMRA+, it will need constant refinement as new scientific insights on sources, treatment and use keep emerging over time. This would require a constant scheme of updating to keep the tool actual and state of the art. For SuTRa tool, its transferability and replicability are highly connected with tools strengths and limitations descried in section 6.3.3. Specifically, while it is usefull as a first estimate of the microbial safety, additional measurements are desired after completion of the system. Such evaluations are important to consider before expanding the tool to other organisms than currently facilitated by the tool. For the storm water management tool, key element that support transferability and replicability are the fact that the code is written modular, making it possible to reuse the parts. Additionaly, it is planned that the stormwater basin part will be transferred to other projects where water from a basin can be used by other receivers than agriculture. Regarding the subirrigation part, if the demonstration is successful within the B-WaterSmart (furhter testing will be done during the last year of the project), it will be easier to convince other farmers to step into similar projects, promoting replicability. Last, for the **East Frisia** case, further testing of the tools in different regions with the LL and beyond to have more applications examples to share with potential users are considered as key elements for initiating/boosting transferability and replicability.

Replicability of the digital tools in other cities/regions is also ensured via the incorporate of FIWARE standard. Six solutions developed and reported under the two the toolkits are FIWARE compliant. Those are: 1. Water-reuse strategic platform (#16), 2. Sludge management platform (#19), 3. Short-term demand forecasting tool (#28), 4. Nessie System (#29), 5. Environmental Dashboard (#30) and 6. Digital Enabler (#32). Most of them are described in detail in D3.4, whereas the short-term demand forecasting tool (#28) can be found under section 5.7 of the current report.

Replicability is also supported by several synergies with other WPs that have been activated and will be further enhanced by:

- Intensifying discussion and exchange among the technology/tool developers in joint WP2/WP3 meetings and conducting additional ones upon demand,
- Allocating efforts for continuous collaboration with WP1 in developing training material and conducting training activities (possibly inviting also CoP members and not only project's colleagues). Most of the training activities are planned for the last year of the project when developments of tools are mature.
- Using recordings of training actions on tools and disseminating them through the colleagues' networks and WP7 (website, social media and Marketplace). Training activities have already taken place and the produced material is available in the WE Marketplace under the detailed page of each tool (https://mp.watereurope.eu/l/Product/) and the project's website (https://b-watersmart.eu/).
- Highlighting replicability aspects and opportunities in the LLs work and communicating reports to a broader audience via WP7 (website, social media and WE Marketplace, e.g., information available in the case study section documenting lessons learned from tools' applications, etc.).

As next steps, contents related to results and lessons extracted for each LL after an extended application of the BWS digital tools will be updated through the new MS32 which is suggested to be added at month 45.

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12 Annex A: Overview tables of tools' attributes and descriptions

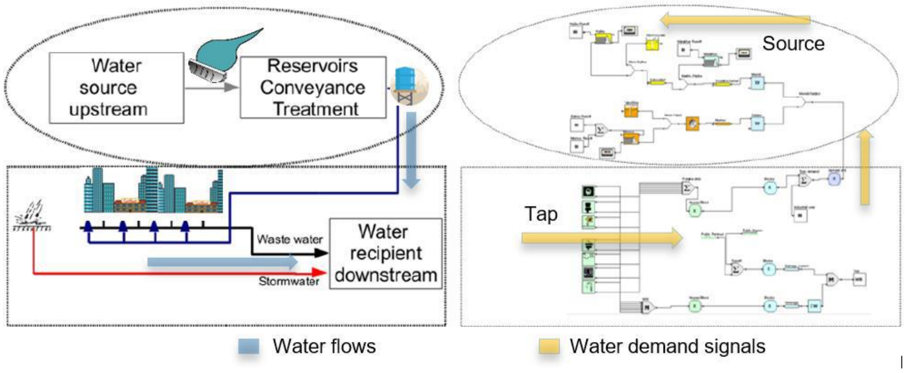
Table 7 - Table 14 below summarise the tool descriptions and attributes documented in sections 5.1- 5.8 in order to be utilised as an initial material for dissemination purposes and the population of the WEM of WP7.

12.1.1 Urban Water Optioneering Tool (#22)

Table 7: UWOT's attributes and description.

Tool's attribute	Description
Type of product	A software supporting the Circular Economy. A service, offered as part of a Circular Economy enabling portfolio.
Name	Urban Water Optioneering Tool (#22)
Description	UWOT is a decision-support tool that allows users to compare different water management technologies (including water saving, recycling, treatment and drainage) at different scales. The tool simulates the urban water cycle by modelling individual water uses and technologies and aggregates their combined effects at development scale. UWOT provides a range of technology combinations, which are ranked according to user-based criteria. This allows the user to determine which combination of technologies will be most appropriate or beneficial for their new development.
Abbreviation	UWOT
URL	https://www.watershare.eu/tool/urban-water-optioneering-tool/; https://mp.watereurope.eu/d/Product/25 https://uwmh.civil.ntua.gr/products/86-uwot.html
Costs	Software is available for research purposes free of charge upon request on a time limited license. For commercial purposes there are commercial agreement options.
Target audience	UWOT is primarily targeted at water planners, developers and relevant consultants and is designed to be used during: • Early and conceptual stage of development, for preliminary design and comparison of different options • Master planning stages of development, to have a holistic system view for the baseline and future (masterplan) scenarios
Actors, roles and interactions	• Water utilities provide data concerning (waste) water supply and quality characteristics of the inflow (e.g., BOD) • Municipalities provide data related to water demand (for example, for irrigation needs of an examined park) or other information about the area of their responsibility (for example, the area of an examined park)
Unique selling points /Added Value/Innovation	• USP: UWOT tool is a bottom-up, component based urban water circle model. It includes multiple components and technologies (drinking water, wastewater/greywater, rainwater/runoff) and can simulate flows on a different temporal scale, in scenarios that span from years to decades. • Added value: UWOT enables the end-user to simulate different future water demand/supply scenarios in a quick and straightforward manner. It allows to construct scenarios based on socio-economic assumptions and supports different temporal and spatial scales.

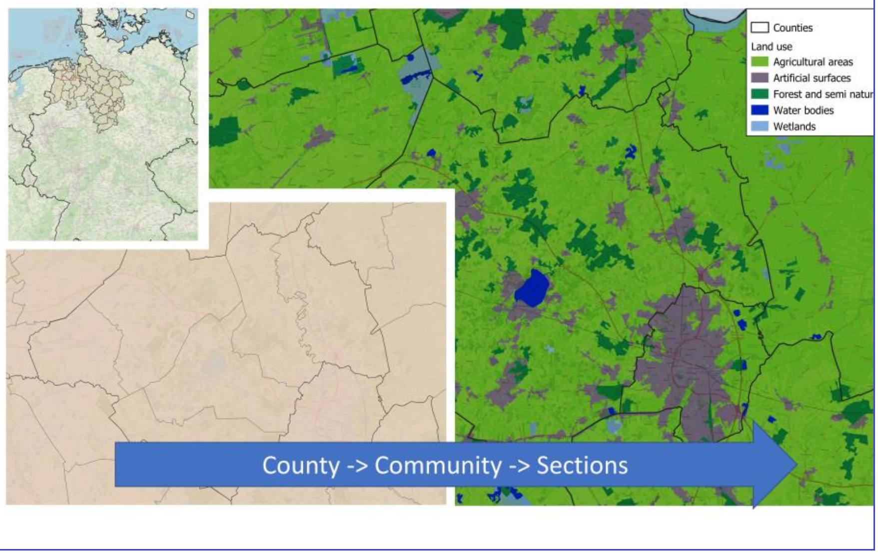
	• Innovation: The tool is able to assist smartness in water, by modelling a range of decentralized, distributed interventions: rainwater harvesting, greywater recycling, blue-green areas, smart appliances and estimate water quantity and quality.
TRL	Level 7
Technical requirements	Available as stand-alone software (.exe) in MS Windows environments. Hardware Requirements: • x86-64 CPU, preferably >= 8GB RAM and 256GB HD Software Requirements: • OS: Windows 10, 8.1, 7, 2008R2, Thin PC as well as Windows Server 2016, 2012, and 2012R2 • Dependencies: Microsoft Visual C++ 2010 x64 Redistributable
Environment	Microsoft Windows
Version	v4
Initial release	2008
License type	Software is available for research purposes free of charge upon request on a time limited license. For commercial purposes there are commercial agreement options.
Programming language/technologies used	C, python
Open interface	None
Graphical User Interface / Headless software	Tool has a dedicated GUI to edit and save projects.
Supported spatial scales	Household, neighbourhood, city, region
Supported temporal scales	Hourly, daily and (in aggregation) monthly and annual
Water Use Types	Urban, industrial, rural and agriculture
Compatibility with FIWARE	The tool is not compatible with FIWARE.
Organisations	ICCS/NTUA
Contact details	• Christos Makropoulos (cmakro@mail.ntua.gr) • Dimitrios Bouziotas (bouziot@mail.ntua.gr) • Stavroula Manouri (stavroula.manouri@gmail.com)
Data Manager	• Christos Makropoulos (cmakro@mail.ntua.gr) • Dimitrios Bouziotas (bouziot@mail.ntua.gr) • Stavroula Manouri (stavroula.manouri@gmail.com)
Technologies	• Resource for Circular Economy • Water recovery technologies for water reuse • Wastewater treatment technologies for water reuse

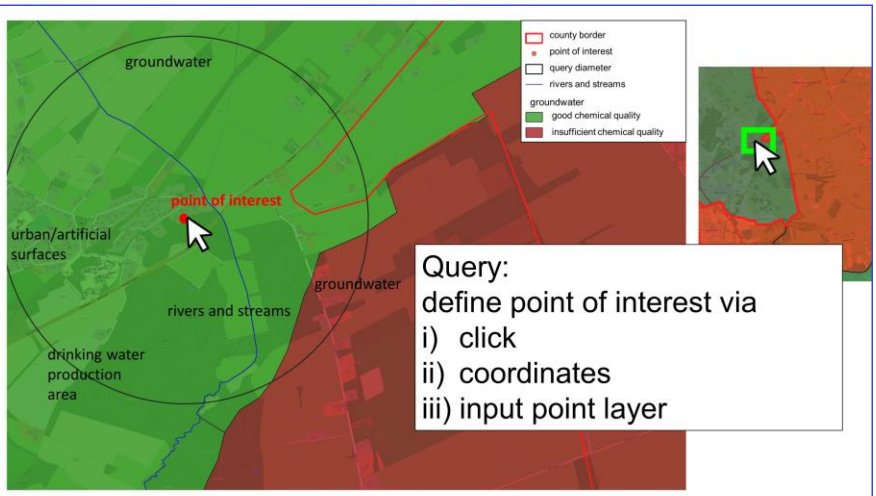
	- Rainwater harvesting systems. - Surface water and infiltration systems - Groundwater systems - Urban Water buffer
Tags	Circularity, circular economy, climate change, efficiency, energy, innovations, performance, rainwater harvesting, re-use, recycling, sewer mining, sustainability, water management, wastewater, water reuse, wastewater treatment technologies, water storage and recovery
Images	
Caption/Source	Modelling the urban water cycle from tap to source using UWOT (adapted from Makropoulos C. (2017))
Publications	- Bouziotas, D.; van Duuren, D.; van Alphen, H.-J.; Frijns, J.; Nikolopoulos, D.; Makropoulos, C. (2019). Towards Circular Water Neighborhoods: Simulation-Based Decision Support for Integrated Decentralized Urban Water Systems. Water 2019, 11, 1227. https://doi.org/10.3390/w11061227 - Rozos, E., C. Makropoulos, and C. Maksimovic (2013). Rethinking urban areas: an example of an integrated blue-green approach, Water Science and Technology: Water Supply, 13 (6), 1534-1542, https://doi.org/10.2166/ws.2013.140 - Rozos, E., and C. Makropoulos (2013). Source to tap urban water cycle modelling, Environmental Modelling and Software, 41, 139-150, https://doi.org/10.1016/j.envsoft.2012.11.015 , Elsevier - Rozos, E., and C. Makropoulos (2012). Assessing the combined benefits of water recycling technologies by modelling the total urban water cycle, Urban Water Journal, 9 (1), https://doi.org/10.1080/1573062X.2011.630096 - Rozos, E., C. Makropoulos, and D. Butler (2010). Design robustness of local water-recycling schemes, Journal of Water Resources Planning and Management - ASCE, 136 (5), 531-538. - Makropoulos, C. (2017). Thinking platforms for smarter urban water systems: fusing technical and socio-economic models and tools. Geological Society, London, Special Publications, 408(1), 201–219. https://doi.org/10.1144/SP408.4 - Makropoulos, C. K., Natsis, K., Liu, S., Mittas, K., and D. Butler (2008). Decision support for sustainable option selection in integrated urban water management, Environ. Modell. Software 23(12), 1448-1460 - Butler, D., Memon, F.A., Makropoulos, C., Southall, A. and Clarke, L. (2010). WaND – Guidance on water cycle management for new developments. C690 CIRIA, London

12.1.2 Regional demand-supply matching GIS tool (#23)

Table 8: Regional demand-supply matching GIS tool’s attributes and description.

Tool’s attribute	Description
Type of product	• A methodology or a process related to the Circular Economy • In addition, a service can be offered to incorporate and evaluate specific local data (non-open source) for a more regionalized analyses or related questions e.g., monitoring or water resource protection
Name	Regional demand-supply matching GIS tool.
Description	Systematic visualization and merging of open-source data (water demand and water sources). Identification of water sources by locations.
Abbreviation	RDSMG
URL	https://mp.watereurope.eu/d/Product/35
Costs	Open source. Costs may relate to a further regionalized study. The amount of costs refers to the scope of the analysis, and work expense e.g., integration of non-commercial data and data evaluation.
Target audience	Water suppliers, public
Actors, roles and interactions	Water utilities: indicate the need of data management.
Unique selling points /Added Value/Innovation	**Unique selling points**: improved decision making based on an enriched data base for East Frisia. **Added value**: Structured GIS-based presentation of available information, enabling “cross-data” analyses. **Innovation**: combining information from different (public) and personal data bases.
TRL	Level 7
Technical requirements	No specific requirements
Environment	QGIS (open-source GIS platform)
Version	-
Initial release	2023
License type	free
Programming language/technologies used	Database software (e.g., R Studio, Python version 3.9.5), GIS (program: QGIS version 3.28.5 Firenze)
Open interface	-

Graphical User Interface / Headless software	Data are visualized and processed in open-source GIS program QGIS via the RDSMG plug-in.
Supported spatial scales	Country, federal province, county, region, city.
Supported temporal scales	Annual (for water demand).
Water Use Types	Urban, industry, agriculture (only on county level).
Compatibility with FIWARE	No
Organisations	Open-source development and maintenance by IWW.
Contact details	Katharina Gimbel (k.gimbel@iww-online.de)
Data Manager	Katharina Gimbel (k.gimbel@iww-online.de)
Technologies	In a broader sense: Water recovery technologies for water reuse.
Tags	Water demand, Water resources, Residential, Industrial, Agricultural.
Images	

	 Query: define point of interest via i) click ii) coordinates iii) input point layer
Caption/Source	Referring respectively to the above figure: • Data visualization on different scales (first figure) • Selection of objects depending on the distance to a certain point (second figure)
Publications	Schwesig et al. (2023): Digitale Lösungen für eine wasserbewusste Gesellschaft, Energie|Wasser-Praxis, 6+7/2023, pp. 54-59. https://energie-wasser-praxis.de/wp-content/uploads/2023/06/2023_06_06_FB-Schwesig_0607_2023.pdf

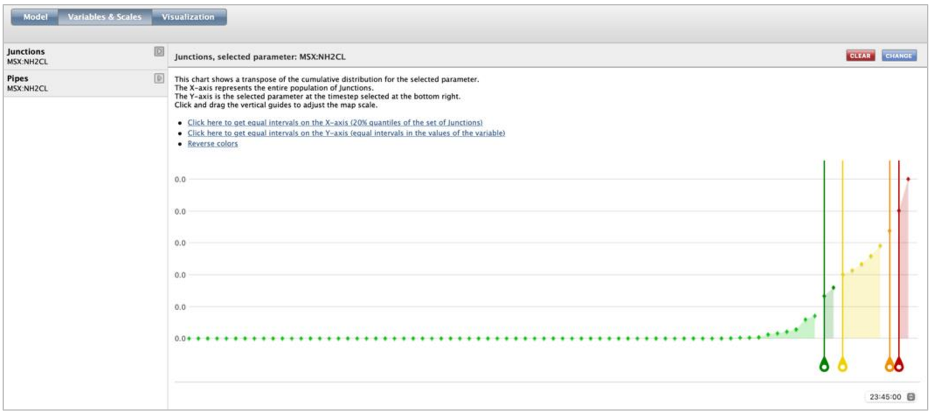
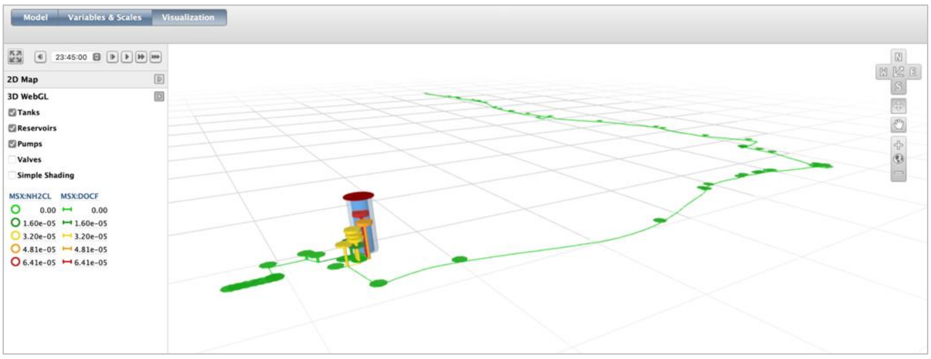
12.1.3 Reclaimed water distribution network water quality model (#24)

Table 9: Attributes and description of the reclaimed water distribution network water quality model.

Tool’s attribute	**Description**
Type of product	A software supporting the Circular Economy
Name	Tool #24 - Reclaimed water distribution network water quality model
Description	A complete hydraulic and water quality extended-period simulation model for pressure flow networks, designed to simulate the advection, mixing and transformation of waterborne parameters in reused water. It aims primarily at mapping and quantifying risk in reclaimed water distribution networks. This tool complements Tool #25 in assessing the additional cost, risk and performance changes introduced in case the supply/demand combinations need to make use of an existing or projected distribution network (see overall schematic presented in Tool #25).
Abbreviation	Not available
URL	https://bwatersmart.baseform.com

Costs	Not available at this stage.
Target audience	Hydraulic engineering experts in urban management, municipal and water utility contexts.
Actors, roles and interactions	This is a specialized model that is best used by hydraulic engineering experts, usually working as part of consultancy in urban management or water utility contexts. It can also be used by the utility staff as part of their operational and engineering tool portfolio.
Unique selling points /Added Value/Innovation	**Unique selling point** – This specialized reused water quality model is a new, dedicated solution to the problem of analysing and assessing the environmental and public health risks posed by using pipe networks for transporting and distributing reclaimed water. It benefits from the BASEFORM software's data compatibility features, capable of handling water supply system data in GIS or hydraulic model formats. **Added value** – The tool is part of a sequence of four apps that jointly provide a complete ability to match water supply to demand, while managing water volume, cost, energy, nutrients and risk, with full GIS-compatible georeferenced capabilities. The apps are made available within the market-tested BASEFORM water analytics package, which is used by utilities around the world servicing over 25 million people. This tool adds full reclaimed water quality modelling capabilities to the BASEFORM software universe. **Innovation** – This tool implements a new, innovative algorithm for modelling the propagation and behaviour of key reclaimed water quality parameters as it travels in reused water distribution networks, on top of a standard hydraulic model. The tool works in conjunction with tool #25 by assessing transport and distribution risk of reclaimed water in candidate supply/demand combinations. The reclaimed water quality modelling algorithm has also been published as a result of the project.
TRL	7 at end of the project.
Technical requirements	Computer, tablet or smartphone with internet access.
Environment	Any updated internet browser in any operating environment.
Version	Version 2.0
Initial release	2023
License type	Commercial
Programming language/technologies used	Java

Open interface	API, web services, text files, MS Excel files
Graphical User Interface / Headless software	Browser-based graphical user interface.
Supported spatial scales	Neighbourhood, city, region.
Supported temporal scales	Minute, Hour, Day.
Water Use Types	Urban
Compatibility with FIWARE	The model uses BASEFORM’s pre-existing internal data model, which is not based on FIWARE. However, it has broad flexibility in terms of data input, being able to read data from any documented file formats, as well as webservices and other common web-accessible supports; and data output, both to files (text, excel and shapefiles/geopkg) and through its own API. Therefore, it can easily accommodate input/output from/to FIWARE-compliant software.
Organisations	BASEFORM
Contact details	Diogo Vitorino (diogo.vitorino@baseform.com)
Data Manager	Diogo Vitorino (diogo.vitorino@baseform.com)
Technologies	Java
Tags	Reuse, water, model, simulation, supply, distribution.

Images	 This chart shows a transpose of the cumulative distribution for the selected parameter. The X-axis represents the entire population of Junctions. The Y-axis is the selected parameter at the timestep selected at the bottom right. Click and drag the vertical guides to adjust the map scale. • Click here to get equal intervals on the X-axis (20% quantiles of the set of Junctions) • Click here to get equal intervals on the Y-axis (equal intervals in the values of the variable) • Reverse colors 
Caption/Source	Referring respectively to figures above. • Selection of the color-coded limits for the water quality parameter chosen (BASEFORM). • 3D representation of simulated reused water quality values (BASEFORM).
Publications	Not available

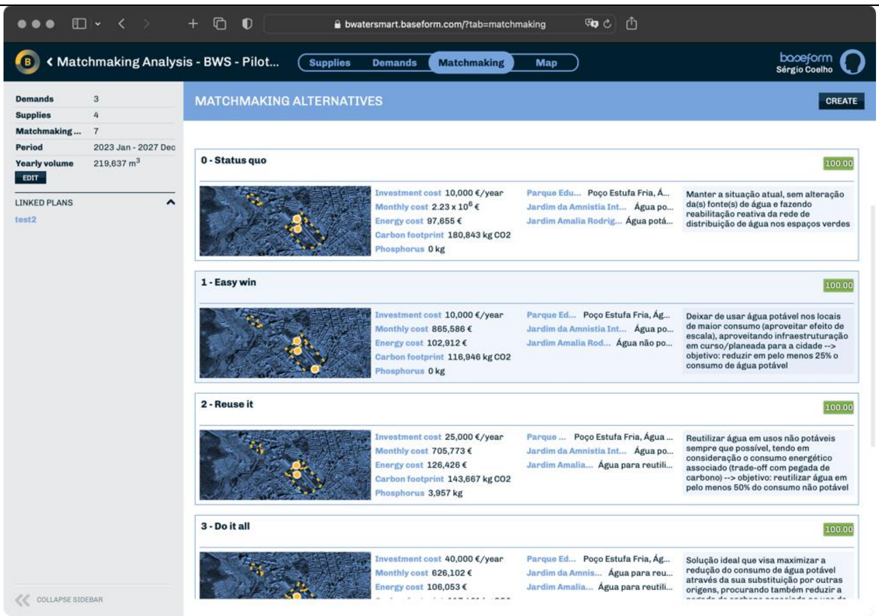
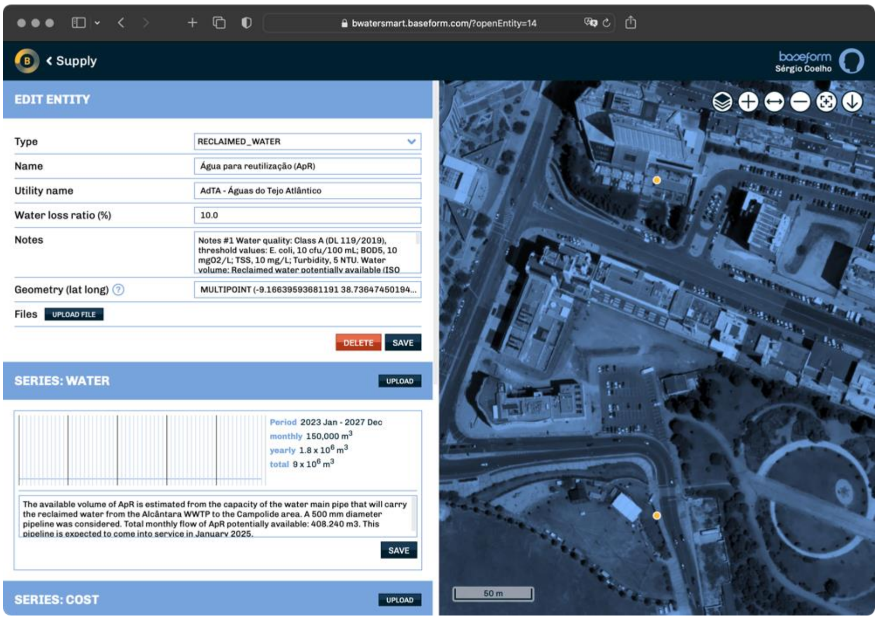
12.1.4 Water-energy-phosphorous balance planning module (#25)

Table 10: Attributes and description of the water-energy- phosphorous balance planning module.

Tool's attribute	Description
Type of product	A software supporting the Circular Economy.
Name	Tool #25 - Water-energy-phosphorous balance planning module.
Description	A matchmaking environment where sources and demand points are combined, with a particular focus on matching and balancing water availability, energy consumption and carbon footprint, as well as nutrient content. The supply and demand alternative combinations are assessed through a range of user-selected metrics that cover not only

	those three key vectors but allow for cost tracking cost and other variables of interest over a targeted period. The integrated use of tools #25 and #17 enables the decision-makers to define and prioritize combinations of two or more supplies, including reclaimed water, in satisfying non-potable water demands in urban or regional contexts, based on factual evidence. It is important to align the bottom-up (i.e., demand-driven) decisions with strategic and tactical planning at city level. This alignment is provided by specifically designed assessment variables such as volume availability, cost, energy, carbon footprint or nutrient content. These variables are used in or contribute for the calculation of metrics of the BWS assessment framework – strategic planning (tool #34). It is also important to have in mind the contribution of water supply-demand management to specific goals, such as energy neutrality and climate action. The combined deployment of tools #25 and #17, together with tools #24 and #27 (in case of water reuse), goes beyond the state-of-the-art because it provides the ability to match water supply to demand, while managing water volume, cost, energy, nutrients and risk, with full GIS-compatible georeferenced capabilities. The result is a streamlined, simple-to-use analysis of supply and demand matchmaking that can be operated by decision-makers without deep technical knowledge, as well as by experts with full depth analysis. As reclaimed water is a sustainable source, largely independent of climate uncertainty, it can contribute to reducing pressure on strategic freshwater resources and to allow resources' recovery, such as phosphorus.
Abbreviation	Not available
URL	https://bwatersmart.baseform.com.
Costs	Not available at this stage.
Target audience	Water demand planners and decision-makers in urban management, municipal and water utility contexts.
Actors, roles and interactions	The tools' central use case is in an internal or external expert consultancy role. The targeted user has access to municipal or regional data on water production and water demand (volumes, costs, energy content, nutrient content), or is equipped to estimate those data in an engineering/planning context.
Unique selling points /Added Value/Innovation	**Innovation** – This tool implements a novel matchmaking framework for formulated and assessing candidate combinations of two or more supplies in satisfying reused water demands in urban or regional contexts, to enable prioritizing strategic and tactical planning options. The framework allows for essential assessment variables such as volume availability, cost, energy, carbon footprint or nutrient content to be factored in. It allows for analysis over projected periods of time, with full time-series representation as well as explicit mapping using a georeferenced mapping interface in the BASEFORM environment. It produces sets of candidate supply/demand solutions to be further assessed for risk in tools #24 and #27, before being compared for prioritization and final decision in tool #17. **Unique selling point** – This tool allows for a streamlined, simple-to-use analysis of supply and demand matchmaking that can be operated by decision-makers with

	without deep technical knowledge, as well as by experts with full depth analysis. It can be used with what-if or simplified supply and demand data for sensitivity gain, as well as with fully automated data from any available source. It benefits from the BASEFORM software's data compatibility capabilities as well as its georeferenced interface. **Added value** – The tool is part of a sequence of four apps that jointly provide a complete ability to match water supply to demand, while managing water volume, cost, energy, nutrients and risk, with full GIS-compatible georeferenced capabilities. The apps are made available within the market-tested BASEFORM water analytics package, which is used by utilities around the world servicing over 25 million people. This tool adds supply/demand management capabilities to the BASEFORM software universe.
TRL	7 at end of project.
Technical requirements	Computer, tablet or smartphone with internet access.
Environment	Any updated internet browser in any operating environment.
Version	Version 1.0
Initial release	2023
License type	Commercial
Programming language/technologies used	Java
Open interface	API, web services
Graphical User Interface / Headless software	Browser-based graphical user interface.
Supported spatial scales	Urban facility (e.g., public park), neighbourhood, city, region.
Supported temporal scales	Monthly, annual
Water Use Types	Urban
Compatibility with FIWARE	The tool uses BASEFORM's pre-existing internal data model, which is not based on FIWARE. However, it has broad flexibility in terms of data input, being able to read data from any documented file formats, as well as webservices and other common web-accessible supports; and data output, both to files (text, excel and shapefiles/geopkg) and through its own API. Therefore, it can easily accommodate input/output from/to FIWARE-compliant software.

Organizations	BASEFORM
Contact details	Diogo Vitorino (diogo.vitorino@baseform.com)
Data Manager	Diogo Vitorino (diogo.vitorino@baseform.com)
Technologies	Java
Tags	Reuse, water, supply, demand.
Images	 bwatersmart.baseform.com/?tab=matchmaking Matchmaking Analysis - BWS - Pilot... Demands 3 Supplies 4 Matchmaking ... 7 Period 2023 Jan - 2027 Dec Yearly volume 219,637 m^3 LINKED PLANS test2 MATCHMAKING ALTERNATIVES 0 - Status quo 100.00 Investment cost 10,000 €/year Monthly cost 2.23 x 10^6 € Energy cost 97,655 € Carbon footprint 180,843 kg CO2 Phosphorus 0 kg Parque Edu... Poço Estufa Fria, Á... Jardim da Amnistia Int... Água po... Jardim Amalia Rodrig... Água potá... Manter a situação atual, sem alteração da(s) fonte(s) de água e fazendo reabilitação reativa da rede de distribuição de água nos espaços verdes 1 - Easy win 100.00 Investment cost 10,000 €/year Monthly cost 865,586 € Energy cost 102,912 € Carbon footprint 116,946 kg CO2 Phosphorus 0 kg Parque Ed... Poço Estufa Fria, Ág... Jardim da Amnistia Int... Água po... Jardim Amalia Rod... Água não po... Deixar de usar água potável nos locais de maior consumo (aproveitar efeito de escala), aproveitando infraestruturação em curso/planeada para a cidade --> objetivo: reduzir em pelo menos 25% o consumo de água potável 2 - Reuse it 100.00 Investment cost 25,000 €/year Monthly cost 705,773 € Energy cost 126,426 € Carbon footprint 143,667 kg CO2 Phosphorus 3,957 kg Parque ... Poço Estufa Fria, Água ... Jardim da Amnistia Int... Água po... Jardim Amalia... Água para reutili... Reutilizar água em usos não potáveis sempre que possível, tendo em consideração o consumo energético associado (trade-off com pegada de carbono) --> objetivo: reutilizar água em pelo menos 50% do consumo não potável 3 - Do it all 100.00 Investment cost 40,000 €/year Monthly cost 626,102 € Energy cost 106,053 € Parque Ed... Poço Estufa Fria, Ág... Jardim da Amnis... Água para reu... Jardim Amalia... Água para reutili... Solução ideal que visa maximizar a redução do consumo de água potável através da sua substituição por outras origens, procurando também reduzir a  bwatersmart.baseform.com/?openEntity=14 Supply EDIT ENTITY Type RECLAIMED_WATER Name Água para reutilização (ApR) Utility name AdTA - Águas do Tejo Atlântico Water loss ratio (%) 10.0 Notes: Notes #1 Water quality: Class A (DL 119/2019), threshold values: E. coli, 10 cfu/100 mL; BOD5, 10 mgO2/L; TSS, 10 mg/L; Turbidity, 5 NTU. Water volume: Reclaimed water potentially available (ISO Geometry (lat long) MULTIPOINT (-9.16639593681191 38.73647450194... SERIES: WATER Period 2023 Jan - 2027 Dec monthly 150,000 m^3 yearly 1.8 x 10^6 m^3 total 9 x 10^6 m^3 The available volume of ApR is estimated from the capacity of the water main pipe that will carry the reclaimed water from the Alcântara WWTP to the Campolide area. A 500 mm diameter pipeline was considered. Total monthly flow of ApR potentially available: 408.240 m3. This pipeline is expected to come into service in January 2025. SERIES: COST
Caption/Source	The above figures are screenshots that depict, respectively:

	• The list of matchmaking alternatives available for a given analysis • Specifying a reused water demand point in the matchmaking environment (BASEFORM). The software is available at https://bwatersmart.baseform.com.
Publications	Not available

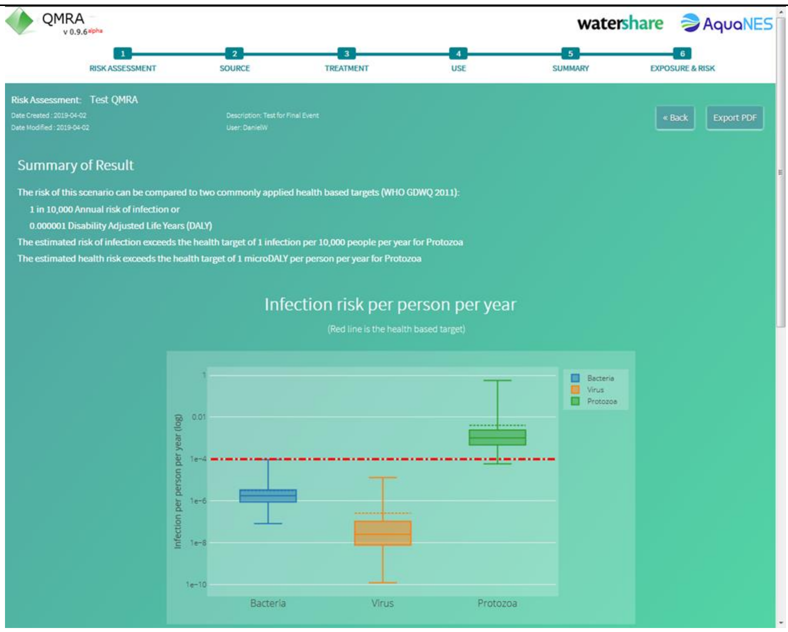
12.1.5 QMRA+ (#26)

Table 11: QMRA+ tool’s attributes and description

Tool’s attribute	**Description**
Type of product	• A software supporting the Circular Economy • A methodology or a process related with the Circular Economy
Name	QMRA+ tool
Description	Quantitative Microbial Risk Assessment (QMRA) is a methodology that can be applied to assess risks of water (re)use and thus support decisions. The QMRA tool enables users to estimate the microbial health risk of using various water sources, including reuse of wastewater. A treatment system can be designed by selecting treatment steps from a wide array of possible treatment technologies. These treatment trains result in a product water quality for which the application can be selected to assess the exposure of humans to this product water and the pathogens it may contain. A calculation is performed according to the QMRA approach that involves the estimation of infection risk per person per year and the DALYs (disability-adjusted life years) per person and year for bacteria (*Campylobacter jejuni*), viruses (rotavirus) and protozoa (*Cryptosporidium*).
Abbreviation	QMRA+
URL	https://tinyurl.com/QMRAplus
Costs	The webtool is freely available.
Target audience	Risk managers, regulators, inspectorates, engineers, stakeholders of water systems (to support discussions), students and water professionals.
Actors, roles and interactions	The tool can be used by individuals to perform risk assessments. The tool can be used for QMRA introduction, education, training. The tool can be used by teams to support discussions and decisions on water system development.
Unique selling points /Added Value/Innovation	**Unique selling points**: The QMRA+ tool is extremely user friendly and can be used without training or previous knowledge. The QMRA+ tool is unique in the sense that all available knowledge to perform QMRA is already incorporated in the tool. The user doesn’t need knowledge on QMRA or data to start using the tool and apply it on their cases. In addition, more experienced users can introduce their own data or knowledge to adapt default values in the tool, making

	the risk assessment more site specific and the outcomes more accurate for the situation at hand. **Added value**: New water supply concepts are only feasible if they are safe. Unsafe practices could quickly lead to outbreaks of disease under their users or the people exposed (e.g. through irrigation water spray). This would lead to discarding the innovative water supply solutions. The tool provides scientific substantiation of the safety of the innovative water concept that can be used to convince regulators, inspectorates and the public that water is safe and thus enhance acceptability of alternative water systems. It can be used to assess vulnerability e.g., due to failure and prepare monitoring and response plans for these situations. **Innovation**: This tool combines various aspects of QMRA to provide an easy to use and scientifically sound tool to evaluate the safety of alternative water resources and uses. Before QMRA+ risk assessment tools required extensive data input from users, which is often not available. Using those tools required expertise in the field of QMRA and often training on how to use the tools as they were not user friendly. Uniquely QMRA+ provides the current scientific knowledge about relevant aspects such as source water quality, the effect of water treatment processes and the exposure through various uses. This allows users that encounter QMRA for the first time to quickly understand the principles and key concepts. The tool also allows them to quickly compare various options or scenarios for new water supply concepts and compare their risks to current internationally applied standards. Where other tools mostly provide a point estimate of risk, the QMRA+ tool incorporates uncertainty and variability in the risk assessment, providing a range for the assessed risk level. Incorporating uncertainty is essential for decision taking, and to define follow-up actions such as collecting the most relevant data to reduce this uncertainty. The tool works intuitively since the end user wat put centrally when developing the tool. It was developed from the point of end user needs rather than providing only scientific outcomes and approaches. More experienced users can introduce their own data to replace default values, thus making the risk assessment more site specific and accurate. Since the tool is provided as an online application, the latest scientific knowledge and insights can be, and are, incorporated in the tool over time.
TRL	7
Technical requirements	The tool can be used through any popular internet browser and doesn't require downloads or computer capacity.
Environment	Web-based
Version	V 0.9.7 alpha
Initial release	2019
License type	Free
Programming language/technologies used	Calculations: R GUI: Java

Open interface	NA
Graphical User Interface / Headless software	GUI web-based
Supported spatial scales	Professionally operated water systems at city level. Knowledgeable users can adapt input parameters to their specific situation by entering data on local water quality, treatment monitoring and use. The tool is not suitable for smaller neighbourhood, industrial or household scale systems since their performance, monitoring and maintenance can deviate from large scale systems run by professionals.
Supported temporal scales	Risks are typically expressed on an annual basis. Daily risk estimates are also provided.
Water Use Types	Drinking, irrigation, toilet flushing and various other uses. Exposure for other use types can be added by experienced users by adapting input parameters.
Compatibility with FIWARE	Not FIWARE compatible.
Organisations	KWR, KWB.
Contact details	Patrick Smeets, KWR (Patrick.smeets@kwrwater.nl)
Data Manager	Patrick Smeets, KWR (Patrick.smeets@kwrwater.nl)
Technologies	Water recovery technologies for water reuse: • Wastewater treatment technologies for water reuse. • Rainwater harvesting systems. • Surface water and infiltration systems. • Groundwater systems.
Tags	QMRA, health risk assessment, microbiology, pathogens, infection risk, DALY.

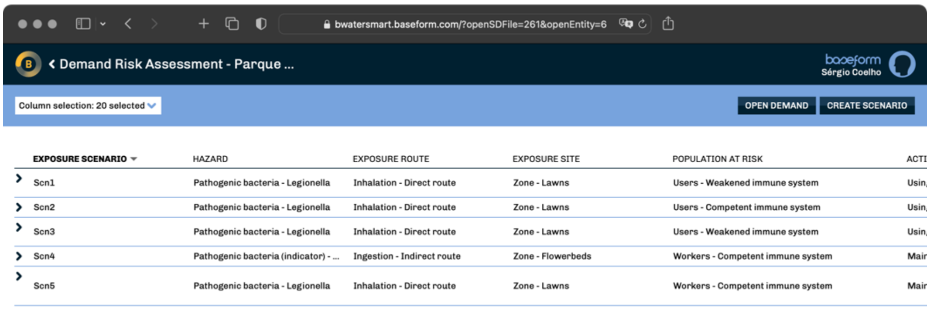
Images	 Risk Assessment: Test QMRA Date Created : 2019-04-02 Date Modified : 2019-04-02 Description: Test for Final Event User: DanielW Summary of Result The risk of this scenario can be compared to two commonly applied health based targets (WHO GDWQ 2011): 1 in 10,000 Annual risk of infection or 0.000001 Disability Adjusted Life Years (DALY) The estimated risk of infection exceeds the health target of 1 infection per 10,000 people per year for Protozoa The estimated health risk exceeds the health target of 1 microDALY per person per year for Protozoa
Caption/Source	Screenshot of the QMRA+ tool risk calculation results.
Publications	Smeets, P. W. M. H., and Miehe, U. (2019, 16 – 20 June). AquaNES QMRA tool: a webtool for quantitative microbial risk assessment of water reuse applications. Paper presented at the 12th IWA International Conference on Water Reclamation and Reuse, Berlin, Germany.

12.1.6 Risk Assessment for urban water reuse module (#27)

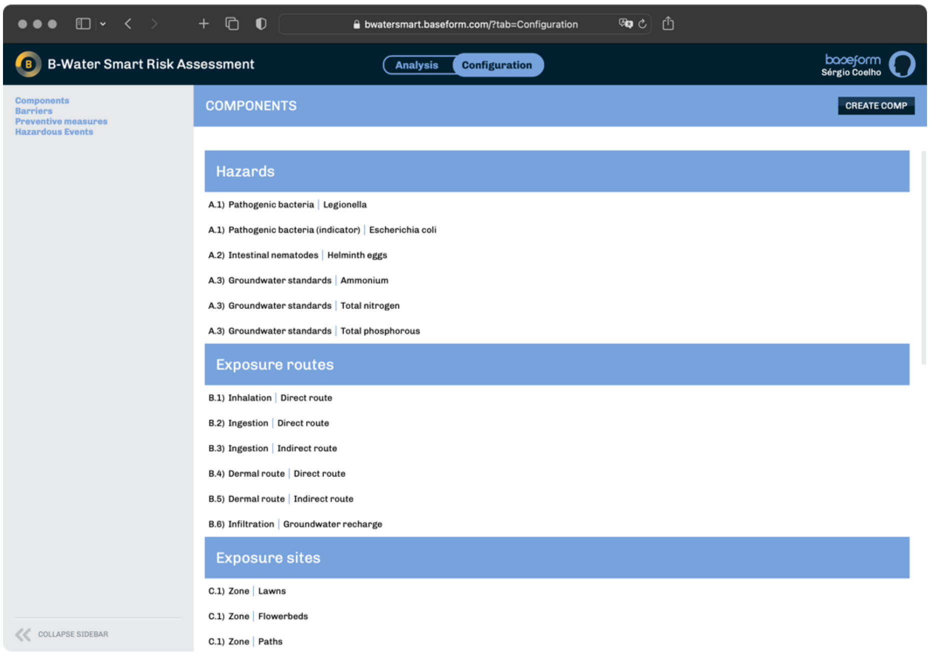
Table 12: Attributes and description of the Risk Assessment for urban water reuse module.

Tool's attribute	**Description**
Type of product	A software supporting the Circular Economy
Name	Tool #27–- Risk Assessment for urban water reuse module
Description	A human and environmental risk framework that assesses supply/demand combinations, based on a range of current risk standards and regulations including: • ISO 16075 Guidelines for treated wastewater use for irrigation projects (2020, 2021), • ISO 20426:2018 Guidelines for health risk assessment and management for non-potable water reuse, • ISO 20761:2018 Guidelines for water reuse safety evaluation, • EU Regulation 2020/741 on minimum requirements for water reuse.

Abbreviation	NA.
URL	https://bwatersmart.baseform.com
Costs	Not available at this stage.
Target audience	Water demand planners and decision-makers in urban management, municipal and water utility contexts.
Actors, roles and interactions	Working in tandem with Tool #25, this tool has a similar central use case based on an internal or external expert consultancy role. The targeted user has knowledge of the risk assessment guidelines mentioned above (5.6.1); usage of the tool may imply access to municipal or regional data on water production and water demand (volumes, costs, energy content, nutrient content), or is equipped to estimate those data in an engineering/planning context.
Unique selling points /Added Value/Innovation	**Unique selling points**: This tool makes expert-knowledge available for risk managers and stakeholders responsible for non-potable water uses, guiding the user through the inherently complex context of public health and environmental risk guidelines and ensuring compatibility with the latest concepts in ISO standardization and EU regulation. **Added value**: The tool is part of a sequence of four apps that jointly provide a complete ability to match water supply to demand, while managing water volume, cost, energy, nutrients and risk, with full GIS-compatible georeferenced capabilities. The apps are made available within the market-tested BASEFORM water analytics package, which is used by utilities around the world servicing over 25 million people. This tool adds full risk-assessment capabilities for water reuse management to the BASEFORM software universe. **Innovation**: This tool implements a user-friendly risk assessment framework based on the latest ISO standards and EU Regulation, for water reuse in non-potable uses. It has been designed specifically to evaluate the candidate supply/demand combinations produced by tool #25, with which it works in tandem; it can also work as a stand-alone app.
TRL	7 at end of project.
Technical requirements	Computer, tablet or smartphone with internet access.
Environment	Any updated internet browser in any operating environment.
Version	Version 1.0
Initial release	2023
License type	Commercial

Programming language/technologies used	Java
Open interface	API, web services.
Graphical User Interface / Headless software	Browser-based graphical user interface.
Supported spatial scales	Urban facility (e.g., public park), neighbourhood, city, region.
Supported temporal scales	Monthly, annual.
Water Use Types	Urban.
Compatibility with FIWARE	The tool uses BASEFORM's pre-existing internal data model, which is not based on FIWARE. However, it has broad flexibility in terms of data input, being able to read data from any documented file formats, as well as webservices and other common web-accessible supports; and data output, both to files (text, excel and shapefiles/geopkg) and through its own API. Therefore, it can easily accommodate input/output from/to FIWARE-compliant software. Read/write compatibility only (through API or webservices).
Organisations	BASEFORM
Contact details	Diogo Vitorino (diogo.vitorino@baseform.com)
Data Manager	Diogo Vitorino (diogo.vitorino@baseform.com)
Technologies	Java.
Tags	Reuse, water, supply, demand.
Images	 bwatersmart.baseform.com/?openSDFile=261&openEntity=6 Demand Risk Assessment - Parque ... baseform Sérgio Coelho Column selection: 20 selected OPEN DEMAND CREATE SCENARIO

EXPOSURE SCENARIO	HAZARD	EXPOSURE ROUTE	EXPOSURE SITE	POPULATION AT RISK	ACTI
Scn1	Pathogenic bacteria - Legionella	Inhalation - Direct route	Zone - Lawns	Users - Weakened immune system	Usin
Scn2	Pathogenic bacteria - Legionella	Inhalation - Direct route	Zone - Lawns	Users - Competent immune system	Usin
Scn3	Pathogenic bacteria - Legionella	Inhalation - Direct route	Zone - Lawns	Users - Weakened immune system	Usin
Scn4	Pathogenic bacteria (indicator) - ...	Ingestion - Indirect route	Zone - Flowerbeds	Workers - Competent immune system	Mair
Scn5	Pathogenic bacteria - Legionella	Inhalation - Direct route	Zone - Lawns	Workers - Competent immune system	Mair

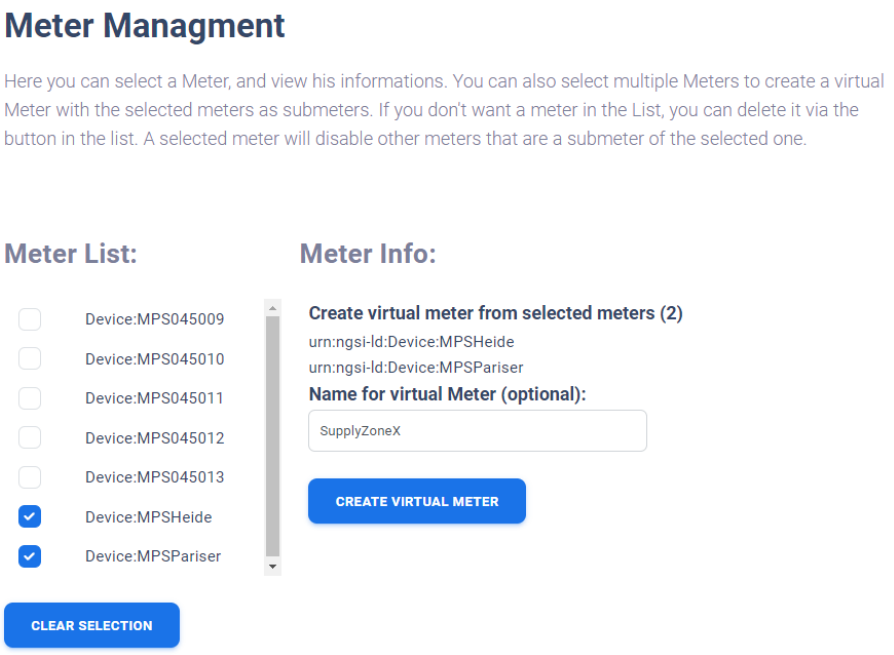
	 Hazards A.1) Pathogenic bacteria | Legionella A.1) Pathogenic bacteria (indicator) | Escherichia coli A.2) Intestinal nematodes | Helminth eggs A.3) Groundwater standards | Ammonium A.3) Groundwater standards | Total nitrogen A.3) Groundwater standards | Total phosphorous Exposure routes B.1) Inhalation | Direct route B.2) Ingestion | Direct route B.3) Ingestion | Indirect route B.4) Dermal route | Direct route B.5) Dermal route | Indirect route B.6) Infiltration | Groundwater recharge Exposure sites C.1) Zone | Lawns C.1) Zone | Flowerbeds C.1) Zone | Paths
Caption/Source	The images above show respectively the main list of exposure scenarios for a given matchmaking alternative, and the configuration tab displaying the risk components (hazards, exposure routes, exposure sites, activities, population at risk). The tool is available at https://bwatersmart.baseform.com
Publications	Ribeiro, R., Rosa, M.J. (2022). Avaliação do risco para a saúde humana associado à reutilização de água: construção de cenários de exposição. 20.º ENASB, Cascais, 24-26 novembro 2022, 5 p. (communication in a conference)

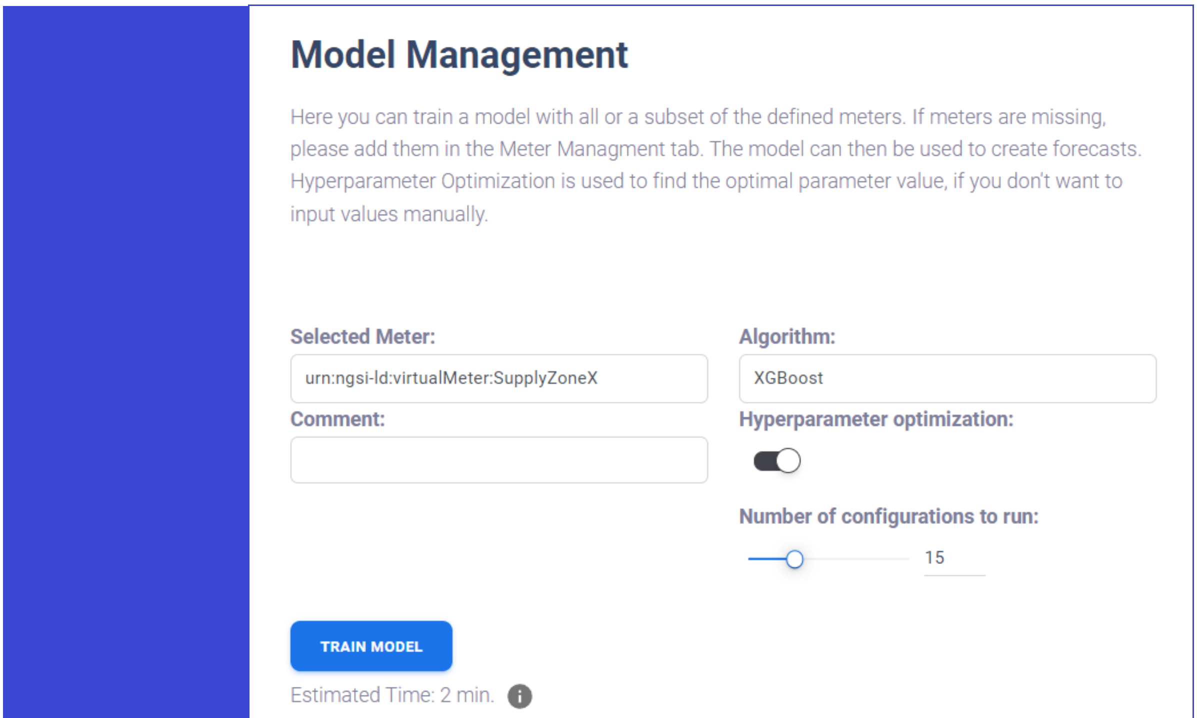
12.1.7 Short-term demand forecasting tool (#28)

Table 13: Short-term demand forecasting tool’s attributes and description.

Tool’s attribute	Description
Type of product	• A software supporting the Circular Economy • A service, offered as part of a Circular Economy enabling portfolio
Name	Short-term demand forecasting tool
Description	Two main components: 1. Backend service that allows to train models and create water demand predictions. The service is reachable through its own REST API (documented in OpenAPI), as well as through the Orion context broker (FIWARE). 2. Frontend service that is used to interact with the backend and visualize forecasts or model training results. This component is optional in case a frontend service already exists at the user’s organization where the product can be integrated.
Abbreviation	SDFT

URL	-
Costs	The tool is freely available. Infrastructure and personnel costs may occur from deploying and hosting the tool.
Target audience	Water utility that has the software engineering capabilities to integrate the tool into their system. The user that interacts with / applies the tool needs to be able to use a browser and interpret data from the water domain (e.g., water demand line plots).
Actors, roles and interactions	The tool is meant to be used by water utilities. Depending on their expertise, they might need help from external IT experts to integrate the tool into their system before it can be applied.
Unique selling points /Added Value/Innovation	Open-source tool that integrates a large variety of algorithms that are based on fundamentally different approaches (statistical, tree-based, deep learning) that allow the user to easily test and choose the right algorithm for the specific dataset. The requirement for Machine Learning expertise is minimized due to the use of a state-of-the-art hyperparameter optimization technique (BOHB). **Unique selling points:** advanced forecasting on a high time resolution with an elevated level of accuracy. **Added value:** short-term demand forecasts based on smart meter data. **Innovation:** machine learning based forecasting, usable based on smart meter data or virtual meter data.
TRL	Level 6
Technical requirements	Software engineering expertise to integrate the components (FIWARE components + backend + frontend) into the network and system of the water utility. All components are provided in form of docker containers. Additional expertise is required to install smart meter devices and connect them to the system such that the pre-processed smart meter data is accessible to the tool.
Environment	The tool comes in form of Docker containers and is thus independent of the specific OS.
Version	1.0
Initial release	2023
License type	Open source
Programming language/technologies used	Python (backend) React.js (frontend) FIWARE Docker (for deployment and networking)
Open interface	The tool can be accessed from a GitHub repository. It offers a REST API documented with OpenAPI and can alternatively be accessed through the Orion context broker using a NGSIv2 API (FIWARE).
Graphical User Interface / Headless software	The tool needs a GUI (either the one developed within the project or one that is developed by the water utility). Since it is possible to interact with the backend using only API calls to create the forecasts, the backend can be used as headless software and can be integrate in other services.
Supported spatial scales	The tool can generate forecasts on household scale and aggregate these results up to regional scale.
Supported temporal scales	Hourly

Water Use Types	Water demand in general (residential, industrial, and agricultural).
Compatibility with FIWARE	It is compatible with FIWARE by offering interactions through the Orion context broker.
Organisations	Open-source development and maintenance by IWW.
Contact details	Marcel Juschak (ma.juschak@iww-online.de)
Data Manager	Marcel Juschak (ma.juschak@iww-online.de)
Technologies	-
Tags	Water demand, Residential, Industrial, Agricultural, Machine learning.
Images	Below, screenshots from the developed user interface are shown that illustrate a typical workflow.  **Meter Managment** Here you can select a Meter, and view his informations. You can also select multiple Meters to create a virtual Meter with the selected meters as submeters. If you don't want a meter in the List, you can delete it via the button in the list. A selected meter will disable other meters that are a submeter of the selected one. **Meter List:** ☐ Device:MPS045009 ☐ Device:MPS045010 ☐ Device:MPS045011 ☐ Device:MPS045012 ☐ Device:MPS045013 ☑ Device:MPSHeide ☑ Device:MPSPariser **Meter Info:** **Create virtual meter from selected meters (2)** urn:ngsi-ld:Device:MPSHeide urn:ngsi-ld:Device:MPSPariser **Name for virtual Meter (optional):** SupplyZoneX Grouping smart meters into a “virtual meter” that represents a whole supply zone and for which models can be trained.



Model Management

Here you can train a model with all or a subset of the defined meters. If meters are missing, please add them in the Meter Managment tab. The model can then be used to create forecasts. Hyperparameter Optimization is used to find the optimal parameter value, if you don't want to input values manually.

Selected Meter: urn:ngsi-ld:virtualMeter:SupplyZoneX

Algorithm: XGBoost

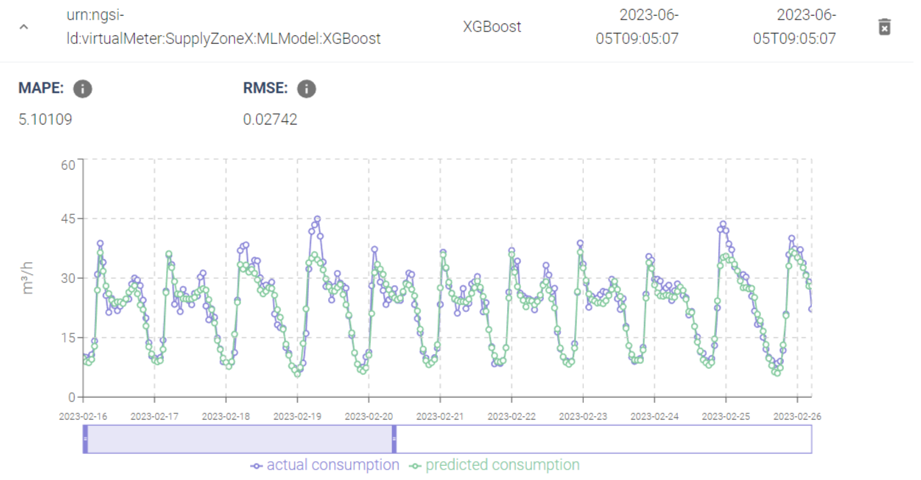
Comment:

Hyperparameter optimization:

Number of configurations to run: 15

Estimated Time: 2 min.

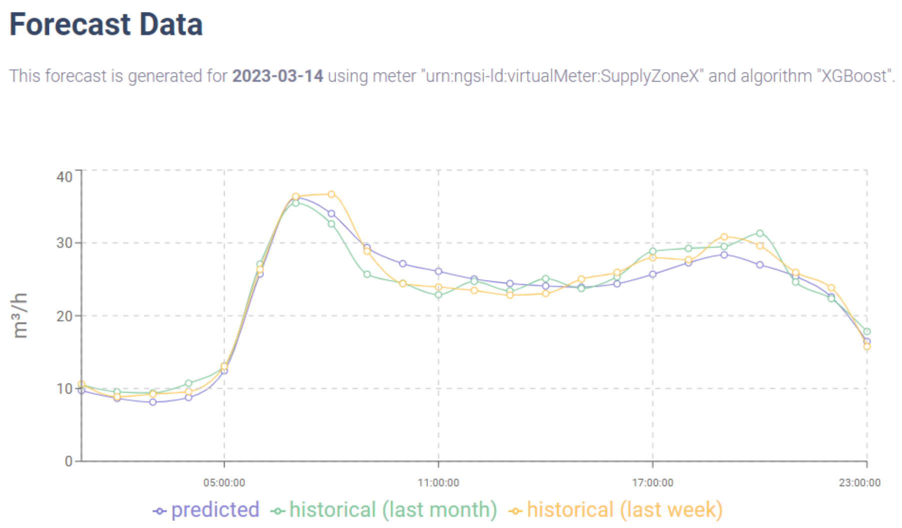
Training an XGBoost model for a supply zone with automatic hyperparameter optimization (algorithm parameters are optimized automatically such that the user does not need to understand and specify them).



urn:ngsi-ld:virtualMeter:SupplyZoneX:MLModel:XGBoost XGBoost 2023-06-05T09:05:07 2023-06-05T09:05:07

MAPE: 5.10109

RMSE: 0.02742

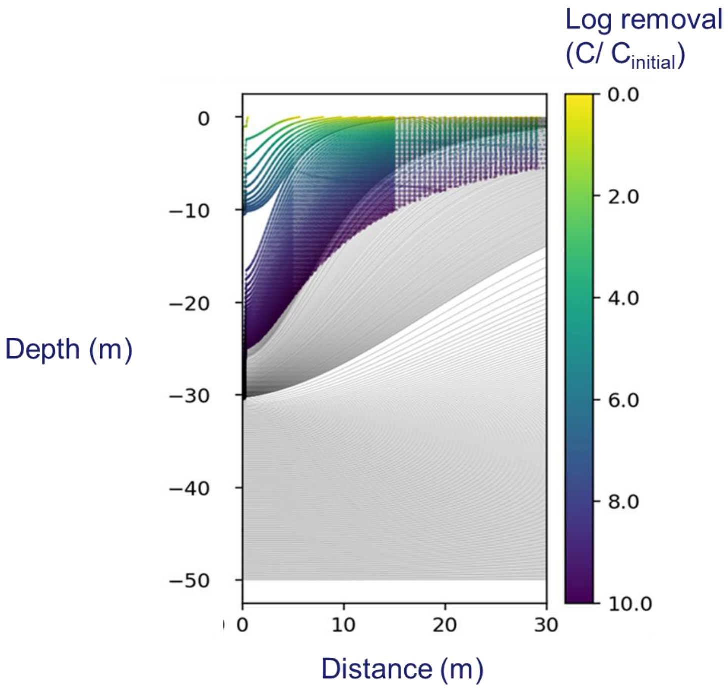
	Model performance on a hold-out dataset for plausibility checking based on error metrics and visualizations of predicted vs. actual water demand.  Forecast Data This forecast is generated for **2023-03-14** using meter "urn:ngsi-ld:virtualMeter:SupplyZoneX" and algorithm "XGBoost". Forecast generation for a specific day, using the already trained model.
Caption/Source	Captions are specified directly with the pictures above. Pictures are provided by IWW.
Publications	Not yet available.

12.1.8 SuTRa (#31)

Table 14: SuTRa tool's attributes and description.

Tool's attribute	Description
Type of product	A software supporting the Circular Economy
Name	Subsurface Transport and Removal
Description	Managed Aquifer Recharge (MAR) offers numerous benefits including storage of water. • The source water for MAR schemes is often contaminated with pathogens. • One of the advantages of MAR is that the pathogens may be removed during storage and transport. Challenge • Existing models for pathogen removal require high expertise (e.g., Hydrus 2D) or are not suited for MAR-applications (QMRAwell). • Removal parameters are hard to estimate. • Dependence on organism related properties (e.g., diameter, survival rate). • Environmental parameters such as temperature, redox conditions, and flow rate. • Existing databases are not tailored to conditions typical for MAR.

	The aim of this tool is to retrieve plant pathogen transport properties and use this information to predict concentration of pathogens after subsurface storage.
Abbreviation	SuTRa
URL	https://sutra.readthedocs.io/en/latest/tutorial.html
Costs	Use is free of charge.
Target audience	Direct users: Professionals involved in the design (e.g., engineers) or in the evaluation of MAR-schemes (e.g., health experts, pest control experts).
Actors, roles and interactions	Indirect beneficiaries: • Agricultural companies: less risk of plant diseases, • MAR-Technology providers: more optimal dimensioning of MAR-schemes.
Unique selling points /Added Value/Innovation	**Unique selling points**: The USP of the tool is to provide a simple method to estimate microbial risks of Managed Aquifer Recharge (MAR) systems. **Added value**: The added value lies in that it thereby provides the user with the ability to optimize the design of the MAR system with respect to hygiene (human health) aspects.
TRL	TRL 6
Technical requirements	Computer with Python version 3.6 or higher installed.
Environment	Computer with Python version 3.6 or higher installed.
Version	First version
Initial release	June 2022
License type	MIT License
Programming language/technologies used	Python
Open interface	None. Parameters are currently downloaded with the package (no API).
Graphical User Interface / Headless software	The tool has no GUI.
Supported spatial scales	Most applicable to field scale (1 to 100 meters) since this is the distance over which pathogen transport typically takes place.
Supported temporal scales	Daily.

Water Use Types	Any water type (urban, industrial, rural and agriculture) infiltrated into the subsurface.
Compatibility with FIWARE	NA
Organisations	KWR Water Research Institute.
Contact details	Martin van der Schans (Martin.van.der.schans@kwrwater.nl)
Data Manager	Gerard van den Berg (Gerard.van.den.Berg@kwrwater.nl)
Technologies	Controlled Agricultural Recharge and Drainage (CARD) Large Scale Aquifer Storage and Recovery System (ASR)
Tags	Plant pathogens, groundwater, inactivation.
Images	
Caption/Source	Example of the removal of pathogens from groundwater following infiltration from the ground surface during transport to a well on the left side of the image. Note that concentration reduction is depicted on a 10log scale.
Publications	NA.

13 Annex B: Technical details of tools

In this Annex more technical and detailed information is provided with regards to each tool. The detailed information introduced in this Annex is related to technical details on developments and advancements made within the project in some tools and the primary functionality offered by the tools along with screenshots of the user interface (when relevant).

13.1 Urban Water Optioneering Tool (#22)

13.1.1 Navigation and primary functionalities

UWOT comes in the form of an executable file (.exe) with its own GUI, where the end user is able to draw topologies, connect different components and perform simulations. The GUI works with Windows 64-bit systems. An example of the tool GUI is provided below (Figure 43).

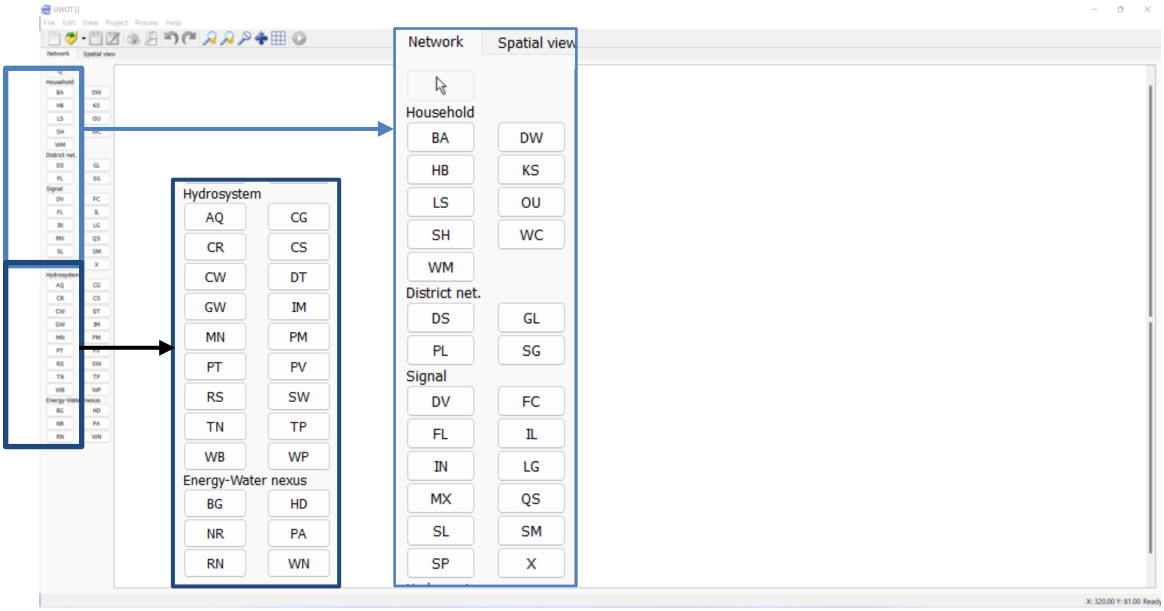


Figure 43: UWOT's Graphical User Interface (GUI).

The main steps to run a simulation on UWOT are the following (Figure 44):

1. Select the appropriate components to construct a topology.
2. Connect the components to form the examined scenario.

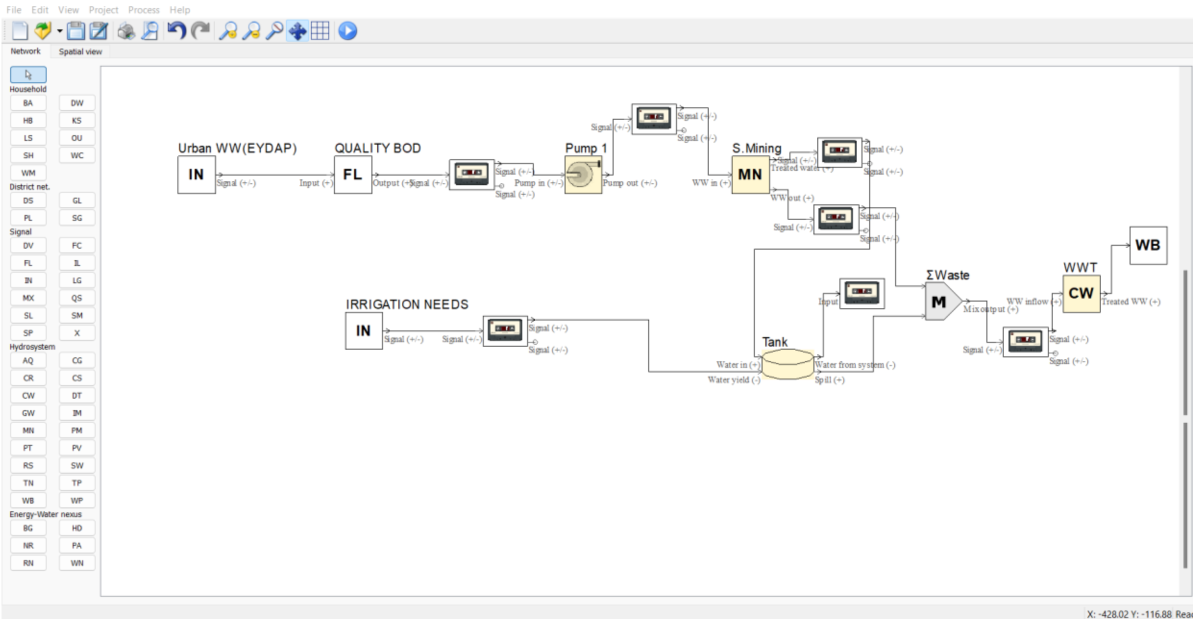
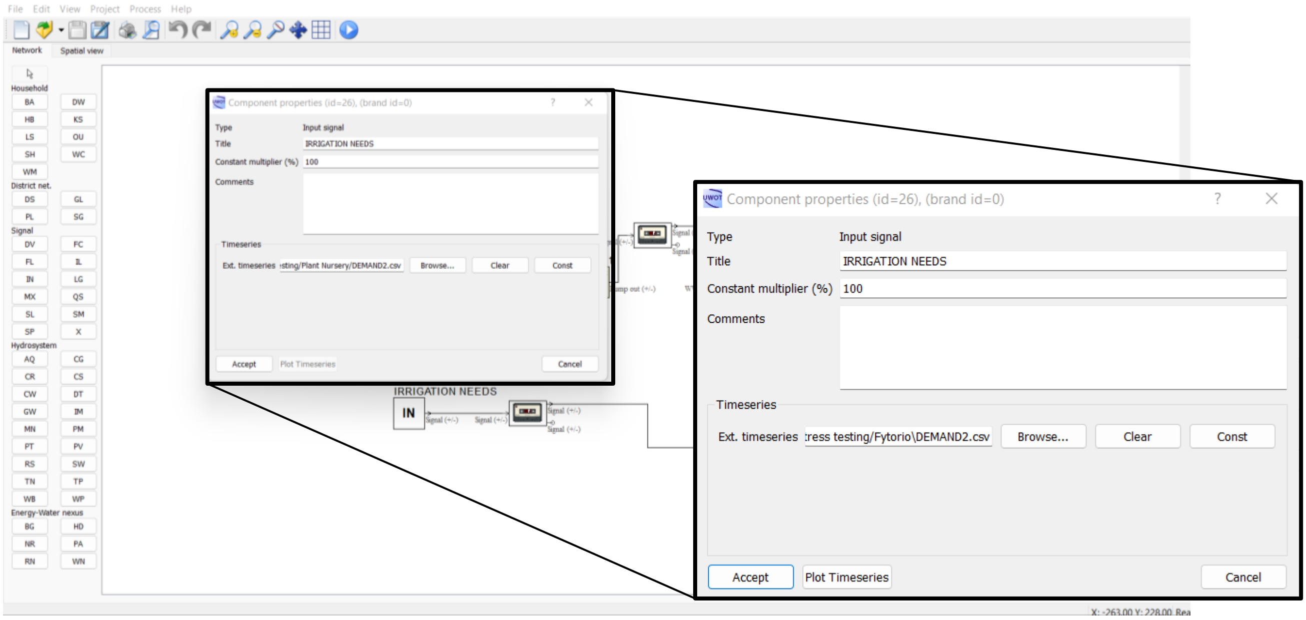


Figure 44: Steps 1 & 2 - Build a topology.

3. After receiving and preparing the input data such as water demand, hydroclimatic time series (to CSV format) etc. for the case study, enter the data and let UWOT check if the data are complete (Figure 45).


Component properties (id=26), (brand id=0)

Type Input signal

Title IRRIGATION NEEDS

Constant multiplier (%) 100

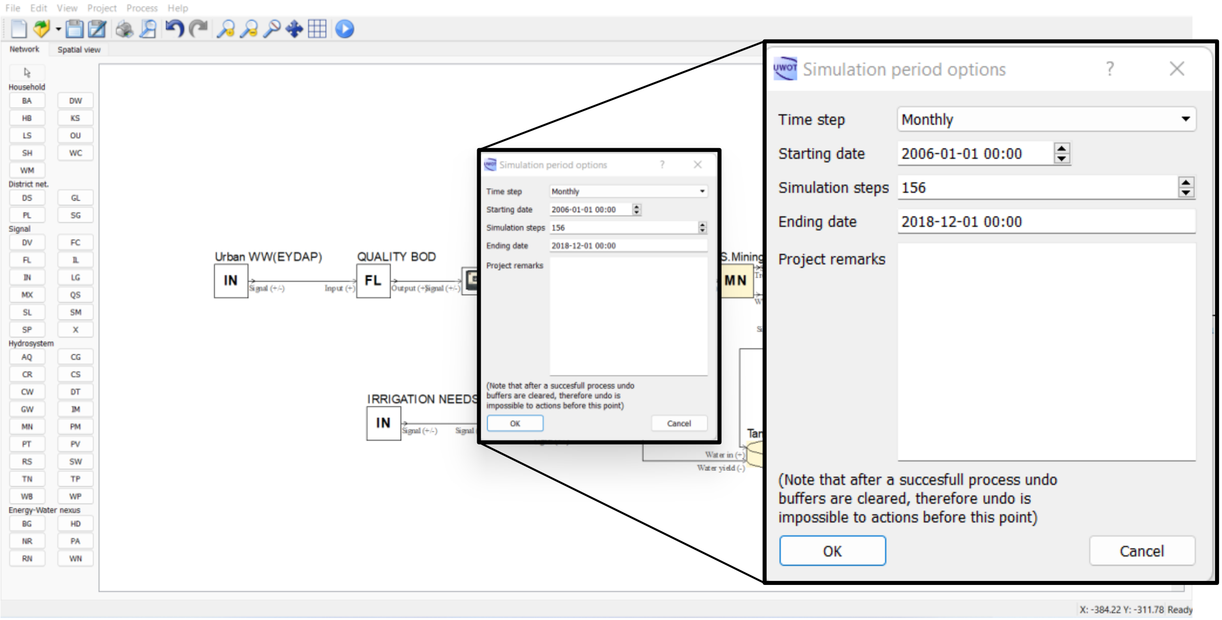
Comments

Timeseries

Ext. timeseries :ress testing/Fytorio\DEMAND2.csv

Figure 45: Step 3 – Input appropriate data (for example, time series to CSV format).

4. Adjust the simulation’s options and run the simulation (Figure 46).



Simulation period options

Time step: Monthly

Starting date: 2006-01-01 00:00

Simulation steps: 156

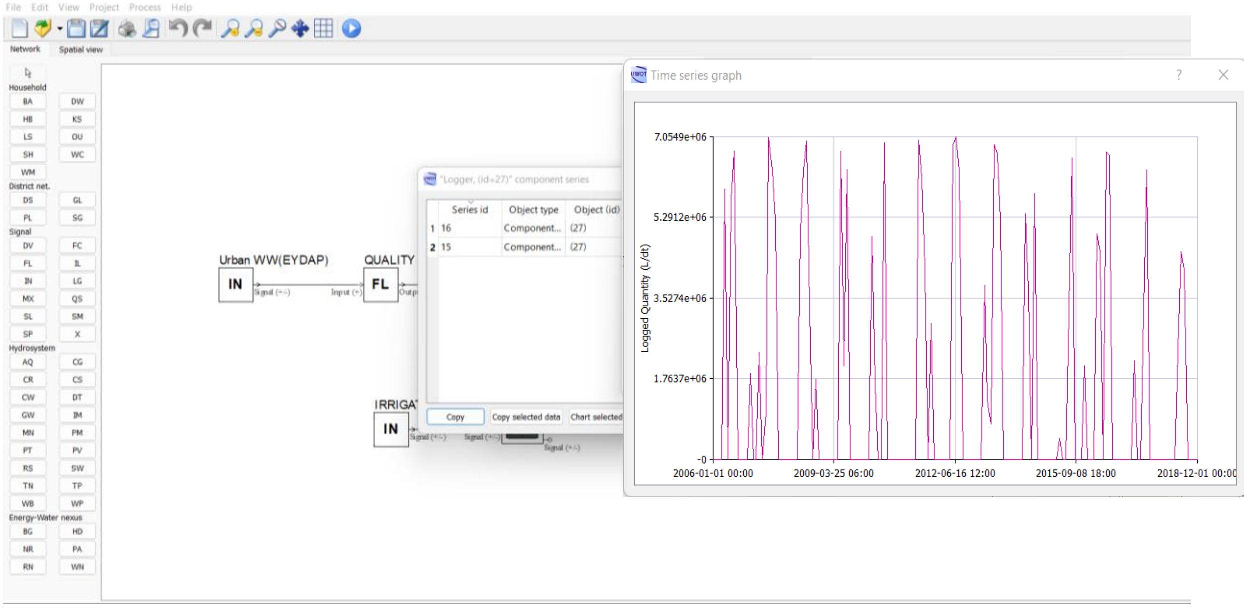
Ending date: 2018-12-01 00:00

Project remarks

(Note that after a succesfull process undo buffers are cleared, therefore undo is impossible to actions before this point)

Figure 46: Step 4 - Adjust the simulation’s options and run the simulation.

5. Access the output data from the user interface, visualize or export the output data to another program or copy the data to the clipboard for further analysis (Figure 47).



"Logger, (id=27)" component series

	Series id	Object type	Object (id)
1	16	Component...	(27)
2	15	Component...	(27)

Figure 47: Step 5 - Visualize output data.

Similarly, the main steps to build a UWOT topology at a household level, signal-based, from demand nodes to sources, are the following (Figure 48):

1. Add household appliances and group them into different households, mix them together under different households.
2. Include rainwater management and (possibly) greywater recycling components.
3. Log stored water, covered demands, energy requirements at each time step.
4. View results for a specified scenario-topology (set of techs).

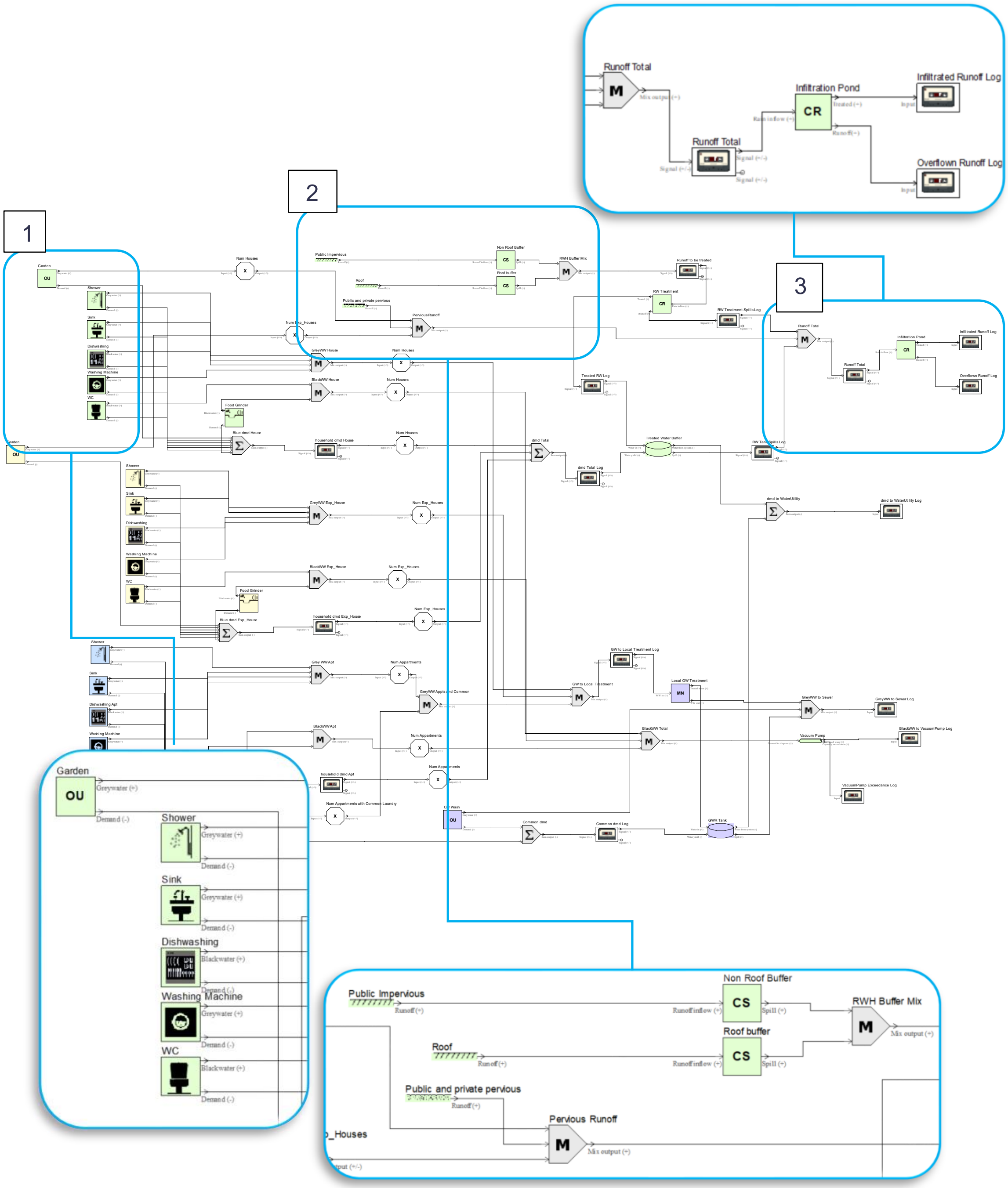


Figure 48: Example of UWOT simulation.

13.2 Regional demand-supply matching GIS tool (#23)

13.2.1 Navigation and primary functionalities

There are five functionalities of the tool that can be used by the end-user (Figure 49):

1) Visualization of data in the viewer mode on different scales:
    a. Data discretization in dependence of scale.
    b. Water demands / water sources.
    c. Heat maps.
2) Automated identification of water sources and possible water reuse resources in the vicinity of a defined location (depending on distance). Water quality level can be selected.
3) Approximate classification of the financial expenditure for the development of the alternative resource (surface water).
4) Display mean annual precipitation data to explore the possibility of using rainwater harvesting as an alternative resource.
5) Use of UWOT data for a five-year projection of water demand (depending on availability of UWOT data for the requested point of interest).

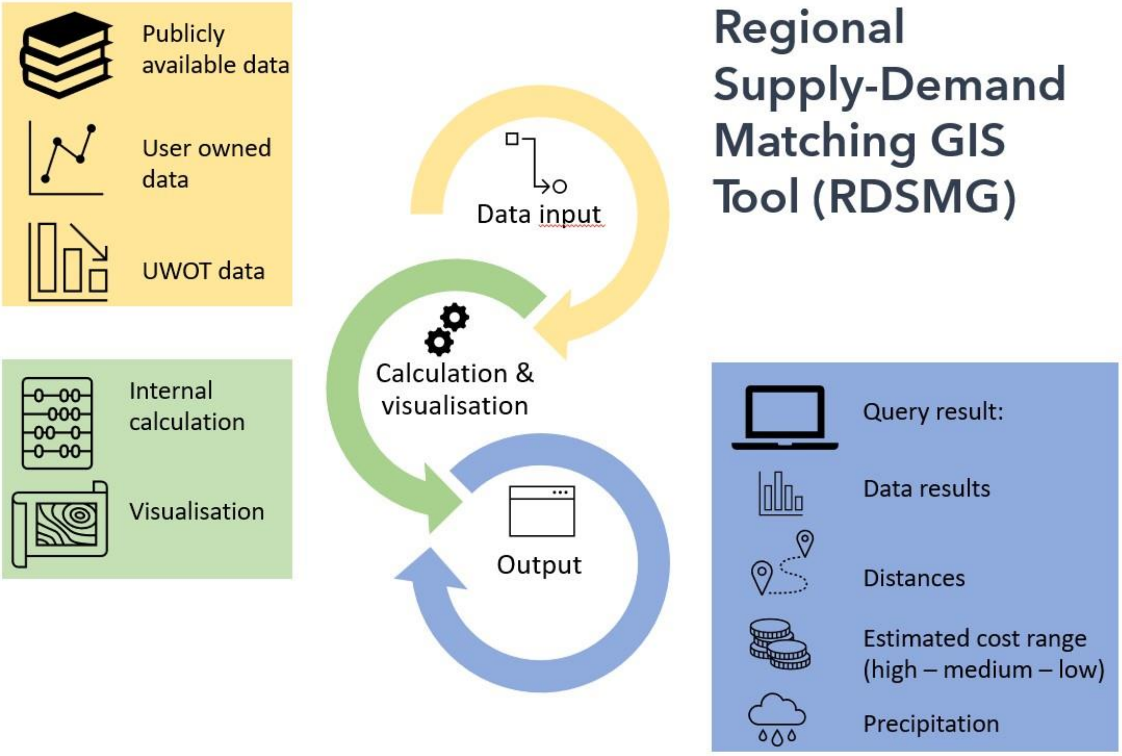


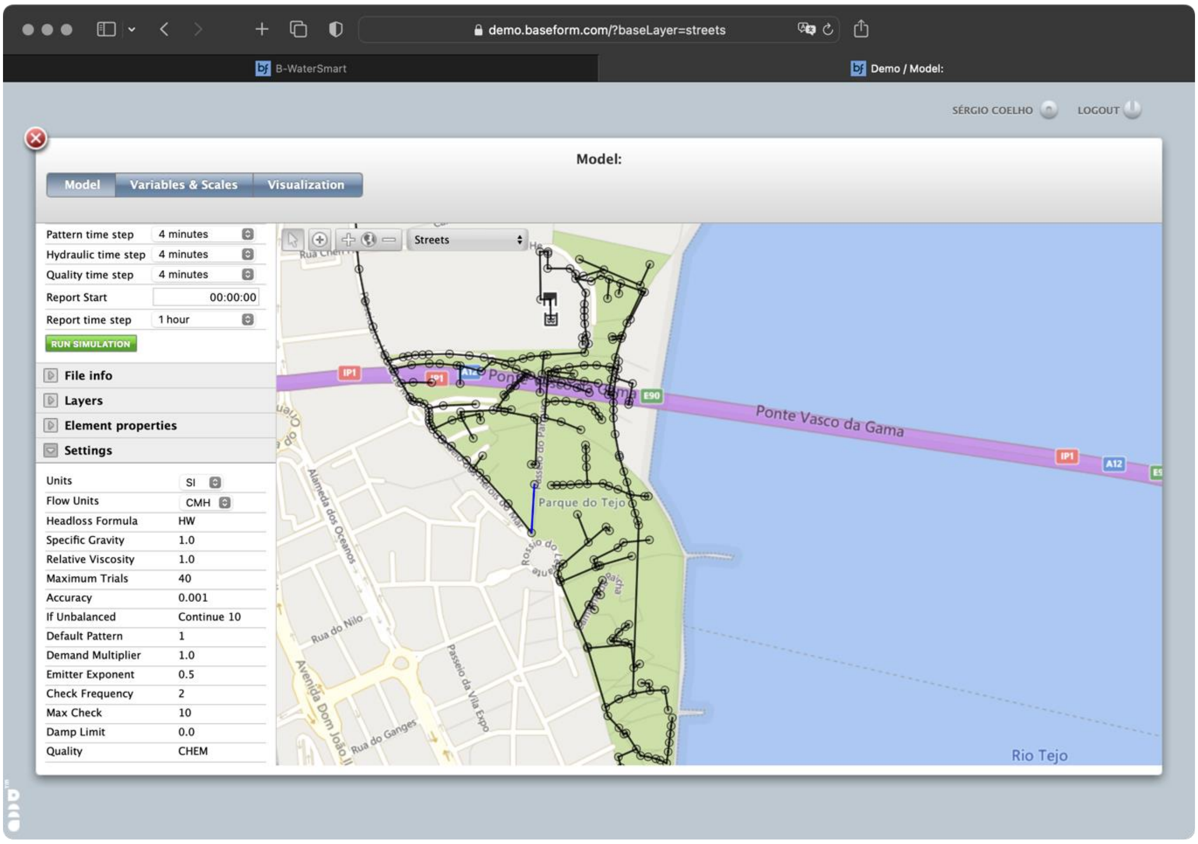
Figure 49: Main functionalities of the regional demand-supply matching GIS tool.

13.3 Reclaimed water distribution network water quality model (#24)

13.3.1 Navigation and primary functionalities

The model runs in BASEFORM's environment as an individual app (see Figure 50). The primary input for the hydraulic model is an EPANET .INP file, and for the water quality an EPANET MSX file. The latter is based on a detailed formulation developed specifically for the project by the LNEC team, which is described in detail in documentation produced by task T2.4.

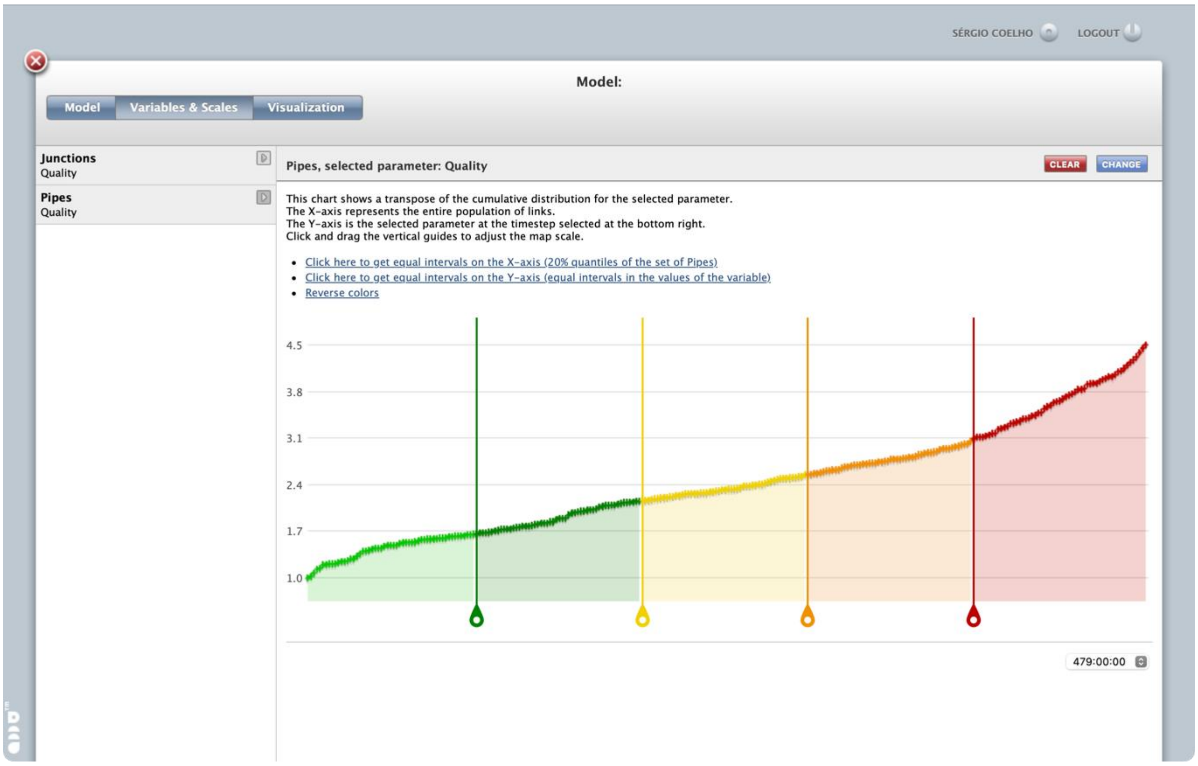
The model runs based on those two files and the interface allows for querying of results as well as full visualisation in BASEFORM's 3D environment. Some screenshots in the figures below illustrate the software's functionality.



Pattern time step	4 minutes
Hydraulic time step	4 minutes
Quality time step	4 minutes
Report Start	00:00:00
Report time step	1 hour

Units	SI
Flow Units	CMH
Headloss Formula	HW
Specific Gravity	1.0
Relative Viscosity	1.0
Maximum Trials	40
Accuracy	0.001
If Unbalanced	Continue 10
Default Pattern	1
Demand Multiplier	1.0
Emitter Exponent	0.5
Check Frequency	2
Max Check	10
Damp Limit	0.0
Quality	CHEM

Figure 50: The app's start page displaying some of the model's key parameters and a 2D network schematic. The properties of physical elements such as pipes can be queried by clicking on a pipe. Besides using the Epanet .INP file standard, the model can also be exported to an Excel® format that facilitates section-by-section editing.



Pipes, selected parameter: Quality

This chart shows a transpose of the cumulative distribution for the selected parameter.
The X-axis represents the entire population of links.
The Y-axis is the selected parameter at the timestep selected at the bottom right.
Click and drag the vertical guides to adjust the map scale.

- Click here to get equal intervals on the X-axis (20% quantiles of the set of Pipes)
- Click here to get equal intervals on the Y-axis (equal intervals in the values of the variable)
- Reverse colors

Figure 51: Inspecting the distribution of values across the network of a given state variable – in this case, the ‘Quality’ parameter translates the specific formulation developed in BWS for reused water – at a given time step.

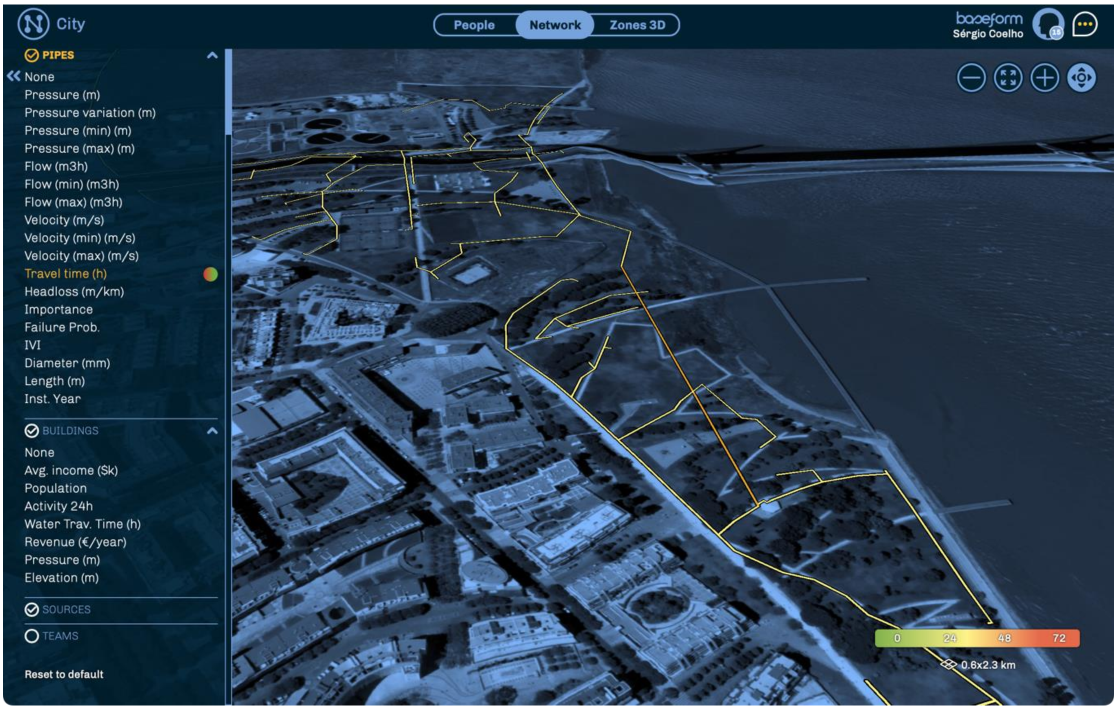
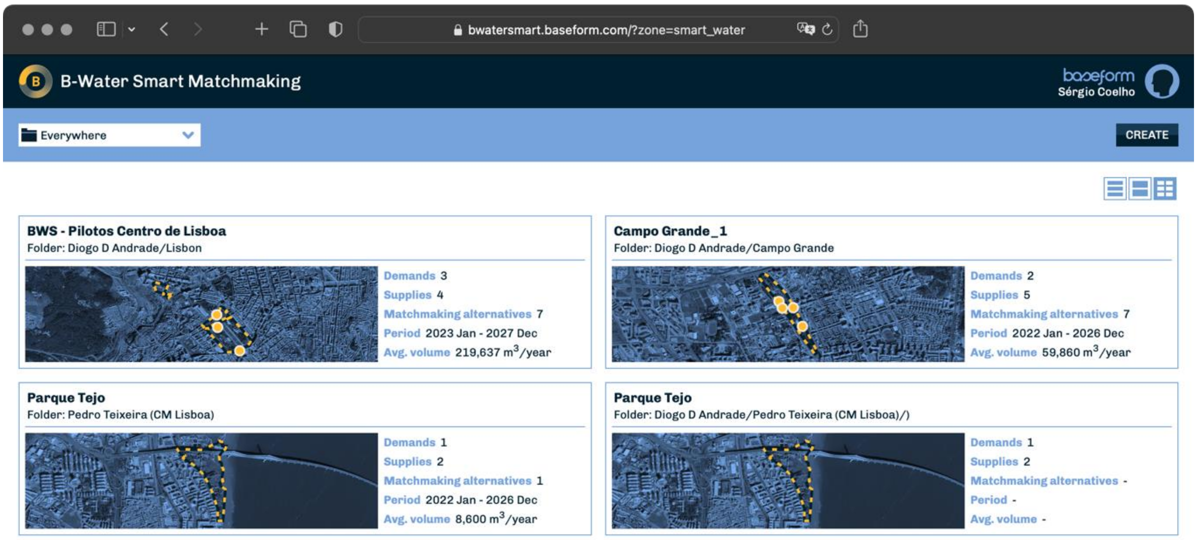


Figure 52: Model results on display through the BASEFORM City 3D network interface.

13.4 Water-energy-phosphorous balance planning module (#25)

13.4.1 Navigation and primary functionalities

The figures below depict the logical navigation sequence across the tool’s key functionality. Figure 53 depicts the GUI when the app is started. It displays the available analyses as well as the option to create a new one (top right). An analysis contains one or more matchmaking alternatives for a given supply/demand application case, as well as a set of metrics and a range of analysis timesteps.



BWS - Pilotos Centro de Lisboa
Folder: Diogo D Andrade/Lisbon
Demands 3
Supplies 4
Matchmaking alternatives 7
Period 2023 Jan - 2027 Dec
Avg. volume 219,637 m^3/year

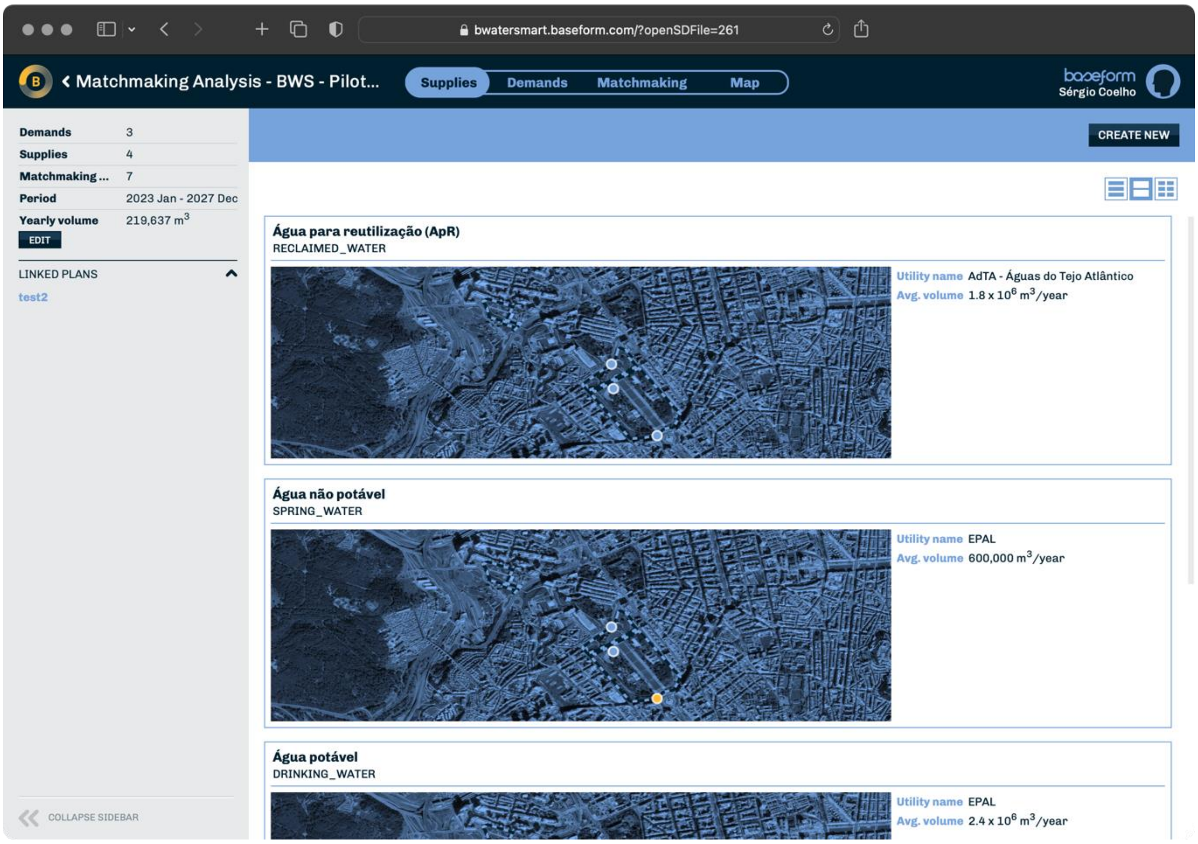
Campo Grande_1
Folder: Diogo D Andrade/Campo Grande
Demands 2
Supplies 5
Matchmaking alternatives 7
Period 2022 Jan - 2026 Dec
Avg. volume 59,860 m^3/year

Parque Tejo
Folder: Pedro Teixeira (CM Lisboa)
Demands 1
Supplies 2
Matchmaking alternatives 1
Period 2022 Jan - 2026 Dec
Avg. volume 8,600 m^3/year

Parque Tejo
Folder: Diogo D Andrade/Pedro Teixeira (CM Lisboa)/)
Demands 1
Supplies 2
Matchmaking alternatives -
Period -
Avg. volume -

Figure 53: GUI when the app is launched.

Figure 54 presents the app’s main screen, showing the Supplies tab, which lists all available supply sources registered for the given case. New supply sources may be registered at the top right.



Demands 3
Supplies 4
Matchmaking ... 7
Period 2023 Jan - 2027 Dec
Yearly volume 219,637 m^3

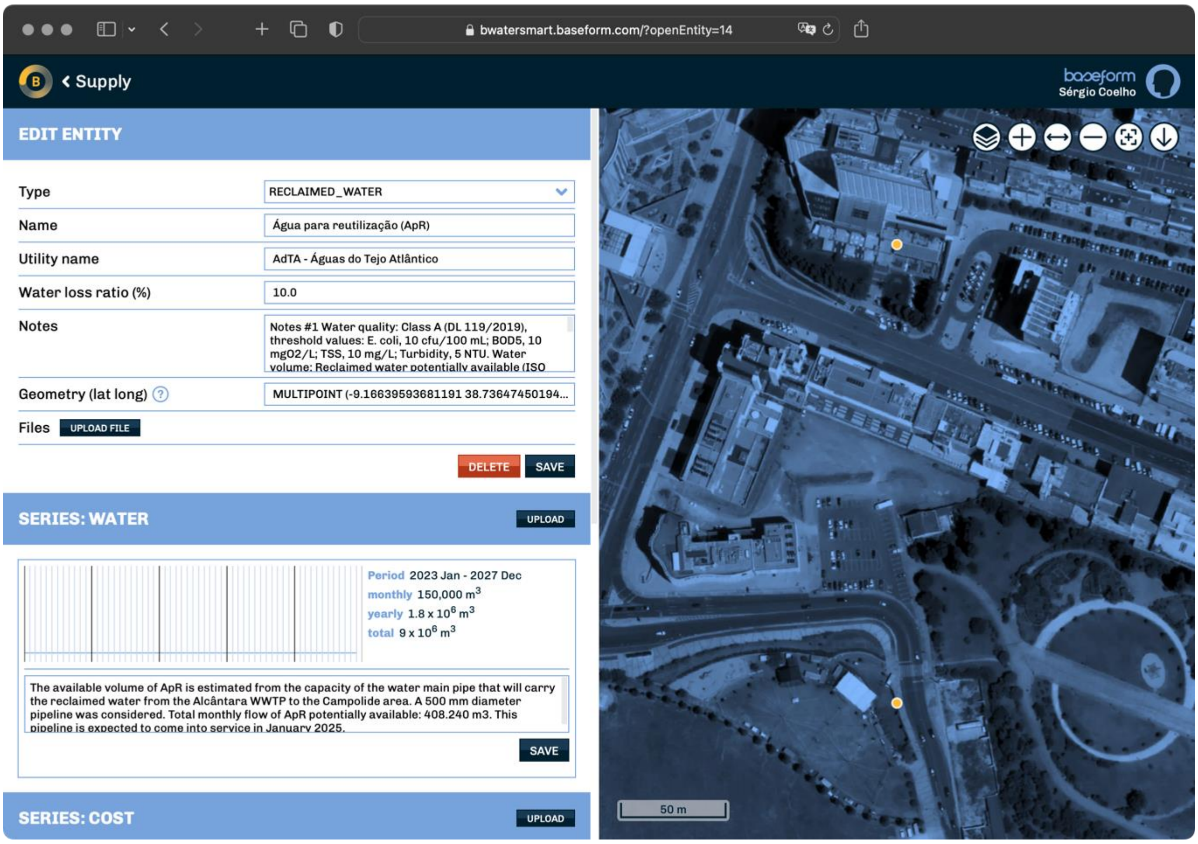
Água para reutilização (ApR)
RECLAIMED_WATER
Utility name AdTA - Águas do Tejo Atlântico
Avg. volume 1.8 x 10^6 m^3/year

Água não potável
SPRING_WATER
Utility name EPAL
Avg. volume 600,000 m^3/year

Água potável
DRINKING_WATER
Utility name EPAL
Avg. volume 2.4 x 10^6 m^3/year

Figure 54: The app's main screen.

While creating or editing a supply source users need to specify its geographical position and add files with time series for water volume available, cost and phosphorus content (Figure 55 and Figure 56).

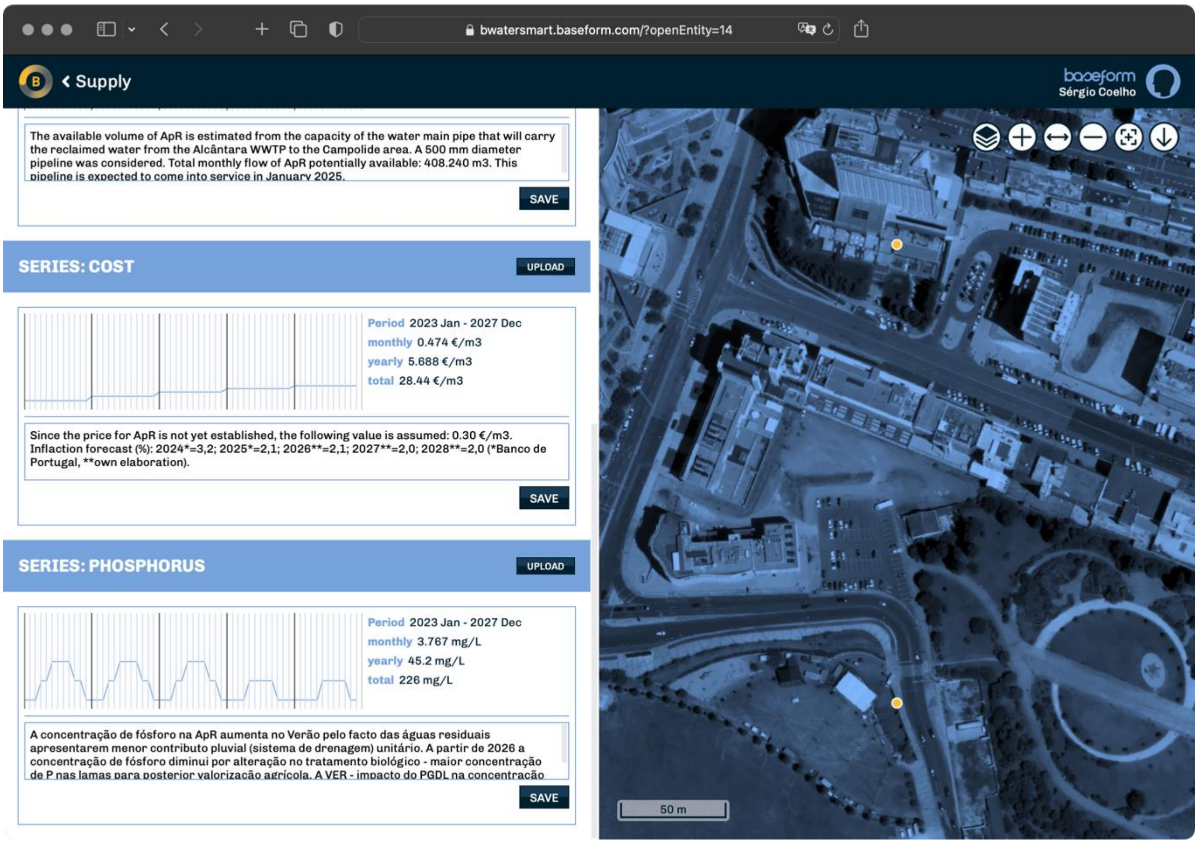


Type	RECLAIMED_WATER
Name	Água para reutilização (ApR)
Utility name	AdTA - Águas do Tejo Atlântico
Water loss ratio (%)	10.0
Notes	Notes #1 Water quality: Class A (DL 119/2019), threshold values: E. coli, 10 cfu/100 mL; BOD5, 10 mgO2/L; TSS, 10 mg/L; Turbidity, 5 NTU. Water volume: Reclaimed water potentially available (ISO
Geometry (lat long)	MULTIPOINT (-9.16639593681191 38.73647450194...
Files	

Period 2023 Jan - 2027 Dec
monthly 150,000 m^3
yearly 1.8×10^6 m^3
total 9×10^6 m^3

The available volume of ApR is estimated from the capacity of the water main pipe that will carry the reclaimed water from the Alcântara WWTP to the Campolide area. A 500 mm diameter pipeline was considered. Total monthly flow of ApR potentially available: 408.240 m3. This pipeline is expected to come into service in January 2025.

Figure 55: Creating or editing a supply source.



The available volume of ApR is estimated from the capacity of the water main pipe that will carry the reclaimed water from the Alcântara WWTP to the Campolide area. A 500 mm diameter pipeline was considered. Total monthly flow of ApR potentially available: 408.240 m3. This pipeline is expected to come into service in January 2025.

SERIES: COST

Period 2023 Jan - 2027 Dec
monthly 0.474 €/m3
yearly 5.688 €/m3
total 28.44 €/m3

Since the price for ApR is not yet established, the following value is assumed: 0.30 €/m3. Inflaction forecast (%): 2024*=3,2; 2025*=2,1; 2026**=2,1; 2027**=2,0; 2028**=2,0 (*Banco de Portugal, **own elaboration).

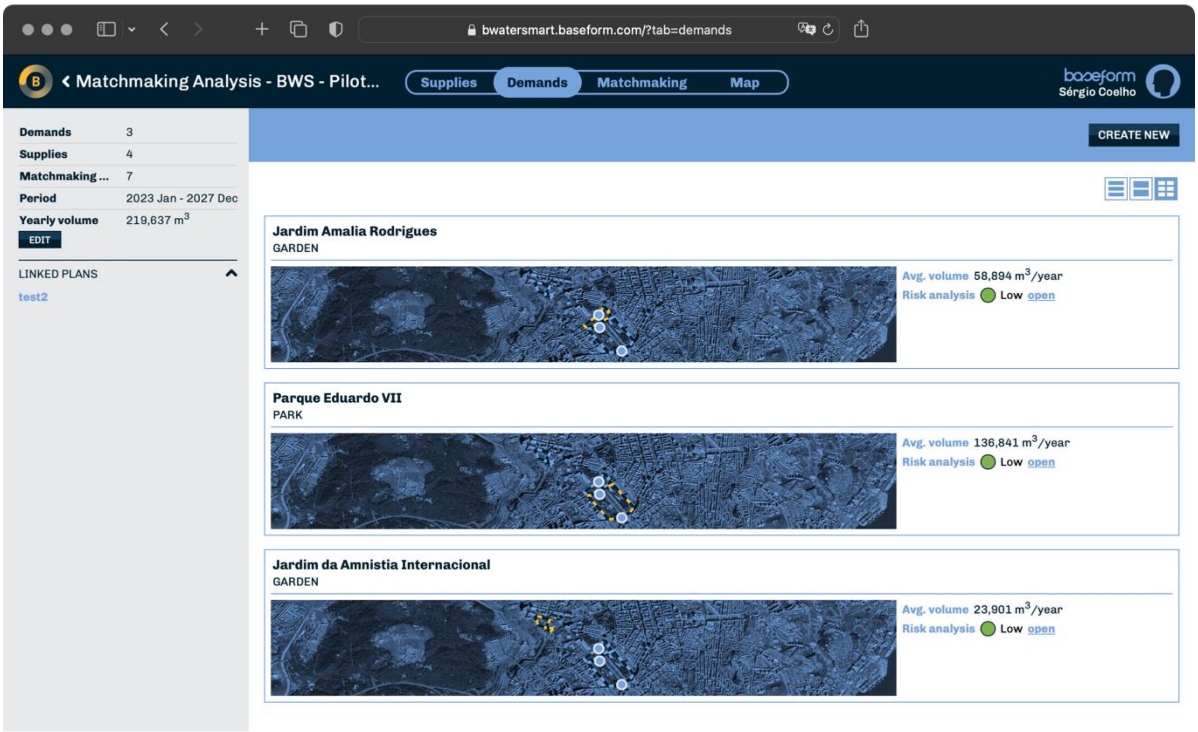
SERIES: PHOSPHORUS

Period 2023 Jan - 2027 Dec
monthly 3.767 mg/L
yearly 45.2 mg/L
total 226 mg/L

A concentração de fósforo na ApR aumenta no Verão pelo facto das águas residuais apresentarem menor contributo pluvial (sistema de drenagem) unitário. A partir de 2026 a concentração de fósforo diminui por alteração no tratamento biológico - maior concentração de P nas lamas para posterior valorização agrícola. A VER - impacto do PGDL na concentração

Figure 56: Creating or editing a supply source, showing the time series for cost and phosphorus content.

Figure 57 presents the demands tab, which lists all the demands registered for the given case, which will drive the analysis. New demands may be registered at the top right.



Demands	3
Supplies	4
Matchmaking ...	7
Period	2023 Jan - 2027 Dec
Yearly volume	219,637 m^3

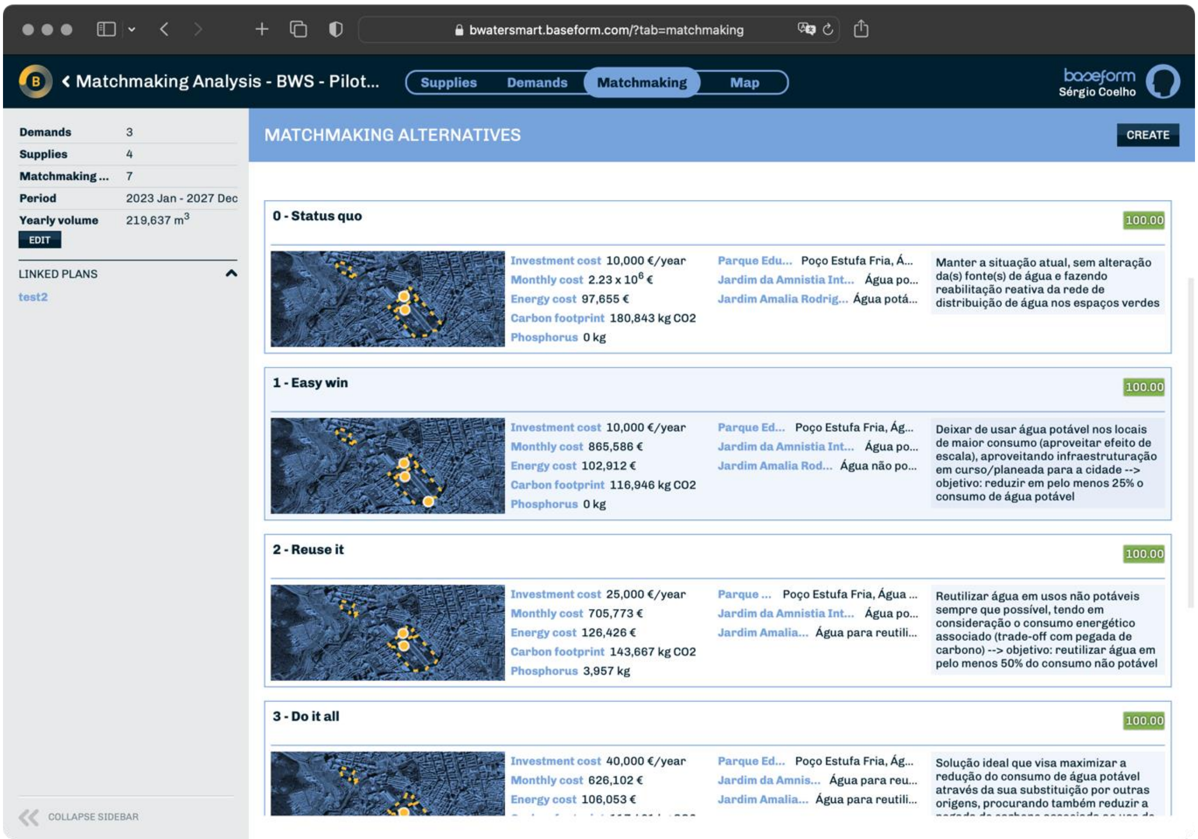
Jardim Amalia Rodrigues
GARDEN
Avg. volume 58,894 m^3/year
Risk analysis ● Low open

Parque Eduardo VII
PARK
Avg. volume 136,841 m^3/year
Risk analysis ● Low open

Jardim da Amnistia Internacional
GARDEN
Avg. volume 23,901 m^3/year
Risk analysis ● Low open

Figure 57: The Demands tab.

The below figure (Figure 58) depicts the Matchmaking tab, displaying the matchmaking supply/demand alternatives developed for the current analysis, along with their key metrics. New alternatives may be created at the top right.



Demands 3
Supplies 4
Matchmaking ... 7
Period 2023 Jan - 2027 Dec
Yearly volume 219,637 m^3

MATCHMAKING ALTERNATIVES

0 - Status quo 100.00

Investment cost 10,000 €/year
Monthly cost 2.23 x 10^6 €
Energy cost 97,655 €
Carbon footprint 180,843 kg CO2
Phosphorus 0 kg

Parque Edu... Poço Estufa Fria, Á...
Jardim da Amnistia Int... Água po...
Jardim Amalia Rodrig... Água potá...

Manter a situação atual, sem alteração da(s) fonte(s) de água e fazendo reabilitação reativa da rede de distribuição de água nos espaços verdes

1 - Easy win 100.00

Investment cost 10,000 €/year
Monthly cost 865,586 €
Energy cost 102,912 €
Carbon footprint 116,946 kg CO2
Phosphorus 0 kg

Parque Ed... Poço Estufa Fria, Ág...
Jardim da Amnistia Int... Água po...
Jardim Amalia Rod... Água não po...

Deixar de usar água potável nos locais de maior consumo (aproveitar efeito de escala), aproveitando infraestruturação em curso/planeada para a cidade --> objetivo: reduzir em pelo menos 25% o consumo de água potável

2 - Reuse it 100.00

Investment cost 25,000 €/year
Monthly cost 705,773 €
Energy cost 126,426 €
Carbon footprint 143,667 kg CO2
Phosphorus 3,957 kg

Parque ... Poço Estufa Fria, Água ...
Jardim da Amnistia Int... Água po...
Jardim Amalia... Água para reutili...

Reutilizar água em usos não potáveis sempre que possível, tendo em consideração o consumo energético associado (trade-off com pegada de carbono) --> objetivo: reutilizar água em pelo menos 50% do consumo não potável

3 - Do it all 100.00

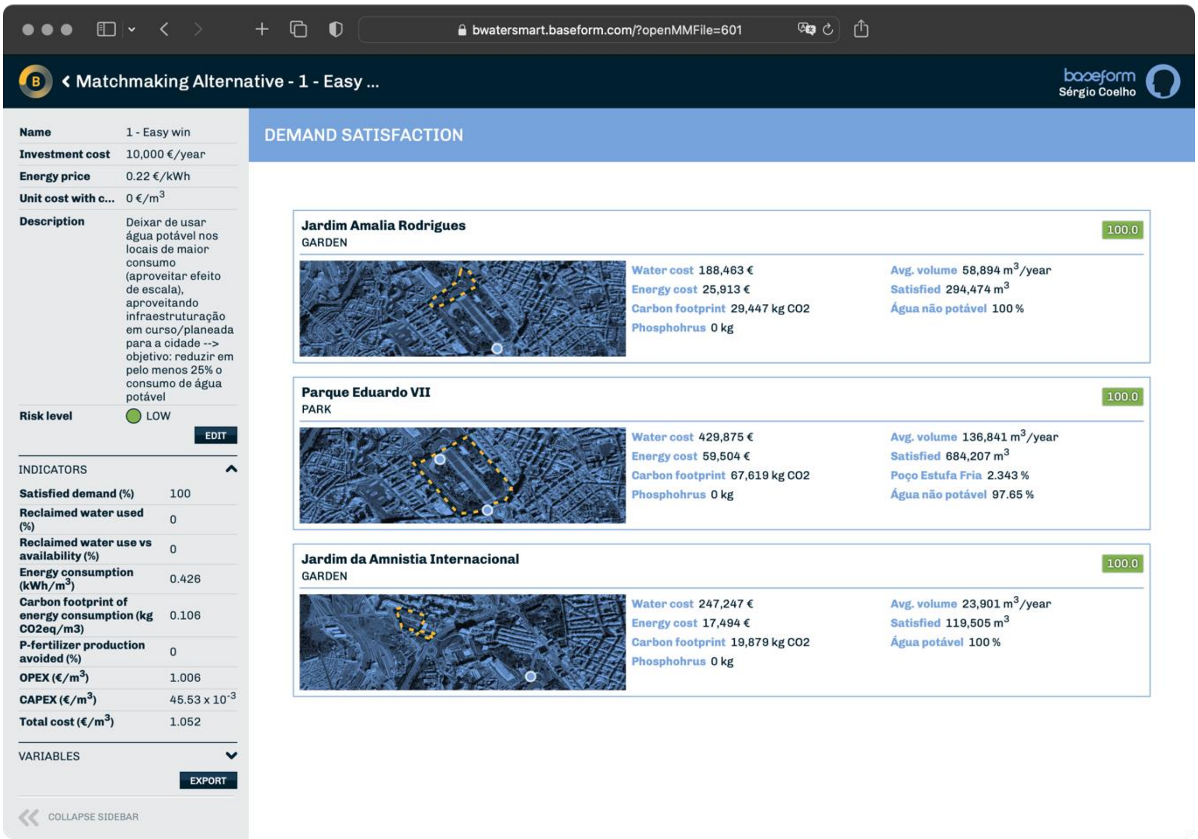
Investment cost 40,000 €/year
Monthly cost 626,102 €
Energy cost 106,053 €

Parque Ed... Poço Estufa Fria, Ág...
Jardim da Amnis... Água para reu...
Jardim Amalia... Água para reutili...

Solução ideal que visa maximizar a redução do consumo de água potável através da sua substituição por outras origens, procurando também reduzir a

Figure 58: The Matchmaking tab.

Figure 59 presents the GUI where users can create or edit a matchmaking alternative, showing investment cost, energy price, unit cost and the indicators' values on the left, as well as the risk score, calculated via the linked Tool #27. The various demands to be satisfied in this case are listed, together with key metrics and their completion % (green field on top right of each demand entry). In Figure 60 the values of the base variables used in the calculation is displayed.



Name	1 - Easy win
Investment cost	10,000 €/year
Energy price	0.22 €/kWh
Unit cost with c...	0 €/m^3
Description	Deixar de usar água potável nos locais de maior consumo (aproveitar efeito de escala), aproveitando infraestruturação em curso/planeada para a cidade --> objetivo: reduzir em pelo menos 25% o consumo de água potável
Risk level	● LOW

INDICATORS

Satisfied demand (%)	100
Reclaimed water used (%)	0
Reclaimed water use vs availability (%)	0
Energy consumption (kWh/m^3)	0.426
Carbon footprint of energy consumption (kg CO2eq/m3)	0.106
P-fertilizer production avoided (%)	0
OPEX (€/m^3)	1.006
CAPEX (€/m^3)	45.53 x 10^{-3}
Total cost (€/m^3)	1.052

VARIABLES

DEMAND SATISFACTION

Jardim Amalia Rodrigues
GARDEN
100.0

Water cost 188,463 €
Energy cost 25,913 €
Carbon footprint 29,447 kg CO2
Phosphohrus 0 kg
Avg. volume 58,894 m^3/year
Satisfied 294,474 m^3
Água não potável 100 %

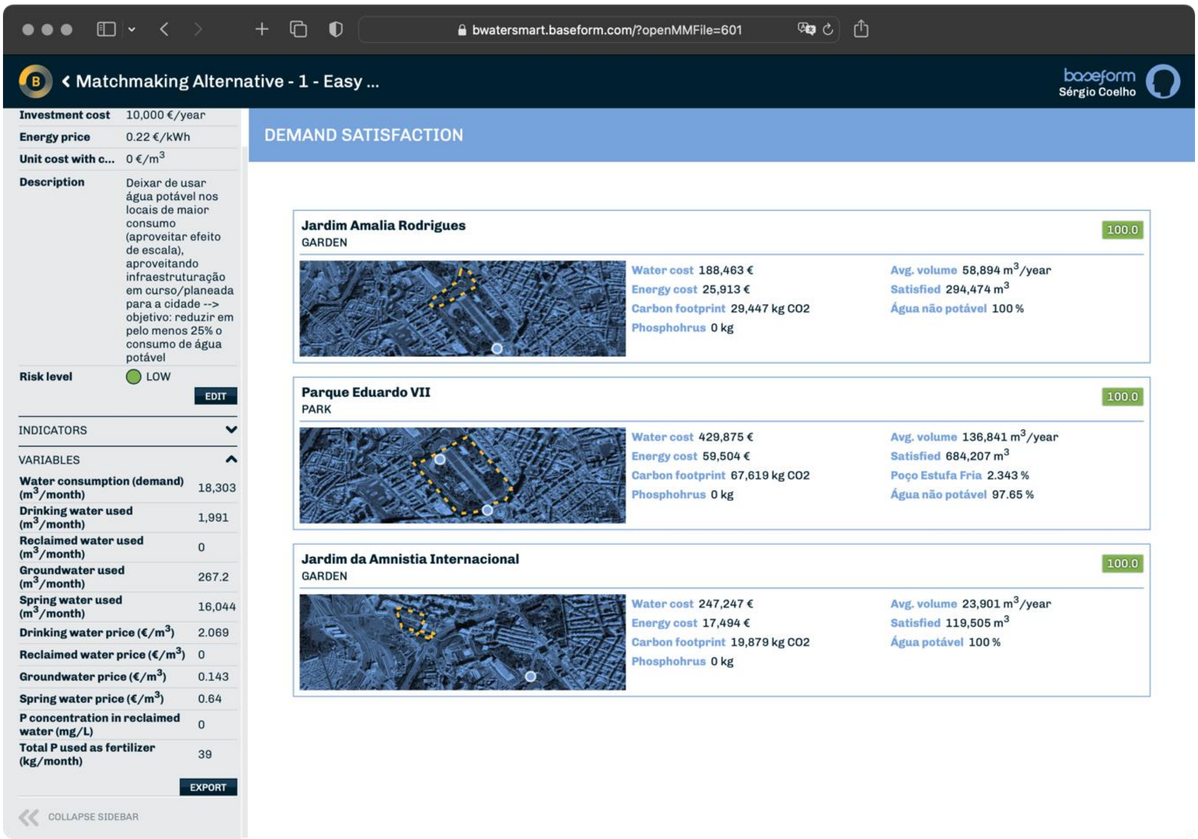
Parque Eduardo VII
PARK
100.0

Water cost 429,875 €
Energy cost 59,504 €
Carbon footprint 67,619 kg CO2
Phosphohrus 0 kg
Avg. volume 136,841 m^3/year
Satisfied 684,207 m^3
Poço Estufa Fria 2.343 %
Água não potável 97.65 %

Jardim da Amnistia Internacional
GARDEN
100.0

Water cost 247,247 €
Energy cost 17,494 €
Carbon footprint 19,879 kg CO2
Phosphohrus 0 kg
Avg. volume 23,901 m^3/year
Satisfied 119,505 m^3
Água potável 100 %

Figure 59: Creating or editing a matchmaking alternative.



Investment cost	10,000 €/year
Energy price	0.22 €/kWh
Unit cost with c...	0 €/m^3
Description	Deixar de usar água potável nos locais de maior consumo (aproveitar efeito de escala), aproveitando infraestruturação em curso/planeada para a cidade --> objetivo: reduzir em pelo menos 25% o consumo de água potável
Risk level	● LOW

VARIABLES	
Water consumption (demand) (m^3/month)	18,303
Drinking water used (m^3/month)	1,991
Reclaimed water used (m^3/month)	0
Groundwater used (m^3/month)	267.2
Spring water used (m^3/month)	16,044
Drinking water price (€/m^3)	2.069
Reclaimed water price (€/m^3)	0
Groundwater price (€/m^3)	0.143
Spring water price (€/m^3)	0.64
P concentration in reclaimed water (mg/L)	0
Total P used as fertilizer (kg/month)	39

DEMAND SATISFACTION

Jardim Amalia Rodrigues 100.0
GARDEN

Water cost 188,463 €
Energy cost 25,913 €
Carbon footprint 29,447 kg CO2
Phosphohrus 0 kg
Avg. volume 58,894 m^3/year
Satisfied 294,474 m^3
Água não potável 100 %

Parque Eduardo VII 100.0
PARK

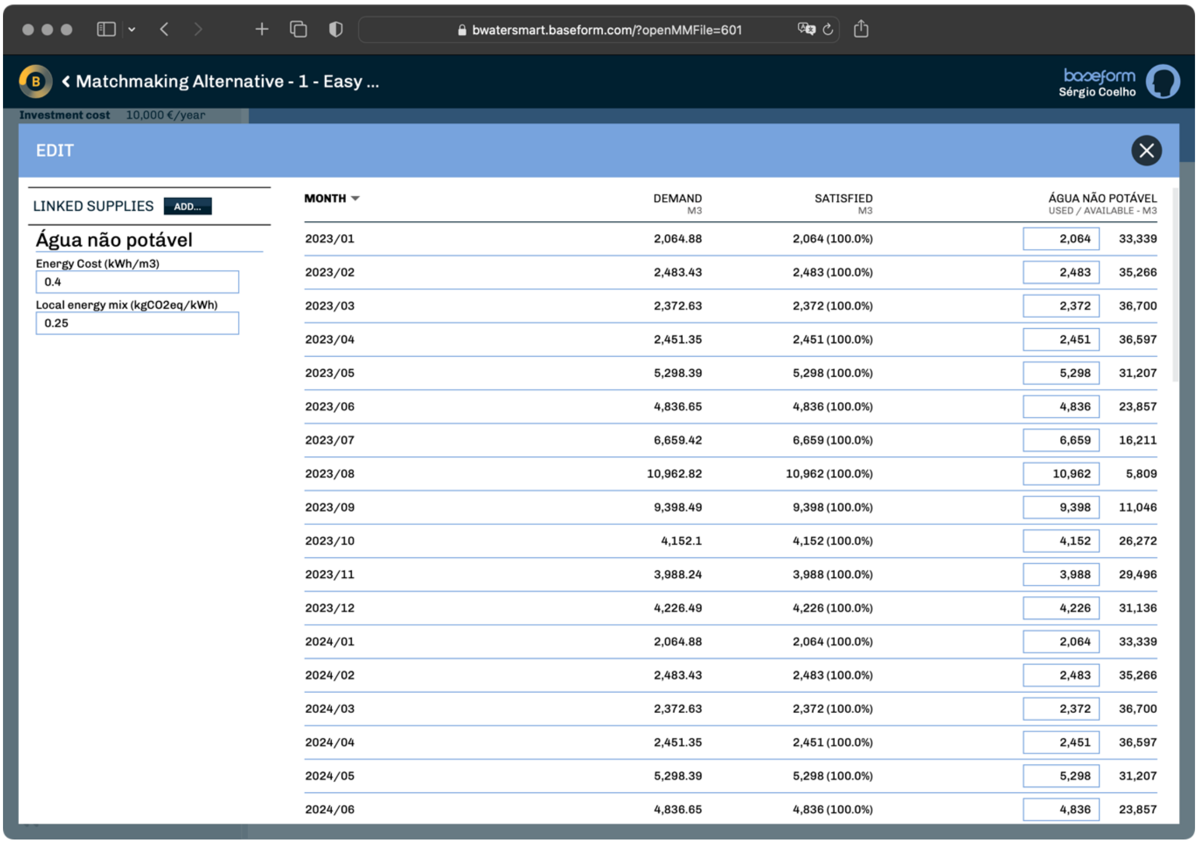
Water cost 429,875 €
Energy cost 59,504 €
Carbon footprint 67,619 kg CO2
Phosphohrus 0 kg
Avg. volume 136,841 m^3/year
Satisfied 684,207 m^3
Poço Estufa Fria 2.343 %
Água não potável 97.65 %

Jardim da Amnistia Internacional 100.0
GARDEN

Water cost 247,247 €
Energy cost 17,494 €
Carbon footprint 19,879 kg CO2
Phosphohrus 0 kg
Avg. volume 23,901 m^3/year
Satisfied 119,505 m^3
Água potável 100 %

Figure 60: Creating or editing a matchmaking alternative, displaying the values of the base variables used in the calculation.

Figure 61 presents the editing screen for each demand to be satisfied, showing the combination of supplies used, whereas Figure 62 shows the Map tab which provides a complete mapping environment to geographically display the registered supplies and demands. A variety of mapping layers are available.



Investment cost 10,000 €/year

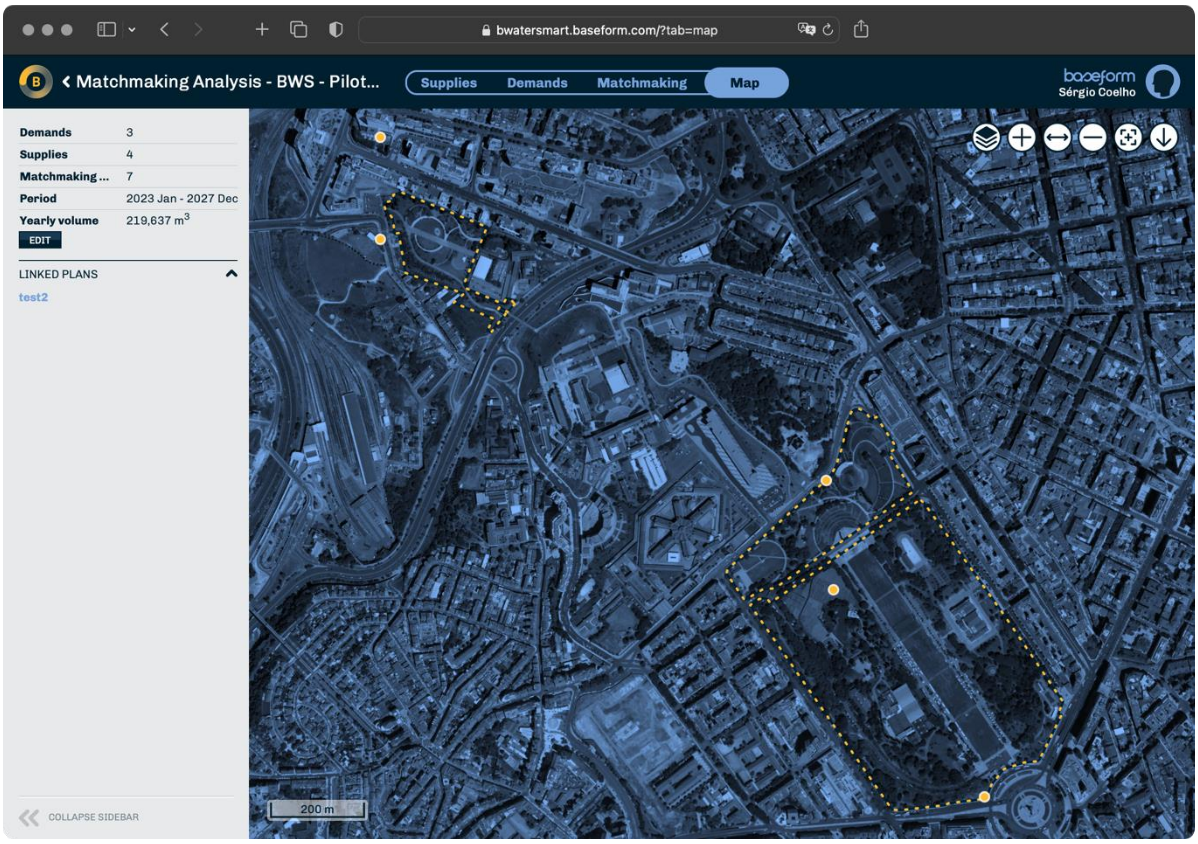
Água não potável

Energy Cost (kWh/m3): 0.4

Local energy mix (kgCO2eq/kWh): 0.25

MONTH	DEMAND M3	SATISFIED M3	ÁGUA NÃO POTÁVEL USED	AVAILABLE - M3
2023/01	2,064.88	2,064 (100.0%)	2,064	33,339
2023/02	2,483.43	2,483 (100.0%)	2,483	35,266
2023/03	2,372.63	2,372 (100.0%)	2,372	36,700
2023/04	2,451.35	2,451 (100.0%)	2,451	36,597
2023/05	5,298.39	5,298 (100.0%)	5,298	31,207
2023/06	4,836.65	4,836 (100.0%)	4,836	23,857
2023/07	6,659.42	6,659 (100.0%)	6,659	16,211
2023/08	10,962.82	10,962 (100.0%)	10,962	5,809
2023/09	9,398.49	9,398 (100.0%)	9,398	11,046
2023/10	4,152.1	4,152 (100.0%)	4,152	26,272
2023/11	3,988.24	3,988 (100.0%)	3,988	29,496
2023/12	4,226.49	4,226 (100.0%)	4,226	31,136
2024/01	2,064.88	2,064 (100.0%)	2,064	33,339
2024/02	2,483.43	2,483 (100.0%)	2,483	35,266
2024/03	2,372.63	2,372 (100.0%)	2,372	36,700
2024/04	2,451.35	2,451 (100.0%)	2,451	36,597
2024/05	5,298.39	5,298 (100.0%)	5,298	31,207
2024/06	4,836.65	4,836 (100.0%)	4,836	23,857

Figure 61: The editing screen for each demand to be satisfied, showing the combination of supplies used.



Demands	3
Supplies	4
Matchmaking ...	7
Period	2023 Jan - 2027 Dec
Yearly volume	219,637 m^3

Figure 62: The Map tab.

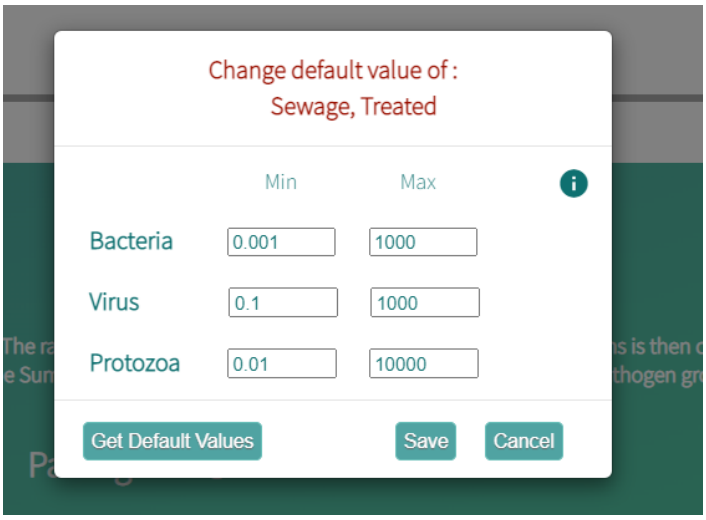
13.5 QMRA+ (#26)

13.5.1 Technical details on the developments and advancements within the project

With B-WaterSmart, some features have been added in the QMRA+ tool which are explained below.

The concentration of pathogens in various types of source water, such as sewage, treated sewage, grey water, rivers and groundwater, is suggested by the tool in number of infectious organisms per litre. However, these concentrations can vary significantly between various locations due to the local conditions. Factors such as the level of dilution, number of people impacting the water source, treatment processes in place and the skill of operation can all affect the number of pathogenic micro-organisms in the water. Therefore, an additional feature was added where the user can adapt these concentrations used by the tool based on local monitoring of the source or other information. The minimum and maximum concentrations can be added to resemble the variability of concentrations in the source

(Figure 63). These adaptations are the responsibility of the user. The tool cannot check the validity of entered data.



Change default value of :
Sewage, Treated

	Min	Max
Bacteria	0.001	1000
Virus	0.1	1000
Protozoa	0.01	10000

Figure 63: Screenshot of added feature to enter local pathogen concentration data or estimates for the risk calculation in number of infectious organisms per litre.

Similarly, the tool provides suggestions for pathogen removal by various treatment processes based on available literature. For most processes the reported efficacy varies among studies as they depend on local conditions, treatment design and skill of operation. Since this can range over multiple orders of magnitude, this information is an important source of uncertainty. Users can gain more insight into their own systems by monitoring surrogate organisms before and after treatment that provide validation of the actual treatment performance. More extensive monitoring will lead to a reduction of this uncertainty. Therefore, the user can enter the monitored removal, its standard deviation and the number of measurements this is based on (Figure 64). This is then used in the stochastic risk modelling.

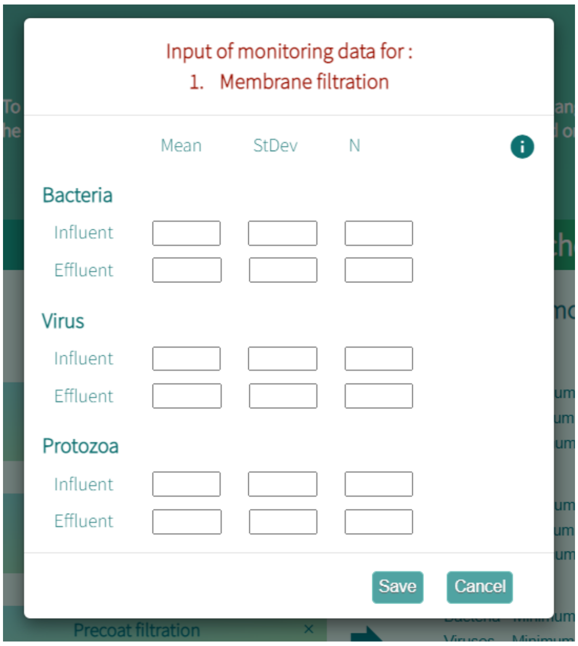
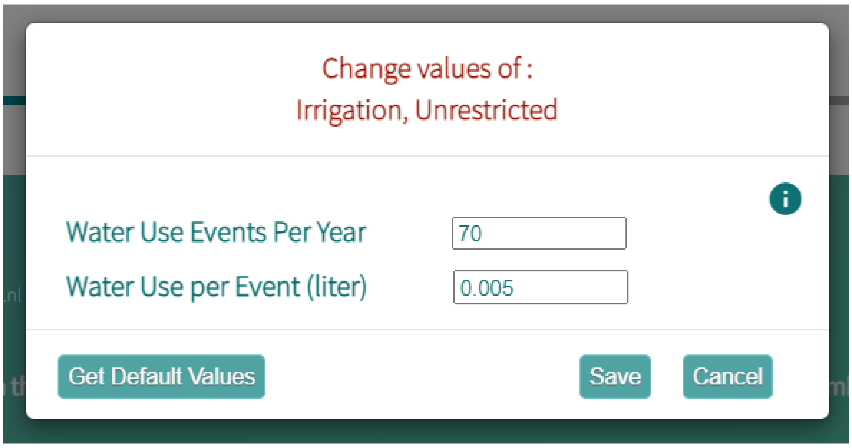

Input of monitoring data for :
1. Membrane filtration

Figure 64: Screenshot of added feature to enter local treatment monitoring data for the risk calculation.

The microbial health risk also depends on the amount of water ingested through various uses. The tool has several types of uses built in such as irrigation, car washing, toilet flushing and drinking. The ingestion is described by the amount of water ingested per use or day and the number of events per year that this use takes place. The amount of water ingested is greatly impacted by the way a person uses the water and the equipment used. There can be very large differences in types of equipment and habits between regions or groups of people. Therefore, the tool allows users to adapt both the volume of water ingested and the frequency of use (Figure 65).


Change values of :
Irrigation, Unrestricted

Water Use Events Per Year: 70
Water Use per Event (liter): 0.005

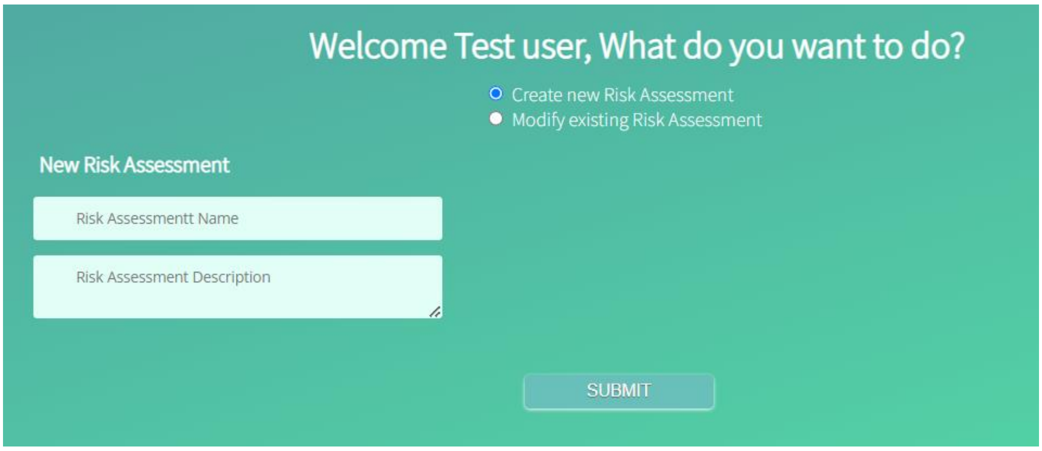
Figure 65: Screenshot of added feature to enter local water use frequency and ingested volume during use for the risk calculation.

13.5.2 Navigation and primary functionalities

The tool consists of the following steps:

Login:

When a user returns to the tool, previous stored work is available. A user can define multiple water use scenarios, e.g., to compare various options for designing new systems (Figure 66).



Welcome Test user, What do you want to do?

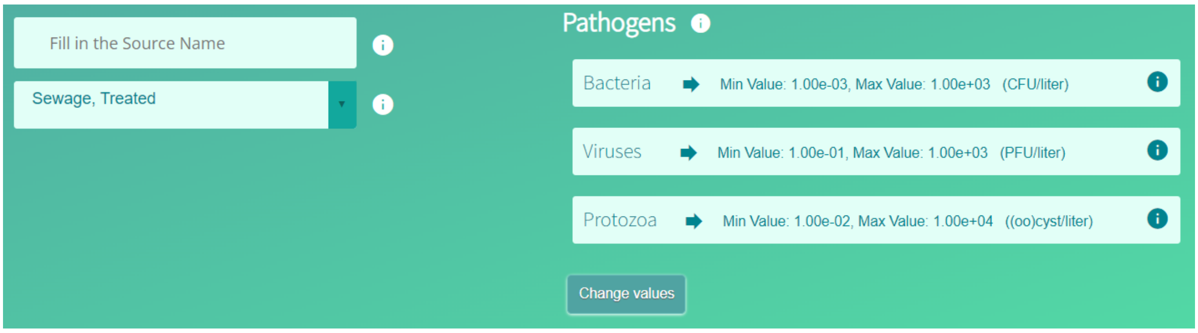
● Create new Risk Assessment
○ Modify existing Risk Assessment

New Risk Assessment

Figure 66: Screenshot of risk assessment name entry and additional description field.

Water source:

The user can select a type of water source (river, sewage, effluent etc.) and name it. The provided pathogen concentrations can be adapted by knowledgeable users (Figure 64). Instructions: *Select the water source used in the system for which you want to assess the risk. The range of expected concentrations of pathogenic micro-organisms is then displayed under Pathogens. This range will be used in the risk assessment. The ranges are based on guidelines and references, which will be displayed on the Summary page. The 'i' button displays an introduction for each pathogen group and the index pathogen for which the risk is calculated* (Figure 67).



Fill in the Source Name

Sewage, Treated

Pathogens

Bacteria ➡ Min Value: 1.00e-03, Max Value: 1.00e+03 (CFU/liter)

Viruses ➡ Min Value: 1.00e-01, Max Value: 1.00e+03 (PFU/liter)

Protozoa ➡ Min Value: 1.00e-02, Max Value: 1.00e+04 ((oo)cyst/liter)

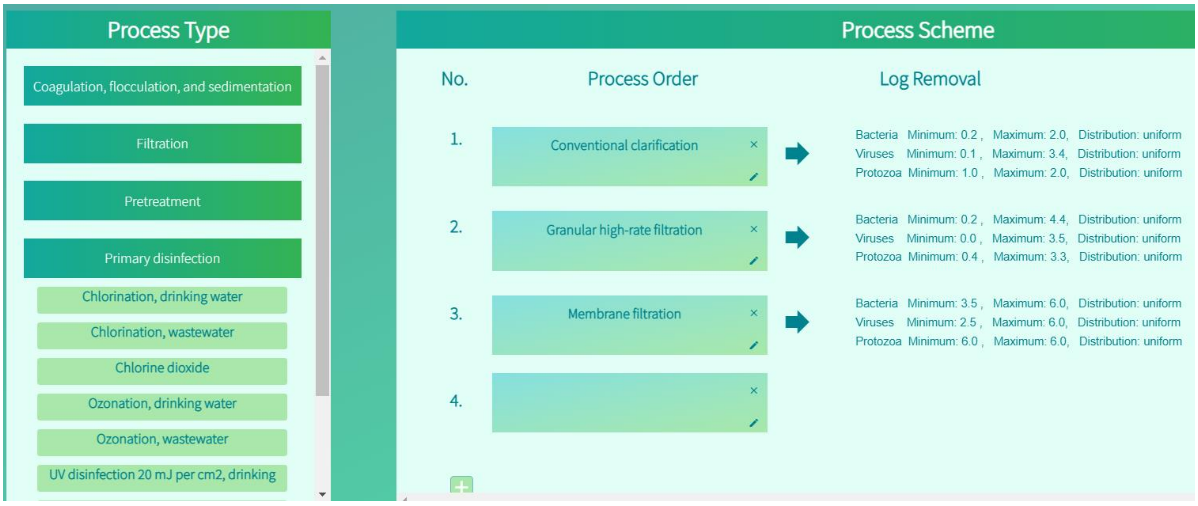
Figure 67: Screenshot of Water source selection and the microbial quality suggested. Hoovering over the information icon provides background on the specific organism for the user.

Treatment:

The user can drag and drop various treatment processes to develop a treatment train. Knowledgeable users can adapt treatment efficacy values (log reduction values) based on their specific data or other knowledge (Figure 68). Support for data interpretation is provided (Figure 68).

Instructions on screen:

- *Drag the treatment processes that are used into an empty box in the process scheme field.*
- *To delete a box click 'x,'.*
- *To add a box click '+' or drag and drop boxes to change the order.*
- *Point at the selected process to display a brief introduction.*
- *The range of log removal of each pathogen group by this process is shown. These log removals are used in the risk calculation.*
- *The references for the log removal values are provided on the summary page.*
- *If you have monitoring data for your processes, add the process here and then adapt the log removal values by clicking the pencil*.



No.	Process Order	Log Removal
1.	Conventional clarification	Bacteria Minimum: 0.2 , Maximum: 2.0, Distribution: uniform Viruses Minimum: 0.1 , Maximum: 3.4, Distribution: uniform Protozoa Minimum: 1.0 , Maximum: 2.0, Distribution: uniform
2.	Granular high-rate filtration	Bacteria Minimum: 0.2 , Maximum: 4.4, Distribution: uniform Viruses Minimum: 0.0 , Maximum: 3.5, Distribution: uniform Protozoa Minimum: 0.4 , Maximum: 3.3, Distribution: uniform
3.	Membrane filtration	Bacteria Minimum: 3.5 , Maximum: 6.0, Distribution: uniform Viruses Minimum: 2.5 , Maximum: 6.0, Distribution: uniform Protozoa Minimum: 6.0 , Maximum: 6.0, Distribution: uniform
4.		

Figure 68: Screenshot of Treatment train selection and the microbial reduction efficacy suggested. Hoovering over the process block provides background on the specific process for the user.

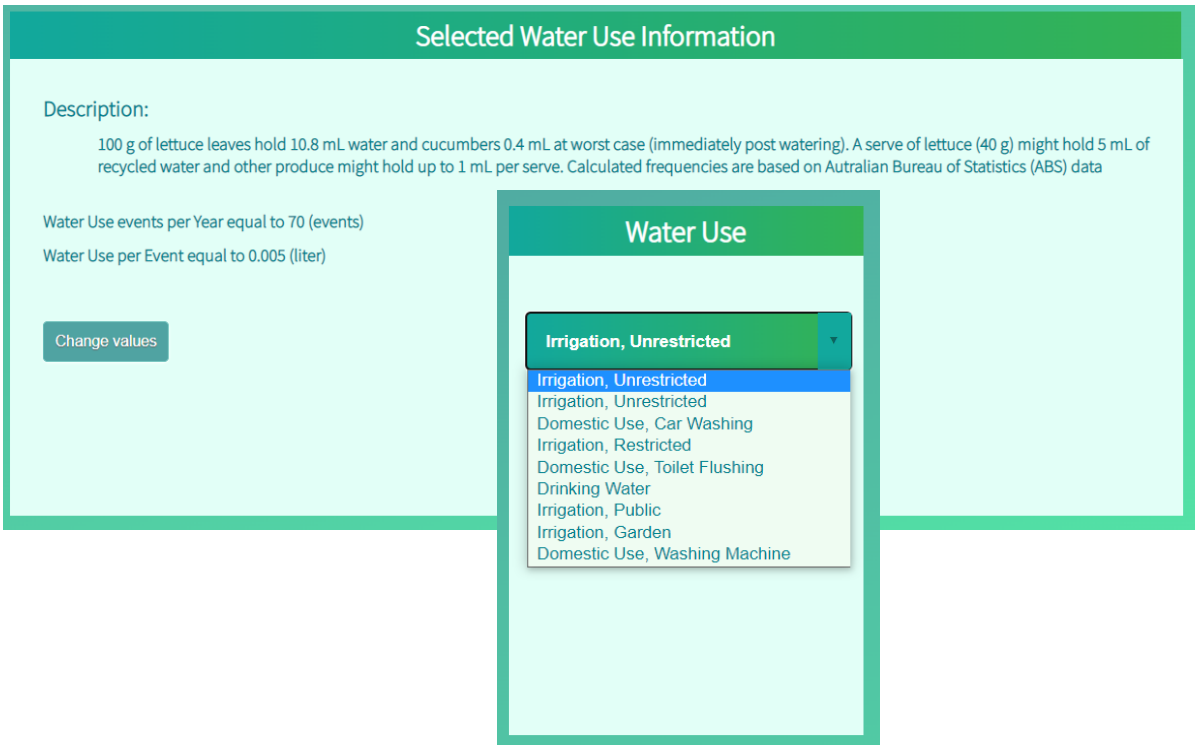
Use:

The user can define a water use (drinking, irrigation, toilet flushing etc.) which is characterised by frequency per year and amount of water ingested (Figure 69). Knowledgeable users can adapt input values to represent their specific situation.

Instructions on screen:

- *Select the intended water use.*

- *If multiple uses are considered, select the one with the highest exposure. 2*
- *The exposure of the chosen water use is shown as the number of times the water is used this way and the amount of water that is ingested each time.*
- *Literature reference for the selected data is shown on the summary page*.



Selected Water Use Information

Description:

100 g of lettuce leaves hold 10.8 mL water and cucumbers 0.4 mL at worst case (immediately post watering). A serve of lettuce (40 g) might hold 5 mL of recycled water and other produce might hold up to 1 mL per serve. Calculated frequencies are based on Autralian Bureau of Statistics (ABS) data

Water Use events per Year equal to 70 (events)

Water Use per Event equal to 0.005 (liter)

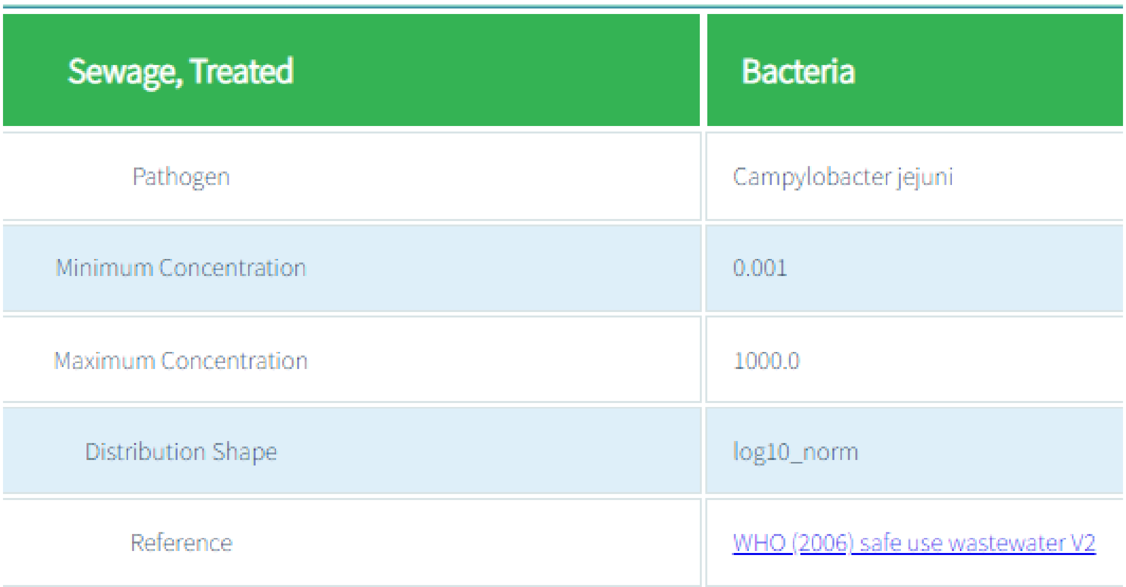
Water Use

Irrigation, Unrestricted

Figure 69: Screenshot of Water use selection and the corresponding volume ingested and frequency of use.

<u>Summary:</u>

Overview of the user input and background on the scientific sources for the input values of all QMRA steps (Figure 70). This overview can be printed or stored. After checking the input, the user can start the calculation by clicking that button.

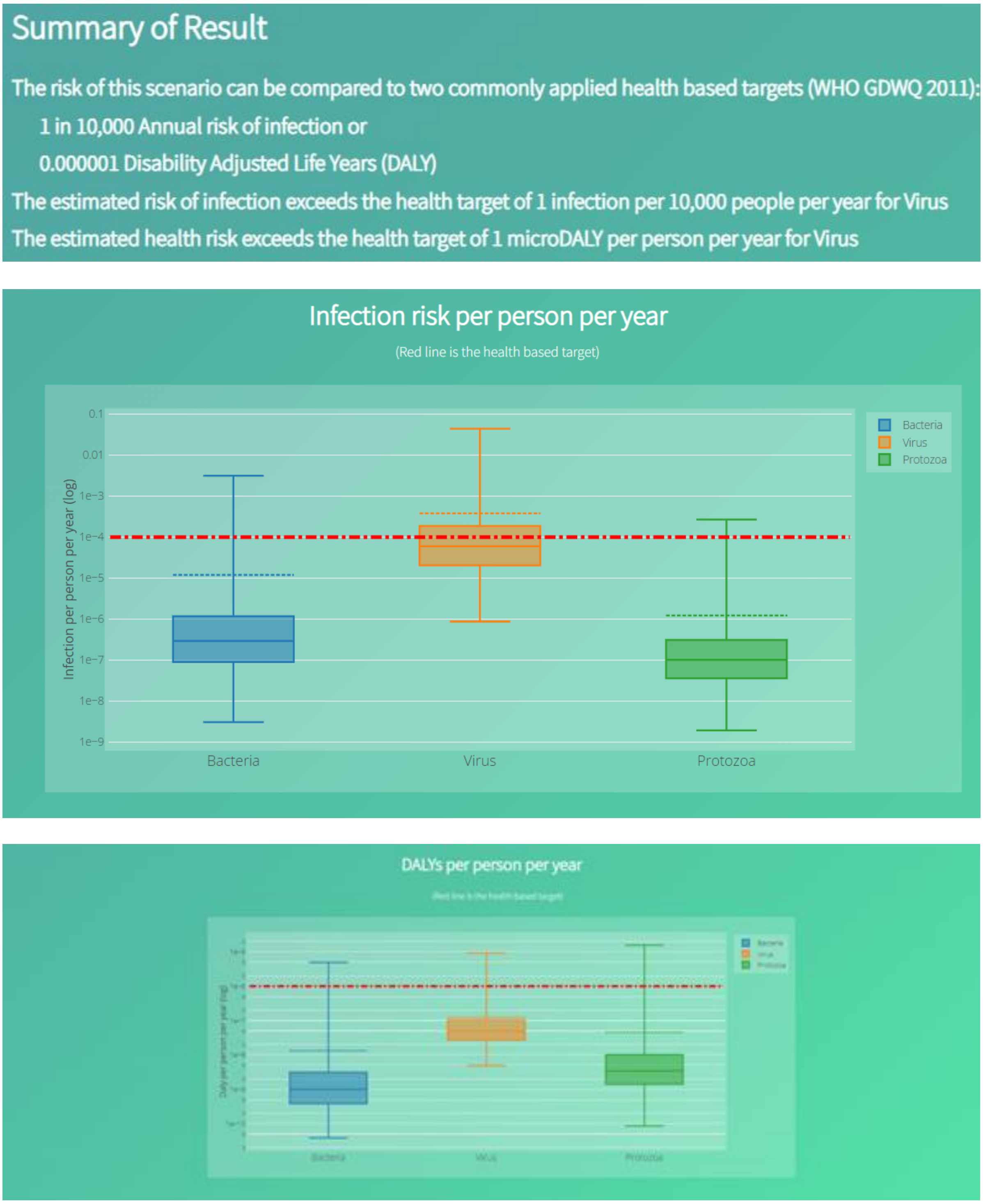


Sewage, Treated	Bacteria
Pathogen	Campylobacter jejuni
Minimum Concentration	0.001
Maximum Concentration	1000.0
Distribution Shape	log10_norm
Reference	WHO (2006) safe use wastewater V2

Figure 70: Screenshot of a detail from the overview of selected inputs, including the data sources used for default values in the tool.

Exposure risk:

Overview of the risk calculation consisting of three parts (Figure 71): i) Textual evaluation of the calculated risk versus risk targets expressed as annual risk of infection or Disability Adjusted Life Years (DALY) for viruses, bacteria and protozoa, ii) Graphical representation of risk estimation including the uncertainty and variability of risk in boxplots, iii) Table representation of calculated risks including percentiles. The user can store or print the results.



Summary of Result

The risk of this scenario can be compared to two commonly applied health based targets (WHO GDWQ 2011):

1 in 10,000 Annual risk of infection or

0.000001 Disability Adjusted Life Years (DALY)

The estimated risk of infection exceeds the health target of 1 infection per 10,000 people per year for Virus

The estimated health risk exceeds the health target of 1 microDALY per person per year for Virus

Figure 71: Screenshots of the output of the calculated risk as risk of infection in textual and graphical form.

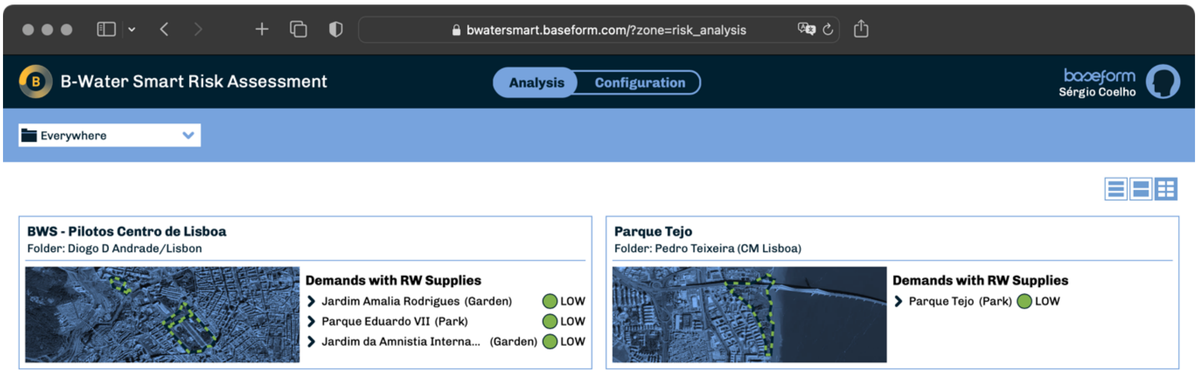
Table 15: Screenshot of the output of the calculated risk both as risk of infection in tabular form.

Data	Number/log10	Mean	5%	50%	95%
Source Concentration	N/l	1.25	0.34	1.03	2.89
Conventional clarification	log10	1.1	0.29	1.1	1.91
Granular high-rate filtration	log10	2.3	0.41	2.3	4.19
Membrane filtration	log10	4.75	3.63	4.75	5.88
Total Treatment	log10	8.14	7.74	8.14	8.58
DALY per Year	/person/year	8.06E-9	3.04E-11	3.94E-10	2.46E-8
Exposure per Year	number/person/year	2.96E-4	1.12E-6	1.44E-5	9.03E-4
Infection Risk per Year	/person/year	5.84E-6	2.2E-8	2.86E-7	1.79E-5
Ingestion per Event	litter/event	0.005	0.005	0.005	0.005
Events per year	number/year	70	70	70	70

13.6 Risk Assessment for urban water reuse module (#27)

13.6.1 Navigation and primary functionalities

The figures below illustrate the tool’s key functionality.



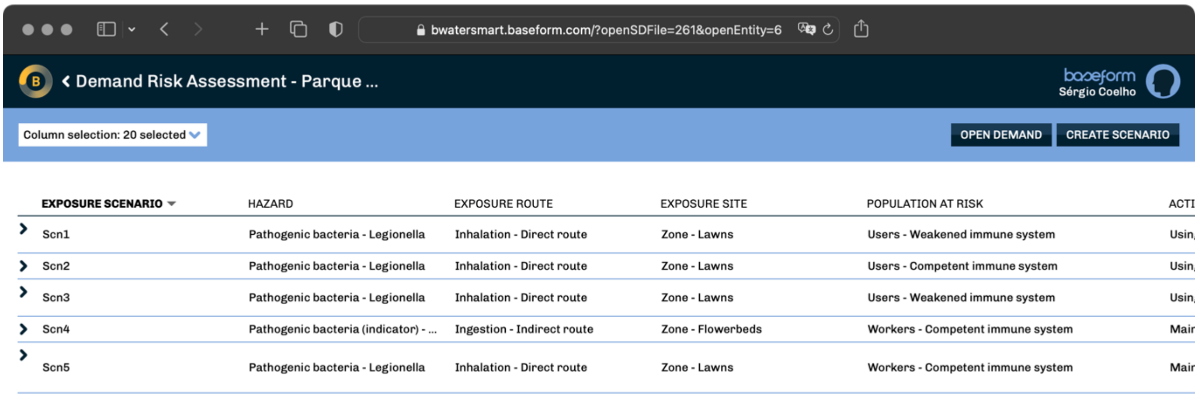
BWS - Pilotos Centro de Lisboa
Folder: Diogo D Andrade/Lisbon

Demands with RW Supplies
- Jardim Amalia Rodrigues (Garden) ● LOW
- Parque Eduardo VII (Park) ● LOW
- Jardim da Amnistia Interna... (Garden) ● LOW

Parque Tejo
Folder: Pedro Teixeira (CM Lisboa)

Demands with RW Supplies
- Parque Tejo (Park) ● LOW

Figure 72: Tool #27’s may screen showing the Analysis tab, which displays the available alternatives in the selected folder. Each alternative comes with a color-coded indication of the risk level for each demand considered.



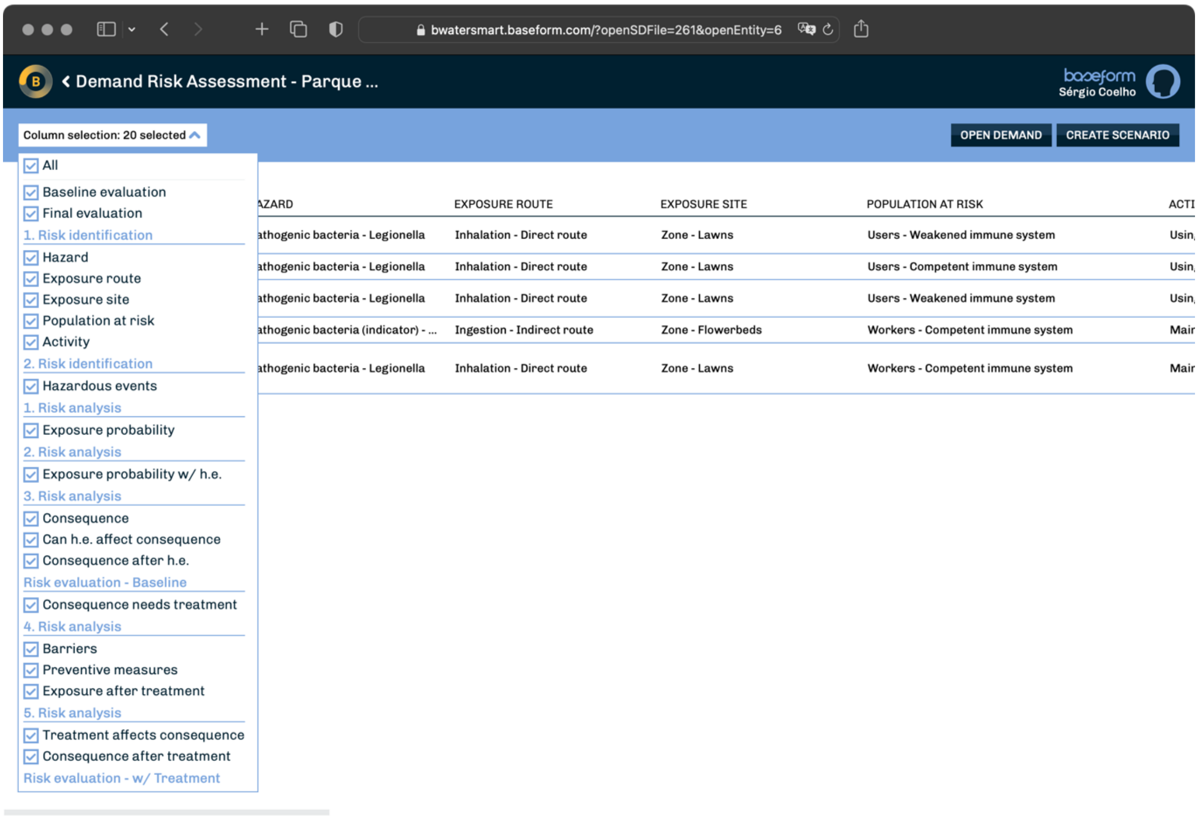
Demand Risk Assessment - Parque ...

Column selection: 20 selected

OPEN DEMAND | CREATE SCENARIO

EXPOSURE SCENARIO	HAZARD	EXPOSURE ROUTE	EXPOSURE SITE	POPULATION AT RISK	ACTI
Scn1	Pathogenic bacteria - Legionella	Inhalation - Direct route	Zone - Lawns	Users - Weakened immune system	Usin
Scn2	Pathogenic bacteria - Legionella	Inhalation - Direct route	Zone - Lawns	Users - Competent immune system	Usin
Scn3	Pathogenic bacteria - Legionella	Inhalation - Direct route	Zone - Lawns	Users - Weakened immune system	Usin
Scn4	Pathogenic bacteria (indicator) - ...	Ingestion - Indirect route	Zone - Flowerbeds	Workers - Competent immune system	Mair
Scn5	Pathogenic bacteria - Legionella	Inhalation - Direct route	Zone - Lawns	Workers - Competent immune system	Mair

Figure 73 Upon selecting one of the alternatives, the user is presented with the list of created risk scenarios. New scenarios can be created via the button at the top right.



Demand Risk Assessment - Parque ...

Column selection: 20 selected

OPEN DEMAND | CREATE SCENARIO

- ☑ All
- ☑ Baseline evaluation
- ☑ Final evaluation

1. Risk identification
- ☑ Hazard
- ☑ Exposure route
- ☑ Exposure site
- ☑ Population at risk
- ☑ Activity

2. Risk identification
- ☑ Hazardous events

1. Risk analysis
- ☑ Exposure probability

2. Risk analysis
- ☑ Exposure probability w/ h.e.

3. Risk analysis
- ☑ Consequence
- ☑ Can h.e. affect consequence
- ☑ Consequence after h.e.

Risk evaluation - Baseline
- ☑ Consequence needs treatment

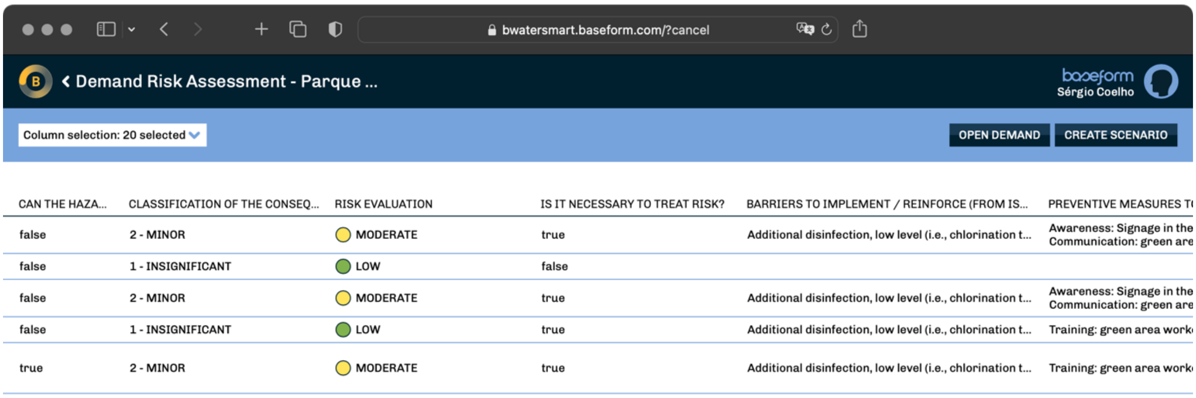
4. Risk analysis
- ☑ Barriers
- ☑ Preventive measures
- ☑ Exposure after treatment

5. Risk analysis
- ☑ Treatment affects consequence
- ☑ Consequence after treatment

Risk evaluation - w/ Treatment

AZARD	EXPOSURE ROUTE	EXPOSURE SITE	POPULATION AT RISK	ACTI
athogenic bacteria - Legionella	Inhalation - Direct route	Zone - Lawns	Users - Weakened immune system	Usin
athogenic bacteria - Legionella	Inhalation - Direct route	Zone - Lawns	Users - Competent immune system	Usin
athogenic bacteria - Legionella	Inhalation - Direct route	Zone - Lawns	Users - Weakened immune system	Usin
athogenic bacteria (indicator) - ...	Ingestion - Indirect route	Zone - Flowerbeds	Workers - Competent immune system	Mair
athogenic bacteria - Legionella	Inhalation - Direct route	Zone - Lawns	Workers - Competent immune system	Mair

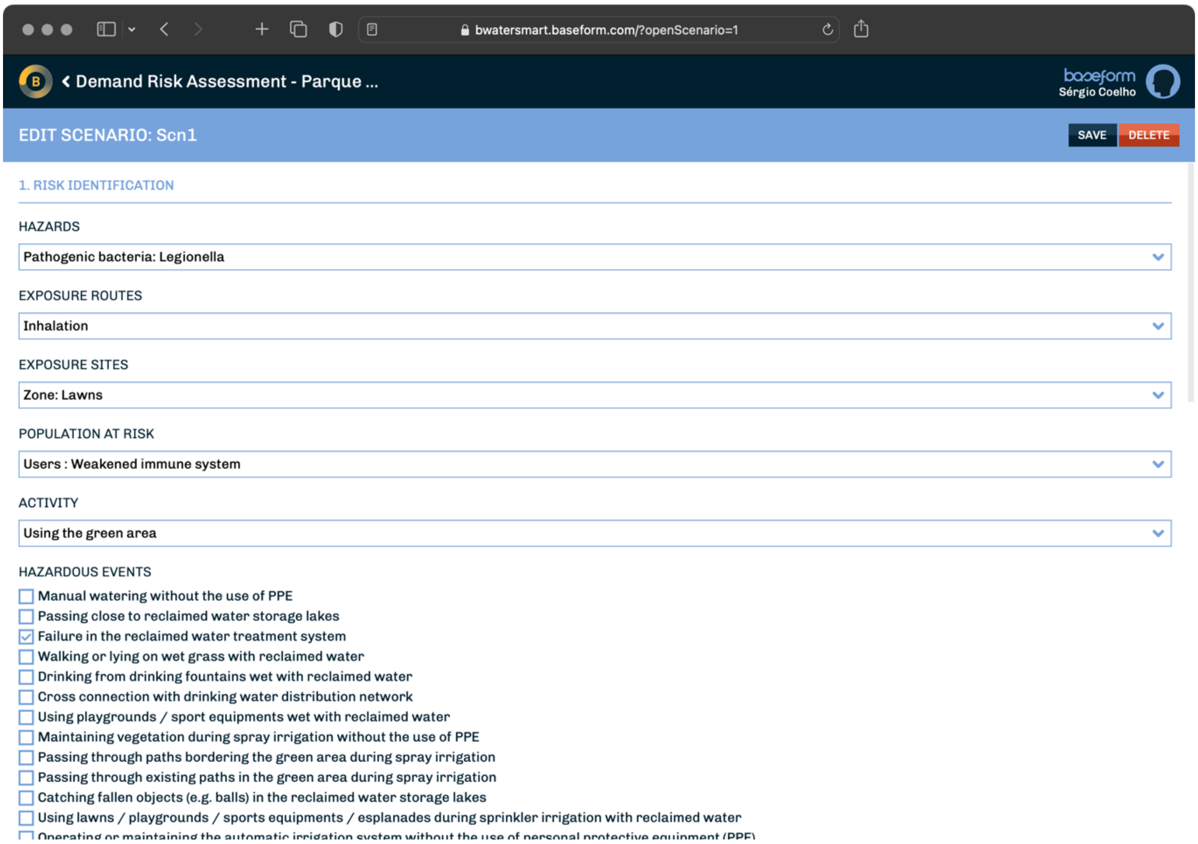
Figure 74: The list of available fields that can be displayed in the scenarios listing.



Column selection: 20 selected

CAN THE HAZA...	CLASSIFICATION OF THE CONSEQ...	RISK EVALUATION	IS IT NECESSARY TO TREAT RISK?	BARRIERS TO IMPLEMENT / REINFORCE (FROM IS...	PREVENTIVE MEASURES T
false	2 - MINOR	🟡 MODERATE	true	Additional disinfection, low level (i.e., chlorination t...	Awareness: Signage in the Communication: green are
false	1 - INSIGNIFICANT	🟢 LOW	false		
false	2 - MINOR	🟡 MODERATE	true	Additional disinfection, low level (i.e., chlorination t...	Awareness: Signage in the Communication: green are
false	1 - INSIGNIFICANT	🟢 LOW	true	Additional disinfection, low level (i.e., chlorination t...	Training: green area work
true	2 - MINOR	🟡 MODERATE	true	Additional disinfection, low level (i.e., chlorination t...	Training: green area work

Figure 75: The scenarios list showing risk evaluation.



EDIT SCENARIO: Scn1

1. RISK IDENTIFICATION

HAZARDS
Pathogenic bacteria: Legionella

EXPOSURE ROUTES
Inhalation

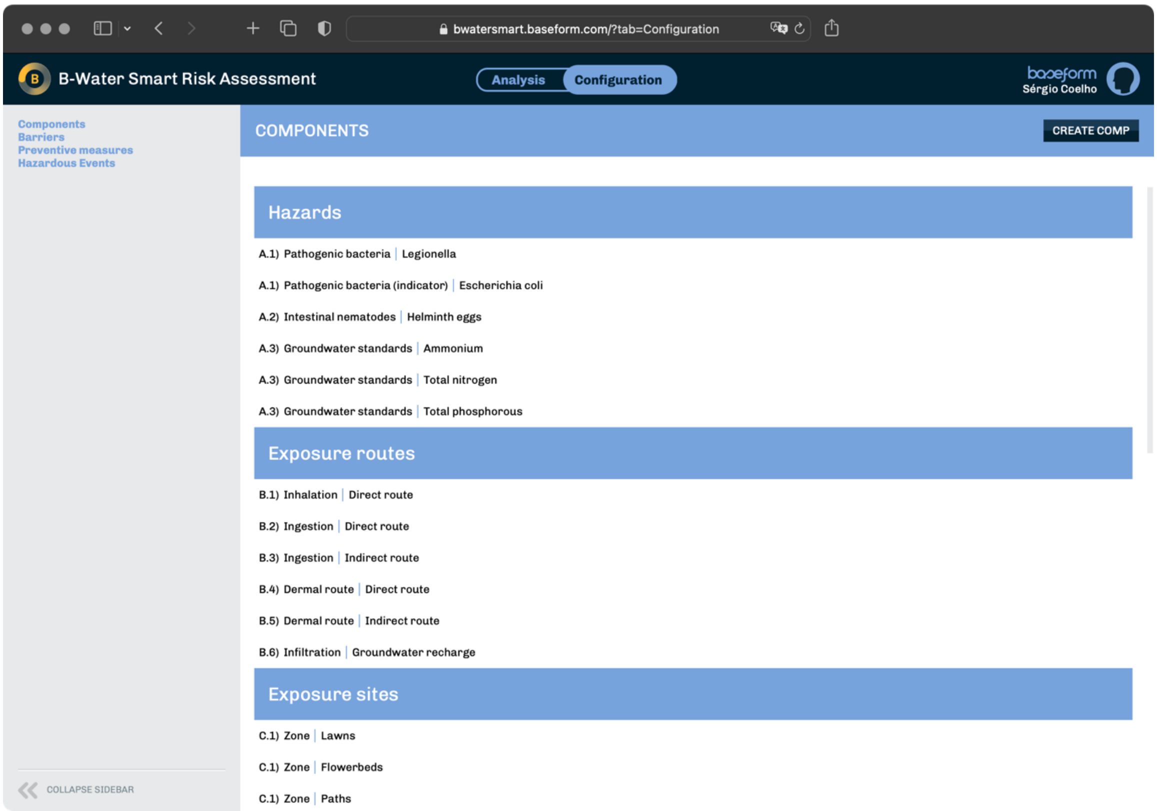
EXPOSURE SITES
Zone: Lawns

POPULATION AT RISK
Users : Weakened immune system

ACTIVITY
Using the green area

HAZARDOUS EVENTS
- ☐ Manual watering without the use of PPE
- ☐ Passing close to reclaimed water storage lakes
- ☑ Failure in the reclaimed water treatment system
- ☐ Walking or lying on wet grass with reclaimed water
- ☐ Drinking from drinking fountains wet with reclaimed water
- ☐ Cross connection with drinking water distribution network
- ☐ Using playgrounds / sport equipments wet with reclaimed water
- ☐ Maintaining vegetation during spray irrigation without the use of PPE
- ☐ Passing through paths bordering the green area during spray irrigation
- ☐ Passing through existing paths in the green area during spray irrigation
- ☐ Catching fallen objects (e.g. balls) in the reclaimed water storage lakes
- ☐ Using lawns / playgrounds / sports equipments / esplanades during sprinkler irrigation with reclaimed water
- ☐ Operating or maintaining the automatic irrigation system without the use of personal protective equipment (PPE)

Figure 76: Editing a risk scenario.



Hazards

A.1) Pathogenic bacteria | Legionella

A.1) Pathogenic bacteria (indicator) | Escherichia coli

A.2) Intestinal nematodes | Helminth eggs

A.3) Groundwater standards | Ammonium

A.3) Groundwater standards | Total nitrogen

A.3) Groundwater standards | Total phosphorous

Exposure routes

B.1) Inhalation | Direct route

B.2) Ingestion | Direct route

B.3) Ingestion | Indirect route

B.4) Dermal route | Direct route

B.5) Dermal route | Indirect route

B.6) Infiltration | Groundwater recharge

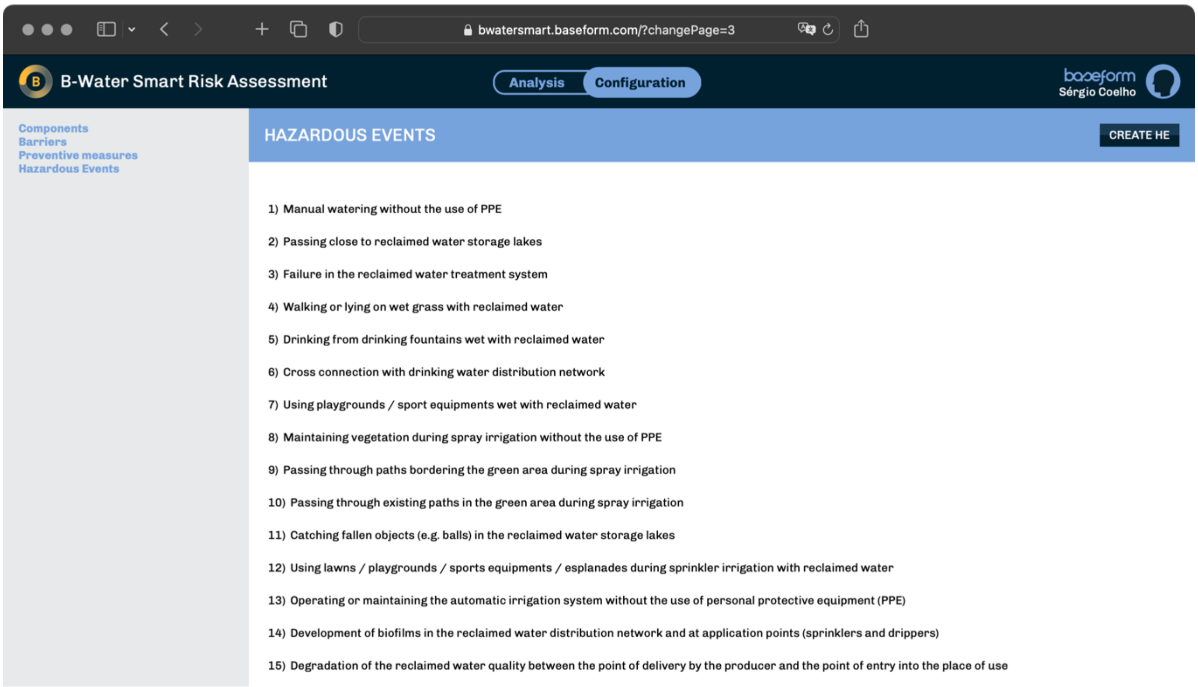
Exposure sites

C.1) Zone | Lawns

C.1) Zone | Flowerbeds

C.1) Zone | Paths

Figure 77: The Configuration tab, giving access to the specification of Components, Barriers, Preventive Measures and Hazardous Events.



1) Manual watering without the use of PPE

2) Passing close to reclaimed water storage lakes

3) Failure in the reclaimed water treatment system

4) Walking or lying on wet grass with reclaimed water

5) Drinking from drinking fountains wet with reclaimed water

6) Cross connection with drinking water distribution network

7) Using playgrounds / sport equipments wet with reclaimed water

8) Maintaining vegetation during spray irrigation without the use of PPE

9) Passing through paths bordering the green area during spray irrigation

10) Passing through existing paths in the green area during spray irrigation

11) Catching fallen objects (e.g. balls) in the reclaimed water storage lakes

12) Using lawns / playgrounds / sports equipments / esplanades during sprinkler irrigation with reclaimed water

13) Operating or maintaining the automatic irrigation system without the use of personal protective equipment (PPE)

14) Development of biofilms in the reclaimed water distribution network and at application points (sprinklers and drippers)

15) Degradation of the reclaimed water quality between the point of delivery by the producer and the point of entry into the place of use

Figure 78: Creating or editing hazardous events.

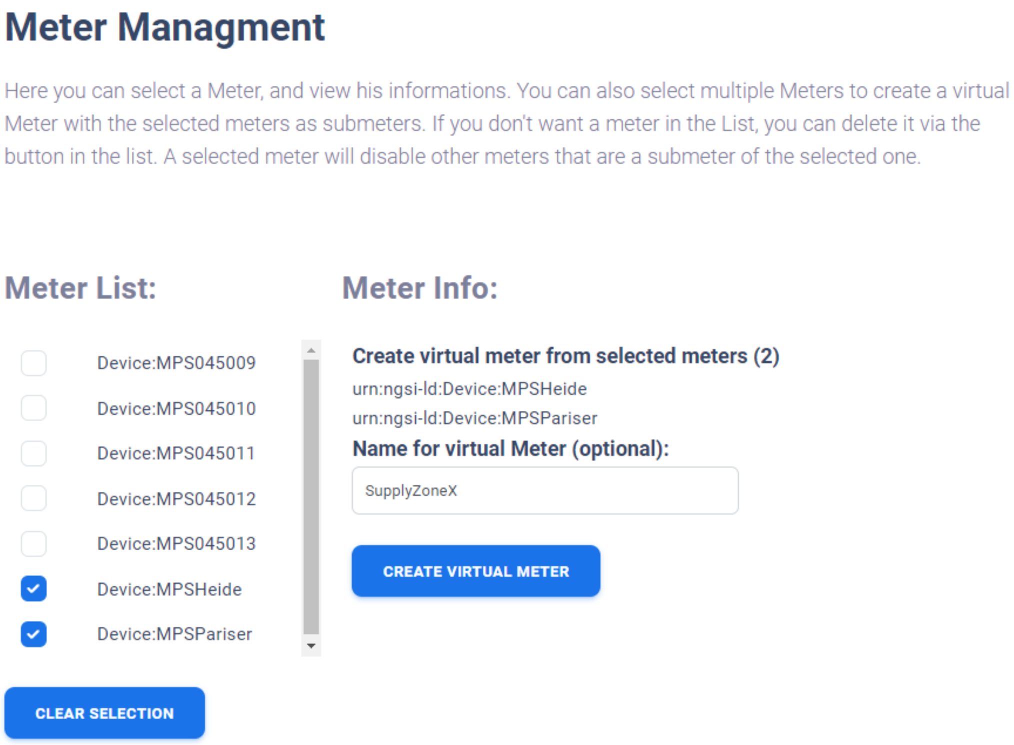
13.7 Short-term demand forecasting tool (#28)

13.7.1 Navigation and primary functionalities

The GUI (frontend) component is provided as a minimalistic browser-based admin dashboard that can be used to apply the tool. All main functionalities are encapsulated in their own web pages that are easily accessible from a sidebar that is shown on the left side of the screen. These pages include:

1. Defining a new virtual meter that can be used to create models and forecasts for a larger area.
2. Training a model for the virtual meter and checking performance based on error metrics and visualizations.
3. Generating forecasts and visualizing the results with historical load curves as context information for plausibility checking.

The mock-ups below show the UI which consists of the following elements (Figure 79, Figure 80, Figure 81):



Meter Managment

Here you can select a Meter, and view his informations. You can also select multiple Meters to create a virtual Meter with the selected meters as submeters. If you don't want a meter in the List, you can delete it via the button in the list. A selected meter will disable other meters that are a submeter of the selected one.

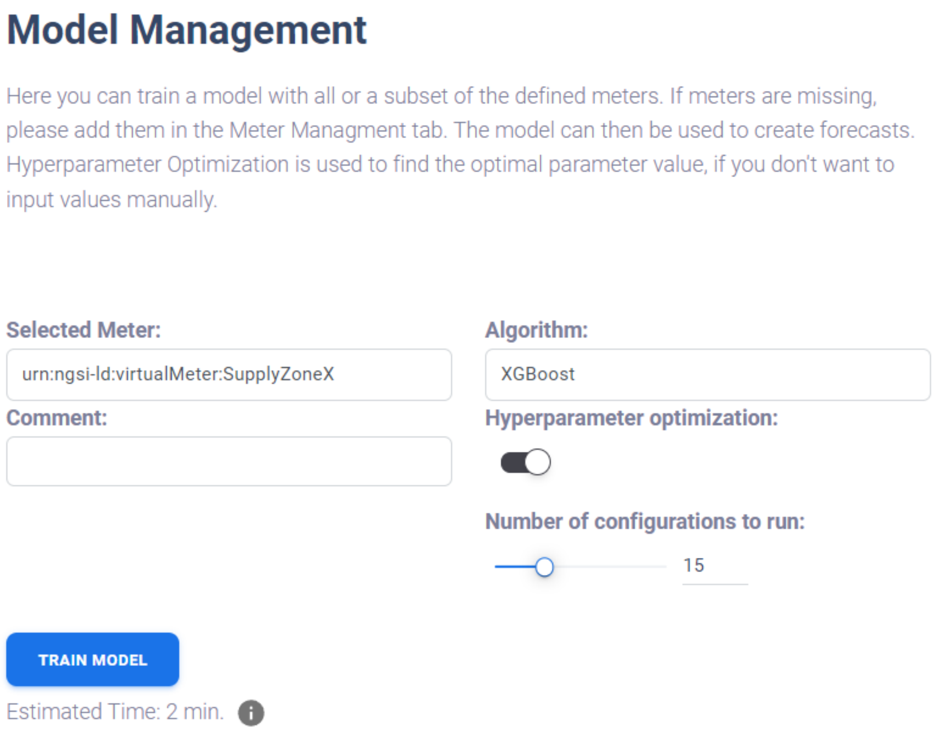
Meter List:

☐ Device:MPS045009
☐ Device:MPS045010
☐ Device:MPS045011
☐ Device:MPS045012
☐ Device:MPS045013
☑ Device:MPSHeide
☑ Device:MPSPariser

Meter Info:

Create virtual meter from selected meters (2)
urn:ngsi-ld:Device:MPSHeide
urn:ngsi-ld:Device:MPSPariser
Name for virtual Meter (optional): SupplyZoneX

Figure 79: Aggregating smart meters (physical meters) to a virtual meter that represents a supply zone.



Model Management

Here you can train a model with all or a subset of the defined meters. If meters are missing, please add them in the Meter Managment tab. The model can then be used to create forecasts. Hyperparameter Optimization is used to find the optimal parameter value, if you don't want to input values manually.

Selected Meter: urn:ngsi-ld:virtualMeter:SupplyZoneX

Algorithm: XGBoost

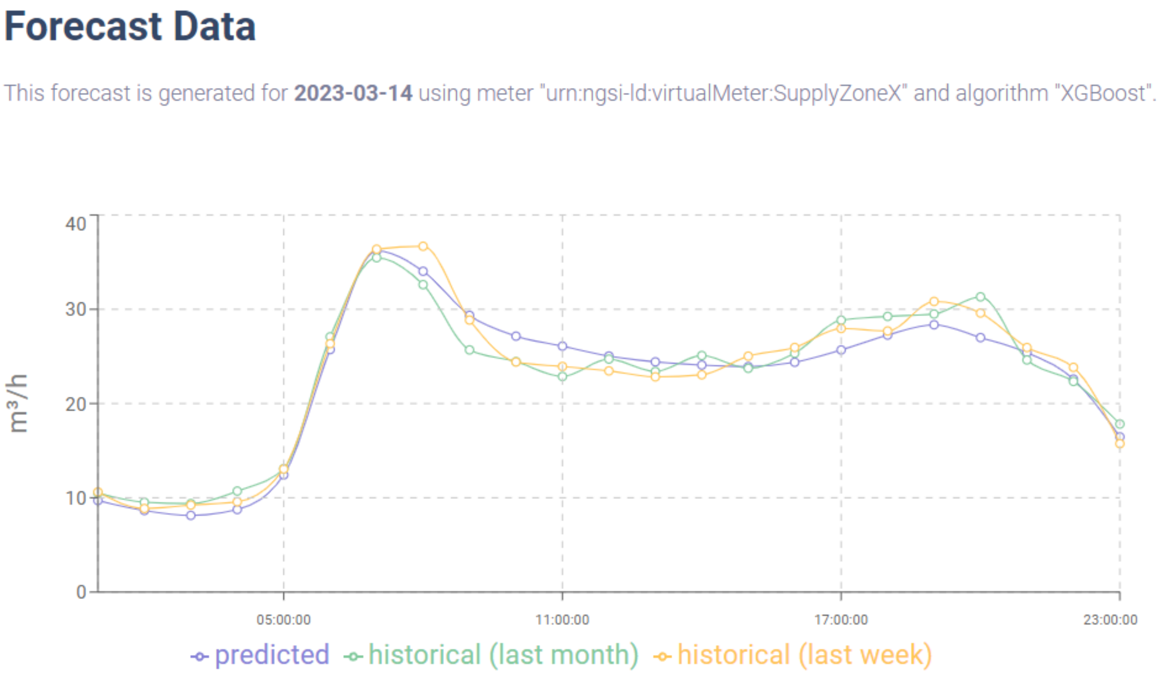
Comment:

Hyperparameter optimization: ●

Number of configurations to run: 15

Estimated Time: 2 min.

Figure 80: Training a model for a previously created virtual meter that represents a specific supply zone using the XGBoost algorithm and hyperparameter optimization based on 15 different configurations that are tested.



Forecast Data

This forecast is generated for **2023-03-14** using meter "urn:ngsi-ld:virtualMeter:SupplyZoneX" and algorithm "XGBoost".

Figure 81: Visualization of a forecast using a previously trained model and comparing the forecast with historical load curves of the recent past for plausibility checking.

13.8 SuTRa (#31)

13.8.1 Technical details on the developments and advancements within the project

During transport in the subsurface, microbial organism removal takes place by both attachment to the soil matrix and inactivation. The virus concentration ‘C’ [m-3] through steady-state transport of microbial organisms along path lines in the saturated groundwater can be approximated by:

$$\frac{dC}{dx} + \frac{k_{att} + \mu_1}{v} C = 0 \qquad \text{Eq. 1}$$

Where:

K_att + mu1 equals the removal rate ‘lambda’,

‘k_att’: attachment coefficient [day-1],

‘mu1’: inactivation coefficient [day-1],

x: the distance travelled [m],

v: the porewater velocity [m day-1] or ‘darcyflux divided by the effective porosity’.

Assuming that the background concentration of the relevant microbial organism equals 0, the relative removal ‘C_x/C0’ can be calculated as follows.

$$log\left(\frac{C_x}{C_0}\right) = -\frac{(k_{att} + \mu_1)}{\ln(10)} \frac{x}{v} \qquad \text{Eq. 2}$$

The attachment coefficient ‘k_att’ depends on the effective porosity ‘epsilon’, the grain diameter of the sediment ‘d_c’, ‘sticky coefficient’ alpha [day-1], the porosity dependent Happel’s parameter ‘A_s’, diffusion constant ‘D_BM’ [m2 day-1], and the porewater velocity [m day-1].

$$k_{att} = \frac{3}{2} \cdot \frac{(1-\varepsilon)}{d_c} \cdot \alpha 4 A_s^{1/3} \cdot \left(\frac{D_{BM}}{d_c \cdot \varepsilon \cdot v}\right)^{2/3} \cdot v \qquad \text{Eq. 3}$$

The sticky coefficient alpha is determined by coefficient ‘alpha0’, which depends on both the soil type and the type of organism. Alpha0 is being determined for a reference pH [pH0], e.g., pH=7.5. Alpha relates to alpha0 as follows [corrected for different pH].

$$\alpha = \alpha_0 \cdot 0{,}9^{\left(\frac{pH - pH_0}{0{,}1}\right)} \qquad \text{Eq. 4}$$

The other parameters are calculated as follows:

Happel’s porosity dependent parameter

$$A_s = 2 \cdot \frac{(1-\gamma^5)}{(2-3\gamma+3\gamma^5-2\gamma^6)} \qquad \text{Eq. 5}$$

Where:

$$\gamma = (1-\varepsilon)^{1/3}$$

Boltzmann diffusion coefficient:

$$D_{BM} = \frac{K_B \cdot (T+273)}{3\pi \cdot d_p \cdot \mu} \cdot 86400 \qquad \text{Eq. 6}$$

with Boltzmann constant K_B [1,38 × 10-23 J K-1], organism diameter d_p [m], water temperature T [degr C], and conversion factor 86,400 [s day-1].

The dynamic viscosity ‘mu’ [kg m-1 s-1] depends on the groundwater density ‘rho’. The water density is assumed to be 999.7 [kg m-3], representative for fresh groundwater in the Netherlands under a reference temperature of 12 degrees centigrade.

$$\mu = \frac{\rho \cdot 497 \cdot 10^{-6}}{(T+42{,}5)^{3/2}} \qquad \text{Eq. 7}$$

13.8.2 Navigation and primary functionalities

The tool can be accessed through python code as specified in the tutorial https://sutra.readthedocs.io/en/latest/tutorial.html.

Running the code involves several steps:

First the type of organism (pathogen) needs to be specified along with its initial concentration. The user also needs to define the environmental conditions for which the pathogen removal rate needs to be computed such as the redox-condition and groundwater flow velocity.

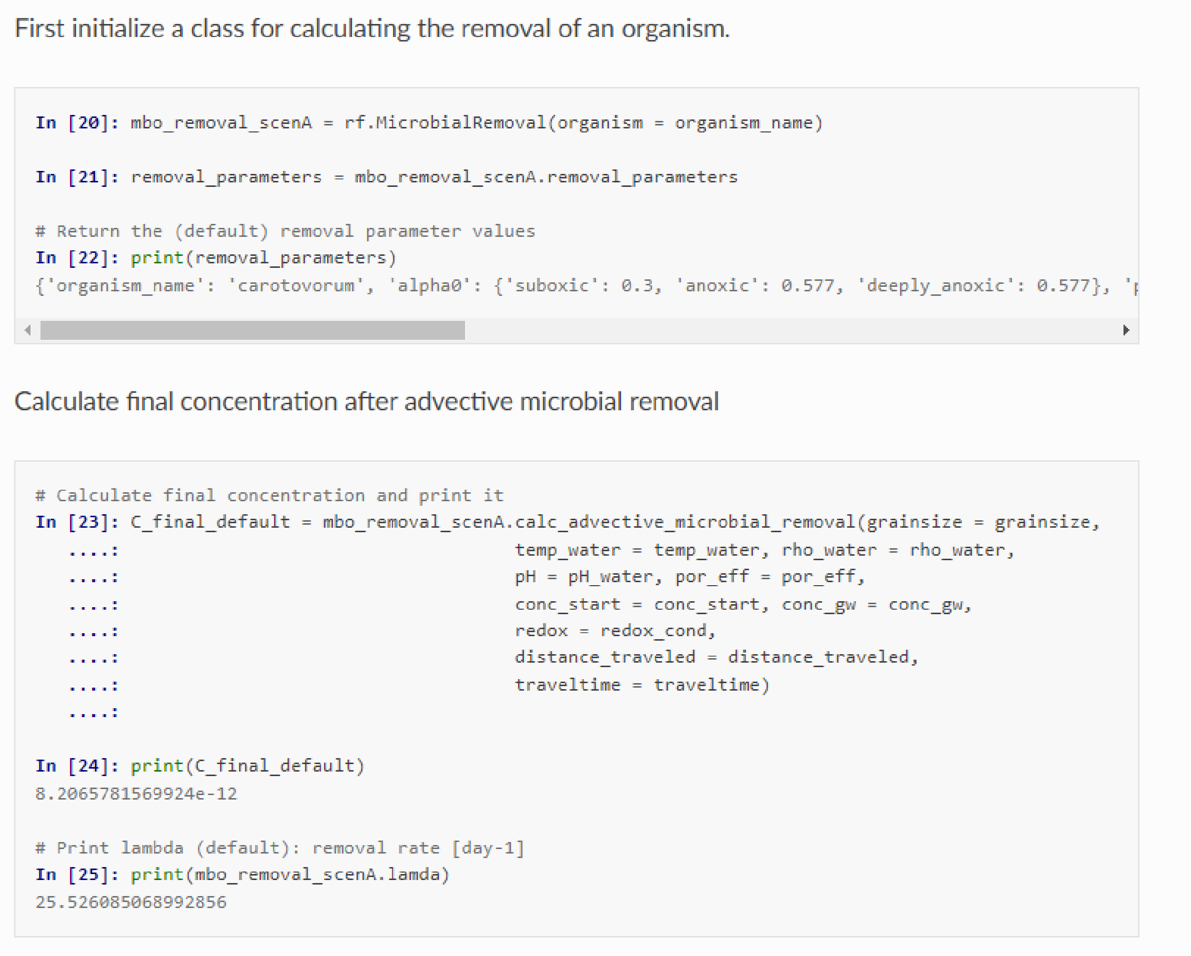
Next, the package retrieves the transport properties of the organism from a database (provided with the software). The user also has the opportunity to manually insert parameters in case they are not provided by the database for a certain organism, or in case the user wants to perform a sensitivity analysis on the parameters provided by the database.

Finally, the removal of the pathogen during soil passage is computed, based on the environmental conditions and transport properties of the organism.

The example below illustrates that the computations are quite easy (for those with a basic knowledge of Python) (Figure 82).

Scenario A: Calculate removal of a microbial organism using default database parameters.

```
## Default removal parameters ##
In [7]: organism_name = "carotovorum"

# Redox condition: 3 options ['deeply_anoxic','anoxic','suboxic']
In [8]: redox_cond = 'anoxic'

# organism diameter [m]
In [9]: organism_diam = 1.803e-6

# Starting concentration
In [10]: conc_start = 1.

# Ambient groundwater concentration
In [11]: conc_gw = 0.

# effective porosity
In [12]: por_eff = 0.33

# Sediment grainsize
In [13]: grainsize = 0.00025

# pH of the groundwater
In [14]: pH_water = 7.5

# Water temperature
In [15]: temp_water = 10.

# Water density [kg m-3]
In [16]: rho_water = 999.703

# Distance traveled along pathline [m]
In [17]: distance_traveled = 100.

# Time traveled [days]
In [18]: traveltime = 1.

# Porewater velocity [m day-1]
In [19]: porewater_velocity = distance_traveled / traveltime
```



First initialize a class for calculating the removal of an organism.

```
In [20]: mbo_removal_scenA = rf.MicrobialRemoval(organism = organism_name)

In [21]: removal_parameters = mbo_removal_scenA.removal_parameters

# Return the (default) removal parameter values
In [22]: print(removal_parameters)
{'organism_name': 'carotovorum', 'alpha0': {'suboxic': 0.3, 'anoxic': 0.577, 'deeply_anoxic': 0.577}, '
```

Calculate final concentration after advective microbial removal

```
# Calculate final concentration and print it
In [23]: C_final_default = mbo_removal_scenA.calc_advective_microbial_removal(grainsize = grainsize,
   ....:                                     temp_water = temp_water, rho_water = rho_water,
   ....:                                     pH = pH_water, por_eff = por_eff,
   ....:                                     conc_start = conc_start, conc_gw = conc_gw,
   ....:                                     redox = redox_cond,
   ....:                                     distance_traveled = distance_traveled,
   ....:                                     traveltime = traveltime)
   ....:

In [24]: print(C_final_default)
8.2065781569924e-12

# Print lambda (default): removal rate [day-1]
In [25]: print(mbo_removal_scenA.lamda)
25.526085068992856
```

Figure 82: Example of computations in python.

14 Annex C: Application of tools outside B-WaterSmart

The purpose of this section is to demonstrate how tools has or can be used in other applications/cases and be conceptually or actually integrated with other technologies of relevance to circular economy (that are not part of the project). The intention is to give the overall potential of each tool and it is believed that it can also inspire other applications and potential synergies, as well as to provide ideas that will support transferability of solutions. The sections that follow (14.1 and 14.2) provide such information for two solutions.

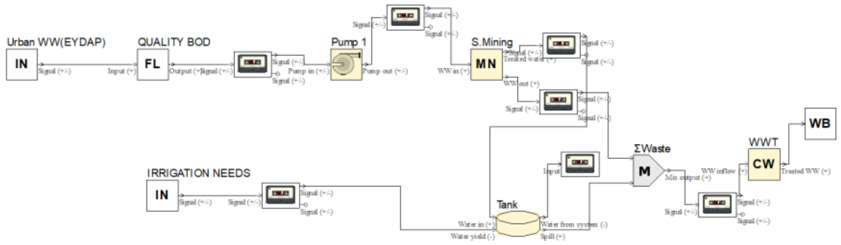
14.1 Urban Water Optioneering Tool (#22)

Some notable applications of high synergistic benefit include the use of UWOT for the ex-ante assessment or upscaling impact of real circular water pilots, such as a Sewer Mining installation for urban water recycling at the local scale (Makropoulos, Rozos, et al., 2018), or the assessment of the efficiency of decentralized technologies at a neighbourhood-level pilot before its construction (Bouziotas et al., 2019b).

Table 16: Application of UWOT out of the BWS project.

Indicative application of the tool	
Title	Athens demo case
Description	In this case study, UWOT is mainly used to assess the water flows of the sewer mining set-up in the Athens Plant Nursery in Goudi area.
Reference point	https://goo.gl/maps/3pLALyf5Y5ry656P9
Location	Athens Plant Nursery in Goudi area
Country (-ies)	Greece
URL	https://nextgenwater.eu/demonstration-cases/athens/
Project	NextGen
Challenges	• Water Scarcity • High or increasing irrigation water demand for urban green spaces. • Need for reuse and recovery schemes for wastewater & sludge.
Tools/Product/Services	UWOT (#22)
Technologies	• Wastewater treatment technologies for water reuse • Resource for Circular Economy • Water recovery technologies for water reuse
Scales	Local

Legislation	As for the quality of the reclaimed water, SM produces water of a quality that meets all national & the international criteria for unrestricted irrigation and urban use and there is complete elimination of organic carbon and pathogenic content.
Synergistic benefits	Sewer mining unit simulation in UWOT tool.
Requirements and conditions	For the purpose of evaluating the quality of the inflow (BOD concentration), sample testing was carried out over a specific time period (August – October 2018). EYDAP (the water utility in Athens) also provided information regarding the wastewater supply as well as the average daily and annual water usage in the Nursery. Furthermore, monthly time series for rainfall and mean temperature for a specific period of time were acquired through the meteorological station at the National Technical University of Athens campus in Zografou, Greece. The estimation of the water demand was used as an input in UWOT at the pre-processing stage.
Key lessons	In the context of this study, the UWOT is used to assess the water flows of the Sewer Mining set-up in the Nursery. The UWOT simulation shows that SM technology in general is a viable and profitable scheme and can be an interesting alternative water source to cover irrigation needs at the point of demand as well as aquifer recharge during the wet period.
Organisations	NTUA, EYDAP, Chemitec, Municipality of Athens
Contact persons	• Christos Makropoulos (cmakro@mail.ntua.gr) (KWR) • Stavroula Manouri (stavroula.manouri@gmail.com) (NTUA)
Data Manager	• Christos Makropoulos (cmakro@mail.ntua.gr) (KWR) • Stavroula Manouri (stavroula.manouri@gmail.com) (NTUA)
Costs	With regard to the capital cost of the technology in the pilot scale this is about 1,74 euros/m^3, whereas the operational cost is estimated at 0.5 euros/m^3.
Tags	Circularity, efficiency, energy, innovations, performance, rainwater harvesting, re-use, recycling, sewer mining, sustainability, water management, wastewater treatment technologies, circular economy, water storage and recovery, etc.
Publications/Reference	• Liakopoulou, A., Makropoulos, C., Nikolopoulos, D., Monokrousou, K., and Karakatsanis, G. (2020). An urban water simulation model for the design, testing and economic viability assessment of distributed water management systems for a circular economy. Environmental Sciences Proceedings, 2(1), 14. • Plevri, A., Lytras, E., Samios, S., Lioumis, C., Monokrousou, K., and Makropoulos, C. (2020). Sewer Mining as A Basis for Technological, Business and Governance Solutions for Water in the Circular Economy: The NextGen Athens Demo. The 4th EWaS International Conference: Valuing the Water, Carbon, Ecological Footprints of Human Activities, 54. https://doi.org/10.3390/environsciproc2020002054 • Plevri, A., Samios, S., Lytras, E., Papadopoulos, K., Lioumis, C., Lazari, A., Tazes, N., Monokrousou, K., and Makropoulos, C. (2019). Installation of a Sewer Mining Unit in the Athens Urban Tree Nursery. 16th International Conference on Environmental Science and Technology. • Plevri, A.; Monokrousou, K.; Makropoulos, C.; Lioumis, C.; Tazes, N.; Lytras, E.; Samios, S.; Katsouras, G.; Tsalas, N. Sewer Mining as a Distributed Intervention for Water-Energy-Materials in the Circular Economy Suitable for Dense Urban Environments: A Real-World Demonstration in the City of Athens. *Water* **2021**, *13*, 2764. https://doi.org/10.3390/w13192764

Images	
Caption/Source	The set-up consisting of a sewer mining unit in UWOT

14.2 SuTRa (#31)

The tool has not yet been utilised, it has only been compared to analytical solutions (as benchmark/ integration test). Similar computations have been made in the past to calculate the risks of virus transport in MAR for drinking water purposes.

The tool can be used, for example, in conjunction with UWOT, where the hydrological model is used to calculate residence time, and the SuTRa package is used to compute the resulting microbial risks.

Table 17: Applications of SuTRa out of the BWS project

Indicative application of the tool	
Title	Various locations (outside B-WaterSmart project).
Description	We anticipate the application of the tool to the design of ASR systems for horticulture where pollution of irrigation with pathogens is a concern. In particular, this is of concern when multiple companies share the same ASR since this could increase the risk of cross contamination in case there is not enough residence time in the subsurface to ensure die-off of pathogens. Other applications may include the computation of microbial safety zones as part of QMRA (Quantitative Microbial Risk Analysis) around drinking water production sites.
Reference point	To be determined. We are open to facilitating the testing of the tool by third parties.
Location	NA.
Country (-ies)	NA.
URL	NA.
Project	NA.

Challenges	- High or increasing irrigation water demand for agriculture, - Increasing water demand by growing industrial sectors, - Need for reuse and recovery schemes for wastewater & sludge.
Tools/Product/Services	NA.
Technologies	Controlled Agricultural Recharge and Drainage (CARD) Large Scale Aquifer Storage and Recovery System (ASR)
Scales	- Local (e.g., single treatment plant, industrial site or city quarter)
Legislation	Water quality standards for both groundwater (EU WFD) and drinking water.
Synergistic benefits	Improved water quality and safety.
Requirements and conditions	A prerequisite is an understanding of the hydrological conditions (travel distance, residence time) and ideally also the redox status of groundwater (oxic, anoxic).
Key lessons	NA.
Organisations	NA.
Contact persons	NA.
Data Manager	NA.
Costs	Several billable hours to days, depending on background knowledge, information available.
Tags	NA
Publications/Reference	NA
Images	NA
Caption/Source	NA

15 Annex D: Technical details about the pre-processing stage, the setup process and the application of the tools at the LLs

This Annex concentrates detailed information on the application of tools to the case studies with focus on the preprocessing stage and input data and the set-up process. It also provides detailed presentation of results for some tools when available.

15.1 LL Flanders

15.1.1 Pre-processing stage and input data

During the initial conceptualization stage ("Concept" stage in Figure 13), different regional issues in Flanders were discussed in a series of meetings with a stakeholder group comprising participants from de Watergroep (DW production), Aquafin (WW treatment plants and actors of WW reuse), the region of Mechelen (provincial and urban development actors) and VITO (technology provider for RW harvesting). Different aspects of the regional water system with regards to water smartness were discussed, such as: safe DW provision and the challenge of river salinization, the potential of WW reuse as an extra source, regional issues with flood risk in urban areas, water used for irrigation and the potential of using RWH as an extra source etc. During these sessions, it was acknowledged that Flanders is an extensive, diverse area that faces multiple issues across water cycle domains. The stakeholder group therefore decided to focus on two regionally representative sub-regional use cases with a high interest in water resources modelling (see Figure 14) that could form the basis of UWOT/Regional Analysis modelling: Woumen (Dijsmuide) and Mechelen. The overview of the two cases is presented in the below figure (Figure 83).

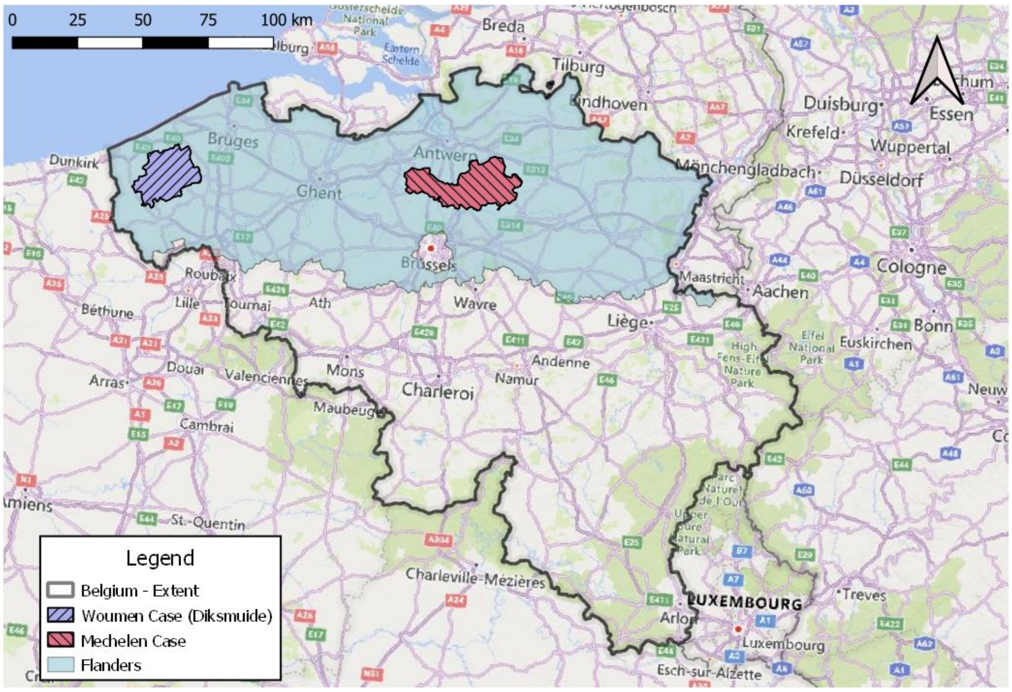


Figure 83: Overview of the two use cases for UWOT/Regional Analysis in Flanders LL.

The first case of Woumen (Dijsmuide area) features an issue of DW availability: the main source of river Ijzer offers insufficient water availability for drinking water production due to operational intake limitations, resulting mainly from a combination of low discharge (especially in summer and autumn months) and high salinity. Likewise, the polder system in the region faces similar problems with water level maintenance and salinisation in dry summers. This puts the DW production facility of Bekken de Blankaart (Figure 84) under stress, as intake limitation restrict the levels of the intake reservoir and translate to unguaranteed DW production. Moreover, the effect of future deteriorating conditions (e.g., due to climate change) on this system vulnerability remains to be explored. Against this issue, there is ongoing research by regional actors to (a.) explore additional RO treatment options of (high salinity) intake water to ensure a safer DW stream, (b.) explore the possibility of using WW reuse (from the effluent of WWTP) as an extra source of water intake for DW.

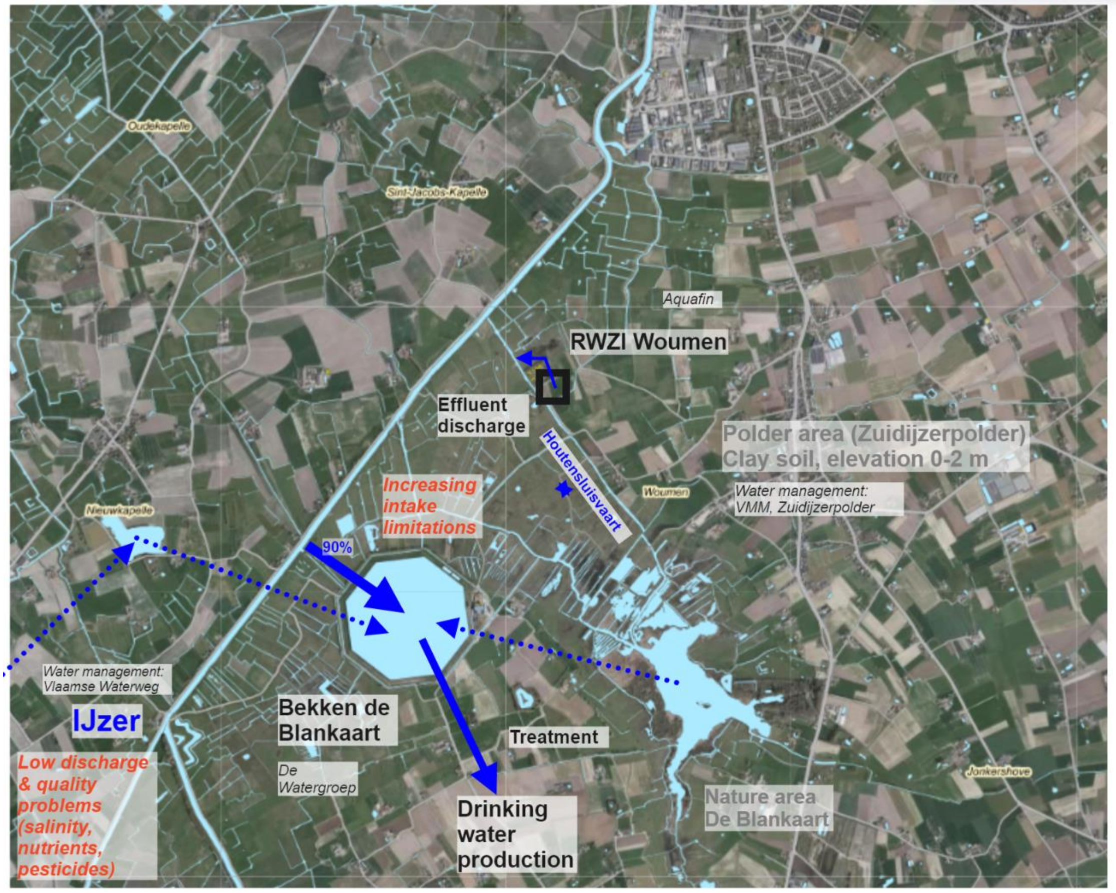


Figure 84: Schematic of the Woumen DW production case.

The second case of Mechelen (Hombeek area, Figure 85) focuses on a peri-urban area that sees agricultural usage and has increased water needs that lead to depletion of local sources (e.g., low surface water and groundwater levels). Moreover, during wet periods, there is risk of flooding damage in neighbouring urban areas due to insufficient capacity of the current stormwater discharge systems. As a result, a stormwater buffer reservoir that will be used as a retention basin during flood events has been built in the area. This reservoir could be used in conjunction with a sub-irrigation network to cover the irrigation needs for agricultural fields in the area. The interplay of these two objectives (flood volume retention vis-à-vis coverage of agriculture needs) could be explored using water systems modelling.

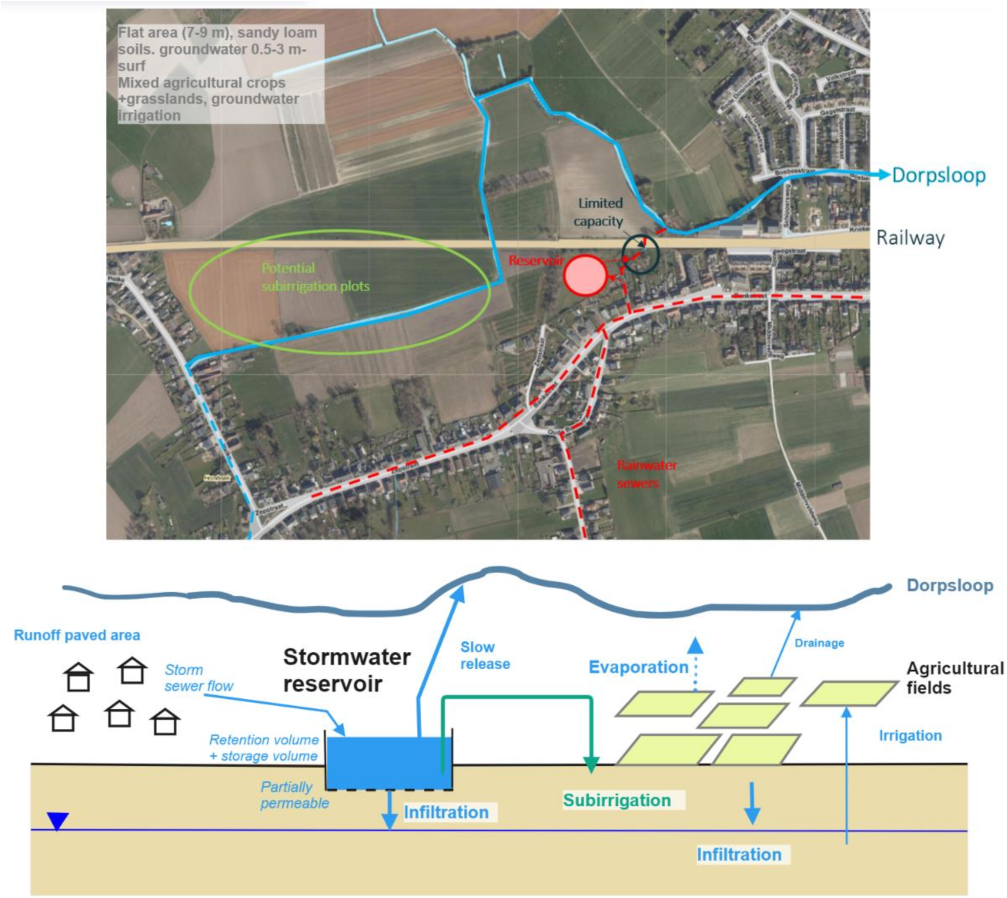


Figure 85: Schematic of the Mechelen RWH-subirrigation case.

Following the delineation of these two cases of interest to the stakeholders, the first model conceptualisations are sketched and the corresponding data needs are outlined. The input data needed for the regional analysis, as well as feedback on the conceptual set-up of the analysis, were collected during several meetings with the stakeholders for the two different cases. During this phase, the stakeholder group was divided into two focus groups (one for each case). The process of conceptualizing models and requesting data (model and data inventorisation stages of Figure 13) is iterative, leading to a sequential improvement of the initial model topologies as well as an inclusive review of the data needed for both cases. Table 18 and Table 19 present an overview of the data needs, which are shared across both methods, as well as the various data sources used to cover them.

Table 18: Input data for the UWOT/Regional Analysis for the Woumen case.

Input data		
Data type	**Description**	**Source**
Precipitation (P)	Point rainfall measurements from Zarren station	Flemish government open data website (waterinfo.be)
Potential evapotranspiration (ET)	Penman-Monteith ET from Zarren station. Missing values in October 2008, May 2009, April and May 2015, June 2016 replaced with station Waregem.	Flemish government open data website (waterinfo.be)
IJzer discharge upstream	Measured discharge IJzer at Keiem (10km downstream), rescaled to discharge at Woumen using modelled mean flows from VMM	DOV portal (https://www.dov.vlaanderen.be/portaal/)
IJzer chloride concentrations	Chlorine (Cl) measurements (location B7 upstream of the intake)	Data obtained from de Watergroep
Inflow brooks to polders	Measured discharge Steenbeek, rescaled using modelled mean discharges from VMM for other brooks	DOV portal (https://www.dov.vlaanderen.be/portaal/)
Chloride levels polder	Cl measurements (location B10 upstream of the Stenensluisvaart)	Data obtained from De Watergroep
WWTP discharge	Measured discharge (effluent, WWTP exit)	Geoloket, VMM
WWTP discharge chloride level	Measured discharge chloride levels	Geoloket VMM
De Blankaart DW facility technical specifics	Basin geometry and volume, average daily DW production capacity, Chlorine intake threshold	Provided by de Watergroep

Table 19: Input data for the UWOT/Regional Analysis for the Mechelen case.

Input data		
Data type	**Description**	**Source**
Precipitation (P)	Point rainfall measurements from Bonheiden station. Missing values April 2014, September 2016, October and November 2018 filled with Boortmeerbeek	Flemish government open data website (https://www.waterinfo.be/)
Potential evapotranspiration (ET)	Penman-Monteith ET model results from Herentals station. Missing values 2010 and 2015 filled with Liedekerke.	Flemish government open data website (waterinfo.be)
RW retention basin pilot specifics	Retention basin geometry and volume, technical schematics	Provided by VITO
RW retention basin serviced areas	Total urban area whose outlet is directed to the retention basin	Provided by VITO/Mechelen municipality

Regarding the preprocessing work of the stormwater reuse management system (tool #21)[10], which is reported in D3.4, this included:

- A buffer basin has to be equipped with a control valve and a PLC that can connect with the control in the cloud.
- All polluting water streams that might have been connected to the stormwater collection system in the past, such as combined sewer overflows, wastewater inlets, etc. must be disconnected from the system to ensure pure rainwater being used as source for the irrigation system.
- The agricultural fields need to be equipped with a subirrigation system, either by constructing a new system or by transforming the existing drainage system into a subirrigation system.
- A water transport network between the buffer basin and the agricultural fields needs to be installed.
- Minimum required sensor data:
    - water level in the buffer basin,
    - water level in the feeding tank of the subirrigation system,
    - groundwater level in the agricultural fields
    - precipitation measurements
    - temperature measurements
- Minimum required systems characteristics:
    - Basin dimensions for storage characteristics, including floor level and external overflow crest level.
    - Connected effective runoff surface area.
- Minimum required external data:
    - Rainfall forecast (volume or intensity) for at least 3-6 hours with high temporal (equal to better than 15 minutes) resolution for a location relevant for the stormwater runoff
    - Characteristics of fields (whether subirrigation wanted, priority of field, max heights of the groundwater at what time of the year, surface area)
- Additional data not essential but desirable for further optimization of the system performance may include:
    - Detailed local weather forecasts covering information such as temperature, solar radiation, etc.
    - Discharge measurements on pipes to the subirrigation system.
- Safe operation of the upgraded system must be ensured. This can be achieved through detailed, model-based hydraulic analysis to determine safe water levels in the buffer basin for the fallback control on the edge device.

The QMRA+ tool requires the user to select its type of source water, the water treatment processes used and the intended use of the produced water. The QMRA+ tool then uses default values from scientific literature and guidebooks to provide concentrations of

---

[10] The stormwater reuse management system (tool #21) is part of D3.4. Nevertheless, the preprocessing work and lessons learned are being documented in D3.5 as part of the LL work in order to provide the complete picture of the Flanders case since it is related with other tools.

pathogens in the source, efficiency of treatment systems, frequency of use and volume ingested per use. The users are allowed to adapt these standard values when they have more accurate information from their specific situation or system. This could be from water quality analysis, treatment challenge testing or user assessment. Point of attention for interpreting the tool results is a lack of expert knowledge of the user. Insufficient understanding can lead to misinterpretation of results. The tool provides a best estimate of water safety based on typical systems elsewhere. However, all input variables show large differences between individual systems. Therefore, it rather assesses the potential of a system. Verification of local water quality and treatment performance is essential to draw conclusions about safety of the actual system. Therefore, in most cases it is recommended to use the tool with consultancy support.

Note that the tool only focusses on microbial risks and does not consider costs, chemical parameters etc. therefore the tool not suitable for complete optimization of e.g., a wastewater reuse plant.

15.1.2 Setup process and application

15.1.2.1 UWOT

Woumen

Following the data inventorisation process described in Section 6.2.2, the data is pre-processed to be inserted into the model and a UWOT model topology with all needed system components to represent the intake system of Woumen is designed (Figure 86).

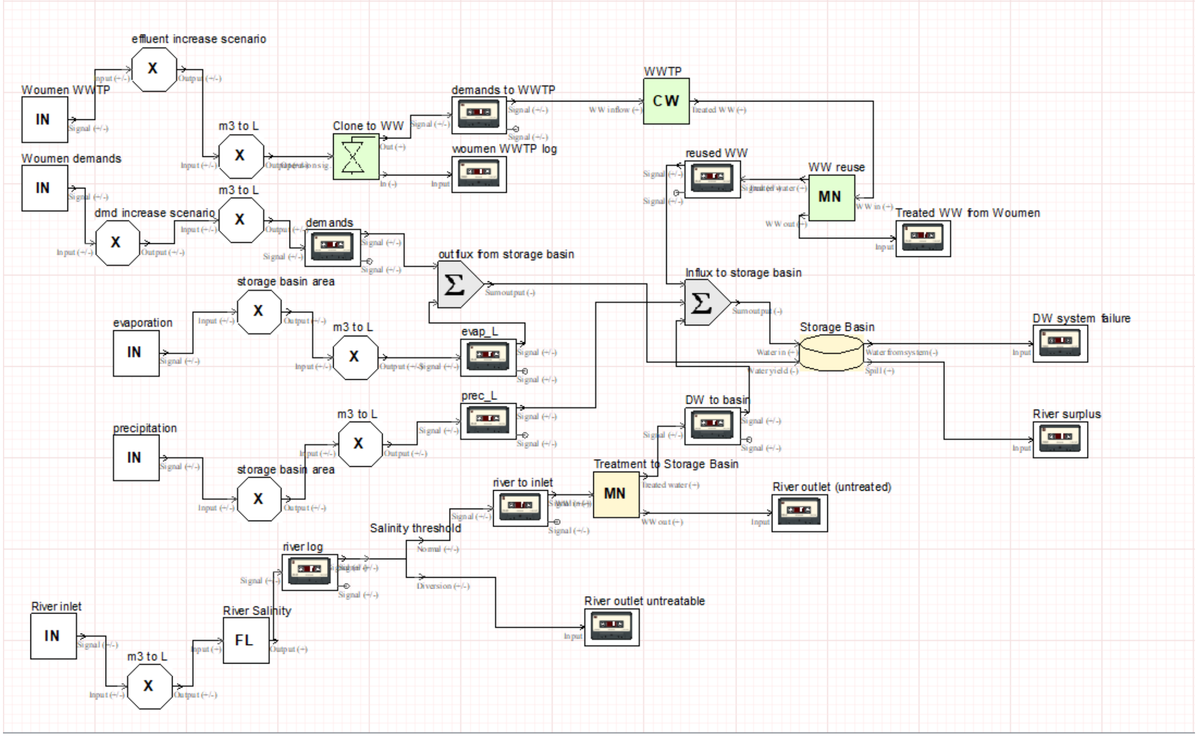


Figure 86: UWOT topology schematic of the Woumen (DW intake) case.

With regard to data preprocessing, data from the shared UWOT-Regional Analysis database (Table 18) is loaded in a python data processing environment (featuring Jupyter Notebooks running python 3.6 with the packages of numpy 1.18.1, pandas 1.3.5, matplotlib 3.1.3, and seaborn 0.10.0), cleaned, and converted to data formats suitable for UWOT modelling (i.e., CSV time series of individual variables). Time series are inserted at a daily timestep for the period 1-1-2006 to 31-12-2020 where most data variables do not have significant missing values or gaps. This data timeframe (simulation period) is shared with the Regional Analysis tool as well. The data preprocessing steps include:

- Cleaning river discharge data and interpolating missing values. Negative values in river discharge indicating flow from the sea (i.e., salinity intrusion) are converted to zero values, as the model requires non-negative flow data as input.
- Extracting point precipitation and evaporation data in millimetres (mm) and checking for missing or erroneous values.
- Extracting salinity data (to accompany river discharge data) in mg/L and checking for missing or erroneous values.
- Extracting WWTP effluent (WW quantity) data and checking for missing or erroneous values.
- Formulating urban demand scenarios and the corresponding time series. Actual urban water demands in Woumen are indicated as unknown from the stakeholder group, so assumptions on demand scenarios are made to generate the corresponding input for UWOT. This is further explained in Section 6.2.3.

- Necessary unit conversions to prepare data for the UWOT model, including converting volumes from m^3 to litters (L), flows from m^3/day and m^3/s to L/day, and hydrological data from mm/day to L/day (by multiplying with the appropriate regional surface).

An example of the processed time series (river discharge Q in m^3/day) is shown in Figure 87.

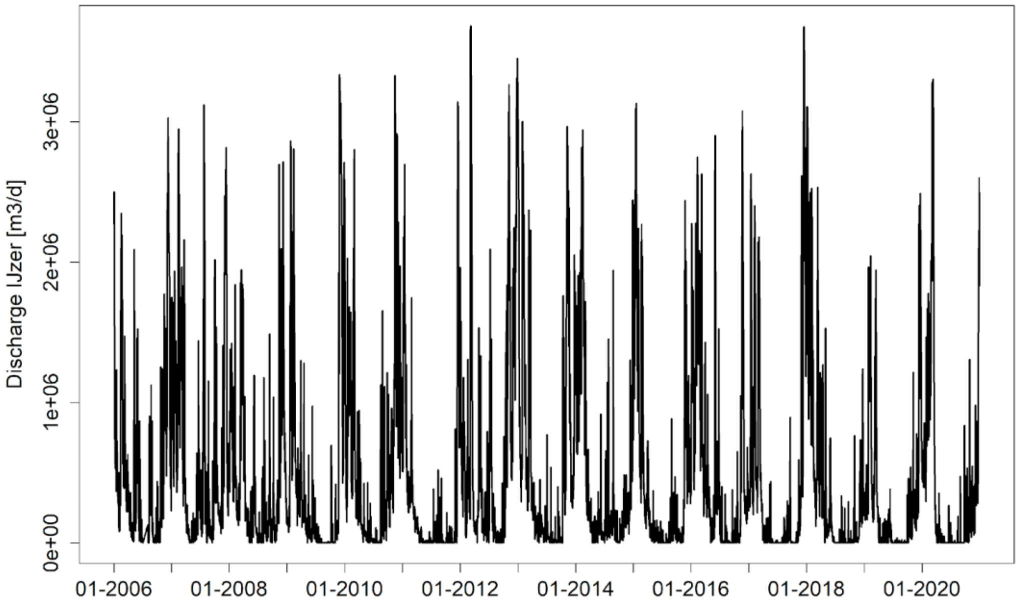


Figure 87: Input data for discharge of the IJzer. Negative discharge values are converted to zero.

For further analysis, a baseline (reference) case that represents present-day system reality is formulated, along with several scenarios featuring the use of water-smart technologies. All scenarios use a common topology file to allow for recursive running (Figure 86), where some components (such as the WW reuse) are only conditionally used. The following assumptions are used for all scenarios:

- The Ijzer river is the sole raw water intake source to the WPC De Blankaart storage basin, with other secondary sources considered too small to contribute to intakes significantly.
- The model extent includes components relevant to the Woumen DW production facility, as well as urban water demand components. Other regional natural systems (e.g., the polder system) are excluded but treated in the supplementary Regional Analysis.
- The drinking water production capacity is constant throughout the year and set at 40000 m^3/d. The actual daily capacity reaches this value, unless: (a.) there are intake availability issues due to low discharge, (b.) the intake source salinity level reaches values higher than 180 mg/L, where production stops and the intake capacity is set to zero. This capacity threshold S_{thr} is a model parameter (Table 20) that can be altered by water-smart technologies, such as the use of CCRO.
- The Woumen unit has a maximum storage capacity of $3 \cdot 10^6$ m^3, which is determined by its 60-ha area and maximum allowable water level.

An overview of the parameters assumed by UWOT is shown in Table 20.

Table 20: Parameters for UWOT and the reference situation for the Woumen case.

Parameters for the UWOT modelling of Woumen DW system	
DW optimal production capacity	40000 m^3/d
Storage basin area	600000 m^2
Maximum storage basin water depth d_{max}	5.5 m
Maximum volume of storage basin	$3.3 \cdot 10^6$ m3
Initial volume of storage basin	$1.8 \cdot 10^6$ m3
Production rules	Production capacity set to optimal unless: (a.) incoming river discharge $Q < 40000\ m^3/d$ or (b.) incoming river salinity $S < S_{thr}$
Salinity threshold S_{thr} for baseline (reference) case	180 mg/L
WW reuse rate at baseline (reference) case	0

Mechelen

Following the data inventorisation process described in Section 6.2.2, the data is pre-processed to be inserted into the model and a UWOT model topology with all needed system components to represent the system of Mechelen is designed. The system corresponds to the RWH pilot being in operation and receiving runoff from the serviced area. The model is a representation of the regional water system, thus representing water fluxes (rainfall, runoff, retention, and coverage of subirrigation demands) in a simplified way. Flows are calculated on a daily timestep for the period 1-1-2006 to 31-12-2022, to be consistent with the Regional Analysis tool. The input data that is needed is described in Table 19. The input data consists of two meteorological variables: potential evaporation and precipitation, as well as the technical characteristics of the retention basin, which are provided by the LL regional stakeholders.

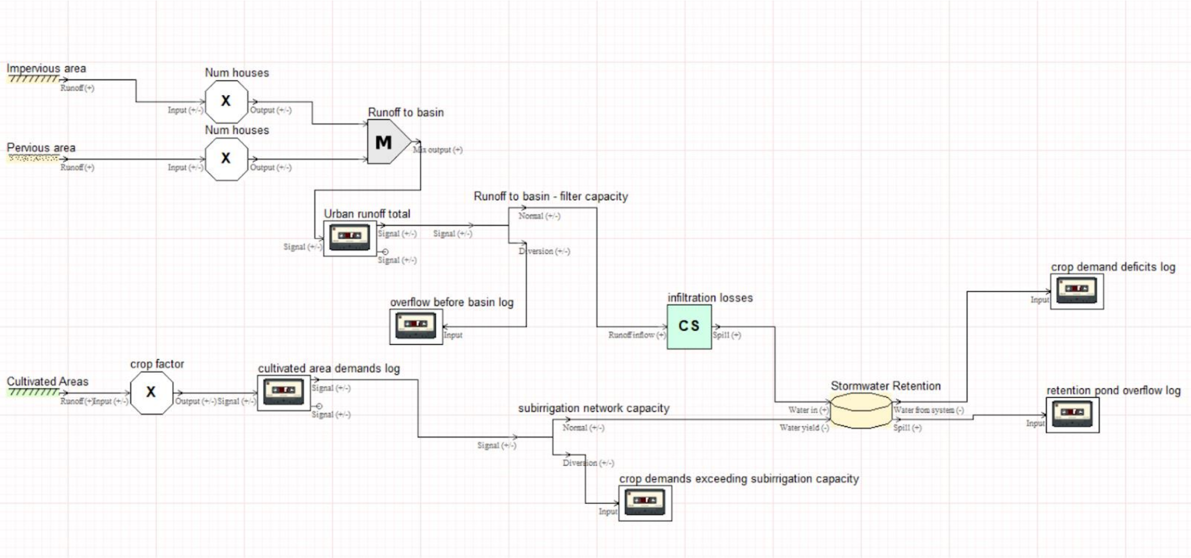


Figure 88: UWOT topology schematic of the Mechelen (RWH basin) case.

For the analysis in UWOT, the baseline (reference) scenario considers the retention basin being operational under the case of implementation with sub-irrigation, i.e., connecting the outlet of the retention basin with a sub-irrigated area, with a set maximum daily subirrigation capacity Q_{sub}. The assumption is made that the retention basin is used to cover (part of) the evapotranspiration demands of a cultivation (using a single crop type) in a subirrigation area A_{sub}. The equivalent crop demands are thus calculated as Dsub=C·PET·Asub, where C is the crop coefficient (similar to calculations as per FAO), which is typically ranging from 0.90 to 1.10-1.25. Seasonal variability in the crops (growth cycles) is not taken into account, and a constant state of crops along the year is assumed. Open water evaporation on the basin is considered small relative to other fluxes (such as inflows and the subirrigation discharge) and is not taken into account. For the urban areas that contribute to rainwater harvesting, 20% of the precipitation is considered to be evaporating. Moreover, the area is split between impervious areas (that fully contribute to runoff, without infiltration, following the interception and evaporation losses), and pervious areas that have a specific infiltration capacity. An overview of the parameters for the Mechelen UWOT topology can be seen in Table 21.

Table 21: Parameters for UWOT and the reference situation for the Mechelen case.

Parameters for the UWOT modelling of Mechelen RWH system	
Total urban areas* serviced by retention basin A_{urban}	120775 m^2 *reflects combined sewer drainage area in Mechelen
Impervious to total ratio	40%
Urban drainage area, impervious $A_{urban, imp}$	48310 m^2
Urban drainage area, pervious $A_{urban, prv}$	72465 m^2
Urban drainage area, pervious soil capacity	200 mm
Urban drainage area, pervious soil capacity (initial value)	50 mm
Filter (pretreatment) capacity for RWH unit to retention basin	500 m^3/day

Subirrigation network capacity Q_{sub}	100 m^3/ha/day
Retention basin infiltration rate	0.14% of maximum basin volume
Reservoir volume V_{basin}	2188 m^3
Reservoir volume V_{basin}, initial value	1000 m^3
Reference case crop factor C	0.9
Irrigated area $A_{irrigation}$	83000 m^2

15.1.2.2 Regional analysis

Woumen

For the regional analysis of the Woumen case, a system dynamics model was developed (Figure 89). The regional analysis consists of four subsystems: the IJzer (top), the polder system (middle), the drinking water production system (bottom) and the WWTP (right). The model represents the water stocks and flows in the system over time in a simplified way, as well as part of the chloride flows. Flows are calculated on a daily timestep for the period 1-1-2006 to 31-12-2020.

Input data for the regional analysis are described in Table 18 and streamflow (discharge values) of the IJzer are shown in Figure 87. The input data consist of meteorological variables and characteristics of the hydrology in the area (discharge values). In Table 22, the values for the different parameters in the regional analysis are given.

A reference situation and several scenarios have been explored for the regional analysis. We have assumed that no water intake from the IJzer can take place when negative discharges occur (due to seawater intrusion). Negative values were therefore converted to zero (Figure 87). A minimum environmental flow was not taken into account. Additional water from sources other than the IJzer (the Blankaartvijver and Driekappellevijver) is not included in the regional analyses, because these flows are small compared to the intake from the IJzer. In the reference situation, the IJzer is the only water source and water intake to the storage basin is stopped when salinity values are higher than 180 mg/l. The desired drinking water production is kept constant throughout the year at 40 000 m^3/d.

The following scenarios were included in the regional analysis:

1. Reuse of effluent. All available water from the wastewater treatment plant (WWTP) in the area, is used as an additional water source for drinking water. Water quality of the effluent and the effect on the minimum environmental flow were not taken into account.
2. Implementation of CCRO system. To overcome issues with high salinity values in the IJzer a CCRO system is installed parallel to the existing treatment. The fraction of water treated with

the CCRO system depends on the salinity values in the storage basin. The water that reaches the production station cannot exceed salinity values of 180 mg/l. If the salinity level in the storage basin is higher than 180 mg/l, the fraction of water treated with the CCRO system depends on the actual salinity level. Water from the existing treatment process is mixed with the outflow from the CCRO system to ensure the salinity level remains below the threshold before entering the production process. When the salinity levels in the storage basin are lower than 180 mg/l, 10% of the water is treated by the CCRO system to minimize the flow but avoid standstill of the system. In this scenario, there is no intake criterium for the intake of water from the IJzer to the storage basin.

3. Implementation of both measures. Effluent is used as additional source for drinking water, the specific treatment of the effluent is not modelled. A CCRO system is installed for the intake from the storage basin. The measures are implemented with the same assumptions as in scenario 1 and 2.

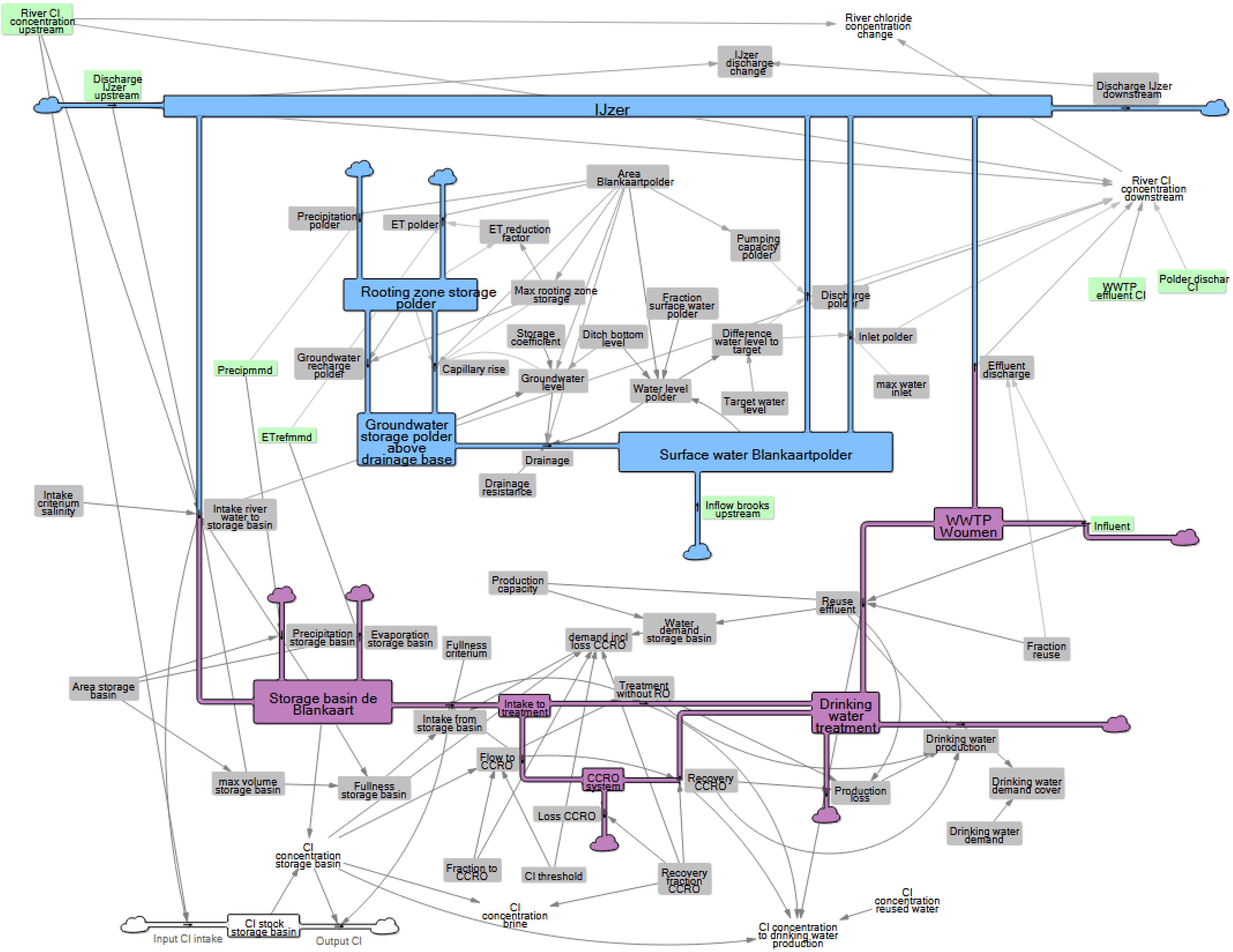


Figure 89: Regional analysis for the Woumen case. Blue: semi-natural water system, purple: human water system; boxes are stocks, coloured lines are flows; grey/no boxes: system characteristics, constants and output; green boxes: input .

Table 22: Parameters and assumptions for regional analysis of the reference situation for the Woumen case.

Parameters drinking water system	
Intake criterium salinity	180 mg/l
Area storage basin	60 ha
Maximum depth basin	5 m
Production capacity	40000 m3/d
Production	Intake from the storage basin decreases when the basin is <80% full, reducing to0 when the basin is 20% full (1m water depth)
Production loss existing treatment	5%
Fraction water to CCRO	0
CCRO recovery fraction	90%
Parameters wastewater system	
Fraction reuse	0
Parameters polder system	
Area polder (managed water level)	1300 ha
Surface level	3 m TAW
Areal fraction surface water	4%; estimated from topographic maps
Ditch bottom level	1.7 m TAW; assumed 1.3 m below surface level following van der Gaast (2006)
Maximum water storage root zone	5.4 cm (available water clay soil (Staring B11) between wilting point and field capacity 0.18 cm3/cm3 (Heinen et al. 2020); root zone depth grass 30 cm)
Evapotranspiration factor	Reduces when soil water is <80% of field capacity decreasing to0 at the wilting point
Capillary rise	Varies between 0 and 4 mm/d depending on root zone water storage and groundwater depth, based on critical z values from Heinen et al. (2020), soil B11
Groundwater storage coefficient	0.1
Drainage resistance	40 days
Target water level	2.7 m TAW (level most of year, overeenkomst peilbeheer 2019)
Pumping capacity polder discharge	1 m3/s. In reality 2 m3/s (overeenkomst peilbeheer), adapted to ensure normal model behaviour

Mechelen

For the regional analysis of the Mechelen case, a system dynamics model was developed as well (Figure 89). The model represents the water stocks and flows in the system over time in a simplified way. Water quality was not taken into account for this case. Flows are calculated on a daily timestep for the period 1-1-2006 to 31-12-2022.

Input data for the regional analysis are described in 6.2.2. The input data consist of two meteorological variables: potential evaporation and precipitation. In Table 21 the values for the different parameters in the regional analysis are given.

A reference situation and two scenarios have been explored for the regional analysis. In the reference situation, it is assumed that precipitation from the region leads to runoff to the Oude Tantelaerloop. We considered a runoff coefficient of 0.8, meaning 20% of the precipitation is lost, for example due to evaporation, before reaching the stream. In the regional analysis, a spatial component is not included, which means all precipitation reaches the stream in the same timestep (daily). The stormwater retention basin is simplified to a rectangular basin with straight edges instead of sloping edges. We explored two scenarios with the proposed measures:

1. Implementation of a stormwater retention basin. Precipitation is stored in a retention reservoir. The reservoir loses water through evaporation and infiltration to the groundwater. Operational rules to optimize the available storage in the system were not taken into account.
2. Implementation of a stormwater retention basin in combination with subirrigation for agriculture. We have assumed that water is pumped into the subirrigation system throughout the year with a capacity of 830 m^3/d to supply an area of 83 000 m^2 (100 m^3/ha per day). Again, optimal management of the reservoir and the subirrigation system was not taken into account.

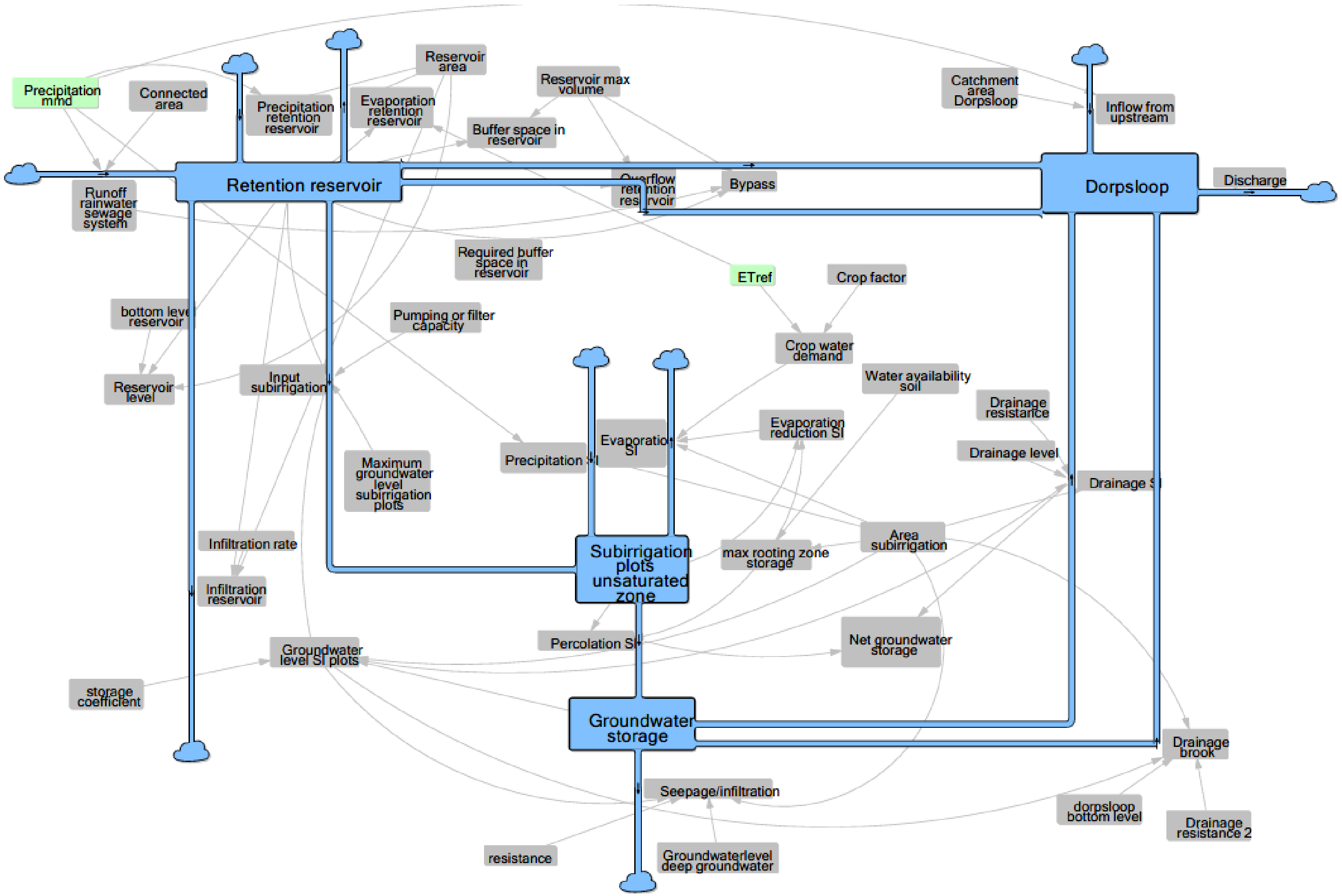


Figure 90: Regional analysis for the Mechelen case. Blue: semi-natural water system; boxes are stocks, coloured lines are flows; grey boxes: system characteristics, constants and output, green boxes: input.

Table 23: Parameters and assumptions for regional analysis of the reference situation for the Mechelen case.

Parameters stormwater reservoir	
Area storage basin	2188 m^2
Maximum depth basin	1 m
Area connected	121000 m^2
Bottom level reservoir	7.5 m TAW
Infiltration reservoir	20 mm/d
Parameters subirrigation system	
Pumping capacity	830 m^3/d
Maximum groundwater level	9.1 m TAW (-0.5m below surface level)
Parameters agricultural area	
Area subirrigation	83 000 m^2
Surface level	9.6 m TAW
Groundwater storage coefficient	0.1
Crop type	Grass
Ditch bottom level	8.3 m TAW; assumed 1.3 m below surface level following van der Gaast (2006)
Drainage level	8.6 m TAW; assumed 1 m below surface level
Maximum water storage root zone	5.4 cm (Water content clay soil (Staring B11, Heinen et al. 2020) at pF=250 cm about 0.49, at pF=16000 cm about 0.32, giving a water availability of 0.18, assuming a rooting zone depth of 30 cm giving 5.4 cm of water storage capacity in root zone
Evapotranspiration factor	Reduces when soil water is <80% of field capacity until it reaches 0 at the wilting point
Drainage resistance drainage system	5 days
Drainage resistance brook	40 days
Groundwater level deep groundwater	6.5 m TAW
Resistance deep groundwater	500 d

15.1.2.3 QMRA+

The QMRA+ tool was used in the Woumen case to explore water safety implications of various concepts involving the use of effluent to supplement the drinking water supply. Options studied included supplementing the Blankaart raw water reservoir with post-treated effluent and direct drinking water production from effluent to supplement the current drinking water supply. Various combinations of treatment processes were evaluated for these purposes. The risk assessment was mostly based on literature data for effluent quality and treatment process efficacy for pathogen removal or inactivation. Limited data for fecal indicator organisms from the current surface water source, the IJzer, were available to estimate the concentration of pathogenic microorganisms.

The QMRA+ tool was also used to demonstrate that the upgraded drinking water treatment is capable to produce safe drinking water from the reservoir water.

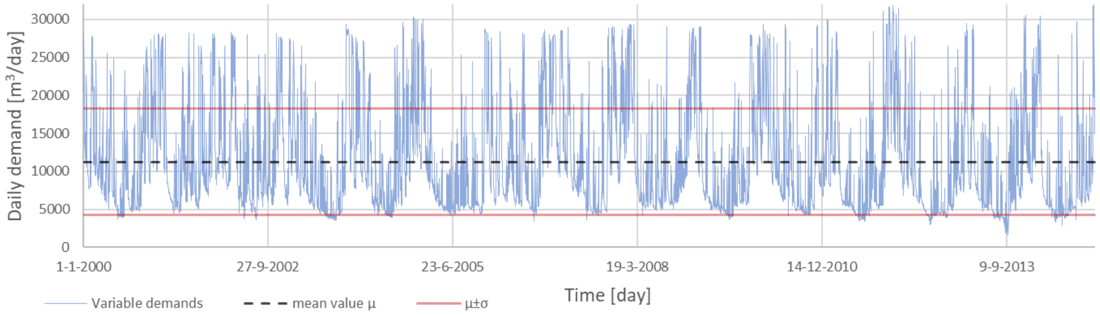
15.1.3 Results

15.1.3.1 UWOT

Woumen

For the case of Woumen, UWOT is used as a stress-testing platform to explore if the current system implementation can satisfy present-day demands. Moreover, stress-testing is extended to predict how vulnerable the current system is towards changes in factors such as the river intake salinity and regional demand, as well as to explore if water-smart technologies can alleviate these (potential) vulnerabilities. To do this, UWOT requires a water supply strategy (defined by the drinking water production rules seen in Table 20), as well as an assumption on the regional demands that are served in the Woumen area. As demand data are not available from any source (third-party sources or stakeholder groups), the following alternative (i.e., mutually exclusive) assumptions are made on the demand side to generate the corresponding demand time series which are required as UWOT input:

- A **variable demand** assumption, which assumes that a similar variable quantity to the observed - and available, as input - WWTP effluent is requested from clients. The main attributes of the variable demand assumption are shown in Figure 91.
- A **constant demand** assumption, which assumes that a set daily quantity D_s of water (in m^3/day) is requested by regional clients.



Variable demand time series attributes		
mean value μ	11260	m^3/day
standard deviation σ	6998	m^3/day

Figure 91: Variable demand time series, cloned from the WWTP effluent data.

The variable demand assumption, while relying on available WW effluent data and taking into account daily variability, has limitations. Firstly, it implicitly assumes that the same area serviced by the WWTP is also serviced by the DW utility. This may be untrue, as the DW facility potentially serves third-party areas in an inter-connected (looped) supply network. Moreover, WWTP effluent data might be affected by rainfall in combined sewer overflow events, leading to deviations between drinking water and observed wastewater. To counteract these limitations, both assumptions (variable and constant) are employed in the stress-testing analysis.

Stress-testing is based on using UWOT to perform simulations at the daily timescale in the system and its components, thus measuring how each component behaves in terms of flow variability, overflows, time points with low or empty storage levels etc. With a time window from 2006 to the end of 2020, a total of 5479 daily timesteps are used per simulation, with UWOT returning time series of flows and water storage for each simulation. An example of the returned time series is given in Figure 92, under the assumption of a constant regional demand $D_s = 25000$ m^3/day, with the upper panel showing DW available in the basin, followed by model logs of the basin being under stress and failing to deliver water, as well as the actual water deficits. This is output in the form of daily time series for a single simulation; one may observe that the stressed states correlate with the failure states, even though an event which leads to low water levels might not necessarily translate to an actual system failure and inability to deliver water.

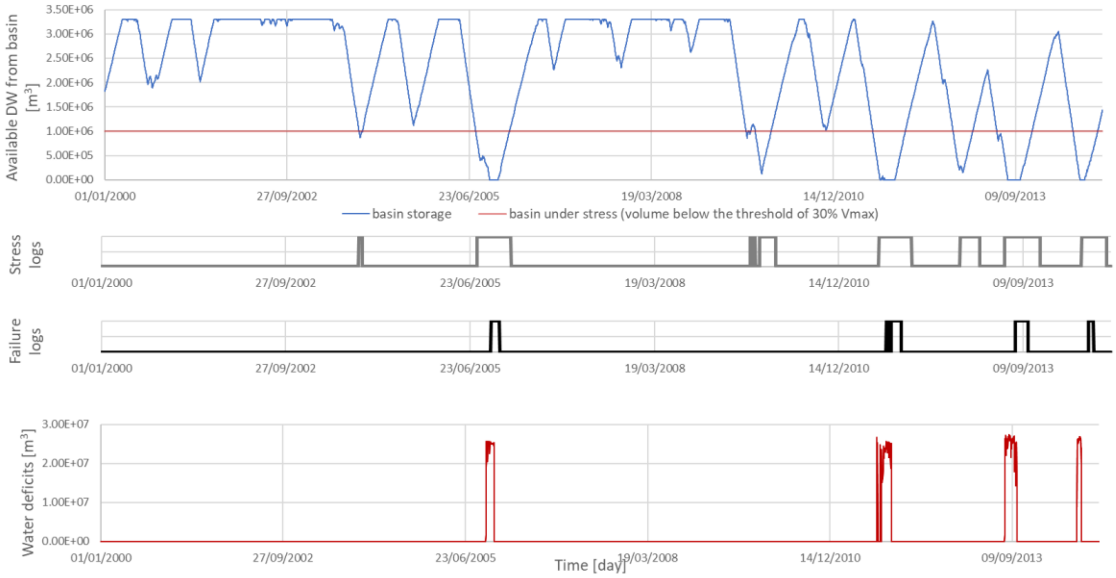


Figure 92: Snapshots of the UWOT model results for the Woumen case, under the assumption of constant demands set to 25,000 m^3/day.

Once these time series are returned by the model, the output data is post-processed to assess the percentage of time the intake basin was under stress (i.e., meaning the volume of available drinking water being alarmingly low) or completely empty (i.e., meaning no availability of drinking water to satisfy demands). Evidently, to make these considerations, one must consider how exactly “low levels” in the basin volume are defined, which has a degree of subjectivity. For instance, in the upper panel of Figure 92, the stress threshold (i.e., red line in upper panel) is arbitrarily set to 30% V_{max}, which results in specific patterns for the stress logs in the panel that follows. To overcome this subjectivity, the results are instead presented in the format of “stress curves” (Figure 93), i.e., a graphical representation of different volume thresholds in the basin water volume (normalised in [0,1] and expressed as the ratio of V/V_{max}, in the x-axis) against the amount of time (%) that these or lower volumes are observed (i.e. $P(V_t \leq V)$) in the y-axis. A stress curve can be thus perceived as the analogue of a Cumulative Distribution Function (CDF) for the water basin and the intake system in general, starting from [0,0] and reaching [1,1]. Its interpretation is intuitive, as the further the curve lies towards the lower right part of the graph and the x=1 line (i.e., the tank being full), the more secure and less vulnerable the system is. For further visual help, we also depict stress curves along with the x=y line, which represents a system that empties in a linear fashion, with a light grey colour.

As a first step of the stress-testing analysis, the effects of an increase in regional demands to the present-day Woumen drinking water system are explored. This increase could be attributed, for instance, to a change in regional population, or a change in the supply strategy of the utility to include and serve additional areas. The results, in the form of stress curves, under both assumptions of variable or constant demand are shown in Figure 93, where:

- the left panel shows the assumption of variable demand being increased by a set percentage, up to a triple amount (increase by 200%). In terms of mean values, the range of increase is from 11260 m^3/day (present-day assumption) to 33780 m^3/day (200% increase), which is deemed reasonable, considering the present-day treatment capacity of 40000 m^3/day.
- The right panel shows the assumption of constant demand starting from 10000 m^3/day and being incrementally increased by 5000 m^3/day up to 40000 m^3/day, which is equal to the drinking water production capacity.

The results of Figure 93 demonstrate that the basin continues to operate well under demands in the range of 10000-25000 m^3/day, but begins to experience significantly more stress and, eventually, failure for larger values. Demand values >30000 m^3/day translate to disturbed operational states in the system, thus rendering the system prone to failure, as less than 50% of its maximum volume is available at more than 50% of the simulation time under both demand assumptions. In these disturbed states, there is also significant failure in delivering drinking water to clients in the range of 15%-40% of the time.

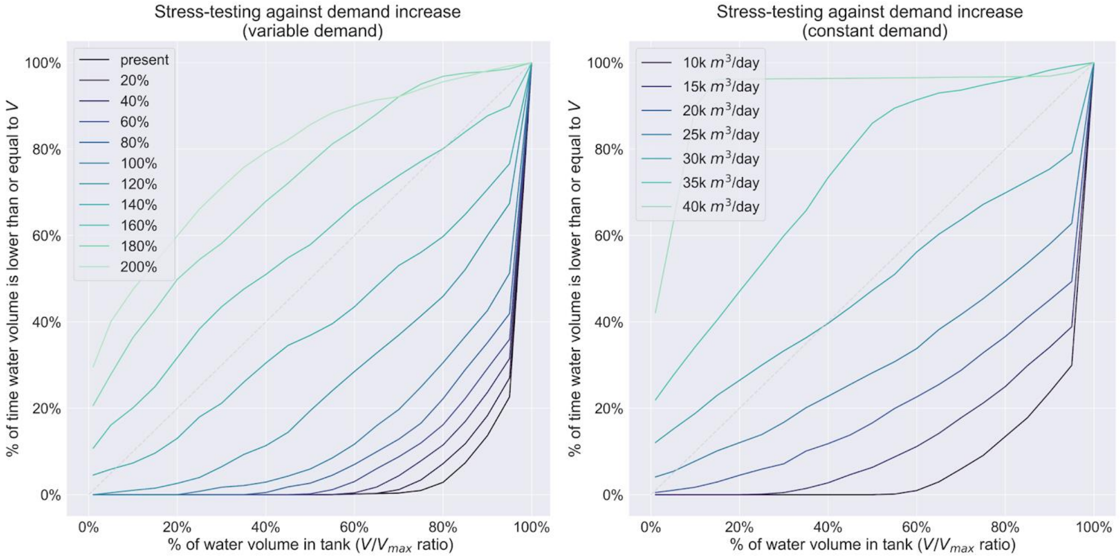


Figure 93: UWOT stress-testing of Woumen against an increase in regional demands, under the assumption of a variable demand that is being increased by a set percentage (left panel) or a constant demand being incrementally increased (right panel).

As a next step of the stress-testing analysis, the effects of increased salinity in the river Ijzer source are explored. For this and to conserve space, the analysis focuses on the constant demand assumption only, assuming constant demands of 15000 and 25000 m^3/day which correspond to normal operational states of the basin (see also Figure 94). River salinity in the source for dry months is then increased by an increment of 25% up to a doubling of salinity rates (increase by 100%). The results demonstrate that, for low water demand values, the drinking water system can mitigate a worsening salinity future without significant loss of reliability or failure rates. However, if water demand requests become significant (e.g., right panel of Figure 94), then any worsening salinity future will translate to significant stress levels and failure rates (>10% for significant (>50%) salinity increase). This means that the drinking water system is particularly prone to the combination of worsening salinity levels paired with increased demand needs.

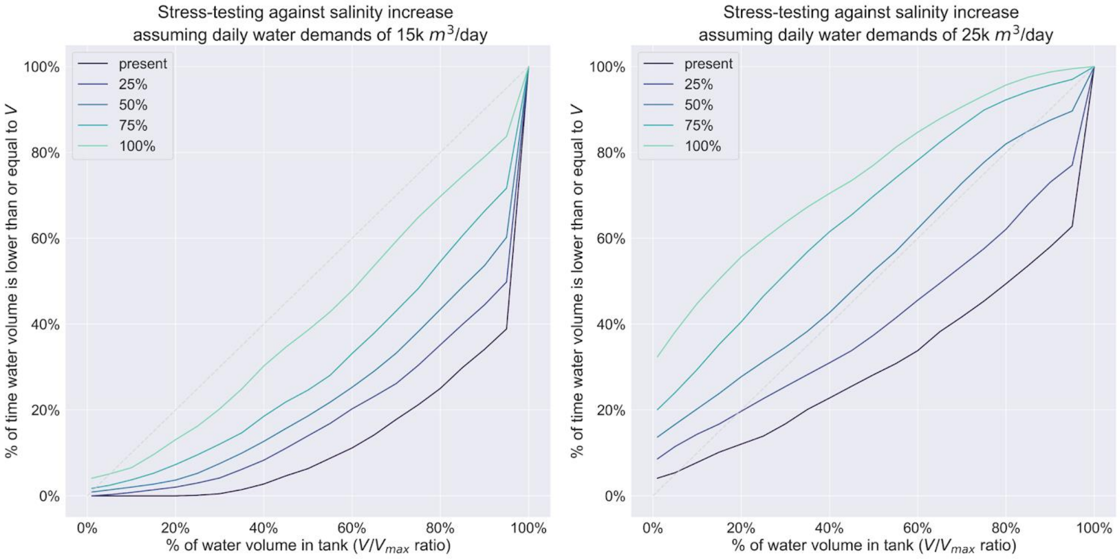


Figure 94: UWOT stress-testing of Woumen against % increase in river salinity, under the assumption of two different constant demand rates D_s of 15000 m^3/day (left panel) and 25000 (m^3/day).

Besides highlighting the vulnerabilities of the current state of the drinking water production system, the stress-testing analysis can assess the efficiency of water-smart technologies for Woumen. Two proposed measures (as discussed and prioritized by regional stakeholders in previous meetings) are considered:

- The **reuse of wastewater (WW) effluent** from the Woumen WW treatment plant (WWTP). To proceed with this scenario, a steady reuse rate Q_r (in m^3/day) is assumed, meaning that (up to) Q_r of WW daily are treated at an acceptable level and added to the production capacity of the system. The daily amount can be lower if the WW effluent does not exceed that reuse rate, i.e., in case of low flows. Three different reuse rates Q_r are considered: 5000 m^3/day, 10000 m^3/day, and 20000 m^3/day. It is noted that the mean flow rates range typically up to 12000 m^3/day, so the first two values can be considered realistic, while the third one is an upper limit reachable only on certain timeframes.
- The installation of a **Closed-Circuit Reverse Osmosis (CCRO) unit** as part of the drinking water production facility in Woumen. This added treatment step leads to uninterrupted drinking water production for intakes with higher salinity. As a result, it is assumed that the CCRO installation leads to an increased salinity threshold S_{thr} compared to the baseline (reference) case. Other factors, such as the CCRO efficiency or capacity are not considered in this analysis but are instead treated in the Regional Analysis. Three different increased thresholds are considered for the analysis, representing different CCRO layouts: 280 mg/L, 380 mg/L and 480 mg/L.

For both of these water-smart technology scenarios, constant demand rates of 15000 m^3/day, 25000 m^3/day and 35000 m^3/day are considered, representing different levels of light, medium and heavy use of the production facility to cover potential regional demands.

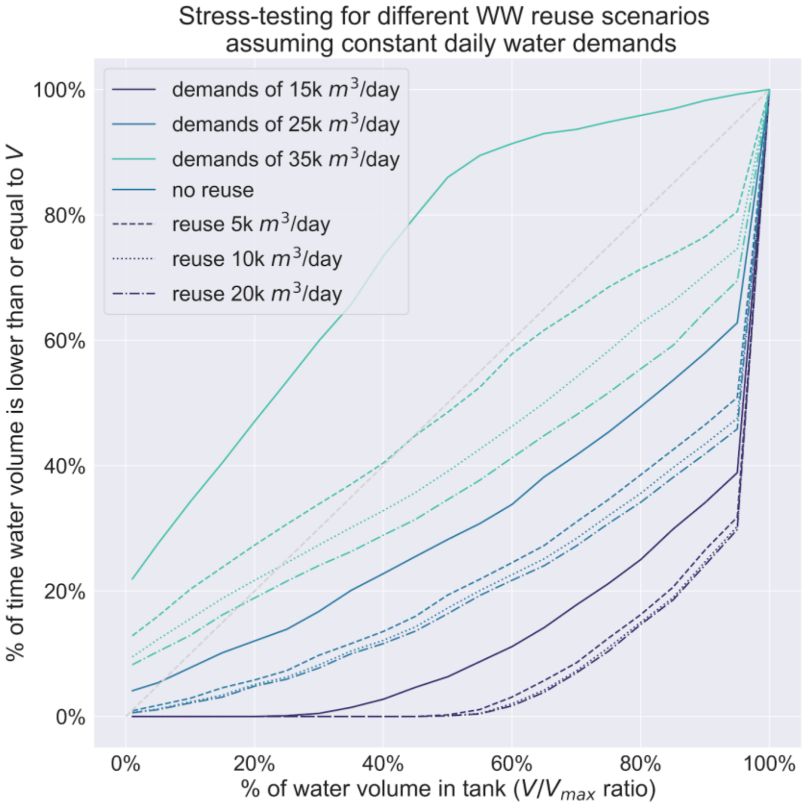


Figure 95: UWOT stress-testing of Woumen for different WW reuse scenarios, under the assumption of different constant demand rates D_s of 15000, 25000 and 35000 m^3/day.

Concerning the measure of WW reuse, the results can be seen in Figure 95, where (a) the continuous line represents present-day conditions, without any reuse, and (b) the dotted lines represent different WW reuse rates (5000 m^3/day, 10000 m^3/day, 20000 m^3/day). Figure 95 shows that the introduction of WW reuse improves the reliability of the DW production unit considerably, particularly for the medium and heavy demand cases of 25000 m^3/day and 35000 m^3/day. Interestingly, differences between larger reuse rates are not significant under the light and medium demand assumption, indicating that there is no added value by investing in large WW reuse capacities. A higher WW reuse capacity (>10000 m^3/day) only becomes important if daily demands become high; in that case, a mostly empty and unreliable drinking water production unit (continuous, teal line) is converted to a reliable one, with system failure rates lowering from >20% to 8-10% and with the basin emptying with a lower rate than the linear equivalent (grey dotted *x*=*y* line).

Concerning the measure of CCRO, the results are demonstrated in Figure 96 (for present-day salinity conditions in the source) and Figure 97 (for 50% worsening salinity conditions in the source). It can be observed that the introduction of added treatment with the CCRO system improves the reliability of the drinking water production system under regular regional demands (15000 – 25000 m^3/day) but becomes less efficient under the high demand scenario. Moreover, higher threshold scenarios prove to be less efficient than the scenario that leads to S_{thr} = 280 mg/L and even partly coincide with the lower threshold scenario in the case of high demands in Figure 96. This means that an added investment in large CCRO capacities has to be significant (i.e., raising S_{thr} considerably higher than the 280-480 mg/L zone) to be translated to improved reliability to the system.

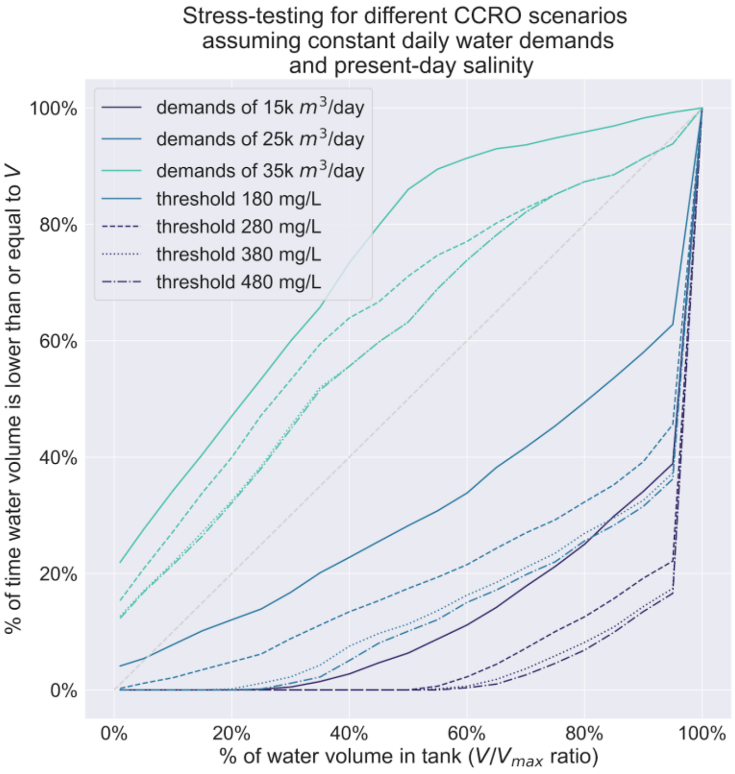


Figure 96: UWOT stress-testing of Woumen for different CCRO layouts that lead to three different production thresholds, under present-day salinity conditions in Ijzer.

Under deteriorating salinity conditions (Figure 97), the importance of a CCRO system increases, as it is able to drastically reduce the stress curve to cover the normal range of regional demands (15000-25000 m^3/day). However, and similarly to Figure 96, the measure appears to be less efficient in the high demand case of 35000 m^3/day. In that case, all layouts manage to decrease a 40% failure rate of the reference case to 18%-22%, but the stress curves continue to indicate a highly stressed system that empties rapidly.

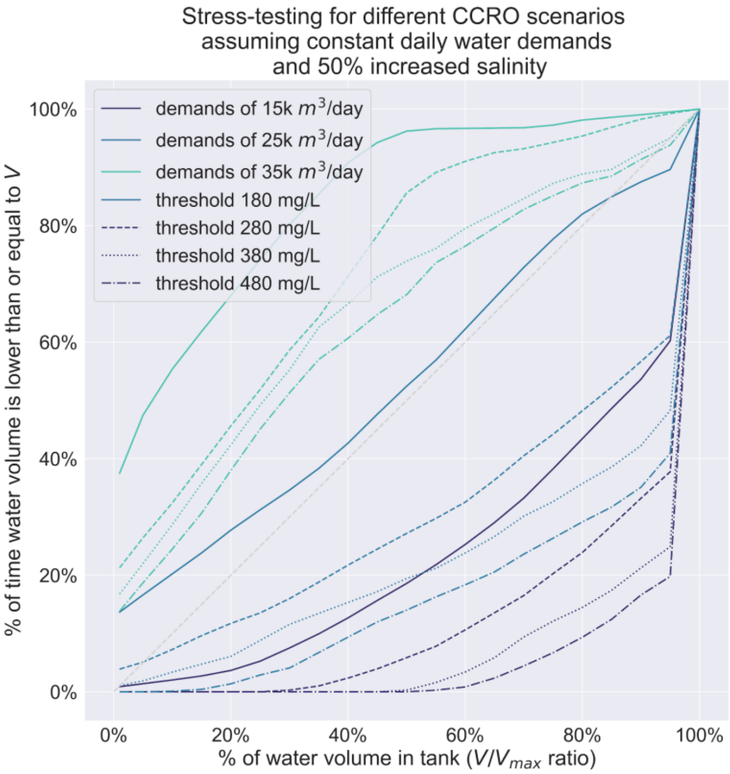


Figure 97: UWOT stress-testing of Woumen for different CCRO layouts that lead to three different production thresholds, under deteriorated salinity conditions in Ijzer (salinity increase by 50%).

Mechelen

The goal of the retention basin in Mechelen is twofold: (a) to mitigate flooding issues and (b) to increase water availability for agriculture in the region. For both of these functions, the Mechelen retention basin is stress-tested and the response of the retention system is evaluated against variability in the urban area used for harvesting, under the assumption that more areas with similar rainfall-runoff characteristics are introduced to the existing RWH system.

Firstly, UWOT simulates the response of the retention basin for the 14 years of simulation at the daily scale. The results, shown as daily time series in Figure 98, show that the retention basin has periods of both full and empty storage, which appears to be seasonal and is affected by (a.) the variability in crop evapotranspiration demands, which are higher during summer, warm months, and (b.) the availability of incoming water in terms of runoff. It is noted, at this point, that the results of Figure 98 reflect the implementation of the basin without any operational rules; the introduction of any extra rules (e.g., discharging before the anticipation of flood events, based on forecasts) will significantly affect basin storage levels and overflows.

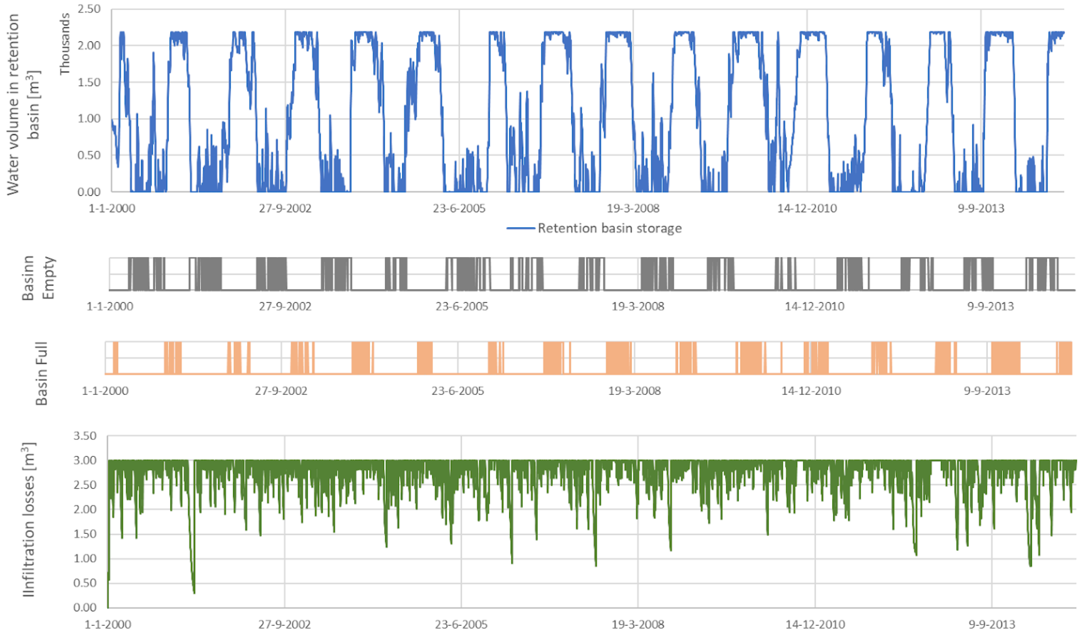


Figure 98: Snapshots of the UWOT model results (retention basin response) for the Mechelen case.

Seasonal effects are further demonstrated by aggregating and presenting results in the monthly average level. Figure 99 shows the monthly variability in multiple aspects of the retention basin system in terms of average water stored per month, modelled runoff and average crop demand deficits. In terms of basin water storage, the basin appears to be filling in winter months and almost empty during the summer season, where the mitigation of runoff (from convective events) also is higher. The reduction in runoff appears to be significant across the entire year (comparing the baseline runoff (before placing the retention basin), in light blue, with the post-basin runoff, in grey), and more profound in spring, summer and autumn months. Again, the introduction of operational rules might change this seasonality and increase effectiveness, in case seasonal rules (i.e., higher discharges during winter months) are applied.

Notably, the retention basin is empty during summer months, resulting in crop demand deficits. The average crop demand deficits correspond to the net effect of using water from the retention basin; they are thus covered by groundwater reserves or other sources beyond the scope of the model (and are partly covered by the infiltration from the retention basin), or they are mitigated by a loss of crop yields due to the inability to provide an amount equal to the potential evapotranspiration of the cultivated area. More elaborate effects of subirrigation on groundwater cannot be captured through UWOT due to model limitations and are thus not included as part of the results; instead, they are explored as part of the regional analysis, which discusses the effects of the retention basin to groundwater tables extensively.

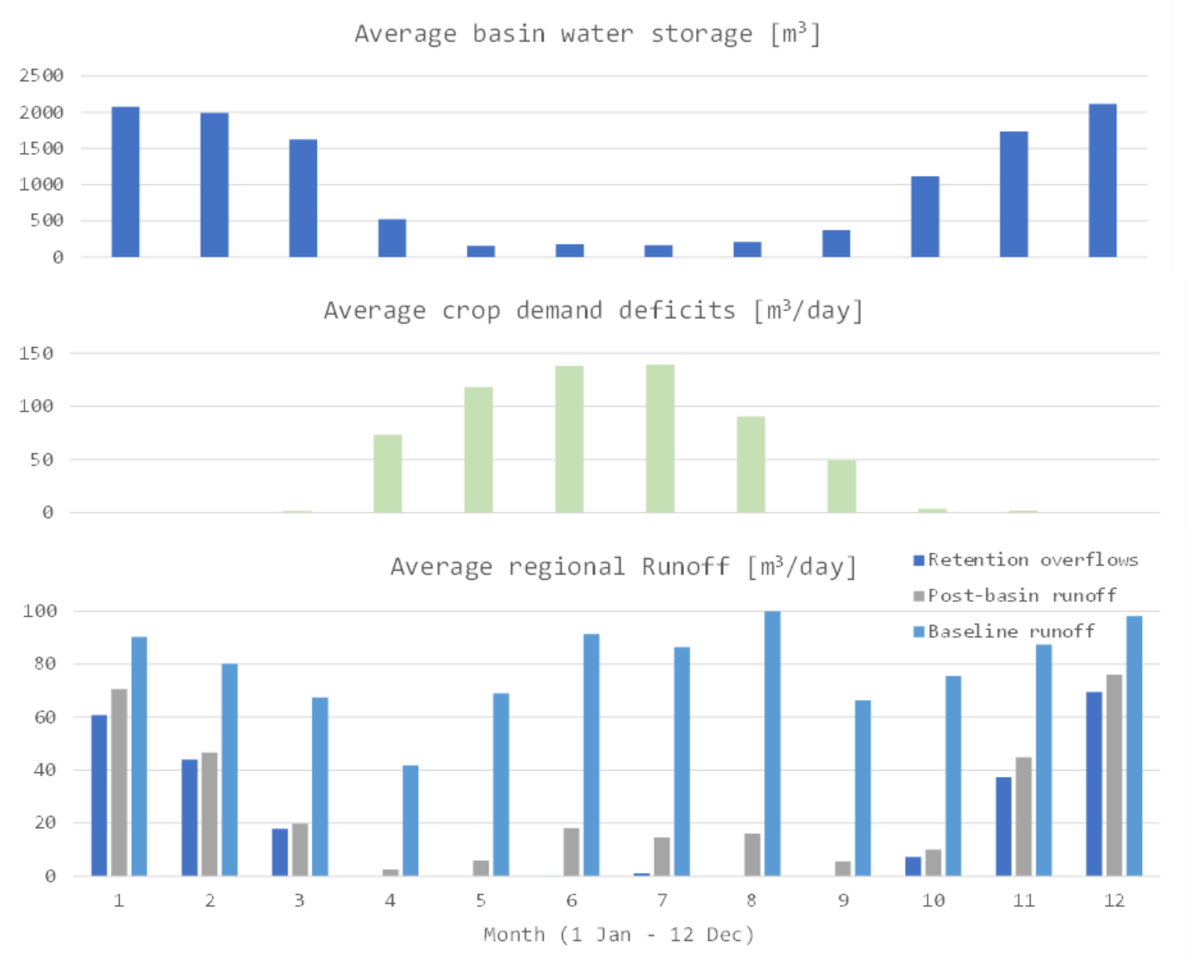


Figure 99: Monthly variability in the Mechelen retention basin in terms of storage, runoff and coverage of crop demands.

The effect of introducing larger urban areas upstream is explored in Figure 100. In this analysis, the retention basin keeps the same design but the serviced urban area upstream (i.e., the area whose discharge is led to the retention basin) grows by 20%, 40% and 60% respectively. The ratio of pervious and impervious areas remains the same, as the household types in the area are uniform. Along with this increase, the pretreatment discharge capacity to the area is increased from 500 m^3/day to 600, 800 and 1000 m^3/day, respectively, to accommodate larger runoff influxes. The results show that the introduction of larger inflows has a beneficial effect on crop demands, leading to lower deficits; however, it comes with a trade-off to the flood-proofing capacity of the retention basin, as the basin remains fuller across multiple months and has a loss in its runoff reduction capacity (around 2%-25%, depending on the month).

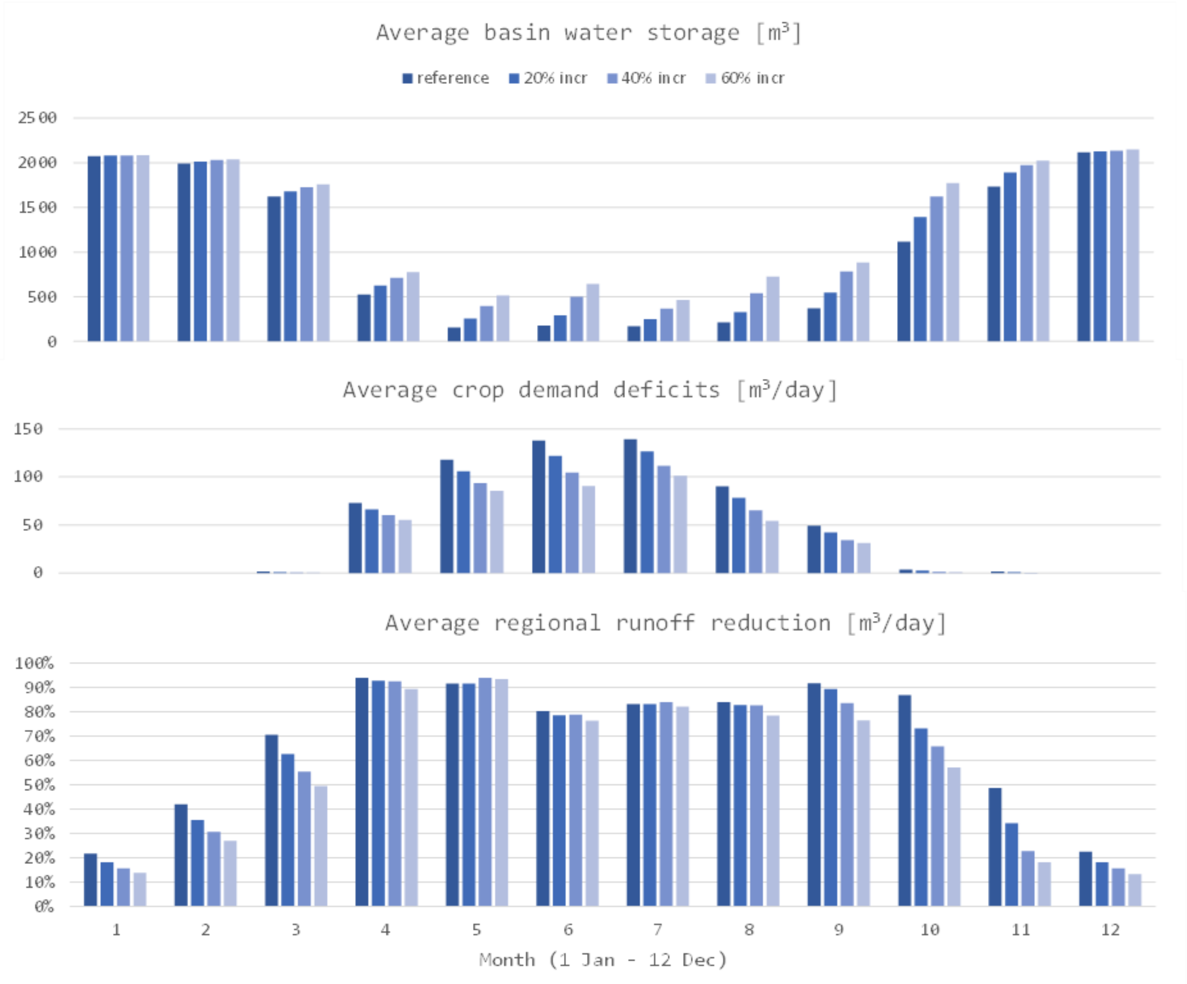


Figure 100: Monthly variability in the retention basin with the introduction of larger harvesting areas (20% - 60% increase in serviced urban areas).

15.1.3.2 Regional analysis results

Woumen

In the reference situation, the salinity levels in the IJzer frequently led to intake stops from the river to the storage basin (Figure 101). Because intake for drinking water production from the basin is reduced as soon as the basin reaches 80% capacity (assumption in the regional analysis), the intake stops from the river had a large influence on the total drinking water production. Actual production was lower than the desired production in almost every summer, except the summer of 2008. Especially in 2011, 2017 and 2019, intake stops due to high salinity levels in the IJzer led to lower drinking water production.

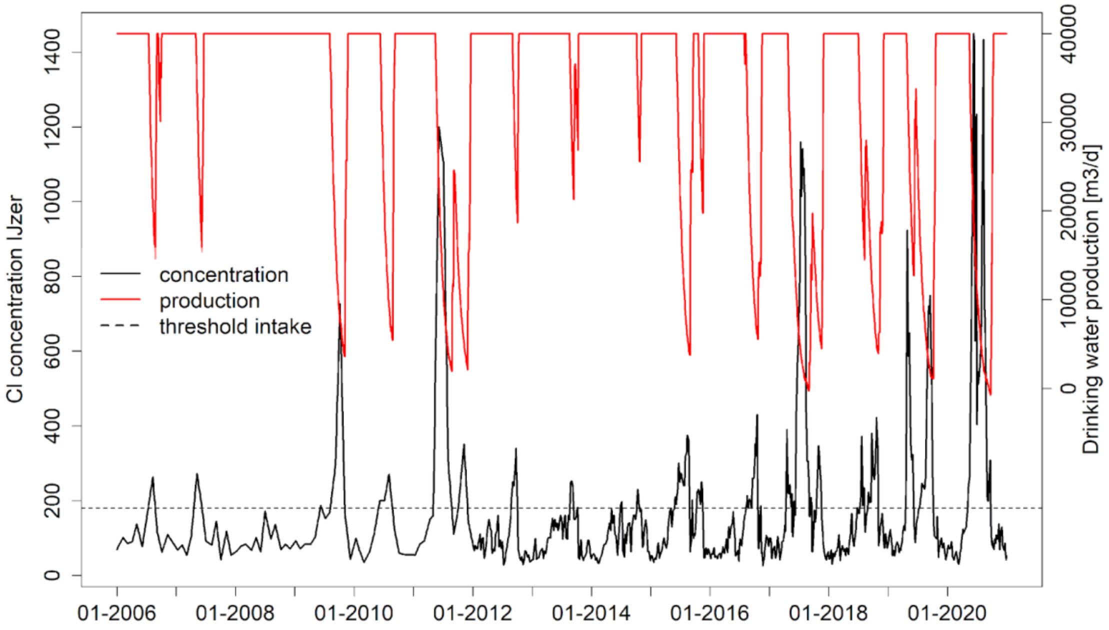


Figure 101: Drinking water production in the reference situation and salinity levels in the IJzer (measured).

The proposed measures to make the drinking water production more robust have different effects. In all scenarios, the total amount of drinking water produced increased when compared to the reference situation (Figure 102 and Figure 103). However, actual production was still lower than the desired production (fraction production lower than 1) in many summers during the time period. In total over the entire time period, the desired drinking water production was reached 70.4% of the time in the reference period, for scenario 1, 2 and 3 this percentage increased to respectively 72.3%, 77.4% and 79.1%.

Figure 103 shows the fraction of production in more detail for the last years in the time period. The largest increase in drinking water production is found when both measures are implemented (scenario 3). Reuse of effluent only (scenario 1) has the lowest increase in production. During dry periods, the amount of water available from the WWTP decreases while at the same time the water quality of the IJzer deteriorated. That means water availability from both sources decreased in dry periods, leading to less drinking water production. Installation of the CCRO system only (scenario 2) led to higher drinking water production compared to the reference situation and scenario 1, but less production compared to scenario 3. In scenario 2 more water was taken from the IJzer, because the water quality did not lead to intake stops. However, the discharge of the IJzer was too low to sustain the drinking water production during dry periods. This is also the case in scenario 3, although the production in this scenario was highest, because effluent was available during the dry periods, albeit in smaller quantities.

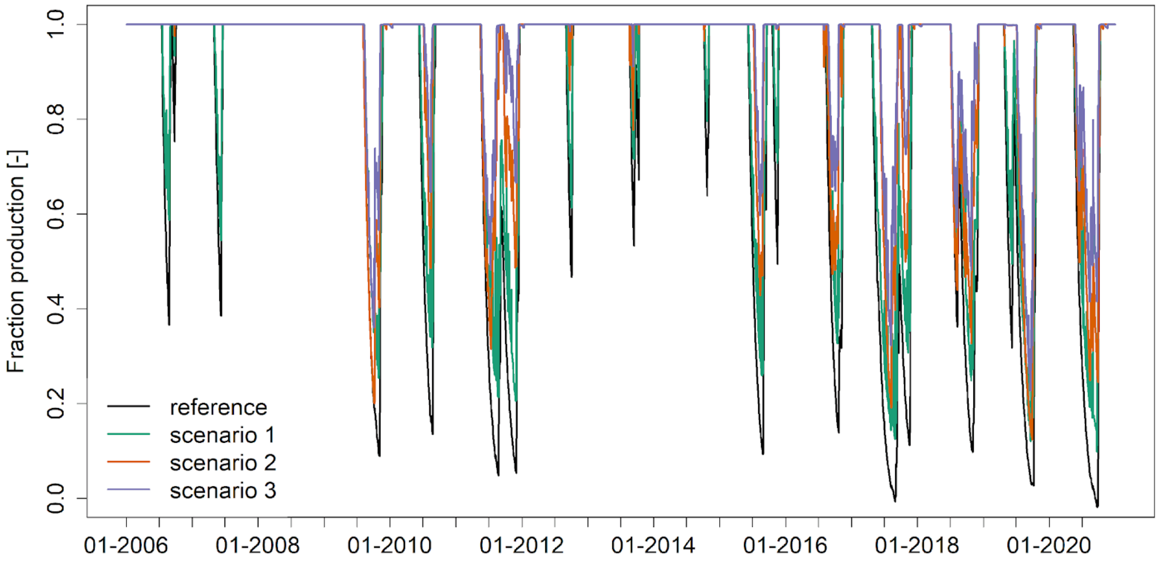


Figure 102: Fraction of the desired drinking water production for the reference situation and different scenarios for complete time series.

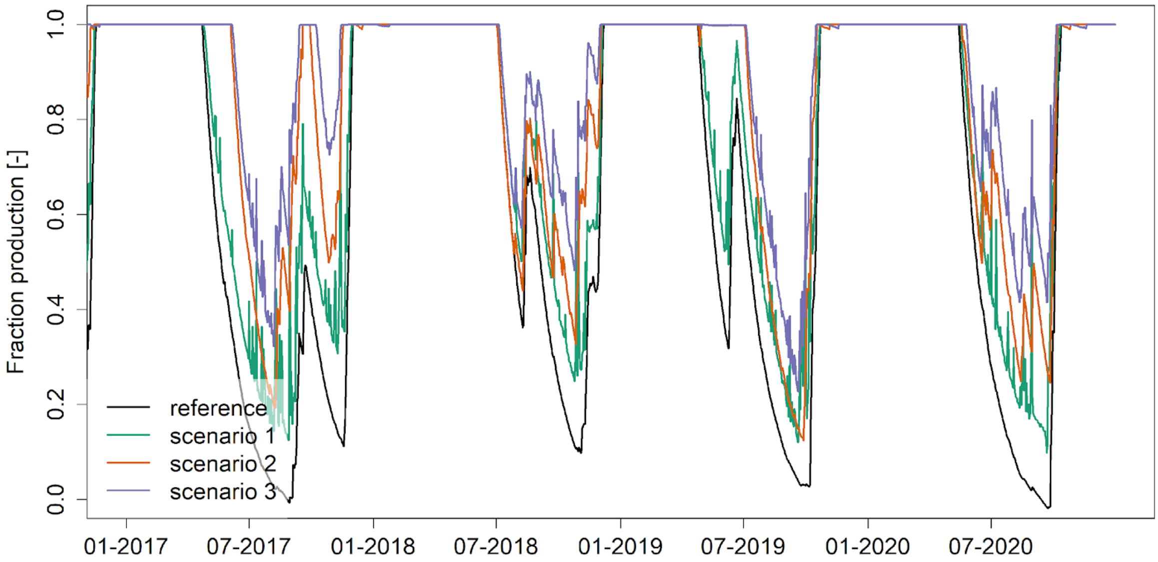


Figure 103: Fraction of the desired drinking water production for the reference situation and the different scenarios for part of the time series.

The implemented measures did not only impact the total drinking water production, but also had different effects on the total water intake from the IJzer to the storage basin. The total water intake from the IJzer per year was lower in scenario 1 (water reuse) compared to the reference situation (Figure 104). For scenario 2 (CCRO system), the total water intake was higher every year, because the high salinity levels did not lead to intake stops anymore. When both measures are implemented (scenario 3), water intake is lower in most years, because the reuse of effluent replaces the water from the IJzer. However, in years when the IJzer had very high salinity levels, 2011 and 2017 (Figure 101), total water intake in scenario 3 was higher than the reference situation, because water from the IJzer was taken over a much longer period when the CCRO system was available.

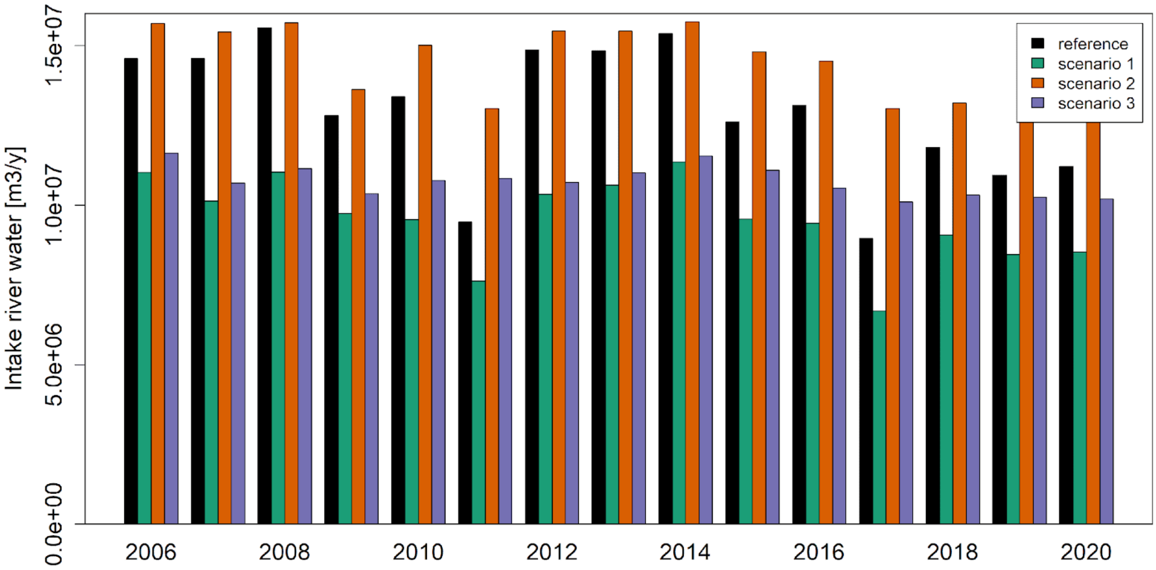


Figure 104: Total water intake per year from the IJzer for the reference situation and the different scenarios.

When both measures are implemented, the total drinking water production originates from three different water sources: effluent, water treated in the existing treatment system, water treated with the CCRO system. In scenario 3, the main water source was still the existing treatment, followed by effluent and the CCRO system (Figure 105). The amount of effluent clearly fluctuated throughout the year, with higher amounts available in winter than in summer. The amount of water treated with the CCRO system was small due to the assumption made that 10% of all water from the storage basin is treated in the CCRO system during periods when water quality is not an issue. When salinity levels were too high, the contribution of the CCRO system to the total production clearly increased (2011, 2017, 2019, 2020). The exact division of the water between the existing treatment and the CCRO system is not known, but this would obviously affect the division between the sources.

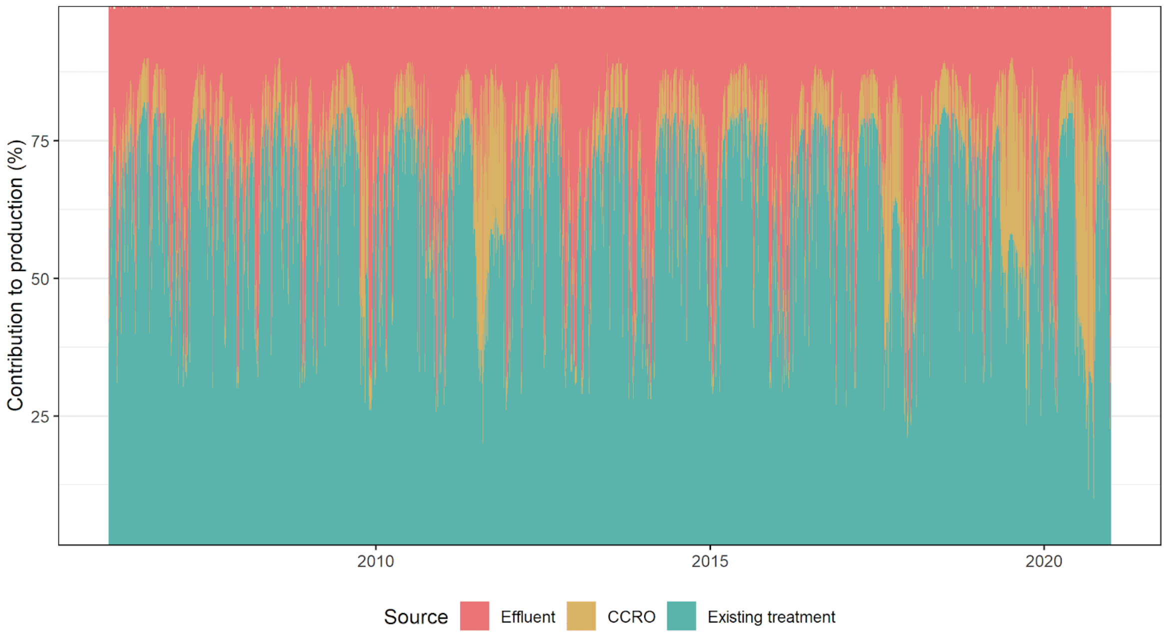


Figure 105: Division of the total production of drinking water across the different sources for scenario 3.

Mechelen

The aim of the stormwater retention basin is to prevent problems with flooding in urban areas and to increase the water availability for agriculture in the region. The implementation of a stormwater basin led to a strong reduction in runoff to the Oude Tantelaerloop, especially when combined with subirrigation (Figure 106). For the complete period the average runoff to the stream was 71 582 m^3/y for the situation without retention basin, 57 888 m^3/y for scenario 1 and 5 632 m^3/y for scenario 2.

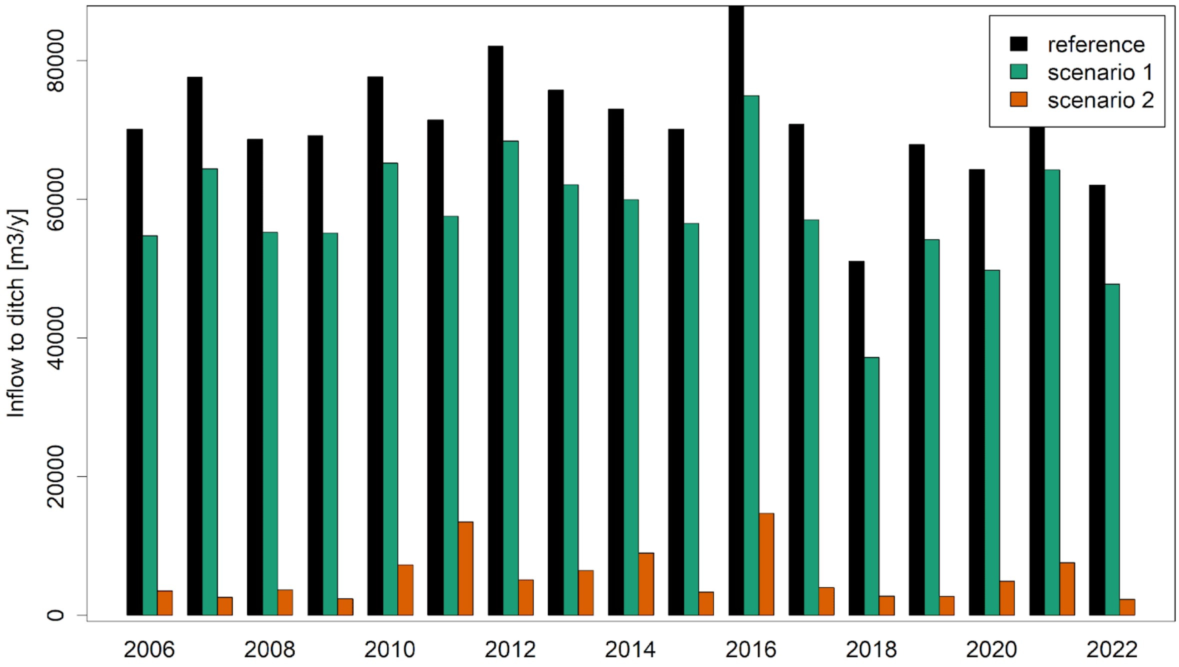


Figure 106: Runoff from precipitation to the Oude Tantelaerloop for the reference situation and after implementation of the retention basin (scenario 1 and 2).

Peaks in daily runoff were also reduced in the scenarios. For the reference situation the peak runoff during the entire period was 6 091 m^3/d, this was reduced to 6 047 m^3/d in scenario 1 and to 4 741 m^3/d in scenario 2. The reduction in peak values was limited in scenario 1, because the basin was filled to capacity most of the time due to the lack of management rules in the regional analysis (Figure 107). The basin was only emptied during very dry periods (2018). When the water is used for subirrigation (scenario 2), more storage was available in the basin and thus peak values and total runoff to the stream could be reduced further. This indicates that proper management of the retention basin and/or use of the stored water is needed to prevent flooding. When operational rules of the basin are optimized, for example, by emptying the basin based on the weather forecast, the peak values can be reduced more efficiently.

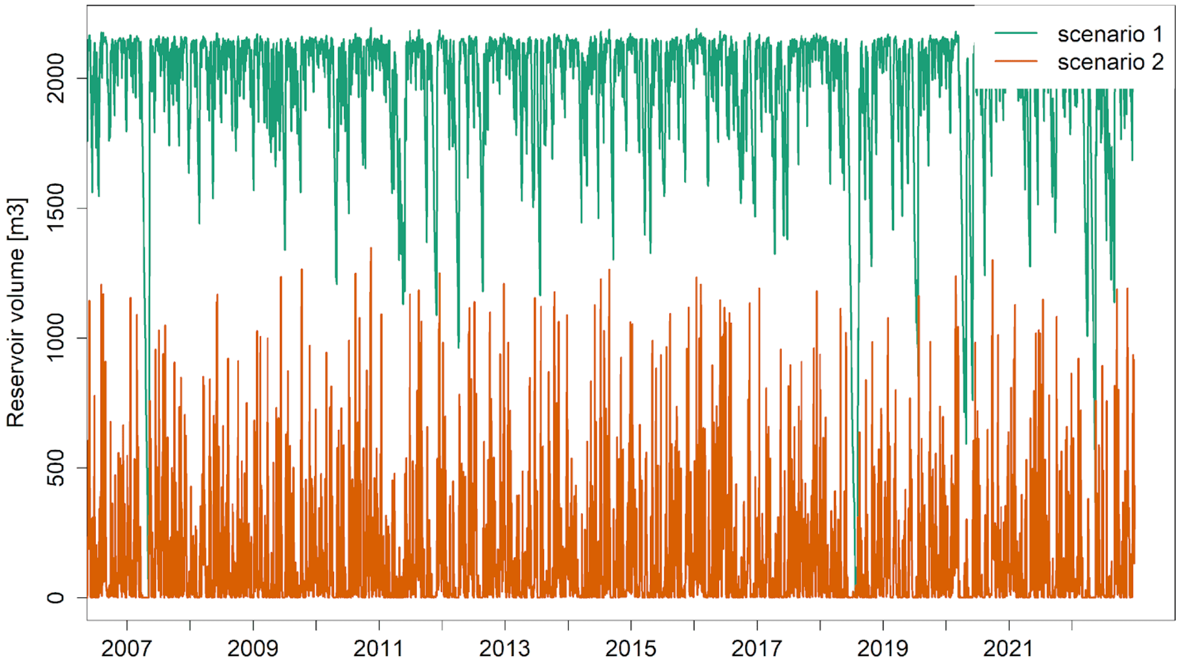


Figure 107: Volume of water in the stormwater retention basin for the two scenarios.

Water from the stormwater retention basin can be used to irrigate nearby agricultural fields through subirrigation. This increases the water availability for agriculture and affects more components of the water system than implementing a retention basin alone. When the water from the retention basin was used for subirrigation, groundwater levels below the fields increased during the entire period (Figure 108). Groundwater levels showed the largest increased during winter with a maximum increase of 1.45 m. During summer, groundwater levels increased by around 0.5 m, with a minimum increase of 0.06 m in the spring of 2020.

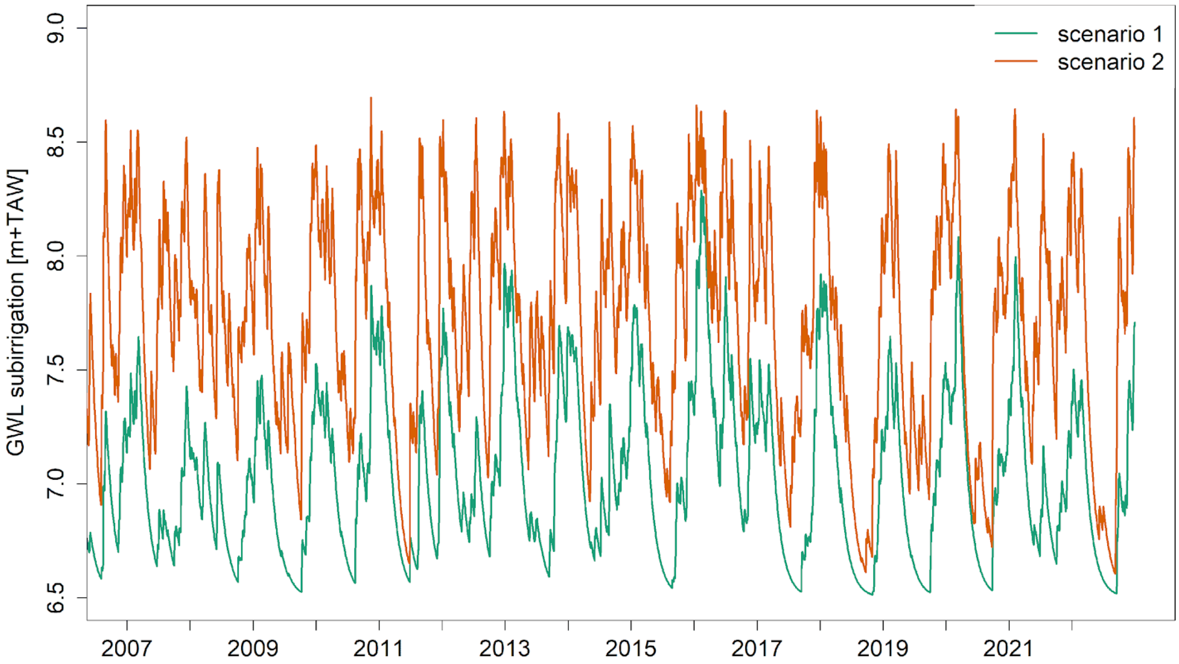


Figure 108: Groundwater levels in the situation without subirrigation (scenario 1, equal to reference situation) and for the situation with subirrigation (scenario 2).

The increase in groundwater levels had a positive effect on the crops. We have used the actual evapotranspiration to illustrate the effect on crops, because more evapotranspiration indicates better crop growth and thus higher yields. Subirrigation led to a higher actual evapotranspiration during the entire period (Figure 109). The average yearly evapotranspiration increased from 351 mm/y in scenario 1 to 406 mm/y in scenario 2. In both scenarios, the average potential evapotranspiration of 496 mm/y was not reached due to water limitations. There is a clear difference in the effect of subirrigation between the years. Yearly average precipitation in the region is 738 mm/y. In a wet year, like 2016 (precipitation 905 mm), actual evapotranspiration was almost equal to potential evapotranspiration for both scenarios. In a dry year, like 2018 (precipitation 527 mm), the actual evapotranspiration in scenario 2 was much higher than in scenario 1, at 349 mm and 271 mm respectively.

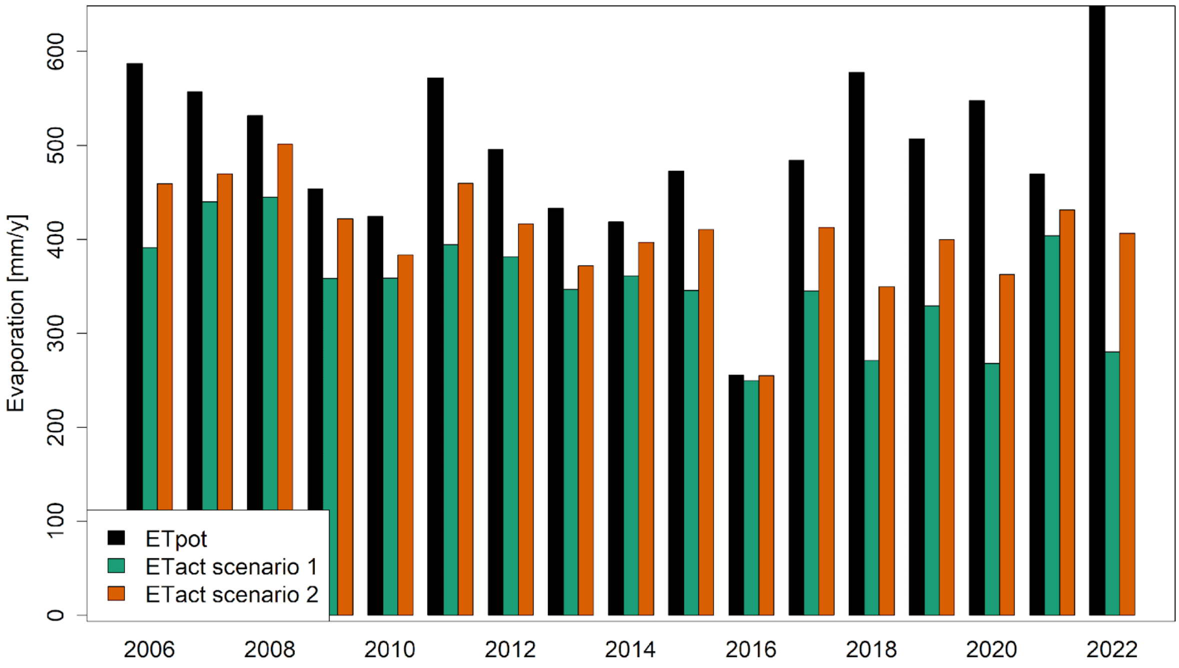


Figure 109: Yearly potential evapotranspiration based on observations (input) and yearly actual evapotranspiration for the different scenarios (scenario 1 is equal to reference situation).

The increased groundwater levels can also impact the drainage to streams. The extra drainage to streams caused by the subirrigation in scenario 2 was limited (Figure 110), because groundwater levels were still relatively deep (in wet periods still about 1 m below surface level). It was also assumed that the groundwater drained towards the Dorpsloop and not to urban areas. That means the extra drainage did not increase the risk for urban flooding.

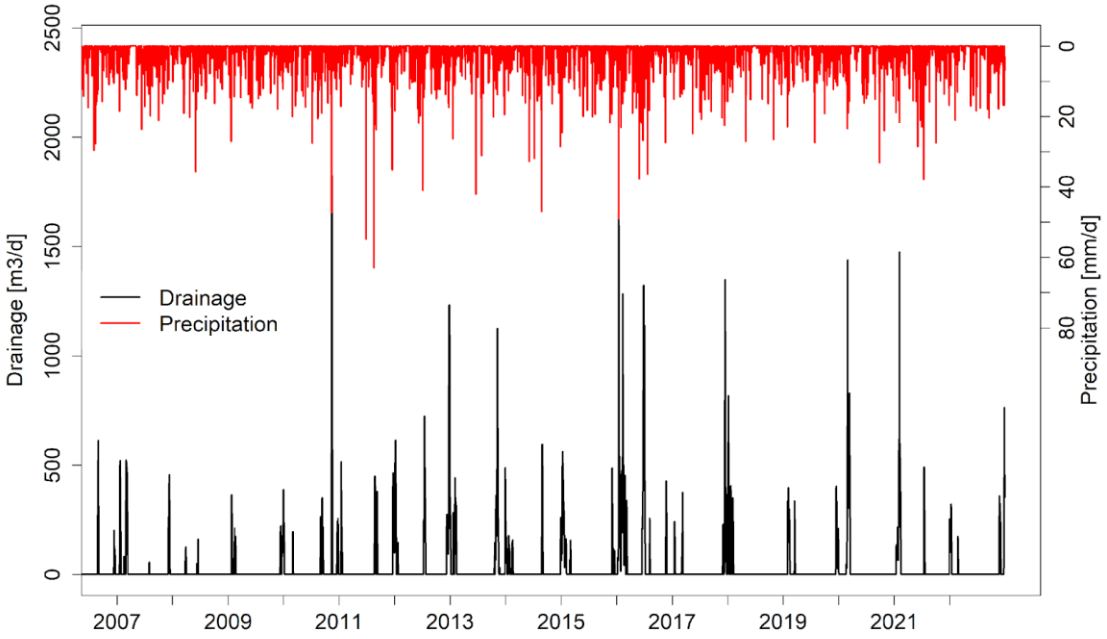


Figure 110: Drainage from the groundwater to the stream in scenario 2 and measured precipitation (input).

15.2 LL East Frisia

15.2.1 UWOT

15.2.1.1 Pre-processing stage and input data

In the case study of East Frisia, UWOT (tool #22) is mainly used to simulate the water flows (water demand and supply points) for a test case and to investigate alternative scenarios based on different climatic and demand change conditions or with the implementation of partially decentralised technologies. The first step to start constructing the UWOT model was to define the test case. The fictitious example region is rather rural with some industrial priorities.

The data chosen for water demand and supply points corresponded to an annual timestep whereas the temporal scale applied in UWOT simulation was daily (in correspondence with the meteorological data), so the data was downscaled to be able to be used with UWOT. In case of missing data, the missing values/parameters used in the model relied on assumptions.

15.2.1.2 Setup process and application

To start building the baseline UWOT model for the test case, it was important to identify the different components that needed to be inserted in the model as well as the connection(s) among them. Four different categories/points of demand were assumed for the test case: (a) the household appliances (domestic uses), (b) industry and corresponding water needs, (c) livestock and (d) agriculture. Typical household appliances which need water for their function were selected for the model simulation. These were the dish washer (DW), the kitchen sink (KS), the hand basin (HB), the shower (SH), the toilet (WC) and the washing machine (WM). The number of households as well as each household's occupancy (approximately two persons) were estimated. The next step is to define the water usage (L/use) and the frequency of use per device. The default values are the following (Table 24):

Table 24: Default values of household appliances

	Water usage/capacity (L/use)	Frequency of use
Dish washer	35	0.3
Hand basin	2.1	7.15
Kitchen sink	2.1	7.15
Shower	35	0.71
Toilet	7	4.64
Washing machine	45	0.34

Considering the characteristics of all devices in the household, the residents per household (occupancy) and the number of households in the test case, UWOT model is used to calculate the total domestic water demand and produce the daily time series for the simulation's period of time. Additionally, it estimates the greywater/blackwater all these devices produce after their function. The UWOT schematisation for households is presented in Figure 111.

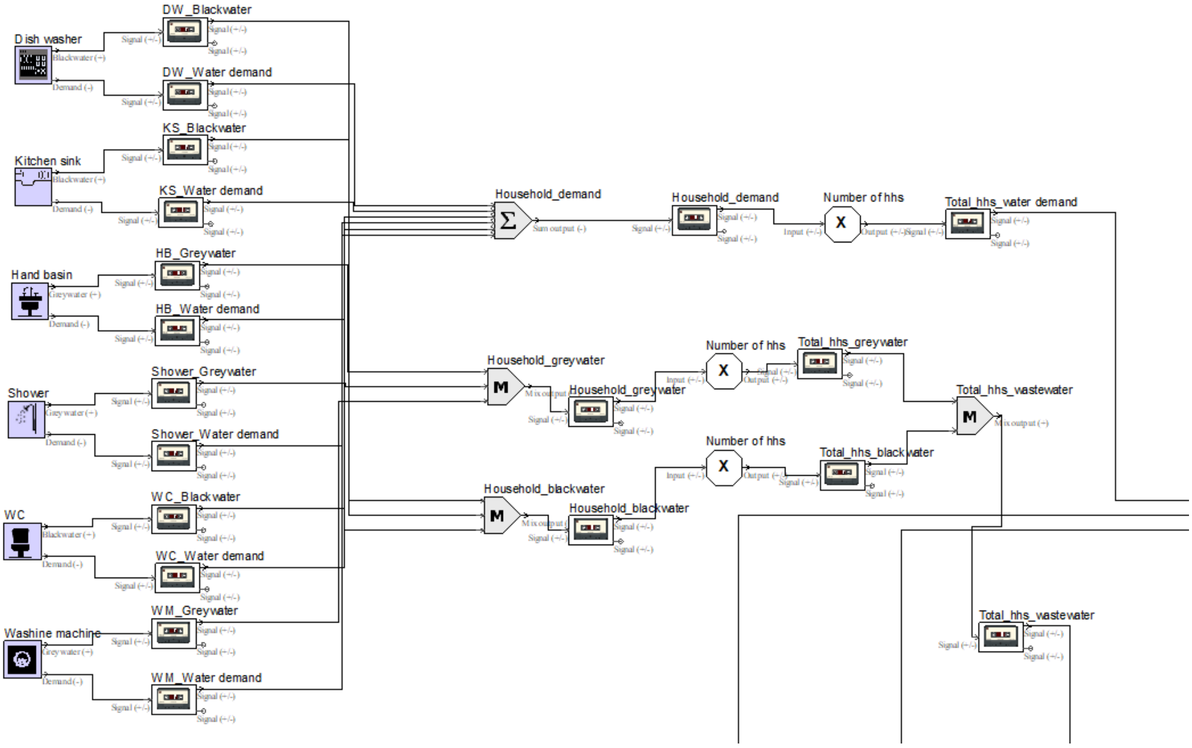


Figure 111: Households' schematization in UWOT.

At this point, it is important to mention that the baseline model was calibrated based on chosen annual domestic water demand data. To run the simulation in a daily timestep, there was a need to disaggregate the annual value into monthly values (seasonal variability) and then daily ones. The seasonal variability of water consumption is taken from literature and varies between 81% and 114% of average monthly household demand (Gerin et al., 2014), as shown in the Table 25:

Table 25: Seasonal variability of domestic water consumption.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Percentages	1.09	1.14	1.08	1.03	0.99	0.94	0.81	0.83	0.94	1.01	1.05	1.09

The following categories were simulated: industry and livestock. The annual quantity of water demand derived from the industry was equally divided into 365 days of the year to calculate the daily water consumption from this use. As for livestock, based on annual water demand data and the assumption of average daily water requirements per animal (Stewart and Rout, 2007), the number of animals was estimated and inserted into the model. The assumptions regarding the water needs are the following:

Table 26: Water demand assumptions per farm animal.

Farm animals	Water demand (L/head/day)
Dairy cattle	45
Beef cattle	30
Sheep	3
Goats	5
Pigs	11
Poultry	30

The components that represent the industry and livestock categories are shown in Figure 112.

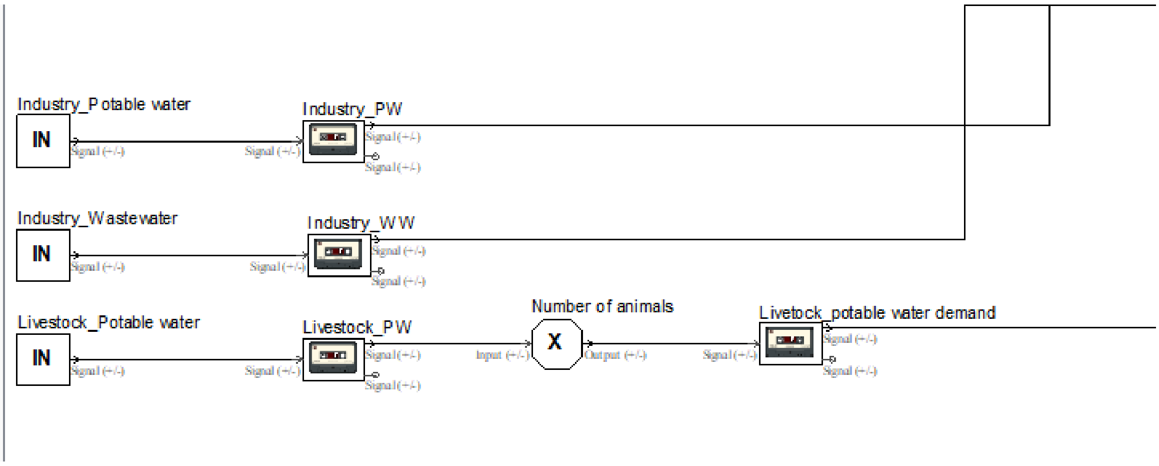


Figure 112: Industry and livestock schematization in UWOT.

The last category of water users introduced in the model was agriculture which is simulated based on data extracted from the CORINE Land Cover (CLC) shapefile[11] for the test case, to have fewer data to manage. Based on the CLC's categories, the main category that represents agricultural areas of different types is considered to be of type "2". The test case region includes the codes "2.1.1 Non-irrigated arable land", "2.3.1 Pastures" and "2.4.3 Land principally occupied by agriculture, with significant areas of natural vegetation". The category "2.1.1" was not selected to be further investigated as it refers to non-irrigated land. As a result, two new components were added to the model to simulate the agricultural areas, as it is shown in Figure 113. The values selected for water usage, evaporation and infiltration are based on assumptions, as the corresponding data was not available. For pastures the selected values were 300 mm water usage/capacity, 20% evaporation and 0 infiltration

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[11] https://land.copernicus.eu/pan-european/corine-land-cover

whereas for the other agricultural areas the corresponding values were 300 mm water usage/capacity, 30% evaporation and 0.002 (days^{-1}) infiltration coefficient. The agricultural water needs are mainly covered by farmers' wells, so there was a need to add another component to simulate this type of source. The water usage/capacity regarding the whole number of wells (used in agriculture) in the area was not known and selected to be equal to 43200 m^3/day (using a default UWOT brand).

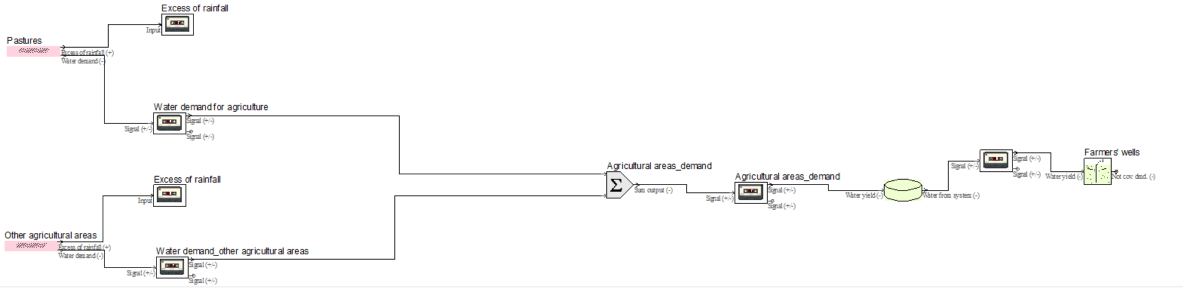

Figure 113: Agricultural areas schematization in UWOT.

The water needs derived from the other uses (households, industry and livestock) are covered by groundwater and tapped springs (Figure 114). The groundwater supplies 99.80% of total water demand whereas the tapped springs only supply the remaining 0.20%.

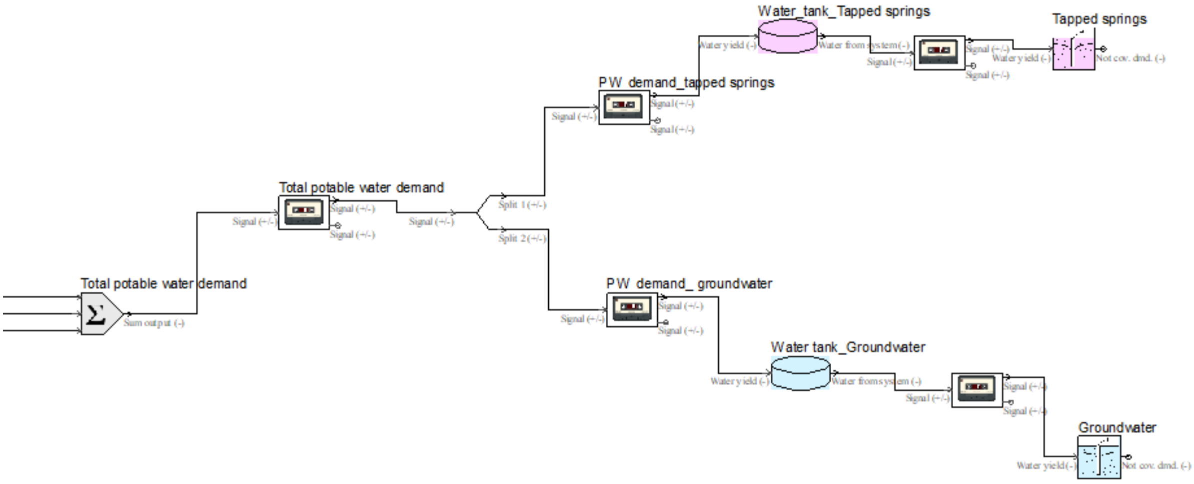

Figure 114: Supply points used to cover water demand from households, industry and livestock.

The completed baseline model is presented in Figure 115 and the zoom windows that follow (Figure 116 - Figure 120).

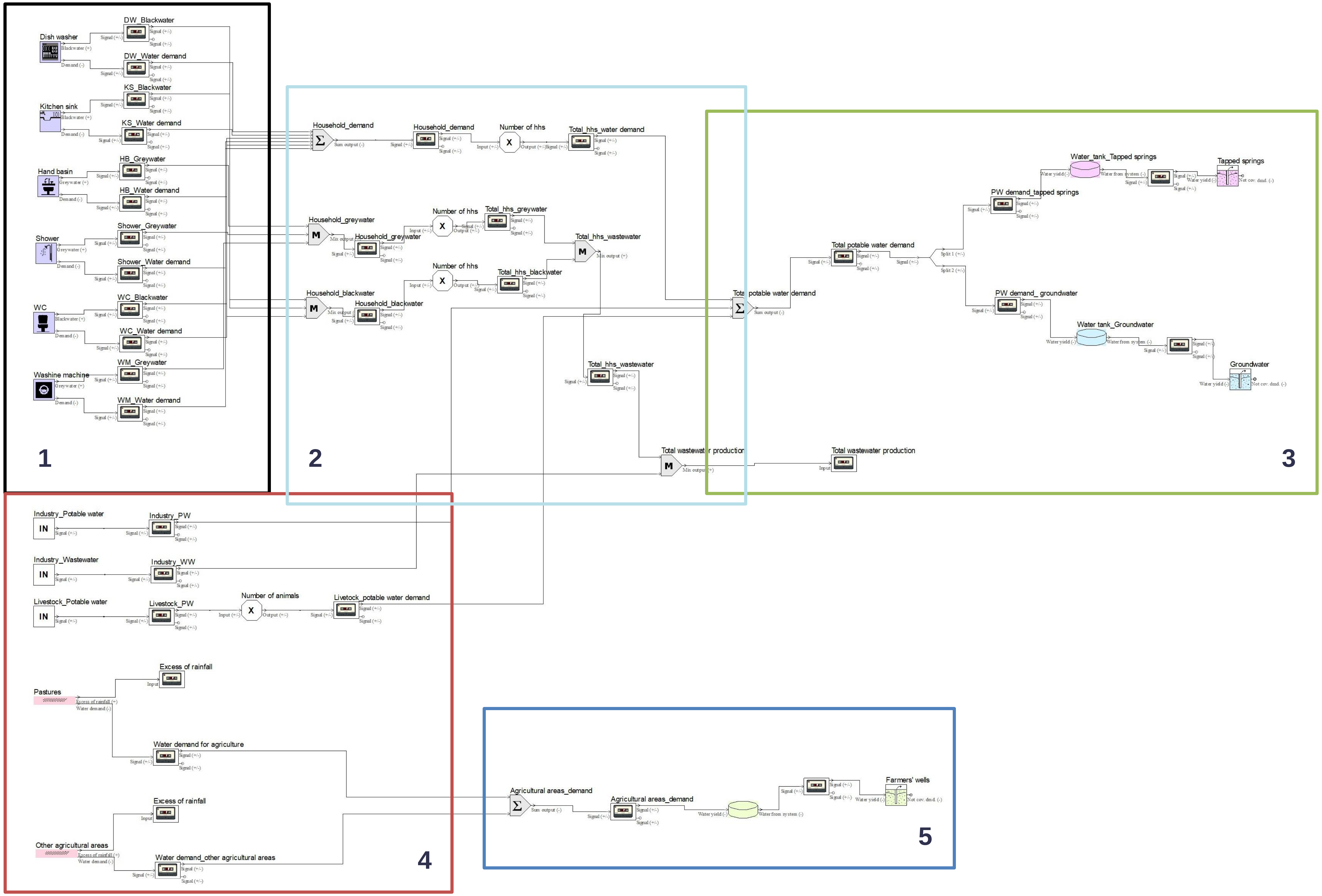

Figure 115: Baseline model for test case.

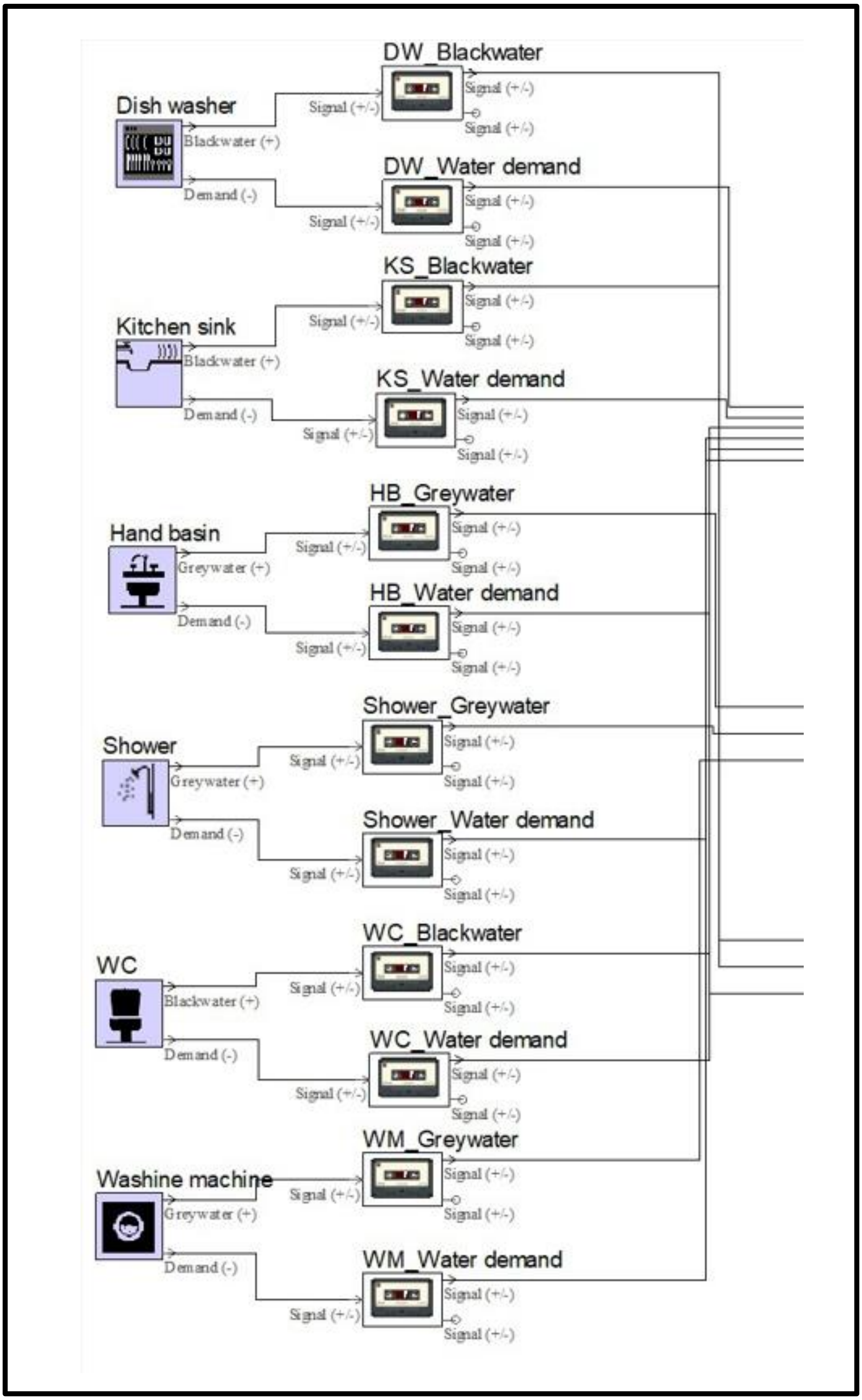

Figure 116: Baseline model for test case – zoom window 1.

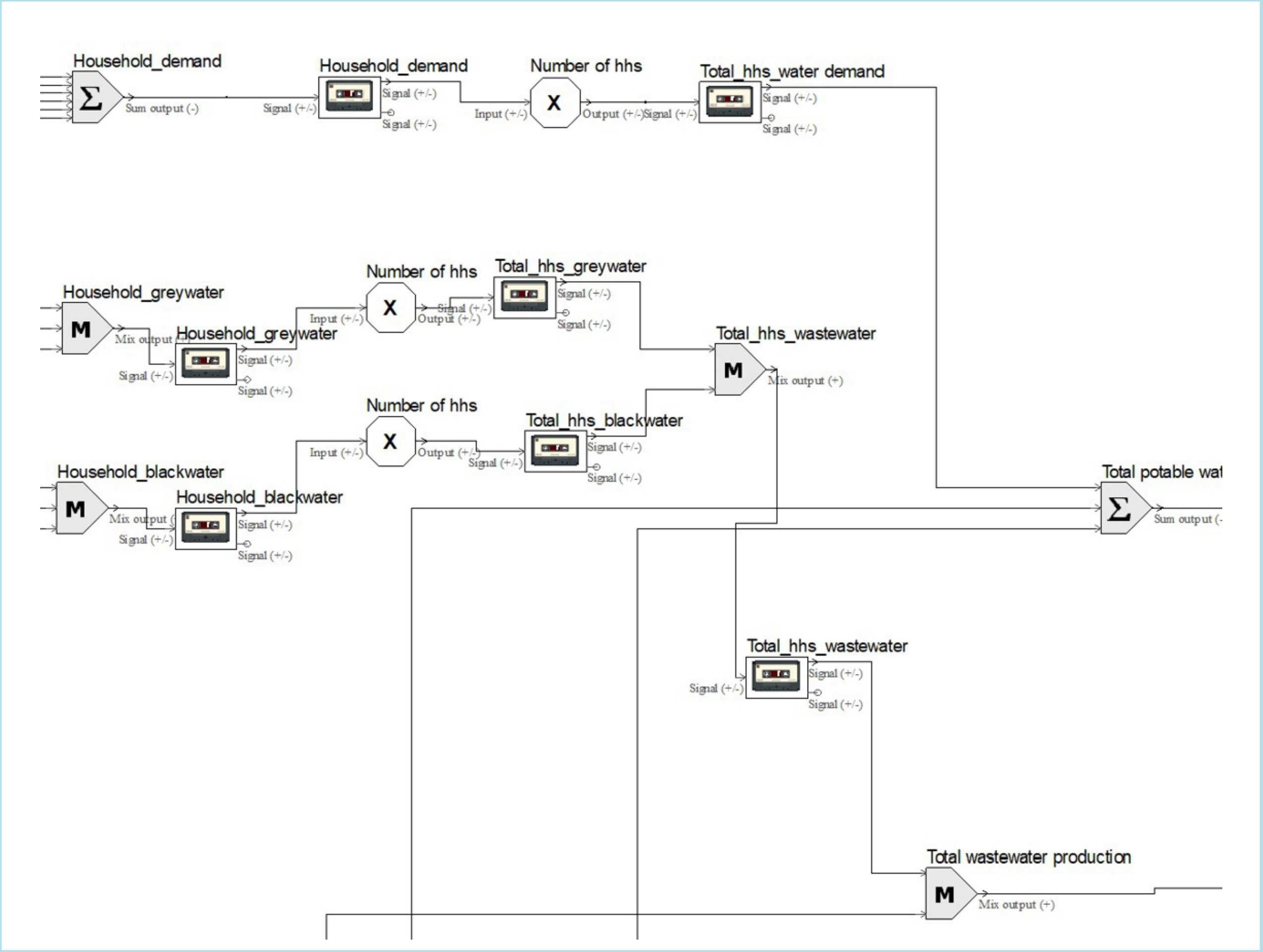

Figure 117: Baseline model for test case – zoom window 2.

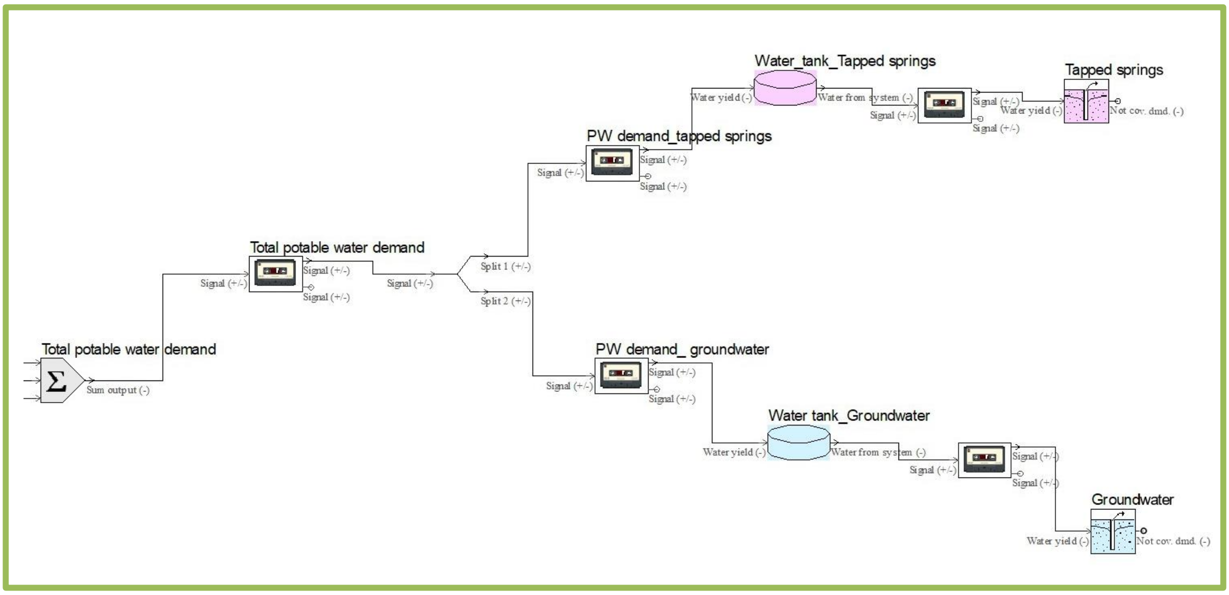

Figure 118: Baseline model for test case – zoom window 3.

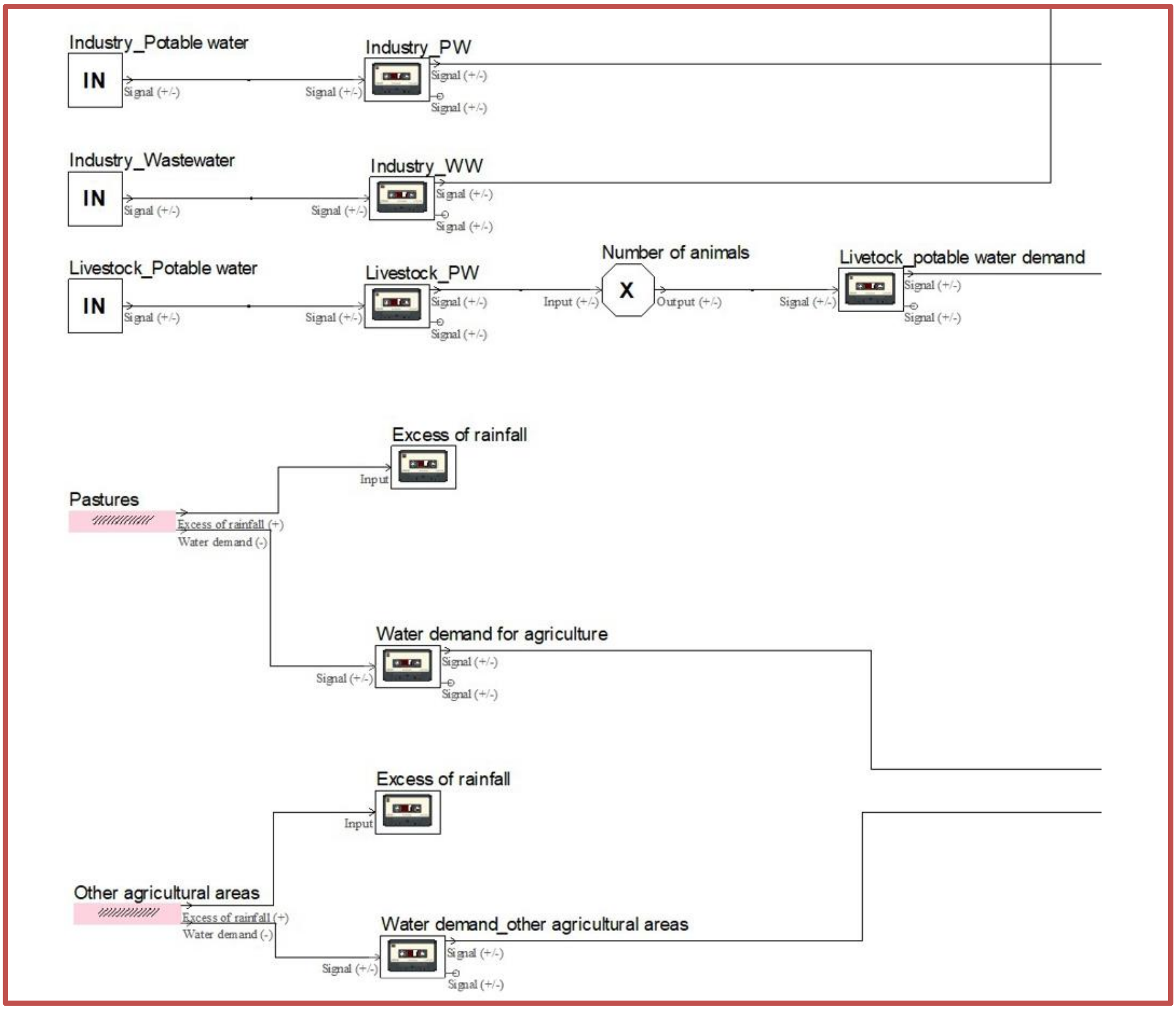

Figure 119: Baseline model for test case – zoom window 4.

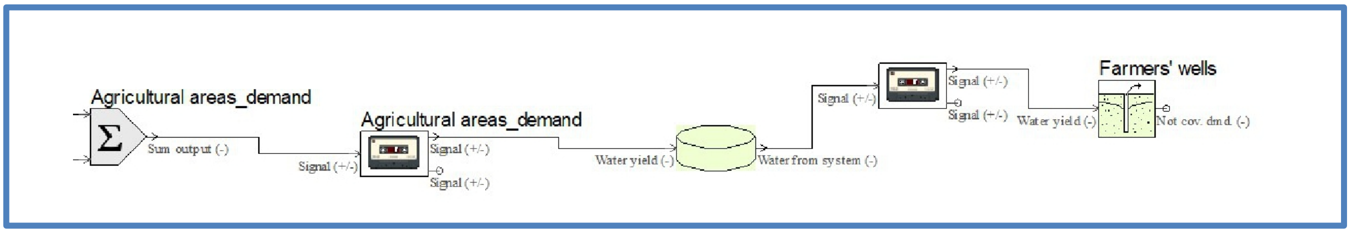

Figure 120: Baseline model for test case – zoom window 5.

Based on the available regional meteorological data, the selected time period for the simulation of the baseline scenario was 01/01/2017-31/12/2021. Considering that the available data regarding the water needs provided refer to a single year, there is the assumption that the different quantities of water demand/supply follow the same annual pattern for the 5-year period of simulation.

After the finalization of the baseline scenario, more future scenarios are examined to investigate the impact of climate change and other external conditions (population increase, changes in livestock/agricultural areas/industrial water demand, implementation of decentralized technologies for water management etc.) on water demand quantities in the test case for the next 5-year period.

The first category of scenarios is related to households' projection for the next years. Two scenarios are created that examine a 1% and 2% increase in the number of households respectively for the next 5 years (based on data derived from the Federal Statistical Office of Germany[12]).

The second category refers to industrial water demand scenarios by examining a decrease from 0.5% to 4% (Wackerbauer, 2017) in order investigate its impact on total water demand. More specifically, the scenarios examined were the following:

- 0.5% decrease
- 2% decrease
- 4% decrease

The third category examines changes in livestock by decreasing animals' population by 1 to 2% (based on Eurostat data for livestock population in the EU, 2010-2021).

The fourth category of scenarios is related to the effect of climate change on water demand by examining percentage changes in meteorological data (precipitation and temperature). The meteorological data are inserted into the model as input data for the BG components that simulate the agricultural areas. As a result, the percentage changes implemented in the baseline model mainly affect the agricultural water demand in the area. The percentage changes that were examined were the following (the assumptions are based on data derived from the World Bank Group[13]):

- 10% decrease in mean annual precipitation combined with a 2% rise in mean annual temperature.
- 20% decrease in mean annual precipitation combined with a 5% rise in mean annual temperature.

This category can also combine changes in agricultural areas, in the range of 0.5-1%.

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[12] https://www.destatis.de/EN/Themes/Society-Environment/Population/Households-Families/Tables/projection-household.html

[13] https://climateknowledgeportal.worldbank.org/country/germany/climate-data-historical

The fifth and last category examines the implementation of decentralized technologies for water management. More specifically, a greywater treatment and recycling scheme is applied to 30% of the households, which will use treated water (instead of groundwater or tapped springs) to cover their WCs' water demand. The greywater treatment plant is lumped as one unit and assumed to have a capacity of 1.400.000 L/d. Its schematization is shown in Figure 121.

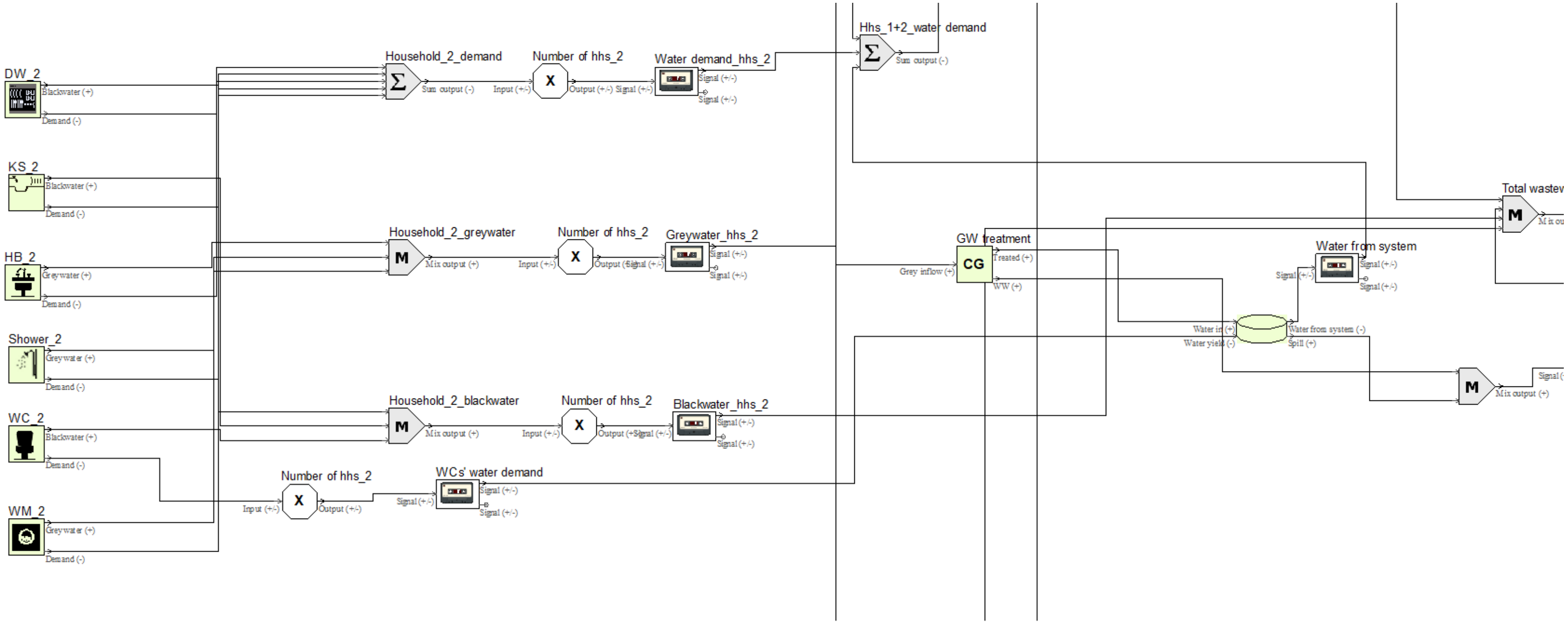


Figure 121: Greywater recycling scheme

Indicative results of all these scenarios (baseline + future), either individual or in combination, are presented in sub-chapter 0 to investigate their impact on water management.

15.2.1.3 Results

Based on the data and the assumptions already described in sub-chapter 15.2.1.2, the selected time period for the simulation of the baseline scenario was 01/01/2017-31/12/2021 (5 years in total), using daily timestep. To avoid the large amount of time series produced, the results are aggregated and presented in a monthly timestep.

At the household level, the pattern of water demand derived from the use of domestic appliances is shown in the Figure 122.

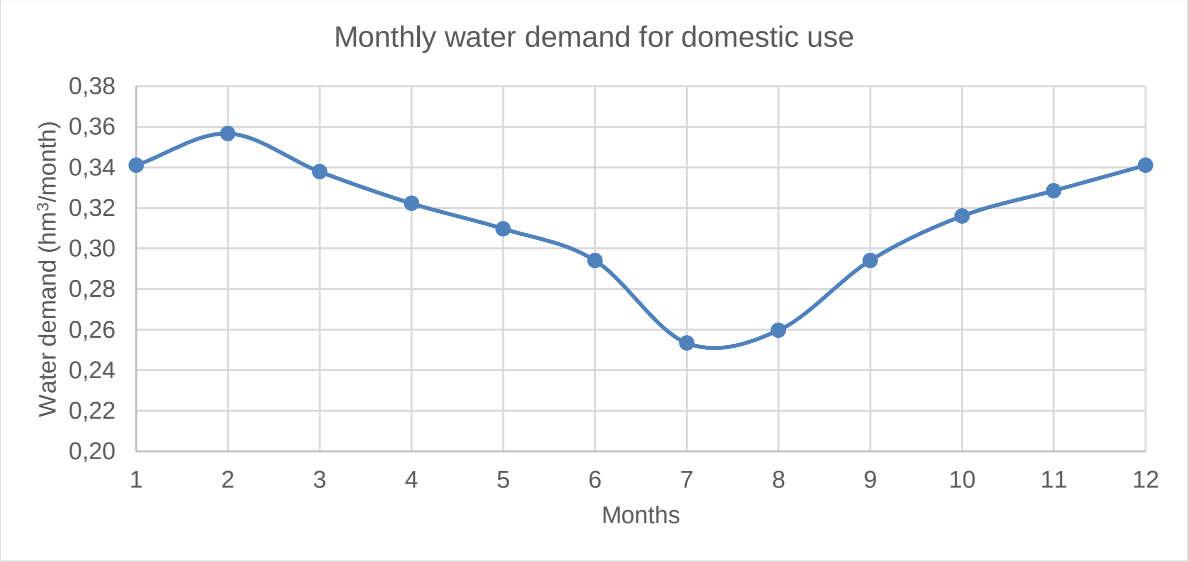


Figure 122: Baseline scenario - Monthly water demand for domestic use.

The decline noted in months 6-8 (June-August) is mainly following holiday patterns in the test case residents.

At this stage, it is useful to also present the greywater production from the households, in order to later be compared with the results of the scenario regarding the implementation of decentralized greywater treatment technology in the area. The monthly greywater production is shown in Figure 123 and shows the potential of greywater reuse in the test case. Naturally, it follows the variability seen in Figure 122.

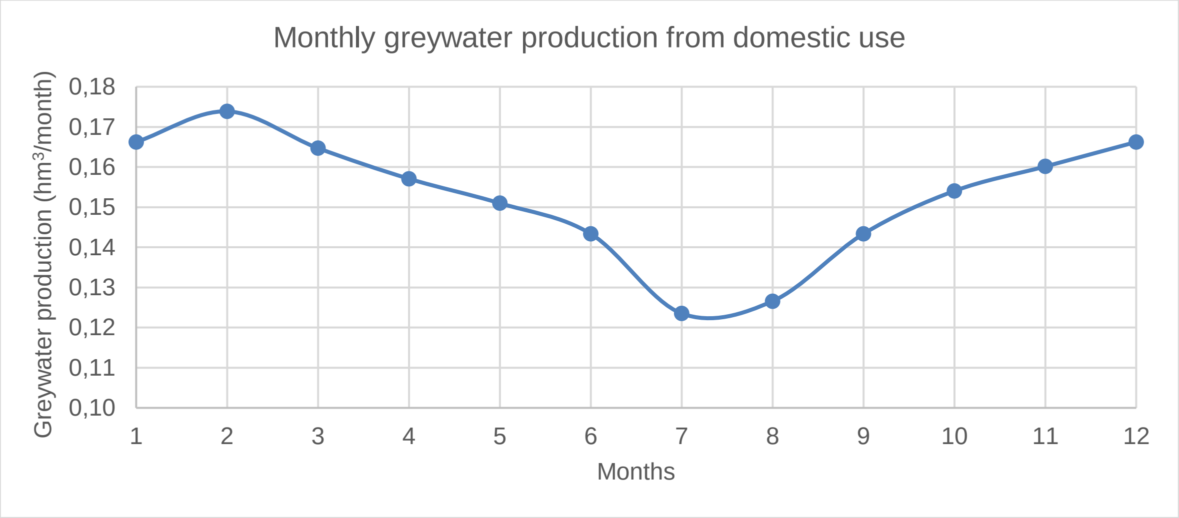


Figure 123: Baseline scenario - Monthly greywater production from domestic use.

The monthly quantities for water demand in industry are equal to about 3.69 hm^3 and for livestock are about 1.40 hm^3.

By summarizing all these water demands into one diagram, taking into account that these needs (from households, industry and livestock) are covered by groundwater and tapped springs, the total monthly potable water demand in the test case is shown in Figure 124. It is important to mention that the agricultural water demand is separately examined due to the fact that its needs are covered by farmers' wells. Therefore, the term "total water demand" doesn't include the agricultural water needs.

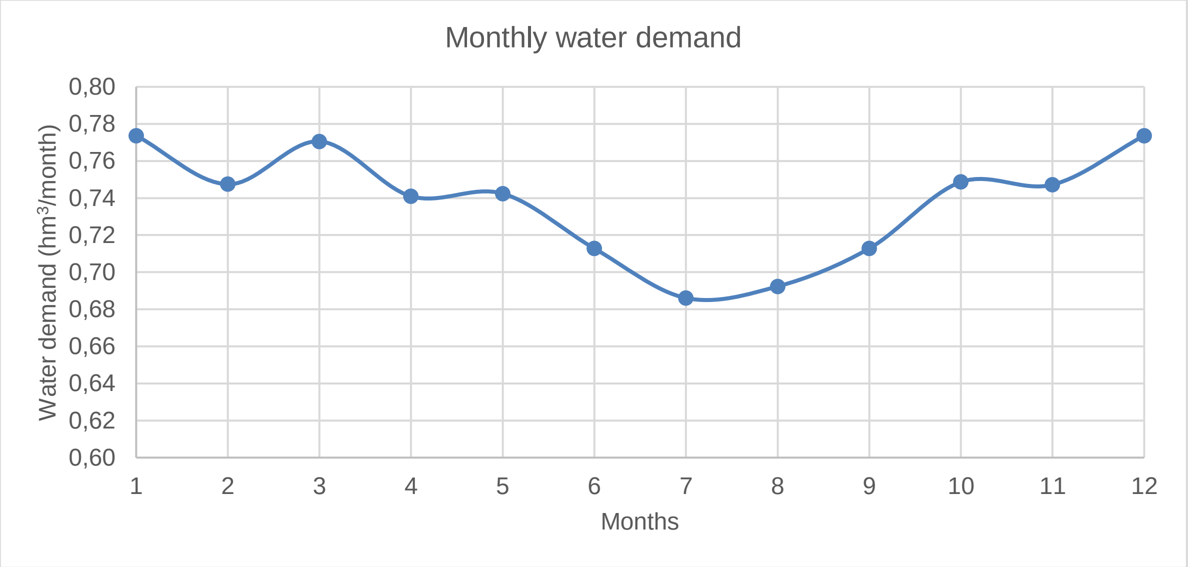


Figure 124: Baseline scenario - Total monthly water demand covered by groundwater and tapped springs.

The last category of water demand in the test case is for agricultural purposes and it is presented in Figure 125. The increased water demand shown for the years 2018 and 2019 is a result of low precipitation combined with high temperatures during the summer-autumn period.

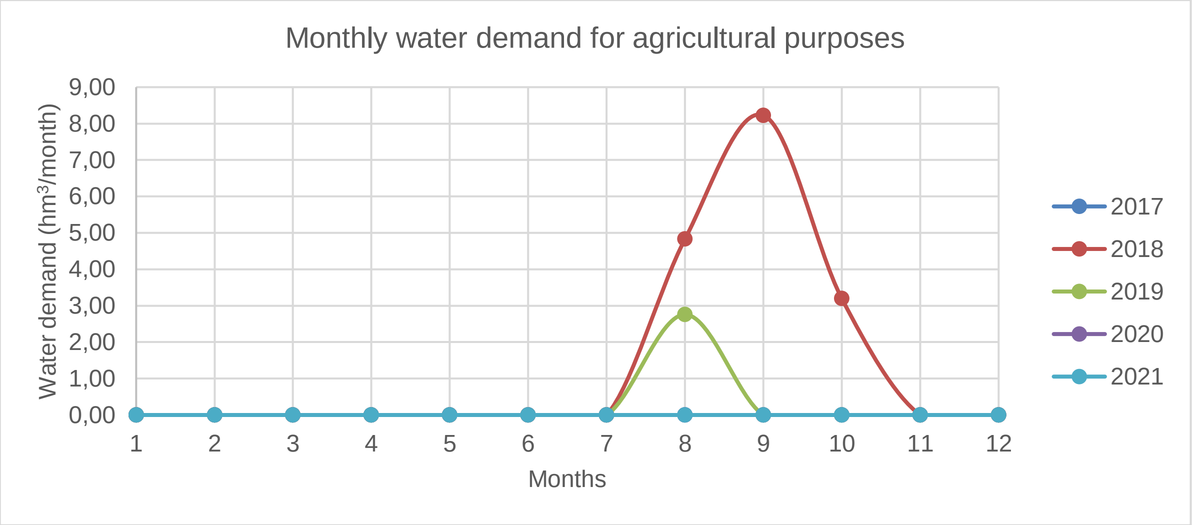


Figure 125: Baseline scenario - Monthly water demand for agricultural purposes

The next step in this process is the comparison between the results from the baseline model and the different categories of scenarios (regarding the next five-year period) that were referred to in sub-section 15.2.1.2. In short, the five categories are the following:

1. 1% and 2% increase in the number of households.
2. 0.5%, 2% and 4% decrease in industrial water demand.
3. Changes in livestock by decreasing animals' population between 1 and 2%
4. Climate change related scenarios, by examining a 10% decrease in mean annual precipitation combined with a 2% rise in mean annual temperature as well as a 20% decrease in mean annual precipitation combined with a 5% rise in mean annual temperature. This category can also combine changes in agricultural areas, in the range of 0.5 - 1%.
5. Implementation of decentralized technologies for water management, by applying a greywater treatment and recycling scheme in the 30% of the households, which will use treated water (instead of groundwater or tapped springs) to cover their WCs' water demand. The greywater treatment plant is assumed to have a capacity of 1400000 L/d.

First category: 1% and 2% increase in the number of households.

A 1% and 2% increase in the current number of households can raise the total annual water demand by about 0.45% and 0.8% respectively, as it is shown in the Table 27.

Table 27: Total annual water demand changes due to an increase in the number of households.

Total annual water demand changes due to an increase in the number of households (hm^3)		
Baseline scenario	1% increase	2% increase
8.85	8.89 (≈0.45% increase compared to the baseline scenario)	8.92 (≈0.80% increase compared to the baseline scenario)

Second category: 0.5%, 2% and 4% decrease in industrial water demand.

A 0.5%, 2% and 4% decrease in the industrial water demand can decrease the annual water demand by about 0.23%, 0.9% and 0.8% respectively, as shown in Table 28.

Table 28: Total annual water demand changes due to a decrease in the industrial water demand.

Total annual water demand changes due to a decrease in the industrial water demand (hm^3)			
Baseline scenario	0.5% decrease	2% decrease	4% decrease
8.85	8.83 (≈0.23% decrease compared to the baseline scenario)	8.77 (≈0.90% decrease compared to the baseline scenario)	8.70 (≈1.70% decrease compared to the baseline scenario)

Third category: Changes in livestock by decreasing animals' population between 1 and 2%

A 1% and 2% decrease in the animals' population can decrease the annual water demand by about 0.23% and 0.34% respectively, as shown in Table 29.

Table 29: Total annual water demand changes due to changes in livestock by decreasing animals' population.

Total annual water demand changes due to changes in livestock by decreasing animals' population (hm^3)		
Baseline scenario	1% decrease	2% decrease
8.85	8.83 (≈0.23% decrease compared to the baseline scenario)	8.82 (≈0.34% decrease compared to the baseline scenario)

Considering that the term "total water demand" refers to the summary of water needs derived from the three examined categories (households, industry and livestock) which cover their needs from groundwater and tapped springs, it was examined the impact that a 2% (in absolute term) change (increase/decrease) in each category can have on the total amount of water demand. The results are presented in Figure 126Figure 27.

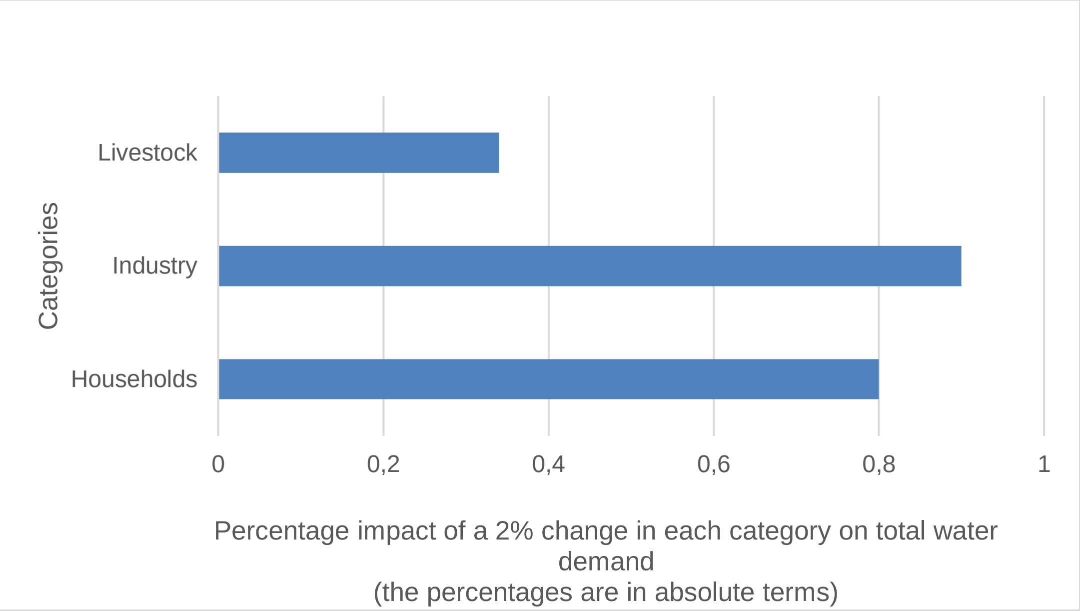


Figure 126: Percentage impact of a 2% change of each category on total water demand

The diagram shows that the total water demand is more sensitive to changes that are related to industry than households and less so than livestock.

Fourth category: Climate change related scenarios.

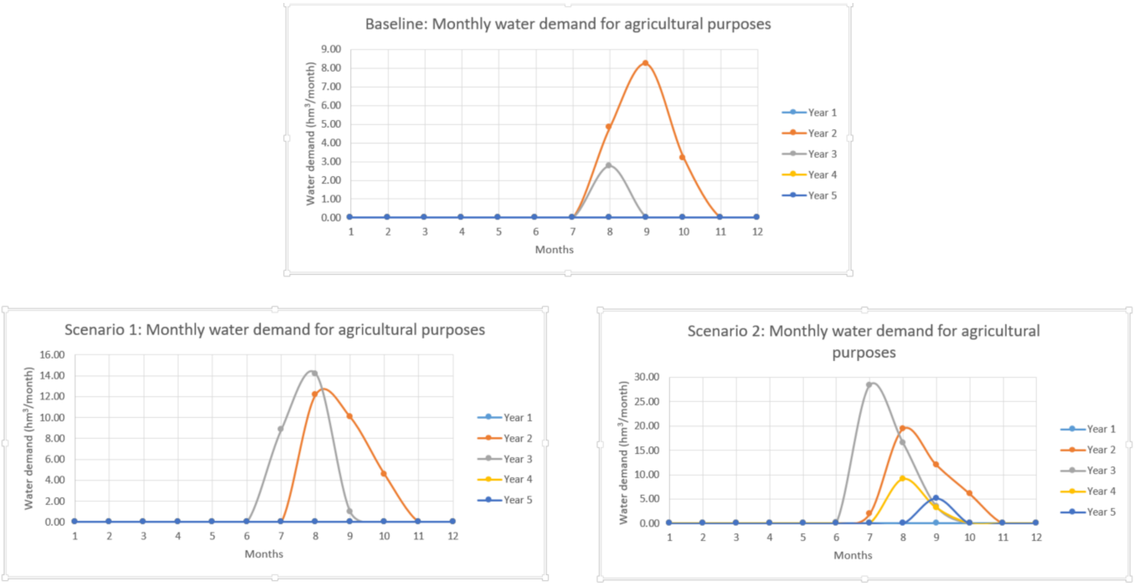
The examined climate change scenarios that are examined to investigate their impact on the agricultural sector are the following (Table 30):

Table 30: Climate change related scenarios and their impact on agricultural water demand.

Climate change related scenarios and their impact on agricultural water demand						
Baseline scenario	Scenario 1: 10% decrease in mean	Scenario 2: 20% decrease in mean	Scenario 3: 10% decrease in mean	Scenario 4: 10% decrease in mean	Scenario 5: 20% decrease in mean annual precipitation combined with a 5% rise	Scenario 6: 20% decrease in mean

	annual precipitation combined with a 2% rise in mean annual temperature	annual precipitation combined with a 5% rise in mean annual temperature	annual precipitation combined with a 2% rise in mean annual temperature. + 0.5% decrease in agricultural area	annual precipitation combined with a 2% rise in mean annual temperature. + 1% decrease in agricultural area	in mean annual temperature. + 0.5% decrease in agricultural area	annual precipitation combined with a 5% rise in mean annual temperature. + 1% decrease in agricultural area

The results are shown in Figure 127.



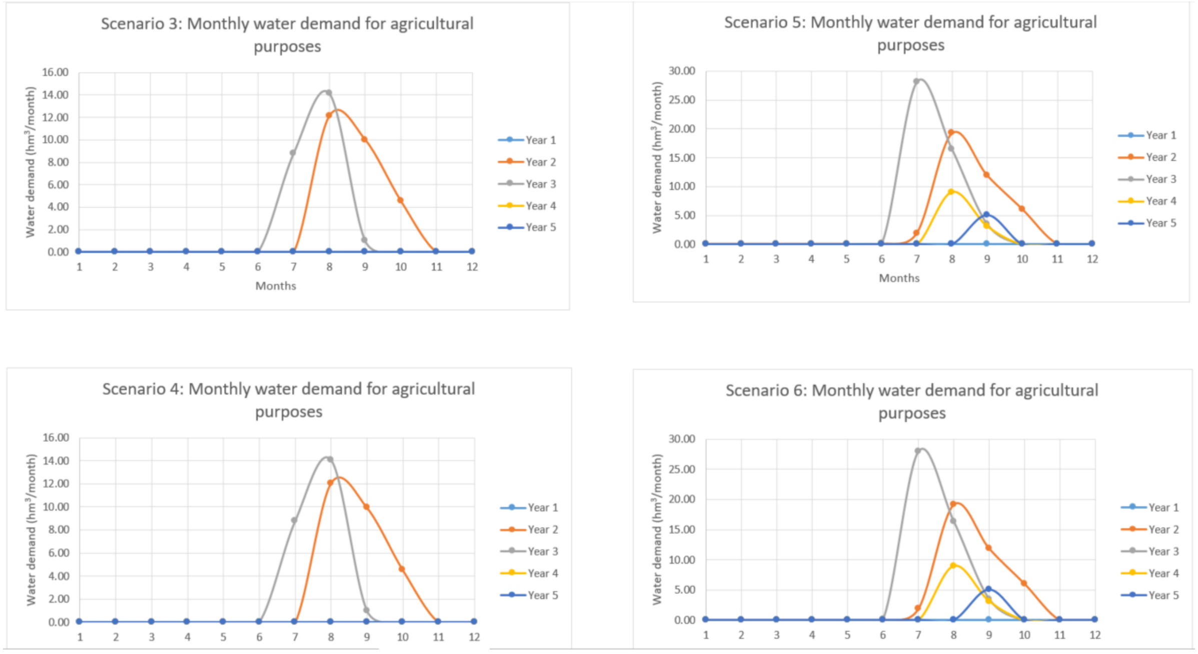


Figure 127: Results from climate change scenarios implemented on agriculture.

The greater difference among the scenarios examined can be found between the Scenarios 1 and 2 (also compared to the baseline) which indicates the impact of temperature and rainfall on agricultural water demand whereas a 0.5 - 1% change on agricultural areas does not seem to play crucial role on the results.

Fifth category: Implementation of decentralized technologies for water management.

The results regarding the domestic water demand (and the total water demand respectively) before and after the implementation of greywater treatment plant (decentralized technology) are presented in Table 31 and Table 32.

Table 31: Annual domestic water demand changes due to the implementation of greywater recycling (GWR) technology

<table>
<tr><th colspan="2">Annual domestic water demand changes due to the implementation of greywater recycling (GWR) technology (hm^3)</th></tr>
<tr><td>Baseline scenario</td><td>GWR scenario</td></tr>
<tr><td>3.75</td><td>3.43
(≈8.50% decrease compared to the baseline scenario)</td></tr>
</table>

Table 32: Annual total water demand changes due to the implementation of greywater recycling (GWR) technology

Annual total water demand changes due to the implementation of greywater recycling (GWR) technology (hm^3)	
Baseline scenario	GWR scenario
8.85	8.53 (≈3.60% decrease compared to the baseline scenario)

The results show that greywater recycling technology has a significant impact on potable water demand and can play a major role in attempts to reduce potable water needs in the household level. Compared the greywater quantities at both scenarios (baseline and GWR), it is obvious that the second approach significantly reduces the amount of greywater finally produced, as it is recycled inside the household (Figure 128).

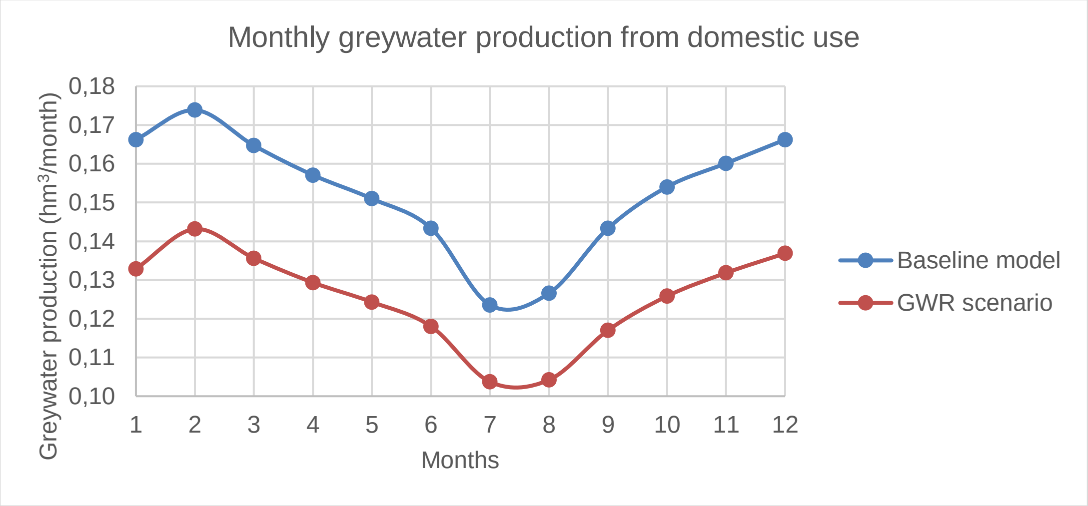


Figure 128: Greywater production in the baseline and GWR scenarios

15.2.2 Regional demand-supply matching GIS tool

15.2.2.1 Pre-processing stage and input data

No special preparation in the sense of measurement campaigns or definition of a baseline was required to use the tool in the LL context. A data package is already provided with the tool. Therefore, only some data sets are specific for the LL and need to be updated for use in other contexts. The data include administrative data (e.g., administrative units, national borders, etc.), meteorological data, population data, data on water production, infrastructure (e.g., extraction facilities, road network, etc.) and others. Not all data need to be available for the use of the tool, and additional categories can be added. However, the functionality of the tool may be limited by missing data. The corresponding data sources for the application in LL East Frisia can be found as a compilation in the tool description. The tool itself is provided as a QGIS plug-in and can be used with the QGIS functions for plug-ins (e.g., batch processing).

15.2.2.2 Setup process and application

The data used in the tool are from publicly available sources. They are subject to the general conditions for the use of public data (use, copy, distribution). The respective terms of use are provided in the tool manual/description for the data along with the respective data sources and links to the corresponding websites. The data were assigned to GIS elements.

A distinction can be made between two types of input: The input of the data that serve as the basis for the calculation of the tool, and the input of the points at which the tool is to be used. The selection of the data used for calculation is done via a drop-down menu. The selection of the query points can be done in three ways: 1) the point can be selected via a click on the map; 2) the coordinates can be entered manually; 3) a point layer can be used. The last option is particularly practical if several points are to be queried at the same time.

Since it may happen that not all data is fully and up-to-date available to the user for the desired query area, the input parameters are divided into necessary and optional parameters. The necessary parameters are those that are at least required to be able to use the tool and used for the internal calculations. If the optional parameters are missing, the tool can be used, but some additional functionalities/statements may be limited.

The tool processes annual totals/annual data. Per capita water consumption is given in litres per day. There is the possibility to use UWOT results in the tool. The UWOT input data is converted into annual data by the tool after input.

To maintain consistency, it is recommended to use only data from within one year when updating, even if some data sets may be available for more recent years.

The data provided is available for the LL East Frisia area, some of the demo data is clipped to the area of Lower Saxony. However, the tool works for all of Europe, as long as the corresponding data is used as input (see also chapter 15.2.2.1).

15.2.3 Short-term demand forecasting tool

15.2.3.1 Pre-processing stage and input data

To apply the tool in the LL, it was necessary to first deploy smart meters that measure hourly water consumption or water flow. The resulting time series data is the core requirement of the tool, as every forecast represents the predicted continuation of the historical measurements. In general, the organisation that plans to apply the tool is responsible for pre-processing the data to ensure a sufficient quality. Furthermore, it is possible to incorporate additional external data into the forecasts, like weather information. The only requirement is that associated time series for all historical water consumption measurements and for the prediction horizon can be provided. This can happen on a per-meter basis, as the user has to define which information will be used for what (set of) meter(s). For example, precipitation data may be used for smart meters with specific ids or lat/lon coordinates, but not for others. Any numerical time series data may be used as additional information for creating the water demand forecast as well. Examples of the expected smart meter meta data, measurement data and optional external data are given in the associated GitHub repository reported in section 5.7.7.

15.2.3.2 Setup process and application

Figure 129 shows the architecture of the tool and contrasts which components have to be provided by the user of the tool (yellow) against the components already included in the tool (blue). The user has to implement a measurement agent that periodically updates the smart meter measurements in the Mongo database (preferably every hour). There is no requirement on how this is achieved, except that new entries appear in the database regularly. The weather agent is an optional module to incorporate additional, external data into forecasts of specific smart meters. To this end, the tool provides a Python interface that needs to be implemented by the organization. In this interface, the organization provides additional data depending on the smart meter ids or coordinates. The main component of the forecasting tool (referred to as “core tool” in the architecture diagram) provides an OpenAPI-documented, RESTful API to make integration with existing systems easy. If the core tool is not integrated into an existing system, a frontend that was co-developed during the project can be used to interact with it. If desired, generated forecasts are made accessible through the NGSI context broker. It is important to note that external apps have read-only access to smart meter forecasts through the context broker. Thus, they rely on the organization that deployed the tool to create forecasts periodically. This is important to ensure that external apps cannot affect the data consistency or computational load on the servers.

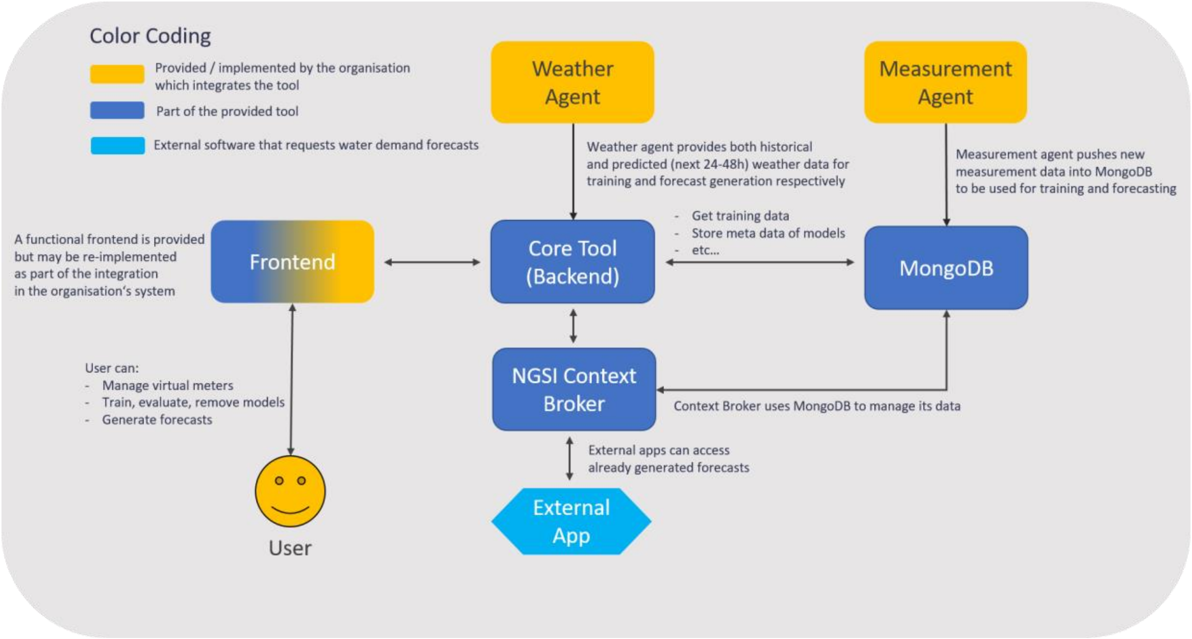


Figure 129: Architecture of Short-term demand forecasting tool (#28).

The tool is organized in Docker containers that are controlled with Docker compose commands. It is highly recommended to deploy the tool on a server that has GPU access, as deep learning-based methods require a lot of computing power. However, this requires additional steps to make communication between the GPU and the Docker container possible (see the tool's readme file for details). The GitHub repository (please refer to section 5.7.7) contains a .env file that defines the configurations that have to be set, for example if the tool should communicate with the context broker or weather agent or how many computational resources it should allocate for training. More specific details on the deployment of the tool can be found in the associated GitHub repository.

15.3 LL Lisbon

15.3.1 Pre-processing stage and input data

The necessary steps and processes that need to be fulfilled before being able to apply the Lisbon LL tools along with related technologies are presented in Table 33 to Table 38. For each tool, the related WP2 task(s) for pilot data collection is(are) presented.

The Pre-Processing Stage includes the following aspects: identification of relevant actors, definition of case extent, definition of baseline, collection and editing of input data, conduction of workshops, and installation of equipment.

The Input Data is organized in the following aspects: primary data, background data, water data, and additional data.

Table 33: Data requirements for tool #17.

T3.5 tools		**#17** Environment for decision support and selection of alternative courses of action
T2.4 subtasks		**T2.4.3a** Urban W-E-P balance **T2.4.3b** Risk management - health component **T2.4.3c** Risk management - groundwater component **T2.4.3d** Reclaimed water quality modelling in the distribution system
Pre-processing stage	Actors	- Water demand planners and decision-makers in urban management, municipal, and water utility contexts.
	Case extent	- Link to other strategic and tactical planning options related to water management in an urban setting, e.g., feeding the infrastructure asset management planning.
	Baseline	- The high-level goal of this tool is to enable users to select the best combination of water sources to satisfy specific non-potable uses, and to enable prioritisation of strategic and tactical planning options on water management in an urban setting.
	Input data	- Metrics from Tools #25 and #27, as well as from Tool #24, if applicable (i.e., when the possible degradation of the distributed water quality is a critical point in the reuse system, namely, when the reclaimed water is class A).
	Workshops	- WP1/T1.3 training action scheduled for April 18, 2024
Input data	Primary data	- Metrics employed to qualify the initial selection in Tool #25 (e.g., volume availability, cost, energy content, carbon footprint, nutrient content, geolocation) and for further qualification through risk assessment in Tool #27 and potentially in Tool #24, if applicable, as illustrated in Figure 39 and listed in Table 35, Table 36 and Table 37, respectively.
	Background data	- Municipal policy/plans, e.g., on water reuse and climate action.
	Water data	- The water data relevant (i.e. the primary data above) for tools #24, #25, and #27, illustrated in Figure 39 and listed in Table 35, Table 36 and Table 37, respectively.

Table 34: Data requirements for tool #20.

T3.5 tool		**#20** Urban Water Cycle Observatory
T2.4 subtask		**T2.4.2** Water matrix and concepts behind water observatory
Pre-processing stage	Actors	- Public access – citizens, urban management authorities, academia, NGOs, media, and other key stakeholders. - Private access – municipalities (especially, Lisbon municipality in the scope of the Lisbon LL), private institutions of public interest, private entities with large water consumption.
	Case extent	- This tool can function as a data repository.

	Baseline	- Public access – provision of information on an annual basis, related with main water flows, consumption disaggregation (by type of use and type of user), amount of treated wastewater and reclaimed water production. - Private access – visualization of aggregated consumptions and costs per typology of water use, water consumption evolution, and individual consumption analysis.
	Input data	- Public access – collection of annual open data regarding the city's urban water cycle (drinking water, wastewater and reclaimed water), edition privileges the use of infographics. - Private access – collection of water consumption data registered through smart meters, edition via a set of analytics.
	Workshops	- WP1/T1.3 training action scheduled for November 16, 2023
	Equipment	- Private access – water smart meters
Input data	Primary data	- Public access – open data of water consumption, wastewater treatment, and reclaimed water production in the city. - Private access – smart meter data on water consumption, location of the consumption points.
	Background data	- Municipal policy/plans, e.g., on water reuse and climate action.
	Water data	- The same as primary data.

Table 35: Data requirements for tool #24.

T3.5 tools		**#24** Reclaimed water quality model in the distribution network
T2.4 subtasks		**T2.4.3d** Reclaimed water quality modelling in the distribution system
Pre-processing stage	Actors	- Hydraulic engineering experts in urban management, municipal, and water utility contexts.
	Case extent	- Assessment of the need for disinfection and residual chlorine in the design of distribution networks or, in the case of already constructed networks, to evaluate the disinfection efficiency and introduce adjustments as needed for water safety.
	Baseline	- Complete hydraulic and water quality extended-period simulation model for pressure flow networks, designed to simulate the advection, mixing, and transformation of waterborne parameters and the chlorine decay (residual disinfectant management) in reclaimed water.
	Input data	- This tool includes complete descriptors for network assets, demands, operational constraints and rules, and state variables describing hydraulics, travel time, and advection/transformation of water quality parameters (incl. free- or combined chlorine content).
	Workshops	- WP1/T1.3 training action scheduled for February 15, 2024
	Equipment	- Water smart meters, chlorine sensors, etc.

Input data	Primary data	- Water demand descriptors. - Reclaimed water supply descriptors.
	Background data	- Municipal policy/plans, e.g., on water reuse, water losses management.
	Water data	- Water quality (WQ) descriptors: WQ boundary conditions (e.g., chlorine concentration, ammonium concentration), WQ formulation(s) - Water network operation descriptors: e.g., flow, velocity, pressure.
	Additional data	- Network descriptors: e.g., irrigation network plant, pipe diameters, location of irrigation devices (e.g., sprinklers), irrigation schedule.

Table 36: Data requirements for tool #25.

T3.5 tools		**#25** Water-Energy-Phosphorus balance planning
T2.4 subtasks		**T2.4.3a** Urban W-E-P balance
Pre-processing stage	Actors	- Planners and decision-makers in urban management, municipal, and water utility contexts
	Case extent	- The tool is applicable to any demand-driven matchmaking problem (as it is, requiring no modification).
	Baseline	- Standardized means to combine and assess water source combinations to satisfy specific demands.
	Input data	- The matchmaking environment is driven by the demand(s) to be satisfied, translated as time series of required monthly volumes over a pre-specified period. - The supply and demand alternative combinations are assessed through a range of user-selected metrics (e.g., volume availability, cost, energy content, carbon footprint, nutrient content).
	Workshops	- WP1/T1.3 training action scheduled for April 18, 2024.
	Equipment	- Water meters – supply and demand.
Input data	Primary data	- Water demand descriptors. - Water supply descriptors.
	Background data	- Municipal policy/plans, e.g., on water reuse and climate action. - National regulations: e.g., Decree-Law 119/2019 on water reuse. - European regulations: e.g., Urban Wastewater Treatment Directive (recast) (new proposal under approval).
	Water data	- Water descriptors: volumes (availability/supply and consumption/demand), water price (supply). - Related energy descriptors: energy content water (supply). - Related phosphorus descriptors: P concentration in reclaimed water (supply).

	Additional data	- Alternative specific costs: CAPEX and OPEX, energy. - Carbon footprint.

Table 37: Data requirements for tool #27.

T3.5 tools		**#27** Risk assessment for urban water reuse
T2.4 subtasks		**T2.4.3b** Risk management - health component **T2.4.3c** Risk management - groundwater component
Pre-processing stage	Actors	- Water demand planners and decision-makers in urban management, municipal and water utility contexts.
	Case extent	- Human health and environmental risk assessment associated to water reuse in agriculture.
	Baseline	- Standardized means for building the hazard exposure scenarios and to assess the risk associated with each scenario.
	Input data	- Descriptors of the main features of the urban facility (e.g., public park) that may impact the human and environment exposure to the hazards present in the reclaimed water. - Human health and environmental risk assessment requires basic knowledge of risk management and of the legislation applicable to water reuse.
	Workshops	- WP1/T1.3 training action scheduled for March 14, 2024.
Input data	Primary data	- Water demand descriptors relevant for risk assessment.
	Background data	- Municipal policy/plans, e.g., on water reuse and climate action. - National (Portuguese) regulation: Decree-Law 119/2019 on water reuse. - European regulation: Reg. (EU) 741/2020 on minimum requirements for water reuse in agricultural irrigation. - International standards: e.g., ISO 16075-2:2020, ISO 20426:2018, ISO 20761:2018.
	Water data	- Reclaimed water quality.
	Additional data	- On risk treatment measures.

Table 38: Data requirements for tool #33.

T3.5 tool		**#33** Climate readiness certification
T2.4 subtask		**T2.4.4** Water-smart for climate ready certificates
Pre-processing	Actors	- Householders, urban planners, municipalities, the building industry, and Climate Ready Certificates auditors.

stage	Case extent	- Link to other housing certification system.
	Baseline	- A single certificate to assess the water efficiency, the water-energy nexus performance, and the climate adaptation evaluation of households, buildings, and neighbourhoods. The evaluated projects can be in the design phase, new construction, or in use.
	Input data	- The CRC methodology has closed questions that can be answered by a single option, multiple options or percentages. Each of the 96 evaluation criteria has an associated score and the answers are ordered by descending score.
	Workshops	- WP1/T1.3 training action scheduled for December 12, 2023
	Equipment	- Water meters, water pressure sensors.
Input data	Primary data	- Households, buildings, and neighbourhoods – description of water distribution network and related equipment and devices
	Background data	- Municipal policy/plans, e.g., on water reuse and climate action. - European standards: e.g., EN 16941 series on on-site non-potable water systems.
	Water data	- Water quality descriptors: e.g., chlorine concentration (if water supplies (e.g., treated greywater) other than drinking water are used for non-potables uses). - Water network descriptors: e.g., flow rates, pressure.
	Additional data	- Energy descriptors (onsite systems): e.g., energy consumption in water distribution, energy consumption in water treatment. - Climate adaptation descriptors: e.g., climate risks maps, climate adaptation measures targeted to housing.

15.3.2 Setup process and application

Table 39 to Table 44 present information about the setup process and application of the Lisbon LL tools #17, #20, #24, #25, #27, and #33, respectively. For each tool, the related WP2 task(s) for pilot data collection is (are) presented.

Table 39: Setup process and application: tool #17

T3.5 tool	**#17** Environment for decision support and selection of alternative courses of action
T2.4 subtask	**T2.4.3a** Urban W-E-P balance **T2.4.3b** Risk management - health component **T2.4.3c** Risk management - groundwater component **T2.4.3d** Reclaimed water quality modelling in the distribution system

Data inputs and model initialisation	• The tool allows for the specification of the key parameters: objectives, timesteps, metrics, alternatives. There is also the ability to import or export from/to a dedicated Excel® format, which facilitates sharing of results or further manipulation of the analysis. • When the tool is started, it displays the available analyses (imported from tool #25) as well as the option to create a new one. When an alternative is created here, its values are either typed in on this screen or imported using the Excel® import/export facility. • An analysis contains a set of alternatives, a set of metrics to assess them, over a set of timesteps. It may include the specification of different scenarios (external contexts).
Parameters and assumptions	• Most of the metrics are imported directly from a linked Matchmaking analysis (tool #25), along with the alternatives, using the option available through the last item on the menu of tool #17. • The user can also add new metrics directly in this environment by filling out the Data Table, which contains the metrics' values for each alternative at each time step. This applies to water reuse risk metrics (tools #24 and #27). Other metrics can be defined by the user. • The user introduces in the Metrics Editor the relationship between the metric's 'real world' values and a standardized 0-to-3 scale that is used throughout the app, effectively turning each metric into an index. • Metrics may be given a relative weight from a closed list (0.5, 1, 2) – this is used later when ranking the alternatives.
Temporal or spatial scales	• Monthly, annual • Neighbourhood, city, region
Design of scenarios	• The baseline scenario corresponds to the "business as usual" alternative (first year of the planning timeline). The supply and demand alternative combinations are assessed over a targeted period (planning horizon). The time frame for evaluating the impact of the plan is the analysis horizon. • The 3D cube of tool #17 provides an overview of the decisional problem with the 3 dimensions – alternatives (Z-axis) over time (Y-axis) and across all metrics (X-axis) – simultaneously displayed. This allows for a unique overall perception of the dynamics of decision among the alternatives.
Deployment of the tool	• This tool may be applied to any decisional problem of the same type (alternatives vs. metrics over time). In the implementation that is embodied in Tool #17, it is designed to work in tandem with Tool #25 and assess the supply/demand matchmaking alternatives developed there.

Table 40: Setup process and application: tool #20

T3.5 tool	**#20** Urban Water Cycle Observatory
T2.4 subtask	**T2.4.2** Water matrix and concepts behind water observatory

Data inputs and model initialisation	- Public access – open data on water consumption, wastewater treatment, and reclaimed water production in the city. - Private access – water consumption per facility, aggregation per type of use, associated costs, performance indicators, georeferencing of facilities.
Parameters and assumptions	- Tool #20 allows the identification and quantification of the main water flows in the city of Lisbon, disaggregating, whenever possible, the consumption by type of user and type of use. In this sense, the information provided allows the characterization of Lisbon's territory regarding water supply and wastewater collection and treatment.
Temporal and spatial scales	- In terms of scale application, public access has a broader implementation at the city scale, as the private access can be implemented at an entity or even at a single water meter scale.
Design of scenarios	NA
Deployment of the tool	- Public access – is in use by the Lisbon Municipality in the scope of the Lisbon Living Lab. Additionally, it is starting to be well known by citizens, resident's associations, NGOs, etc. - Private access – is in use by the Lisbon Municipality in the scope of the Lisbon Living Lab. Additionally, there are two other entities, associated to Lisboa E-Nova, that are using this private access for water, such as the public passenger transport company (buses and trams).

Table 41: Setup process and application: tool #24

T3.5 tool	**#24** Reclaimed water quality model in the distribution network
T2.4 subtask	**T2.4.3d** Reclaimed water quality modelling in the distribution system
Data inputs and model initialisation	- Cadastral and demand data and operational parameters to simulate the movement, mixing, and dynamics of key reclaimed water parameters throughout the network. - The primary input for the hydraulic and water quality model is an Epanet.INP file and an EPANET MSX file, respectively. The model runs based on those two files and the interface allows for querying of results as well as full visualisation in BASEFORM's 3D environment.
Parameters and assumptions	- Parameters for water quality modelling of reclaimed water distribution networks, incorporating sensor data (e.g., flow, chlorine residuals, temperature, turbidity, pH).
Temporal and spatial scales	- Minutes, days. - Urban water distribution network or bulk water network.
Design of scenarios	- This tool offers a unique standardized means to compare reclaimed water supply/demand combinations through multiple criteria, with a purposefully developed formulation for reclaimed water (for non-potable, unrestricted urban reuse in Lisbon LL), on top of advanced hydraulics simulation capabilities.

Deployment of the tool	• The tool #24's model is self-contained and as such may be used on its own to fulfil its primary purpose. However, in the context of the project, it aims at being used in conjunction with tool #25 to qualifying the supply/demand alternatives developed there, from the viewpoint of assessing the risks incurred in transport and distribution of the reclaimed water, in the Lisbon LL case, for non-potable, unrestricted urban reuse.

Table 42: Setup process and application: tool #25

T3.5 tool	**#25** Water-Energy-Phosphorus balance planning
T2.4 subtask	**T2.4.3a** Urban W-E-P balance
Data inputs and model initialisation	• The tool allows for the specification of the key parameters: geolocation of water demands and water supplies, metrics (e.g., costs, energy content, carbon footprint, nutrient content), alternative descriptors. • The tool allows the import of time series from a dedicated Excel® format for the following data: water volumes (availability/supply and consumption/demand), water price (supply), phosphorus content in water (supply), phosphorus fertilization (demand). These data series consist of the user's forecast for the evolution of the values of these variables over the planning period. • When the tool is started, the user is asked to register potential sources, with corresponding time series of available volumes taking place in the same time window, though not necessarily spanning its entirety. • The user is then asked to combine the available sources to make up the required monthly volumes, while complying with the energy and nutrients contents as desired. Such combinations are called 'alternatives' and are characterized by the degree to which they satisfy the required volumes over time, as well as by their energy consumption, nutrients contents, and cost. One or more alternatives will be designed to solve the demand problem at stake.
Parameters and assumptions	• The supply and demand alternative combinations are assessed and matched through a range of user-selected metrics (e.g., volume availability, cost, energy content, carbon footprint, nutrient content) over a targeted period.
Temporal and spatial scales	• Monthly, annual. • Urban facility (e.g., public park), neighbourhood, city, region (the software allows for full geographic representation of the sources and demands).
Design of scenarios	• When the tool #25 is started, it displays the available analyses as well as the option to create a new one (top right). An analysis contains one or more matchmaking alternatives for a given supply/demand application case, as well as a set of metrics and a range of analysis timesteps.
Deployment of the tool	• The tool #25 is autonomous and may be deployed on its own or in conjunction with tools #17 and #27. The tool is applicable to any demand-driven matchmaking problem without requiring modification.

Table 43: Setup process and application: tool #27

T3.5 tool	**#27** Risk assessment for urban water reuse
T2.4 subtasks	**T2.4.3b** Risk management - health component **T2.4.3c** Risk management - groundwater component
Data inputs and model initialisation	• In each alternative, each urban facility (e.g., public park) with water demand satisfied with reclaimed water is tested for human health and for environmental risks. • Tool #27 provides a structured analysis of the water reuse system. In the menu “Configuration”, the user is asked to describe the following groups of information: ○ “Components” organized in 5 subgroups: “Hazards”, “Exposure routes”, “Exposure sites”, “Activities”, and “Population or environment at risk”. The user must fill in the fields “Category” and “Name” of every component. ○ “Barriers”, including the indication of “Name”, “Expected Log removal value”, “Number of barriers”, and “Reference” of this information. ○ “Preventive measures”. For each one, the user must fill in the field “Name” of every measure. ○ “Hazardous events”. The user must fill in the field “Name” of every hazardous event. • The data input in the configuration menu provides the necessary information for the risk assessment process, which is organised in the following steps: risk identification, risk analysis and risk treatment. • The risk analysis is carried out in the “Analysis” menu, scenario by scenario. After selecting the demand (i.e., a green area irrigated with reclaimed water), the user describes the scenarios together with the respective risk assessment using the menu “Create scenario”. This menu sequentially presents a set of fields that are filled in with information provided in the "configuration" menu or require rating a of the likelihood of exposure to hazards or the potential damage to the population or environment at risk.
Parameters and assumptions	• The risk analysis is done for every defined exposure scenario, assigning to each scenario a rating for the likelihood of exposure to the hazards, as well as a rating of the harm that might result to the recipient (persons and environment). The levels used for the classification of likelihood and harm are predefined (i.e., not available for configuration by the user). • The risk assessment ends with the comparison of the results of the risk analysis with the established criteria to determine whether the residual risk is tolerable, using a risk matrix.
Temporal and spatial scales	• Annual. • Urban facility (e.g., public park).

Design of scenarios	- Tool #27 is a standardized means for building hazard exposure scenarios and assessing the risk related to each scenario. - Exposure scenarios set out how and under what circumstances people and the environment may be exposed to hazards. To facilitate the construction of exposure scenarios to hazards, a structured methodology was developed based on three questions: "what?", "why?", and "how?" (Ribeiro and Rosa, 2022). In the first moment ("what"), an analysis of the water reuse system is made to identify the constituent elements, those that may be at the basis of the risk. Next ("why"), the link between the elements of the system is identified. Finally ("how"), credible combinations between system elements are described that correspond to normal situations of system use that may, through the influence of hazardous events, result in a risk to the recipients. This methodology is embedded in tool #27.
Deployment of the tools	- The tool #27 is autonomous and may be deployed on its own or in conjunction with tools #17 and #25. The tool is applicable to human health and environmental risk assessment related with water reuse in irrigation and other non-potable urban uses, aligning with principles established in European and Portuguese legislation (Reg. (EU) 741/2020 and Decree-Law 119/2019, respectively), as well as with relevant ISO standards (e.g., ISO 16075-2:2020 and ISO 20426:2018).

Table 44: Setup process and application: tool #33

T3.5 tool	**#33** Climate readiness certification
T2.4 subtask	**T2.4.4** Water-smart for climate ready certificates
Data inputs and model initialisation	- The methodology has closed questions that can be answered by a single option, multiple options or percentages. Each criterion has an associated score and the answers are ordered by descending score. The answer with the most points is always the first option. In the case of a criteria that does not apply and as such is not evaluated, the auditor can exclude it and its score is proportionally distributed to the other methodology criteria.
Parameters and assumptions	- The CRC methodology encompasses three dimensions: water efficiency, water-energy nexus and climate adaptation. Overall, it has 96 evaluation criteria: 53 criteria in the water efficiency dimension, 23 criteria in the water energy nexus, and 20 in the climate adaptation. - All these criteria are evaluated on three different scales of applicability: household, building and neighbourhood, though some of the criteria are not applicable to the household and outdoor space analyses.
Temporal and spatial scales	- NA - Household, building and neighbourhood.
Design of scenarios	- NA
Deployment of the tools	- Once the web tool is operational (October 2023), the auditors will be able to select the building typology to be certified, fill out the CRC methodology directly in the web tool and the platform will calculate the class of each dimension, the overall class and issue the CRC certificate.

16 Annex E: Summary tables of LLs

This Annex concentrates the summary table that have been created in order to form the first draft of case study factsheets in order to be used for the population of WEM. The fields requested by the tables have been aligned with the WEM online forms. The sections that follow 16.1 - 16.3, include the 3 summary tables (Table 45-Table 47) of the LLs that are documented in this toolkit report.

16.1 Flanders

Table 45: Summary table for LL Flanders.

Title	Assessment of alternative water sources and increasing freshwater availability for drinking water and agriculture in Flanders
Description	The smart stormwater reuse management system (tool #21) is used to control the outflow from the basin and the water distribution for irrigation to optimize the functioning of the basin for flood prevention and availability of water for irrigation during dry periods. There is a need to place these technological demonstrations in a broader context to assess how they can contribute to a more robust and smarter water system at a regional level. The regional analysis and UWOT (tool #22) were used to assess the demonstrations in their regional context with regard to their impact on water availability and resilience of the water system. Next to that, the potential to include alternative water sources while minimizing negative impact on local nature and environment in order to design a sustainable water supply for the future was analysed. The regional analysis was used to identify regional effects of changes in water supply and demand. A critical success factor for water reuse is the assessment and control of microbial safety risks. The QMRA+ (tool #26) is developed to support the design and assess the required treatment needed for water reuse. QMRA+ is a valuable tool for quantitative microbial risk assessment that can be used to assess existing purification systems and to help determine the design requirements of purification systems for e.g., alternative water sources with regards to microbial safety requirements. Within BWS, QMRA+ is used to help design the effluent reuse demonstration system by back casting the required removal rate. The SuTRa tool builds on microbial risk assessment to specifically model (plant) pathogen removal during subsurface passage of managed aquifer recharge and infiltration schemes. This helps determine the minimum design parameters and residence time required for pathogen removal. The outputs from SuTRa may support the regional analysis or similar studies in related projects by providing input parameters on subsurface passage if these are included in the conceptual design.
Reference point	Woumen: https://shorturl.at/mCUZ4 Mechelen: https://shorturl.at/ayEFP
Location	LL Flanders combines case studies on smart alternative water solutions from different locations in Flanders. Extension of the drinking water production capacity and potential effluent reuse for drinking water is studied at the combined case studies of Woumen. Stormwater reuse for agriculture is studied in the city of Mechelen. The findings of the UWOT and regional analysis modelling can be used to put these local case studies in the regional context of Flanders.

Country (-ies)	Belgium, (UWOT is also applied in East Frisia, Germany)
URL	NA
Project	BWS
Challenges	• Water scarcity, • Limitations to water reuse due to high salinity/nitrates, • Untapped efficiency potential of water resources, • High or increasing irrigation water demand for agriculture, • Water quality deterioration, • Usage of captured rainwater for non-potable (irrigation) uses, • Groundwater overexploitation, • Limitations to water reuse and recovery due to low acceptance.
Tools/Product / Services	1. Stormwater reuse management system (#21) 2. Urban Water Optioneering Tool (#22) 3. QMRA+ for water reuse and agriculture (#26) 4. SuTRa (#31)
Technologies	QMRA: Water recovery technologies for water reuse including: • Biological systems ○ Membrane systems ○ Adsorption systems ○ Advanced oxidation processes (AOP) UWOT (#22) • Including any other Tools/Product/Services, around the Circular Economy, that have been applied in the case study/Living Lab. • Water recovery technologies for water reuse: (Local) wastewater treatment technologies, rainwater harvesting systems, surface water and infiltration systems. Stormwater management: urban water buffer technologies
Scales	Stormwater reuse management system: Local (e.g., single treatment plant, industrial site or city quarter). QMRA, SuTRa: local UWOT: Local, neighbourhood, regional, city/provincial
Legislation	EU Legislation for water reuse (both for potable and non-potable reuse). Drinking Water Directive, Flemish drinking water law
Synergistic benefits	Use of UWOT for the ex-ante assessment or upscaling impact of real circular water pilots. The QMRA+ tool allowed users to balance health risk versus other impacts such as costs, environmental impact and resilience.
Facts of the applied technologies	NA

Key Performance Indicators	NA
Requirements and conditions	UWOT: Data input from specific partners (water utilities, technology providers, pilot project managers). QMRA+: Since very little location specific data (e.g., pathogens in effluent and in the current water source) were available, the uncertainty about the risk is relatively large. Still, the comparison between different scenarios was feasible and helped support decisions on system design.
Key lessons	QMRA is a new and complex topic for most water professionals and other stakeholders. The QMRA+ tool proved to be very accessible, and users quickly learned the principles of QMRA through the tool and were at the same time able to apply this through the tool in the project. It also provided a common ground for discussions, thus avoiding discussions about the safety of various scenarios. UWOT can be used to model the expected effectiveness of measures with regards to water quantity under different scenarios. However, results can be limited by data availability, and results should be validated together with stakeholders.
Lessons learned from technology operation	NA
Technology performance and best practices	NA
Outcome of assessments	NA
Organisations	De Watergroep, Aquafin, Proefstation voor de Groenteteelt, City of Mechelen, Vito, KWR Water Research
Contact persons	Geertje.pronk@kwrwater.nl, Han Vervaeren (De Watergroep, han.vervaeren@dewatergroep.be, Birte Raes (Aquafin) birte.raes@aquafin.be, Joris De Nies (Joris.De.nies@proefstation.be), Stijn Van Goethem (stijn.vangoethem@mechelen.be), Patrick Smeets (KWR) Patrick.smeets@kwrwater.nl (QMRA+), Marjolein van Huijgevoort (KWR) (Marjolein.van.Huijgevoort@kwrwater.nl)
Data Manager	Glotzbach, Raul <Raul.Glotzbach@kwrwater.nl>
Costs	NA
Tags	Stormwater, buffer, rainwater harvesting. Water system modelling, hydrology Effluent reuse, wastewater reuse, drinking water, QMRA, health risk assessment
Publications/ Reference	NA

Images	NA
Caption/Source	NA

16.2 East Frisia

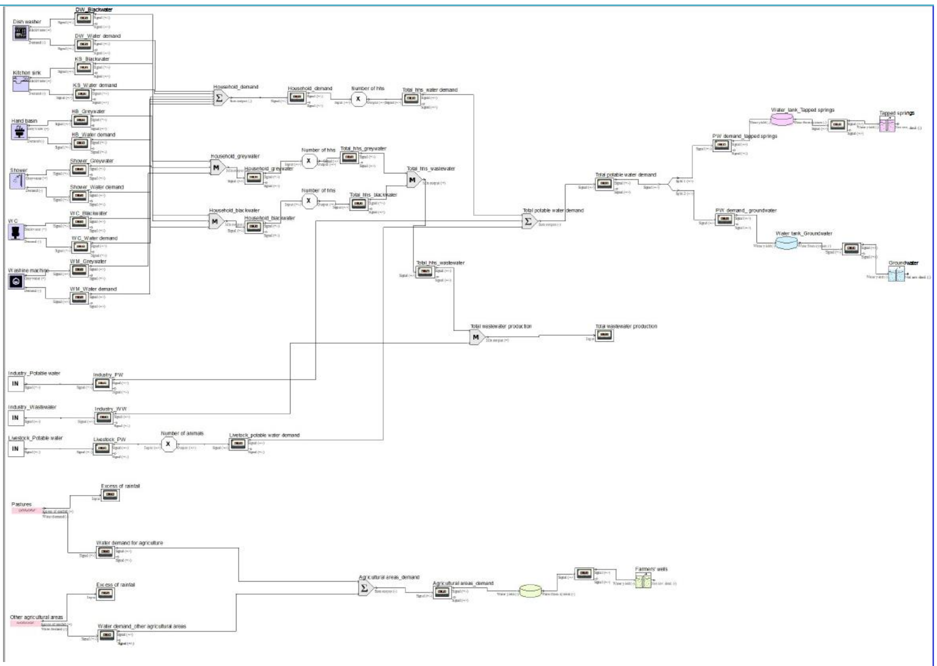
Table 46: Summary table for LL East Frisia

Title	East Frisia LL
Description	In the case study of East Frisia, the UWOT (tool #22) is mainly used to simulate the water flows (water demand and supply points) in a test case and to investigate alternative scenarios based on different climatic and demand change conditions or with the implementation of partially decentralised technologies. The regional demand-supply matching GIS tool is used to identify i) possible consumption hotspots and areas of water shortage, ii) alternative water resources or areas with available water sources and iii) water drains from one region to another. The short-term demand forecasting tool is used to generate water demand forecasts for the next (or current) day, which can e.g., be used to identify high peak loads in certain regions that require actions by the water utility.
Reference point	City of Lohne in Germany: https://goo.gl/maps/L52XBGhKqkib8mdGA (application area for tool #28)
Location	City of Lohne
Country (-ies)	Germany
URL	https://mp.watereurope.eu/d/CaseStudy/19
Project	BWS
Challenges	• High drinking water demand due to a dense or growing resident population, • Impact of climate change on irrigation water demand for agriculture, • Need for reuse and recovery schemes for greywater. • Other
Tools/Product/Services	1. Urban Water Optioneering Tool (#22) 2. Regional demand-supply matching GIS tool (#23) 3. Short-term demand forecasting tool (#28)
Technologies	• Resource for Circular Economy • Water recovery technologies for water reuse • Wastewater treatment technologies for water reuse • Groundwater systems • Urban rainwater harvesting systems.
Scales	• Local (e.g., single treatment plant, industrial site, or city quarter), • Regional (across several municipalities and/or administrative borders, incl. rural areas)
Legislation	• Climate Adaptation Strategy & Plans + Circular Economy Action Plan (EU); Water Framework Directive (WFD)

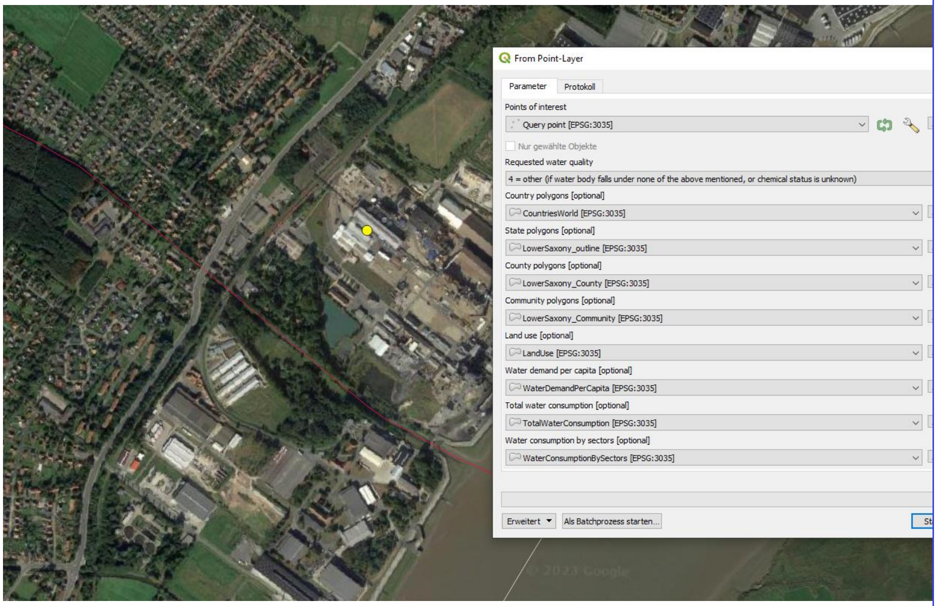
	• Smart meters: Metering Point Operation and Data Communication in Intelligent Energy Networks Act; IT Security Act • Federal Water Act (Wasserhaushaltsgesetz, WHG, in German) • Drinking water Ordinance (Trinkwasserverordnung, TrinkwV) • Metering Point Operation and Data Communication in Intelligent Energy Networks Act (Gesetz für den Messstellenbetrieb und die Datenkommunikation in intelligenten Energienetzen, MsbG) • Law on the Federal Office for Information Security (German: Gesetz über das Bundesamt für Sicherheit in der Informationstechnik, BSIG) • IT Security Act (German: IT-Sicherheitsgesetz, IT-SiG)
Synergistic benefits	Pilot plant data can be embedded in the water demand-supply tool in the way that increased industrial reuse by recirculation strategies will be included as a potential future water saving potential in large scale water management and upscaled to regional water saving potentials for industrial water demands. UWOT and the Short-term demand forecasting tool are based on a small-scale analysis, while the regional demand supply matching tool is used for large scale analyses. The data flow between the tools can therefore be described in the way that UWOT and STDFT are producing water demand scenarios that can be included in the RDSMG for future-oriented scenarios.
Facts of the applied technologies	-
Key Performance Indicators	-
Requirements and conditions	For the purpose of constructing a baseline model for the testcase, data related to water demand per user (household, livestock, and industry), water supply option and meteorological conditions are estimated. Agricultural data are extracted from CORINE Land Cover (CLC) shapefiles. Based on the CLC's categories, the main category that represents agricultural areas of different types is considered to be of type "2". The test case region is considered to include the codes "2.1.1 Non-irrigated arable land", "2.3.1 Pastures" and "2.4.3 Land principally occupied by agriculture, with significant areas of natural vegetation". The category "2.1.1" was not selected to be further investigated as it refers to non-irrigated land. Other parameters regarding the agriculture, livestock and households are missing and assumptions are included in the model, based on relevant references. No special preparation in the sense of measurement campaigns or the definition of a baseline was required to use the regional demand-supply matching GIS tool in the LL context. A data package including only publicly available information is already provided with the tool. Therefore, only some data sets are specific to the LL and needed to be added and the data were assigned to GIS elements. To apply the short-term demand forecasting tool in the LL, it was necessary to first deploy smart meters that measure hourly water consumption or water flow.
Key lessons	The implementation of the UWOT tool in the test case produced useful results for water use in the different sectors. It could have multiple benefits for water management strategies in case more data becomes available regarding the different water users and sources. Additionally, it could be useful to know the policies and measures related to water management in order to further investigate possible future scenarios based on real data and not assumptions. The model can be adjusted to account for changes in any scenario parameters, (e.g., population increase, livestock changes, industry changes, climate-driven scenarios etc.).

	The RDSMG tool has great potential to become a key monitoring and decision-making tool for sustainable water resources and water demand management in the region. However, its acceptance and usefulness very much depend on the input data available. For this first-time implementation the main ambition was to make the most use of publicly available information from national, regional, and local databases. In the future, highest benefits from the tool can be derived if data sets are regularly updated and enriched by new information collected from stakeholders. The STDFT was successfully implemented in the city of Lohne. The results of the case study application prove the usefulness of the tool for predicting future load profiles of municipal water demand in the districts under investigation. Nevertheless, the accuracy smart meters in the network and the prognosis depend very much on the positioning and demographic information available in this section of the supply network. For future studies a large-scale implementation of smart meters would be desirable instead of summarized measurements of small city districts in order to enhance the prognoses´ quality.
Lessons learned from technology operation	-
Technology performance and best practices	-
Outcome of assessments	-
Organisations	OOWV IWW ICCS/NTUA
Contact persons	• Julia Oberdörffer (oberdoerffer@oowv.de) • Kristina Wencki (k.wencki@iww-online.de) • Katharina Gimbel (k.gimbel@iww-online.de) • Marcel Juschak (ma.juschak@iww-online.de) • Stavroula Manouri (stavroula.manouri@gmail.com) • Dimitrios Bouziotas (Dimitrios.Bouziotas@kwrwater.nl) • Christos Makropoulos (cmakro@mail.ntua.gr)
Data Manager	• Katharina Gimbel (k.gimbel@iww-online.de) • Marcel Juschak (ma.juschak@iww-online.de) • Stavroula Manouri (stavroula.manouri@gmail.com) • Dimitrios Bouziotas (Dimitrios.Bouziotas@kwrwater.nl) • Christos Makropoulos (cmakro@mail.ntua.gr)
Costs	The UWOT software is available for research purposes free of charge upon request on a time limited license. For commercial purposes there are commercial agreement options. The other tools are open source and free of charge.
Tags	climate change, re-use, recycling, water management, greywater, rainwater, groundwater, water reuse, water demand, water supply, machine learning, GIS
Publications/Reference	Schwesig et al. (2023): Digitale Lösungen für eine wasserbewusste Gesellschaft, Energie|Wasser-Praxis, 6+7/2023, pp. 54-59. https://energie-wasser-praxis.de/wp-content/uploads/2023/06/2023_06_06_FB-Schwesig_0607_2023.pdf

Images

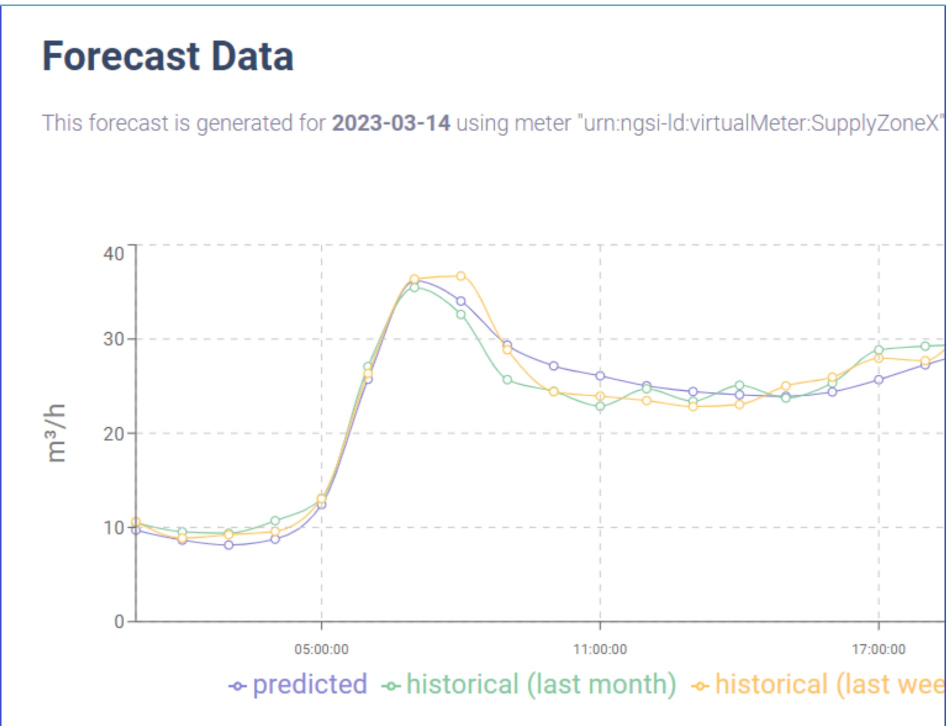


UWOT baseline model for the test case



Points of interest
Query point [EPSG:3035]
☐ Nur gewählte Objekte
Requested water quality
4 = other (if water body falls under none of the above mentioned, or chemical status is unknown)
Country polygons [optional]
CountriesWorld [EPSG:3035]
State polygons [optional]
LowerSaxony_outline [EPSG:3035]
County polygons [optional]
LowerSaxony_County [EPSG:3035]
Community polygons [optional]
LowerSaxony_Community [EPSG:3035]
Land use [optional]
LandUse [EPSG:3035]
Water demand per capita [optional]
WaterDemandPerCapita [EPSG:3035]
Total water consumption [optional]
TotalWaterConsumption [EPSG:3035]
Water consumption by sectors [optional]
WaterConsumptionBySectors [EPSG:3035]

Screenshot data selection regional demand-supply matching tool (#23)

	 Forecast Data This forecast is generated for **2023-03-14** using meter "urn:ngsi-ld:virtualMeter:SupplyZoneX" Short-term demand forecast with historical reference values for plausibility checking
Caption/Source	Captions are specified directly with the pictures above. Pictures are provided by ICCS (picture 1) and IWW (picture 2 and 3).

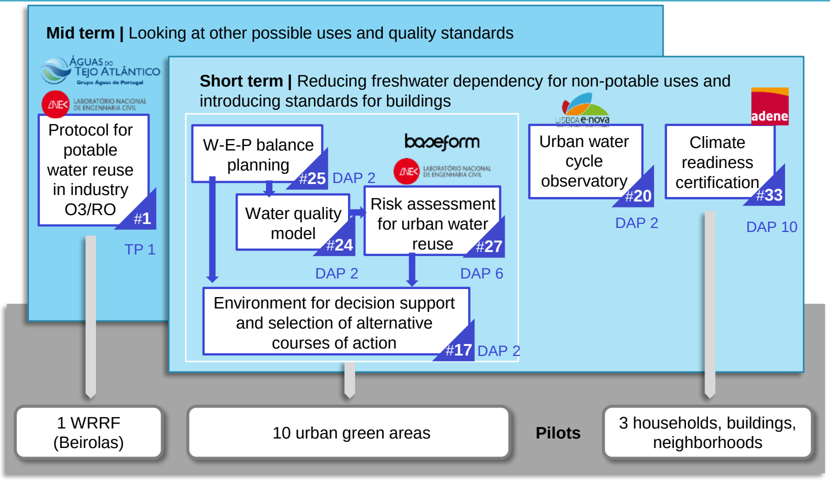
16.3 Lisbon

Table 47: Summary table for LL Lisbon

Title	Methods, algorithms and software for a smart allocation of the water quality (fit-for-purpose) and quantity (water efficiency) in Lisbon. The ambition is to (i) improve the water supply / demand management and ultimately the city's water-energy-phosphorus (WEP) footprint while increasing the green areas, (ii) promote the safe use of alternative sources (e.g., reclaimed water), and (iii) promote climate-ready (water-energy efficient, climate-change proof) housing.
Description	Making Lisbon a water-smarter city implies the involvement of different stakeholders in the provision and use of water. The following approaches were considered for the desired transformation into a water-smarter society: ▪ To increase the citizens' awareness about the local context regarding the water use in the city via the provision of appellative information and to inform individual entities about their water consumption, in case of smart water metering (Tool #20). ▪ To support the decision-making process of water demand planners and managers in urban, municipal and water utility contexts, by delivering an overview of the current water supply and water demand in the city to enable prioritizing strategic and tactical planning options (Tools #17, #24, #25, and #27). ▪ To guide or assess the promotion of climate adaptation in housing via a certification process used by housing owners and planners (Tool #33).

Reference point	https://earth.google.com/web/@38.73328057,-9.14002902,76.18325293a,14074.25418275d,35y,0h,0t,0r
Location	Lisboa, Portugal
Country (-ies)	Portugal
URL	NA
Project	BWS
Challenges	▪ Water Scarcity, ▪ High drinking water demand due to dense or growing resident population and economy, ▪ Dependent on distant freshwater resources, ▪ Untapped efficiency potential of water resources, ▪ Need for safe water reuse schemes, including building and managing a dedicated, reclaimed water distribution system.
Tools/Product/Services	▪ Environment for decision support and selection of alternative courses of action (#17) ▪ UWC observatory (#20) ▪ Reclaimed water quality model in the distribution network (#24) ▪ Water-energy-phosphorous balance planning (#25) ▪ Risk assessment for urban water reuse (#27) ▪ Climate-readiness certification tool (#33)
Technologies	1 ozone oxidation/reverse osmosis (O3/RO) pilot installed at Beirolas water resource recovery facility (WRRF) for demonstration of water reuse in the food industry, namely, in artisanal craft beer production (direct potable reuse, DPR)
Scales	▪ Tool #20: city level ▪ Tools #17, #24, #25, and #27: urban facility (e.g., public park), neighbourhood, city, region ▪ Tool #33: household, building and neighbourhood
Legislation	▪ National (Portuguese) legislation: Decree-Law 119/2019 on water reuse. ▪ European regulations: Reg. (EU) 741/2020 on minimum requirements for water reuse in agricultural irrigation and Urban Wastewater Treatment Directive (recast) (new proposal under approval).
Synergistic benefits	To be reported in MS32.
Facts of the applied technologies	To be reported in MS32.
Key Performance Indicators	To be reported in MS32.
Requirements and conditions	To be reported in MS32.

Key lessons	A selection of key lessons Pros: ▪ Since the goal is to optimise the use of water in the city for non-potable uses, the decision-making process should be demand driven, i.e., with a fit-for-purpose quality to satisfy an efficient water use. ▪ Decision-making tools must provide structured, user-friendly methodologies for human health and environmental risk assessment, making expert-knowledge available for risk managers and stakeholders responsible for non-potable water uses in the city. ▪ There is interest in the housing market in providing information on environmental aspects of buildings. Challenges: ▪ Compiling information about water demand for non-potable uses in the city and available water sources can be difficult. Applying tools that function as data repository catalyses a proper data management. ▪ The results naturally depend on the quantity and quality of the information available for the calibration and use of the hydraulic and water quality models. The effort required to obtain this information is largely compensated by the benefits that the control of the disinfection process of reclaimed water has on the risk management associated to water reuse, as well as on the investment and operational cost of the reuse system. ▪ Exploiting the full potential of a smart-water allocation in Lisbon requires the existence of a public reclaimed water distribution network (nowadays available only in some areas), with sound asset management.
Lessons learned from technology operation	To be reported in MS32 (suggested to be added in M45).
Technology performance and best practices	To be reported in MS32 (suggested to be added in M45).
Outcome of assessments	To be reported in MS32 (suggested to be added in M45).
Organisations	The Lisbon LL gathers six partners: ▪ CML (Lisbon Municipality), with a linked third-party – LEN (Lisboa E-Nova). ▪ LNEC (Laboratório Nacional de Engenharia Civil) ▪ ADTA (Águas do Tejo Atlântico) ▪ ADENE (Agência para a Energia) ▪ ICS-UL (Instituto de Ciências Sociais da Universidade de Lisboa)
Contact persons	Maria João Rosa, mjrosa@lnec.pt, LNEC (LL mentor) Rita Ribeiro, rribeiro@lnec.pt, LNEC (LL deputy-mentor) Pedro Teixeira, pedro.teixeira@cm-lisboa.pt, CML (LL owner)
Data Manager	Not available at this stage.
Costs	Not available at this stage.
Tags	#reuse #water #multicriteria #supply #demand
Publications/Reference	Costa, J., Mesquita, E., Ferreira, F., Rosa, M. J., and Viegas, R. M. (2021). Identification and modelling of chlorine decay mechanisms in reclaimed water containing ammonia. Sustainability, 13(24), 13548. Ribeiro, R., Rosa, M.J. (2022). Avaliação do risco para a saúde humana associado à reutilização de água: construção de cenários de exposição. 20.º ENASB, Cascais, 24-26 November 2022, 5 p. (communication in a conference)

Images	
Caption/Source	Lisbon LL aims (i) to demonstrate the potential for safe potable water reuse in the beverage industry in the mid to long run, and (ii) in the short term, to promote water (and related energy and phosphorus) efficiency, water smart allocation (fit-for-purpose quality), circular economy, and safe non-potable urban water reuse.

17 Annex F: Technology Readiness Level

Where a topic description refers to a TRL, the following definitions apply, unless otherwise specified.

Table 48: Technology readiness levels.

Level	Description
Level 1 - Basic Research: basic principles are observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include fundamental investigations and paper studies.
Level 2 – Applied Research: technology concept and/or application formulated	Once basic principles are observed, practical applications can be formulated. Examples are limited to analytic studies and experimentation.
Level 3 – Critical function, proof of concept established	Active research and development are initiated. Laboratory studies aim to validate analytical predictions of separate components of the technology. Examples include components that are not yet integrated or representative.
Level 4 – Laboratory testing of prototype component or process	Design, development and lab testing of technological components are performed. Here, basic technological components are integrated to establish that they will work together. This is a relatively “low fidelity” prototype in comparison with the eventual system.
Level 5 – Laboratory testing of integrated system	The basic technological components are integrated together with realistic supporting elements to be tested in a simulated environment. This is a “high fidelity” prototype compared to the eventual system.
Level 6 – Prototype system verified	The prototype, which is well beyond that of level 5, is tested in a relevant environment. The system or process demonstration is carried out in an operational environment.
Level 7 – Integrated pilot system demonstrated	Prototype is near, or at, planned operational system level. The final design is virtually complete. The goal of this stage is to remove engineering and manufacturing risk.
Level 8 – System incorporated in commercial design	Technology has been proven to work in its final form under the expected conditions. In most cases, this level represents the end of true system development.
Level 9 – System ready for full scale deployment	Here, the technology in its final form is ready for commercial deployment.
Level beyond 9 - Market introduction	The product, process or service is launched commercially, marketed to and adopted by a group of customers (including public authorities).

18 Annex G: Template tables

Below there are the template tables that have been used in previous sections for the description of tools and their application to the different cases studies. Instructions of anticipated information are included in each field. It is noted that the definition of those tables and their fields has been done in collaboration with WP7. The collected information is used to populate the Water Europe Marketplace (aka. the Knowledge Portal of WP7, Task 7.1).

Table 49: Template table for tool's attributes and description.

Tool's attribute	**Description**
Type of product	*Select which of the following statements describe best your product. You may choose more than one statement.* • *A software supporting the Circular Economy* • *A hardware product or a technological device around the Circular Economy* • *A service, offered as part of a Circular Economy enabling portfolio* • *A methodology or a process related with the Circular Economy*
Name	*Name of the tool/product.*
Description	*General information on the product, its components and the scope of application*
Abbreviation	*The acronym/abbreviation of the tool/product (if available)*
URL	*Related URL, providing further information on the product/tool, if available*
Costs	*If applicable, describe the costs and conditions for purchasing the product, obtaining a license or providing the service*
Target audience	*Profile of users who would find the tool/product useful or/and are qualified to use it.*
Actors, roles and interactions	*Actors involved (e.g., water utilities, industries, technology providers, end-users), their roles and their interactions.*
Unique selling points /Added Value/Innovation	*Description of the unique selling points, added value and innovation elements of the tool, product or service*
TRL	*The Technology Readiness Level (TRL) giving an estimate of the technology maturity of the related tool, product or service.*
Technical requirements	*Technical requirements to obtain, install or run the tool, product or service*
Environment	*Operating environment in which the tool/application runs e.g., Microsoft Windows (if applicable)*
Version	*Current stable version number or version code of the tool, product or service (if applicable)*
Initial release	*Year of the initial release of the tool (if applicable)*
License type	*General license type (free or commercial) (if applicable)*

Programming language/technologies used	*The programming languages or/and major technologies which are used to implement the tool/application (if applicable).*
Open interface	*Describe the different integrations options, if any, which are supported by the tool/product e.g., web service, libraries, etc. (if applicable)*
Graphical User Interface / Headless software	*Describe if the tool can be executed in headless mode, batch mode, if it is command line executed and/or if it has GUI, etc. (if applicable)*
Supported spatial scales	*Different spatial scales that can be supported by the tool and applied e.g., household, neighbourhood, city, region, etc. (if applicable)*
Supported temporal scales	*Different temporal scales that can be supported by the tool and applied e.g., daily, annual, etc. (if applicable)*
Water Use Types	*Indicate the water use types with which the tool is related e.g., urban, industrial, rural and agriculture*
Compatibility with FIWARE	*Indicate whether the tool is compatible with FIWARE or not.*
Organisations	*Organisation(-s) that own the tool, product or service.*
Contact details	*Contact details of the person related to the tool, product or service. Needs to include at least first name, last name and email.*
Data Manager	*Indicate the persons who will be responsible to monitor and update the information about the tool/product/service in the Water Europe Marketplace (https://mp.watereurope.eu/l/Product/). Include the contact details by providing at least first name, last name and email.*
Technologies	*Circular economy technologies related with the tool, product or service. You may examine the Overview of Technologies available in the Water Europe Marketplace (https://mp.watereurope.eu/technologies/) and select among them or add new technologies in order to be included.*
Tags	*Tags related with the tool, product or service.*
Images	*Characteristic images or schematic representations of the tool. In cases where the file is provided as a separate file, all known formats up to a certain size which are supported by web browsers are accepted (e.g., jpeg, png). The file must not exceed the size of 5MB*.
Caption/Source	*Caption needs to be provided for each illustration in textual format, as well as its reference/source that should be included.*
Publications	*Publications related with the tool, product or service*

Table 50: Template table for the application of tools/technologies to case studies and LL.

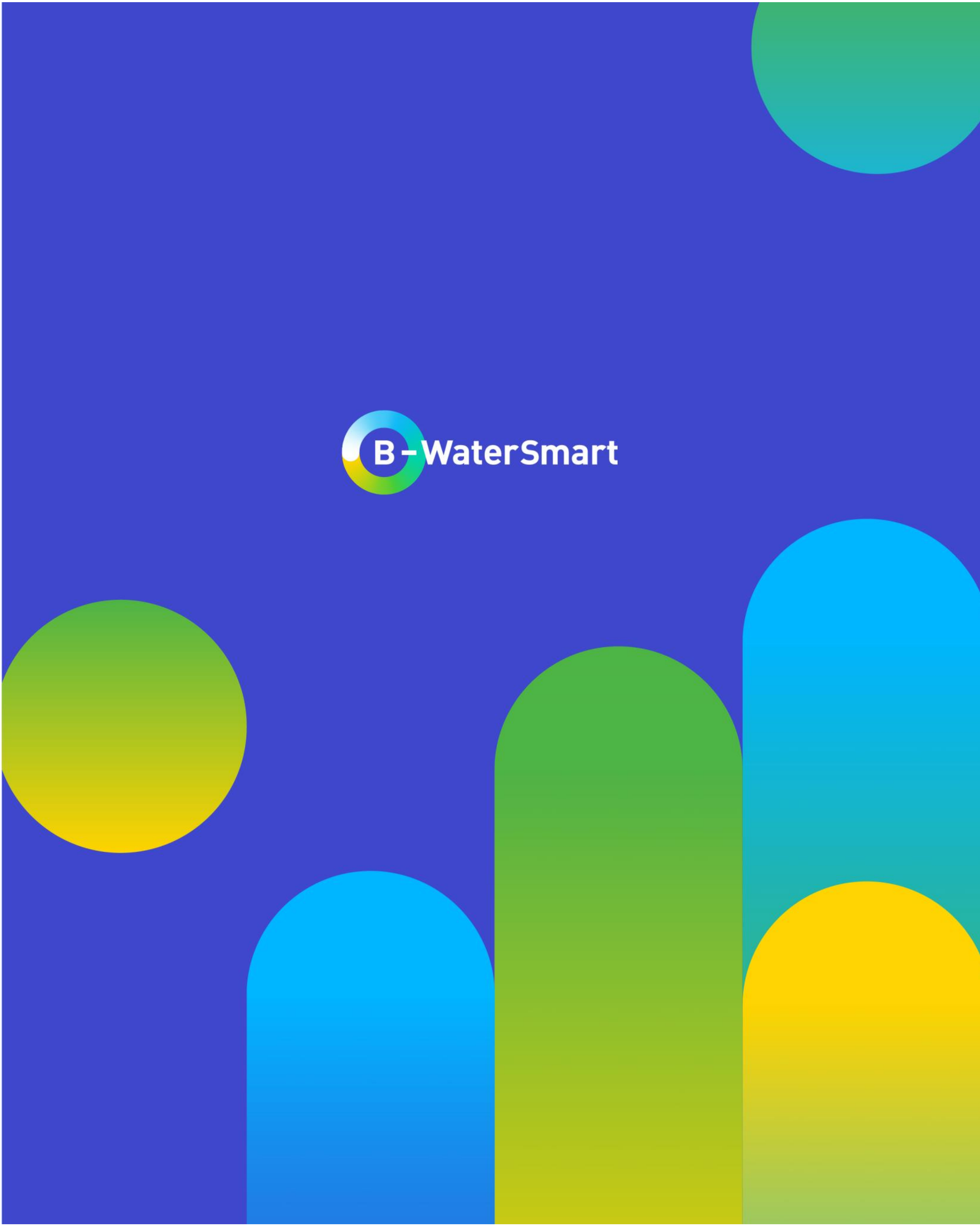
Indicative application of the tool	
Title	*Title of the case study where the tool/product/service is applied.*
Description	*Brief description of the application of the tool/product/service to the case study/Living Lab.*

Reference point	*Indicate a point location that best represents the application of the tool to the Case Study/Living Lab by sharing a Google's maps location link.*
Location	*The name of the city /area/geographical location which best represents the application of the tool to the Case Study/Living Lab.*
Country (-ies)	*Countries hosting the case study/Living Lab where the tool has been applied.*
URL	*Related URL, providing further information on the application of product/tool to the Case Study/Living Lab, if available*
Project	*Related project where the application of tools to the Case Study/Living Lab has been applied (if applicable)*
Challenges	*Select the challenges that are addressed through the application of tools and/or technologies. Multiple selection can be made:* • *Water Scarcity,* • *Limitations to water reuse due to high salinity/nitrates,* • *Limitations to water reuse and recovery due to low acceptance,* • *High drinking water demand due to dense or growing resident population and economy,* • *Untapped efficiency potential of water resources,* • *High or increasing irrigation water demand for agriculture,* • *Groundwater overexploitation,* • *Water quality deterioration,* • *Dependent on distant freshwater resources,* • *Increasing water demand by growing industrial sectors,* • *Need for reuse and recovery schemes for wastewater & sludge,* • *Other*
Tools/Product/Services	*Tools/Product/Services that have been applied in the case study/Living Lab.*
Technologies	*Circular economy technologies related with the tool, product or service. You may examine the Overview of Technologies available in the Water Europe Marketplace (https://mp.watereurope.eu/technologies/) and select among them or add new technologies in order to be included.*
Scales	*Typical operational scales of this case study/Living Lab related to the application of tool(-s)/technology(-ies), i.e., the scales at which the solutions/technologies are implemented and have an impact.:* • *Local (e.g., single treatment plant, industrial site or city quarter),* • *City (whole city level),* • *Metropolitan (extending beyond the city e.g., into neighbouring cities or peri-urban fringe area),* • *Regional (across several municipalities and/or administrative borders, incl. rural areas),* • *National (relating to a whole country),* • *Other*
Legislation	*EU/National/Regional/Local regulations that are related to the application of tools/technologies to the LLs e.g., limits of quality parameters of reused water, etc (if applicable).*
Synergistic benefits	*Description of the synergistic benefits that came along from the application of the tool/product/services to the case study and its combination with other tool(s) and/or related technologies.*
Facts of the applied technologies	*Capacity, production rate or yield, energy consumption, CAPEX, OPEX. (If applicable, related to the technologies and the WP2 work).*

Key Performance Indicators	*KPIs for every technology and comparison to the situation before its implementation (if applicable, related to the technologies and the WP2 work).*
Requirements and conditions	*Requirements, conditions or constraints that might have been encountered for the application of the tool/product/service in the case study.*
Key lessons	*Brief textual description of the key lessons learned from the application of tools to the case study and the potential combined used of technologies/tools.*
Lessons learned from technology operation	*Required competence, maintenance, technological risk (downtimes and its avoidance). If applicable, related to the technologies and the WP2 work.*
Best practices	*Best practice guidelines to construct and operate the applied technologies (if applicable, related to the technologies and the WP2 work).*
Outcome of assessments	*LCA, LCC, QMRA, QCRA, Technical RA, etc. (if applicable, related to the technologies and the WP2 work)*
Organisations	*Entities which are involved in the case study/Living Lab.*
Contact persons	*Contact persons for this case study where the tool/product has been applied. Needs to include at least first name, last name, email and organisation.*
Data Manager	*Indicate the persons who will be responsible to monitor and update the information about the application of the tool/product/service to the specific case study/LL in the Water Europe Marketplace (https://mp.watereurope.eu/l/CaseStudy). Include the contact details by providing at least first name, last name and email.*
Costs	*Approximate costs for tool/technology implementation including e.g., purchase, setup, etc.*
Tags	*Keywords that capture knowledge about the specific case study/Living Lab and the application of the tool.*
Publications/Reference	*Issued publications that refer to the application of tool/technology to the case study/Living Lab.*
Images	*Characteristic images or schematic representations of the tools' applications to the Case Study/Living Lab. In case provided as a separate file, all known formats up to a certain size which are supported by web browsers are accepted (e.g., jpeg, png). The file must not exceed 5MB in size.*
Caption/Source	*Caption needs to be provided for each illustration in textual format, as well as its reference.*

19 Annex H: Summary table of the tools documented in D3.4/D3.5

#No.	Tool name (leading partners)	Living Lab using the tool	Deliverable
16	Water reuse strategic platform (VERI/ENG)	Venice	D3.4
17	Environment for decision support and alternative course selection (BASEFORM)	Lisbon	D3.4
18	Re-Actor (CET, AMA)	Alicante	D3.4
19	Sludge management platform (VERI/ENG)	Venice	D3.4
20	UWC observatory (Lisboa E-Nova, third party linked to CML)	Lisbon	D3.4
21	Stormwater reuse management system (AQUAFIN/VITO)	Flanders	D3.4
22	UWOT (ICCS/KWR)	Flanders/East Frisia	D3.5
23	Regional Demand-Supply Matching GIS tool (IWW)	East Frisia	D3.5
24	Reclaimed water distribution network water quality model (BASEFORM)	Lisbon	D3.5
25	Water-energy-P balance planning module (BASEFORM)	Lisbon	D3.5
26	QMRA+ (KWR)	Flanders	D3.5
27	RA-Reuse (BASEFORM)	Lisbon	D3.5
28	Short-Term Demand Forecasting Tool (IWW)	East Frisia	D3.5
29	Nessie System (ICCS/NTUA)	Bodø	D3.4
30	Environmental Dashboard (Nordkontakt AS)	Bodø	D3.4
31	SuTRa (KWR) (former ASR-pro tool)	Flanders	D3.5
32	Digital Enabler (ENG)	Venice	D3.4
33	Climate-readiness certification tool (ADENE)	Lisbon	D3.4



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 869171. The publication reflects only the authors' views and the European Union is not liable for any use that may be made of the information contained therein.