nextGen
Circular Water Solutions

D3.7 Serious Game for Water in the CE final version

AUTHORS : MEHDI KHOURY & BARRY EVANS (UNEXE)

DATE : 26 OCTOBER 2022

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

Technical References

Project Acronym	NextGen
Project Title	Towards a next generation of water systems and services for the circular economy
Project Coordinator	KWR
Project Duration	01/07/2018 – 30/11/2022

Deliverable No.	D3.7 Serious Game for Water in the CE final version
Dissemination level [1]	PU*
Work Package	WP3
Task	3.2.3
Lead beneficiary	UNEXE
Contributing beneficiary(ies)	ICCS, NTUA, EUT
Due date of deliverable	30-11-2022 (M53)
Actual submission date	26-10-2022 (M52); revised 9-1-2023

[1] PU* = Public, but temporary embargo (restricted for members of the consortium, including the Commission Services) until published in open access paper form

Document history

V	Date	Beneficiary	Author
1	26/08/2022	UNEXE	Mehdi Khoury, Barry Evans – outline
2	26/10/2022	UNEXE	Mehdi Khoury, Barry Evans – final, after quality review by ICCS
3	09/01/2023	UNEXE	Mehdi Khoury - revised

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N°776541

Updates of previous version

To answer the reviewer's comment: **"However, the recommendation of the previous review for linking the serious game to the Augmented Reality app was not followed"**, although an interesting idea, building a Serious Game representation of a virtual town that would reflect changes made by users through their phone with Augmented Reality was unfortunately out of the scope of the current project (not in DoA), and we therefore did not have the resources to build such substantial additional work.

In answer to the reviewer's comment: **"The deliverable should present more clearly the specific features and results of the game for the 2 specific demo cases and give an outlook how it will be used in future",** we have updated the deliverable by adding the following in the results section.

*"In the **Athens** case study, a virtual neighbourhood connects the household's wastewater to a sewer mining unit. Energy and water savings made available by this sewer mining unit are linked to a tree nursery. These saving when made from sewer mining are put into perspective with the savings that can be achieved while switching water related household technologies. Typically, changes at the household level tend to have a much greater effect on the overall water and energy footprint than sewer mining. For example, changing the shower heads in every bathroom in households to a "fog-shower" can increase the ability of the overall neighbourhood to supply water by at least 15%, and increase energy savings up to 30%. By comparison, scaling all sewer mining activities to the maximum (50 units) will produce a 2% increase the ability of the system to meet water demand, and a 9% increase in energy savings. As far as the tree nursery is concerned, players are made aware that the bottleneck on reusing heat, producing fertilizer, and saving on waste pruning costs is the number of sewer mining units required to process the sludge. This serious game can help understanding relevant questions in the future for novel tree nurseries that seek to use sewer mining technology: finding the optimum number of sewer mining units depending on the size of the neighbourhood and produced sludge in order to minimise energy and water footprint, increase fertilizer production and minimise pruning waste landfill costs*

*The **Costa Brava** case study, shows the simultaneous impact of two coexisting different urban areas: a touristic urban area that concentrates 90% of hotels and tourism activity and hosts 30% of the local residents, and a residential urban area that concentrates only 10% of hotels and tourism activity and hosts 70% of the local residents. The effects of different scenarios can be observed, and combinations of helpful measures can be explored. For example, excessive tourism corresponding to a tripling of the tourist population person-night stays in summer and winter results in an increase of 28% of the blue water demand and energy demand in the touristic area, and an overall increase aquifer stress from 43% to around 68%. Compounding this situation with a drought scenario will rise aquifer stress to 100%, meaning that the aquifer level goes below a critical threshold for the months of June, July, and August for every one of the 20 simulated years. One of the advantages of using the*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

game, is that it allows a better understanding of what are the best measures that can help to mitigate this problem. As usual, switching water related technologies can have a major impact. For example simply changing shower heads to NASA inspired "fog showers" in hotels will reduce the blue water consumption by 11% in the touristic area. Similarly, adding vacuum toilets, front loader eco laundry, and energy saving dishwashers in the same hotels will reduce the touristic area blue water consumption from 2.1 million cubic meters/year to 1.2 million cubic meters/year (a 43% reduction). In this context, the serious game becomes a useful tool for exploring the future possible impacts of installing certain combinations of water technologies in an area like Costa Brava, dominated by tourism based economic activities and plagued by drought and aquifer management problems."

In answer the reviewer's comment: **"It is not clear whether the game was implemented in different languages of demo sites as foreseen in the DoA"**, we have updated the deliverable by adding the following in section 3.2 about the user interface:
*"Regarding the facilitation of language access for the demo sites, the introductory text on the splash screen that describes each respective case study is now available in the given local language (for Athens, the description of the game for that case study is in Greek, and for Costa Brava, it is in Spanish) as shown in the screenshots now visible in **appendix A11**. It is also worth highlighting that the common working language was in English during development and that it was agreed that during the local engagement gaming sessions, someone familiar with the game who speaks the local language would be facilitating the session and that there was therefore no need to translate in-game indicators."*
Appendix A11 has been added with screenshots of welcome screens in different languages.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

Summary

This deliverable describes the final version of the Serious Game for water in the circular economy, developed within the NextGen project. It accompanies the actual game available online: http://nextgen-serious-game.s3-website.eu-central-1.amazonaws.com/nextgen-choice.html

The NextGen Serious Game aims to allow participants to understand circular economy for water by observing interactions between different components in the urban water cycle and energy and their effects on flows of water and energy and material recovery. Participants can range from the general public to policy makers, to water, energy, and environment specialists.

The NextGen Serious Game has been developed in three different versions: a virtual generic urban catchment area referred to as "Toy Town", the demo case for Athens that focuses on sewer mining, and the demo case for Costa Brava that focuses on a Mediterranean touristic setting with aquifer management and desalinisation.

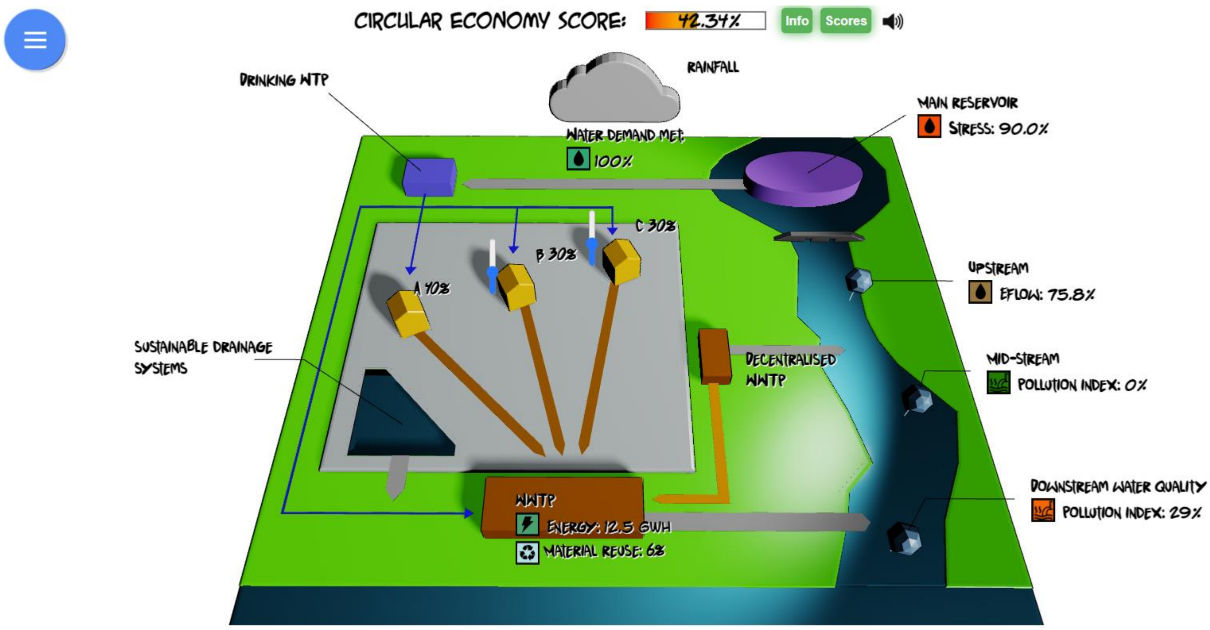


Figure: Screenshot of the NextGen Serious Game (Toy Town).

Several physical and online game-playing events took place where participants were able to take the appropriate measures to maximize Circular Economy for water when a virtual catchment was exposed to challenging scenarios, e.g., lower rainfalls and population growth. The players included students, environmental scientists, engineers, policy makers, and members of the public.

The NextGen Serious Game was successfully used as a teaching tool in student classrooms. Participants who joined the supervised training sessions were on average 26% more likely to

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

answer correctly technical questions despite the added complexity of the subject studied: Circular Economy in the context of the urban water cycle.

As a debate facilitation tool, the game also proved to be a surprisingly effective and thought-provoking tool able to contribute to the discussion by bringing multi-disciplinary insights: the most notable one being the potential of metal mining wastewater to save exergy and carbon emissions.

Finally, the NextGen Serious Game was used to organize the first e-sport competitive tournament between water professionals at an industry conference. The software architecture allowed rapid and reliable deployment to be done at the scale required for the estimated number of users and at a reasonable cost. This achievement could mark the start of a new series of hybrid events that could soon take place in the water industry: conferences where experts compete against each other to solve complex problems via Serious Games.

To conclude, the NextGen Serious Game proved to be a powerful tool that allows players to visualise and understand options, scenarios, opportunities and challenges in a more circular approach to water management.

Disclaimer

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

Table of Contents

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N°776541

1. Introduction

NextGen aims at actively involving and engaging stakeholders from the whole water value chain, with a particular emphasis on end-users and the general public and offering an engagement environment around the innovations demonstrated. This is done among others by demonstrating Serious Games activities with the purpose of engaging end-users and citizens in experiencing and visualising circular water solutions.

In contrast with the natural regional hydrological cycle that focuses on environmental condensation, precipitation and evaporation, the urban water cycle focuses on how human activity changes stormwater intake, water conveyance, groundwater use, water drainage, wastewater treatment and discharge. As an anthropogenic water cycle, it can be easily associated with “Circular Economy”, itself defined by The Ellen MacArthur Foundation (2010) as a “systematic approach to development designed to benefit businesses, society, and the environment.” It relies on three principles to decouple growth from the consumption of infinite resources: reducing waste and pollution, reusing products and materials, and the regeneration of natural systems. When applied to the urban water cycle, it becomes a complex multidisciplinary endeavour that demands in-depth knowledge of interconnections between areas such as wastewater treatment, energy and water management, environmental health, and material reuse. Providing a broad understanding of the essential mechanisms behind the water in the circular economy for a general audience can therefore be quite problematic.

The NextGen Serious Game responds to this challenge: a Serious Game taking the shape of a simulation based online educational tool designed to engage all types of stakeholders including citizens, businesses, and policy makers on the topic of Circular Economy for Water. Serious Games were introduced by Abt (1970) as “games used for purposes other than mere entertainment”. Now viewed as an integral part of Simulation based Education (SE), they have taken advantage in substantial advances in the field of computing to allow innovative methodologies to be applied for educational purposes, decisions support, and public policy making (Campos et al., 2020). Many serious games have been developed on the topic of sustainability (Katsaliaki and Mustafee, 2012; Stanitsas et al., 2019) as a broad concept related to people, the planet, and the economy. Regarding the related and more specific concept of Circular Economy, there is evidence of a smaller body of work (De la Torre et al., 2021) with an emphasis on resource management, individual economic benefits through input reduction, efficiency gains, waste avoidance and reduction of environmental impacts. There are examples of serious board games focusing on material criticality (“In the loop” - Whalen et al., 2018) and mostly energy transition toward sustainable generation (with the examples of Energy Safari (Gugerell and Zuidema,2017) and Energy Transition Game (2020) with an emphasis on role playing. Digital Serious gaming is being applied to topics such as the impact of renewable energy policies on carbon emissions (Climate Change Serious Game, 2020), the economic, environmental and security trade-offs and opportunities associated with different energy sources (Energyville, 2020), energy conservation for householders (Encon City - Stanitsas et al., 2019), and industrial training to support sustainable practice (Rai and Beck, 2017).

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N°776541

Although serious games on Circular Economy do often mention and include water as an important of part of the problem, they do not, to our knowledge show in a cohesive way how combinations of components inside the urban water cycle such as households water reuse technologies can have for example a major impact on water stress, energy use, and water quality; how wastewater treatment technologies like biogas generation and sewer mining can lower carbon emissions; and how nature based solutions such as sustainable drainage systems can deliver cost-effective ways to limit discharges of untreated water into rivers. Similarly, although surveys looking at the use of Serious Gaming in the domain of water (Savic et al., 2016; Mittal et al., 2022) show a focus on the management of water systems (Savic et al., 2016; Geneva Water Hub, 2016; Games at the World Water Day, 2015; Tygron Engine, 2016, Susnik et al, 2018), flood and drought prevention (Rijcken and Christopher, 2013; Khoury et al., 2018; Hill et al., 2014), training for emergency response (Wang and Davies, 2015; De Kleermaeker et al., 2011; De Kleermaeker et al., 2012), and conflict resolution (Seibert and Vis, 2012), there is no systematic emphasis on a link to Circular Economy.

This work aims at bridging this gap by introducing a serious game that aims to raise public awareness of circular economy for water, to increase understanding of the interactions between different components of the urban water cycle in circular economy, and to facilitate the dialogues between different stakeholders to reach consensus in decision making. The learning methodology in use combines a pedagogically driven design that gently introduce participants to the relevant concepts in an interactive way based on constructivism (Devries and Zan, 2003) (where learners take an active role constructive knowledge by “doing”) and experiential learning (Kolb, 1984; Angehrn and Maxwell, 2009) (where experience leads to the formulation of hypotheses and then their validation). Furthermore, building on previous work (Khoury et al., 2018) that incorporates the Socratic method (Hunnicutt, 1990), participants are prompted to question some of their own assumptions and replace them with more sound alternatives uncovered while exploring the serious game.

In this document, we will first discuss the conceptual design, and then look at the implementation. Finally, we will analyze the results and discuss further work in conclusion.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N°776541

2. Conceptual design

The NextGen Serious Game aims at enabling both experts and neophytes to reach three sequential goals: goal one - understand the building blocks of the urban water cycle; goal two - discover the influence of external factors such as rainfall and population growth; goal three - discover what actions lead to minimising stress on the system and maximising circular economy. Furthermore, basic concepts of the urban water cycle need to be made clear and easy to explore for the benefit of the general public and, at the same time, it is also necessary to inject specific facts from different disciplines for the benefit of experts (typically, water, energy, or environmental sciences professionals will be offered interesting insights that can only be gathered from running the model - for example, how installing a fog shower in every household can reduce the overall energy footprint for water usage inside the virtual catchment by up to around 30%).

2.1 Learning methodology

Concretely, in order to reach these three learning goals, the Serious Game implements the following five learning stages (hybrid learning) methodology (as shown in **Figure 1**) extending work done by Khoury et al. (2018):

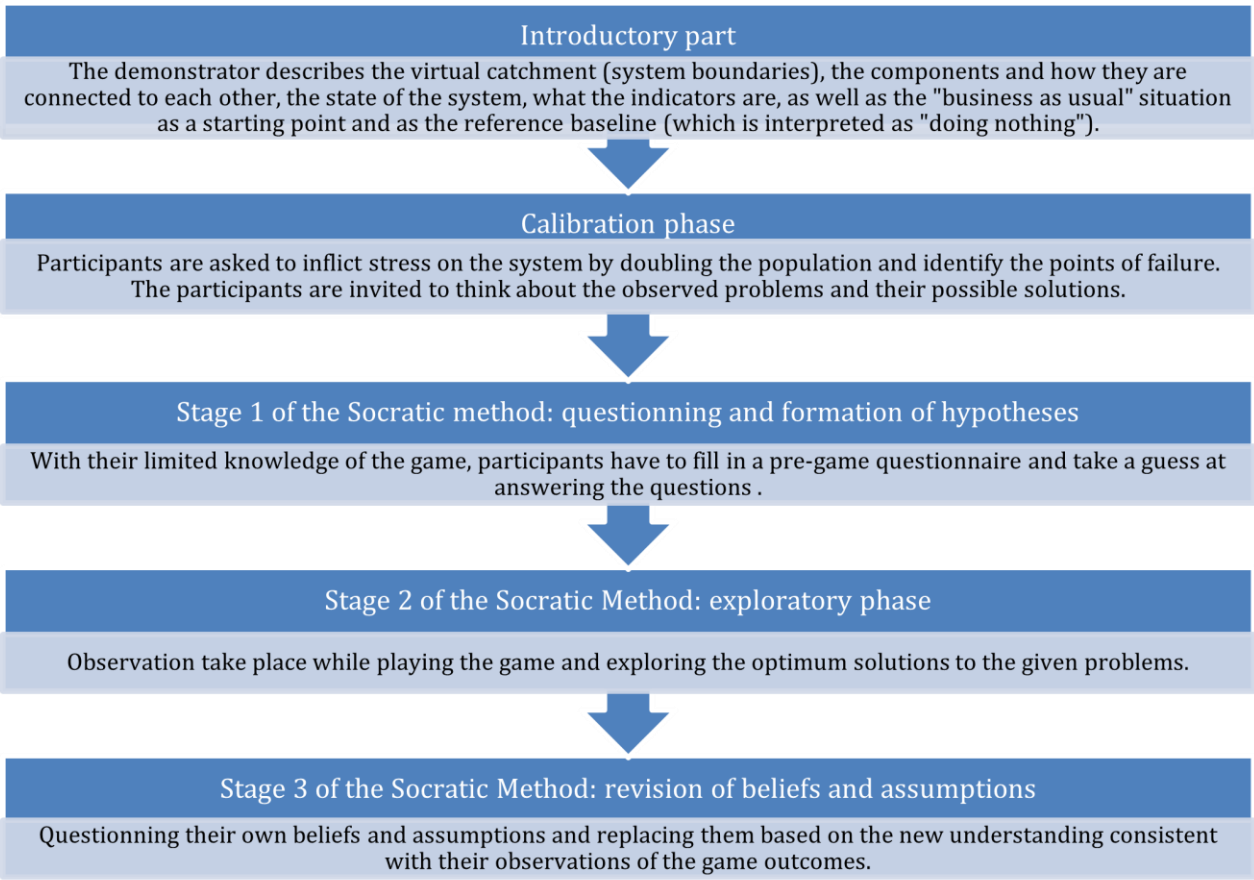


Figure 2. The serious game uses a five learning stages methodology mixing constructivist experiential learning (introduction followed by a calibration phase) and the disruptive three stages Socratic method.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

The introductory phase contributes to the first learning goal where users are shown the building blocks of the urban water cycle. The water resources are first identified (municipal water supply and precipitation) in a virtual catchment. Elements that cover the distribution, storage, use, collection, treatment, and the discharge of stormwater and wastewater are identified. The system is shown in its default starting state (akin to a "business as usual" situation) and game score indicators tend to show minor water and environmental stress, as well as an average Circular Economy health score.
The calibration phase contributes to the second learning goal. Different initial states corresponding to different typical crisis scenarios are simulated. For example, the demonstrator suggests observing the consequences of doubling the population and reducing rainfall. Points of failure are then identified in front of the whole group: observations are made about the system not being able to meet the town water demand, the town reservoir being constantly stressed, the environmental flow reduced, thereby threatening the balance of the river ecosystem, and the water quality in the river downstream being poor. Emphasis is put on the fact that water is not an infinite resource, and that the urban water cycle is a system on edge that can easily break down. It is then suggested to the players that they will have to explore how they can improve the situation, by trying combinations of measures and playing the game.
In stage 1 of the Socratic method, participants must fill in a pre-game questionnaire. This is the beginning of a series of steps aiming to help participants to achieve their third learning goal. They are asked to answer multiple choice questions and therefore are guided towards validating some of the hypotheses implied by the different possible answers. In other words, with their limited knowledge of the game, they have first to guess what the best possible initial set of measures is that will improve the Circular Economy score.
Stage 2 of the Socratic method is an exploratory phase. Participants are asked to improve the overall Circular Economy score while minimizing some additional requirements, e.g., making sure that the town water demand is always met at 100% and that pollution stays below a certain threshold. This phase requires players to actively experiment with the components and how they can be connected, to find the combinations of factors leading to the worst and best outcomes, respectively. While doing so, they will stumble upon answers to the questions asked previously and will need to think about them and "act" within the game.
Stage 3 of the Socratic method capitalizes on the previous explorative work. Participants must fill in a post-game questionnaire identical to the first one. As the participants answer based on their experience playing the game, they are brought to question their initial assumptions and replace them with new ones based on model outcomes.
Having chosen a methodology, the next challenge is to find out what aspects of real-world problems to include in the Serious Game.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

2.2 Choosing what real-world problems need to be included in the Serious Game

The game models a virtual urban catchment named "**Toy Town**" built to be representative of many common medium-sized towns. From a scale point of view, the catchment area is 314 square kilometres (roughly one fifth of the size of London), with a population of around 300,000 inhabitants. The catchment features a reservoir fed by a river that ultimately flows into the sea. Rainfall patterns represent the typical hydrological characteristics of a Mediterranean area, with seasonal fluctuations (concentrated rainfall in the autumn/winter and long dry periods in the summer). Water demand, energy footprint, and water quality downstream are influenced by the incorporation of water-saving and reuse technologies within households and the ability to connect runoff and wastewater to sustainable drainage systems and secondary wastewater treatment plants. A system dynamics model, running behind the game, as a computational engine, captures how water flows throughout the urban catchment via the water supply, stormwater, and wastewater systems. The model is designed to capture the following real-world problems:

Water supply problems are considered by allowing scenarios to start with a lowered rainfall or a depleted reservoir, or by allowing the user to change these parameters. Rainfall has an immediate impact on the ability to satisfy water demand and to maintain river flow. Heavy rainfalls also have the capacity to overwhelm wastewater treatment and can lead to uncontrolled discharges of untreated water.

The impact of water use is analysed by changing the size of the population, and the type of devices and technologies in use in selected groups of households. The population is the main driver behind water and energy demand, as well as a determining factor behind the volume and the toxicity of the sludge generated by the town. The choice of devices in use in households can drastically impact the energy footprint linked to water use at the catchment level as well as the associated carbon emissions.

The effects of variations in the water storage management are covered by allowing users to change the settings of diverse types of reservoirs (ranging from the main town reservoir to sustainable urban drainage systems). These are control systems with non-linear behaviours that require some measure of careful exploration to optimise.

Changes in the collection of stormwater and greywater (the wastewater that comes from sinks, washing machines, bathtubs and showers) as well as the collection of black water (wastewater from bathrooms and toilets that contains fecal matter and urine) can have various impacts on the system.

Diverse types of water treatments are considered. Parameters allow the activation and regulation of local household-based treatment (for rainwater and greywater reuse), as well as the management of the primary and secondary wastewater treatment plants. These settings can influence water quality downstream in the river and change energy savings and carbon emissions associated with material reuse and biogas generation.

The discharge of treated and untreated wastewater is affected directly by the volume of runoff water as well as the wastewater treatment capacity. When the user indirectly changes these factors, the water quality in the river is impacted significantly.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

Finances are impacted by the diverse types of technologies in use due to installation and operational costs.

We chose to primarily focus on a virtual Toy town because of its capability to interest a larger audience. This type of setting presents a broad set of problems and solutions that is representative of most urban water catchments and is the most successful at facilitating the engagement of diverse groups of citizens and other stakeholders in the innovation chain itself, through Communities of Practice and Living Labs.
Two case-specific versions of the Serious Game were also developed to fit the “Athens” and “Costa Brava” demonstration cases. These versions were not tested as extensively as the “Toy Town, they are functional and relate to problems specific to each demo case.

The “**Athens**” game shows a virtual neighbourhood of 7000 inhabitants that connects household’s wastewater to a sewer mining unit that is able to reuse heat and produce fertilizer for a tree nursery. As a result, emphasis is put on *(a)* the amount of energy that can be saved by reusing the heat produced by sewer mining unit, *(b)* the benefits associated with the production of a surplus of compost (after subtracting the compost needed for maintaining the tree nursery), and *(c)* the reduction of costs in pruning waste due to the reuse of branches to produce fertilizer.

The “**Costa Brava**” game shows a virtual neighbourhood of 38,000 inhabitants where a desalinisation plant is used to supplement water demand on top of an existing aquifer. The water demand is divided between a touristic neighbourhood with a highly seasonal water demand concentrating 90% of hotels, and a residential urban neighbourhood concentrating 70% of the population. A Water Reclamation Plant is also set to treat and reuse a portion of the wastewater for public gardens, street cleaning, and golf courses. Typically, emphasis is put on looking at the effects of tourism on water resources, and the benefits of desalinisation and water reuse technologies on water and environmental stress.

All three games are available online:
nextgen intro (nextgen-serious-game.s3-website.eu-central-1.amazonaws.com)

A video explaining the NextGen Serious Game is available as well:
https://youtu.be/EjfZlRwquVs

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N°776541

2.3 Game components and connections between them

To improve usability and readability for end users, only the components that give the most important information from both an urban water cycle perspective and a circular economy point of view are shown in the game (see **Figure 1**).

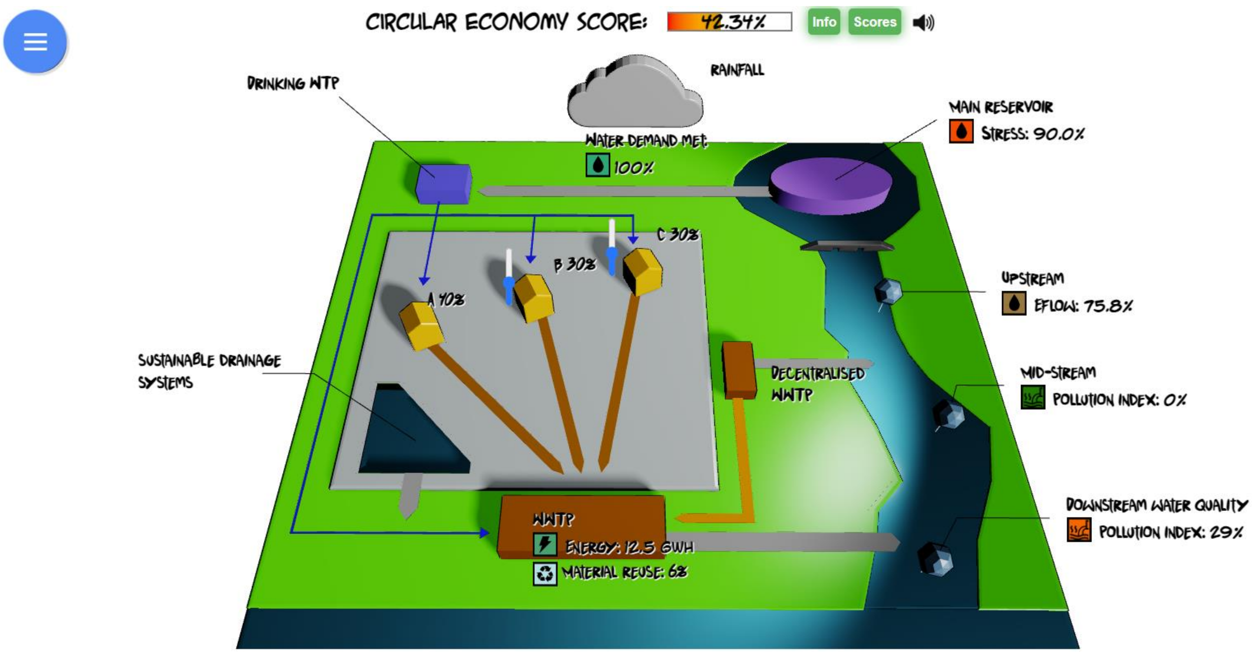


Figure 1. Screenshot of the ToyTown serious game showing selected urban water cycle components.

"Toy Town" is a refined and user-friendly representation of a virtual catchment presenting only the most essential components for monitoring the urban water cycle and at the same time check on circular economy:

The reservoir that depends on rainfall to supply water for both human activity and the river ecosystem. Any measure of stress on the reservoir (here, the percentage of years where the reservoir stays below a certain threshold for a given number of days per year) will provide a useful indicator on water scarcity and its possible impact on town needs and natural ecosystems linked to the river.

The households that make the urban environment (with indicators such as water demand met i.e. the volume of water supplied to the houses, which could be less than the actual water demand in case of water shortage; water-saving or reuse technologies, associated energy footprint, and financial costs). Households can be divided into three neighborhoods A, B, and C of varied sizes (sliders can adjust what percentage of the population they represent), and where different choices of technologies can be made regarding water use.

The river that contains indicators such as environmental flow (i.e. the amount of water left for the natural ecosystem of the river after abstracting water for supply the town) and water quality (using Chemical Oxygen Demand-COD as an indicator, where the pollution index represents the cumulative debt of oxygen resulting from the growth of algae fed by uncontrolled discharges of nutrients).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

The primary and secondary wastewater treatment plants (WWTP) use energy to treat water and reintroduce it into the river once up to standard. They sometimes release untreated water if their treatment capacity is overwhelmed by the volume of runoff in case of heavy rainfall. They also have the potential to be the center point of energy and material reuse practice that can significantly impact resource recovery in the context of circular economy.
Sustainable drainage systems (SuDS): these nature-based solutions are small reservoirs that help retain or detain surface runoff from a site and prevent wastewater treatment sites from being overwhelmed by huge volumes of runoff water due to excess rainfall.
Because the emphasis is on simplicity, while still showing “hard” technical concepts (such as the mass balance of flows), it is essential to show how the individual components that make the urban water cycle connect and interact with each other. The connection between urban water cycle components has undergone a simplification following a process of co-design and users’ feedback resulting from consultations with experts and engineers whose expertise ranged from water systems, to modelling and policy. Different components of grey water reuse and rainwater harvesting treatment are hidden, while emphasis is put on connectivity. The user can see the resulting visual connections showing if households “greywater” is connected to SuDS or not. Similarly, the user can confirm at a glance if the households “black water” (the wastewater from bathrooms and toilets containing fecal matter and urine) is redirected to either a primary or a secondary WWTP (as shown in **Figure 2** schematic).

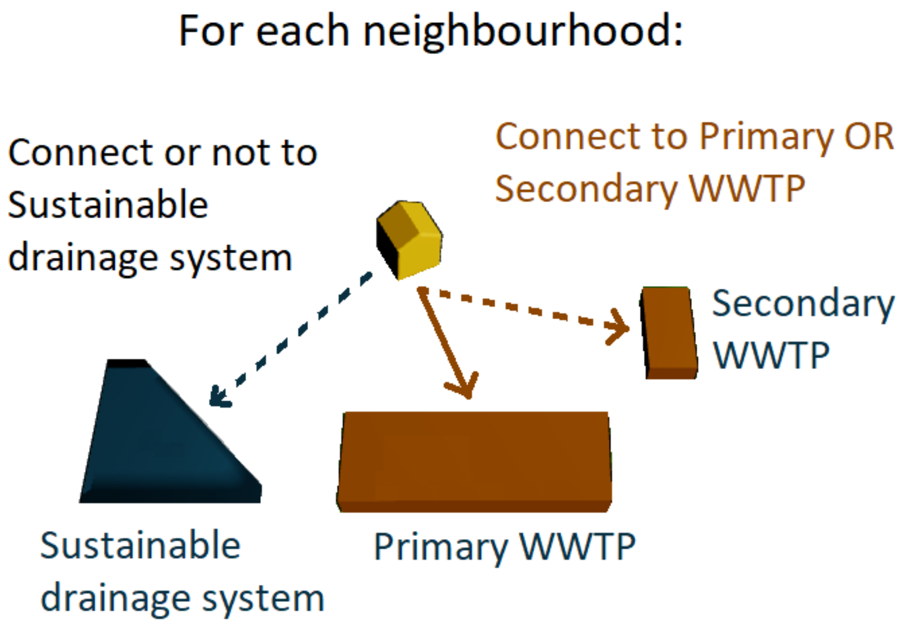


Figure 2: Schematic showing how households’ greywater can be connected to sustainable drainage systems or not, and how the black water from households can be redirected to either a primary or a secondary WWTP

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N°776541

The “Athens” and “Costa Brava” Serious Games also had their own sets of components as shown by Figures 3 and 4.

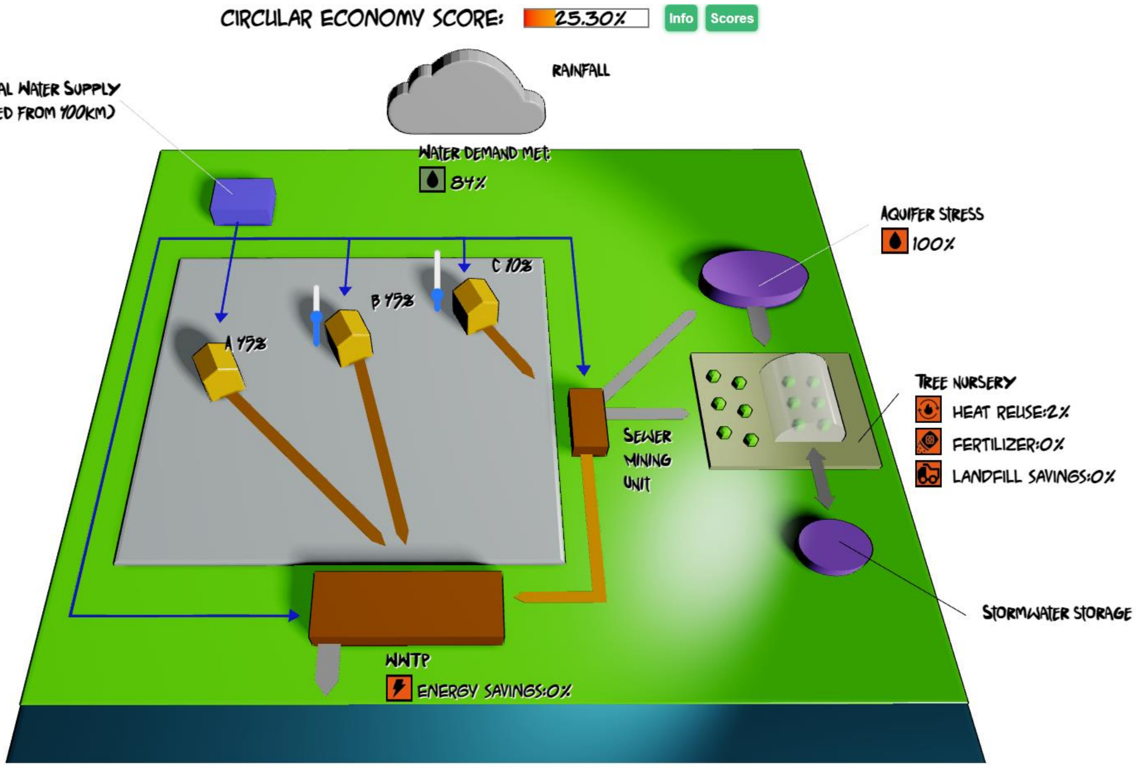


Figure 3. Screenshot of the Athens serious game showing selected urban water cycle components.

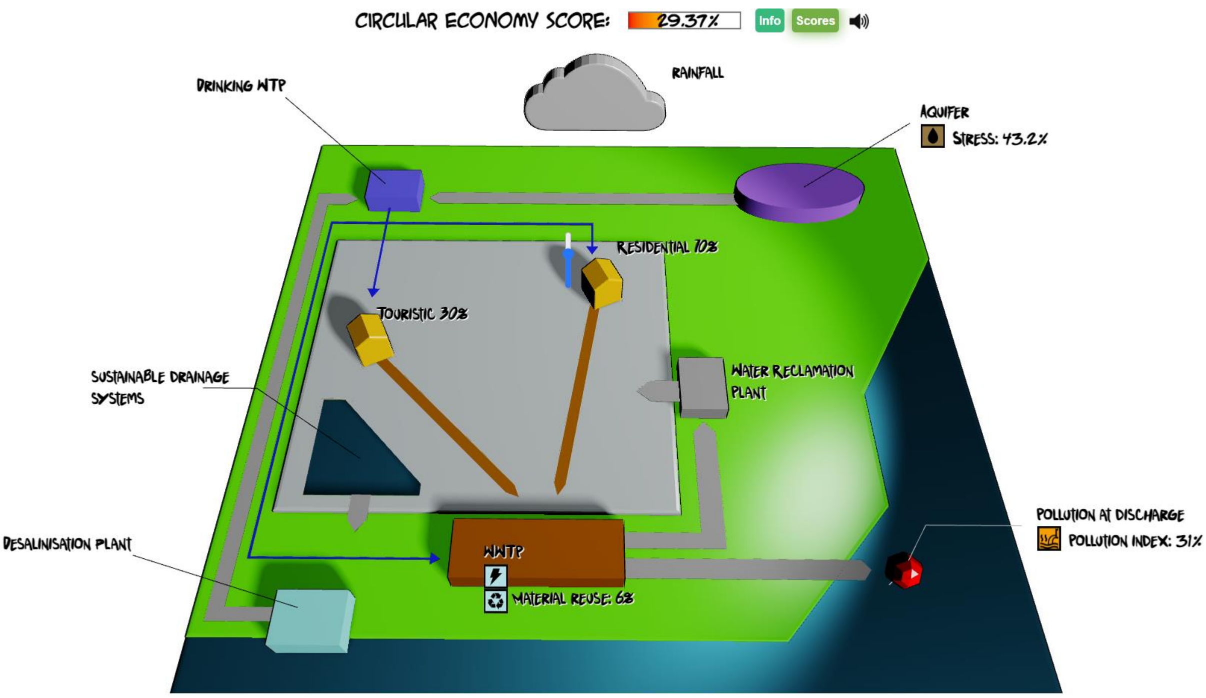


Figure 4. Screenshot of the Costa Brava serious game showing selected urban water cycle components

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N°776541

2.4 Game goals and participatory process

The goal of the game is simple and specific: to maximise the circular economy score at the very top of the screen (it is a weighted average of various Key Performance Indicators as shown in **Figure 5** - detailed table in appendix **A2**).

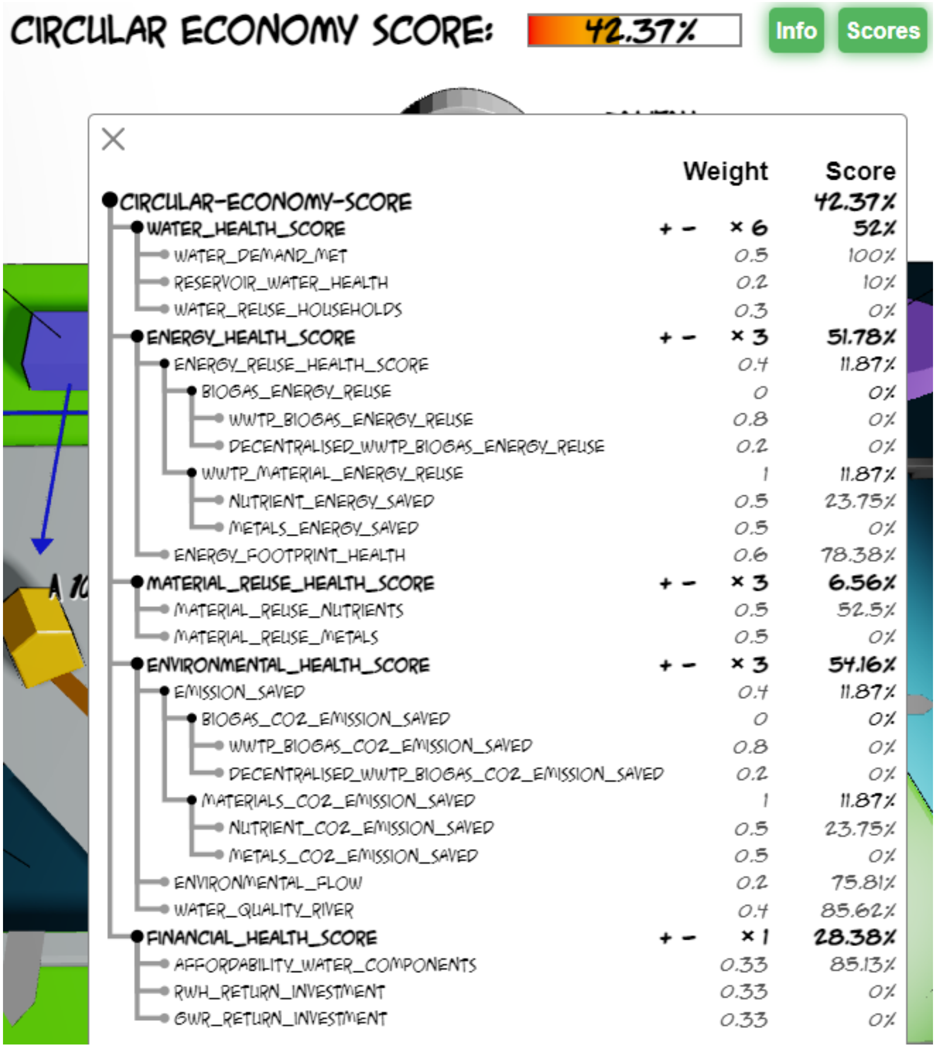


Figure 5: Screenshot of all the KPIS that make the Circular Economy Score

Depending on the type of audience, the weights can be adjusted. For the NEXTGEN playing sessions, the water availability indicator was given a weight factor of 6, while indicators of energy consumption, material and energy reuse, and environmental were considered secondary and given a weight factor of 3. Finally, indicators of financial health was given the smallest weight (equal to 1). In practice, depending on the event and audience targeted, if there is a need to center the game around environmental problems, the environmental health score can be given a higher weight than all other scores. Participants face significant challenges such as overpopulation, water stress, elevated costs, poor water quality, a high energy footprint and resulting carbon emission. To maximise the circular economy score, players need to understand the roles of the different components and technologies and their influence on KPIs (Key Performance Indicators) regarding water availability, energy use, environmental impact, material reuse and costs.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

The game can be played as a single-player experience, or a competitive multi-player online event. Participants can submit their best solution and compare it with an online high-score table that is updated in real-time.

As a teaching tool, the serious game takes the form of supervised learning sessions with pre and post-game questionnaires (Shown in **appendix A9**) where understanding circular economy for water was narrowed down to making participants explore the game to try to answer seven questions. These questions were chosen to be sufficiently generic to be useful to a wide audience while fitting an hour-long training session:

Players were asked in the first two questions to compare rainwater harvesting and greywater reuse technologies. Both technologies have different strengths and weaknesses and understanding the best way to use them is fundamental to resolve some of the issues posed by water scarcity and pollution. If installed at substantial coast inside all households, greywater reuse can have independently from rainfall the greatest impact on decreasing water stress. On the other hand, rainwater harvesting, can be an adequate and cost-effective solution to reduce both water stress and pollution downstream as long as rainfall remains sufficient.

Users were then asked to compare the relative importance of the wastewater treatment energy footprint (2% of the total) with the energy footprint of households' water-related devices (98%). This gave the participants a generic perspective regarding how engaging households can unlock the greatest potential for saving energy as opposed to wastewater treatment.

Players were tasked with changing the behaviour related to the use of the reservoir to maximise the environmental flow in the river downstream. By manipulating two variables (the "baseline" and the "stress" discharge rate to the river), users can observe that the reservoir is a control system that oscillates between stressed (or reduced discharge to the river) and normal modes (or greater discharge to the river). This is followed by a fairly generic but invaluable observation, namely that, in a control system, to minimise stress, there is need to know the particulars of the problem sufficiently, so as to be able to explore the whole search space to find optimum solutions (which do not necessarily lie in extreme values).

Participants we also asked to check what are the effects of connecting households to different components such as secondary wastewater treatment plant or a sustainable drainage system. In doing so, they had to realize that some technologies work particularly well together e.g. the option of adopting both greywater reuse and a connection to sustainable drainage systems is a potent combination to reduce both water stress and pollution downstream.

Finally, the players had to find which one between nutrients or metals from wastewater had the potential to save the most *exergy* (Calvo and Valero, 2017) (i.e., the energy that would be spent mining and refining these materials from scratch) and therefore contribute significantly to the overall circular economy score. This last question emphasizes the greater potential in terms of lowering carbon emissions of mining wastewater for rare and common metals (as opposed to only mining nutrients).

When the Serious Game is used inside a multi-player online competitive tournament, the participants' goal is to compete by solving two scenarios and by finding solutions with the highest possible score.

The first scenario, used as an introductory "warmup", refers to a situation where "Aquatech Town" is experiencing a prolonged period of extreme drought with rainfall being reduced by

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

50%. The mayor wishes to ensure that water demand is met 100% of the time via retrofitting neighbourhoods. Participants have to modify properties while maximizing the circular economy score, and make sure that the water demand met stays at 100%.
The second scenario is used for the tournament evaluation. A dramatic increase in the population of “Aquatech Town” coupled with a reduction in rainfall has put a significant strain on water resources. Water demand is met less than 50% of the time, environmental flows in the river are under 50% and there are high pollution values downstream. The mayor has released funding for modifying properties in a portion of the town called neighbourhood B representing 50% of all households. He is also calling for a review of the reservoir management (i.e. controlling the discharge parameters). Participants compete to find the best solution which involves maximising the circular economy score while making sure that the water demand met stays at 100%, the upstream environmental flow is greater than 70%, and the pollution index remains smaller than 20%.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N°776541

3. Implementation

An online digital game translates into the need for a responsive interface that can deliver results to the player in real-time, and therefore implies an additional challenge in building a model that can output results from user queries fast, in under a second.

3.1 The modular and real-time simulation engine behind the game

The first modelling attempt behind "Toy Town" was initially based on the Urban Water Optioneering Tool (UWOT) model outlined for decentralised water solutions in the Dutch neighbourhood SUPERLOCAL and presented in Bouziotas et al. (2019). As the model grew in complexity and started to integrate more input variables, the number of possible outputs resulting from different combinations of input parameters grew exponentially. Beyond a certain threshold, the only way to deliver results in real-time is either to compute them on the fly or store them in some sort of database. As UWOT was not built to provide batch computation (where one would be able to compute multiple results in one run) nor to deliver results in real-time, it became necessary to consider building our own simulation engine. The NextGen simulation engine was therefore specifically created to satisfy the following requirements:

The simulation engine must be able to compute results in daily and sometimes hourly resolution, compact them in yearly format for the next twenty years, and send them in a timely fashion to the browser of the user, so that they can be visualized less than one second after pressing a button.

The structure of the model must be modular, allowing the game to be easily extended and adapted to different case studies or situations (for example, allowing the addition of a desalination plant or an aquifer management component).

The system dynamic model must be able to simulate water balance analysis and volumetric flows in the context of the urban water cycle in its core layer, but also be able to integrate an additional layer of computations related to circular economy that include elements such as material reuse, energy, carbon emissions, and finance as shown in **Figure 6**.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

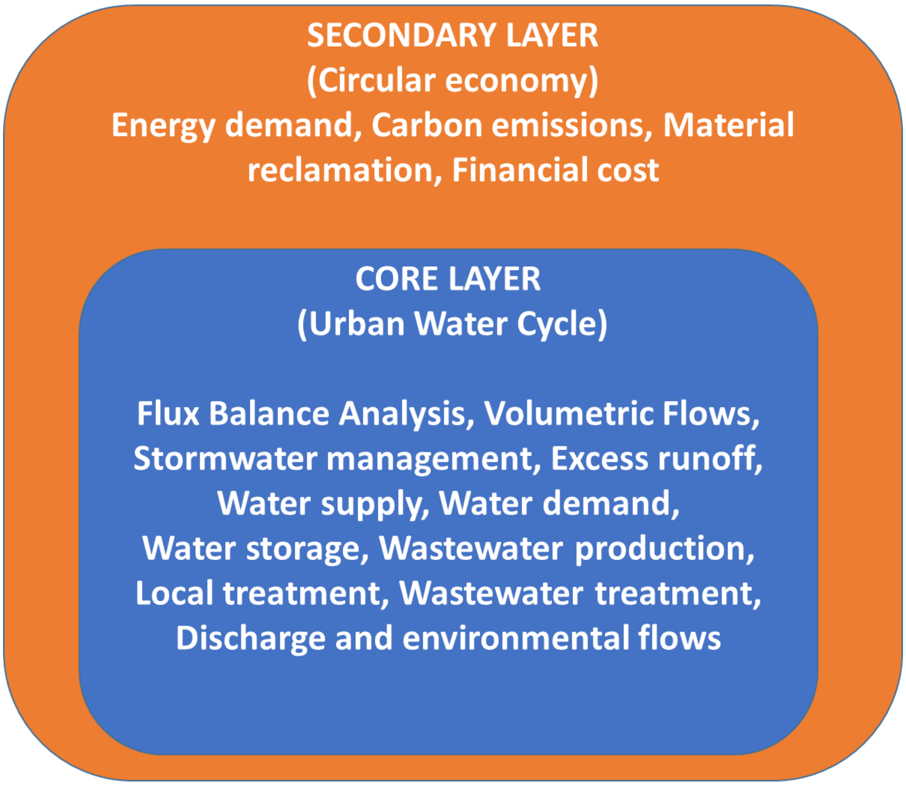


Figure 6: The layers of computational tasks behind the NEXTGEN simulation engine

After several subsequent iterative developments, the NextGen System Dynamics Model was successfully implemented in the Julia programming language (Bezanson et al. 2012). The simulation engine takes 159 parameters as input and gives the corresponding results under the form of 163 lists of variables corresponding to outputs computed over 20 simulated years and does it quasi instantly. It should be pointed out that the NEXTGEN simulation engine is fully detailed in the complementary article written for the same publication (Evans et al., 2022). The model was recently extended to accommodate different case studies. For example, an "Athens" instance of the model was built to focus on looking at the benefits of sewer mining for heat reuse as well as the production of fertilizer in tree nurseries. Similarly, a "Costa Brava" variation of the model is presently being finalised with an emphasis on a standard Mediterranean setting with an emphasis on aquifer management and the use of a desalination plant.

3.1.1 Modelling the Water Supply

The direct supply of water to a region can come from variety of sources including but not limited to, groundwater, reservoir, rainwater, desalinated water, and external municipal supply. For simplicity, the testbed considers one primary source of freshwater from a nearby reservoir and a secondary source of rainfall that falls directly upon the region. In this example (shown in Figure 7) the reservoir volume is recharged solely via inflow from an upstream catchment with outflows via (i) a Compensation Release system designed to control outflows to preserve environmental flows downstream of the reservoir, (ii) water use driven by the demands of the urban environment (town/city), and (iii) a spillway, referring to instances where the reservoir capacity is exceeded. Additional inflows such as direct rainfall onto the reservoir and the outflow of evaporation of water from the reservoir

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

are relatively small, and do not significantly affect the water balance. Consequently, they have been neglected at this stage.

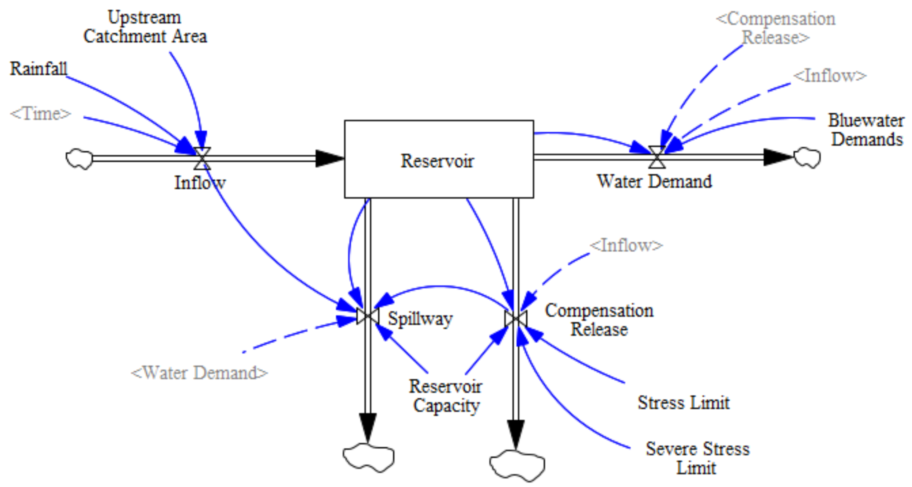


Figure 7. Simplified Reservoir Setup

The storage and release of water from the reservoir are controlled via a spillway (if reservoir levels are above a threshold value) and compensation release parameters that are dependent upon the inflow and current water levels within the reservoir. Equation 1 outlines the conditional rules applied within the model for determining the outflow of the reservoir/upstream via compensation release.

$$
\begin{gathered}
IF\ \left(\frac{Reservoir\ Volume}{Reservoir\ Capacity}\right) \geq Stress\ Limit\ Threshold\ THEN \\
Compensation\ Release = Baseline\ Discharge\ Coeff\ \times Inflow \\
ELSE\ IF\ \left(\frac{Reservoir\ Volume}{Reservoir\ Capacity}\right) \geq Severe\ Stress\ Limit\ Threshold\ THEN \\
Compensation\ Release = Stress\ Discharge\ Coeff\ \times Inflow \\
ELSE \\
Compensation\ Release = 0.0
\end{gathered} \tag{1}
$$

Energy requirements for the supply of freshwater are defined through the water demand and a volumetric coefficient (ρ) that relates to the energy required in treatment and pumping of water from the reservoir to properties requesting freshwater supply (Equation 2).

$$Energy\ Water\ Supply = V \times \rho \tag{2}$$

3.1.2 Modelling the Water Demands

Within an urban context the primary demand for freshwater comes from the residential population and their water requirements. Within the Toy Town model, these demands are driven by seven household component classes. Their specific per capita daily water requirements are determined by their respective subclassifications as outlined in Table 1. Using the default household components outlined in Table 1 the typical internal use of water

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

within the model is 168 L/Person/Day when using the standard (default) technologies. The internal water demands at the household and subsequent regional levels can be customised through the swapping of subclasses, for example replacing standard toilets within households with vacuum toilets in this model would result in a 21% reduction in daily water use at the household level.

Table 1. Household water demands/internal water consumption and energy use

Household Component Class	Household Component Sub Class	Water Demand (litre/person/day)	Energy Use (kWh/person/day)
Washing Machine	Front Loader*	15.3	0.40
	Front Loader Eco	9.945	0.26
	Top Loader	22.95	0.63
Sink	Standard*	8.75	1.22
	Water Saving	6.25	0.87
	Recirculation Pump	7.5	0.26
Shower	Standard*	70.0	2.44
	Water Saving	60.0	2.09
	Fog	24.5	0.85
	Recirculation	35.0	1.22
	WTW	60.0	2.09
Dishwasher	Hand*	30.0	1.25
	Conventional	18.0	1.14
	Energy Certified	6.0	0.95
Cooking	-	1.4	-
Food Grinder	-	1.0	-
Toilet	Standard*	42.0	0.00
	Vacuum	6.0	0.01
	Dual Flush	24.0	0.00
	Water Saving	18.0	0.00
	High Pressure	15.0	0.00
	Compost	1.2	0.00
	Dry Flush	0.0	0.00

*Default selected technology for region

In addition to the water demands for houses for internal use, there is the potential of properties having external water demands relating to garden irrigation. Unlike that of the internal components, demands for the garden are dependent upon its area, the crop demand, the irrigation methods applied and whether any of the demand requirements have been met by rainfall. Secondary demands, such as tourism, commercial, agricultural, and industrial uses could also be included within the water demands for regions, although they are beyond the scope of this paper.

Figure outlines the SDM view of water management at the household level. Here the demands at the household level are driven by the population. The production of domestic wastewater is broken down into greywater and blackwater, while the “recycle demand” by the households relates to the use cases for rainwater or treated greywater at household level.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N°776541

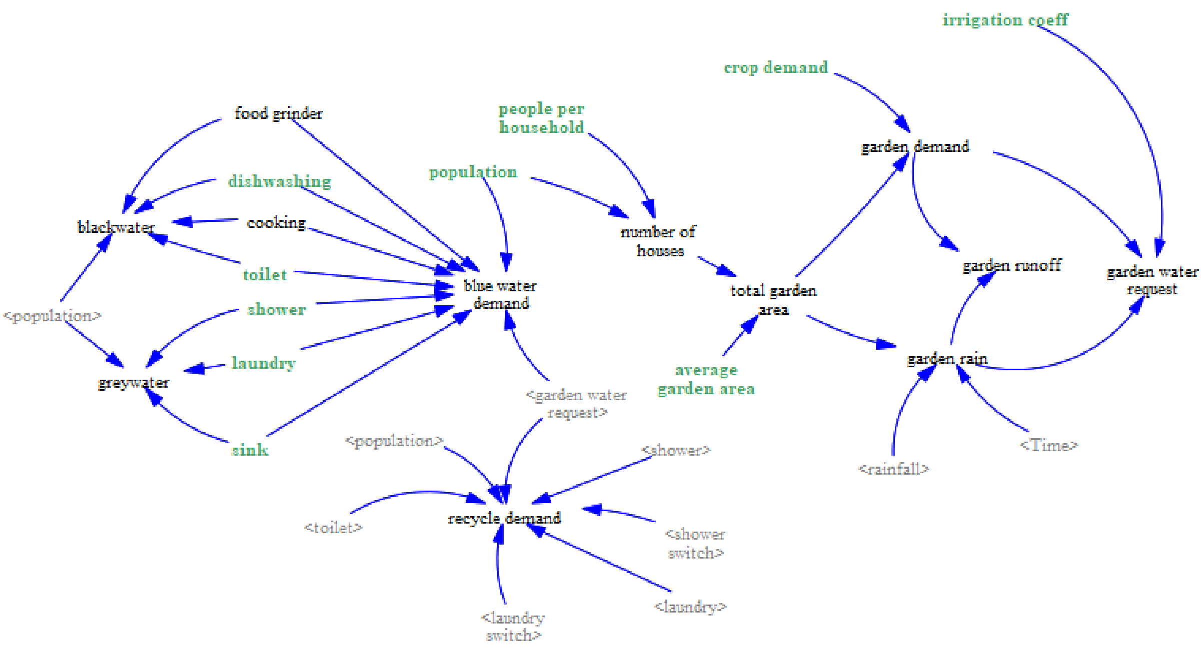


Figure 8. Household Bluewater Demands

For the material component, estimated COD mass (COD_m) inflows are used as reference, derived from their influent sources. These sources at the household level are divided into four classes, laundry, hygiene, kitchen, and toilet and expressed in terms of COD_m per person per day (Table 2).

Table 2. COD sources within Household Wastewater

House Wastewater Classification	Source	COD (g/person/day)	Household Component Class
Greywater	Laundry	24.4	Washing Machine
	Hygiene	5.25	Sink
			Shower
Blackwater	Kitchen	17.0	Cooking
			Dishwasher
			Food Grinder
	Toilet	55.7	Toilet
Combined	**Total**	**102.35**	**All**

An additional source of COD into the wastewater stream (when considering combined sewer systems) is that of stormwater runoff, following rainfall events. The COD value for stormwater is expressed directly as a concentration value (COD_c). In (Butler et al., 2018) the Event Mean Concentration (EMC) of COD for stormwater ranges from 20 – 365mg/l. For the testbed model an upper default value of 324.66mg/l was selected though this value can be adjusted. Using the default water-use technologies outlined in Table 1 the modelled volume of wastewater produced per person day is 168.45 litres and the equivalent mass of COD_m within the wastewater is 102.35g deriving a COD_c of domestic wastewater to be 605.5mg/l. Swapping a household component such as a standard toilet to a vacuum toilet will alter the volume of wastewater produced but not the equivalent COD_m thus increasing the domestic COD_c in the model to 770.12mg/l.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

Within the Energy layer of the model initial estimates in terms of energy use are derived in relation to the energy required by the water dependent components being associated with each household outlined in Table 1. Household fitted with rainwater harvesting (RWH) or greywater (GW) reuse will have additional energy requirements associated with the localised treatment of water.

3.1.3 Modelling the Local Treatment

There are two locally available water sources used by the domestic population within this testbed model. These are rainwater via the Rainwater Harvesting (RWH) system and the Greywater (GW) reuse system. Based on behaviours outlined in (Bouziotas et al., 2019) the localised treatment configuration can consist of a combination of up to six individual tanks (Figure).

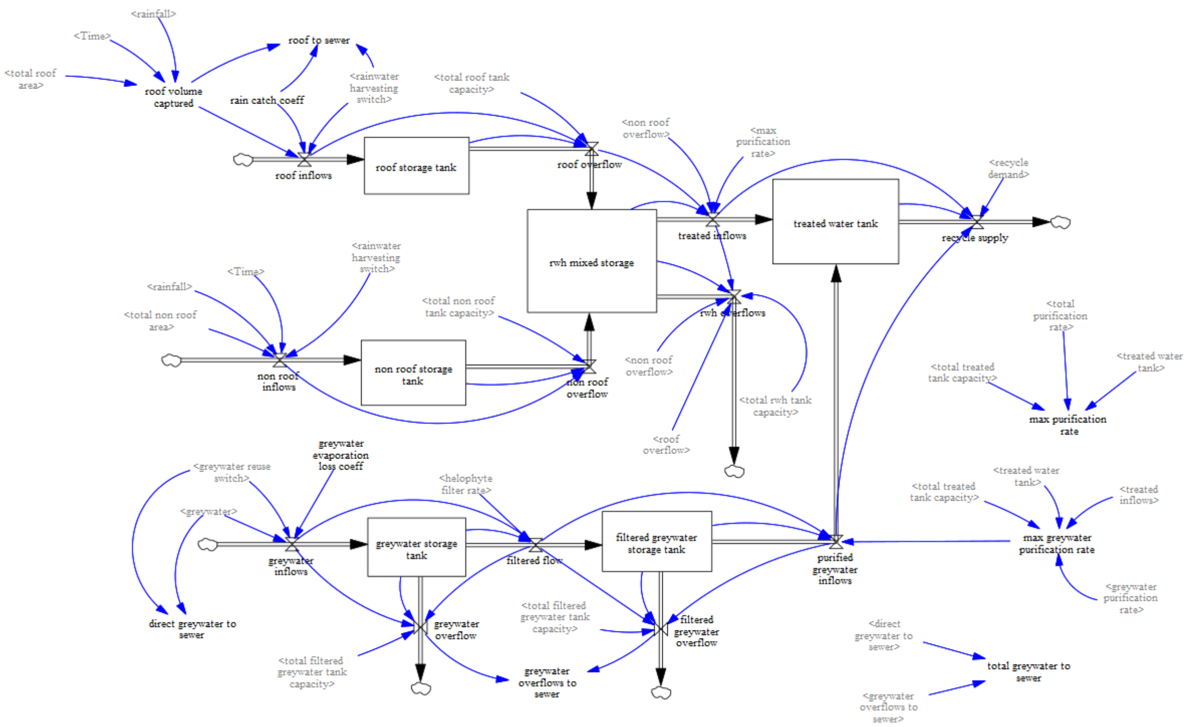


Figure 9. SDM representation of localised water treatment processes

With regards to the RWH technology, each property in that region can be fitted with rainwater harvesting storage tanks above ground and below ground. The storage capacities of these storage tanks can be customised accordingly. The option of a below-ground storage tank allows for the future inclusion of greater storage volumes for high-density conurbations such as apartment complexes. Within this model, if both rainwater reuse and greywater reuse are activated then an additional mixing tank is included with each property. The treated greywater is mixed and stored with collected rainwater for reuse in a combined system. The control of flows into and between tanks is determined via a range of parameters (Figure). For the RWH these include the average roof area and external non-roof areas that captures rainfall, the tank capacities, and the purification rate. The GW reuse system is dependent upon tank capacities, an initial helophyte filter rate and secondary purification rate.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

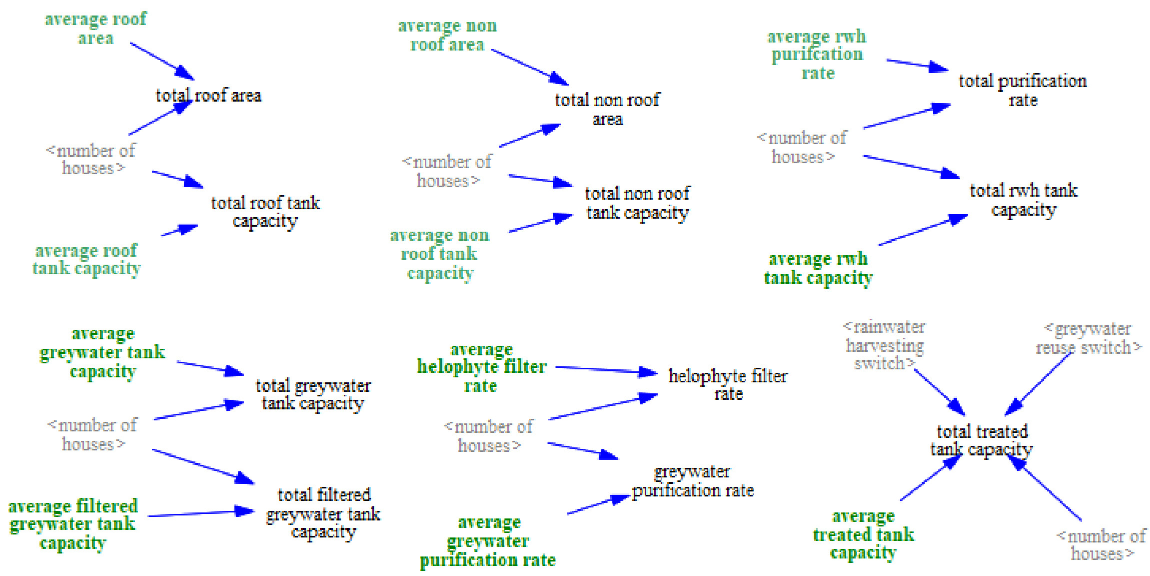


Figure 10. RWH and GW Reuse parameters

The demand for recycled water is dependent upon its defined use cases. The default use cases for rainwater and treated grey water within properties has been defined for use solely within toilet flushing and gardens. Within the model, however, users can specify whether to additionally allow for a percentage of this water to be used for laundry and showers. In that case, though parameters for additional treatment costs need to be modified accordingly where required.

3.1.4 Modelling the Stormwater Management and Wastewater Treatment

The treatment of wastewater that has entered the sewer system is either carried out at the Primary Wastewater Treatment Plant (WWTP) or a Decentralised WWTP. The Primary WWTP is the main WWTP for the testbed and designed with the entire population being considered. The volume of water treated by the WWTPs is limited by their Treatment Rates. To prevent incoming flows exceeding the WWTPs operational capacity when utilising combined sewer system approach, the use of a Combined Sewer Overflow (CSO) system has been employed. Any excess stormwater mixed with domestic wastewater is diverted away from the WWTP and is discharged as untreated effluent. Within the urban water cycle, the wastewater management system can consist of combined and/or separate sewer systems (Figure). In this configuration Sustainable Drainage systems (SuDs) can also be utilised for stormwater management. Here the SuDs are regarded as consisting of a pervious storage basin that captures rainfall that lands directly upon them and any overland flow from regions connected to the SuDs system (Figure). Overland flow, referred as surface runoff, comes from both pervious and impervious surfaces. Pervious areas within the model are regarded as being green spaces. These areas have an infiltration rate defined for the removal of rainwater that lands upon them. For the simplified modelling approach followed in Toy Town, it is assumed that water infiltrating the previous area is removed from the system. If, however, the rainfall that lands on these pervious areas exceeds the infiltration rate of the soil, then the excess rainfall is directed either to the SuDs or the sewer system as stormwater runoff. The impervious area is initially predefined to be the largest area in the model. Rainfall landing upon impervious areas, will immediately become surface runoff,

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

again to be directed either to the SuDs or the sewer system as stormwater runoff. Not all surface runoff enters SuDs and/or sewer system as a percentage is deemed to be lost, due to ponding and evaporation determined by a stormwater coefficient.

The performance of the SuDs within this model are determined by three parameters:

- **Infiltration Rate**: This is the rate at which rainfall is expected to infiltrate into the porous medium of the SuDs. If the rainfall intensity is higher than the SuDs infiltration rate, then overland flow across the SuDs and into the sewer system will occur.
- **Storage Capacity**: This is the maximum storage volume/buffer within the SuDs based on its area and depth. Water that has infiltrated the SuDs can be temporarily stored within the SuDs whilst it infiltrates into the soil beneath. If the storage capacity of the SuDs is exceeded, then any additional inflows will become surface runoff.
- **Soil Infiltration Rate**: This value determines the rate at which water is removed from the SuDs.

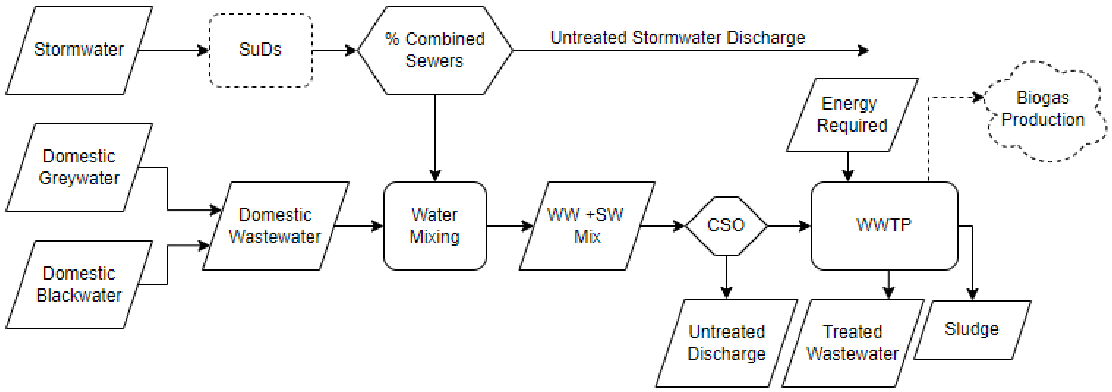


Figure 11. Overview of Stormwater and Wastewater management system

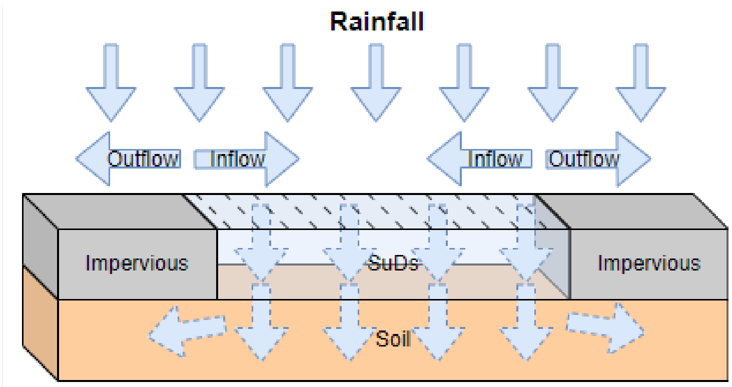


Figure 12. SuDs implementation within Toy Town

The first stage in the stormwater management process is to determine the volumes of direct rainfall and surface runoff into the SuDs. Figure outlines a modelling approach used for calculating combined inflows into a SuDs system if they have been installed in a region. Here

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

water that lands on pervious area may infiltrate the soil (determined by the soil infiltration rate). The SuDs activation switch represents whether a region is connected/contains SuDs and the capture/removal or surface water into the SuDs is determined by its area and infiltration rate.

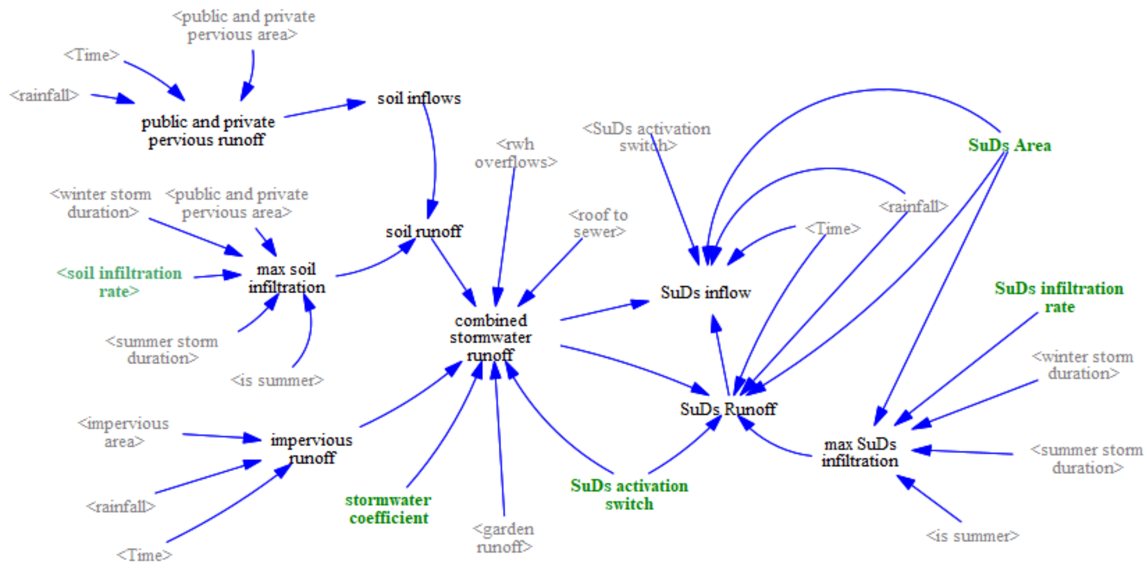


Figure 13. Stormwater runoff modelling

Once the inflows of SuDs have been determined, the removal of stormwater into a porous medium beneath can be calculated, along with any excess flows that will enter the sewer system if the SuDs capacity is exceeded (Figure).

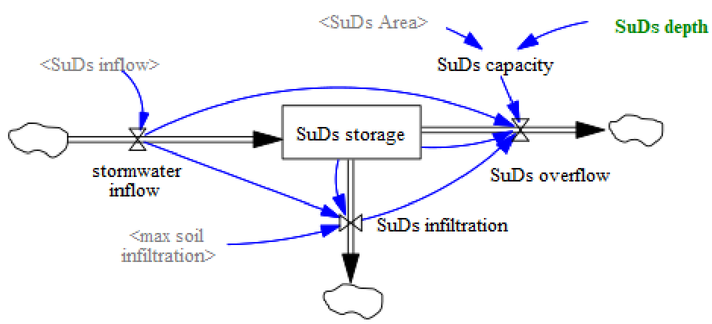


Figure 14. SuDs storage diagram

Stormwater not captured by SuDs, either enters the combined sewer system, mixing with domestic wastewater, or enters a separate sewer system and is later discharged untreated (Figure).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

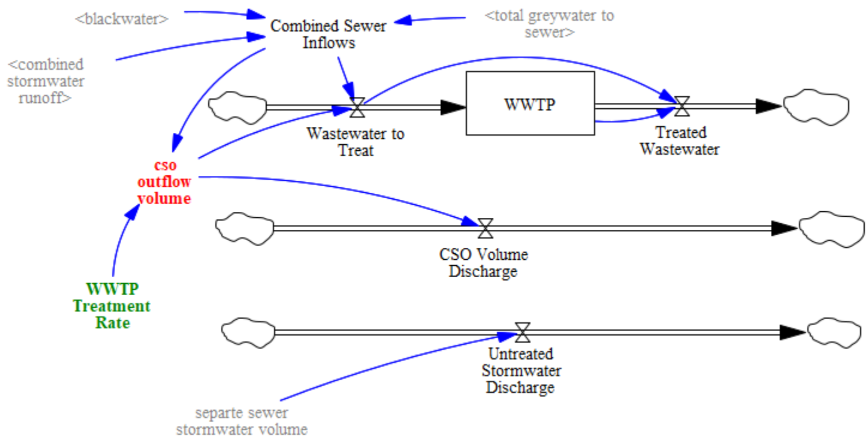


Figure 15. WWTP and Sewer Flows

To capture the behaviour of CSOs, daily resolution rainfall data is redistributed using a rainfall hyetograph derived from design hyetograph presented in (Tony Ladson, 2017) (Figure).

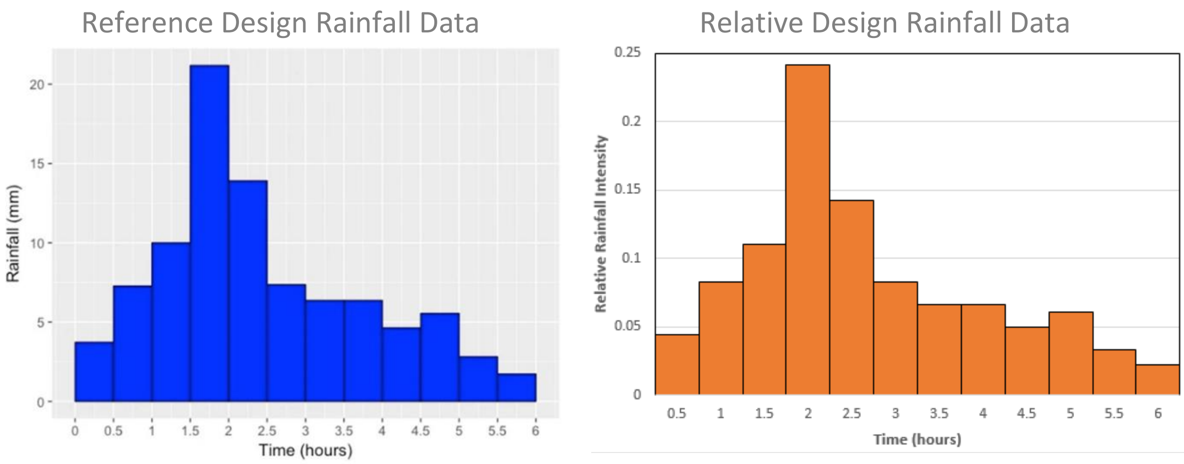


Figure 16. Defining stormwater inflows using r relative rainfall hyetographs derived from design hyetograph depicted in Tony Ladson, (2017)

The CSO design/threshold limit is set at eight times daily Dry Weather Flow (DWF) assuming 100% combined sewer value. Using this DWF threshold yields zero CSO events over the 20-year simulated timeframe. In contrast, redistributing rainfall, using relative rainfall hyetographs for combinations of 6-hour winter storms and 3-hour summer storm durations, results in an average of 180 CSO events per year (Figure). Based on this analysis, the model re-distributes daily rainfall data using the provided relative design hyetographs. This was done to ensure a more accurate depiction of stormwater propagation within combined sewers.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

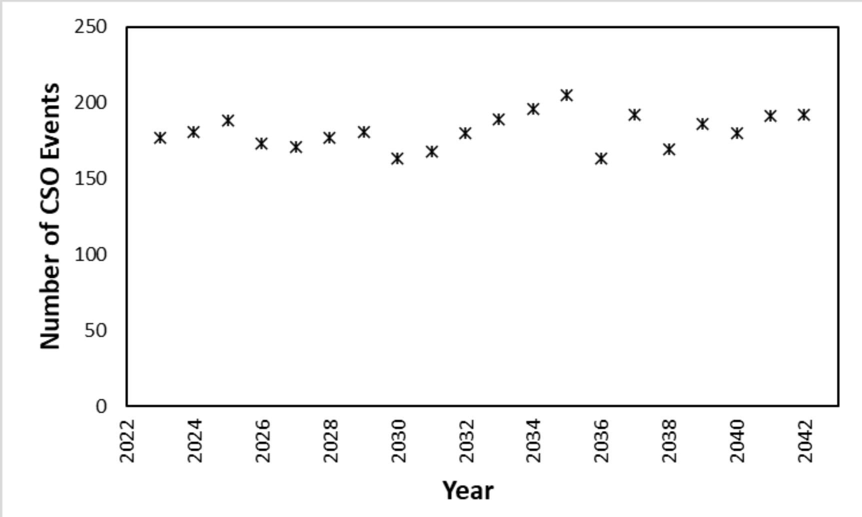


Figure 17. Comparison of CSO events using daily rainfall data vs 6-hour relative hydrographs

The Decentralised WWTP is regarded as being at a smaller scale than that of its Primary counterpart. It is utilised for trial purposes and a range of alternative wastewater processes. The baseline configurations of both the Primary and Decentralised follow the same design (Figure). However, the incoming flows, operational parameters and geographical locations will vary. The COD_c of wastewater present within a combined sewer system is dependent upon the COD_c of the domestic wastewater and the volume of stormwater it is mixing with. On days where the rainfall value is below a minimum value that would trigger a CSO event, the COD calculations for wastewater influent to the respective WWTPs are calculated using daily values. When the stormwater inflow is sufficiently high to trigger a CSO event, the stormwater volumes is redistributed over the relative design hyetograph and the untreaded COD_c values are derived for each sub-daily time interval to determine the volume and concentrations of uncontrolled discharge to either the river or the sea. The remaining wastewater and stormwater mix is routed to the WWTP where sludge mass and sludge volumes are calculated along with the treated effluent COD_c values.

WWTPs within this model are designed to remove a percentage of the COD from the influent before discharging the treated effluent into the river or sea. The energy required to treat wastewater at the WWTPs is derived from a simplified equation (Equation 3) based on a treatment coefficient (μ) that determines the energy required to reduce the COD of wastewater by X% in terms of kWh/m^3.

$$Energy = \mu \times V \qquad (3)$$

On the energy production/potential side, enabling anaerobic treatment of wastewater at the decentralised site, triggers the model to calculate potential biogas production. Adapting an approach outlined by Metcalf & Eddy Metcalf & Eddy Inc. (2013), based on influent COD_m values and COD removal via anaerobic treatment, an estimate is made as the volume of methane that can be produced (Equation 4).

$$biogas\ volume = (COD_{methane} \times 0.4)/1000 \qquad (4)$$

Where: $COD_{methane} = bsCOD_m - COD_{eff} - COD_{vss}$

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N°776541

$$bsCOD_m = Inflow \times bsCOD_c$$

$$bsCOD_c = 0.5 \times COD_c$$

$$COD_{eff} = (1 - \%COD\ Removal) \times\ bsCOD_m$$

$$COD_{vss} = 1.42 \times 0.04 \times \%COD\ Removal \times\ bsCOD_m$$

A by-product of the treatment process is that of the production of sludge that either needs to be disposed of utilised in nutrient and/or bio recovery processes. The volume, mass and composition of sludge produced during the treatment processes are dependent upon the volume (V) of wastewater being treated, its chemical composition, and the WWTPs treatment characteristics. A simplified approach has been adopted for determining the mass of sludge produced at the Primary WWTP and Decentralised WWTPS outlined in Equation 5, where β refers to the COD removal efficiency of the treatment facility and θ is a coefficient relating to the treatment approach e.g., aerobic, anaerobic treatments and the subtypes.

$$Sludge\ Mass = \frac{\beta \times V \times COD_c \times \theta}{1000} \quad (5)$$

3.1.5 Modelling the Discharge and Environmental Flows

The large scale Primary WWTP in the model has been located near the sea (Figure 14). The smaller scale Decentralised WWTP is placed at a midstream location where it discharges into the river system (Figure). Having a Decentralised WWTP at a midstream point can have potential positive benefits of restoring river flows via flow augmentation within the river network. However, it is important to ensure the water quality of the effluent is not detrimental to the system (Luthy et al., 2015).

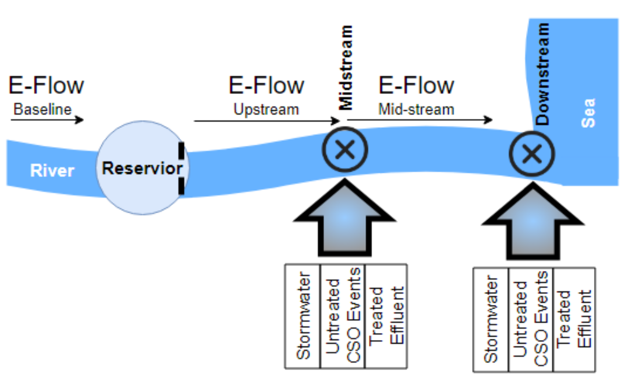


Figure 18. River network and modelled discharge locations

To model the potential benefits of localised improved water management by the town and discharge the midstream via a Decentralised WWTP, the model assesses river flows upstream and midstream relative to the baseline river flow (Figure). It simultaneously monitors the water quality of the combined discharges at the midstream location and at the downstream location as part of the overall model performance analysis.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

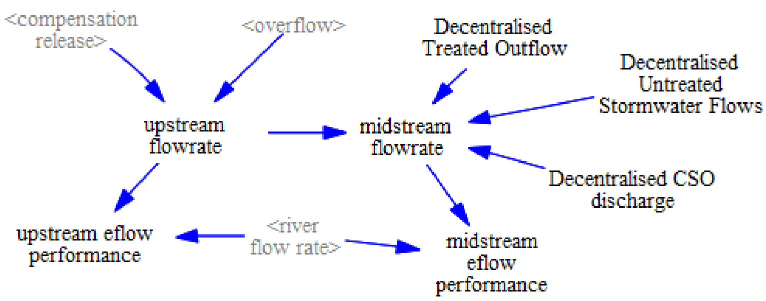


Figure 19. Monitoring river flow rates

3.2 The user interface and the ranges of choices and actions available

The user can press a button on the top left of the screen to access at any moment a single radial menu (shown in the highlight **Appendix A3**) that contains all actions. Once deployed, the radial menu offers a choice of eight icons leading to different types of actions grouped by themes. Pressing the population icon will, for example, lead to sliders allowing to change the size of the population and the tourism seasonal population increase (thus directly influencing water demand and the resulting volume of wastewater). **Figure 20** shows the range of interactions triggered by the top four icons (population, rainfall, nature-based solutions, and the reservoir management), while **appendixes A4 and A5** show interactions for household related water use and wastewater related material recovery.

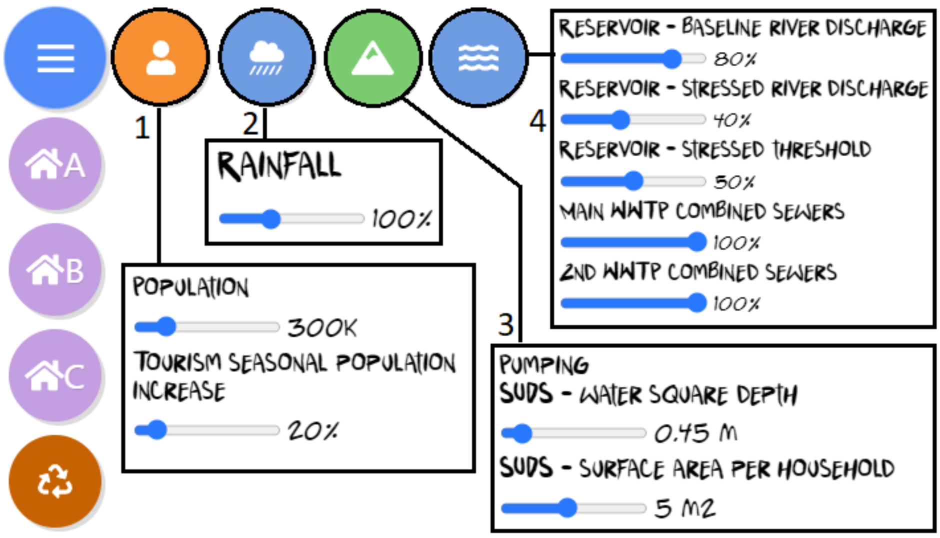


Figure 20. Part of the interface allowing to changing the population size (1), rainfall (2), sustainable drainage systems capacity (3), reservoir management settings and degree to which sewers are combined (4).

The User Interface does also provide rich visual information when clicking on indicators (as shown in **Appendixes A6 to A8**), as well as audio content (tracks containing detailed information automatically play pre-recorded explanations).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

Players can change water technologies in use by the residents as well as the connection from the household's greywater and blackwater to nature-based solutions and primary and secondary wastewater treatment plants. The list of water saving technologies available to the user is quite comprehensive as shown in **Table 3.**

Table 3. List of household devices that users can experiment with.

Shower	A water saving shower is a shower featuring an efficiently designed nozzle, which reduces water use.
	A fog shower a shower with a water-saving nozzle that is activated in "mist"; or fog mode, drastically reducing water use.
	A recirculation shower feeds back water as you shower, reducing water use even further.
	A WTW or "Warmteterugwinning" shower (or heat recovery unit) is a shower with an easy drain heat exchange system that conserves energy.
Toilet	A vacuum toilet drastically reduces water use by introducing a pressure difference while flushing. It is fairly expensive, as the wastewater network of pipes needs to remain under vacuum pressure condition.
	A high pressure toilet employs a secondary tank to create additional air pressure and save water while flushing. It is less expensive to maintain than vacuum based systems.
	A dual flush toilet design introduces a dual flushing system; one low-water and one full flush, to match types of uses and save water.
	A water saving toilet is a smarter toilet design that uses multiple nozzles and centrifugal washing to ensure that water consumption remains low, while cleaning capacity is high.
	A compost toilet works by separating liquids from solids using two distinct tanks. It uses a minimal amount of water.
	Dry flush toilets are self-contained systems that are entirely waterless, but rely on chemicals and a mechanical system for flushing.
Sink	A water saving sink features water-saving nozzles that reduce water use per minute.
	A recirculation pump sink comes with an autonomous device that heats water upon demand. The recirculation pump saves a significant amount of water per year, as well as energy due to a more efficient heating of water.
Laundry	An eco-front loader washing machine utilizes lower temperatures, reduced load programs and the eco function. It can save a significant amount of water per wash.
Garden	A garden aeration hose will control the amount of water that flows through the tap without affecting the water pressure as it mixes the water with air.
	A garden drip irrigation is a micro irrigation system with small underground pipes that allow water to drip slowly to the roots of plants.
	A garden spray timer allows a greater control of the water quantities used to irrigate the garden.

Regarding the facilitation of language access for the demo sites, the introductory text on the splash screen that describes each respective case study is now available in the given local language (for Athens, the description of the game for that case study is in Greek, and for Costa Brava, it is in Spanish) as shown in the screenshots visible in appendix A10. It is also worth highlighting that the common working language was in English during development and that it was agreed that during the local engagement gaming sessions, someone familiar with the game who speaks the local language would be facilitating the session and that there was therefore no need to translate in-game indicators.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

3.3 Software architecture and deployment

The frontend of the game is a web page (the "client") that interacts with a simulation engine running the System Dynamics model located remotely (the "server") that delivers simulation results in real-time. The software infrastructure uses containerization – meaning that software code is packaged with all its necessary components and dependencies in a self-contained virtualized unit that can be easily moved around. The game can run as multiple server instances, scaling up with the number of players connected without any disruption to the service using Amazon "Elastic Container Service technology" (AWS Fargate, 2022). A direct consequence is that it is now possible to set up an online game session in a few minutes that could equally accommodate a group of 40 players, or a conference with 4000 participants! This flexibility has allowed the NextGen serious game to be used in various scenarios ranging from teaching students in a small classroom, to the animation of an online event gathering members of the public, to running a competitive e-sport tournament between experts at an international industrial water conference (Aquatech Innovation Forum, 2021).

The "Toy Town" serious game was iteratively refined following a mix of user feedback (mostly centred on observed bugs and generic simplification of the questionnaire and user interface) and a time-consuming testing activity on the behaviour of the model (with an emphasis on the detection of spurious behaviours e.g. an increase in population should be followed by an increase in pollution, not the opposite) between modellers and software developers.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

4. Results

The NextGen Serious Game Toy Town has been demonstrated to all project partners in a number of online sessions (e.g. CoP Gotland, CoP Timisoara, PSB06 Final Event). The Athens Serious Game was presented to the stakeholders in their final CoP meeting (September 2022).

In the **Athens** case study, a virtual neighbourhood connects the household's wastewater to a sewer mining unit. Energy and water savings made available by this sewer mining unit are linked to a tree nursery. These saving when made from sewer mining are put into perspective with the savings that can be achieved while switching water related household technologies. Typically, changes at the household level tend to have a much greater effect on the overall water and energy footprint than sewer mining. For example, changing the shower heads in every bathroom in households to a "fog-shower" can increase the ability of the overall neighbourhood to supply water by at least 15%, and increase energy savings up to 30%. By comparison, scaling all sewer mining activities to the maximum (50 units) will produce a 2% increase the ability of the system to meet water demand, and a 9% increase in energy savings. As far as the tree nursery is concerned, players are made aware that the bottleneck on reusing heat, producing fertilizer, and saving on waste pruning costs is the number of sewer mining units required to process the sludge. This serious game can help understanding relevant questions in the future for novel tree nurseries that seek to use sewer mining technology: finding the optimum number of sewer mining units depending on the size of the neighbourhood and produced sludge in order to minimise energy and water footprint, increase fertilizer production and minimise pruning waste landfill costs

The **Costa Brava** Serious Game is only recently finalised and shows the simultaneous impact of two coexisting different urban areas: a touristic urban area that concentrates 90% of hotels and tourism activity and hosts 30% of the local residents, and a residential urban area that concentrates only 10% of hotels and tourism activity and hosts 70% of the local residents. The effects of different scenarios can be observed, and combinations of helpful measures can be explored. For example, excessive tourism corresponding to a tripling of the tourist population person-night stays in summer and winter results in an increase of 28% of the blue water demand and energy demand in the touristic area, and an overall increase aquifer stress from 43% to around 68%. Compounding this situation with a drought scenario will rise aquifer stress to 100%, meaning that the aquifer level goes below a critical threshold for the months of June, July, and August for every one of the 20 simulated years. One of the advantages of using the game, is that it allows a better understanding of what are the best measures that can help to mitigate this problem. As usual, switching water related technologies can have a major impact. Simply changing shower heads to NASA inspired "fog showers" in hotels will reduce the blue water consumption by 11% in the touristic area. Similarly, adding vacuum toilets, front loader eco laundry, and energy saving dishwashers in

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

the same hotels will reduce the touristic area blue water consumption from 2.1 million cubic meters/year to 1.2 million cubic meters/year (a 43% reduction!). In this context, the serious game becomes a useful tool for exploring the future possible impacts of installing certain combinations of water technologies in an area like Costa Brava, dominated by tourism based economic activities and plagued by drought and aquifer management problems."

The NextGen Serious Game was used during three types of events: a supervised training session, a debate, and an e-sport tournament. The supervised teaching sessions involved a total of 44 participants and were the events that were concerned with gathering results. Two sessions organized by KWR took place online and involved a mixed audience of stakeholders, water professionals, and industry experts of NextGen project partners. Another was a hybrid online/physical workshop involving Civil Engineering students from NTUA. They were organized in early 2022 to gather information following the methodology described in **section 2.1** about how playing the game changed the players' understanding of the Circular Economy for water problems by measuring differences in the way they answered the pre and a post-game questionnaires (**section 2.4** and **appendix A9)**.

Details about question 1 (*"Does using greywater reuse in households lead to a better water quality in the river downstream than using rainwater harvesting?"):* Initially, participants were split roughly 50/50 on deciding which technology between greywater reuse or rainwater harvesting would be best to minimise the pollution in the river downstream. After playing the game, **Figure 21** shows a 12% increase in the number of players answering the correct answer and realizing that installing rainwater harvesting in households significantly lowers the pollution index in the river downstream (the model behind the game captures the fact that rainwater harvesting tanks act as micro reservoirs that contain some of the rainfall and therefore prevent some of the runoff water to completely overwhelm the treatment capacity of wastewater treatment plants).

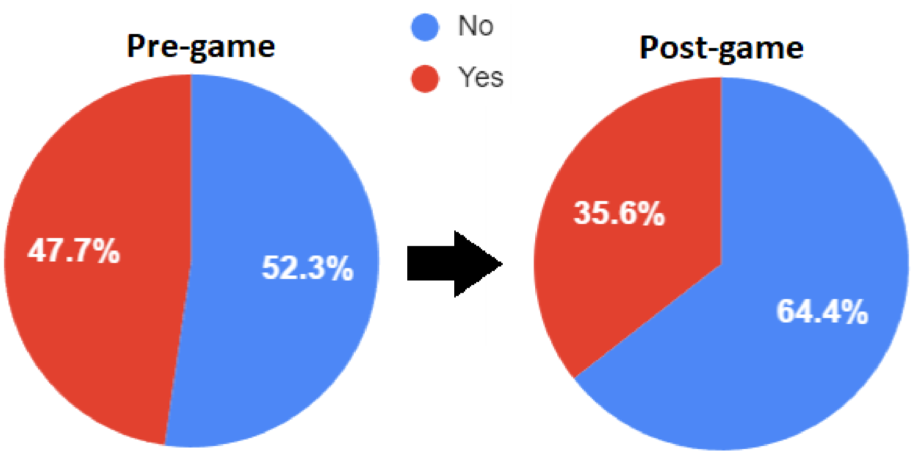


Figure 21. Answered to the question "Does using greywater reuse in households lead to a better water quality in the river downstream than using rainwater harvesting?" before and after playing the game.

A similar analysis for the answers to question 2 was not possible, because the formulation of the question was changed in between sessions following user feedback: participants

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

reported that being asked to tick a box to confirm a negative statement ("Tick the box if you think this is INCORRECT" - that A is better than B) induced confusion. In contrast, in a live setting, most players were able to answer correctly when asked if the statement was CORRECT.

In question 3: (*"What is the relative importance of the wastewater treatment energy footprint compared to households water related devices?"),* more than half the players initially assumed wrongly that wastewater treatment and households would share the energy footprint in a fairly balanced 4:6 ratio. Post-game answers show a 37% increase towards the correct response (as shown in **Figure 22**) - that wastewater treatment only represents a tiny portion (2%) of the energy footprint, and that most of the energy savings could be done at the level of households.

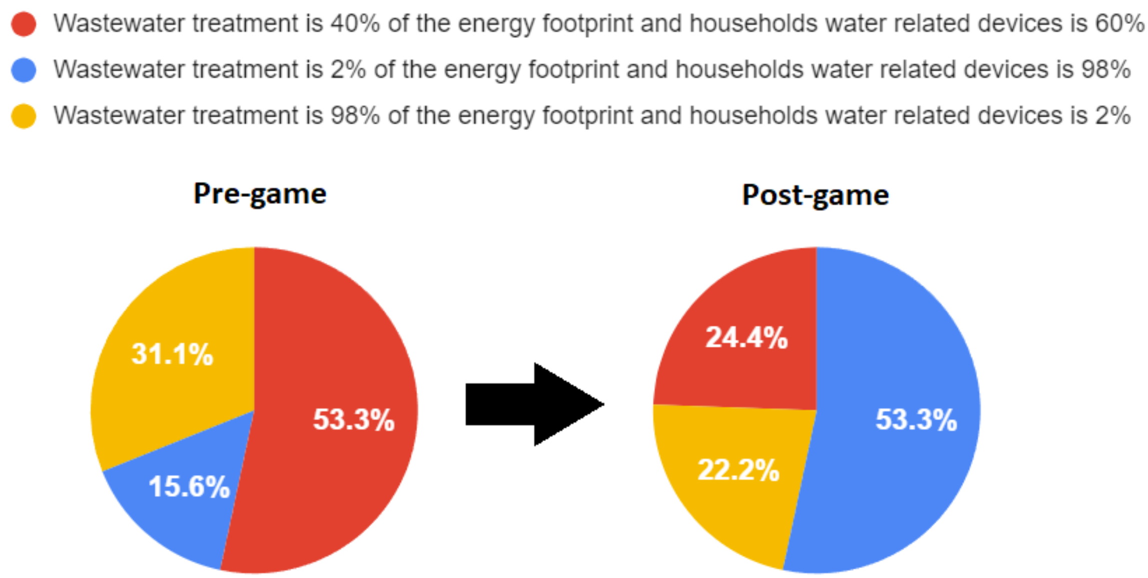


Figure 22. Answers to the question "What is the relative importance of the wastewater treatment energy footprint compared to households water related devices?" before and after playing the game.

Answering question 4 (*"We assume a reservoir is organized as a control system with a fairly high "baseline" discharge rate to the river and a lower "stressed" discharge rate that is applied when the reservoir is less than half full. Would maximising the "baseline" discharge rate to the river guarantee a greater environmental flow in the river?"*) correctly, requires either the participants to be familiar with control systems, or to have experimented with both the "baseline" and the "stressed" discharge rate of the reservoir enough to know that min-maxing these two parameters would not necessarily lead to the optimum solution. **Figure 23** shows that playing the game allowed 15% more participants to choose the correct answer.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

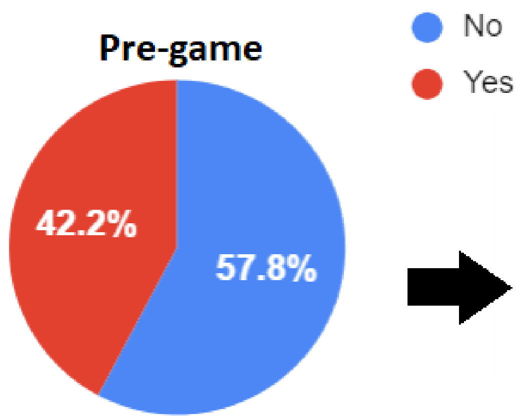


Figure 23. Answers to question 4 before and after playing the game.

Question 5 *("What would happen to the overall energy footprint and water quality in the river if you were to connect 20% of households of your town to decentralized wastewater treatment plants?")* is relatively difficult to answer from prior knowledge because it requires understanding how connecting households to a secondary treatment plant can impact water quality and energy use in opposite directions in the virtual catchment. Post-game answers show (see **Figure 24**) a 28% increase towards the correct response: players understood that connecting households to a nearby secondary wastewater treatment plant would consume less energy because of the reduced distance and associated pumping requirements. The game also displayed to the players an increase in the water quality downstream, because the game indicators show that discharges of untreated water are "shared" between the midstream and the downstream point of the river.

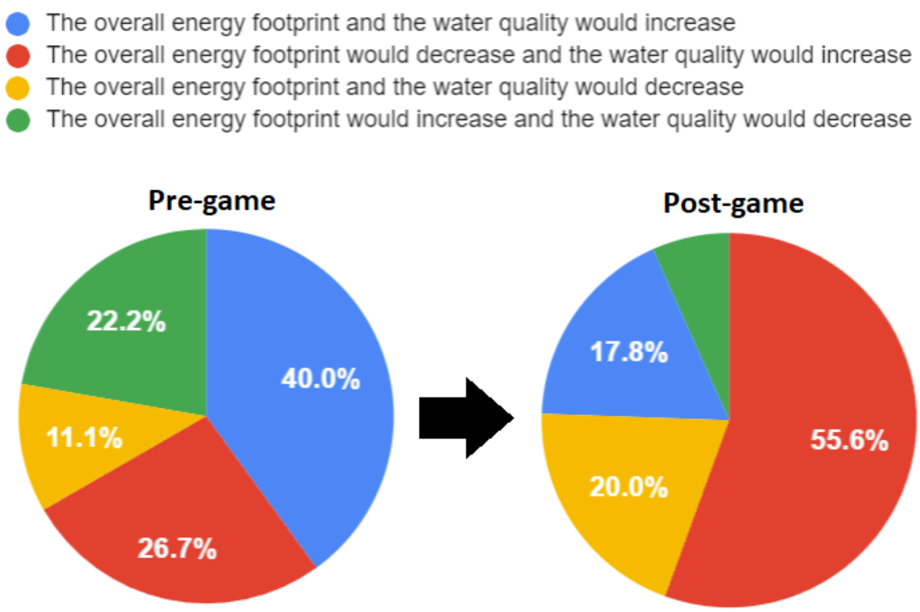


Figure 24. Answers to the question "What would happen to the overall energy footprint and water quality in the river if you were to connect 20% of households of your town to decentralized wastewater treatment plants?" before and after playing the game.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

In question 6 (*"What would be the most important effect of installing a sustainable drainage system?"*), playing the serious game increased the perception of the role of Sustainable Drainage Systems as a way to reduce pollution downstream (**Figure 25** shows a 13% increase towards the correct answer).

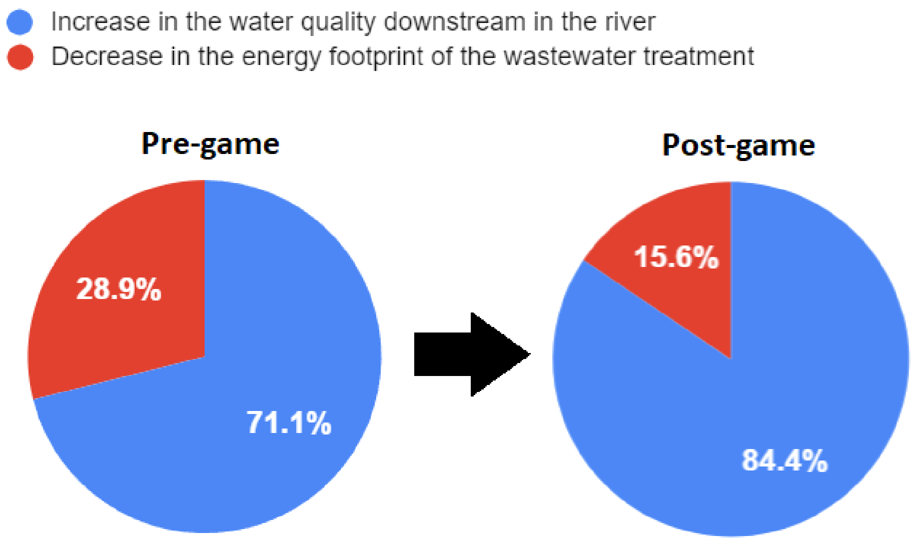


Figure 25. Answers to the question "What would be the most important effect of installing a sustainable drainage system?" before and after playing the game.

Finally, the answers to question 7 ("*which action would have the potential to save the most exergy and associated carbon footprint from domestic and industrial wastewater? Recycling nutrients from wastewater, or recycling traces of metal from wastewater?*"), show how the players, by playing the game, were influenced to revise their initial assumption about nutrients reuse having a greater potential to save energy and carbon emissions than metal reuse. (**Figure 26** shows a 51% increase towards the correct answer: recycling metals from wastewater**).**

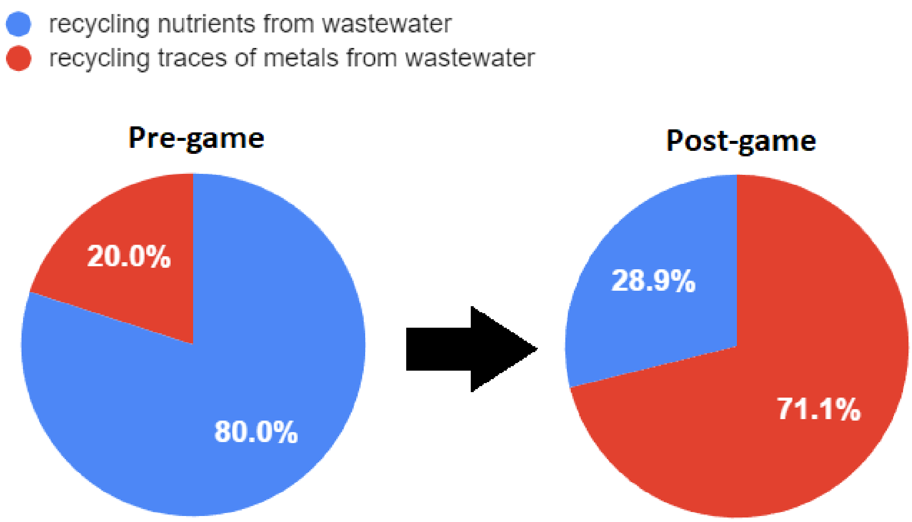


Figure 26. Answers to the question "Which action would have the potential to save the most exergy and associated carbon footprint from domestic and industrial wastewater?" before and after playing the game.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

Playing the game led to an average improvement of 26% in the number of correct answers (where some of the given questions required understanding fairly technical concepts linked to the urban water cycle as detailed **in section 2.2**).

As a debate facilitation tool, the NextGen Serious Game was used to support and illustrate points made by experts during a debate involving a panel of experts discussing at a "Net Zero roundtable" webinar organized by the Water Industry Process Automation & Control in November (2021). Firstly, potential energy savings for wastewater treatment plants were put into perspective compared to the households energy footprint (where the former represent about 2% of the water related energy footprint, while the latter represents around 98% of it), showing where the most savings could be achieved (see video available online at Water Industry Process Automation & Control, 2021; at minute 28). Secondly, the potential benefit for recycling metals going into the inlet of the wastewater treatment plant for a town of 300,000 inhabitants was emphasized because of the benefits in terms of exergy. Due to the fact that some metals have a relatively high and always increasing thermodynamic rarity, with the passing of time, they can take a substantial and greater amount of energy to mine further into the earth crust, refine, and transport. The exergy saved by recycling them when expressed in terms of carbon emission can be considerable. When expressed in equivalent Carbon sequestered quantified by the numbers of hectares of temperate forests planted yearly (same video at minute 31), interesting conclusions emerge regarding the overall potential of metal recovery technologies for the reduction of carbon emissions in the future.

Finally, the NextGen Serious Game was used inside the Aquatech Innovation Forum in Amsterdam (November 2021) to create the world's first e-sport tournament event adapted to a professional water industry conference. Water experts from diverse backgrounds were first exposed to a generic demonstration of the virtual catchment and were then able to compete while contributing their own solutions to given problems of Circular Economy for water using the game interface, leading to one participant being elected as the winner at the end of the event. During the event, several companies expressed an interest in using the NextGen Serious Game to showcase their newest products (e.g. a novel type of greywater reuse filter for example) in a virtual catchment. This underlines the potential for a novel form of Serious Game based engagement akin to interactive marketing.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

5. Conclusion

Within NextGen, a Serious Game has been developed that allows participants to understand circular economy for water by observing interactions between different components in the urban water cycle and energy and their effects on flows of water and energy and material recovery. The NextGen Serious Game has been developed in three different versions: a virtual generic urban catchment area referred to as “Toy Town”, the demo case for Athens that focuses on sewer mining, and the demo case for Costa Brava that focuses on a Mediterranean touristic setting with aquifer management and desalinisation

By combining a five-step hybrid learning methodology with a state-of-the-art real-time simulation engine, an innovative and flexible design, the NextGen Serious Game has been successful at teaching classrooms and engaging audiences. Participants who joined the supervised training sessions were on average 26% more likely to answer correctly technical questions despite the added complexity of the subject studied: Circular Economy in the context of the urban water cycle.

As a debate facilitation tool, the game also proved to be a surprisingly effective and thought-provoking tool able to contribute to the discussion by bringing multi-disciplinary insights: the most notable one being the potential of metal mining wastewater to save exergy and carbon emissions.

Finally, the NextGen Serious Game was used to organize the first e-sport competitive tournament between water professionals at an industry conference. The software architecture allowed rapid and reliable deployment to be done at the scale required for the estimated number of users and at a reasonable cost. This achievement could mark the start of a new series of hybrid events that could soon take place in the water industry: conferences where experts compete against each other to solve complex problems via Serious Games.

To conclude, the NextGen Serious Game proved to be a powerful tool that allows players to visualise and understand options, scenarios, opportunities and challenges in a more circular approach to water management.

Even though it shows promise as a training tool in the context of a classroom, and as an event enabler, it remains to be seen if this kind of Serious Game can address the biggest challenge that water operators face nowadays: engaging and sensitising the general public, businesses, and policy makers to the problems and reality of water in the context of climate change, growing resources scarcity, and environmental decline. Further work still needs to be done to expend the reach of such Serious Games to an even wider audience.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N°776541

References

Abt, C.A. Serious Games; Viking: New York, NY, USA, 1970.
Angehrn, A.A. and Maxwell, K.,"EagleRacing: Addressing Corporate Collaboration Challenges Through an Online Simulation Game", Innovate, Journal of Online Education,Vol. 5, Issue 6, Aug/Sept 2009
AWS Fargate: Serverless compute for containers. [Online]. Available: https://aws.amazon.com/fargate/. [Accessed: 01-May-2022].
B.K. Leisure and play in Plato's teaching and philosophy of learning. Leisure Sci. 1990, 12, 211–227.
Bezanson, J., Karpinski, S., Shah, V. B., & Edelman, A. (2012). Julia: A fast dynamic language for technical computing. ArXiv Preprint ArXiv:1209.5145.
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 11 (6), 1227
Butler, D., James Digman, C., Makropoulos, C., & Davies, J. W. (2018). *Urban Drainage*. CRC Press LLC. http://ebookcentral.proquest.com/lib/exeter/detail.action?docID=5303411
Calvo, G., Valero, A. (2017). Assessing maximum production peak and resource availability of non-fuel mineral resources: Analyzing the influence of extractable global resources. Resources, Conservation and Recycling, 125, 208-217.
Campos, N., Nogal, M., Caliz, C., & Juan, A. A. (2020). Simulation-based education involving online and on-campus models in different European universities. International journal of educational technology in higher education, 17(1), 1-15.
Climate Change (Serious Game). Available online: https://www.bbc.co.uk/sn/hottopics/climatechange/climate_challenge/ (accessed on 16 December 2020).
De Kleermaeker, S.; Arentz, L. Serious gaming in training for crisis response. In Proceedings of the 9th International ISCRAM Conference, Vancouver, BC, Canada, 22–25 April 2012
De Kleermaeker, S.; Zijderveld, A.; Thonus, B. Training for crisis response with serious games based on early warning systems. In Proceedings of the 8th International ISCRAM Conference, Lisbon, Portugal, 8–11 May 2011.
De la Torre, R., Onggo, B. S., Corlu, C. G., Nogal, M., & Juan, A. A. (2021). The role of simulation and serious games in teaching concepts on circular economy and sustainable energy. Energies, 14(4), 1138.
Devries, B. & Zan., "When children make rules",Educational Leadership, 61 (1), pp.64–67, 2003
Ellen Macarthur Foundation , 2010. Circular economy introduction. [online] Available at: https://ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview (Accessed 6 September 2022).
Energy Transition Game. Available online: https://energytransition.games4sustainability.org/en/ (accessed on 16 December 2020).
Energyville (Serious Game). Available online: http://zielonegry.crs.org.pl/gamepedia/energyville-2/ (accessed on 16 December 2020).
Evans B., Khoury M., Vamvakeridou-Lyroudia L., Chen O., Mustafee N., Chen A.S., Djordjevic S., and Savic D. Demonstrating the Circular Economy in the Context of Water through the use of a System Dynamic Model within an Artificial Case Study, Journal of Cleaner Production , Vol , 2022
Games at the World Water Day; Centre for Systems Solutions: Wroclaw, Poland, 2015. Available online: https://watergames.games4sustainability.com/water-games/ (accessed on 10 October 2016).
Gugerell, K.; Zuidema, C. Gaming for the energy transition. Experimenting and learning in co-designing a serious game prototype. J. Clean. Prod. 2017, 169, 105–116.
Hill, H.; Hadarits, M.; Rieger, R.; Strickert, G.; Davies, E.G.; Strobbe, K.M. The Invitational Drought Tournament: What is it and why is it a useful tool for drought preparedness and adaptation? Weather Clim. Extremes 2014, 3, 107–116
K. Wang, E.G.R. Davies "A water resources simulation gaming model for the invitational drought tournament" J. Environ. Manag., 160 (2015), pp. 167-183, 10.1016/j.jenvman.2015.06.007
Katsaliaki, K., & Mustafee, N. (2012, December). A survey of serious games on sustainable development. In Proceedings of the 2012 Winter Simulation Conference (WSC) (pp. 1-13). IEEE.
Khoury M., Gibson M. J., Savic D., Chen A.S., Vamvakeridou-Lyroudia L. , Langford H. , Wigley S. A serious game designed to explore and understand the complexities of flood mitigation options in urban–rural catchments Water, 10 (12) (2018), p. 1885, 10.3390/w10121885

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

Kolb, D.,"Experiential Learning", Englewood Cliffs, Prentice Hall, pp.20-38, 1984.

Luthy, R. G., Sedlak, D. L., Plumlee, M. H., Austin, D., & Resh, V. H. (2015). Wastewater-effluent-dominated streams as ecosystem-management tools in a drier climate. *Frontiers in Ecology and the Environment*, *13*(9), 477–485. https://doi.org/https://doi.org/10.1890/150038

Mittal, A., Scholten, L., & Kapelan, Z. (2022). A narrative review of serious games for urban water management decisions: Current gaps and future research directions. Water Research, 118217.

NextGen Serious Game, 2022. [online] Available at: http://nextgen-serious-game.s3-website.eu-central-1.amazonaws.com/ (Accessed 28 September 2022).

NextGen Water, 2022. nextGen - Circular Water Solutions - NextGen Water. [online] Available at: https://nextgenwater.eu/ (Accessed 6 September 2022).

Rai, V.; Beck, A.L. Play and learn: Serious games in breaking informational barriers in residential solar energy adoption in the United States. Energy Res. Soc. Sci. 2017, 27, 70–77

Rijcken, T.; Christopher, D.K. SimDelta global: Towards a standardised interactive model for water infrastructure development. Eur. J. Geogr. 2013, 4. Available online: http://repository.tudelft.nl/islandora/object/uuid:00654999-6ff3-4f9f-ae50-85e1564cbc26 (accessed on 10 October 2016)

Savic, D.A.; Morley, M.S.; Khoury, M. Serious Gaming for water system planning and management. Water 2016, 8, 456

Seibert, J.; Vis, M.J.P. Irrigania—A web-based game about sharing water resources. Hydrol. Earth Syst. Sci. 2012, 16, 2523–2530.

Serious Games; Geneva Water Hub: Geneva, Switzerland. Available online: https://www.genevawaterhub.org/resource/serious-games (accessed on 10 October 2016).

Stanitsas, M.; Kirytopoulos, K.; Vareilles, E. Facilitating sustainability transition through serious games: A systematic literature review. J. Clean. Prod. 2019, 208, 924–936.

Sušnik, J., Chew, C., Domingo, X., Mereu, S., Trabucco, A., Evans, B., Vamvakeridou-Lyroudia, L., Savic, D. A., Laspidou, C., & Brouwer, F. (2018). Multi-Stakeholder Development of a Serious Game to Explore the Water-Energy-Food-Land-Climate Nexus: The SIM4NEXUS Approach. Water, 10(2). https://doi.org/10.3390/w10020139

The Aquatech Innovation Forum, Aquatech (2021). [Online]. Available: https://www.aquatechtrade.com/innovation-forum/. [Accessed: 01-May-2022].

Tygron Engine. 2016. Available online: http://www.tygron.com/ (accessed on 10 October 2016).

Water Industry Process Automation & Control (WIPAC) @WWEM - Net Zero Roundtable (2021) www.youtube.com. https://www.youtube.com/watch?v=lud3INDjZkg (accessed Sep. 19, 2022 - starting at 27min17s).

Whalen, K.A.; Berlin, C.; Ekberg, J.; Barletta, I.; Hammersberg, P. 'All they do is win': Lessons learned from use of a serious game for Circular Economy education. Resour. Conserv. Recycl. 2018, 135, 335-345

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

Appendix

A1: Table of household devices with different associated water saving technologies that users can experiment with in the serious game.

Shower	A water saving shower is a shower featuring an efficiently designed nozzle, which reduces water use.
	A fog shower a shower with a water-saving nozzle that is activated in "mist"; or fog mode, drastically reducing water use.
	A recirculation shower feeds back water as you shower, reducing water use even further.
	A wtw shower (or heat recovery unit) is a shower with an easy drain heat exchange system that conserves energy.
Toilet	A vacuum toilet drastically reduces water use by introducing a pressure difference while flushing. It is fairly expensive, as the wastewater network of pipes needs to remain under vacuum pressure condition.
	A high pressure toilet employs a secondary tank to create additional air pressure and save water while flushing. It is less expensive to maintain than vacuum based systems.
	A dual flush toilet design introduces a dual flushing system; one low-water and one full flush, to match types of uses and save water.
	A water saving toilet is a smarter toilet design that uses multiple nozzles and centrifugal washing to ensure that water consumption remains low, while cleaning capacity is high.
	A compost toilet works by separating liquids from solids using two distinct tanks. It uses a minimal amount of water.
	Dry flush toilets are self-contained systems that are entirely waterless, but rely on chemicals and a mechanical system for flushing.
Sink	A water saving sink features water-saving nozzles that reduce water use per minute.
	A recirculation pump sink comes with an autonomous device that heats water upon demand. The recirculation pump saves a significant amount of water per year, as well as energy due to a more efficient heating of water.
Laundry	An eco front loader washing machine utilizes lower temperatures, reduced load programs and the eco function. It can save a significant amount of water per wash.
Garden	A garden aeration hose will control the amount of water that flows through the tap without affecting the water pressure as it mixes the water with air.
	A garden drip irrigation is a micro irrigation system with small underground pipes that allow water to drip slowly to the roots of plants.
	A garden spray timer allows a greater control of the water quantities used to irrigate the garden.

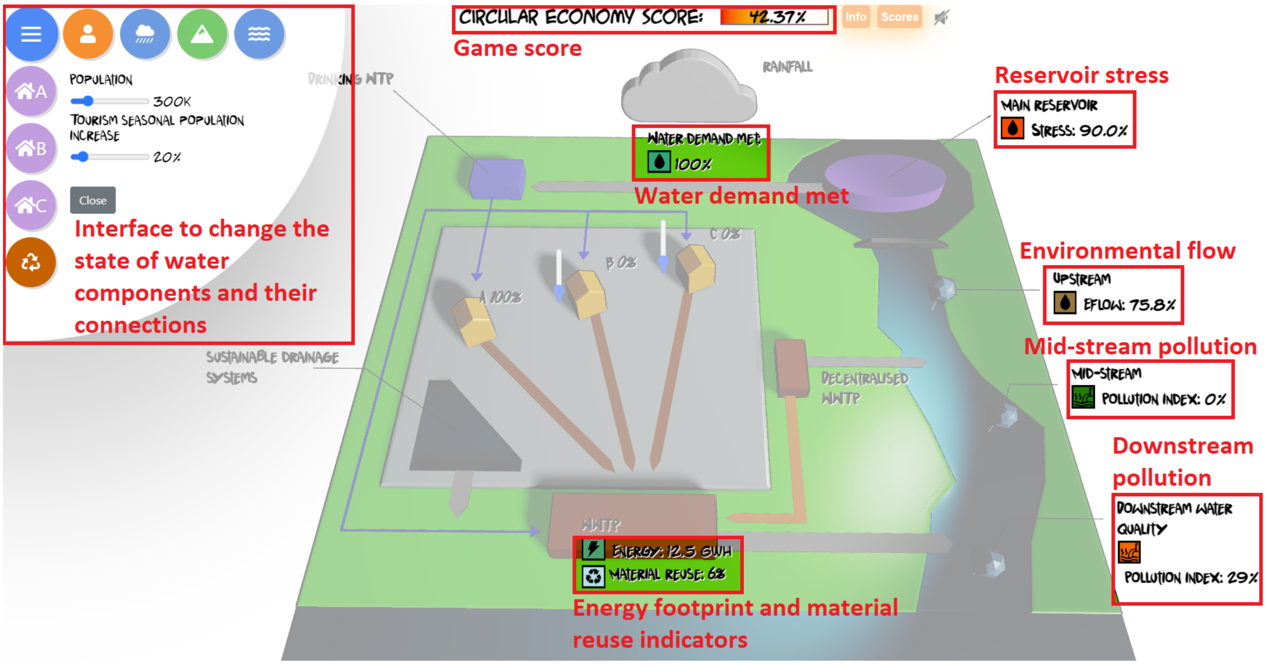
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

A2 : Table detailing the different Key Performance Indicators that make the Circular Economy Score.

Water health score	**Water demand met:** the fraction of years where the water demand cannot be satisfied because the reservoir level is insufficient for at least 10 days.	
	Reservoir health score: the fraction of years where the reservoir is considered under stress because its level is less than half full for at least 10 days.	
	Households water reuse score: how much of the water demand of the household is met by the recycled water supply.	
Energy health score	**Energy reuse health score:** a weighted average between the energy reused via biogas energy generation and material reuse.	**Biogas energy reuse:** the biogas energy generated in both primary and secondary wastewater treatment plants can be directly reused locally. We look at the ratio of that biogas energy generated over the amount of energy needed for wastewater treatment.
		Energy savings based of material reuse: nutrients (Nitrates, Phosphates, Potassium and Sulfur) and metals contentred by human activity are transported to the wastewater treatment plant via runoff. The quantity of energy saved by recycling these materials is linked to their thermodynamic rarity (the amount of exergy resources needed to obtain a mineral commodity from an accessible common rock, using the best prevailing technology).
	Energy footprint health score: the sum of the energy needed for the wastewater treatment plant, and also the energy consumption related to water devices at the households level.	
Material reuse health score	**Material reuse from nutrients:** the quantities of nutrients are derived using the estimated COD concentration in the sludge.	
	Material reuse from metals: the quantities of metals are derived from estimations from the literature regarding concentration of metal in sludge in urban domestic wastewater (expressed in mg per kg of dry sludge).	
Environmental health score	**Emission saved**: the amount of carbon emission saved via the economy of energy derived from the use of biogas generation and material reuse.	
	Environmental flow: expressed as a percentage of the original river flow retained after abstracting the water used for human activity	
	Water quality in the river: a yearly pollution index representing the cumulative debt of oxygen resulting from uncontrolled discharges of untreated water.	
Financial health score	**Affordability of water components**: teh complement of the ratio of present expenses over maximum possible expenses. It includes total installation and operational cost for all households components, sustainable drainage systems, and the primary and secondary wastewater treatment plant.	
	Return on investment for rainwater harvesting: ratio estimated in number of years over 20 by taking into account the installation cost, the average yearly operational cost and the average yearly savings on water bills.	
	Return on investment for graywater reuse: ratio estimated in number of years over 20 by taking into account the installation cost, the average yearly operational cost and the average yearly savings on water bills.	

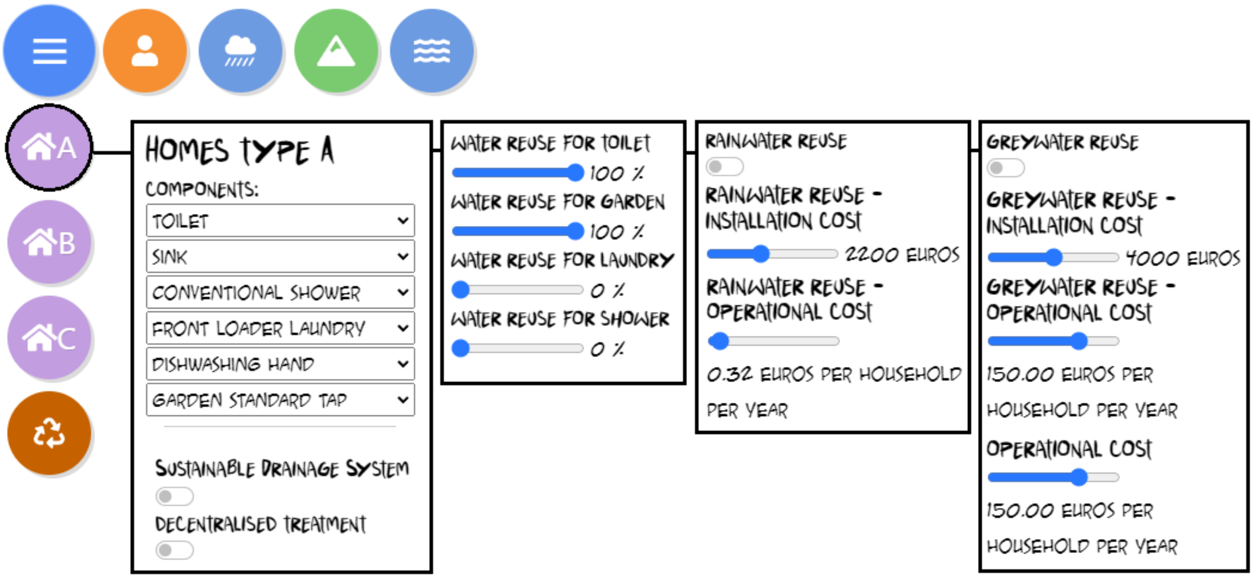
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

A3: Highlighting the serious game interface and essential indicators



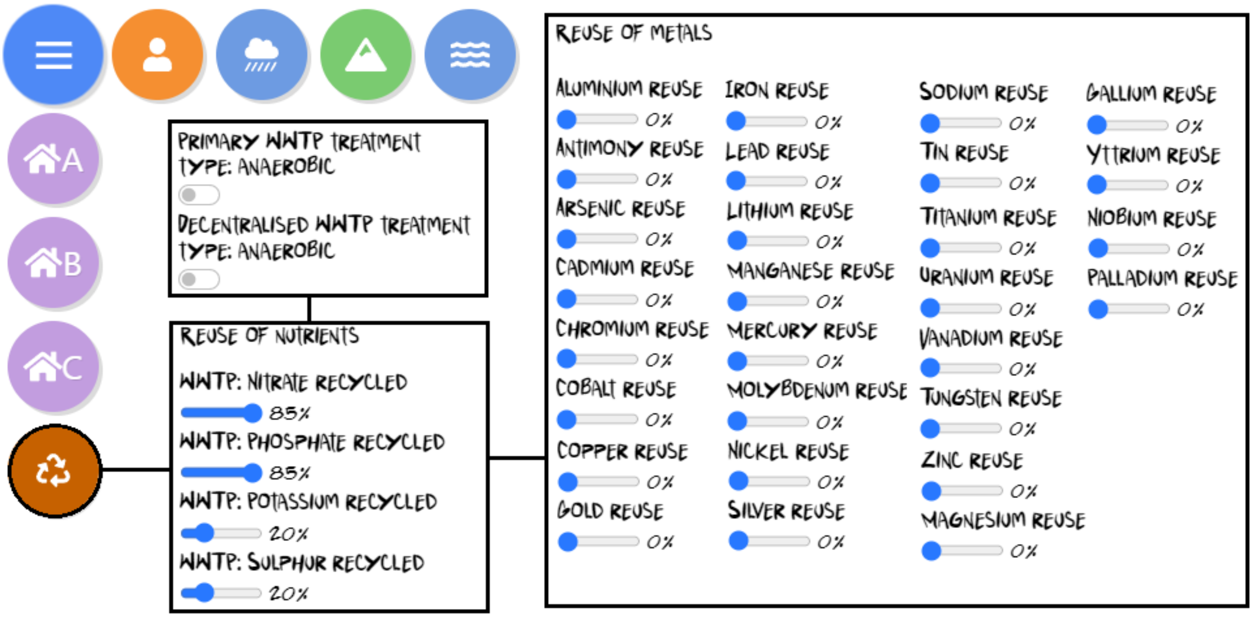
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

A4: Part of the interface allowing to swap water technologies within households, and switch connections with sustainable drainages systems and primary or secondary wastewater treatment



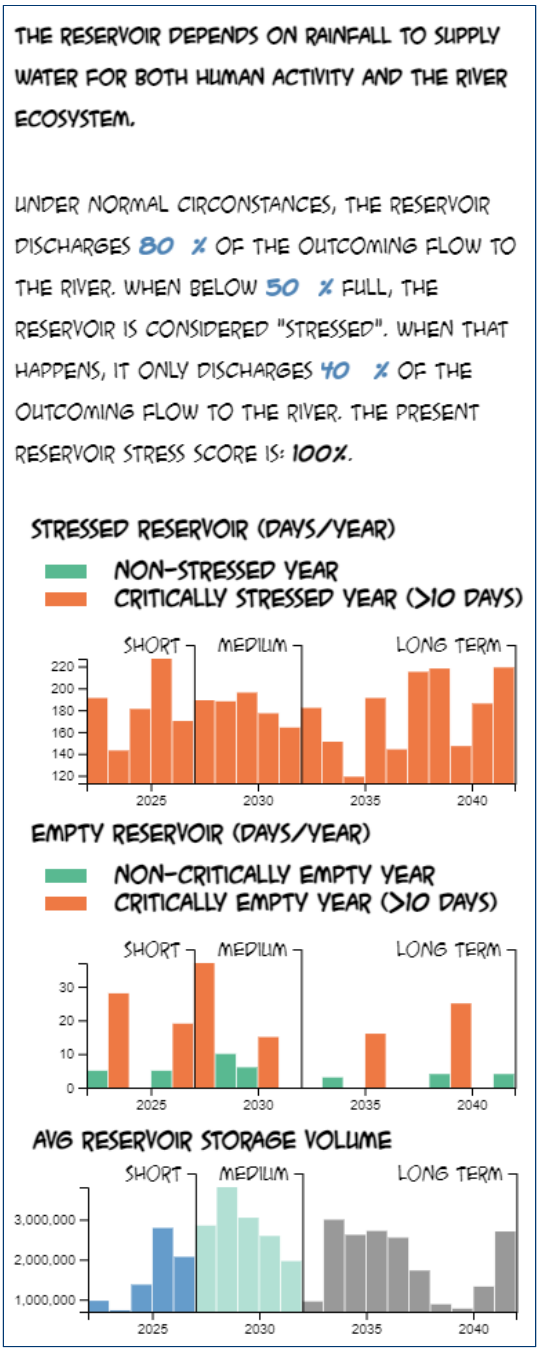
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

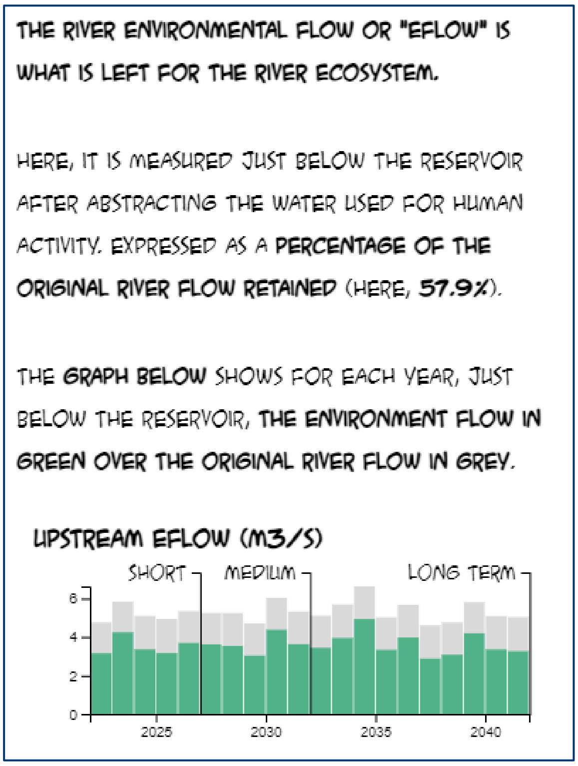
A5: Part of the interface allowing to activate anaerobic wastewater treatment (biogas generation) and recycle nutrients and metals present in the sludge

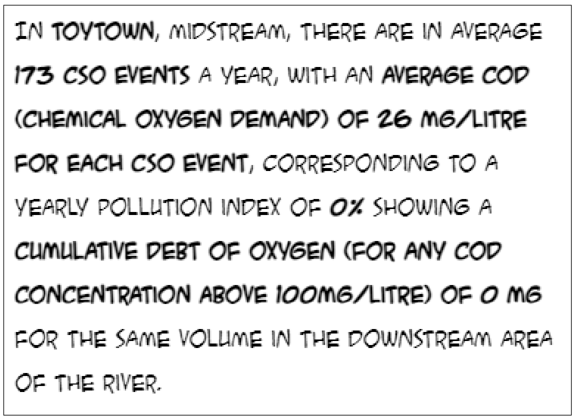


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

A6 : Screen capture of reservoir information (left), environmental flow information (top right), river midstream pollution information (lower right) that popup when a user click on the related icons.







This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

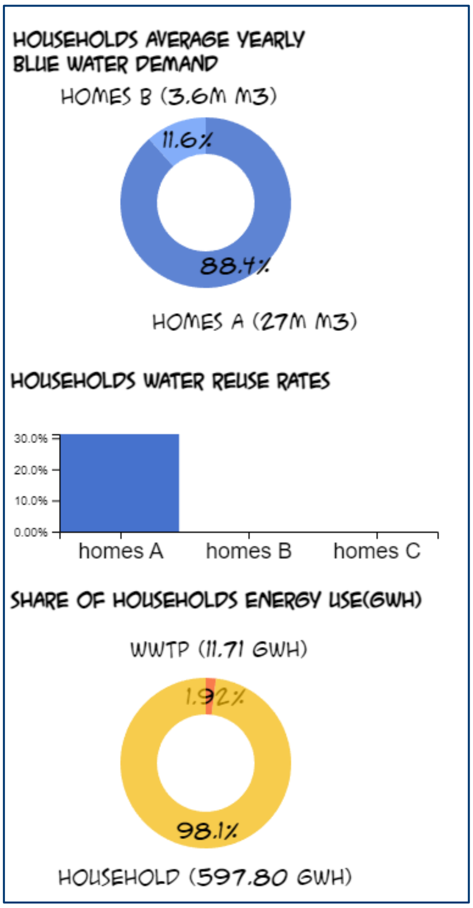
A7: Screen capture of household's water reuse information

HOUSEHOLDS USE A LOT OF WATER AND ENERGY. INSTALLING WATER AND ENERGY SAVING COMPONENTS CAN LEAD TO VERY SIGNIFICANT GAINS AT THE CATCHMENT LEVEL. THE AVERAGE YEARLY TOTAL ENERGY USED BY ALL HOUSEHOLDS IS 597,798 MWH.

THE AVERAGE YEARLY TOTAL WATER REUSE RATE FOR ALL HOUSEHOLDS IS 27.7%.

THE TOTAL INVESTMENT COST FOR ALL HOUSEHOLDS COMPONENTS IS 6.55B EUROS AND THE TOTAL OPERATIONAL COST IS 1.12B EUROS

FOR TYPE A HOUSEHOLDS, THE INSTALLATION COST OF RAIN WATER HARVESTING INCLUDING LOCALISED TREATMENT IS ESTIMATED AT 255M EUROS . THE AVERAGE YEARLY OPERATIONAL COST IS ESTIMATED AT 37.1K EUROS/YEAR. THE AVERAGE YEARLY SAVINGS ON WATER BILLS ARE ESTIMATED AT 13.5M EUROS/YEAR. THIS LEADS TO A AN ESTIMATED RETURN ON INVESTEMENT PERIOD FOR RAIN WATER HARVESTING OF 18.9 YEARS.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

A8: Screen capture of material reuse information related to nutrients

WASTEWATER TREATMENT HAS THE POTENTIAL TO PRODUCE REUSEABLE MATERIALS AND NUTRIENTS.

WE LOOK AT NUTRIENTS AND METALS REUSE BY CHECKING THE POTENTIAL QUANTITY OF NUTRIENTS OR METALS (IN T) THAT CAN BE RECOVERED THROUGH WASTEWATER TREATMENT, AS WELL AS THE APPROXIMATE MARKET VALUE, AND THERMODYNAMIC RARITY (THE AMOUNT OF EXERGY RESOURCES NEEDED TO OBTAIN A MINERAL COMMODITY FROM AN ACCESSIBLE COMMON ROCK, USING THE BEST PREVAILING TECHNOLOGY).

BETWEEN NITRATES, PHOSPHATES, POTASSIUM AND SULPHUR, THE POTENTIAL FOR RECOVERABLE **NUTRIENTS** REPRESENT A TOTAL MASS OF **2,821 T/YEAR**, A MARKET VALUE OF **856,811 EUROS/YEAR**, AND GLOBAL ENERGY SAVINGS QUANTIFIED AS A THERMODYNAMIC RARITY OF **137.1 GWH/YEAR**. THIS AMOUNT OF ENERGY REPRESENTS **37,715 T OF CO2 EMISSION** /YEAR, OR THE GREENHOUSE GAS EMISSIONS AVOIDED BY **8 WIND TURBINES** WORKING FOR A YEAR, OR EVEN THE EQUIVALENT CARBON SEQUESTERED BY **53,879 HECTARES OF TEMPERATE FORESTS** (THE EQUIVALENT OF **5.93% OF THE SURFACE AREA OF THE NETHERLANDS** COVERED IN FOREST).

Name	Quantity	Market value	Thermodynamic rarity
Nitrate	1,734 t	739k€	N/A
Phosphate	272 t	16.7k€	0.4 Gwh
Potassium	401 t	87.2k€	136.8 Gwh
Sulphur	414 t	13.6k€	N/A

PRESENTLY, YOU ARE REUSING **52%** OF THE NUTRIENTS – LEADING TO AN ACTUAL RECOVERED MASS OF **2,197 T/YEAR**, EQUIVALENT TO A MARKET VALUE OF **779,768 EUROS/YEAR**, AND A THERMODYNAMIC RARITY OF **32.6 GWH/YEAR**. THIS AMOUNT OF ENERGY REPRESENTS **8,957 T OF CO2 EMISSION /YEAR**, OR THE **GREENHOUSE GAS EMISSIONS AVOIDED BY 2 WIND TURBINES** WORKING FOR A YEAR, OR EVEN THE EQUIVALENT CARBON SEQUESTERED BY **12,795 HECTARES OF TEMPERATE FORESTS** (THE EQUIVALENT OF **1.41% OF THE SURFACE AREA OF THE NETHERLANDS COVERED IN FOREST**)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

A9 : Screen capture of material reuse information related to metals

POTENTIALLY, RECOVERABLE **METALS** REPRESENT A TOTAL MASS OF **1,787 T/YEAR**, A MARKET VALUE OF **2.61M EUROS/YEAR**, AND GLOBAL ENERGY SAVINGS QUANTIFIED AS A THERMODYNAMIC RARITY OF **119.2 GWH**. THIS AMOUNT OF ENERGY REPRESENTS **32,771 T OF CO2 EMISSION**, OR THE GREENHOUSE GAS EMISSIONS AVOIDED BY **7 WIND TURBINES** WORKING FOR A YEAR, OR EVEN THE EQUIVALENT CARBON SEQUESTERED BY **46,815 HECTARES OF TEMPERATE FORESTS** (THE EQUIVALENT OF **5.16% OF THE SURFACE AREA OF THE NETHERLANDS** COVERED IN FOREST). THIS IS A CONSERVATIVE ESTIMATE FOR URBAN DOMESTIC AREAS. IF WE WERE TO ADD WASTEWATER RESULTING FROM INDUSTRIAL ACTIVITY, THESE FIGURES COULD BE EASILY MULTIPLIED BY 10.

Name	Quantity	Market value	Thermodynan rarity
Aluminium	100 t	207.28k€	26.0 Gwh
Antimony	0.0324 t	0.15k€	0.004 Gwh
Arsenic	0.2579 t	0.24k€	0.031 Gwh
Cadmium	0.0916 t	0.21k€	0.164 Gwh
Chromium	1 t	11.29k€	0.017 Gwh
Cobalt	0.0886 t	2.38k€	0.271 Gwh
Copper	10 t	54.26k€	0.492 Gwh
Gold	0.0078 t	418.06k€	6.2 Gwh
Iron	1322 t	459.73k€	11.7 Gwh
Lead	0.6176 t	0.93k€	0.007 Gwh
Lithium	0.4539 t	30.70k€	0.123 Gwh
Manganese	40 t	57.82k€	0.788 Gwh
Mercury	0.0354 t	0.88k€	0.283 Gwh
Molybdenum	0.1990 t	6.54k€	0.058 Gwh
Nickel	0.7037 t	8.01k€	0.171 Gwh
Silver	0.4237 t	8.92k€	1.1 Gwh
Sodium	50 t	119.43k€	1.1 Gwh
Sodium	50 t	119.43k€	1.1 Gwh
Tin	0.9462 t	13.88k€	0.119 Gwh
Titanium	20 t	225.38k€	0.953 Gwh
Uranium	0.0962 t	7.97k€	0.029 Gwh
Vanadium	0.6997 t	209.41k€	0.306 Gwh
Tungsten	0.0319 t	0.92k€	0.071 Gwh
Zinc	20 t	29.65k€	0.291 Gwh
Magnesium	200 t	344.41k€	1.8 Gwh
Gallium	0.2081 t	25.25k€	43.6 Gwh
Yttrium	0.0501 t	1.27k€	0.019 Gwh
Niobium	0.0491 t	2.82k€	0.062 Gwh
Palladium	0.0089 t	359.61k€	23.5 Gwh

PRESENTLY, YOU ARE REUSING **0%** OF THE METALS ELEMENTS PRESENT IN THE WASTEWATER - LEADING TO AN ACTUAL RECOVERED MASS OF **0 T/YEAR**, EQUIVALENT TO A MARKET VALUE OF **0 EUROS/YEAR**, AND A THERMODYNAMIC RARITY OF **0.0 GWH/YEAR**. THIS AMOUNT OF ENERGY REPRESENTS **0 T OF CO2 EMISSION /YEAR**, OR THE **GREENHOUSE GAS EMISSIONS AVOIDED BY 0 WIND TURBINES** WORKING FOR A YEAR, OR EVEN THE EQUIVALENT CARBON SEQUESTERED BY **0 HECTARES OF TEMPERATE FORESTS** (THE EQUIVALENT OF **0.00% OF THE SURFACE AREA OF THE NETHERLANDS COVERED IN FOREST**)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

A10 : Screen capture of online pre-game (also identical to post-game) questionnaire

NEXTGEN pre-game questionnaire

Learning more about circular economy for water

Email *

Your email address

Is using rainwater harvesting in households more efficient than using greywater reuse to reduce water stress in the town reservoir?

☐ Tick the box if you think this is CORRECT

Does using greywater reuse in households lead to a better water quality in the river downstream than using rainwater harvesting?

☐ Yes

Justify your answer: *

Your answer

What is the relative importance of the wastewater treatment energy footprint compared to households water related devices? *

○ Wastewater treatment is 98% of the energy footprint and households water related devices is 2%

○ Wastewater treatment is 40% of the energy footprint and households water related devices is 60%

○ Wastewater treatment is 2% of the energy footprint and households water related devices is 98%

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

We assume a reservoir is organized as a control system with a fairly high "baseline" discharge rate to the river and a lower "stressed" discharge rate that is applied when the reservoir is less than half full. Would maximising the "baseline" discharge rate to the river guarantee a greater environmental flow in the river ?

- [ ] Tick the box if you think this is CORRECT

Justify your answer: *

Your answer

What would happen to the overall energy footprint and water quality in the river if you were to connect 20% of households of your town to decentralized wastewater treatment plants? *

- ◯ The overall energy footprint and the water quality would decrease
- ◯ The overall energy footprint and the water quality would increase
- ◯ The overall energy footprint would increase and the water quality would decrease
- ◯ The overall energy footprint would decrease and the water quality would increase

Justify your answer: *

Your answer

What would be the most important effect of installing a sustainable drainage system? *

- ◯ Increase in the water quality downstream in the river
- ◯ Decrease in the energy footprint of the wastewater treatment

Justify your answer: *

Your answer

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

Which action would have the potential to save the most exergy and associated carbon footprint from domestic and industrial wastewater? *

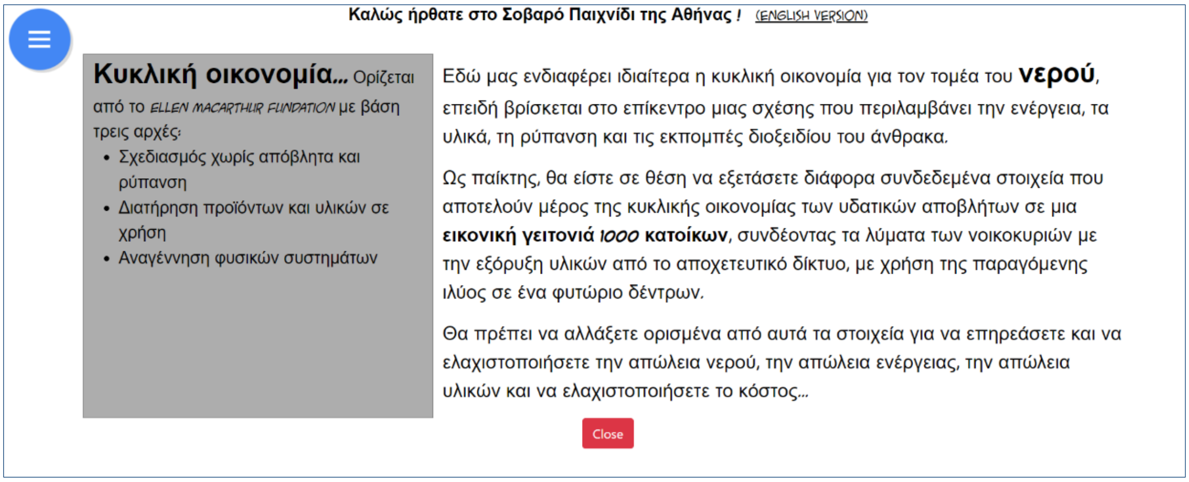
- recycling nutrients from wastewater
- recycling traces of metals from wastewater

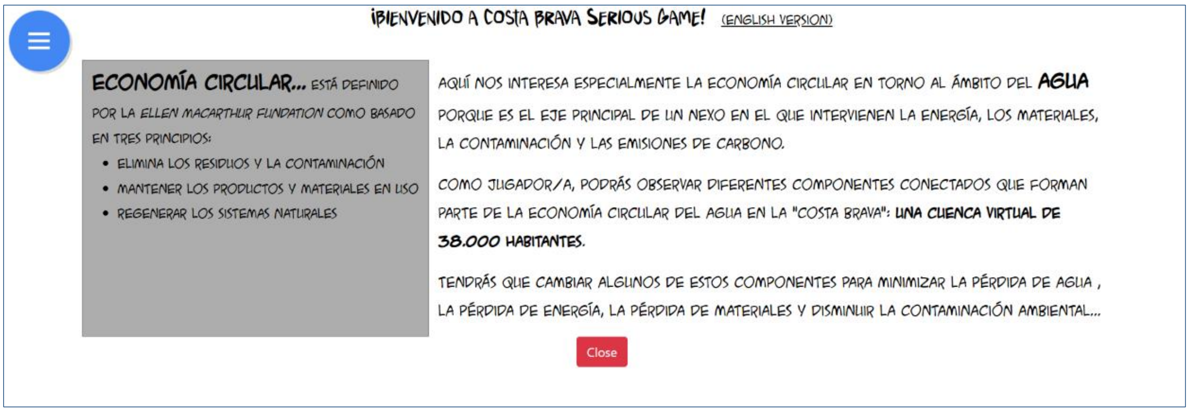
Justify your answer: *

Your answer

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

A11: Screen capture of introductory message in different local languages for the Athens and the Costa Brava case studies.





This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541