D3.3 Serious Game for Water in the CE

Initial version

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DATE : 25 JANUARY 2021

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 – 30/06/2022

Deliverable No.	D3.3: Serious Game for Water in the CE
Dissemination level [1]	PU
Work Package	WP3
Task	3.2.3
Lead beneficiary	UNEXE
Contributing beneficiary(ies)	ICCS, NTUA
Due date of deliverable	31-12-2020 (M30)
Actual submission date	25-01-2021 (M31)

[1] PU = Public
PP = Restricted to other programme participants (including the Commission Services)
RE = Restricted to a group specified by the consortium (including the Commission Services)
CO = Confidential, only for members of the consortium (including the Commission Services)

Document history

V	Date	Beneficiary	Author
1	11/12/2020	UNEXE	Mehdi Khoury, Barry Evans – draft
2	25/01/2021	ESCI	Mehdi Khoury, Barry Evans – final, after quality review by NTUA

Summary

This deliverable describes the initial version of the Serious Game for water in the circular economy, developed within the NextGen project.

The 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 initial prototype version of the Serious Game is developed for a virtual urban catchment area referred to as "Toy Town". This initial version will be used for the Serious Games related to the specific conditions of the demo cases Athens and Costa Brava.

This Serious Game is still at the prototype stage, and therefore described features might change in the development process.

Disclaimer

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1. Introduction

1.1 Background

For successful introduction of circular water solutions, engagement of stakeholders is essential. An effective way to engage citizens and end-users is through Serious Games. The present 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. Within the initial prototype version of the Serious Game, participants are able to view how these different components are impacted by water stress, how they interact together, and how they in turn can be tuned to maximise the circular economy of water in a virtual urban catchment area referred to as "Toy Town" that is comprised of 600,000 inhabitants.

The game was developed using two elements:

- A System Dynamic Model (SDM) engine running from a server, specifically made to respond in real-time to game queries using the Julia programming language.
- A Serious Game user interface allowing the participants to observe from a browser consequences of stress inflicted on the "Toy Town", to change individual components and the way they are set up, and to explore the space of possible responses and their consequences on the urban water cycle and material and energy reuse.

The result is a serious game that tells "stories" showing different ways in which the delicate balance of the urban water cycle can be affected. The serious game also offers the ability to measure how changing the individual urban water cycle components can affect flows of water, energy consumption, material reuse, and environmental stress.

This Toy Town Serious Game not only serves for any virtual city, but will also be used as a basis for the Serious Games developed for the specific conditions of the NextGen demo cases Athens and Costa Brava.

1.2 Artificial Case Study (Toy Town)

The initial design of an artificial case study ("Toy Town") model was based on the UWOT model outlined for decentralised water solutions in the Dutch neighbourhood SUPERLOCAL and presented in Bouziotas et al. 2019[1] (Figure 1). This SUPERLOCAL model analyses the interactions and effectiveness of rainwater and greywater harvesting as a means of supplementing water demand from a local supply network and additionally the localised processing of black water as a means of both heat and nutrient recovery.

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[1] 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
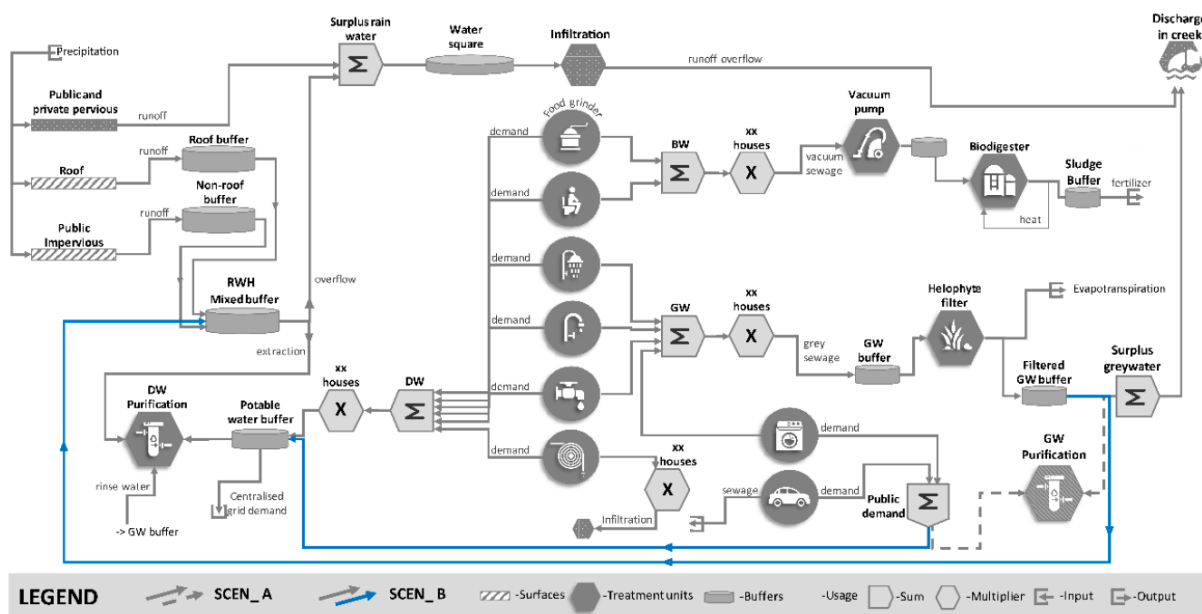
Figure 1. The urban water cycle map of SUPERLOCAL in the signal language of UWOT (Bouziotas et al. 2019)

The scale of SUPERLOCAL model is relatively small, consisting of a total of 129 properties with only 3 connected to the rainwater harvesting system and a limited number connected to greywater reuse system whereby greywater is used to supplement demand for communal laundry and car washing facilities. The Toy Town model used as the first case study in NextGen is designed as a large scale, region sized model, with 600,000 inhabitants whereby some of its components and structure are taken from the SUPERLOCAL model and scaled up accordingly. Figure 2 shows the conceptual layout of the Toy Town model with individual components described in Table 1.
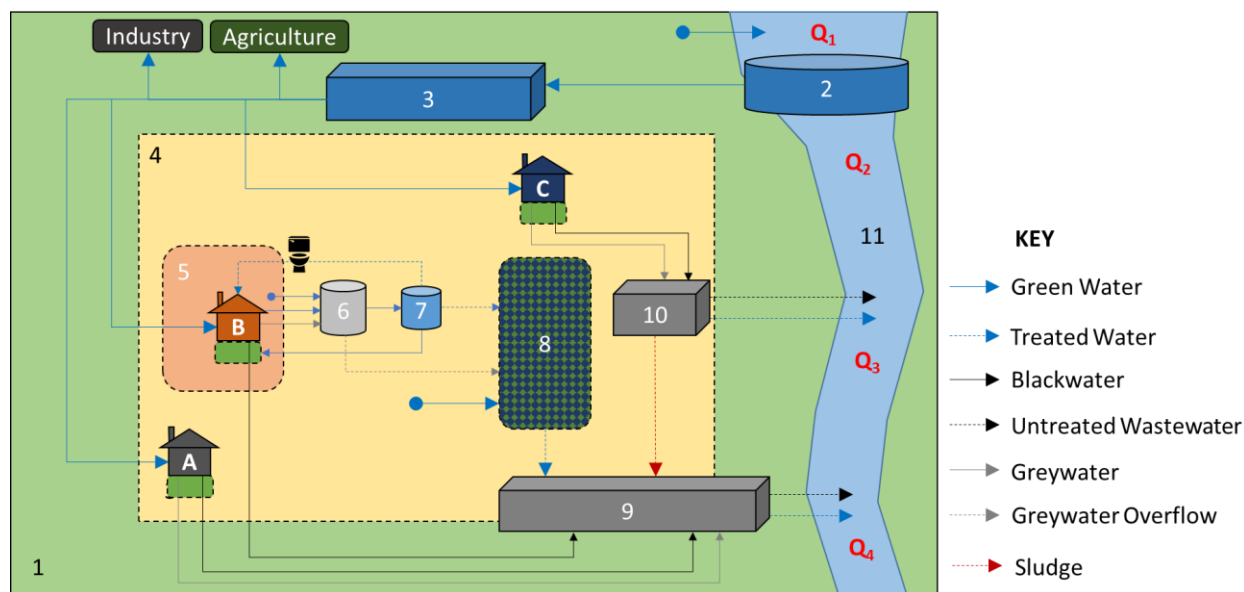

Figure 2. Toy Town conceptual layout

Table 1. Toy Town model components

ID	Description
1	Catchment Area
2	Reservoir
3	Drinking Water Treatment Plant
4	Pervious Area
5	Impervious Area
6	Rainwater and Greywater Harvesting
7	Treated Water Storage
8	Sustainable Urban Drainage (SUDs)
9	Primary Wastewater Treatment Plant (Primary WWTP)
10	Decentralised Wastewater Treatment Plants (Decentralised WWTP)
11	River
A	Standard Housing Units
B	Experimental Housing Units (utilises 6 & 7)
C	Distributed Waste processing houses (utilises 9 for wastewater treatment)
Q_1	River Inflow to Reservoir
Q_2	River Flow (Environmental Flow) after reservoir
Q_3	River Flow (Environmental Flow) after Decentralised Treatment
Q_4	River Outflow

2. Model Prototyping

2.1 SDM Conceptual Model

For modelling the complex interactions and feedback loops inherent within circular economy, we opted to utilise experience gained within a previous EU project SIM4NEXUS (https://www.sim4nexus.eu/) and develop a System Dynamic Model (SDM) linked to a Serious Game. The creation of an SDM allows to conceptually visualise interactions between different components of a model and additionally incorporate data to analyse the behaviour of these interactions such as how resources enter, propagate and leave the system. This SDM model is utilised for reference as the initial validation step either by cross-model validation or feedback from stakeholders or a combination of both. For the creation of an SDM there are a variety of software packages available, including but not limited to STELLA, AnyLogic, Vensim, and Simile. For the purpose of this project we opted to use Vensim (https://vensim.com/) due to prior familiarity with the software and it is also freely available for academic and research use. Figure 3 shows the depiction of the rainwater and greywater re-use components of the Toy Town model in an SDM within the Vensim environment. Within this part of the model there two primary inflows/sources of water: rainwater and greywater. The inflows are time-variant driven where roof inflow is driven by rainfall from climate data whereas the greywater inflow is seasonal defined by the baseline population plus increased tourist demands in summer. A secondary variable in the production of greywater is also dependant on water-use/water-saving technologies present within the properties that the player of the SG can later specify.
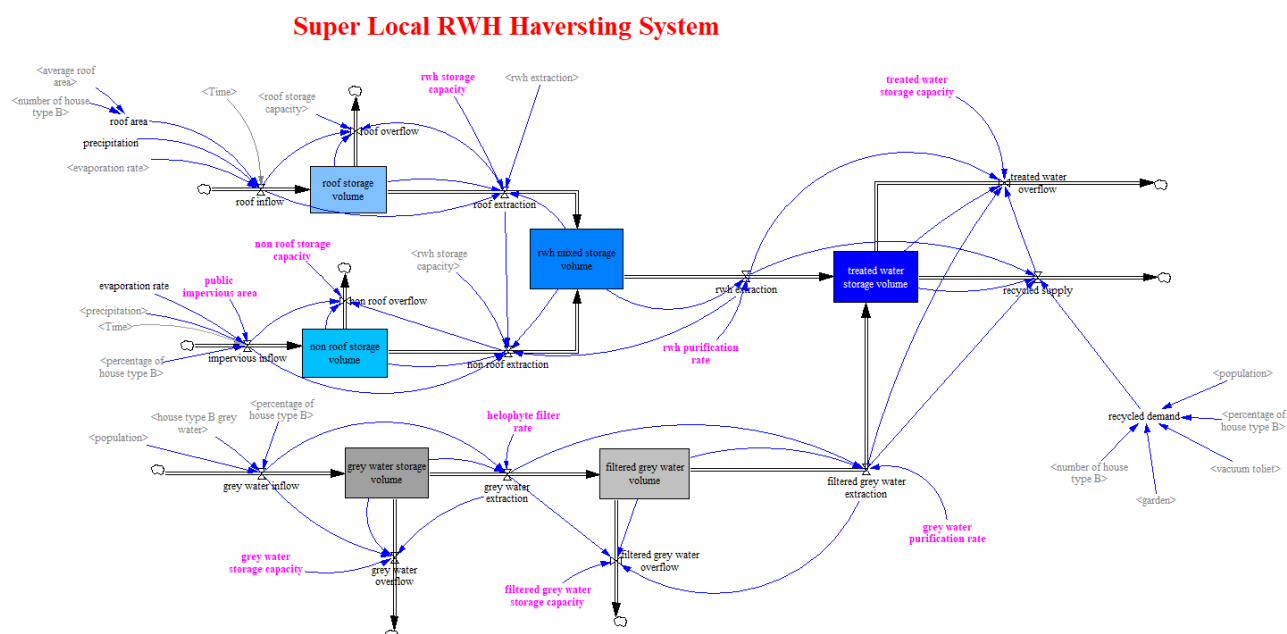

Figure 3. SDM of Rainwater and Grey Water re-use components within the Toy Town model in Vensim

2.2 Julia Translation

Using the SDM developed in Vensim for reference, the model is replicated within the Open Source programming language Julia (https://julialang.org/) (Figure 4). The Julia programming language was selected due to its ease of implimention (user friendly structure) and that it has a performance close to C. Replicating the SDM within Julia allows for fast computation of results and the coupling of model to a front-end web-based Serious Game.

The initial configuration of the Toy Town model focuses on the underlying volumetric components of the movement of water within the system. From this, the following effects and influences can be analysed:

- Supply limitations from river and reservoir network
- Rainwater harvesting
- Greywater reuse
- Water saving technology in selected houses
- SUDs as means of reducing overland flows and stormwater inflows to WWTP
- Primary and Decentralised WWTPs
- Environmental Stresses

Figure 4. Snippet of SDM code within Julia programming language

With the underlying volumetric components captured, the finalised SDM and respective Julia models that capture elements of the circular economy are built using a layered based development approach (Figure 5), whereby the initial volumetric flows of water are first captured and evaluated (since these are the primary drivers of the model) and additional layers relating to material and energy are added respectively.
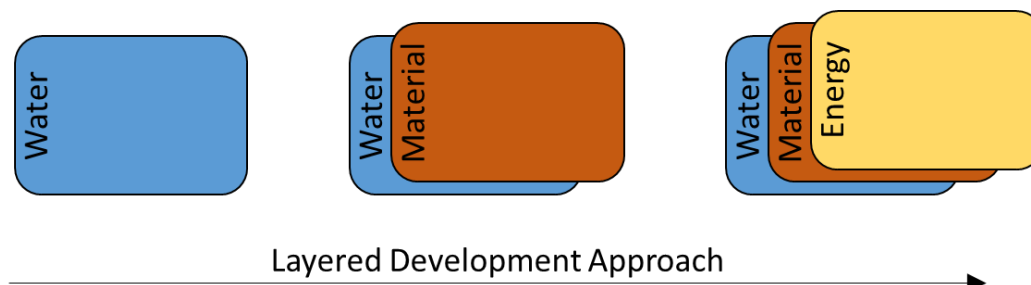
Figure 5. Layered development approach

When developing a Serious Game it is important to find the right balance between complexity and playability. The SG needs to be both easy and intuitive to use yet still have the underlying functionality to model complex real-world scenarios to provide both meaningful information and a learning experience to the player. From the performance aspect, with the game being played within an online environment the aim is to keep the computational time to a minimum (ideally under 1 second) to allow the appearance of almost instantaneous feedback to the player. The computational efficiency of Julia helps facilitate this by keeping computational times down but additional consideration is also required from the complexity side of the model to ensure computational times are kept low.

2.3 Game design and resulting user interface

The game is being designed to see how stress factors such as population growth and drought propagate through the virtual catchment components, and discover how parameters in these components can be changed to maximise the circular economy of water under these conditions. In the virtual "Toy Town", users can:

- increase the ratio of houses with built-in water saving technologies such as rainwater harvesting and grey water reuse and measure the resulting change on the urban water cycle.
- change the capacity of connected SUDs (Sustainable Urban Drainage systems) as means of reducing overland flows, and volume of stormwater entering into the WWTP when using combined sewer systems. This change, in turn can impact the amount of energy needed to treat the water and recover reusable materials in the context of circular economy.
- change parameters defining the reservoir and its connection to the river and see the consequences on overall water availability.

- change the ratio of houses connected to primary and secondary Waste Water Treatment Plants and observe effects on environmental stresses upstream, midstream, and downstream.
- change the way Waste Water Treatment Plants operate to maximise the amount of exergy[2] saved by recycling materials coming to sewages i.e. reusing 50% of the aluminium found in sewages would save 32,300 Gj per year – the energy equivalent of 562,000 electric vehicles driving 100kms each…
- supply limitation from river and reservoir network, rainwater harvesting, greywater reuse, SUDs (Sustainable Urban Drainage systems) as means of reducing overland flows, primary and distributed secondary Waste Water Treatment Plants

The Circular Economy Score is a weighted average of a hierarchy of different KPIs that reflect different aspects of the problem of circular economy. We use the definition of Circular Economy from the Mac Arthur Foundation emphasising the three principles to choose our KPIs (designing out waste and pollution, keeping products and materials in use, and the regeneration of natural systems), but with an emphasis on the domain of water. The different KPIs used to compute the top Circular Economy Score are divided in three categories: water, environment, energy and materials. The full list of KPIs is still a work in progress and being refined as the case studies move forward.

In order to derive top score, all the KPIs will have to be normalised. For example, in the Water category, for the moment, we can distinguish two sub KPIs: the ability to satisfy the water demand, and the KPI for Water Reuse. Water reuse itself is a weighted average between the water reuse rate (a percentage) and a measure between 0 and 1 that reflects how expensive recycled supply is. This last measure will have to be a normalised score derived from the cost of recycling the volume of water described in the model.

Similarly, we intend to build the environment KPI on top of normalised water quality indicators as well as normalised environment flow KPIs for upstream and midstream points in the river.

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[2] Exergy - The thermodynamic value of a natural resource could be defined as the minimum work (exergy) needed to produce it with a specific composition and concentration from common materials or reference substances in the Reference Environment. Therefore exergy can account for the concrete physical characteristics which make natural resources valuable: a particular composition, which differenciates them from the surrounding environment, and a distribution which places them in a specific concentration. Hence, quantifying natural capital in terms of exergy is more rigorous, coherent and comprehensive than with mass or money.

Here one example of the Serious Game use – this is off course subject to change as the model is undergoing substantial amount of tuning and parameters might change. Figure 6 shows the overview of the urban water cycle components in toy town.
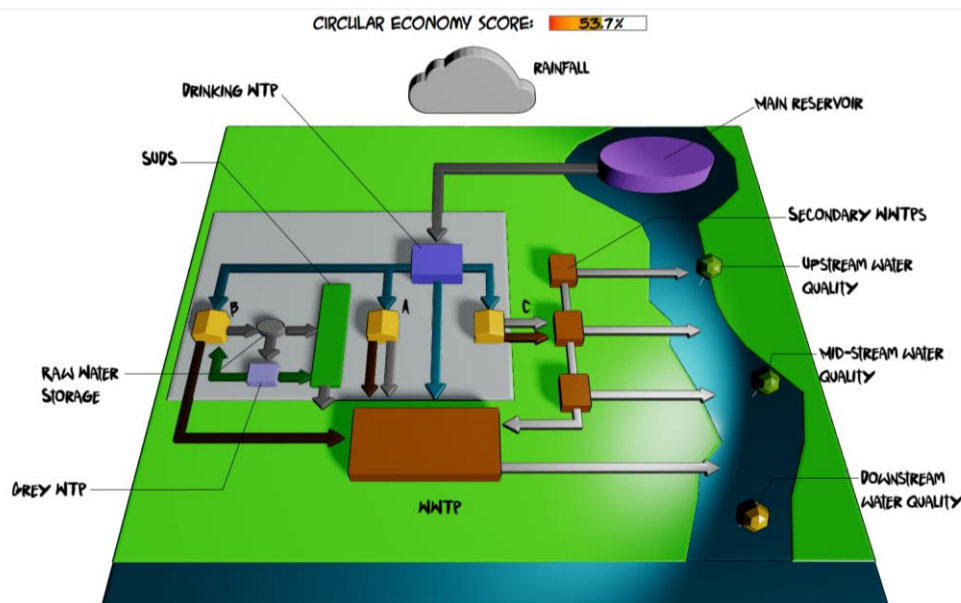

Figure 6. Overview of "Toy town" and different urban water cycle components

One can measure the amount of water available to satisfy the demand by looking at the predicted levels of water in the main reservoir. If one click on the main reservoir component, a detailed view of the main reservoir parameters and output can be seen as in Figure 7.
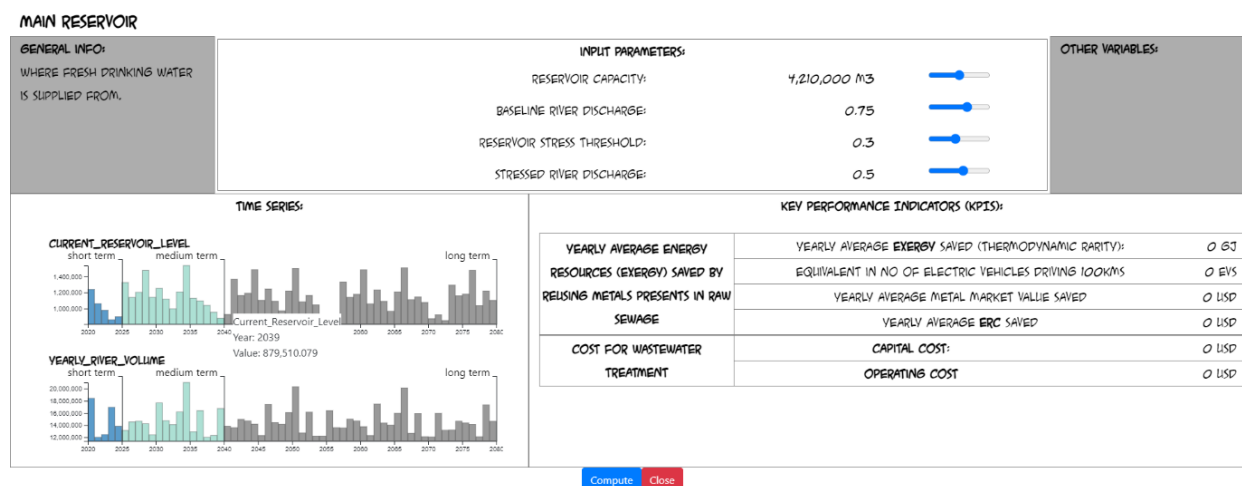

Figure 7. Predicted level of water in the main reservoir

What would happen if the population and therefore the demand of water in the catchment were to double? To answer this question, the user can click on the catchment and change to population slider, and then click compute. The main reservoir level is now predicted as going "negative" – in the sense that demand increasingly outstrips supply (see Figure 8).
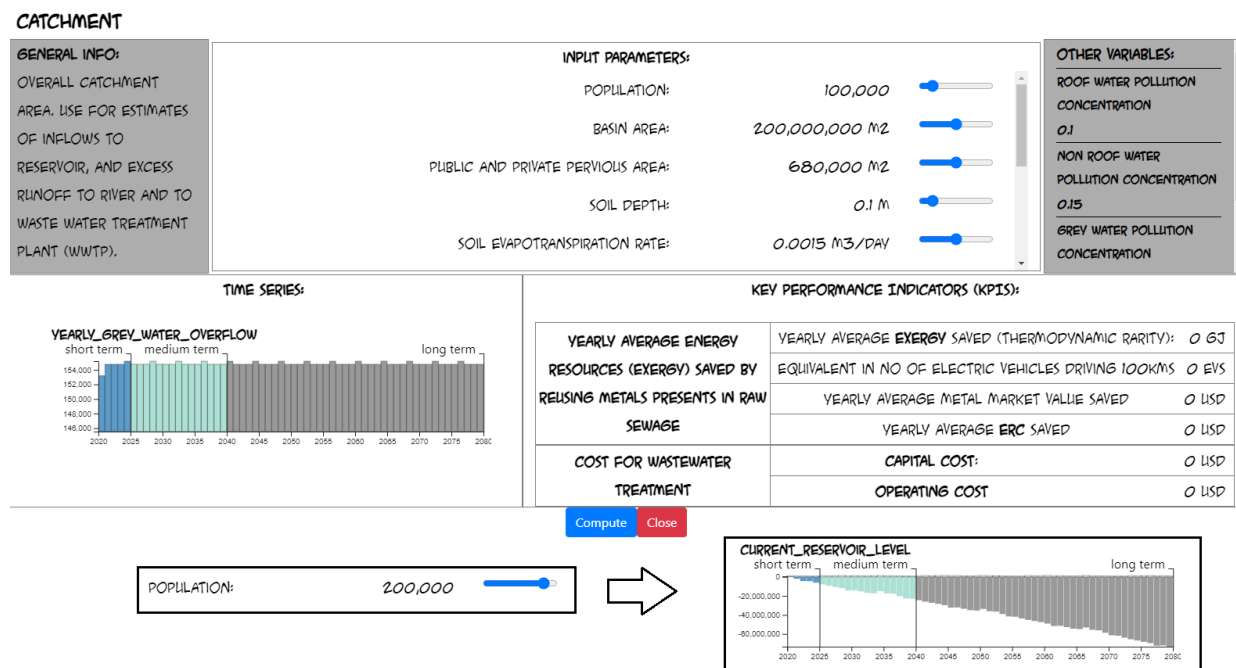

Figure 8. Doubling the catchment population makes water demand outstrip what the main reservoir can supply.

One way to respond to that problem is to reduce the "stress" discharge or environmental flow from the reservoir to the river to be 40% of the water inflow instead of 50%. As seen in Figure 9, this will boost the predicted levels of water in the main reservoir back to positive values.
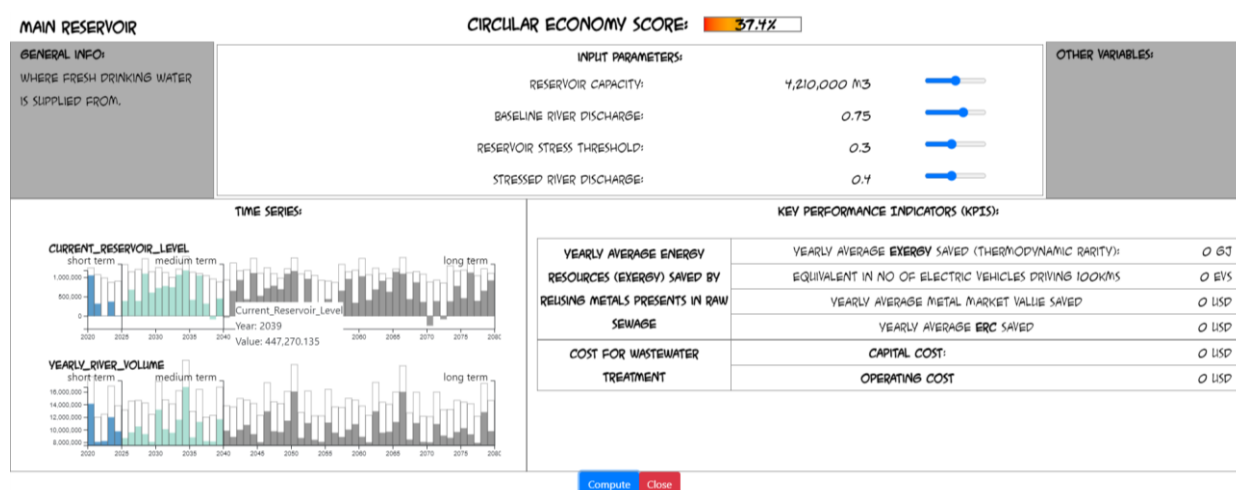

Figure 9. Decreasing the amount of discharge to the river when the reservoir level is low will replenish the reservoir.

One unintended consequence is that the river ecosystem is negatively impacted (we are presently working on adding KPIs for environmental flow reflecting changes on aquatic ecosystems). Another effect is that the amount of wastewater treated by the main Waste Water Treatment plant is such that downstream water quality deteriorates significantly (see red downstream marker on Figure 10).
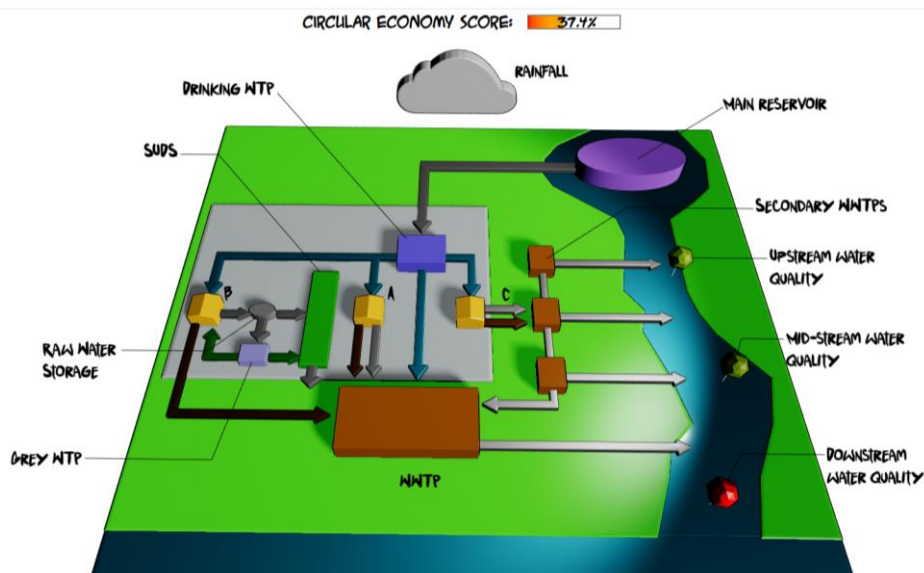

Figure 10. Red marker showing low water quality downstream.

One solution to that problem is to increase the ratio of houses linked to secondary Waste Water Treatment Plants (houses type C) and decrease the ratio of houses linked to the primary Waste Water Treatment Plant (houses type A and B) so as to decrease the amount of untreated wastewater downstream– as shown in Figure 11.
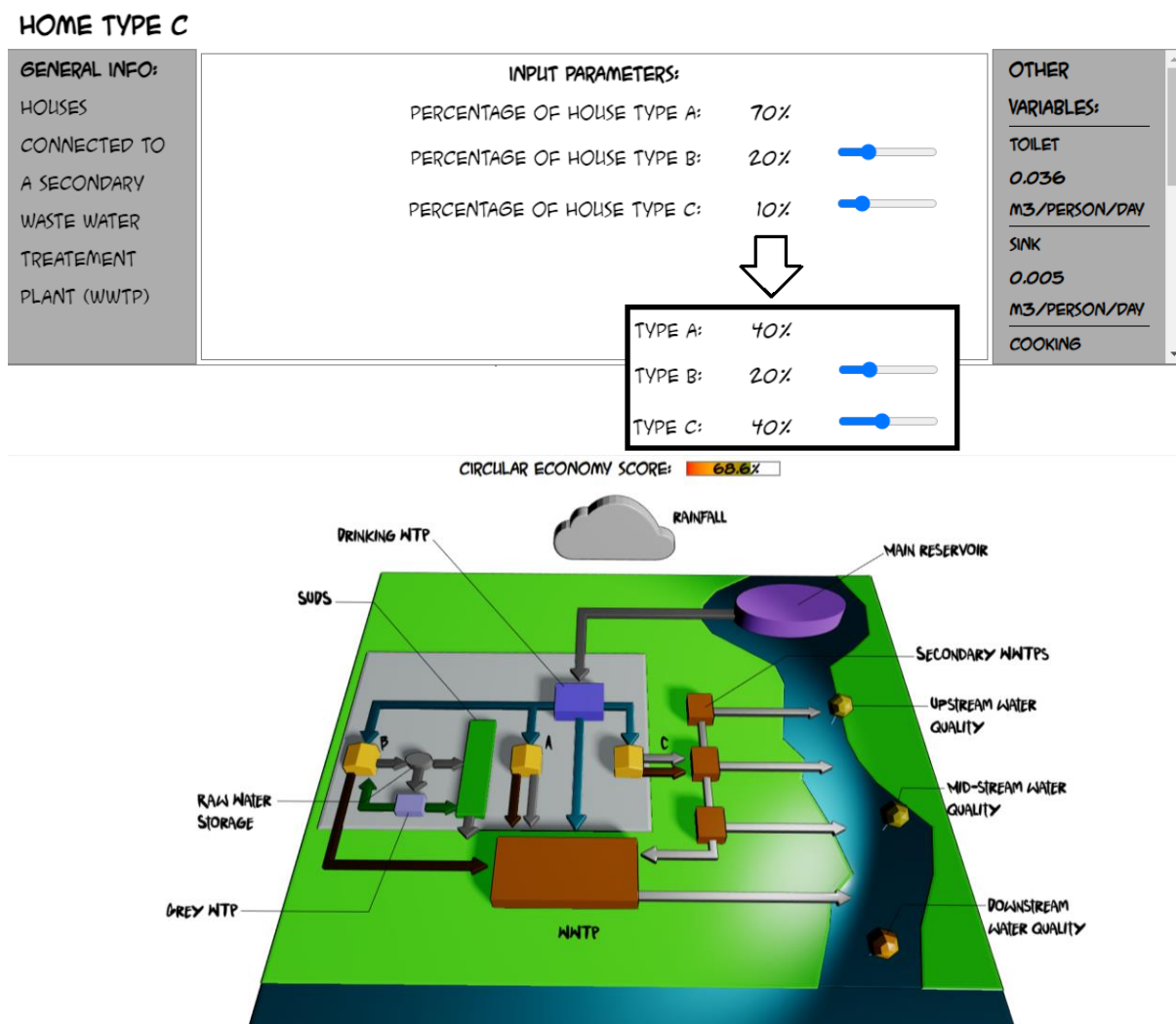

Figure 11. Increasing the ratio of houses linked to secondary Waste Water Treatment Plants (houses type C) allows a more even distribution of the pollution along the river – see the downstream marker - green again.

2.4 Details on participatory process

The game is designed to be played as a single player experience, but this does not prevent several participants to be able to play it in parallel in the same room. Communication between participants can then definitely be encouraged.

Participants can range from the general public to policy makers, to water, energy, and environment specialists.

Game portability is fairly good as the game can be played online from any laptop or desktop with a chrome web browser and a working internet connection.

The goals of the game are still being refined as they are highly dependent on the KPIs and are a work in progress.

3. Conclusion and next steps

The Serious Game in its present form allows participants to explore "stories" showing the different ways in which the delicate balance of the urban water cycle can be effected. It also offers the ability to, partially measure the impact that changing individual urban water cycle components can have on flows of water, energy consumption, material reuse, and pollution.

Further work on adding Key Performance Indicators (KPIs) is needed so as to refine the sensitivity of the overall Circular Economy for Water score, so as to give the system a more relevant and informative measurement of success. The developed system is not a fully-fledged game yet, as we still need to add goals for participants – in order to make them maximise or minimise chosen scores depending on given scenarios. Similarly, there is a need to add help in the form of visual information, tutorial popup messages, and simplify some of the information to make the system more accessible – there are still too many parameters at this stage.

Finally, the "Toy Town" case study needs to be adapted to fit the Athens and the Costa Brava case studies whereby these adaptation will coincide with the further development of KPI's specific to the case studies. The Athens demo case will see the addition of heat pumps for energy reuse as well as the production of fertiliser from sludge for tree nurseries and parks. The Costa Brava demo case will focus on the management of aquifer and energy intensive water recycling resources in a Mediterranean context, where water scarcity exacerbates the competition between tourism oriented urban centres and agricultural and industrial centres.

Appendix

The overall state of progress

Progress summary

The available functionalities	Remaining functionalities
SDM related work: A System Dynamic Model for a generic case that delivers in real time results linking together concepts such as Sustainable Urban Drainage Systems, built-in water saving technologies, rainwater harvesting, grey water reuse, environmental flows, water quality, centralised and decentralised wastewater treatment plants, exergy in the context of material reuse.	• Integration of energy consumption or generation in the SDM (and possibly associated costs) at three levels: water transport, water treatment, and biogas generation. • Adaptation of the generic "Toy Town" system dynamic model to the Greek and Costa Brava vase studies. The Greek case study is likely to have components related to heat based energy recovery and fertiliser production. The Costa Brava case study will have additional components such as a desalinisation plant, aquifer management including salt intrusion.
User Interface related work: A working browser based online user interface that visually shows all the components associated with the described concepts and connect them to the SDM, instantly showing results of any changes inflicted on the system Remaining functionalities	• Refinement of KPIs, game goals, and derived gameplay design so as to show different stories related to the Circular Economy of Water. • Refinement of the user interface to focus on showing only the parameters and variables relevant to the different stories related to given stories. • Addition of interactive information and in browser tutorial popup messages to guide the user.