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Serious Game for Water Wise Neighbourhoods

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KWR

Bridging Science to Practice

Report

Serious Game for Water Wise Neighbourhoods

BTO 2021.067 | Juni 2022

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Managementsamenvatting

Een serious game ondersteunt de ontwikkeling van waterwijze wijken

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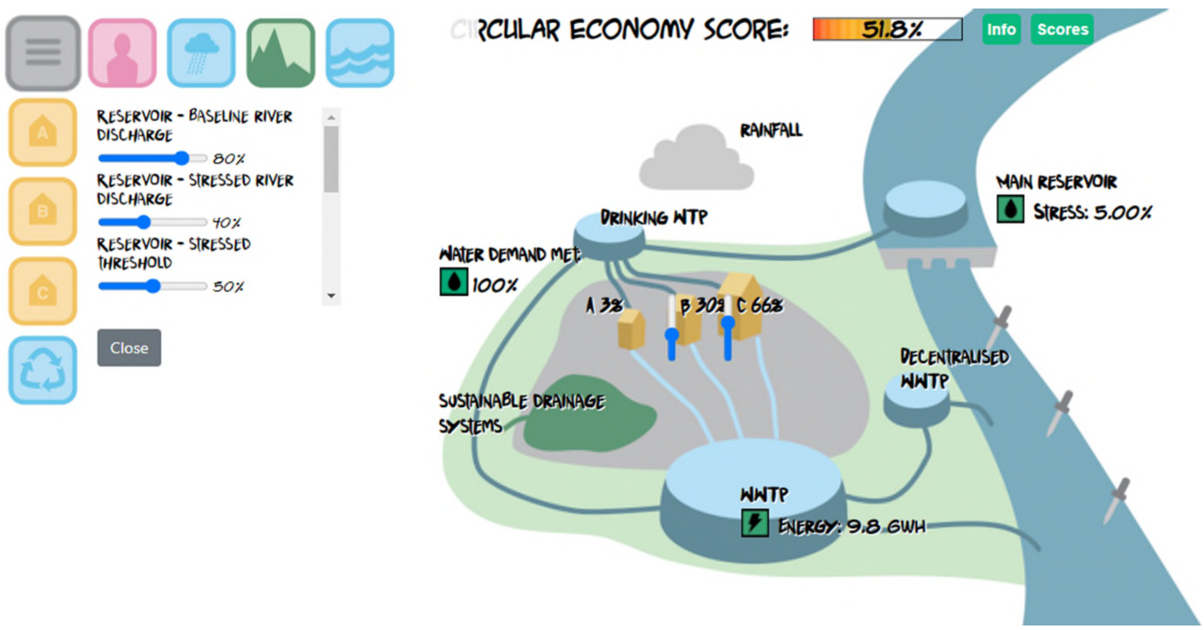
Serious games spelen een belangrijke rol bij de bewustwording van en kennisontwikkeling over toekomstige uitdagingen en mogelijke oplossingen daarvoor. In dit onderzoek is een serious game ontwikkeld voor het ontwerpen van een waterslimme wijk. Spelers kunnen op huishouden- en wijkniveau technieken en oplossingen kiezen en het effect daarvan op hun “circulariteitsscore” berekenen. Dit rapport beschrijft hoe dit spel tot stand is gekomen, hoe het ontwerp eruit ziet en hoe het spel ingezet kan worden om inzicht en kennis te vergroten.



Interface van het hoofdscherm van het serious game met een overzicht van de waterslimme wijk en enkele belangrijke indicatoren

Belang: Ondersteuning bij het ontwerpen van waterslimme wijken
Waterbedrijven worden in toenemende mate betrokken bij de inrichting van het watersysteem van nieuwe en bestaande wijken. Vaak wordt daarbij gekeken naar alternatieven voor de bestaande centrale infrastructuur in combinatie met technieken in en om de woning. De kennis over dit soort technieken is vaak versnipperd over verschillende partijen en over de interactie van verschillende oplossingen is bij de ontwerpende partijen nog weinig bekend. Een serious game kan het ontwerpproces ondersteunen door deze kennis expliciet te maken en de ontwerpende partijen de mogelijkheid te geven verschillende opties uit te proberen.

Aanpak: Het ontwikkelen van een digitaal serious game
De ondersteunende tool is vormgegeven als een digitaal serious game, waarbij spelers modelwoningen kunnen ontwerpen en die woningen kunnen combineren tot een waterslimme wijk. Het is gebaseerd op het UWOT-model (Urban Water Optioneering Tool), dat de vraag naar stedelijk water simuleert en de waterbalans in de wijk berekent.

UWOT functioneert als back-end (het onzichtbare deel) van het spel waarmee de gebruiken aan het front-end speelt. Daarnaast berekent het spel een "circulariteitscore" die is gebaseerd op een breed bereik aan indicatoren, variërend van duurzaamheid tot financiële waarde.

Resultaat: Een serious game voor waterslimme wijken
De voornaamste opbrengst van dit onderzoek is de digitale serious game die voor iedereen online toegankelijk is. De serious game is mede ontwikkeld en ook toegepast in het Horizon 2020-project NextGen. Daarnaast hebben onderzoekers van KWR en de Universiteit van Exeter ervaring opgedaan in de samenwerking rond de ontwikkeling van serious games. Deze samenwerking is inmiddels voortgezet voor de ontwikkeling van twee nieuwe serious games.

Implementatie: Serious Game kan worden ingezet ter ondersteuning van duurzame wijkontwikkeling
Waterbedrijven die betrokken zijn bij duurzame wijkontwikkeling kunnen deze serious game toepassen ter ondersteuning van dit proces. Onderzoekers van KWR werken aan vervolgprojecten om de serious game in de praktijk toe te passen.

Rapport
Dit onderzoek is vastgelegd in het rapport *Serious Game for Water Wise Neighbourhoods* (BTO 2021.067).
De serious game is toegankelijk via: http://wise-water.s3-website.eu-central-1.amazonaws.com/

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Contents

1 Introduction

Water Utilities and Water Authorities are increasingly involved in the development of new sustainable neighbourhoods. Recent examples are Superlocal (Kerkrade, WML) and Brainport Smart District (Helmond, Brabant Water). In these development projects, innovative water technologies, such as water saving, water reuse, resource recovery, rainwater harvesting and decentralised water production, play a vital role in achieving sustainability. Often, these developments are designed as a co-creation process with organisations from outside the water sector, such as municipalities, regional governments, project developers, housing corporations and citizens. These co-creation processes require the input of knowledge about water treatment, distribution and hydrology, as well as socio-economy and governance. KWR has developed knowledge on these topics, yet this knowledge is not always readily available to the co-creation teams. Without this knowledge, it is difficult for the co-creation teams to make design decisions and to assess the impact of the decisions they make regarding potential technologies or practices. Serious Games can be helpful in the transfer of knowledge as well as applying the knowledge in a controlled and safe setting.

KWR has expressed the ambition to develop knowledge and skills in the field of serious games. This study will be one of the first steps in this field. In earlier projects, serious game practices were already developed, such as in the field of *area processes in well protection* (Gebiedsprocessen in bronbescherming) and *radically new sources* (radicaal nieuwe bronnen) and a design game for water solutions for circular neighbourhoods.

This report describes the Serious Game for water-wise neighbourhoods, developed in the context of the Explorative Research of KWR in conjunction with BTO WiCE and the H2020 project NextGen. The document is structures as follows: After the introduction (Chapter 1), Chapter 2 provides an overview of the recent literature on serious games. In Chapter 3 stakeholder involvement in the form of a workshop and interviews is described, leading to the development of a first concept. This conceptual design is further explained in Chapter 4. Chapters 5 and 6 focus on the backendand frontend design respectively, while the final chapter (Chapter 7) includes some recommendations for further development.

The game itself is accessible through http://wise-water.s3-website.eu-central-1.amazonaws.com/.

2 Literature review

2.1 Lessons learnt from serious gaming

2.1.1 General tools and their gamification

Tools that provide insight into the possibilities and consequences of decisions, scenarios or calamities for a multi-sector (i.e., a system that integrates as a single system multiple sectors such as, water safety, society, energy and/or food supply) are of interest to the drinking water sector with regard to their approach, conceptualization and functioning. The combined consideration of all these in an integrated way is called the Nexus approach. Similar to this approach, drinking water companies are responsible for a variety of systems that are influenced by each other and need to connect and interact in a satisfactory way. These systems must not only connect well under normal circumstances, but also in cases of calamities and under the influence of various external factors such as changing legislation, increasing automation, artificial intelligence capacities or within the energy transition (Van Aalderen et al. 2020). By definition, these are complex systems, in need of an interdisciplinary approach, assessed under a high degree of uncertainty, requiring decisions at operational, tactical and strategic scales. It is therefore helpful to review and analyze how Nexus issues are tackled through models, either within a single sector or involving cross-cutting issues across multiple sectors.

In recent years, there have been developed methodologies to bridge the conventional sectoral, thematic models (e.g. surface water models, groundwater models, treatment process emulators, sectoral policy models etc.), mainly with the aim of taking into account key nexus elements in an integrated and unified design approach. The majority of these models are based on systems thinking techniques and more notably system dynamics (Winz et al., 2008; Ford, 1999). Example applications include frameworks to model water systems as integrated entities that also account for other sectors such as power generation (Feng et al., 2016), agriculture (Susnik et al., 2013), urban growth Bouziotas et al., 2014; Rozos et al., 2016), sustainable energy transition (Brouwer et al. 2018), but also broader frameworks where water is only one dimension across multiple nexus elements along with energy, food, land and climate (Susnik et al., 2021). More recently, System Dynamics have been adopted as a suitable methodology for investigating the complex health, climate, societal and economic interlinkages, impacts and feedback mechanisms related to the COVID-19 pandemic (e.g. Haley et al., 2021). Many more similar references can be found through the System Dynamics Society webpage (https://systemdynamics.org/covid-19/)

It may be desirable to develop a NEXUS-based approach to account for interdependencies external to the system itself and obtain a more integrated view, but it introduces significant complexity (Holling, 2001; Ruth & Coelho, 2007) that has the risk of leading to wicked problems (Buchanan, 1992; Head, 2008) or designs that are too detached from the actual management reality and too complicated to be readily applied in realistic, data-scarce environments. The aforementioned drawbacks underline the necessity to increase the level of abstraction and simplification when gaining a higher vantage point, i.e. a 'bird's eye view' on complex systems that includes multiple domains and disciplines. Moreover, another emerging issue is that the added complexity leads to more intensive data needs, which are not always matched with the current status of data management in real cases. The latter issue can improve by the introduction of smart systems encompassing real-time data assimilation, data management and data-driven decision support (Mutchek et al., 2014; Schultz et al., 2018). However, such systems, despite increasing applications in recent years, are far from being adopted as the status quo on water asset management practice, especially when the focus is on the tactical and strategic timescales.

One way to alleviate the complexities and data needs of nexus-integrated system designs is to gamify their use cases (Savic et al., 2016). This is a case also for wicked problems design (Cooke et al., 2020). By introducing a simplified, gamified approach, case studies need not be accurate representations of reality but abstracted, high-level paradigms, frequently dubbed as “toy models”, based on or inspired from reality, but refraining from the constraining limitations (e.g. data availability and/or accuracy) of actual systems. Moreover, gamification in toy models removes the pressing need to base the models on extensive, real data which have to be collected across different scattered ‘traditional’ management domains, a problem that is also common for asset management (Macchi et al., 2018). For instance, the multi-stakeholder model for the SIM4NEXUS project (Susnik et al., 2021), which integrated several nexus domains, is designed specifically for serious gaming, while other integrated models are first developed in a toy model-hypothetical case before being extended to fit real systems (Makropoulos et al., 2018; Nikopoulos et al., 2019). It should be pointed out that the process of gamification does not preclude the potential of these tools to provide assistance for decision-making in practice, as they are still designed to be means for awareness, stakeholder participation and multi-stakeholder engagement in complex settings. On the contrary, gamification enables a higher degree of abstraction in cases that expect less realism (e.g. toy models) or offers more room for modelling assumptions in their parameters to be acceptable (e.g. multiple unknown quantities with regards to climate, society, policies etc.).

2.1.2 Different functionalities offered by serious games

Simply put, serious gaming is defined as ‘gamification used for purposes other than mere entertainment’ (Savic et al., 2016). The goal of serious gaming is to integrate educational aspects, such as teaching, training and awareness raising via simplifying and mimicking reality (i.e.. through the use of simulation), along with an emphasis on experiential learning and end-user (inter)action (Wilkinson, 2016). The application areas of serious games are diverse but emphasize on systems with complex dynamics and/or multiple stakeholders; typical use cases include awareness raising, education and conflict resolution for policy-making, with topics including government, healthcare, military, corporate training, as well as tactical and strategic management of nexus domains and resources, e.g. water, land, energy, climate, ecosystems (Kato & De Klerk, 2017; Boyle et al., 2016; Flood et a., 2018).

Recent years have seen extensive developments of serious gaming in water management as well, particularly in the domains of catchment and river basin management (i.e. flood risk management)(Khoury, 2018) or water supply/distribution management (Savic et al., 2016) other domains such as urban water quality are less represented and thus have greater development potential, although recently circular economy oriented serious games are being developed and promoted to larger audiences (e.g. https://www.aquatechtrade.com/news/water-treatment/aquatech-town-serious-game/) . Gamification from the perspective of asset management is even less explored, with fewer studies focusing on assets and investment decisions as part of the game computational engine; most gamification attempts on asset management typically focus on stakeholder interactions and employ a board-game approach (Martinetti et al., 2017), while digital games focus on the complexity of interactions in large infrastructure networks (Van Riel et al. 2017; McBurnett et al., 2018).

Following the classification seen in the literature (Savic et al., 2016; Boyle et al., 2016; Van Aalderen et al. 2019), serious gaming for water can be further distinguished using the following criteria:

- **The application area (domain)**, which is the water system domain for which a serious game has been designed. Frequent domains in existing applications are: (i) river basin and flood management, (ii) urban water.
- **The user interface design (UI)**, which defines how the players interface within the game design and with each other. With regard to this criterion serious games are divided in **board (tabletop) games**, i.e. games that are played via a physical board, and **digital games**, which rely on computer technology and simulation to represent (part of) the system computational engine. Hybrid forms also exist (Vayanou et al., 2019), combining board game elements with digital elements that assist players in calculations and visualization of information. Interestingly, board games have been traditionally developed in earlier stages of serious gaming (Wilkinson, 2016), but are becoming recently less frequent as a research approach, due to the rapid advances in computational speed and other technological advancements (e.g. Artificial Intelligence) in water systems modelling and the knowledge elicitation engine of the serious game (Savic et al., 2016). However, the market of tabletop gaming has seen a significant revival in recent

years, with interesting concepts being developed, particularly in casual applications (Barr et al., 2019). In general, board serious games are fit for multi-player settings and focus more on stakeholder interactions and the overall learning experience (Zagal et al. 2006), while digital serious games focus on the interaction of players with (and within) a digital setting by introducing advanced digital technologies and water system modelling (Khoury et al., 2018). In the subcategory of digital games, another criterion of interest is the simulation model that is used to represent the water system (Savic et al. 2016); some digital games employ simple conceptual model constructs (e.g. the AQUATECH case, (e.g. https://www.aquatechtrade.com/news/water-treatment/aquatech-town-serious-game/), while others rely on more elaborate hydraulic models that have been used for consultancy and design (e.g. Khoury et al., 2018).

- The design aim (motive) of the game, which refers to the general aim and scope of the serious game (by design). This could be, for instance, increased public or stakeholder awareness, increasing understanding of a complex issue, building trust in a community, willingness to participate, etc. This characteristic reflects the top level of a hierarchical model of gaming based on activity theory (Carvalho et al., 2015) and is distinct from the goal of the game (below), which refers to the specific game objective, as it refers to the learning outcomes embedded in the game design (Van Aalderen et al., 2019).
- The goal of the game, which is the in-game target (ideal) outcome for the players, e.g. achieving the largest net income, reaching a specific area first etc. Note that there are gaming cases that emphasize learning and interaction over specific in-game goals and thus are not constrained in specific goals (while they do have a motive). These are known as sandbox games (Ocio & Brugos, 2009).
- Game facilitation (initialization), which categorizes games based on how the players are introduced to the game operational procedures and the problem at hand. Some games rely on in-game materials to introduce the game procedures to players, such as tutorials or manuals, while a large part of the learning process comes by the playing itself. The majority of games, however, rely on the role of facilitators, which guide players at the beginning or throughout the gaming process (e.g. https://www.kwrwater.nl/en/actueel/what-is-sim4nexus/?highlight=SIM4NEXUS) .
- Number and type of players, which highlights the number of stakeholders playing the game. Most serious games are multi-player games, made in order to study the learning goals and experience of different human actors that compete or assume different roles in a complex system (e.g. Burton, 1993). Albeit less common, other serious games focus on a single-player experience, hence labelled as a single player game (e.g. the AQUATECH toy town https://www.aquatechtrade.com/news/water-treatment/aquatech-town-serious-game/). In multi-player games, the game can be further categorized as competitive, where actors compete against each other (e.g. for the allocation of resources), or collaborative, where multiple actors work towards a common goal[1] (Buchinger & da Silva Hounsell, 2018).
- The target (stakeholder) group, which defines the user groups or subgroups that the game is built for (Van Aalderen et al., 2019). There are serious games designed for audiences in a specific domain (e.g. students and water professionals in distribution networks, Morley et al. 2017) while other games have a broader scope and aim at including multiple, diverse stakeholder groups, such as administrators, local communities, policy makers, entrepreneurs or the wider public (e.g. https://www.kwrwater.nl/en/actueel/what-is-sim4nexus/?highlight=SIM4NEXUS) .
- Game portability, is a criterion related to whether the game is played offline or is a web- or server-based application (which ban be played online). Offline games are more common as they do not require complex server-client interactions. Board games are by definition portable and, unless a hybrid approach that requires an internet connection is introduced, are offline. Online games can be further distinguished between open games, i.e. games that everyone can access and play, and restricted games, i.e. games designed for and enabled to specific stakeholder groups (Boyle et al., 2016).

[1] There are also hybrid forms in casual gaming, i.e. games where one player has a role of power and other players have to collaborate in order to win against him.

Other criteria that have been introduced in literature deal with technical and functional aspects such as the game realism, the different roles players assume, the distribution platform (e.g. Windows, Linux, Android), the way performance feedback is given from players, the display technology used, the way progress is monitored while playing, the game duration etc. For the interested reader, Savic et al. 2016 and Boyle et al. 2016 provide more exhaustive classifications.

2.1.3 Lessons learnt from serious game literature

Besides serious gaming classification, an analysis on existing serious gaming literature reveals that:

- Most of the serious gaming applications focus on complex water systems that are abstracted and simplified in a controlled game environment. The majority deals with river basin management, while applications for urban and irrigation water systems also exist (Savic et al., 2016).

- In terms of game design, most games address resource allocation and conflict resolution among groups of stakeholders and thus require the role of a facilitator (i.e. a technical expert with knowledge of the game who also helps pass the learning curve for players). This multi-stakeholder perspective leads to simple designs and is traditionally supported by the board game type. However, digital games have also emerged in recent years (Khoury et al. 2018).

- Most applications are highly abstracted, with a low degree of game realism. User interfaces are often rudimentary and only rarely take into account technological advances from the video gaming industry (Khoury et al., 2018). More emphasis is put on the technical design aspects and the overall conceptualization, at the expense of aesthetics or aspects of user friendliness; the latter, however, is deemed important to facilitate the lessons learned from the users. Recently, serious games with a heavy scientific modelling approach, have started emulating concepts from well-known general games (e.g. the Monopoly game), including also artists in their design, to overcome this barrier. The SIM4NEXUS Serious game concept and video is such an example (https://www.kwrwater.nl/en/actueel/what-is-sim4nexus/?highlight=SIM4NEXUS) .

- Fewer analytical studies focus on the impact of serious gaming to stakeholders, or study analytics derived from past game changes (Van der Wal et al., 2016). The community response to serious gaming is often overlooked, as it requires a timeframe extending well beyond the end of the design phase which usually is the focus of research. Moreover, many games do not allow for consistent registration of user experience as part of their design; this makes any assessment on the game usability harder, as the data from past plays and the overall user experience is not stored for future use.

2.1.4 The role of computing in modelling and serious games

Given that simulation models are complex and usually rely on high-quality, aggregated data from multiple contexts, there is a constant need to enhance and support them with advanced computational approaches. Serious games face similar challenges in the computing industry, since the early stages of computer development (Olson et al., 1992). Computing and increased computational power and speed has aided models (decision support systems, operational tools, serious games) in various ways, for instance by:

a. Developing new approaches for data management, with which data are treated, processed, aggregated and, ultimately, visualized. The science of storage, updating and retrieval of digital information has led to the development of management information systems (MIS), databases (DBs) and knowledge bases (KBs), which are able to manage raw data, categorise and analyse them, and ultimately feed them to the decision-making process and the knowledge elicitation engine. Over the recent decades, the role of data in decision support has been increasingly central; rapid technological changes have transformed multiple service fields – including water systems – into data-rich environments, where managers and decision-makers are increasingly called to handle, evaluate and decide based on data (McAfee et al., 2012; Kitchin, 2014).

b. Elaborating on computational models that mimic real systems (e.g. with the use of evolutionary approaches in water systems) and act as blueprints for decision support. The introduction of computational modelling as a means to aid decision-making has led to Decision Support Systems (DSS), i.e. digital interfaces vis-à-vis MIS and DBs where users are able to define scenarios, simulate, visualize alternative futures or network layouts and, through the process of consecutive simulations and interpretation of their results, support decisions (Power et al., 2007; Doukas et al., 2020). The latter definition implies that the nature of DSS is not repetitive and trivial, but an interaction exercise between the decision maker and computer-based system models that can be complex, unstructured or exploratory.

Some important challenges to be considered when developing DSS is that they are context-specific, technology-aware and that their scale is linked to data availability. The fact that they are context-specific implies that the models introduced and embedded in DSS depend on the domain of application and can range from very specific mathematical models with operational context to abstract notions for integrated, strategic modelling. Technology awareness means that the models need to benefit from advancements in computational techniques such as systems analysis, simulation and optimisation algorithms (Power et al., 2007), as well as generic software/hardware advances (e.g. edge and cloud technologies, distributed computing etc.). This makes DSS a very dynamic environment which needs to be updated continually. Finally, linking the scale to data availability means that the more elaborate models are introduced in DSS, the more (and finer) data are needed to properly calibrate, run and validate them in order to make well-informed decisions. The latter two characteristics introduce a strong trade-off between what is (technologically) possible and what is (operationally) reasonable for DSS, i.e., the elaboration on models and technologies needs to scale according to data availability. In the case of serious gaming, the process of gamification means that less realism and data restrictions are expected from multiple data sources that would otherwise be problematic. This is more important for simulating systems under uncertainty (e.g. climate- or society-driven integrated systems). In short, information that cannot be directly obtained (e.g., either from open access data or from proprietary DBs) can be reasonably assumed, without reducing its validity, since the model is used to explore gamified scenarios and not mimic the response of a real system. The approach of serious gaming leads to a 'gamification of data' as well; data need not be based in spatial or temporal reality to be included in serious gaming. This means that more elaborate gaming concepts can be developed based on less data and more demanding future operational scenarios can be examined. Moreover, serious games exhibit potentially transformative capabilities to strategic decision-support tools, in order to provide better management of complex water systems compared to purely technical simulation or optimisation methods that focus on a single thematic area (scientifically) and thus have difficulty in capturing the socio-technical dimensions of complex systems (Savic et al., 2016).

3 Stakeholder involvement & concept development

3.1 Applying a first concept

The first concept of the serious game was applied in a co-creation workshop in Brainport Smart District. In this Living Lab, water professionals from several organisations were developing a conceptual design for a water system at neighbourhood level. At this development phase the water professionals had to select technologies at different levels (household, neighbourhood, city) in such a way, so that several targets regarding sustainability, circularity and water saving could be met. This was not an easy task, since knowledge about these different technologies was fragmented. Also, there was a focus on individual technologies and less on the interactions among the different technologies at the neighbourhood and city level.

In response to this challenge a workshop format was designed to help the participant in the selection of technologies. In preparation, all relevant technologies were printed on cards. Also, three large (A0) worksheets were printed, one containing a house, one containing a neighbourhood and one containing a city. In the workshop, the participants were asked to select the relevant technologies, starting at the household level. They could for instance chose from different types of toilets (compost, vacuum, low flush, rain water) showers, and washing machines. Also newer technologies such as the Hydraloop (Saint, 2020) were available for selection.

After selecting the technologies at the household level, the participants were asked to discuss:

1. the compatibility of the selected technologies (e.g. a rainwater toilet requires some sort of rainwater collection system)
2. the contribution of the technologies to the preselected targets
3. any possible requirements of the selected technologies at different scale levels (e.g. a vacuum toilet requires a pressurised sewer system).

If incompatibilities were revealed between the different scale levels, or, if requirements for certain technologies were missing, the participants could add, remove or replace technologies. In this way, two scenarios were developed. One with baseline sustainability targets (e.g. 40% reduction in potable water use), one with more ambitious (a so called 'plus') sustainability targets (e.g. 70% reduction in potable water use). Researchers from KWR then used the Urban Water Optioneering Tool (UWOT), which is an urban water cycle model (Bouziotas et al., 2019, Rozos & Makropoulos, 2013) , to model the impact of the two technology scenarios. The model outcomes supported the claim that these bundles of technologies result indeed in attaining the baseline and plus targets, respectively.

The workshop and subsequent modelling work gave rise to the idea of developing a serious game, in which these steps could be taken in one go and with support of digital devices. Based on the experience from the Brainport Smart District, a project proposal was submitted and granted to start a VO project to develop a serious game for water wise neighbourhoods.

Stakeholders were consulted again (water utility, water authority, municipality) through interviews to get a better picture of the needs and requirements regarding such a serious game. A number of goals for the serious game were identified:

1. Get all stakeholders at the same level of knowledge. The game should accelerate the process of mutual understanding and understanding decentralised technologies and the effect they have.

2. The game should reveal interdependencies and synergies between technologies and stakeholders.

3. Stakeholders should get familiar with decentralised technologies, to the extent that they can “sell” them to their own organisations.

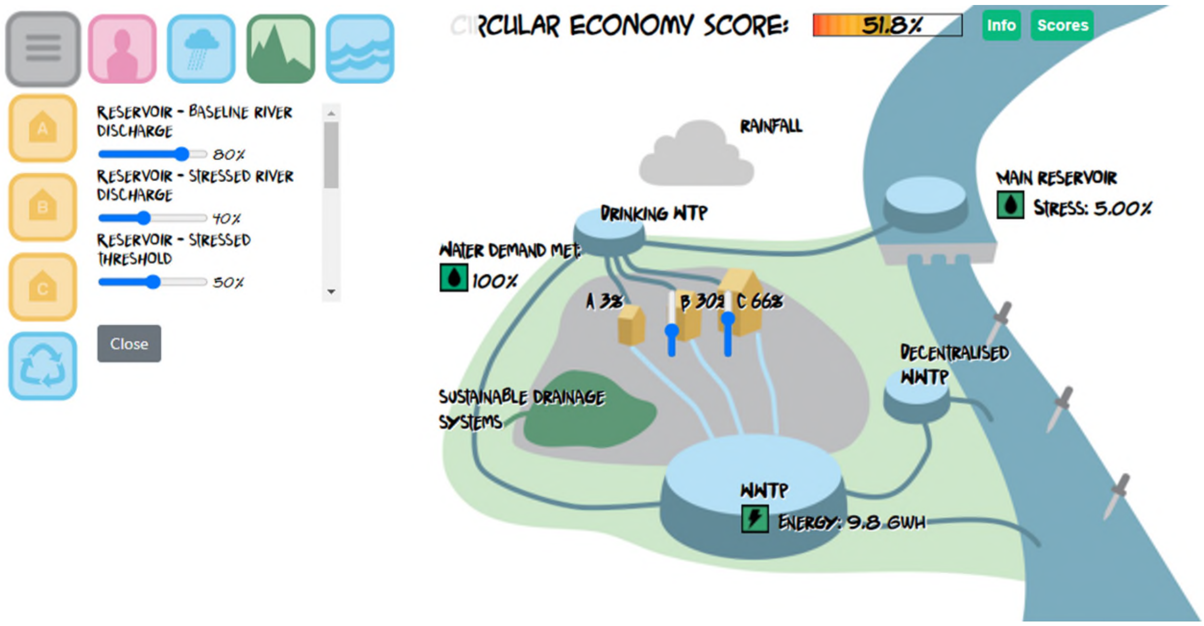
The scope of the game would be the complete water cycle, from source to treated effluent, but in a circular economy perspective. This is particularly important, because in the current governance arrangement, the water cycle is segmented, with different (governmental) organisations being responsible for different segments of the water cycle. This segmentation poses serious challenges to the design of an integrated water cycle at the neighbourhood level. Therefore, the game should address the players as jointly responsible for the complete water management at neighbourhood level.

3.2 Concept development

The serious game was further developed based on this the first concept. It was decided to divide the game in two screens. Screen one, showing a city with water related infrastructure and three neighbourhoods (A,B,C) and screen two, showing a household editor on which technologies at the household level can be selected.

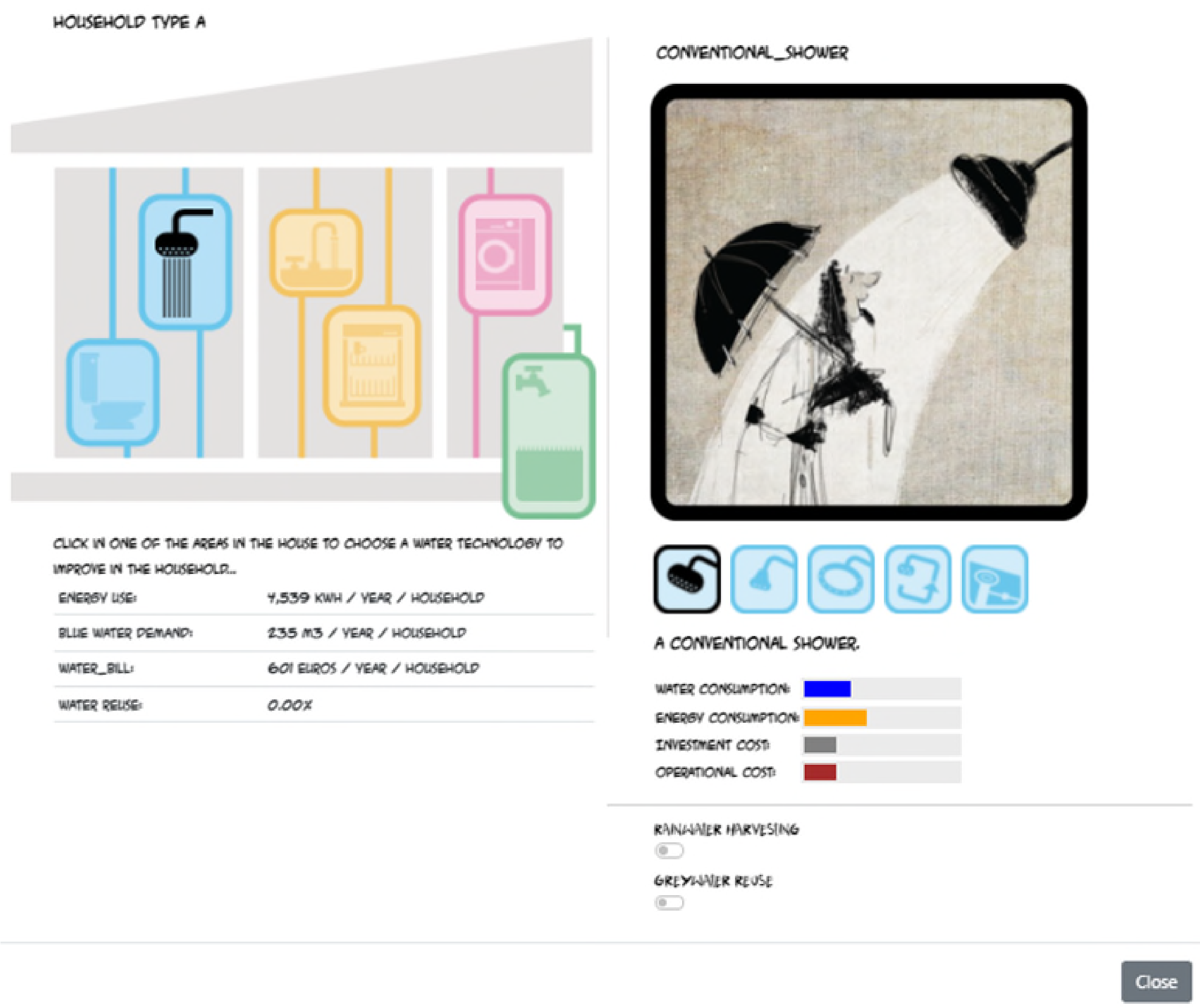
Screen 1: city

This screen deals with the neighbourhood up to city scale. Here several city level parameters can be adjusted and neighbourhood to city level technologies can be selected. The city consists of three neighbourhoods (A,B and C) of which the number of households can be manually adjusted. The three neighbourhoods consist of the corresponding household designs (A,B,C). The city screen shows the “circular economy score” which is a combination of different, weighted scores, such as the amount of water and energy used, as well as related financial costs.



Screen 2: household editor

This shows a household, including a small private plot. In this screen players can select technologies for different water related functions in the household, such as bathing, toilet flushing, washing and watering the garden. Different options for each function are presented to the player with some relevant information, such as water use, energy use, and costs. Three designs can be made in this way and will fill up the corresponding neighbourhoods in the city level screen.



More details on the conceptual design will be provided in the next chapter.

3.3 Sandbox with optional goals

The game can be primarily played as a sandbox exercise, in which players can try different household designs and neighbourhood technologies and see the effect on the circular economy score. External parameters such as the number of households or yearly precipitation can be changed as well. Even the weights of different aspects of the circular economy score can be adjusted to reflect different views of the relative importance of these aspects. In this mode, the game is useful for exploring the effect of different technologies and interventions on circularity.

To make the game more challenging, different goals can be formulated, such as a target for the circular economy score, or the required use of certain technologies. Also, external parameters can be fixed to particularly challenging values, such as high population and low precipitation. This can also be used to tailor the game for particular circumstances or scenarios.

3.4 Testing and evaluation

Different versions of the game have been develop and will be tested and evaluated in a follow up to this project. In the context of the EU funded H2020-project NextGen (https://nextgenwater.eu/) a serious game version has been developed with a pre- and post-game questionnaire to assess the learning effect of playing the game. The questions are mostly focused on knowledge of the comparative effect of different technologies on for instance water use and energy use.

Several organisations have expressed interest in testing the game to help them design new or improve existing neighbourhoods with the use of the technologies featuring in the game. The serious game can potentially help them in assessing the impact of (a combination of) different technologies.

4 System design

4.1.1 Introduction

During the past decade, substantial efforts have been made in research to develop serious games in different contexts and scientific domains – and, naturally, in the water industry as well (Savic et al., 2016). Most of these projects, further studied and categorized in earlier phases of this project (see Chapter 2), have relied, at least partly, on existing computer technologies for their development. Moreover, they have evolved alongside the rapid technological developments seen in the gaming industry (Arsenault, 2009), which is the main driver of tools and technology for serious gaming as well. While initial serious gaming efforts were more focused on the so-called 'traditional' means of actor interaction and gaming, e.g. using board game elements, more recent attempts have incorporated, partly or fully, the technological products of ICT and the digital gaming industry. For instance ICT innovations have been used to:

- Store and manipulate data before, throughout, or after the gaming session, i.e., to create records of gameplays and store them as a reference point for the future. These records can be then manipulated and further re-organized to serve future gaming needs. By standardizing the storage of information in serious game by, e.g. by using a database (DB), helps efficiently in writing game records, accessing past records, understanding previous results and reflecting on past gaming experiences.

- Employ a simulation model, in order to mimic the real system and produce detailed outputs in each game. A simulation model is defined as a simplification of reality, usually in the form of a mathematical model that is further represented with code (in a digital form), built to mimic (i.e. simulate) the real system. In the water industry, simulation models typically represent and mimic a specific part of the water system, e.g. a water treatment (processing) system or a drinking water distribution network system. However, there are simulation models, which are able to model generic socio-technical systems as well, such as the methodology of system dynamics (Mashaly et al., 2020). Simulation models have been found to be a formidable tool to help experiential learning through serious gaming, particularly for complex infrastructure systems (McBurnett et al., 2018).

- Visualize the gaming input efficiently. In this case, digital media are used to present information to the users, in order to train them about the game or stimulate them to learn. Digital media can include (a combination of) pictures, videos, computer graphics, sketches/cartoons etc. Besides facilitating user learning, a secondary goal is to present the user with a friendly interface where information can be easily entered. This is where the contribution of specialised artists is needed. A specialised artist was also used in this game to provide illustrated content in an understandable (sometimes even humorous) context.

- Visualize the gaming output efficiently, In this case, the same technology that presents input information may be used to present output information, e.g. that is produced from a simulation model, to the user. This step helps the user interpret and understand the gaming output, draw conclusions and make decisions more easily.

4.1.2 Examples of serious game design

An example of a serious game that employs state-of-the-art (SoTA) technological products is Sim4Nexus (Susnik et al., 2021), which is a cross-sectoral, policy implementation game that explores the complex interactions between elements of the water-energy-food-land-climate nexus (Figure 1). Game users are confronted with different policies for each of the nexus elements (e.g. water, energy, land), make their selection of different sectoral policies and can explore the implication of this selection to the whole system (in terms of resources, benefits and damages) in real-time using the underlying simulation model. The simulation model is not a physical model (as one would see in a sectoral application, e.g. a water distribution network model) but is a rather complex application based on the System Dynamics approach (Mashaly et al., 2020; Laspidou et al., 2020) and is built in using proprietary modelling and graphics environment (STELLA). STELLA is a tailored visual programming environment used to visualize and design system dynamics models. For its input, the model utilizes the content of multiple third-party databases hosting sectoral data such as land uses and climate scenarios and regionalizes them by employing disaggregation algorithms (Laspidou et al., 2020), which are algorithmic techniques that localize/regionalize the global, open data used. The model is then converted from the STELLA output to an open-source platform that can be then further integrated with the visualization interface, which is provided through a web service using OpenGIS. Initially the code was translated to R language scripts, whicle for the final version of the game Puthon was adopted. The selection of this programming language is based on a number of reasons, including ease of use, modularity, access to specific platforms and having open access to (non-proprietary) software.

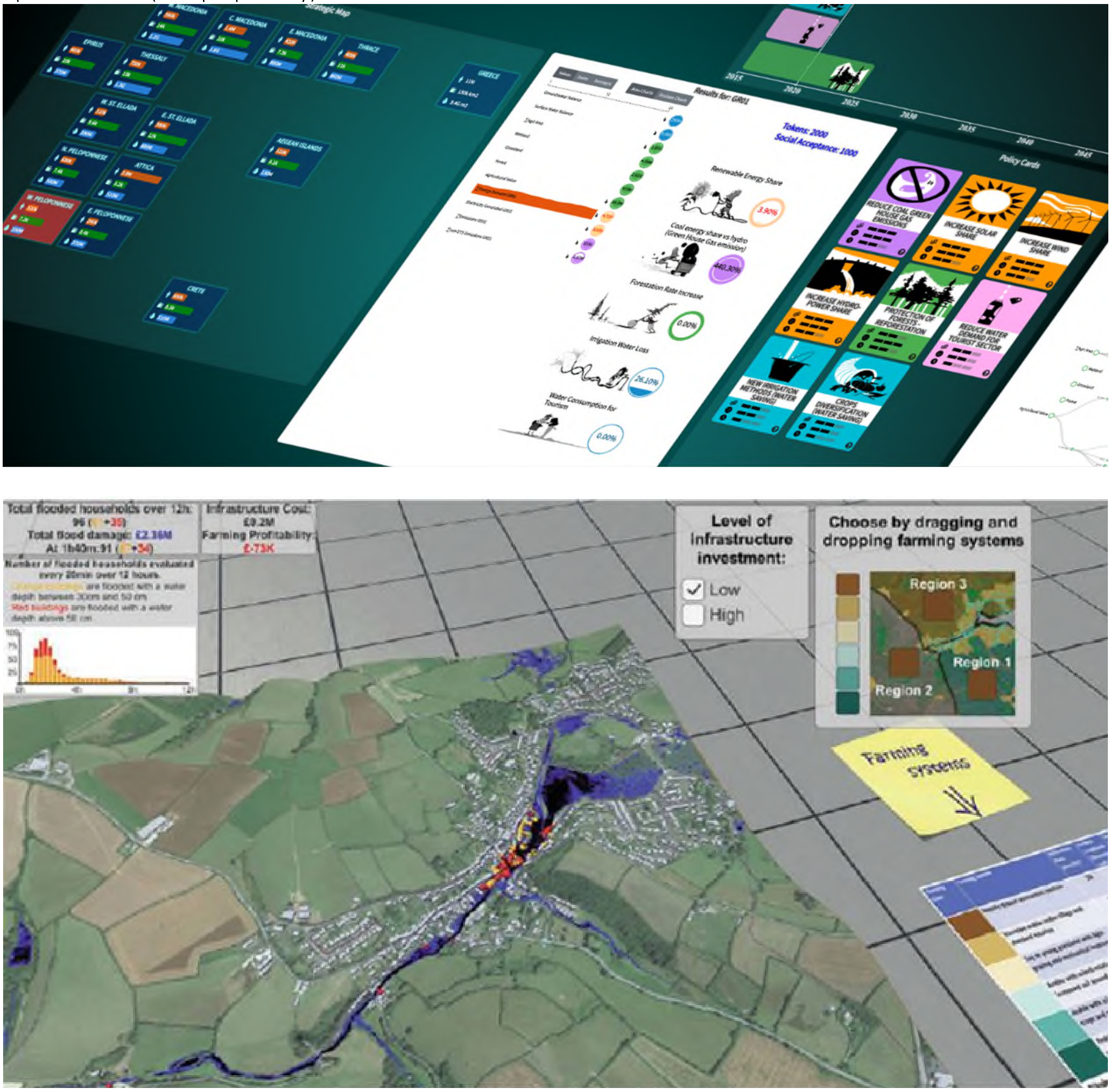


Figure 1: Examples of the digital user interface of the Sim4Nexus and Millbrook cases. In the upper panel, the 3D digital user interface of Sim4Nexus is seen, where the user can choose cross-sectoral policies and view results. In the lower panel, a top-down view of the Millbrook catchment can be seen, where the user makes land use and engineering design choices to manage flooding.

Another example of a digital serious game that utilizes different technologies is given in Khoury et al. (2018). In this so-called “Millbrook” case, a serious game for flood risk mitigation is designed for the case of Millbrook catchment, UK, where different mitigation options can be selected by the user. The user can then visualize the results of a flood event in the catchment and see the results of the selected mitigation policy. Through an iterative policy selection process, the user can understand how different mitigation measures (land uses upstream, ‘hard’ engineering measures etc.) add up and lead to less damage in the downstream urban area. In this case, a 2D fast-flood (physical) model, based on cellular automata, is used as the simulation model, in order to simulate the catchment response to a rain event that causes flooding. This model is paired with a 3D display front-end environment called the Virtual Table (Figure 1), which was created using free available technologies such as the Unity rendering engine and OpenGL , where diversified information about the catchment, as well as the flood model results, are presented to the user. The Unity engine as well as OpenGL are technologies used to design and visualize 3D graphics. The user also explores and chooses his mitigation policy before the simulation through the same environment.

4.1.3 Software design of the Serious Game for Water Wise Neighbourhoods

By definition, serious games are complex exercises of experiential learning, relying on a gamified environment – and a simplification of reality, formulated as a set of rules or a simulation model – in order to educate end-users about the complexities of managing a real system. At the same time, digital serious games are software products, and rely on hardware systems and their contemporary technology to function and enhance the user experience. For the system design, the serious game is perceived primarily with the latter perspective, i.e., as an encapsulated software product that relies on other (different) technological building blocks.

Thus, the first step of the system design is to identify the building blocks and analyse the overall software architecture, i.e. the generic template upon which the game will be built as a single piece of software. This is done by considering them, following the Separation of Concerns (SoC) computer science principle (Laplante, 2007), as a set of distinct modules (also known in literature as *sections*). Each module addresses a different concern, i.e. a flow of information that deals with different software functional aspects and affects how a program is coded. Modular software architectures can grow in complexity if needed; however, most architectures follow a fundamental distinction that distinguishes two layers of information (Noskov & Zipf, 2018):

- the data access and manipulation layer, which groups the actions needed to efficiently store and retrieve software information, as well as analysing and manipulating it accordingly before presenting it to the user. This layer is closer to the physical infrastructure (hardware) and is called the backend module. The simulation model, as the computational engine of the game, is typically part of the backend module and covers functional aspects that are required ‘under the hood’, such as the storage and manipulation of data and the simulation engine. The user does not need to know in detail about these tasks, even though they are vital to the game functionality. Specific design aspects of the frontend module for the VO serious game are discussed in Chapter 5.
- the presentation layer, i.e. the actions that display information to the user, which is then called frontend module. The frontend covers all interface aspects, such as visualizing input and output, getting information from the user, as well as presenting results from the game calculations and simulation. Typical frontend applications include interactive dashboards featuring a visualization of game aspects with 2D and/or 3D graphics, where the user is able to see information in (near) real-time and execute actions. These actions are, in fact, propagated in the backend module, where the system response is computed and sent back to the frontend in order to visualize the output. Specific design aspects of the frontend module for the VO serious game are discussed in Chapter 6.

It should be pointed out that a clear distinction between backend and frontend modules allows the use of dedicated software technologies that excel at one of the two. For instance, web interfacing programming languages such as

CSS and JavaScript are typically used for frontend development, while other languages (C, C++, SQL) typically address backend functions. There are also technologies that may be employed at both backend and frontend level (e.g. Python and its libraries). The choice of a technology depends on multiple aspects, such as the language capabilities (speed, ease of use, available Integrated Development Environments (IDEs), ease of communication with other technologies, interfacing etc.), and the experience of the team in working efficiently using a specific technology.

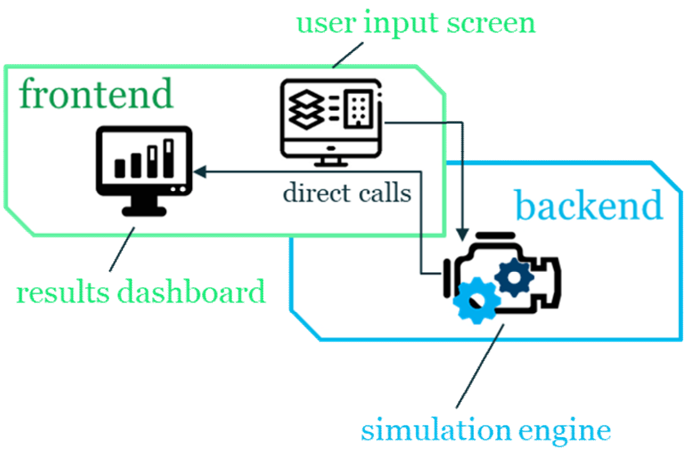


Figure 2: The backend-frontend architecture (template) used in the Water-Wise neighbourhoods serious game.

The Serious Game for Water Wise Neighbourhoods follows the afore-mentioned template (Figure 2), with a distinction between the frontend, which is web-based and includes the interface and visual cues seen by the user, and the backend that handles computations and includes the simulation engine. In the serious game design, these two modules interact with direct calls; when prompted by the user, the frontend sends all input information (i.e. the user-selected parameters for the water-wise neighbourhood) to the backend, which then uses the information to perform a simulation of the system. Inversely, the backend propagates the results of the simulation with a direct call to the frontend, which uses them to display (aggregate) results to the user. The specifics of each module are discussed in the chapters that follow.

4.1.4 Conceptual system design of the Serious Game for Water Wise Neighbourhoods

Alongside the software perspective, the Serious Game for Water-Wise Neighbourhoods includes water systems modelling in its conceptual design. In this context, a case study (hypothesized catchment and agglomeration of 300,000 people, hereinafter mentioned as “toy town”) is considered a set of interconnected water components. These components start from the supply side (river inlet and corresponding water treatment facility), propagate through relevant water connections (flows) to the demand side (different household units, belonging to different household types) and, eventually, lead to the effluent/wastewater recipient (a surface water body which, in the case of toy town, is a river outlet). This conceptualization is inspired by a previous application of a water cycle component-based (simulation) model, the UWOT model, applied for decentralised water solutions in the Dutch neighbourhood of SUPERLOCAL (Bouziotas et al., 2019). In that case, the system design focused on rainwater harvesting (RWH) and greywater recycling (GWR) as a means of supplementing water demand from a local supply network. It additionally analysed the localised processing of concentrated black water (BW) as a means of both heat and nutrient recovery. While the scale of SUPERLOCAL model is local, consisting of a single neighbourhood with a total of 129 properties, the toy town model is upscaled and designed as a large-scale, regional (catchment) model, with 300,000 inhabitants and the corresponding centralised infrastructure that includes drinking water treatment (DWT) from a single river inlet and a wastewater treatment plant (WWTP). Additionally, decentralized options are made optionally available to certain houses, such as a sustainable urban drainage system (SuDS) to mitigate runoff and a decentralized wastewater treatment plant, as a smaller-scale alternative to the central WWTP. Figure 3 offers a schematized conceptual layout of the toy town case, along with a depiction of its main components. A description of these components is given in Table 1.

The toy town conceptualization assumes three different household types (A, B and C) that may have different technologies installed at household level (e.g., water-saving appliances) or at neighbourhood and decentralized level (e.g. access to a RWH/GWR system, access to a decentralized WWTP or to a SuDS system). These technological combinations can differ for every house type (chosen by the user). For the sake of simplicity, Figure 3 depicts a setting where: (a.) house type A is conventional and has access to the centralized WWTP, (b.) house type B features a RWH system and also has access to a regional-scale SuDS system, (c.) house type C has access to a decentralized (smaller-scale) WWTP that produces effluent at another, mid-stream section of the river.

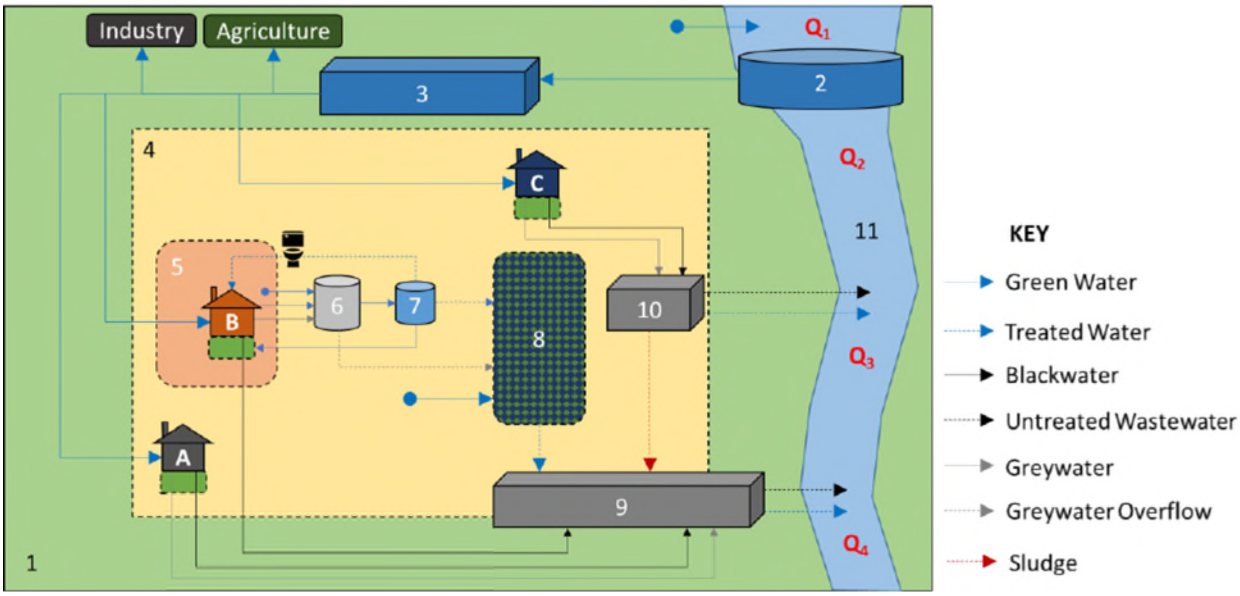


Figure 3: Conceptual layout of the toy town case, with an indication of main components.

Table 1: Description of the main components modelled in the toy town.

Notation	***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	Example - Standard Housing Units
B	Example - Experimental Housing Units (utilises 6 & 7)
C	Example - Distributed Waste processing houses (utilises 9 for wastewater treatment)
Q1	River Inflow to Reservoir
Q2	River Flow (Environmental Flow) after reservoir

Q3	River Flow (Environmental Flow) after Decentralised Treatment
Q4	River Outflow

The game has been designed as a single player experience, but this does not prevent several participants to be able to play it, for instance concurrently and in collaboration in the same room. The target group for participants can range from the general public (e.g., with an intention to explore the impact of household measures) to policy makers. As the model treats primarily water but also includes water-energy, water-nutrient and water-environment interactions, it is obvious that water, energy, and environment specialists can also participate to explore the impact of different options for their relevant domain. To maximize game portability, the frontend was decided to be made as a web-based service, accessible online from modern browsers, while the backend is constrained by speed but also by technologies that communicate efficiently with a web interface (see also Chapter 5). The main goal of the game is for the player to explore combined water-wise options and interventions at different scales (household, neighbourhood and centralized). To assist in the exploration, various Key Performance Indicators (KPIs) are interactively displayed to the user through the frontend, and a single aggregate performance score is given to assess overall performance. The user is able to follow his main score, as well as individual KPIs in the interface and, through an iterative process, (re-)select technologies in order to find the optimal, water-wise response to the water management of toy town. Chapter 6 describes the different displayed goals and overall performance metrics (as part of the frontend) in more detail.

5 Backend design

5.1.1 Requirement analysis for the backend

The backend is the engine of the serious game; it covers all functional aspects that are required 'under the hood', such as the simulation engine and storage and manipulation and analysis of data. The user does not need to know details about these tasks, even though they are vital to the game functionality. Key issues for the design of the backend module are:

a) to ensure that the technology (programming language) used to create the backend is fast, so as to allow for (near-) real-time applications by keeping the simulation time minimum (e.g., in the order of milliseconds to seconds). Specific programming languages that are compiled, such as C, C++, Java and Julia, allow for rapid deployments of simulation engines. Evidently, all computational aspects of the backend module such as the simulation model have to be coded in such a language.

b) to ensure proper data storage, management and analysis. This is accomplished by pairing the backend language computational capabilities with a technology to store and retrieve data, such as a SQL database. There can be also cases where data is propagated from the frontend to the backend with a direct call (see Figure 2), processed on the fly (e.g. by using the simulation model) and then returned back to the frontend, without intermediate or final storage in the read-only memory (ROM). These applications typically use the (faster) random-access memory (RAM) for these calculations, which is flushed after each use without saving data.

c) to ensure proper communication with the frontend and direct exchange of data. This is done with proper interfacing between the backend parts (e.g., the simulation model) and the frontend interface and by using a file transfer protocol; the latter ensures that data is stored properly (according to a specific standard) and transmitted efficiently. A simple and efficient file transfer protocol, for instance, is the JSON notation (JavaScript Object Notation), as files created using JSON store simple data structures and objects in a standard data interchange format. A JSON file is primarily used for transmitting data in web-based applications, e.g., between a web interface and a server. JSON files are lightweight, text-based, human- and machine-readable, and can be edited using a simple text editor.

5.1.2 Backend design specifics

The design for the backend by deciding on the selection of the simulation model, is a major aspect of the game process. In the initial stages of the project, it was decided to enhance the game experience by adding a simulation engine (see Figure 2), i.e. a model to simulate aspects of the urban water system as a whole, at a neighbourhood level, , including the major water flows (stormwater, wastewater and drinking water) relevant to water-wise systems. Consequently, the researchers looked into the inventory of available models within KWR. The most likely candidate for the use case of interest (water-wise neighbourhood neighbourhoods) was UWOT, an urban water cycle model that has been extensively applied in the past for urban water consultancy and design projects, including applications for circular water neighbourhoods (Bouziotas et al., 2019).

UWOT is a mature simulation-based Decision Support System (DSS), of the metabolism modelling type, able to simulate the complete urban water cycle by modelling individual water uses and technologies/options for managing them and assessing their combined effects at multiple scales, starting from the neighbourhood level (Makropoulos, 2017). UWOT follows a signal-based systems analysis approach that starts from individual components (i.e. in-house appliances, units that use water and generate wastewater or runoff), and proceeds to the generation, transmission, aggregation and transformation of water demand signals that start from the household level and propagate towards the source of water demands, i.e. the central drinking water network (Rozos & Makropoulos, 2021). This demand-oriented conceptualization places household and neighbourhood demands as the starting point of every study and enables UWOT to simulate the whole urban water system from tap to source [46]. This particular feature makes UWOT suitable for a gamified application as well, since the serious game also starts from the end user (household) level, so the demand side (rather than the supply side) is important to the game mechanics. UWOT is able to simulate both standard urban water flows, i.e. potable water, wastewater and runoff, modelled as signals, as well as integrated interventions at household and neighbourhood level, targeting these flows in order to create feedback loops that cover household demand.

While the UWOT model was conceptually close to the type of urban water system modelling ideal for a serious game for water-wise neighbourhoods, a deeper analysis with regard to the backend requirements (explained in Section 5.1.2) revealed that:

- the UWOT model was a standalone executable and, at the time of the project development, lacking an efficient application programming interface (API) that would allow it to communicate efficiently with other components (e.g., for the frontend part). That rendered requirement (c) on communication unreachable, without extensive redevelopment of the model (API development and interfacing) that would span over several years.

- the UWOT model did not have supplementary tools to connect with web services, such as an online interface or the ability to readily convert input/output to the JSON format.

- more importantly, some test runs using the UWOT simulation engine revealed that the simulation engine was robust but not fast enough for (near) real-time applications; simulation times spanned in the order of seconds to minutes, which, while acceptable for consultancy or design runs, would make users wait a relatively long time before exploring other options in a gamified environment where the user is called to try more options in a shorter timeframe. Requirement (a) was thus not met.

Based on the afore-mentioned limitations, the decision was made not to use UWOT as-is, but make a separate backend simulation model, designed to be able to communicate more efficiently with web services by using the JSON notation. This model is hereinafter mentioned as the toy town model. While the UWOT mechanics were not duplicated in the toy town model, UWOT was used in parallel to the development of the toy town model as a control model. More specifically, using data from a past case of a water-wise neighbourhood (Bouziotas et al., 2019), both models were run and their output was compared at an aggregate neighbourhood level (drinking water demands, generated runoff and wastewater) in order to find out and eliminate errors in the toy town model.

As opposed to UWOT, which is a generic micro-component model (at the household appliance scale) with an arbitrary topology, the toy town model includes inter-connected components at a higher level for a specific neighbourhood topology and is set up based on the following seven main components:

1. Household Water Use
2. Reservoir (Water Supply)
3. Rainwater Harvesting
4. Greywater Harvesting
5. Sustainable Drainage Systems
6. Primary Wastewater Treatment
7. Decentralised Wastewater Treatment

Household Water Use

The Toy Town model was designed to allow for three neighbourhoods: A, B, and C. These neighbourhoods may employ different technologies and reflect different house types. The user can specify the configuration of each of these neighbourhoods accordingly. In terms of Water Use and Wastewater Production the model assumes a set amount of demands, given in Table 2.

Table 2: Water Use and Wastewater Production assumptions

Component Type		Demand (m^3/Person/Day)	Wastewater Type	
Type	Subtype	Volume of Water	Greywater	Blackwater
Toilet	Standard	0.042		X
	Vacuum	0.006		X
	Dual Flush	0.024		X
	Water Saving	0.018		X
	High Pressure	0.015		X
	Compost	0.0012		X
	Dry Flush	0.0	-	-
Food Grinder	-	0.001		X
Sink	Standard	0.00875	X	
	Water Saving	0.00625	X	
	Recirculation Pump	0.0075	X	
Cooking	-	0.0014		X
Dishwashing	Hand	0.03	X	
	Dishwasher	0.018	X	
	Energy Certified Dishwasher	0.006	X	
Washing Machine	Standard	0.0153	X	
	Top Loader	0.02295	X	
	Eco	0.009945	X	
	Hotel	0.057	X	
Shower	Standard	0.070	X	
	Water Saving	0.060	X	
	Fog	0.0245	X	
	Recirculation	0.0350	X	
	WTW	0.060	X	
Garden*	Standard Tap	1.31	-	-
	Drip Irrigation	1.06	-	-
	Aeration Hose	1.26	-	-
	Sprinkler	1.4	-	-
	Spray Timer	1.37	-	-

*Water demand for Gardens are expressed as m^3/household

From the wastewater perspective, the backend model tracks the concentration of chemical oxygen demand (COD_c) present within the wastewater and uses this value as a basis for determining pollution levels in discharge events (treated discharge and Combined Sewer Overflows) and also as basis for determining Sludge Volumes and Biogas production. The model assumes that individuals produce a predefined amount of COD mass (COD_m) per day and this mass is diluted within the wastewater they produce. In this simplified assumption if the property uses less wastewater as a direct result of using water saving technologies then the volume of wastewater will be lower but the concentration of COD (COD_c) will be higher. In a combined sewer system approach the wastewater from the connected houses is mixed with that of Stormwater that also has a predefined COD_c value.

Reservoir

The toy town model assumes a single reservoir is the main source of water. The volume of water entering the reservoir is determined based on the rainfall falling on the surface of a large catchment area. The catchment area is assumed to be:

$$Catchment\ Area = 31{,}400ha = 314km^2$$

Not all of this rainfall enters the reservoir so the volume of rainfall entering the reservoir is adjusted using a runoff coefficient, in a similar manner to using the rational method to estimate runoff at an outlet (Thompson, 2006).

$$Reservoir\ Inflow = Rainfall \times Catchment\ Area \times Runoff\ Coefficient$$

A runoff coefficient of 0.7 was assumed for initial testing, which can be seen as a representative estimate of a neighbourhood that has (limited) pervious areas, with most areas being impervious. The model also assumes a river in the proximity of the neighbourhood, that is also the recipient of the combined sewer overflow. Based on the incoming rainfall data, the Environmental Flow Q_{Env} of the river is estimated. This is used as a basis for comparison of the environmental flows that are downstream of the reservoir after water demands have been met.

The outflow of the Reservoir downstream is managed via two stress parameters. The volume water released from the reservoir after demand requirements are met is referred to as the “Compensation release”. This volume of water released is dependent upon the current water level within the reservoir. The logical rule that is coded for this case is seen in Figure 4.

```
IF (Reservoir Volume/Reservoir Capacity) >= Stress Threshold:
Compensation Release = Baseline Discharge Coefficient X Reservoir Inflow
ELSE IF (Reservoir Volume/Reservoir Capacity) < Stress Threshold AND (Reservoir
Volume/Reservoir Capacity) >= Severe Stress Threshold
Compensation Release = Stress Discharge Coefficient X Reservoir Inflow
ELSE
Compensation Release = 0.0
```

Figure 4: Logical rule for the reservoir release.

Rainwater Harvesting

The Toy Town model has a dual approach, allowing the user to select whether rainwater harvesting (RWH) is selected or not for a particular house type. If a property is using RWH systems, then rainfall that falls upon the roof or onto a localised catchment (area immediately around the property) is directed into rainwater storage and treatment processes. Figure 5 and Figure 6 show the routes that rainfall can enter the sewer system in the default configuration (i.e., no RWH) and when rainwater harvesting (RWH) is enabled by the user. In the latter approach excess rainfall (rainfall that exceeds RWH storage capacity) overflows and enters the sewer system.

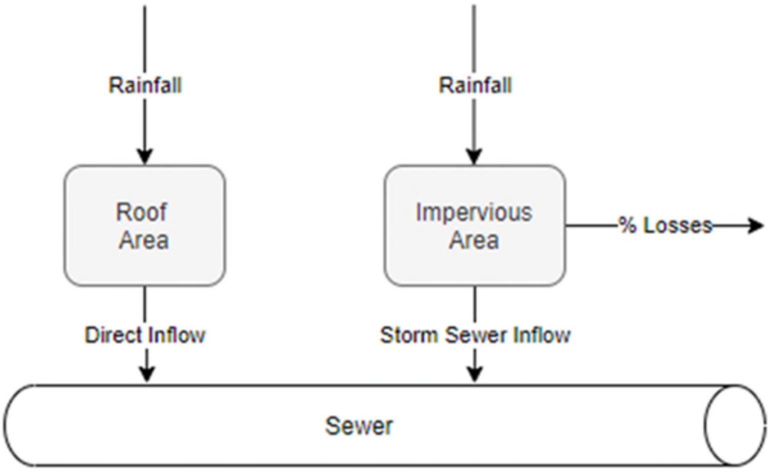


Figure 5. Rainwater Routes to Sewer (Standard Configuration)

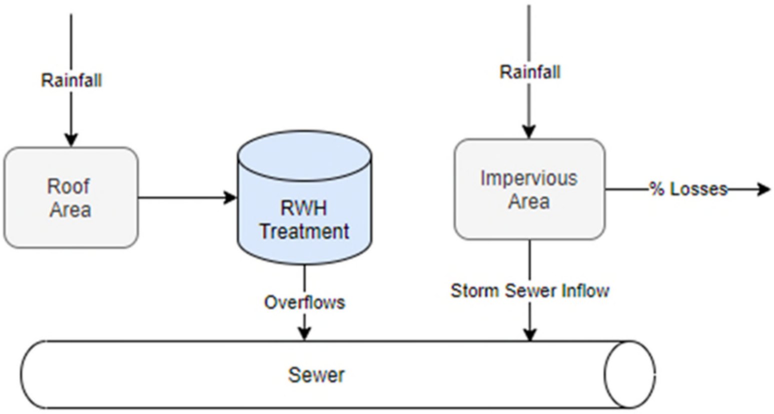


Figure 6. Rainwater Routes to Sewer (Rainwater Harvesting Configuration)

The extraction of rainwater from the RWH system is limited by the treatment and subsequent "treatment rate" (i.e., the percentage of rainwater to be directed to the RWH for treatment) and supplied to the houses as a supplementary source of water for different use cases. These use cases would be dependent upon the user and scenario, with the default case including non-potable uses as potential recipients of the treated rainwater.

Greywater re-use

Similar to rainwater reuse, greywater outflows from properties have the potential to be treated locally and to be re-used by the property or other properties as a supplementary source of water. Unlike rainwater reuse, however, the supply of greywater is more continuous as is dependent upon daily use of components within the households and not by external, weather related factors. However, greywater is likely to contain a higher concentration of contaminants than rainwater and thus requires (depending upon the prospective re-use) a greater degree of treatment. For this reason, the treatment costs associated to it are assumed to be higher within the game.

Sustainable Drainage (SuDs)

Sustainable urban drainage systems (SuDs) are designed to capture rainfall that would otherwise be lost as surface runoff from impervious areas, and allow it to infiltrate into soil beneath it. The SuDs themselves, in the toy town model, are modelled considering a number of parameters:

1. SuDs Infiltration Rate: This is the rate of which rainfall can 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 will occur.

2. SuDs 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 capacity is exceeded, then any additional inflows will become surface runoff.
3. Soil Infiltration Rate: This value determines the rate of which water is removed from the SuDs. A steady soil infiltration rate is assumed for the toy town.

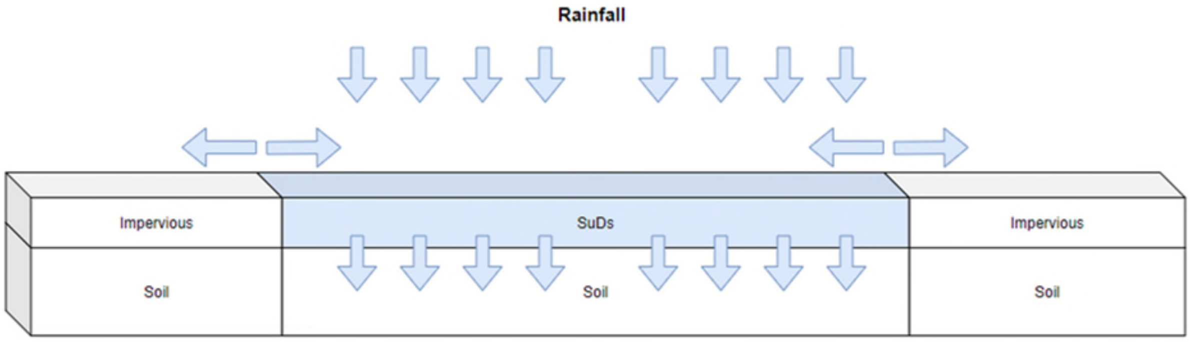


Figure 7. SuDs configuration within the model

Within the toy town model, the user may specify which house types/regions are connected to SuDs. In addition to this, the size (area and volume) of the SuDs is computed automatically and is proportional to the number of properties connected to it. The default configuration is 5m^2 per connected household and 2.25m^3 of storage per household.

Primary and Decentralised WWTPs
The Wastewater Treatment Plants (WWTPs) have some of the more complex interactions within the model. Within the game, it is assumed that the entire area is serviced by a small-scale, regional WWTP unit and that the player can specify the type of wastewater treatment to be using either Aerobic or Anaerobic digestion. There is a trade-off between these approaches, as aerobic treatment is set to remove more COD from the wastewater during treatment but results in higher sludge volumes and no biogas production. ON the other hand, Anaerobic treatment does not remove as much COD from the wastewater as the aerobic one, but produced less sludge for disposal and produces biogas as a by-product, which can be used for energy generation.

5.1.3 Backend deployment

The backend simulation model was implemented using the Julia programming language, following a number of tests in both Python and Julia. The reason for this selection was that:

- Julia is an open-source (GPL) programming language that general-purpose and is better suited for computational science applications, so it is adept at simulation tasks.

- Julia includes a number of libraries to facilitate data processing, as well as communication with the frontend. Julia also includes efficient libraries for required computational tasks such as floating-point calculations, linear algebra and random number generation.

- When tested against python, which is an interpreted language, Julia is a compiled language. This means that Julia is executed fast, and the tests against python proved that a backend simulation model based in Julia for the toy town executes a simulation in the order of milliseconds, thus satisfying requirement (a).

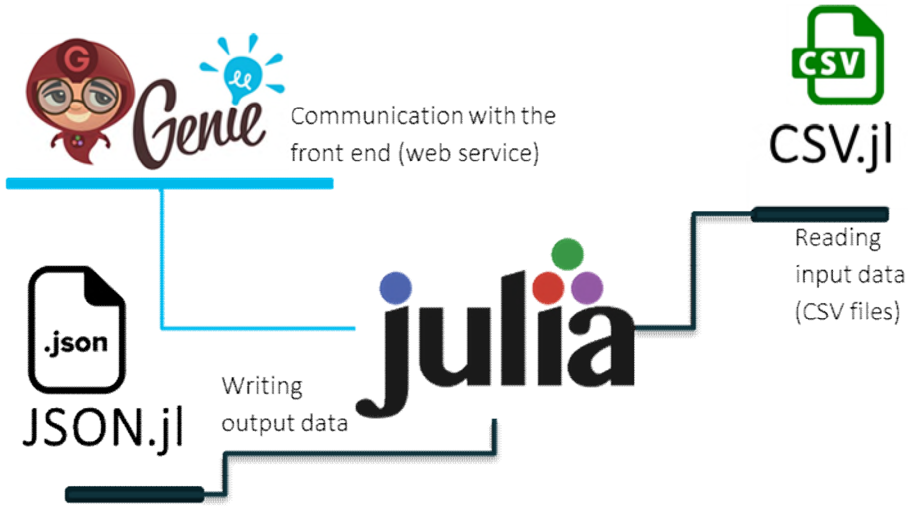


Figure 8: Technologies used for the backend module.

For the implementation, 64-bit Julia v.1.5 was used, along with the following libraries: Genie to communicate with the web application (frontend), Dataframes for data formatting, JSON.jl to generate JSON files and CSV for reading data from CSV files (Figure 8). The backend comes in a form of Julia scripts that can be directly called by the frontend (browser-based interface, upon a call initiated by the user). Running these scripts generates output in the form of time-series (20 years of synthesized data) that is exchanged back to the frontend takes less than a second, using a JSON file for communication. The backend system was tested successfully on a 64-bit Windows 10 laptop with 16GB of RAM.

6 Frontend design

6.1.1 Requirement analysis for the frontend

The frontend is the presentation layer of the serious game. Its main function is to receive input from the user (i.e., the user decisions when it comes to water-wise options and parameters), transfer it to the backend and to process and visualize the output information coming back from the simulation engine. The user interacts directly with the frontend functionality, so issues like response speed, graphics and aesthetics are important. Key issues for the design of the frontend module are:

a) to ensure a **quick response** (speed) when the user makes some selections and minimal waiting times until the user sees output. The user has to be able to choose parameters and make decisions using an intuitive user interface (UI) and (ideally through the same interface, without changing environments/windows) be able to see the water system response.

b) to **visualize** the outputs in a meaningful, aggregated and aesthetically pleasant way, including proper performance metrics (average values, statistics etc.) that can be calculated on-the-fly. The visualization of outputs can be implemented through a dashboard that may include multiple graph types, for instance bar charts, pie charts, time-series line graphs etc.

c) to ensure good **transferability** of input/output data to the backend module. This is a technological requirement that is typically covered with specific standards and protocols (e.g. JSON notation) or software libraries.

6.1.2 Frontend design specifics

Main interface - input

Figure 9: Main user interface (UI) of the serious game, showing parameter settings on the top left as well as the top-down view of toy town.

The frontend of the serious game is designed as an interactive web page, i.e., a single-paged environment where the user is able to decide on water-wise measures, set the corresponding parameters and view the results of their actions. Upon logging in the web service, the user is presented with a short text tutorial followed by an isometric view of the toy town (Figure 9), the virtual catchment of 300,000 inhabitants, where the three different neighbourhood types are also visible (representing house types A, B and C). The isometric view includes the main water system flows, from the main reservoir (river inlet), through the drinking water treatment plant (WTP) and the service neighbourhoods and towards the wastewater (WW) treatment facilities (centralized and decentralized one, which are built in different river outlet positions).

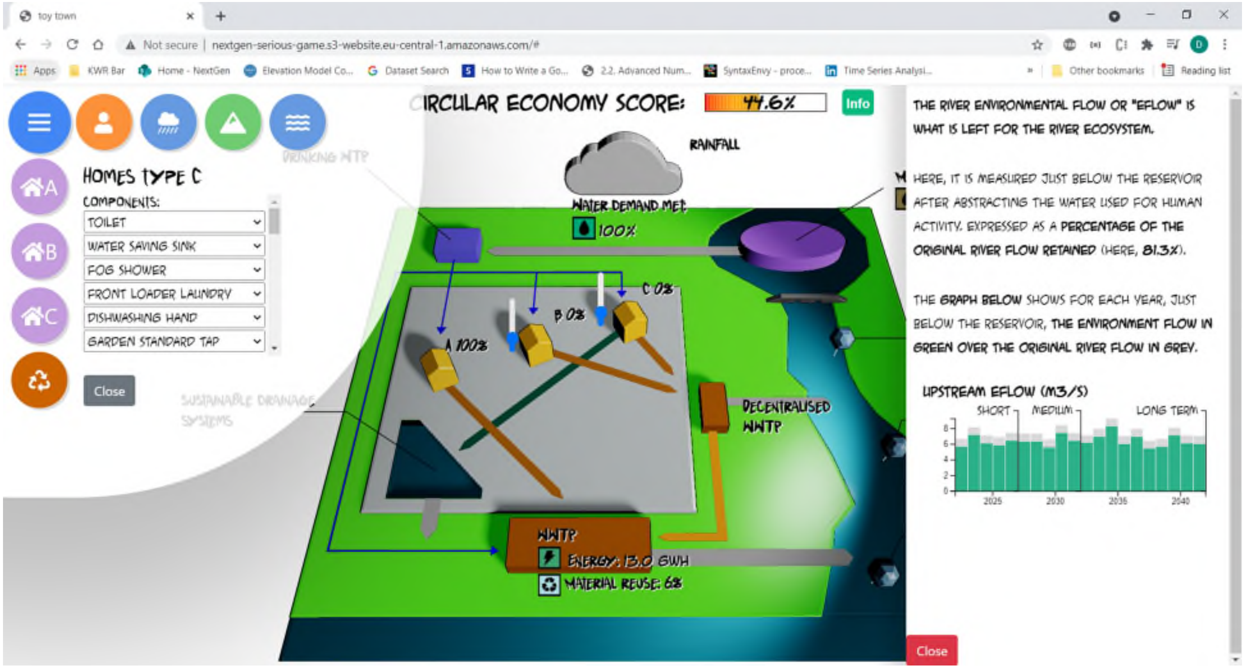


Figure 10: Main user interface (UI) of the serious game, reflecting changes of the user parameters with regards to the links with decentralized WWTP and SUDS. A view of the results of a specific KPI (river environmental flow) is also visible on the right.

The user is then able to change a number of parameters through visual-friendly controls such as sliders and buttons. The following model aspects can be changed from this interface:

- The percentage of households in the toy town belonging to type A, B and/or C. The starting screen has 100% of households belonging to a single house type (Figure 9).
- Home appliance types for home types A,B,C, which include conventional and water-saving technologies. The inventory of available technologies is visible to a user as a scrollable list.
- The option to use rainwater harvesting or greywater recycling in a specific neighbourhood type.
- Whether the particular home type is linked to the SuDS (employed at catchment scale) or the decentralized WWTP - instead of the default centralized option. The links of each house type to these options are dynamically updated to the central isometric view of the toy town seen in the interface, so that the user can directly see the resulting flow network. For instance, Figure 10 shows an updated view of the household links, where the user has decided that house types B and C are served by the decentralized WWTP, while house type C directs its runoff to SuDS.

- External factors that drive the simulation, such as the population (total number of inhabitants) and the rainfall amount[2]. These parameters are scenario dependent, but were allowed to be changed by the user at this stage of the serious game development to allow for further experimentation and play-testing.
- Central neighbourhood options, such as the type of WWTP and decentralized WWTP (aerobic or anaerobic) and the reservoir stress threshold (see also Section 5.1.2). Likewise, the user can also alter SuDS parameters, such as the surface area per household and water square depth (design depth).

The game engine at the backend runs upon a change of any parameter (e.g. a slider or switch in the user interface), so there is a direct call, execution of simulation and update of its results to the frontend every time a parameter is changed. While this means multiple communication calls per user round, it is made feasible because of the low runtime of the simulation engine (in the order of milliseconds to seconds).

Main interface – output and performance metrics

With regards to the performance metrics available through the frontend, the goal of the game is to maximize the circular economy score (CES), a weighted average of different subscores that reflect different flows within the water system. These subscores are:

- the water health score, which is primarily linked to water demand covered through the main reservoir.
- the energy health score, linked to the energy footprint of the various user choices (e.g., in terms of WW treatment),
- the material reuse health score, linked to the reuse options set by the user, and
- the environmental health score, which is linked to the environmental flows to river and reflects a state of low stress to the river ecosystem,
- the financial health score, which is linked to the affordability of water components, and the return of RWH and GWR technology investment.

The user is able to view more information about the scoring system and the different subscores by clicking on the CES display. At the same time the user is able to click in different 'bullet points' of the main screen (polygons seen in Figure 9) and explore different aspects of the system response and modeling results, such as:

- The water demand as a target met, which is expressed as the percentage of years when the reservoir is not empty for more than 10 days. The water demand met is dependent on the supply created by rainfall and the demand that is proportional to population size.
- The reservoir stress level, which depends on rainfall to supply water for both human activity and the river ecosystem. Under normal circumstances, the reservoir discharges 80% of the outcoming flow to the river. When below 50% full, the reservoir is considered "stressed". When this happens, it only discharges 15% of the outcoming flow to the river. The present reservoir stress score is: 25.0%.
- The river environmental flow or "eflow", which is the flow allowed downstream (i.e., not retained by the reservoir) for the river ecosystem. The flow is assumed to be measured just below the reservoir, after abstracting the water used for human activity. It is expressed as a percentage of the original river flow retained. Figure 10 demonstrates information depicted about the eflow on the right part, which also shows

[2] This amount is normalized against baseline rainfall and expressed as a percentage, so that when a user sets this parameter as 200%, double the rainfall amount falls in the catchment.

a detailed graph about environmental flows each year, with the environment flow in green while the original river flow[3] in grey.

- The pollution index mid-stream, which can change due to combined sewer overflow (CSO) events. These events in turn depend on the decentralized WWTP specifics.
- WWTP response specifics such as the energy needed for the WWTP operations and the mass of nutrients reclaimed, which are affected by the options of the user.
- The downstream pollution index, which usually changes when the centralized WWTP discharges untreated water during a CSO event . At some point, a large quantity of water caused by heavy precipitation comes to the doors of the WWTP. As it exceeds the maximum volume treatment capacity of the WWTP, the untreated water then has to be released to rivers and sea so as not to overwhelm and damage the facility. The serious game then calculated the average number of CSO events per year, as well as the average water quality parameters (Chemical Oxygen Demand, COD, in terms of mg/litre per CSO event) to calculate an annual pollution index.
- Household statistics, such as energy savings and consumptions, water savings and consumption, the water reuse rate, and the OPEX/CAPEX (total investment costs)

At the same time, the user is presented with textual information about what each metric is and how it is related to the user decisions. This helps the player understand the impact of their actions and, on a longer-term perspective, structure their decisions in order to improve a specific domain within the water system.

6.1.3 Frontend deployment

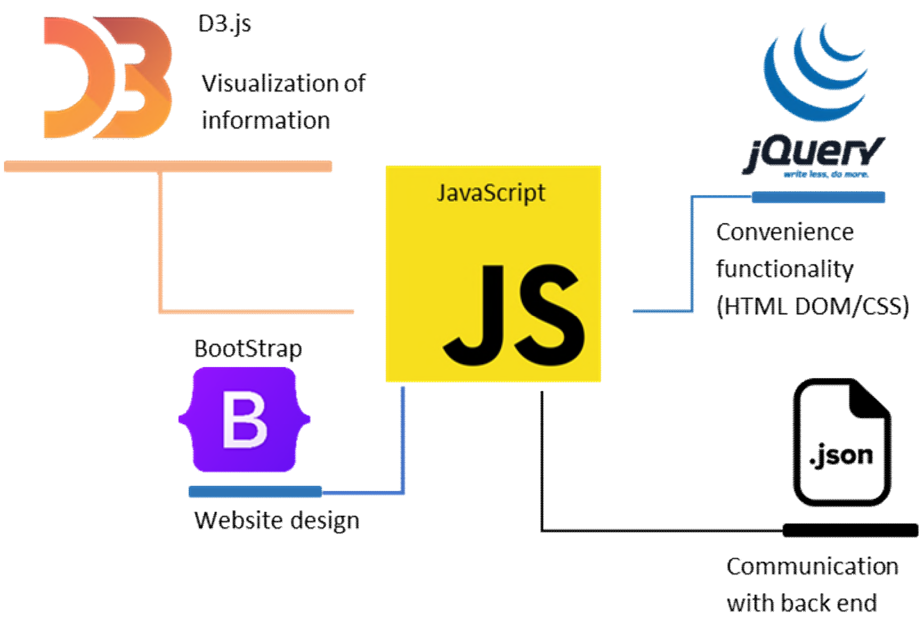


Figure 11: Technologies used for the frontend module.

[3] The original river flow is assumed to be the flow without any abstractions to serve human activity (i.e., drinking water needs).

The frontend module was implemented using web-oriented services, built around the JavaScript programming language and the underlying HTML/CSS web framework. The libraries that were used include BootStrap (BS) for the overall webpage design, d3.js for the interactive visualizations (toy town view and produced graphs) and jQuery as a convenience interface to simplify setup tasks (Figure 11). The JSON notation is used as the transfer protocol between the frontend and backend modules; a JSON file with the user-selected parameters is transferred to the backend with each call, and the backend also produces a JSON file with the model results.

The frontend interface is tested primarily on a Windows 10 laptop with 16GB of RAM using the following compatible browsers: Google Chrome (version 93.0) , Microsoft Edge, Firefox, and Safari. Following the initial tests on local systems, it was decided to deploy the serious game using an online (cloud) service via the Amazon AWS Fargate service, which uses a hosting fee but avoids localisation issues (i.e., having to set up a dedicated server within the KWR premises). The implementation was done using a docker instance that facilitates software infrastructure requirements; it is also possible to create multiple instances if multiple user groups would like to play the game within the same Amazon service. As of September 2021, the game can be accessed using the following link through any modern web browser, such as Google Chrome or MS Edge:

http://wise-water.s3-website.eu-central-1.amazonaws.com/

7 Conclusions and Recommendations

This report presented the first version of a serious game for developing Water Wise Neighbourhoods. It showed how the different parts of the game were developed an which needs of potential end-users it addresses. The game combines a intuitive user interface with hydrological modelling. In conclusion, this report shows that this serious gaming can be used for raising awareness of water related issues such as drought, increasing water use and the impact of new sanitation on water quantity and water quality. It also gives insight into the different water technologies and their interactions at different levels of scale.

At the current serious game version, the serious game is generic, with multiple game parameters being exposed to the frontend and able to be changed by the user. This is intended by design, to maximize user exploration at this point, increase feedback back to the developers and help playtesting and the corresponding identifications of game errors. However, following the first rounds of playtesting, it is suggested that some of the parameters become constrained, e.g., in the form of a pre-set scenario on city size, climate and technology availability that is presented to the user as a narrative and cannot be altered by the players. This will help the user focus on specific parameter changes and to have a smoother learning curve with regards to how the game functions. Evidently, such scenarios are context-specific and can be co-created with specific user groups, for instance to fit in a particular application (e.g. a regional case with specific household characteristics) or to focus in a particular water-wise narrative (e.g., climate-proofing neighbourhoods that face droughts or wet years).

Another significant improvement would be to alter the software architecture in order to allow for long-term storage of (past) game data and records. At its present form, the game utilizes the random access memory (RAM) of the server side to exchange data and results quickly between the frontend and backend (Figure 2) but does not store any of the input (user preferences and decisions) or the output (model results) to a long-term memory. In future versions of the model, a local database can be added (e.g., using SQLite) so that user can submit results by clicking a 'Submit' button at any time (Figure 12). This will allow for a view of past game results (and comparison, e.g., using a ranking board web page), but will also allow for an analysis and review of user actions and model results at future game reflections.

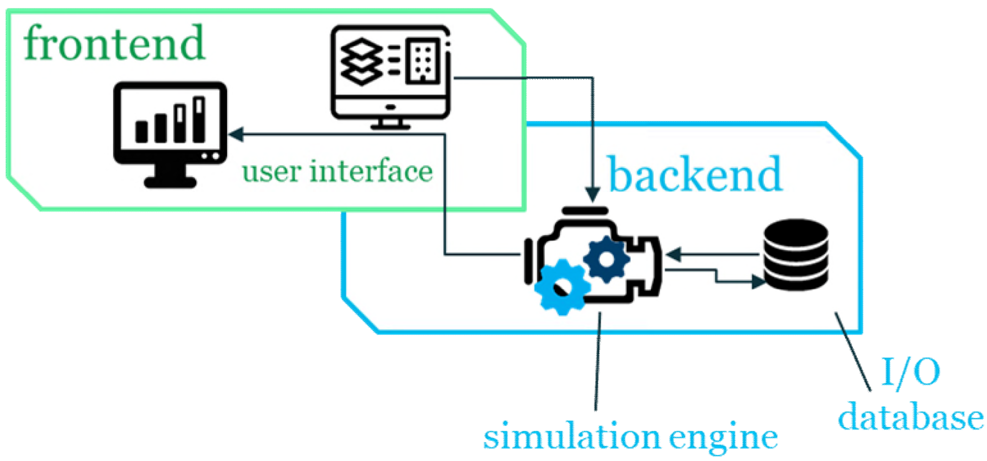


Figure 12: Recommended software architecture improvement at a future iteration.

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