AquaNES

Demonstrating Synergies in Combined Natural and Engineered Processes for Water Treatment Systems

Deliverable 5.5

Gaming approach for stakeholder engagement

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BF	Bankfiltration
cNES	Combined natural and engineered treatment system
CW	Constructed wetland
DSS	Decision Support System
MAR	Managed aquifer recharge
SAT	Soil Aquifer Treatment

Executive Summary

The aim of the AquaNES subtask on serious gaming is to explore the potential application of serious gaming in urban water and wastewater management, with a focus on combined natural and engineered treatment systems (cNES). Drawing on recent research in serious gaming in the field of water management, the task underlying this report developed a gamified approach to raise awareness of cNES and support citizen and stakeholder engagement in planning and decision making for cNES. The proposed serious gaming framework draws from the AquaNES project, and has been tested through real game play, resulting in structural refinements based on player feedback. As part of this report, the considerations made during the development phase of this concept are illuminated and the serious game itself is presented and explained. The presented game is a prototype based on multiple actual AquaNES sites. It is not site-specific and can therefore be deployed in any cNES site (real or planned) in order to engage stakeholders and raise awareness on the usefulness and challenges of cNES. Its structural simplicity and generic framework structure make it applicable beyond AquaNES as well, as an awareness tool for the sustainable management of urban water and wastewater, but also as an engagement method to foster knowledge, understanding, collaboration and interaction among different stakeholder and public groups.

1 Introduction

1.1 Games and serious games

The field of gaming as a leisure activity has gone through an extraordinary development over the last 50 years. As of the 1980s, games became increasingly appreciated by scholars as potentially cognitive beneficial. In prior decades games had been mainly judged as childish activities or a waste of time. Since the 1990's, the number of academic articles on the positive outcomes of games in people's life grew substantially (Felicia, 2011). The benefits of gaming are plenty and can vary widely. In the fourth century BC, Plato already emphasized the ability of games to establish a connection between play and education. Plato supported the premises that strengthening certain behaviours via a game during one's childhood can lead to these behaviours as an adult (Susi et al., 2007; Wilkinson, 2016). Nowadays, games are recognized to have the power to entertain, train, teach, and educate and they can come in both digital or non-digital form. Games can be played by people of all ages, either individually or in groups; the duration and the place of a game is specific and specific rules apply for every game (Susi et al., 2007). Moreover, games can produce a variety of feelings; positive feelings such as happiness and pleasure and more negative feelings, such as anxiety, disappointment or embarrassment. Additionally, Salen and Zimmerman (2004) claim that games can bring to the surface the most profound feelings and characteristics of a personality. Finally, a game can be, and according to Fullerton et al. (2004) should always be, "fun". It should combine challenge, competition and interaction among the players (Fullerton et al., 2004) in a gamified way.

Games are since the 1990s increasingly included in other parts of society, such as schools and businesses (Felicia, 2011) and are used in a wide variety of fields (Susi et al., 2007). Besides playing for leisure, games can also be purposefully applied for a wide variety of other tasks, such as education or training. In this form, they are commonly referred to as serious games. The definition of serious games varies widely, but there is a common core definition stating that a serious game is used for a purpose other than mere entertainment, enjoyment or fun (Michael & Chen, 2005; Djaouti et al., 2012, Susi et al., 2007; Wilkinson, 2016). Zyda (2005, p. 26) elaborated on this as they wrote: "*Serious games (…) involve pedagogy: activities that educate or instruct, thereby imparting knowledge or skill. This addition makes games serious*". However, although serious games are not primarily played for amusement, it does not mean that they should not be entertaining (Djaouti et al., 2012). De Jans et al. (2017) emphasize the fact that serious games, besides being educational, have to be entertaining, as the entertaining part of the game engages people in a topic and increases their motivation to play the game, as well as the positive feelings derived from it.

1.1.1 History of serious games

Even though the market of serious games has been increasing over the last decades and is estimated to reach the $5,448.82 Million by 2020, the history and the concept of serious games lie thousands of years ago. Plato characteristically stated that games could be used as a tool to explore different viewpoints of governing an issue (Susi et al., 2007). This viewpoint was mainly explored from a military standpoint, as strategic and tactic games form the predecessor of serious games. Some of the most ancient strategic games, which were created after 600 AC, are the Chaturanga (the precursor of chess which was the first militaristic board game), Go (Wei Qi, Baduk) and Xiang Qi (Chinese Chess) (Michael & Chen, 2005; Djaouti et al., 2012). Another pre-digital game that was designed to simulate societal and governmental issues was the Landlord's Game in 1902 (precursor to Monopoly). The era of simulation/gaming, which introduced experiential learning, started in the 1950's by the military

(Djaouti et al., 2012). The first serious game, called Army Battlezone, was designed for military training in 1980. However, the great serious games movement began in 2002 with the video game America's Army (Susi et al., 2007) and has been growing ever since, also in different fields. In 2009, over 2200 serious games had been released (Djaouti et al., 2012).

1.1.2 Goals of serious games and application areas

The goal of serious gaming is to integrate all aspects of education, such as teaching, training and informing via simulations, along with experiential learning (Michael & Chen, 2005; Wilkinson, 2016). Furthermore, these games aim to motivate and engage players to achieve defined (by the designer of the game) purposes and develop different skills and abilities. Games are known to enhance public engagement and collaboration (Lieberman, 2009). Lieberman (2009) added that serious games contribute to develop and expand knowledge on a specific topic. Likewise, Rusca et al. (2012) reported that serious games are successful tools to generate expertise and understanding. They argue that knowledge is much more easily retained when the learners are actively participating in a game, compared to when they passively hear or read (Rusca et al. 2012). Finally, serious games allow players to experience situations, which are difficult to experience in real life, in terms of safety, time and cost (Susi et al., 2007).

Consequently, serious games have been used in a variety of fields. As mentioned before, serious games were initially used for military purposes, as serious games can train leaders in taking the appropriate strategic decisions by simulating a battle. Those simulations are low-cost, safe, accurate and engaging for the soldier. Yet, apart from military purposes, the applicability of serious gaming in other fields of society is also increasingly recognized. Serious games have been used in the field of strategic communication, healthcare, public policy and awareness, education, corporation, training, religion, science, ecology and more (Susi et al., 2007; Barnes et al., 2009).

Serious gaming has been used by both public and private actors. Governments can use serious games in order to deal with critical incident management such as terrorist attacks, diseases, fires, as well as with healthcare policy issues, city planning and more. In these cases, the participants of the game are diverse (fire-fighters, police, medical personnel etc.) and they get trained with low budget and in non-dangerous conditions. Besides, serious games can be used in the educational domain, as they enhance strategic thinking, planning, communication skills, decision making and negotiation skills. For these same reasons, they can be very useful for companies and enterprises, since the development of all these skills is also required for the employees. In the field of healthcare, serious games can be particularly used on physical fitness, nutrition and healthy eating habit development, distraction therapy (e.g. dealing with pain or anxiety before a surgery); and patient recovery with other applications also being possible (Susi et al., 2007; Lieberman, 2009).

1.1.3 Serious games through the prism of activity theory

A higher level of abstraction is needed to understand the aspects of human interactions serious games have, with regards to the general aim of the game designers, the specific objectives the human players undertake but also the actions seen by players within the game environment. To understand this aspect of serious gaming, the Activity System Model (based on the Activity Theory) is followed, which describes gaming as a three-level hierarchy of activities (Carvalho et al., 2015). In the top level of the activities comes the **motive** (the purpose of the game), which is the goal of the game designer – the message he wants to convey to the player as a learning outcome from the game experience. The second level consists of two parts: the subject and the object. The object is the literal **goal of the game**, which is the direct objective of the subject (i.e. the player). Although the player (subject) knows the goal (object) of the game, maybe he does not know the motive (purpose) of the game. This motive is known by and created according to the designer. At the third level of activities, there are operations (unconscious actions) that are taken based on given conditions (rules, challenges etc.) (Carvalho et al., 2015). These operations are executed based on the game rules, in a sequential fashion (e.g. in turns in a turn-based game) or at real time. Serious gaming is distinguished from simple gaming because of a different motive, i.e. to educate, provide learning tools and raise awareness, instead of providing leisure.

Given this definition, the **motive**, as a higher aim of game design, should be clearly distinguished from the game **goal**, which is the aim of the players that play the game. This duality is used to define one of the – multiple – characteristics of serious gaming.

1.1.4 Serious games and water management

A serious game can be a very useful tool to illustrate the various conflicts, different interests and perspectives that exist among stakeholders. Besides, it can be effective in stimulating informed decision-making. Complexity and stakeholder conflicts are common phenomena in the field of water management. In this sector, there is a need for dealing with socio-technical challenges and multiple environmental and socioeconomic objectives and interests simultaneously (Bressers & Lulofs, 2010; Pahl-Wostl, 2007; Giordano et al., 2007; Dombrowsky, 2007). Rusca et al. (2012) observe that (integrated) water management provides an interdisciplinary challenge. Handling this requires training to gain better understanding and interaction among the different disciplines, stakeholder groups and their often-conflicting interests (Rusca et al. 2002). Hence, serious games are used in water management as a tool for strategic decision support, collaborative decision-making, consensus building and conflict resolution (Seibert & Vis, 2012; Savic et al., 2017; Hill et al., 2014; Van der Wal, 2016).

These applications are also directly relevant to the management of urban water systems. Whilst these systems are crucial for human well-being, they are under increasing pressure from climate change, urbanization, demographic changes and increasing economic activities. In light of these phenomena, sustainable planning of these systems can be deemed a necessity. More specifically, these trends require a better knowledge of the potentials and capacities of the urban water systems to allow the natural environment, economy and society to be more adaptive and resilient to these changes (Guest et al., 2009; Tjandraatmadja et al., 2005; Makropoulos et al., 2008; Zhou, 2014). Serious gaming seems to allow for this better understanding. As urban water systems are often complex and the coherence of different aspects of the system poses a challenge, serious gaming allows participants to explore multiple viewpoints of stakeholders and issues of collaboration (Zhou et al., 2016).

Yet, besides its usefulness on strategic decision-making, or management level, serious gaming can also be used as a tool to increase citizen engagement. Tjandraatmadja et al. (2005) observe that the urban public is not sufficiently aware of the sustainable use of, and potential threats to, urban water and wastewater systems. These threats include health risks from poor water quality, natural risks from an extended use of water resources or degraded water quality discharge; and economic risks due to high-energy consumption or limited water capacity. All of these threats are highly influenced by human behaviour (Howe et al., 1994), yet remain larger unseen to the public. Serious gaming can be applied as a tool to enhance community awareness of these commonly disregarded threats. In their study on the use of serious gaming to increase community awareness of underexposed tropical diseases, Luz et al. (2016) show that participants in a serious game report increased awareness of risks at hand. Likewise, also in water management contexts, serious games have proven to be able to raise awareness amongst participants. Cho et al. (2014) observed participants reporting increased awareness of the interconnectedness of water, especially when the game was supported by additional educational material. Also, when developed as multi-player game, a serious game can contribute to the enhancement of citizens' understanding of decision-making processes (Cho et al., 2014). Moreover, the public involvement and engagement with urban water management can increase the level of acceptance of the system and the management decisions (Howe et al., 1994; Tjandraatmadja et al., 2005; Guest et al. 2009;). In conclusion, serious gaming can be applied to enable social learning and stakeholder collaboration, while fostering increased engagement in water management (Medema et al., 2016).

A more comprehensive review of the application of serious gaming in water management is provided in Appendix 1. As illustrated there, the majority of games developed in the relation to water management tend to focus upon river basin management (e.g. flood risk management) or water supply management, whilst urban water management seems underrepresented (Savic et al., 2016). This study therefore aims to develop a gaming approach that contributes to this often overlooked aspect of water management. This ambition is strengthened by the statement of Savic et al. (2016) that urban water management is a domain only sparsely studied in the context of serious gaming and therefore has significant potential for further development.

1.2 AquaNES and serious gaming

Besides the technological objectives of AquaNES – i.e. to validate the performance, storage capacity, cost effectiveness, energy efficiency and environmental benefits of cNES – one of the main project aims is to demonstrate and communicate the benefits that cNES treatment can offer to the city. The premise of this task, central in this deliverable and in line with the aforementioned project aim, is that serious gaming could potentially foster enhanced general knowledge of, and social acceptance of, combined systems, while allowing stakeholders to become more knowledgeable of site-specific challenges and characteristics. Serious gaming could allow for a playful tool to discuss different options and explore the limitations and benefits of various measures. Moreover, stakeholders and citizens can be involved in this process and engagement, participation and collaboration could potentially be fostered (Medema et al., 2016). A serious game can thus contribute to – as well as feed from - the goal of AquaNES to validate the performance, cost effectiveness, energy efficiency and environmental benefits of the combined systems at the various sites, given the local requirements and community characteristics.

To explore this potential, a serious game has been developed in the context of AquaNES and is described in this report, based on available information about the cNES technologies and demonstration sites. Following a literature review on serious gaming for water, a gamified framework that utilises information from all AquaNES demo sites was implemented. The proposed game design was then tested in two demonstration rounds and player feedback was used to make structural improvements, and also to evaluate the serious game usefulness in light of the aforementioned potential. This deliverable therefore includes a literature review, the game content and a description of the outcomes of two test rounds.

1.3 Structure of the report

To design a serious game around urban water and wastewater systems in the context of AquaNES, the state-of-the-art in serious gaming for water was first outlined by performing an extensive literature review (presented above and in Appendix 1). As part of this review, the most important characteristics of these games were identified and were used as a basis for the serious game developed in this study. In Chapter 2, the design of the AquaNES serious gaming concept is analysed. A description is provided for the game itself, the main characteristics, elements and game mechanics, an analytical description of the game components and details about the conceptualization of the game. Finally, Chapter 3 provides a discussion on the benefits and limitations of the use of serious games, based on the feedback received from the user demo rounds. Results of the testing process for the designed serious game are discussed and its potentials for improvement, or application in different contexts, are analysed.

2 A serious gaming template for AquaNES

In the following chapter, the game design for AquaNES is described, along with the corresponding mechanics, rules and game elements. Emphasis is put on the conceptualization, the description and the rationale behind structural elements of the game such as the rule set. A link with the designed game characteristics, based on the classification from the literature review seen in Appendix 1, is also provided.

2.1 Motive and goal of the game

As described above, the departure point of the game design starts from setting the game motive and goals, as it is considered one of the most crucial game characteristics. Setting the scope and learning objectives of the game correctly – and, as a result, correctly identifying player target groups, use cases, the necessary knowledge background etc. – largely defines significant structural game attributes (Catalano et al., 2014) such as the mechanics, characteristics, knowledge requirements from the users etc. and, up to a point, guides the design the game realm itself. The starting point for the AquaNES serious game was that it should be:

1. Targeting broader citizen and stakeholder audiences (instead of targeting specific stakeholder groups)
2. Able to support the engagement of said audiences with combined Natural and Engineered Systems (cNES) for the treatment of urban water.
3. Including information on cNES that have direct relevance to the project – and demonstration sites – of AquaNES.

In light of these requirements, the AquaNES gamified approach is designed with the **motive** to provide an experiential learning platform for cNES targeted at multiple stakeholder groups, but also suitable for general public dissemination. Besides this main objective, important side aims of the game design are to:

- Raise awareness and social acceptance on cNES, given that non-expert knowledge on these systems tends to be limited;
- Provide learning blocks and educate stakeholders on the socio-technological aspects of cNES, and provide a learning base for aspects of technology, climate and society related to urban water in general; and
- Provide learning material, in a simplified environment, for the demonstration sites of AquaNES, in order to increase public awareness about the project in its whole.

The aforementioned motive is realised in the form of a multi-player board game, in which players evaluate different management choices in a competitive setting, while at the same time getting actively informed on emerging topics related to urban water by answering trivia questions. Each player assumes the role of an urban water manager and is called to choose management options and implement the most appropriate combinations of cNES on the sites of the AquaNES project. The **goal** of the game for each individual player is thus to discover the best management options and invest, in the best possible way, in sustainable, combined treatment technologies, in order to guarantee that the demonstration sites improve their treatment options and successfully adapt to changing, challenging environments. In order to realise this goal, the game draws from the technologies and demonstration sites of AquaNES. They feature an array of technological combinations that include any of three natural process treatment systems (bank filtration, managed aquifer recharge and constructed wetlands), along with a variety of pre- and post- treatment options (advanced oxidation, carbon filtration, reverse osmosis etc.) in a number of locations with diverse geographic, climatic and social characteristics.

2.2 Game conceptualization

Given the motive and goal of the game, the serious gaming template for AquaNES is conceptualized as an active learning tool for stakeholders and the public interested in urban water, eager to learn about cNES and the way they are implemented in AquaNES. Active learning is achieved by combining knowledge questions on important issues related to urban water management (and its implementation in the AquaNES sites) with decisions on how to properly manage cNES. The important issues emerge from different domains that directly affect water management, such as Climate, Society, Technology and the Environment. Through this learning tool, players learn about how natural treatment processes can be combined with engineered solutions and gain insight on the challenges of managing combined systems. Moreover, the game is based on the AquaNES demonstration sites and technologies, thus allowing the players to discover and apply – in a gamified fashion – a range representative of the demonstrated technologies seen in AquaNES.

This game is conceived as a combination of two main types of common games; the first one follows the concept of *Monopoly*[1] and the second one the concept of *Trivial Pursuit*[2]. The selection of the concept of *Monopoly's* stems from two needs: Firstly, to enhance the managerial skills of the player and emphasize on the fact that basic accounting is incorporated into decision-making too, because the player needs to choose an appropriate water system for the site with the money that he owns. Secondly, to engage the public to the topic with an easier and funnier way that promotes decisions on asset investments (Shanklin & Ehlen, 2007). Furthermore, the choice of the players playing individually in a sequence (more freedom of action) increases the intrinsic motivation (Wouters et al., 2013). *Monopoly* was not the only game that had these characteristics; in the water management field there are games with similar concept, such as the *Lord of the Valley* and *Irrigania*. Finally, the concept of *Trivial Pursuit* (the knowledge of definitions or concepts) aims to actively engage payers and increase their learning, enhance their knowledge during the game (Wouters et al., 2013), and make it more interesting by introducing a combination of knowledge and luck as a financial (money-generating) mechanism.

The game realm is conceived based on the array of demonstration sites of AquaNES, as a geographic extent that includes Europe, India and Israel (see also Figure 1), where the players can move freely between sites. At the sites, players are able to invest in asset changes, in order to introduce cNES to that site. In order to buy a water system for a specific site, the player needs to invest money (buy it). In turn, money is generated by answering trivia (knowledge) questions that are answered every time the player lands in spaces in between the sites. These trivia questions allow the player to enhance his knowledge on different topics (environment, climate, water and society) and at the same time make the game more active, amusing and interesting. Being tested and also knowing that there is a possibility to fail makes the game more fun and exciting (Lieberman, 2009). Money is collected not only from answering correctly to the Trivia questions, but also from the profit, ''yield'', of the water systems. This money from the water systems constitutes an extra motivation for the best selection of a system. This is an extra element of examining the management skills of the player, since he has to deal with costs (from asset investments) as well as profits (from asset yield, but also based on his trivia knowledge).

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[1] https://www.hasbro.com/common/instruct/monins.pdf

[2] https://en.wikipedia.org/wiki/Trivial_Pursuit

This idea is also inspired by *Monopoly*[3]. Hence, the interplay between these two types of game introduce different kind of skills (management, knowledge) and more suspense and fun, since luck is incorporated as well, along with knowledge (as the basic funding mechanism) and wisdom in decisions (which drive the game goal).

The sites show different requirements in terms of water purification (drinking water, wastewater discharge for irrigation, enhancing water capacity in the area or purifying wastewater for drinking purposes) and the player should pay attention to these requirements. For example, if an area requires wastewater treatment for irrigation, the player should not apply an advanced water treatment technology. Some sites do not require advanced systems, and a decision to put one is not only financially suboptimal but there can be events during the game that require payment for the high energy consumption. This drives the player to understand that this system was not appropriate for the area. Furthermore, the potentials, the climatic characteristics and the demands differ among the sites, which is something that the player has to take in consideration too. Similar to previous works (e.g. *SimDelta* (Rijcken et al. 2013)*, Hill et al., Valkering et al.* and *Van der Wal et al.*), future scenarios and problems based on climatic or other factors are incorporated as challenge events. Therefore, the player needs to choose a system which can deal with these problems, in case a relevant challenge will come up.

In order to install the urban water and wastewater systems, some "character" cards are designed (the System Cards, see Figure 4). The System Cards (available water treatment techs) convey knowledge to the player about the functions, capabilities and weaknesses of the water systems. This is realized by including a description of the system, an evaluation of the characteristics of these water systems, a list of weaknesses and its compatibility with other pre- or post- water systems on the cards. More specifically, there is an ordinal rating (from negative to positive) for basic characteristics for each system. These characteristics are the following:

- Performance, which determines how effective the system is in terms of purification;
- Maintenance, cost effectiveness and maintenance frequency which give an idea to the player on how often a system should be maintained and how expensive maintenance is;
- Flexibility to change of demands, which means how easily the system can adapt to serve more people or in general can purify more water in some time periods;
- Environmental Friendliness, which means how beneficial or not damaging it is for the environment;
- Flexibility to Droughts and Floods, which shows how prone to these particular events or not the current system is;
- Energy Efficiency, which determines the level of energy that the system requires to work.

The ordinal rating of these characteristics is illustrated in the way of negative (red) to positive (green), to make the procedure of evaluation faster for the player. Having this information, the player should be capable of assessing the abilities, potentials and weaknesses of the systems in-game and therefore take the right decisions by applying them on a Site. For instance, if a system is vulnerable to droughts, the player should not place it on a site where the climate is hot and dry because it will not be able to function optimally.

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[3] https://www.hasbro.com/common/instruct/monins.pdf

Meanwhile, the concept of the “challenges” is introduced to make the decision making more complex and also introduce change and uncertainty to the game dynamics, in the form of events that progressively occur in the game. An example is installing a system vulnerable to drought: during the playtime, a challenge could be released that invokes the following rule:

“[…] summer is coming and a long dry period is expected. If the player has applied a vulnerable to droughts system at site [X], the player needs to protect the system or expose it to drought, thus damaging the system and thus paying higher maintenance costs.”

The challenges are formulated on a way that the player needs to take decisions about changing, improving or losing a water system (if his primary choice of a water system is not sufficient for the site, given the event). Two types of challenges are introduced and shuffled together: the “surprise” and the “serious”. The “surprise” challenges are more random and generic (not for specific sites) and introduce changes to the whole board realm. These challenges are created to make the game more fascinating because they rely on luck. The players need to throw the dice and see what number they will get. The number will determine the least amount of plus signs “+” that their system needs to have on a specific characteristic in its ordinal scale. For example, if the challenge is about a drought and the player gets two “+”, if he has one “+” on the flexibility to droughts then he needs to follow the ‘’punishment”. If he has two “+” and over, then he is safe from the challenge. This detail is added to increase the suspense of the players. The ‘’serious” challenges, on the other hand, are played in the later phase of the game, refer to specific sites and have a specific learning outcome. Through these challenges the game tests the player, because the challenges are formulated on a way to educate the player on possible vulnerabilities and needs of a site. During the game and by facing these challenges, the player will be able to learn and evaluate himself/herself about his choices.

Finally, as an extra gameplay mechanism, a ‘’battle” side on the six-sided dice is introduced. This “battle” side, which is a knowledge (trivia) battle for all players, aims at triggering the competition among the players and providing extra income to the winner.

2.3 Serious game characteristics and mechanics

2.3.1 Game characteristics

The motive and goals of the serious game design pinpoint most of the characteristics that the game follows. According to the analysis and classification seen in Appendix 1, the serious game for AquaNES has the features seen in Table 1.

Table 1: AquaNES serious game’s characteristics

Characteristic	AquaNES serious game
Domain	Urban water treatment – drinking water and wastewater Combined Natural and Engineered Treatment Systems (cNES)
Goal	To do the best management on implementing the most appropriate combinations of urban water and wastewater treatment systems on the Sites of AquaNES project.
Facilitator	A facilitator is needed for guidance at the beginning and throughout the game.
Number of players	Multiplayer game (2-4 players)
Level of interaction	Players will play individually in sequence.

Characteristic	AquaNES serious game
Role	The players will have one (the same) role of the urban water manager across sites.
Target group	Influential or affected stakeholder groups at any site. General public.; This game is designed to be played by anyone with an interest in urban water. No expertise on water management or prior technical knowledge is needed.
Interface	Board game; however, the model design can also readily be converted to a computer-based case.
Simulation model	No simulation model needed. The game mechanics are based on simple player-generated decision-making and answering trivia questions.
Realism of the game	Simplified
Correspondence with real cases	Based on the case study areas of the AquaNES.
Performance feedback	Provided at the end of the game.
Progress monitoring	The results are not saved.
Portability	Inherently portable (board game, fully printable, available in .pdf sheets).

2.3.2 Learning and game mechanics

Besides the characteristics sketched above, it is useful to also provide information on the learning mechanics provided by the game structure. “Mechanics” are defined as the mechanisms of the game that connect the player with the objective and the challenges of the game (Sicart, 2008). The relation between the learning outcome and game mechanics is very crucial. The purpose of the Learning Mechanics-Game Mechanics Model (Michael & Chen, 2005) is to translate all the desired learning mechanics (pedagogical practices) into the actual game mechanics. Inspired from this model we decided to choose some learning and game mechanics that are useful to give an overview of the basic elements of this serious game (see Table 2).

Table 2: Learning and Game Mechanics of the serious game for AquaNES

Learning and Game Mechanics	AquaNES serious game
Guidance	Facilitator and written guidelines.
Participation/Roles	2-4 players, one role (Water manager) playing individually
Questions and answers	Yes
Plan	Combination of Knowledge and Strategy/Planning
Sites	Multiple (12 simplified cases, based on AquaNES cases)
Storyline	No
Scenarios-Challenges	Yes, as in-game events, for one or more players each time
Levels	No
Competition	Yes
Reflection-Discussion	Yes, during the game – Discussion at end of game.
Evaluation	At end of game.

2.4 Analytical game description

Following the game conceptualization and the brief analysis of the main characteristics and mechanics, an analytical description of the game is provided, in order to describe and analyse in more depth the different game elements, player actions, driving game motives, etc. This section builds upon the general elements of the game that are briefly sketched in Section 2.2.

2.4.1 General game description

The serious gaming template for AquaNES is a multi-player board game that can be played by 2 to 4 people. The players of this game act as urban water managers that invest on asset changes at different AquaNES sites, with the aim of introducing cNES to urban settings. The goal of the game is to implement the most suitable drinking water and/or wastewater treatment for the different sites of AquaNES. During each turn, players throw a dice and move from site to site (see Figure 1), taking actions depending on which box they land:

- Coloured boxes (yellow, red, cyan, blue) mean that the player has to answer a trivia question with a chance to earn coins.
- Numbered stars represent sites; when a player lands upon them, he/she can decide on whether to invest in cNES for that particular site.
- A black box initiates a round-dependent action: in the first round, the player may choose any category of his liking and answer a question. From the second round and until the end of the game, black boxes introduce challenge events in the AquaNES serious gaming realm.

Any time the result of a dice roll is six (6), after the player who threw it moves, a battle round is initiated: a competition follows with all players having to answer one common special (battle) question. The first one to answer (i.e. to press the buzzer beeper and provide the correct answer) wins coins.

The duration of the game is at least two rounds (so that challenge events are also introduced to the game), with the optimal duration being three to four rounds (this is set by the game facilitator *a priori*). Earlier endings of the game are possible, as long as all sites have switched to cNES technology chains and there is nothing left to invest to. The winner in a game is the players who: (a.) has claimed most sites, by investing treatment systems in them, (b.) has placed the largest number of techs on the board, up to three per area (in case of a tie on the number of sites owned), (c.) has the highest yield value of techs placed on the map (in case of a tie on (a.) and (b.)). Along with the players, a facilitator is required to guide the game, provide and check question answers, read challenge events and act as the Bank (i.e. give and take money from the players). The game realm consists of a map-visualized board picturing the different sites of AquaNES (Figure 1) and comes with pawns, a dice, trivia question cards, system cards, challenge cards and a buzzer for the battle rounds (Figure 2).

All players start from the starting point (Start) with the same amount of money from the bank and they follow the same (counter-clockwise) direction on the board. The players follow a route with their pawn, and fall on trivia question boxes or AquaNES sites, where they can implement a cNES technology. Every AquaNES site shows different needs, characteristics and vulnerabilities. The water manager takes the decision of choosing the most suitable combined water system on each site he lands on. Upon landing on a site, the player can decide if he is going to settle and build a system on a site or not (e.g. in case he does not have money or in case he does not want to invest in that particular site). If he does not like the site he can ignore it. It should be emphasized that each Site can only have one “owner” – as long as at least one technology is invested on that site by one player, that player becomes the sole manager of that site. He or she can then proceed to invest pre- and post- treatment technologies in that site as well, in order to create a more efficient technology chain, by choosing from a variety of pre- and post- treatment options that are available as system cards.

In order to apply water system(s) on a Site the player needs to earn money. The player can earn money via two ways; by answering to Trivia questions correctly and through the systems he owns at the end of each round (system yield value). Meanwhile, there are some challenges inside the game that the player needs to overcome. These challenges are related to the Sites and reflect challenges in urban water systems.

The board of the second design iteration of the game is presented in Figure 1, which features a base map retrieved from the AquaNES project. The map features sites in Europe, India (placed in the southern part of the map) and Israel (southeast) are shown. The board includes the starting point (Start), the coloured boxes of the route which represent a different category of a Trivia question (26 boxes), the challenge boxes (eight black boxes) which lead to a challenge and the sites (12 star-shaped places in the map).

Figure 1: The game board (game realm) in the second design iteration of the game.

Six-sided dice

Pawns in different colors

Game cards & board

Buzzer beeper

Figure 2: Physical elements required along with the game board

2.4.2 Analytical Description of Game Components

Different game components are materialised in the game, including:

- The AquaNES sites where the player can opt to apply a cNES in a pre-treatment, treatment, post-treatment chain (a combination of up to three natural and engineered solutions);
- The system cards, which describe water treatment systems available for the water manager to use on sites. Each system card is a step in the treatment chain of the AquaNES sites;
- The trivia question categories; and
- The dice roll mechanics and challenge events.

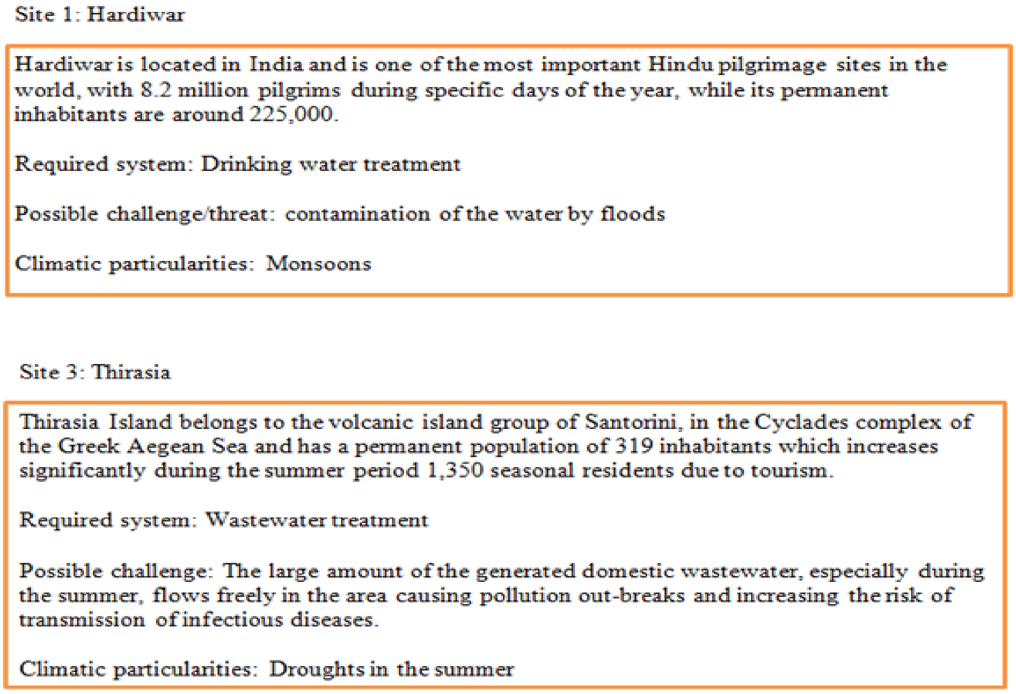
Following the analysis of these game elements, some important supplementary rules and details are considered at the end of this section.

a.) Site selection and description

The site selection is inspired from the case studies of AquaNES project. The selected Sites are 12 out of the 13 total demonstration sites, as two of them were in the same geographical space (Berlin); for the case of Berlin, the drinking water system (Berlin Waterworks) was chosen over the WWTP case of Schonerlinde, in order to demonstrate a wider array of natural solutions such as bank filtration. The names of the sites follow the same naming convention as the ones demonstrated in AquaNES and their characteristics are a (gamified) representation of real site attributes.

To guide the players in decisions for appropriate technologies, site description cards are provided as in-game material. These cards provide basic site information such as place location, water treatment type (drinking water or wastewater) and the most noticeable characteristics. Demographic characteristics, such as population, or other characteristics that may are important, e.g. if it is a touristic place or not, are added as well, to provide a broader socio-technological background for each site. Furthermore, climatic or geological particularities that affect the solution choices are mentioned. For instance, the hydrological regime of the area, along with proximity to the sea, is included as part of the site description. Finally, possible future challenges for the site are mentioned as well, e.g. contamination of the water due to floods. Outlining these challenges better prepares the (careful) player for possibly occurring challenge events at his/her sites during the second game round.

This information can be considered important for player decisions on cNES, because it highlights system weaknesses and vulnerabilities, as well as unique characteristics that lead to the choice of specific techs. This should enhance player's strategic thinking and planning in order to place the most appropriate water system on the sites. Each site description comes in the form of a **site description card**; the first time any player falls on each site, he picks up the card and reads loudly the description. He can then proceed to implement (or not) a solution in that site, provided that he has the coins. Two examples of site description cards are shown in Figure 3, for the Site of Hardiwar (India) and Thirasia (Greece).



Site 1: Hardiwar

Hardiwar is located in India and is one of the most important Hindu pilgrimage sites in the world, with 8.2 million pilgrims during specific days of the year, while its permanent inhabitants are around 225,000.

Required system: Drinking water treatment

Possible challenge/threat: contamination of the water by floods

Climatic particularities: Monsoons

Site 3: Thirasia

Thirasia Island belongs to the volcanic island group of Santorini, in the Cyclades complex of the Greek Aegean Sea and has a permanent population of 319 inhabitants which increases significantly during the summer period 1,350 seasonal residents due to tourism.

Required system: Wastewater treatment

Possible challenge: The large amount of the generated domestic wastewater, especially during the summer, flows freely in the area causing pollution out-breaks and increasing the risk of transmission of infectious diseases.

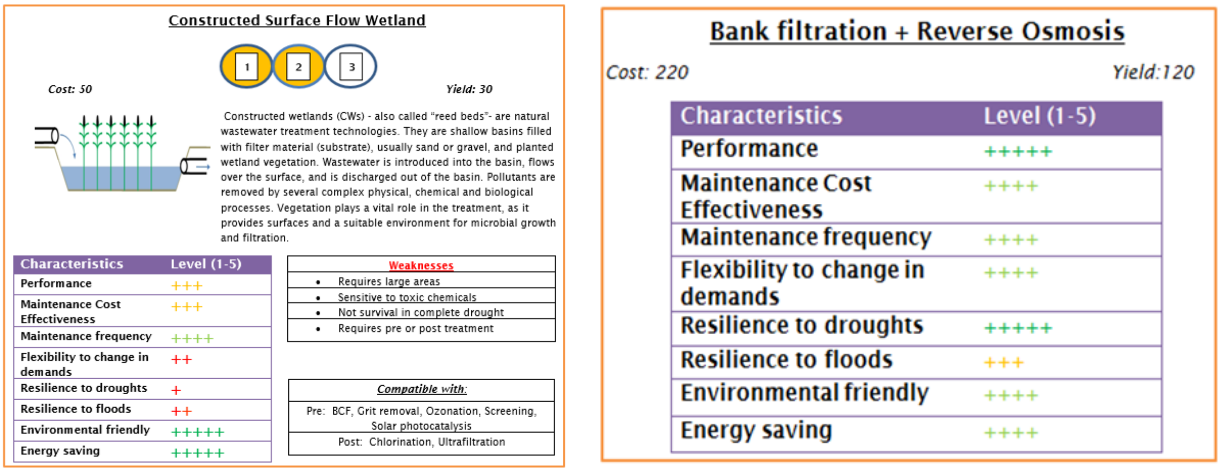
Climatic particularities: Droughts in the summer

Figure 3: Examples of site description cards

b.) System cards and application of systems on sites

At each one of the sites, combined natural and engineered treatment systems (cNES) can be applied. These systems consist of individual pre-, post- and regular treatment technologies that can be combined together and are materialised in the in-game form of a **system card** (Figure 4). If the owner wants to implement one particular technology, he needs to buy the corresponding system card. The available cards are divided in cleaning water and wastewater treatment technologies and can be applied individually (i.e. one main treatment technology) or in conjunction with pre- and post- treatment options to create a full cNES treatment chain.

Evidently, each drinking water and wastewater treatment technology has different characteristics. To facilitate player choices, several categories of system characteristics are identified: these are the performance, the maintenance cost effectiveness and the frequency of maintenance, the vulnerability in droughts and floods, the energy-saving level, the level of environmental friendliness and its flexibility to changes in demand. These characteristics are validated in an ordinal range from negative to positive (one cross means a low score, five crosses mean a good score), seen in the lower left panel of Figure 4. Furthermore, the weaknesses of each technology and its compatibility with other pre- and post-treatment options are mentioned. Having this information combined with the unique characteristics of each site lead to possible cNES site-specific solutions.



Constructed Surface Flow Wetland

Cost: 50

Yield: 30

Constructed wetlands (CWs) - also called "reed beds"- are natural wastewater treatment technologies. They are shallow basins filled with filter material (substrate), usually sand or gravel, and planted wetland vegetation. Wastewater is introduced into the basin, flows over the surface, and is discharged out of the basin. Pollutants are removed by several complex physical, chemical and biological processes. Vegetation plays a vital role in the treatment, as it provides surfaces and a suitable environment for microbial growth and filtration.

Characteristics	Level (1-5)
Performance	+++
Maintenance Cost Effectiveness	+++
Maintenance frequency	++++
Flexibility to change in demands	++
Resilience to droughts	+
Resilience to floods	++
Environmental friendly	+++++
Energy saving	+++++

Weaknesses

- Requires large areas
- Sensitive to toxic chemicals
- Not survival in complete drought
- Requires pre or post treatment

Compatible with:

Pre: BCF, Grit removal, Ozonation, Screening, Solar photocatalysis

Post: Chlorination, Ultrafiltration

Bank filtration + Reverse Osmosis

Cost: 220

Yield:120

Characteristics	Level (1-5)
Performance	+++++
Maintenance Cost Effectiveness	++++
Maintenance frequency	++++
Flexibility to change in demands	++++
Resilience to droughts	+++++
Resilience to floods	+++
Environmental friendly	++++
Energy saving	++++

Figure 4: Example of a system card (left) and a super system card (right).

Besides basic information and characteristics, system cards are characterised by the cost of installation (top left panel of Figure 4), as well as the yield (top right panel of each system card in Figure 4). The latter is a secondary profit-generating mechanism that gives a set amount of coins to the players that have invested in these technologies at the end of each round. The top panel seen at the left picture of Figure 4 provides the stage(s) in the pre-treatment/treatment/post treatment chain (i.e. treatment sequence) where each technology can be applied. For example, the solution of a Constructed Wetland can be applied in the first position followed by 2 post treatment systems, or in the second position having one pre- and one post-treatment system.

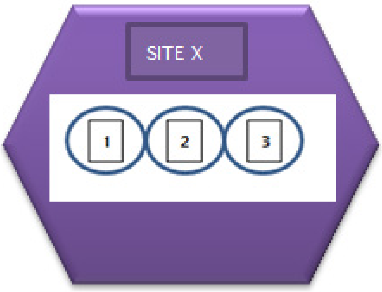


Figure 5: The site scheme with the three possible levels of treatment (stages of system card application).

System cards are applied on each site based on a **site scheme** (Figure 5) that represents the pre-treatment/treatment/post treatment chain and has three levels. Similarly to the rules of Monopoly, each player can claim a site by applying one technology (system cards) at any of the treatment levels shown in the site scheme. These treatment levels (stages) represent a position that a water system can be applied. For example, the first one represents a pre-treatment system position, the second one represents the main system position and the third one represents a post-treatment position. However, in some cases the main system could be applied in the first position followed by two post treatment systems. Therefore, the player must make feasible decisions on the systems that he/she is going to buy, in order to be aligned with these stages. The player can then continue his investments to add a second or third system card at that site, in order to complete a cNES treatment chain. System cards can be moved freely from the second to the first or third position in a site depending on what kind of chains the player wants to create.

Finally, to facilitate the end game, a number of "AquaNES Super System Cards" are provided (Figure 4, right panel), which depict common combinations of system cards that can be implemented on sites. These super system cards can replace existing system cards, in order to save up space and make the techs available for other players as well. The full catalogue of system cards is given in Appendix 2.

c.) Treatment system selection

The system cards are selected based on the portfolio of solutions that are featured in AquaNES. The types of systems are two and they are divided based on natural and engineered process treatment systems. The natural process treatment systems include the bank filtration (BF), the soil aquifer treatment (SAT), the managed aquifer recharge (MAR) and the constructed wetlands (CW), which are all demonstrated as natural-based solutions in AquaNES sites. The engineered process treatment systems that are mentioned in the AquaNES project are more numerous than their natural counterparts, but this range was narrowed to the most appropriate (two or three) pre- and post- treatment systems that are compatible with each natural water system, as well as common treatment systems that can fit in multiple AquaNES sites. Table 3 provides an overview of the natural treatment systems included in the game, along with the chosen pre- and post- treatment options; these solutions constitute the range of cNES demonstrated in the serious game.

Table 3: The natural treatment systems and their pre- and post-treatment options

Natural	Pre-Treatment	Post-Treatment
BF	-	Nanofiltration
		Reverse Osmosis
		Activated Carbon Filtration (ACF)
		Ozonation
		UV Disinfection
MAR/SAT	Advanced Oxidation	Activated Carbon Filtration (ACF
	Biological Carbon Filtration (BCF)	Ultrafiltration
	Ozonation	UV disinfection
CW	Grit Removal	Clorination
	Solar photocatalysis	
	Ozonation	Ultrafiltration

Based on Table 3, which was made according to the information that was given in the DSS of AquaNES project[4], the compatibility and the position of the system (pre-treatment, main treatment or post-treatment) are determined on the top panel of the system cards (see the left picture of Figure 4). This will help the players to identify combinations of natural with engineered systems. As mentioned, the player has the option to combine systems by implementing the systems on the ''stage" (i.e. treatment level) the technologies fit into. Some of them can be used as either pre- or post-treatment options.

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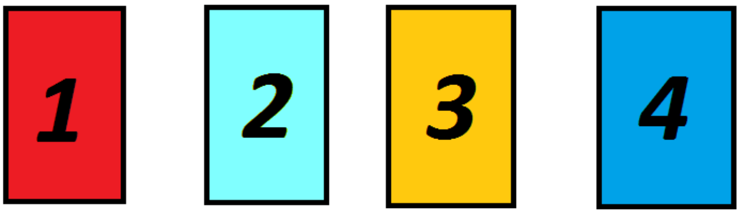
[4] http://dss.aquanes.eu/

d.) Trivia questions

When a player lands on a coloured box, a trivia round is initiated, where the player has to answer to a knowledge question that belongs to a specific category that matched the colour of the box in order to generate coins, that in turn enable him/her to buy technologies. These questions belong to different categories depending on the box colour and aim at testing both general and site-specific trivia related to water management, climate, environment, technological options and society. Trivia (knowledge) cards are meant to test (and assist in the formulation of) player knowledge on different water-related issues. Besides general issues, some of the questions are related to site or country specific characteristics, thus providing insight on unique features seen at each site.

The initial version of the game featured Water, Environment, Climate and Society-Economy as the four categories. However, during the second design iteration of the game, these categories were changed to: Water, Environment & Climate, Technology and Society (Figure 6). A new category (Technology) was introduced in order to facilitate the understanding of technological solutions at the site. These changes, further analysed in Section 3.2.1, were driven by player feedback, which reported difficulties in understanding all technological options in time merely from the information contained in the system cards.

While initially in the form of a numbered list, these trivia questions come - at the final game design - in the form of a stack of cards, shuffled at the beginning of the game. The player then checks the answer against the facilitator, which has all question answers. Examples from each question stack are provided in Appendix 2.

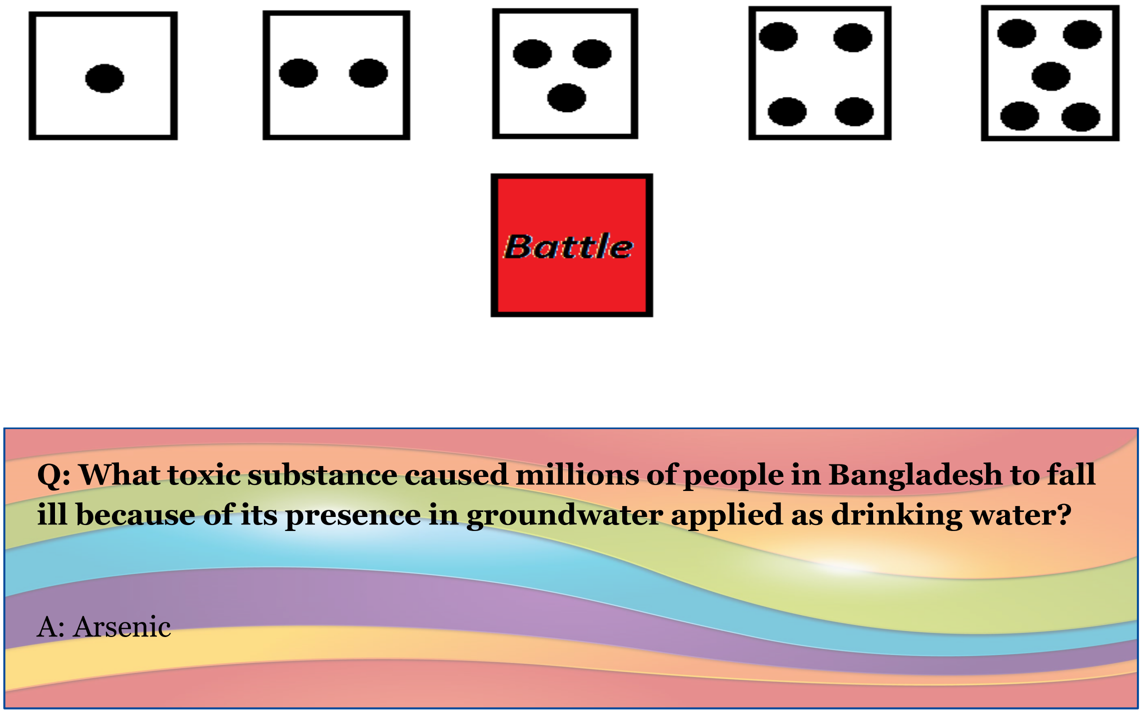


1: Technology, 2: Society, 3: Water, 4: Climate and Environment

Figure 6: The coloured boxes of the board and the category of knowledge questions that they represent

e.) Dice rolls and outcomes

At the beginning of his/her turn, each player throws a six-sided dice to move in the game realm. Most outcomes {1,2,3,4,5} result in regular movement, with the exception of a dice roll of six (6). In that case, the player moves and then a “battle” round follows, where all players are called to answer to one battle Trivia question, read loudly by the facilitator. The player who presses the buzzer faster and gives the correct answer is rewarded with money (coins). If the person who presses the buzzer first does not answer correctly, then a small penalty is introduced to that player and the rest of the players may try to answer again.



Q: What toxic substance caused millions of people in Bangladesh to fall ill because of its presence in groundwater applied as drinking water?

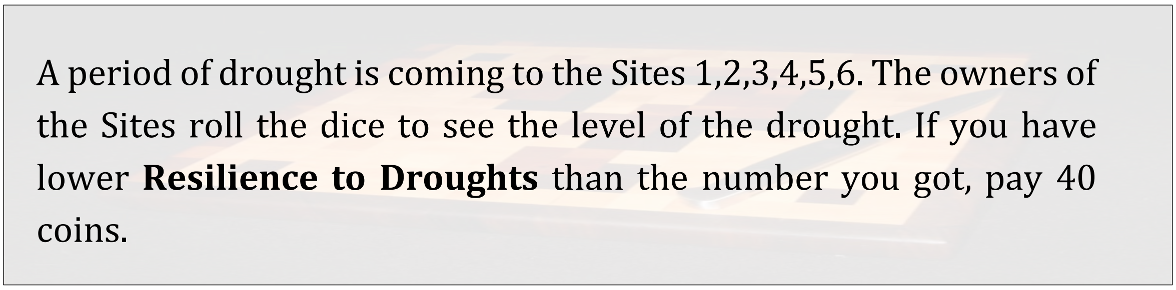
A: Arsenic

Figure 7: Dice outcomes and example of a battle question card.

f.) Challenge events

In order to trigger the player's strategic and decision-making thinking, challenge events are incorporated into the game (Figure 8:). A player falling on a specially coloured (black) box from the second round and on triggers a challenge event that has implications on a specific site or on the whole of the game realm. These challenges reflect drivers of change or uncertainty that pose a risk to specific (or all) sites, gamifying drivers such as climate change, extreme events, social changes etc. and relate to the installed site characteristics.

Since the first round is more devoted on building the necessary finance for investment in cNES, the design choice was made not to include challenge events in the first round; instead, when a player steps on a black box during the first round, he can choose a question card from any category and try to answer it. When a player falls on a challenge box (from the second round and on) he has to read the challenge aloud; the affected players then have to react to it. Reactions may include paying a fine, gaining money, paying a price to keep a technology and prevent system collapse etc. Characteristic challenge examples are given in Appendix 2.



A period of drought is coming to the Sites 1,2,3,4,5,6. The owners of the Sites roll the dice to see the level of the drought. If you have lower **Resilience to Droughts** than the number you got, pay 40 coins.

Figure 8: Example of a challenge event.

g.) Other rules

A number of secondary rules are provided in this section, supplementing the basic aforementioned elements. These rules include the following:

- The players are provided with information on the site and the system cards ten minutes before the game starts. This will help them get introduced to the AquaNES sites as well as get acquainted with the range of available treatment options.
- Every player starts with 50 coins from the bank (the initial design was 30 coins, but this was increased following player feedback).
- Each correct answer to a Trivia question gives 30 coins (the initial design was 25 coins, but this was increased following player feedback).
- A correct answer to a battle question gives 50 coins. A wrong answer incurs a 10 coin penalty.
- The pawn can only move forwards in the counter-clockwise direction. After Site 6 there are multiple pathways forward and the player can choose to which direction he wants to go.
- A site belongs to a player if the player has invested at least one technology (system card) in it.
- If somebody falls on a Site that belongs to another person, he can become the new owner of the site only if he implements (buy) a Super AquaNES System, for which its **Performance** is larger than the existing system card. The other player then gets the old system card as part of his/her inventory, able to be applied elsewhere (i.e. he doesn't need to buy it again) and loses management for that particular site.
- When a player wants to add an extra system to a site, they can do it when their turn comes. He does not need to step on that site again. Players are allowed to add systems only at sites that belong to them.
- If two or three systems are combined at one site, site characteristics are evaluated as follows:
- If the player has two or three systems, he takes in consideration the highest value of each characteristic among the cards. For example, if two systems have performance 3+ and the third one has 4+, then the performance of the whole combined system is 4+. The same holds for all the characteristics. The most positive value counts, in order to promote treatment chains.
- The systems that the player applies at one site cannot be replaced. However, their position in the treatment chain (site scheme) may change, should the player require so.
- In the challenge there is a possibility of a system collapse; this means that the whole combined system will be lost, along with all system cards at that site. To prevent this, the challenge poses specific actions that the player can do. When a system is lost, all system cards are returned to the stack and the player loses the "ownership" (i.e. management) of that site.

3 Designing a serious game for AquaNES: lessons learnt

3.1 Reflection on the game conceptualization and chosen characteristics

Following the development of the AquaNES serious game, but also its testing in real demonstrations (see also section 3.2), it is useful to reflect on these points, given also the specific motives (aims) of the AquaNES serious game seen in section 2.1. As mentioned previously, designing a serious game can be a complex matter, as multiple factors of the real system need to be taken into account and have their dynamics modelled in a gamified environment, without however resulting in high complexity that potentially limits player understanding and engagement. Cases of water management are inherently complex, as they feature multiple entwined environmental drivers, actors and governance mechanisms (Ruth and Coelho, 2007), and are subject to change from many environmental factors, such as climate, demographics, technological input, social behaviours etc. Given this context, it is perhaps easier to create complicated representations of the reality in serious gaming for water management, rather than providing simple, concise gaming templates; this tendency to complicate gamified environments is also reflected in the literature review of Appendix 1.

Against this tendency to transform complexity from reality to game, this study presents a serious gaming template that is based on simple rules, is understandable by non-experts, and comes with a structure that combines knowledge, luck and simple decision making on cNES. The main motive of this game is to provide experiential learning on urban water management and enhance the learning process of cNES across different stakeholder groups, as well as the wider public. The simplicity of the game structure comes from the need to have a clear idea of the motives and learning outcomes of the game, as well as to easily understand different game elements, as this is the prerequisite that leads to successful facilitation of learning (Arnab et al., 2015, Carvalho et al., 2015). Since the main motivation in designing the AquaNES serious gaming template was to allow for experiential learning on urban water, the so-called “constructivist approach” was applied. In this approach, a player has an active role and constantly tries to learn during the game to reach its specific goals, while at the same time being required to understand the challenges, resolve problems and develop some skills (Lieberman, 2009). The structural simplicity of the game allows the player to grasp the main concepts and be ready to play in a matter of minutes, so that the learning process can start without lengthy introductions on unnecessarily complex elements from water systems. The required complexity of each technology is represented through ordinal qualities, as described in Section 2.2, which give the player overview of the advantages and disadvantages of each technology without a large investment in learning time before playing the game. Meanwhile, the combination of active gameplay, random events, knowledge questions and decisions on asset investments aims at balancing the active elements of gameplay with the actual – and more passive – learning process on the potential and limitations of each technology.

The aforementioned traits were evaluated during the test rounds of the game as well. During actual play rounds of the game, it became apparent that this approach not only potentially allowed for continuous learning throughout the game duration, but also fostered active involvement of participants in the game itself. Players had to answer questions throughout to proceed in the game, but also unexpectedly collaborated with each other and exchanged information on technologies in order to reach better decisions for their sites. This balance between knowledge-based competition and collaboration in decision-making sparked enthusiasm and player willingness to perform well. The feedback from actual game applications is analysed further in the following section.

3.2 Test cases and improvements on the AquaNES serious game

Following the conceptualization and initial development of the game, the game was played by different stakeholder groups twice; once by water management researchers and experts at KWR (Netherlands), and once by students at the National Technical University of Athens (Greece). These two game testing (trial) rounds organized for the AquaNES game provided the necessary feedback to significantly improve aspects of the game structure, but also provided play input that allows a reflection on the model usefulness and on whether the model succeeds at the motive set in Section 2.1. The following section analyses these topics, after which potential additional points of consideration are given in section 3.2.2.

3.2.1 Game improvements based on real testing

The first test of the game was at the KWR research institute in Nieuwegein, the Netherlands. The game was played by KWR researchers, who tested the functionalities of the initial conceptualization (see Figure 9). The first game trial has shown that, despite the quick learning pace of the players, the rounds over the board of the game ran slowly, due to limited movement ability during the game. The possibility to fall on a site was also found not to be very high, with half of the sites being taken in the first round. As it is important for the game that most of the sites are taken after the first round, in order to allow the challenges of the second round to be effective, another way of falling on a site was added to the game mechanics: upon throwing a six in a dice roll, players are called to answer a question in a battle round. Whoever answers correctly gains money, but also has two options: to move his pawn to any site (and thus be able to buy a technology at that site), or to throw the dice again and thus be able to move forward.

Figure 9 **Pictures of the trial of the AquaNES serious game at KWR research institute at the 12th of March, 2018.**

Furthermore, the amount of money provided in the beginning, and after a correct answer to a Trivia question, was found insufficient to easily buy systems. This amount was also increased to allow players to make rapid decisions on asset investments and promote investment in technologies from the first round.

A second trial round was also organized in Athens with students from the National Technical University of Athens (NTUA) as players. The second testing progressed faster with the implemented changes. However, the game did not come to an end, since the participants could not dedicate more than one hour and 15 minutes to the game. Based on the actual test cases, it was deduced that the game requires a minimum of two hours to complete a minimum of two rounds. Of the time needed, the most demanding tasks were to understand and answer trivia questions, but also to read and understand technology cards before making decisions about the sites. Furthermore, another interesting observation is that although the game is competitive, players were really willing to help each other, especially when it comes to choices and decision-making on the sites. Therefore, it was suggested that asking for help between players should be allowed. Suggestions included an option of asking consultancy from the other players when the player faces a difficulty with a selection of a system could be added. By including this, the player can pay each player 10-20 coins to have a short interactive discussion; furthermore, a "trust" option was suggested, which gives him the opportunity to choose one player to help him by paying him 40 coins. By including this option, the game could potentially benefit from both the motivational advantages of playing a competitive game, as well as from the insight collaboration can offer players. Of these two options, the option of 'consultancy' was chosen, allowing the player to pay 20 coins to be able to get feedback from another player of his/her choice.

Figure 10: Pictures of the trial of the AquaNES serious game at the National Technical University of Athens at the 13th of May, 2018.

Besides minor improvements after each trial round, major improvements were carried out after both rounds, based on the pooled feedback collected from both player groups. The general remarks of both teams were that:

- The game was easy to understand, with most of the gameplay time being devoted to understanding different technological characteristics and site needs.
- The game takes about ~2 hours of playtime, as most players need to read the technologies and understand their usage prior to investing their money.
- The money-gathering mechanisms were rather conservative; players found it hard to collect money – especially at the beginning of the game. Likewise, buying a set of technologies for a single site exhausted the money pool of most players. This meant that most players preferred to keep moving and answering questions instead of landing on sites.

- The game played more like a trivia challenge than a strategy game, but that this balance actually made the game fun and promoted active gameplay over static actions devoted to decision-thinking.
- The questions initially came along with the board game in the form of a list (a number of A4 pages with numbered questions). This made the gameplay essentially a one-off experience, as the players had to progress through the same questions at each game iteration. After this, the players could not replay the game and were not able to answer questions later on in the list unless the game length permitted it so.
- The questions asked were sometimes outside the scope of the game, and felt disconnected to the decision-making mechanism on cNES technologies. More specifically, players found many of the questions as – quoting player remarks - "*too generic*", "*not related to water at all*", or "*too specific to irrelevant site or locality information*".

To address these remarks, the following structural changes were made to the game:

1. A major revision of the questions was performed, with many questions that were too site-specific or unrelated to water issues being excluded from the questionnaire. The old four categories "Water-Climate-Environment-Society", that featured 30-36 questions each, were now reformed to "Water - Environment & Climate – Technology - Society"; a fourth category "Technology" was added with questions from scratch that mostly address cNES technology trivia. This fourth technology aims at speeding up understanding of available treatment systems and providing the missing link behind the 'trivia' mechanism and the mechanism of making decisions on technologies, by engaging players on issues of technology in water and educating them on the techs seen in game.
2. The questions are not now given in the form of a numbered list (questionnaire), but are instead given as **question cards** with different colours that correspond to the four categories. These cards are shuffled in each round and answered when any players steps on the corresponding colour. This adds significant replayability to the game, as the players will not see the same sequence of questions every time the game is played. The facilitator holds the list with the questions and is responsible of checking the answers of each players, as well as giving the rewards upon a correct answer.
3. Likewise, battle questions and challenges were converted to **battle and challenge cards** respectively, thus randomizing the process of battling rounds and getting challenge events.
4. Generation of money throughout the game was made easier. The number of coins taken from the bank at the beginning of the game was increased from 30 to 50 coins. Likewise, every right answer now gives 30 coins instead of 25 coins.
5. The player objective of the game was reworked to exclude money generation as one of the winning mechanisms (as seen in the initial version of the game). This was deemed important as the goal of the game should not be profit maximization but understanding and investment in technologies. The game objectives were changed so that the player who wins has the following features (in priority):
   - He has claimed the most sites (i.e. invested the first tech in them).
   - If the number of sites are tied, he has placed the largest number of (combined) technologies in cNES sites.
   - If the number of technologies is tied, he has the highest value of techs placed in total on sites.

These redesigned objectives ensure that money is merely intermediate means and not the ultimate goal of the game. Obtaining and keeping a lot of money does not help ensure a victory condition, unless the player invests in techs.

6. An anti-motive was included in the battle rounds, to exclude players from continuously answering at random quickly. In every battle round, the first player to press the buzzer and answer correctly wins 50 coins. If he provides a wrong answer, he loses 10 coins and the round is repeated with the rest of the players. The players can also choose not to answer at all; if no one answers in a valid timeframe (e.g. 15 seconds), the battle is over.
7. A number of aesthetic changes was also made to increase the game attractiveness; the board of the game was redesigned to a higher-resolution setting (see Figure 9, compared to the initial version of Figure 11), along with aesthetic changes in the question, battle and challenge cards pictures.

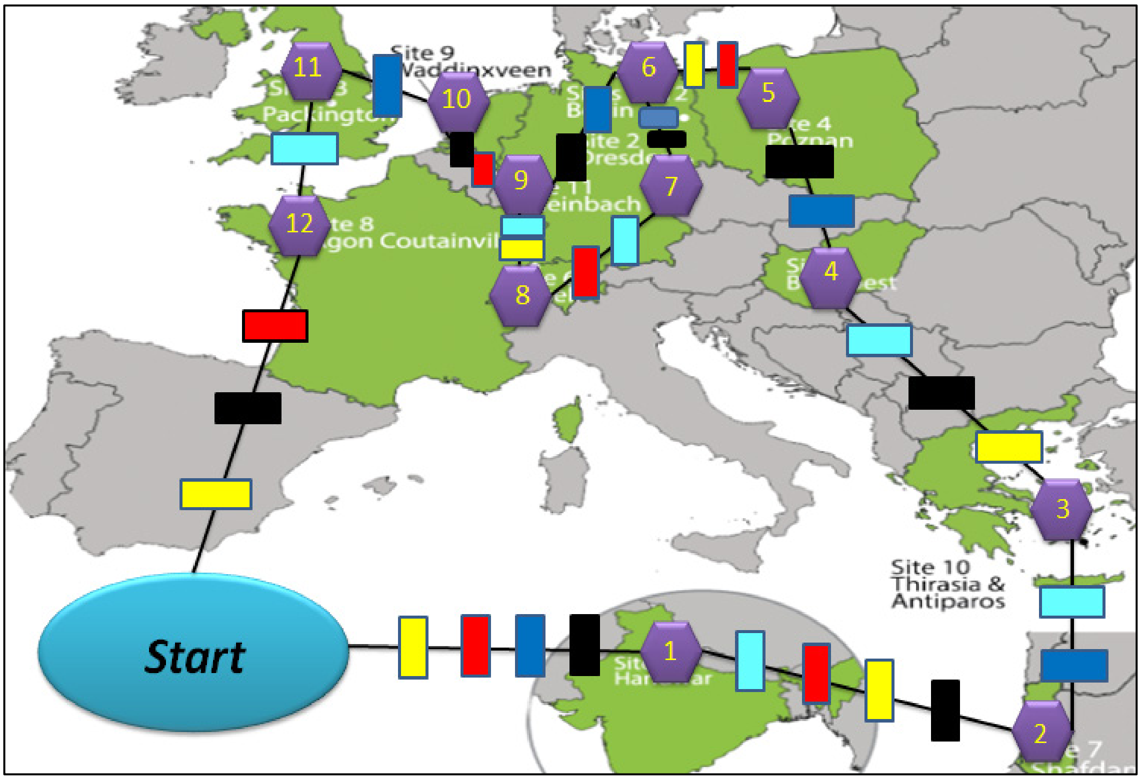


Figure 11: The initial game board version.

These changes aim at promoting the underlying motive envisioned by the game designers: to create an active game with trivia challenges and simple decision-making that, at the same time, educates about urban water and available cNES technologies.

3.2.2 Evaluation of the game based on player feedback

Besides driving structural changes, player feedback was very important to validate whether the game motive – and the underlying educational and learning objectives – are delivered well or not. The basis of the evaluation was the performance feedback session, held at the end of the game, where the players could discuss their game experience and feelings, whether they felt educated by the game on cNES and

AquaNES or not. This reflective session was accompanied with suggestion about structural game changes.

One of the main conclusion that drawn from the players after performing both trial games is that the players understood the aim of the game well and were optimistic with its potentials. Moreover, they amused themselves, were satisfied by the simplicity of the game structure and the combination of its mechanics; the also seemed very willing to play it again. The core of the game, the mechanics and the elements that it consists of seemed to be reasonable to them and provided, as quoted by the players, "*a unique combination of trivia and actions on sites*". The trivia and especially the battle questions made the players enthusiastic and generated an active response of casual competition. Players seemed to understand the consequences of an inappropriate selection of a system on a site, which was also an important piece of the game. Therefore, the authors trust the specific game design to potentially be a good training and knowledge tool for different stakeholder groups.

However, a second lesson that could be drawn from the trial rounds is that, especially when aiming to include the general public (non-experts), the complexity of the game could form a barrier, despite its seemingly simple structure. In gaming this is referred to as *analysis paralysis,* a phenomenon which can occur when players are confronted with such a wide variety of options that creating an overview of consequences is experienced as overwhelming, especially given the casual context of the game. This can have negative effects on the gameplay, as *analysis paralysis* forces players to spend time on deciding what to do, rather than interacting with the game systems. As a result, players might perceive their chance to win as determined by sheer luck (Björk et al., 2003), since there is limited understanding of the dynamics in decision-making. In the AquaNES serious game, the major source of complexity was found to be the information contained within each technology and each site, which is a prerequisite to make decisions about site asset investments; in contrast to this, players appreciated the understandable mechanics and approachable level of question difficulty of the trivia mechanism.

3.3 Points of consideration for further development

3.3.1 Testing

This serious game developed in the context of AquaNES is, based on the undertaken literature review, one of the few games – if not the only one – on combined urban water and wastewater treatment systems. It can be considered a prototype of potential games developed in this field. Although inspired by other games, it comes with a unique combination of mechanics and ideas that focus on decision on cNES. Since it is a prototype and it was not designed based on statistical analyses, testing to account for any unforeseen functionalities of the game (Smith et al., 2009) was performed, along with the required structural changes. Despite the rounds of testing during the development stage and the corresponding game changes, extensive widespread testing and evaluation is still needed to validate the long-term game performance and impact in different communities; such extensive testing could not be performed during the development phase due to time and resource limitations. As such, the serious game has to be considered as a serious gaming template (i.e. a skeleton framework), instead of a mature engagement end product. Still, the feedback from the player rounds was encouraging and the authors envision that a gaming approach very close to the demonstrated concept can be a strong awareness raising and engagement tool for AquaNES and beyond.

Another aspect of the game that hasn't been revealed yet but might be revealed during further testing is the occurrence of an *imbalance* (or 'imba' in gaming jargon). This potential flaw, also sometimes referred to as being 'cheap', occurs when a combination of game options provides and unfair advantage to the player using it. Imbalanced options are considered an exploitation of a game's mechanisms and detrimental to the fairness of the game. A call for an imbalance is most commonly made by players themselves and finding them requires extensive testing of the game (Harrop, 2009). Furthermore, in future applications of the AquaNES game we advise not only to do test runs regarding the logistics of the game itself, but also a structured evaluation of player's experiences during the game and learning outcomes.

3.3.2 Target audience and interface

This game was designed to engage different public and stakeholder groups interested in cNES. The main approach used to reach this is to enhance their knowledge on these systems. The game, in its present form, could potentially be enjoyable, suitable and informative for groups such as university students, urban water planners and generally people who have a minimum knowledge of (but a strong interest in) water systems and issues. Through this game, interested individuals, water experts and scientists that work with urban water could train their knowledge and their skills. Currently, the trivia questions have a medium level of difficulty so the players need to have a moderate level of education relevant to the environment. This might pose a challenge, especially when combined with the large amount of information on sites and technologies, for the wider public that is not acquainted to urban water issues and terminology.

However, the game structure allows the game to become readily accessible for wider public groups with slight changes. More specifically, the questions can be altered to be made slightly simpler. Alternatively, another set of questions could be developed, applicable to the target public group the designer would like the game to be played with. In principle, the main mechanics of the game can remain as-is as a basis, and a number of different versions could be created, depending on the target group. Finally, while this game is presented as a board game, the structure and rules could be readily ported into a software version; having such a realisation would be very useful in terms of speed, practicality and replayability, due to the system cards presentation, the counting of the coins, the description of the site and the trivia mechanisms. Such a version would not require a facilitator and could come with helpful visualization on the sites and technologies, which are more information-heavy. However, the interaction and the fun among the players will not be physical, and this could pose a challenge for the attractiveness of the game.

3.3.3 Complexity

Feedback provided by the players also referred to the complexity of the information provided. Even though this game was designed to be simple and easy to gasp for a wide audience, players still considered the amount of information excessive at points, which resulted in reduced gameplay speed. For the further development of this game, it would be thus better to reword the suggested system mechanics (System Cards), in order to limit the amount of information contained within them. This could help the player read the cards faster and memorize the most important information.

3.3.4 Limitations of the current gaming template

Considering the limitations of using a game to achieve specific learning outcomes, it is crucial to regard serious gaming as one part of a wider experience. As referred to by Chew et al. (2014), serious gaming performs optimally when offered in interplay with other teaching and learning tools, rather than as a standalone option. In addition to this, the role of facilitator as a learning medium can be crucial in ensuring the effectiveness of the game. While learning can still occur without an instructor, (s)he ensures careful reflection and guidance throughout the game. Therefore, their contribution should not be underestimated (Chew et al., 2014). Nonetheless, this dependency on effective facilitation also poses a potential limitation, as it reduces the ease of playing the game; this was also the finding players experienced during the AquaNES serious game test trials. Other limitations to playing the game are the number of people needed, the time needed to play the game and the relative similar base knowledge players need. The AquaNES game is designed as a multi-player game, and therefore needs a minimum of 2 players, while it is optimally played by 4 players. Also, the game takes approximately two hours, and requires learning-intensive tasks – related to the selection of the right techs for the appropriate sites – along with quick-paced tasks such as question answering and battle rounds. This already proved to be a challenging balance during the trials, as players took a considerable time per round and, in one of the two cases, did not have the time to play the game till the end – also due to the limited time allocated to that particular game demonstration.

Another limitation of serious gaming, and specifically the AquaNES designed template, is the fact that, no matter how accurate it is, it is always a simplification– and gamification – of reality. Whilst the AquaNES game provides players with an opportunity to explore the wide variety of treatment options and site specifics at hand, it does not aim to replace scientific data sources and the dialogue of corresponding groups. Moreover, due to the gamification process, it cannot present fully accurate information on sites and technologies; some technologies feature simplified characteristics, and there are combinations of technologies that are uncommon in practice.

4 Conclusions

4.1 Outputs of the AquaNES serious game

This study has presented a serious gaming template, based on AquaNES project elements, that provides a learning platform for combined natural and engineered systems (cNES). Reflecting on the motivations and learning objectives of the AquaNES serious game, several conclusions can be drawn. The aim – and motive of the game – is to target broader citizen and stakeholder audiences and engage them in the application of cNES for the treatment of urban water/wastewater, whilst including specific information regarding AquaNES sites. The developed AquaNES game includes all of the aforementioned aspects, links them through a relatively simple but not simplistic game structure, and has thus the potential to educate citizens and stakeholders in an informal, non-expert environment. By including different site characteristics related to both drinking water and wastewater, players are stimulated to analyse and discuss the usage of different treatment options and relate them to site-specific technological, climatologic and societal factors. As the game includes many sites, systems and treatment options, one can conclude that the game does not contribute to improving the knowledge on and management of one specific site, but rather gives an overview of the wide variety of options and combinations possible in different socio-technological and climate settings. Since water management is recognized for its complexity and context dependency, applying suitable approaches and finding compatible combinations is crucial for each individual case. Playing the AquaNES serious game provides players with the insight that there exists no one-size-fits-all solution and that each case should be assessed based on its own characteristics and capabilities. Moreover, the game allows for an understanding of the wide variety of issues different cases are dealing with, while the inclusion of challenge events forces them to consider uncertainty in their planning.

Despite the lack of extensive testing, the two trial runs still provided valuable feedback on these desired game outcomes and sparked improvements on game design. Players rated the game as – in their own words – "*fun*" and "*informative*", and made careful considerations on applying specific measures at sites, which was one of the main targets of the game. Moreover, player experience and feedback shows that the game enhances knowledge about urban drinking water and wastewater systems, with a specific focus on cNES. As players thus enhance their understanding of site-specific problems and broader socio-technical challenges, they are potentially more inclined to accept combined technologies in systems seen in their cities. Another interesting insight provided by the trial rounds was that – although the game was designed to be competitive – players still discussed various measures and consulted each other, thus nurturing an atmosphere of collaboration and knowledge exchange. Therefore, a consultancy option was included in the final game, allowing collaboration to be also fostered by the game itself and balancing elements of competition with drivers of player collaboration.

4.2 Relevance in the serious gaming field

To date, urban water management needs the inclusion of various technologies, as well as planning techniques. Although the planning of large infrastructures like water treatment systems increasingly aspires to be collaborative and co-created, in practice this sector is still often exclusive, unresponsive and over-standardized (Savini et al., 2015). Applying serious gaming in this sector beholds a broad potential as it could include actors from various backgrounds in thinking together on these issues and collaborate in an informal, fun way. More specifically, it is argued that the AquaNES template allows for a broader understanding of issues at hand for different geographical locations and the creation of a community of practice between these different sites. Also, it enables the consideration of various measurements for each site in a fun and entertaining manner. The fact that each player has access to all sites makes the player aware of key differences across sites, driven by diverging contextual factors related to the climate, environment and societies.

However, despite these potential benefits, the study of serious gaming in water, seen in Appendix 1, has shown that most of games focus on river basin management issues and disregard more generalised opportunities to link communities in different water systems or across catchments. The urban water and wastewater treatment focus applied in the AquaNES serious game therefore provides a first step in the exploration of these treatment types through a serious gaming approach, as urban water has been mainly disregarded in the serious gaming field up till now (Savic et al., 2016). The game thus offers a high novelty value, and the authors aim that it can spark the design for more serious gaming concepts in the field of urban water management.

In addition, Savic et al. (2016) recognize many water management games to be hindered by their sole online application (thereby excluding participants with no access to the internet). This is no issue for the AquaNES serious game as it is presented as a board game and can be played fully offline. Besides this, the AquaNES serious game fits in with the vast majority of water management games, focusing on the enhancement of system understanding, rather than specified, context-bound learning. This systemic focus of the AquaNES game originates in the diversity of water management seen at each individual site, as well as from one of its main motives to provide citizens and stakeholders (non-experts) insights on the application of combined treatment chains (rather than on e.g. one specific treatment option). A high degree of case specific realism in a game can cause it to become complicated and less user-friendly (Catalano et al., 2014), making it less attractive for our target audience. Keeping design motives in mind, a more systemic focus was chosen that has a clear, simple game structure. Player feedback has shown that even at this introduced level of simplicity, the amount of information contained can be at times overwhelming, further suggesting that simplicity in serious gaming is the only way to achieve holistic, systemic learning objectives in water. This simplicity has to be combined with smart – and easily understandable – presentation of information.

The consideration of motives and learning outcomes in every development step of a serious game is one of the key aspects of the Activity Theory-based Model of Serious Gaming, as was designed by Carvalho et al. (2015) and implicitly used throughout the development of this game. This conceptual model was used for the design of the AquaNES template and allowed the structuralized development of the serious game. By clearly distinguishing motives, goals and operations, the game could be designed accordingly from the high (motive) to the low (operational) levels, safeguarding the functionality and clarity of each level. The clarity of the concept was further reinforced by the positive player feedback from the two trial rounds. Further testing and evaluation is suggested to provide a more systematic, structured insight on the functioning of the game and the degree of achievement of desired outcomes.

4.3 Application beyond AquaNES

While the gaming approach described in this report is built based on the AquaNES sites and demonstrates the range of their cNES, the design of the game is simple and versatile enough to allow for the application of the game framework to different sites that potentially include other technologies beyond AquaNES. Versatility in the game allows the template to be replicated in different urban water management projects for instance by:

1. Changing the question types and question content, in order to appeal to wider – or narrower, more knowledgeable – audiences and target stakeholder groups.

2. Adding different sites to the board, along with different technologies, to reflect not necessarily cNES but a wider array of natural or engineered treatment systems in urban water.
3. Adding technological and management dimensions to the sites, such as flood protection or stormwater management tech chains – besides the treatment chains of drinking water and wastewater presented here.
4. Changing the site locations to allow localizations of the game, possibly in developing countries, in order to create an awareness tool that targets specific community groups and experts from these countries.
5. Creating variations of the game where collaboration is promoted against competition. An interesting spin-off concept would be to create a fully collaborative version of the game, where players are called to make the right decisions and future-proof treatment systems before severe challenge events happen – that will eventually lead to widespread system collapse across many sites. This game could be considered a version of collaborative urban water management against major shifts such as climate change.

The basic framework of the game, including the combination of explorative learning, collaboration and competitive elements, can be further expanded by adding (or changing) sites, technologies, trivia questions, and playing with the balance between trivia (questions) and actions (decisions on asset investments) through the game rules. Instead of its current intercontinental set up, the game could also be adapted to smaller scales to create a better understanding of e.g. regional site differences and potential measures taken within a single country. Moreover, also additional technologies, to expand or replace the range of optional measures, and challenges, to include for instance currently other factors of change, could be added. Finally, the factual learning throughout the game could be tailored to specific contexts by altering the Trivia questions.

Besides altering the game itself, the context in which the game is embedded can also be changed. As Chew et al. (2014) advised, serious gaming to be considered as part of a wider learning experience, careful consideration of other tools and methods used in compliance with the AquaNES serious game, could strengthen the learning outcomes achieved. The authors believe that a similar gaming template can be linked not only to cNES but to any integrated urban water management context, such as climate-proofing cities, building resilient urban environments, achieving circularity in water etc.

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Appendix 1

A1.1 Existing serious games in Water Management

Serious gaming has already been incorporated in different forms and with diverse functions in water management. To assess the state of the art in this field of study, we reviewed 17 different serious games applied in the water management sector. These included both computer-based and board-based games. Some of them were designed for the domain of river basin management, whilst others focussed on the water supply or flood management domain. In the following table (Table A1), the serious games related to water management that have been reviewed are presented, together with the application area the creator of the game and the user interface.

A1.2 Characteristics of serious games in water management

Analysing the characteristics of these serious games and their variations allows for understanding and classification of their function and usage. Discussing specific characteristics of games not only provides insights on what has been done by other serious game design groups, but also reveals which considerations were made in relation to these characteristics. Moreover, carefully observing serious games based on these characteristics also gives information input for our own game, as well as tools to evaluate it. Savic et al., (2016) offer a useful selection of the characteristics that can serve as criteria for classification of the serious games in water management. Based on a literature review they offer the following classification of characteristics that this study follows as well: application area (domain), goal of the game, initialisation of the game, number and type of players, user interface, simulation model used, realism of the game, performance feedback and game portability. In the following sections, the aforementioned classification is discussed, with regards to the pool of reviewed serious games for water (Table A1). To tailor these characteristics to the scope of this study, some characteristics are slightly modified to a broader perspective that includes both computer-based and board serious games.

Table A1: Overview of serious games in water management.

	Name	Created by	Application Area	User Interface
1	Aqua republica[1,2]	DHI and UNEP-DHI	river basin management	Computer-based
2	Shariva (Shared river)[1] game	Bots and van Daalen (2007)	river basin management	Computer-based
3	Valkering et al. and Van der Wal et al.[1,3]	Valkering et al. (2013) and Van der Wal et al. (2016)	river basin management	Computer-based
4	Stefanska et al.[1]	Stefanska et al. (2011)	flood management	Computer-board based
5	Irrigania[4]	Seibert and Vis (2012)	river basin management	Computer-based
6	WATERSTORY[5]	MEDB -Maui Economic Develeopment Board	water supply and demand management	Computer-based
7	SimDelta[6]	Rijcken et al. (2013)	river basin management and fresh water supply	Computer-based
8	IDT[7]	Hill et al. (2014)	river basin management	Computer-based
9	Ravilla	Rusca et al. (2012)	river basin management	Computer-

	Name	Created by	Application Area	User Interface
	simulation game[8]			based
10	River Basin Game[9]	Bruce Lankford, University of East Anglia	river basin management	Board-based
11	SeGWADE[1]	Dragan A. Savic, Mark S. Morley and Mehdi Khoury	water supply and demand management	Computer-based
12	NEXUS game[10]	Centre for Systems Solutions (CRS) and International Institute for Applies Systems Analysis (IIASA)	water supply and demand management	Computer-based
13	LORDS OF THE VALLEY THE BOARD GAME[11]	Centre for Systems Solutions (CRS)	river basin management	Board-based
14	FLOOD RESILIENCE GAME[12]	Centre for Systems Solutions (CRS) and International Institute for Applies Systems Analysis (IIASA)	flood management	Board-based
15	FLOOD CONTROL GAME[13]	iLab Flood Control	flood management	Computer-based
16	FLORIMA[14]	Delft university of Technology (TU Delft)	flood management	Board-based
17	FLOOD-WISE[15]	Play-Time and Hastijns	flood management	Board based

[1]Savic et al., 2016 [2]https://games4sustainability.org/gamepedia/aqua-republica/ [3]Van der Wal et al., 2016 [4]Seibert & Vis, 2012 [5]Bassi et al., 2015 [6]Rijcken et al., 2013 [7]Hill et al., 2014 [8]Rusca et al., 2012 [9]Lankford et al., 2004 [10]https://systemssolutions.org/social-simulations/nexus-game/ [11]https://systemssolutions.org/social-simulations/lords-of-the-valley-board-game/ [12] https://floodresilience.games4sustainability.org/#about-the-game [13]https://games4sustainability.org/gamepedia/flood-control-game/ [14]https://games4sustainability.org/gamepedia/florima/ [15]http://floodwise.nl/results/the-game/

A1.2.1 Motive and goal of the game

The first characteristic of importance is the motive of the game, which – as was already briefly described in section 1.1.3- refers to the desired outcomes of the game by the game developers. This could be increased public or stakeholder awareness, understanding, trust, willingness to participate, etc. (Carvalho et al., 2015). Besides these motives, one can identify different goals of the game, relating to the desired outcomes for participants (Carvalho et al., 2015).

A small number of the reviewed games have a specific goal that deals with a distinct part of water management, such as cost/yield maximization or water resources optimal allocation. Examples of games that do include this are *Irrigania,* which aims to show water conflicts among stakeholders in a more simplified way and in which the player needs to have the largest income at the end, and *SeGWADE,* in which the players need to find solutions on minimizing the costs of duplicated pipes[5]. However, most of the reviewed games focus on broader motives and try to combine management tasks, often by utilising cross-disciplinary or integrated concepts of water management such as Sustainable Water Resources Management (SWRS) or Integrated Water Management (IWM). These focal points

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[5] The references for the different games mentioned in these sections are found in Table 1.

reflect the more general motive to develop and upgrade knowledge, enhance understanding and improve multiple skills around water management related issues, rather than train a specific skill in the players.

For instance, *Aqua Republic* and *Shariva* aim to enhance awareness and build capacity on water related issues and challenges among the stakeholders, as well as to allow stakeholders to practise decision making on a basin level. The motive of *Aqua Republic* is mainly educative; it focuses on providing understanding of the ecosystem value and water resources, the existence of different perspectives among the stakeholders and finally, the importance of the ecosystem-based Integrated Water Resource Management (IWRM) approach. Similarly, *WATERSTORY* aspires to promote understanding of the relationships between the stakeholders and the complex domain of flood management by providing management options to various stakeholders. *SimDelta* desires to provide insights of the interactions between different scenarios, problems and solutions. *Valkering et al.* and *Van der Wal et al.* created a simulation game in order to find different options on adaptation strategies depending on different future scenarios in the Netherlands. More precisely, this game aims to an exploration of possible future river and policy management dynamics of the area. It gives insights for better no-regrets strategies, better timing of management and better adaptation roadmaps. The *Invitational Drought Tournament (IDT)* focuses on enhancing drought preparedness by calling the team to create the best management plan concerning the environmental, social and economic pillars. Of the models that rely on Integrated Water Management, *Ravilla* has the motive of promoting learning about (integrated) water management and its aspects using the case of Ra basin. The *River Basin Game* has as an aim to provide a better and mutual understanding on the level of water access and distribution, understanding on the benefits of the positions (upstream, downstream), as well as on experiencing water shortages.

In conclusion, there are varying motives in serious gaming, but the vast majority of games aim at enhancing general system understanding over more specific, context-bound learning. There are games designed to provide better knowledge, better understanding, to train, to enhance critical thinking, management skills or awareness around water related issues. Only very few games focus on specific traits of water management, restricted to the introduced game realm. Relating this to our own design aim, it can be deduced that having a simple concept that demonstrates and informs the player on multiple aspects of AquaNES sites (on a technological, environmental and social level) is preferred over having a site-specific game that focuses on particular technologies and/or quantitative tasks such as yield maximisation, process management, etc.

The aforementioned review on game motives implies that determining the motive (and goal) of a game is a crucial consideration in the development of a serious game and should be taken into account since the initial phase of the game design. Although versatile, motives can have a differentiating effect on the development and architecture of a game. Catalano et al. (2014) have also emphasized this in their *guidelines for effective design of serious games,* as they stress the impact of learning objectives on the suitability of other characteristics. Likewise, David and Sande (2006) emphasize the importance of a right motive as they highlight the difficulties experienced when designing a serious game. Games consists of multiple features and can provide various types of learning experiences. The more realism a game contains, the more complex it becomes and more difficult it is for the player to grasp underlying messages and thus motive. Especially in the domain of water management, there are topics that are significantly complex due to the large number of scenarios and challenges that can arise from the interplay of different physical dynamics, social sectors and governance actors. Consequently, the tendency of developers in this field is to insert multiple phenomena and scenarios as possible into the game. However, this can be troubling for the game itself and its outcomes (David & Sande, 2006).

Having a clear idea of the motives and learning outcomes of the game, as well as of the different game elements can result in successful facilitation of learning (Arnab et al., 2015). Additionally, each action incorporated into a game, should be designed to reach a specific learning goal and motive (intrinsic instructional activity) (Carvalho et al., 2015).

A1.2.2 Domain

The second characteristic of the serious game classification is related to the application area (domain) of water management that the game is applied in. Most of the games are applied in the domain of river basin management, such as *Aqua Republica, Shariva, Irrigania, Valkering et al.* and *Van der Wal et al. simulation, IDT, Ravilla* and *River Basin Game*. Moreover, there are games applied in the water supply and demand management domain, such as *WATERRSTORY, NEXUS* and *SeGWADE*. *Sim-Delta* game combines both river basin management and water supply management. There are also games applied on flood management domain, such as the work of *Stefanska et al., FLOOD-WISE, FLORIMA, FLOOD RESILIENCE and FLOOD CONTROL GAME* and a game on agriculture such as the *Lord of the Valley*. As mentioned before, the field of urban water management seems relatively underrepresented based on the pool of reviewed games. This lack of games in urban water management is also acknowledged by Savic et al., (2016). Having a game in this domain will therefore provide opportunities to explore often overlooked aspects of water management and contribute to a still developing field in serious gaming for water.

A1.2.3 Facilitator lead

Facilitator lead is another characteristic of the game, closely correlated with the structural simplicity and rules complexity. Some games may require a facilitator to explain the game and lead the players at the beginning and during the game, whereas others do not and are thus stand-alone products that can be self-learnt. Including the need for a facilitator lead in a game influences the way in which the game can be played independently (Savic et al., 2016). Carvelho et al. (2015) make a similar distinction between games that include or exclude a facilitator in their Action Theory-based model for Serious Gaming, only referring it more explicitly to the instruction provided by him/her. *Intrinsic instructed* games do not have a facilitator lead and the player is guided throughout the game using tips, help-messages and automatic assessment, while in an *extrinsic instructional* activity a facilitator provides the players with feedback and support before, during and after the game. Accordingly, Carvelho et al. (2015) argue, these types require different evaluation methods. Intrinsic instructed games can be analysed excluding the context in which the game is played, while in extrinsic instructed games the instructor can strongly influence the outcomes of the game and should therefore be included in the analysis. In the water management domain almost all of the serious games require a facilitator either to explain the game, or to serve as a referee during the game (extrinsic instruction).

A1.2.4 Number of players and level of interaction

Another characteristic that has been identified is the number of the players and level of interaction; this means that there is a division between games that require one player or multiple players and also a division between a game that the players play individually or in (collaborating or competing) groups. The former refers to whether or not the game can be played by one player. The latter one describes if players play together in a common board or computer game or individually. Advantages of a multi-player approach are that these games allow experiencing different roles and draw from the interaction among players that potentially act as different actors in the system. Multi-player games can contribute to creating an understanding of other stakeholders' interests and how to create 'win-win' situations.

These aspects can enable learning on the decision-making processes at hand (Chew et al., 2014). Single player games, however, are in principle more easy to implement there is no need for a group to play it, and might foster individual learning experiences. Choosing between individual (competitive) versus group (collaborative) games, can also be dictated by the defined goals of the game. Individual goals are known to spark intrinsic motivation (as players have more freedom of action) (Wouters et al., 2013), whilst collaborative games foster stakeholder collaboration (Medema et al., 2016) during complex tasks and objectives.

During the literature review, games that belonged to all of the aforementioned categories were identified. There are games that can be played by a single player (individual plays), such as *Aqua Republica* and *SeGWADE*. In these games the player is called to make the best management solutions. In *Aqua Republica*, specifically, the player has a black canvas, which represents the real world and needs to be shaped according to the information he gets. It is his responsibility to maintain the balance of the natural environment, while the better he does it, the more points he gets. Similarly, in *SeGWADE*, the player has to find a solution to combine an adequate distribution system with the least cost. In the *Lord of the Valley*, there are four players playing individually (not in groups but competitively). However, most of the games are played by multiple players who interact with each other like in *FLORIMA* and *Flood Resilience Game*. A notable example of a multi-player environment is the *River Basin Game* which can be played by 50 people at once. The affinity of water-oriented serious games with multiplayer settings can be perhaps attributed to the nature of water management issues, where system complexity is high, the actions of specific users affect the rest of the group and multiple different actors are needed to act in a collaborative fashion to reach a goal.

A1.2.5 Role of the player

The role of the player is another characteristic that can be used as a criterion of classification; there can be cases where there is one role or multiple player roles in the game. The inclusion of different roles in a game is recognized to contribute to experiential engagement of the learner and active knowledge building throughout the game (Catalano et al., 2014). There are simulation games in which a role playing is necessary and is useful for sharing knowledge, interests and concerns regarding a water related issue. Via these games, players are able to learn how to deal with water conflicts and challenges. The role can be the same, such as in *Irrigania* and *the Lord of the Valley*, the players take the role of the farmers; in the first one, each farmer takes a different village and they are responsible to make the best decision, on how they are going to use the fields, in order to get the largest net-income. In *Stefanska*, there are multiple roles such as farmers, local authorities and water authorities, there is a different spatial influence and different conflicting objectives. In this game the differences among the interest are much larger and environmental issues may conflict more with economic interests. Therefore, it requires a good conflict resolution strategy. *WATERSTORY* consists of water professionals, business experts, farmers, landowners, conservation groups who try to find policy options by analyzing the environmental and socio-economic impacts across the sectors. In *Valkering et al.* and *Van der Wal et al* simulation, the case is the Rhine delta and the players are multiple and divided in two stakeholder teams. Therefore, the stakeholders (both teams) concerning of all these objectives (different interests and perspectives) and factors should collaborate and negotiate and end up with the minimization of the impacts and the best adaptation pathways. In *Invitational Drought Tournament (IDT)*, the team needs to create a management plan, which is suitable for the drought scenario and diminishes all the possible socio-economic and environmental impacts on the river basin. *Ravilla* encompasses different scales among the roles of actors (e.g low, medium, large scale farmers) and three different institutional settings (level of (de)centralization, involvement of private sector, level of cost recovery etc.), which are useful in order to understand the different management requirements that these differences cause. *River Basin Game* is used as a role-playing dialogue tool among the decision-makers and water users.

A1.2.6 Target group

The target group of the players is also an important characteristic. This determines to a great extent on how the game is going to be formulated. There are games that can be played by many different stakeholders, such as administrations, local communities, policy makers, business people, NGOs, children and youth. This variety of players can be found in games such as *Aqua Republica*, *Stefanska* and *River Basin Game*. However, there are games that have a specific target group or that require specific prior knowledge from the players; for example, *SeGWADE*'s target group is post-graduated engineering students, *Valkering et al.* and *Van der Wal et al* simulation's target group is Dutch water managers and academics, *IDT*'s is graduate students, water stakeholders and water managers and *Ravilla*'s UNESCO-IHE students. These requirements from the players also correlate with the motive of the game (i.e. whether to inform and raise awareness on the general public or to support learning for a specific stakeholder group), but also with the game complexity (i.e. games addressed to the general public should be simple and understandable by everyone, while games that target specific groups can have more elaborate rules that focus on specific water system functions).

A1.2.7 Interface

There are three interface types of serious games: those that are board-based, those that are computer-based (digital) and those that are hybrid (combined). Most common are the digital games; from the reviewed pool, the only board-based games are the *River Basin Game, Flood Resilience* and the *Lord of the Valley*. A combined game by *Stefanska et al.* was also reviewed. Board games and computer games may have similar goals, however their design mechanics are very different, with each type having different challenges (Silverman, 2013). The selection of interface influences also the accessibility of the games, as for instance Chew et al. (2014) recognize the importance of the development of also an offline version of *Aqua Republica* to foster its distribution also in areas where internet access is limited.

A1.2.8 Simulation model

Another criterion for classifying a serious game is to determine if it uses a simulation model or not. Simulation modelling is a computer-based approach which mimics real system response by using a mathematical simplification (model) and is used for to support decision-making in complex systems. Serious games in water frequently rely on simulation modelling to enhance their capabilities in systems representation, and there are therefore many types of tools used for simulations in serious games in water management sector. Savic et al. (2016) observe a correlation between the high occurrence of computer-based serious games (instead of board-game environments) for water and the extensive use of simulation modelling in serious gaming, which stems from the affinity of the water sector for simulation-based decision support and the existence of many readily available water system models. The main benefit of including a form of simulation into a game is the direct feedback it can provide and the indication of consequences (Savic et al., 206; Catalano et al., 2014). For example, *Aqua Republica* uses the MIKE HYDRO Basin model, a water allocation model which provides results and information to the player about his decisions. An integrated meta-model is responsible for showing the cause-effect relations regarding the climate change and the socio-economic development of each scenario in *Valkering et al.* and *Van der Wal et al.* simulation. *WATERSTORY* uses a System Dynamics model to show the performance of implemented policies and how to resolve any potential conflicts. This model is able to provide two simulation modes (simple and advanced) in order to engage stakeholders to different levels of technical expertise. *Shariva*, for instance, uses a hydrodynamic simulation model which assesses the policy implementations and their consequences. Moreover, *SeGWADE* uses a model (EPANET) which simulates the hydraulic characteristics of the water distribution system. Finally, there are individual models linked together into the SimDelta Model.

A1.2.9 Realism

Serious games can be classified depending on the realism of the game. This can be translated as the level of simplification at which the socio-technical-environmental system is illustrated (Savic et al., 2016). As serious games are known to provide a rich experience in a gamified environment, the realism of a game can contribute to reaching this (Catalano et al., 2014). However, sometimes a game is intentionally designed to be simplified and not entirely realistic, in order to avoid needless complexities of the real system, as well as large learning curves and confusion in the players. Such games are *Irrigania* and *WATERSTORY* and partly *SeGWADE*. Yet, there are also serious games designed to be realistic and to reflect the real complexity and issues of a water system, using real data, factors and possible scenarios, such as *Aqua Republica*, *Shariva, Valkering et al.* and *Van der Wal et al.* simulation, *Stefanska et al, IDT* and *Ravilla*. Catalano et al. (2014) observe that a high level of realism of a game can contribute to the involvement of players and the level to which they feel touched by the game. Nonetheless, realism is a double-edged sword as it can also contribute to increased game complexity, a low degree of user friendliness and complicated rule sets that lead to low desire to play the game.

A1.2.10 Correspondence with real cases

Another characteristic, linked to the previous one mentioned, is the extent to which the game is based on an actual case study. Although not mentioned by Savic et al. (2016) this characteristic is added as it potentially influences the identification of participants with aspects of the game. There are games that are created based on an actual case such as *Valkering et al.*, *Van der Wal et al* simulation, *WATERSTORY* and *Ravilla*. Creating a game based on a case study instead of a hypothetical system can be easier, as the basic goals and challenges of the case and the area are well-determined and perhaps more clear and intuitive to players. However, it can also be challenging as the introduction of simplifications necessary to create the game might not properly represent reality as participants know it, thus causing confusion in the players.

A1.2.11 Performance feedback

The performance feedback is another characteristic of the serious games which determines if, how and when players can get a feedback for their answers. This characteristic potentially influences participants engagement and enthusiasm, as constant feedback throughout the game allows for experiential learning (Catalano et al., 2014). Firstly, there are games that do not include feedback, such as *WATERSTORY*, *SimDelta* and *IDT*. In *IDT* for instance, feedback is not included because there is a voting process for the best management plan among the teams. However, most of the games provide feedback either via the model or via a facilitator. There are some games that indicate evaluation before feedback, such as *Aqua Republica, Shariva, Stefanska* and *Valkering et al.* and *Van der Wal et al.* simulation, while others that give feedback after finishing the game, such as *Irrigania, Ravilla* and *SeGWADE*. A characteristic example is the case of *Ravilla*, which by providing feedback at the end, gives the opportunity to the players to rethink and reformulate their management plan. It uses a trial-error approach from which the players learn from previous decisions.

A1.2.12 Progress monitoring

Another useful characteristic is the progress monitoring, which presents the capability of the game to save the results of the game. This is a characteristic intrinsically close to computer-based games that, however, can appear in board games that can be with repetitions as well, such as Gloomhaven (Wildman & Woodward, 2018). Most of the games reviewed are not capable of saving the results, however, *SeGWADE* is one of the few games which allows the player to save his results.

A1.2.13 Portability

Finally, another characteristic of the serious games is the portability, which defines whether the game has to be played online (e.g. through a server or internet access) or not. In a more general context, this characteristic describes the extent to which a game can be played outside a controlled and facilitated setting. In general, *Irrigania*, is the only game that can be played online by anyone who registers. *Aqua Republica, SimDelta* and *SeGWADE* can be also be played online, however, under supervision of a facilitator. Other games can mainly be played offline. By definition, most board games – with the exception of hybrid games that have computer-based supplements – can be played offline.

Appendix 2

A2.1 Examples of trivia questions

Society:

The population of the world in 1950 was about 2.6 billion. The world population is currently about:

a) 3.4 billion
b) 7.2 billion
c) 9.3 billion
d) 11.5 billion

Normal monsoons have a positive economic effect and correlate with a booming economy

a) True

b) False

Urban sprawl is best defined as:

a) The rapid spread of urban areas into surrounding suburbs and rural areas
b) The rise of very high buildings (e.g. skyscrapers) within the city
c) The breakdown of infrastructure within cities
d) Air pollution caused by factories

The percentage of people without access to safe and sustainable clean water sources that live in **rural** areas is:
a) 50%
b) 30%
c) 70%
d) 80%

Approximately how many primary schools around the world do not have access to safe drinking water?

a) Three in seven
b) One in 100
c) One in four
d) One in twelve

Climate and Environment:

Which is the economic sector that leads to the largest greenhouse gas emissions and thus climate change?

a) Electricity and Heat Production
b) Transportation
c) Agriculture, Forestry and other Land Use activities
d) Industry

The largest contributor to greenhouse gas emissions in recorded history is:

a.) China
b.) EU countries (EU-28)
c.) the United States
d.) India
e.) U.S.S.R and Russia

What is the ecosystem living in salty soil that is flooded and exposed by alternating tides found along the shores of oceans, bays and rivers in tropical and subtropical areas?

a) riparian forest
b) freshwater marsh
c) salt marsh
d) mangrove forest

Which is the driest month in Antiparos and Thirasia in Greece?

a) May
b) June
c) July
d) August

Which of the following options is not regarded as a climate adaptation measure?

a) Alternative crop use
b) Rainwater harvesting and water conservation
c) Cyclone resistant houses
d) Renewable energy

Water:

How much percent of the world's water is available for human use?

a) Less than 1%
b) 3%
c) 5%
d) 10%

What is a combined sewer?

a) A spot where a lot of different sized sewer lines combine together and go into a combined sewer
b) A mixture of different pipe sizes
c) A sewer that receives both sanitary sewage and storm water
d) A pipe made of concrete and plastic

Rainwater that flows over the land and into streams and lakes, often picking up soil particles along the way, is called what?

a) runoff
b) sediment carrier
c) groundwater
d) blue stream

What is the name for the wastewater generated by domestic uses that is heavy in organic material (e.g. BOD), such as toilet water?

a) Blue water
b) Green water
c) Black water
d) Grey water

Which product requires the largest amount of water to be produced?

a) 1 microchip
b) 1 cotton t-shirt
c) 1 hamburger
d) 1 cup of coffee

Technology:

Which one of the following practices is considered Direct Potable Reuse?

a) Introducing treated wastewater into a groundwater source (aquifer).
b) Using Reverse Osmosis to provide drinking water from a saline source.
c) Introducing treated wastewater into the drinking water treatment plant.
d) Treating rainwater to provide potable water.

How much of the total energy consumption of drinking water is due to pumping and distribution (instead of actual treatment)?
a) 40%
b) 80%
c) 60%
d) 50%

Which one of the following is NOT a natural treatment system?

a) Settling tank
b) Bank Filtration
c) Aquifer Recharge
d) Constructed Wetlands

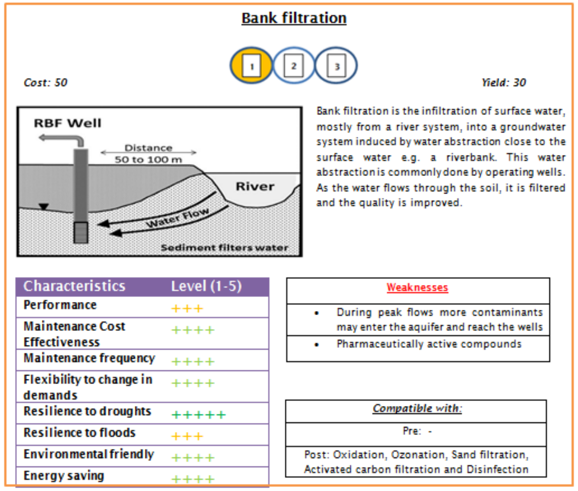
Which of the following processes uses an underground source as the recipient of treatment?
a) Bank Filtration
b) Aquifer Recharge
c) Constructed Wetlands
d) Settling Tank

Oxidation processes are most commonly used in water treatment to:

a) Remove inorganic material
b) Remove organic material
c) Remove fine sediments in water
d) Fully treat water as an integrated measure

A2.2 System cards designed for the serious game

Natural Systems



Bank filtration

Cost: 50

Yield: 30

Bank filtration is the infiltration of surface water, mostly from a river system, into a groundwater system induced by water abstraction close to the surface water e.g. a riverbank. This water abstraction is commonly done by operating wells. As the water flows through the soil, it is filtered and the quality is improved.

Characteristics	Level (1-5)
Performance	+++
Maintenance Cost Effectiveness	++++
Maintenance frequency	++++
Flexibility to change in demands	++++
Resilience to droughts	+++++
Resilience to floods	+++
Environmental friendly	++++
Energy saving	++++

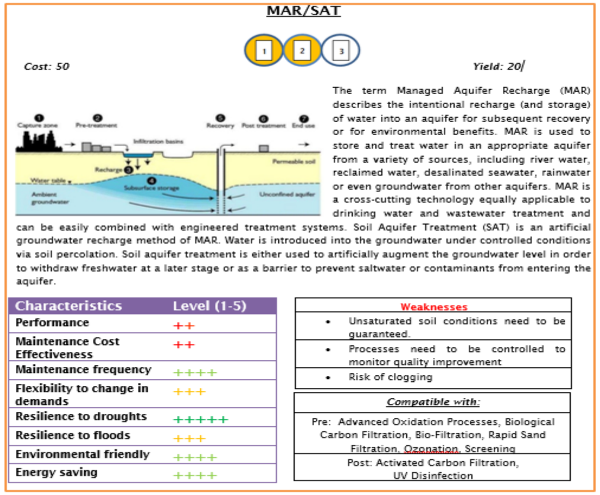
Weaknesses

- During peak flows more contaminants may enter the aquifer and reach the wells
- Pharmaceutically active compounds

Compatible with:

Pre: -

Post: Oxidation, Ozonation, Sand filtration, Activated carbon filtration and Disinfection



MAR/SAT

Cost: 50

Yield: 20

The term Managed Aquifer Recharge (MAR) describes the intentional recharge (and storage) of water into an aquifer for subsequent recovery or for environmental benefits. MAR is used to store and treat water in an appropriate aquifer from a variety of sources, including river water, reclaimed water, desalinated seawater, rainwater or even groundwater from other aquifers. MAR is a cross-cutting technology equally applicable to drinking water and wastewater treatment and can be easily combined with engineered treatment systems. Soil Aquifer Treatment (SAT) is an artificial groundwater recharge method of MAR. Water is introduced into the groundwater under controlled conditions via soil percolation. Soil aquifer treatment is either used to artificially augment the groundwater level in order to withdraw freshwater at a later stage or as a barrier to prevent saltwater or contaminants from entering the aquifer.

Characteristics	Level (1-5)
Performance	++
Maintenance Cost Effectiveness	++
Maintenance frequency	++++
Flexibility to change in demands	+++
Resilience to droughts	+++++
Resilience to floods	+++
Environmental friendly	++++
Energy saving	++++

Weaknesses

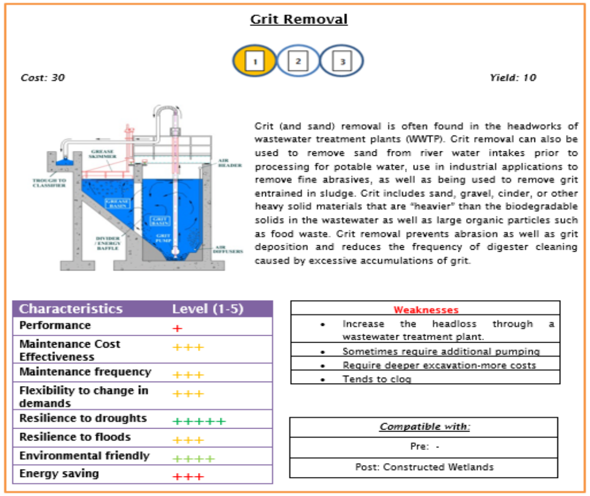
- Unsaturated soil conditions need to be guaranteed.
- Processes need to be controlled to monitor quality improvement
- Risk of clogging

Compatible with:

Pre: Advanced Oxidation Processes, Biological Carbon Filtration, Bio-Filtration, Rapid Sand Filtration, Ozonation, Screening

Post: Activated Carbon Filtration, UV Disinfection

Pretreatment Options



Grit Removal

Cost: 30

Yield: 10

Grit (and sand) removal is often found in the headworks of wastewater treatment plants (WWTP). Grit removal can also be used to remove sand from river water intakes prior to processing for potable water, use in industrial applications to remove fine abrasives, as well as being used to remove grit entrained in sludge. Grit includes sand, gravel, cinder, or other heavy solid materials that are "heavier" than the biodegradable solids in the wastewater as well as large organic particles such as food waste. Grit removal prevents abrasion as well as grit deposition and reduces the frequency of digester cleaning caused by excessive accumulations of grit.

Characteristics	Level (1-5)
Performance	+
Maintenance Cost Effectiveness	+++
Maintenance frequency	+++
Flexibility to change in demands	+++
Resilience to droughts	+++++
Resilience to floods	+++
Environmental friendly	++++
Energy saving	+++

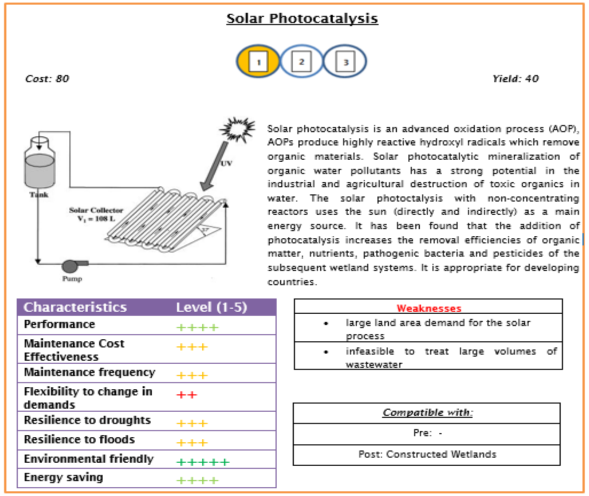
Weaknesses

- Increase the headloss through a wastewater treatment plant.
- Sometimes require additional pumping
- Require deeper excavation-more costs
- Tends to clog

Compatible with:

Pre: -

Post: Constructed Wetlands



Solar Photocatalysis

Cost: 80

Yield: 40

Solar photocatalysis is an advanced oxidation process (AOP), AOPs produce highly reactive hydroxyl radicals which remove organic materials. Solar photocatalytic mineralization of organic water pollutants has a strong potential in the industrial and agricultural destruction of toxic organics in water. The solar photoctalysis with non-concentrating reactors uses the sun (directly and indirectly) as a main energy source. It has been found that the addition of photocatalysis increases the removal efficiencies of organic matter, nutrients, pathogenic bacteria and pesticides of the subsequent wetland systems. It is appropriate for developing countries.

Characteristics	Level (1-5)
Performance	++++
Maintenance Cost Effectiveness	+++
Maintenance frequency	+++
Flexibility to change in demands	++
Resilience to droughts	+++
Resilience to floods	+++
Environmental friendly	+++++
Energy saving	++++

Weaknesses

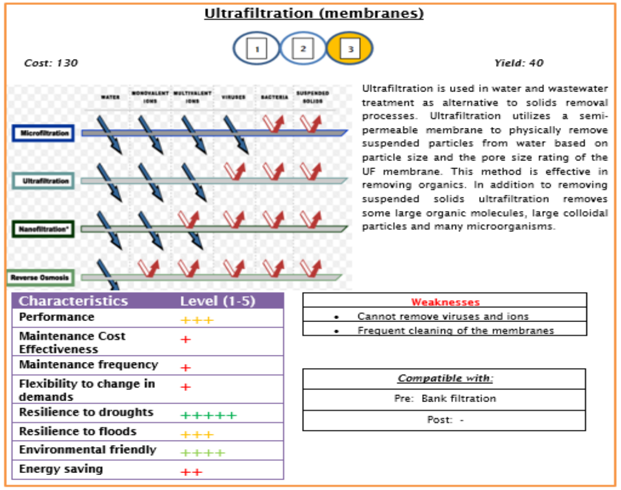
- large land area demand for the solar process
- infeasible to treat large volumes of wastewater

Compatible with:

Pre: -

Post: Constructed Wetlands

Post-Treatment Options



Ultrafiltration (membranes)

Cost: 130

Yield: 40

Ultrafiltration is used in water and wastewater treatment as alternative to solids removal processes. Ultrafiltration utilizes a semi-permeable membrane to physically remove suspended particles from water based on particle size and the pore size rating of the UF membrane. This method is effective in removing organics. In addition to removing suspended solids ultrafiltration removes some large organic molecules, large colloidal particles and many microorganisms.

Characteristics	Level (1-5)
Performance	+++
Maintenance Cost Effectiveness	+
Maintenance frequency	+
Flexibility to change in demands	+
Resilience to droughts	+++++
Resilience to floods	+++
Environmental friendly	++++
Energy saving	++

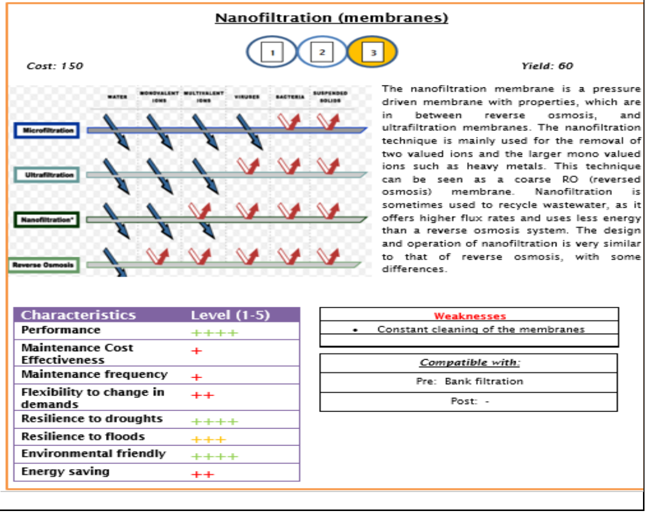
Weaknesses

- Cannot remove viruses and ions
- Frequent cleaning of the membranes

Compatible with:

Pre: Bank filtration

Post: -



Nanofiltration (membranes)

Cost: 150

Yield: 60

The nanofiltration membrane is a pressure driven membrane with properties, which are in between reverse osmosis, and ultrafiltration membranes. The nanofiltration technique is mainly used for the removal of two valued ions and the larger mono valued ions such as heavy metals. This technique can be seen as a coarse RO (reversed osmosis) membrane. Nanofiltration is sometimes used to recycle wastewater, as it offers higher flux rates and uses less energy than a reverse osmosis system. The design and operation of nanofiltration is very similar to that of reverse osmosis, with some differences.

Characteristics	Level (1-5)
Performance	++++
Maintenance Cost Effectiveness	+
Maintenance frequency	+
Flexibility to change in demands	++
Resilience to droughts	++++
Resilience to floods	+++
Environmental friendly	++++
Energy saving	++

Weaknesses

- Constant cleaning of the membranes

Compatible with:

Pre: Bank filtration

Post: -

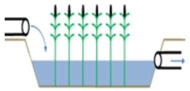
Natural Systems

Constructed Surface Flow Wetland

1 2 3

Cost: 50

Yield: 30



Constructed wetlands (CWs) - also called "reed beds"- are natural wastewater treatment technologies. They are shallow basins filled with filter material (substrate), usually sand or gravel, and planted wetland vegetation. Wastewater is introduced into the basin, flows over the surface, and is discharged out of the basin. Pollutants are removed by several complex physical, chemical and biological processes. Vegetation plays a vital role in the treatment, as it provides surfaces and a suitable environment for microbial growth and filtration.

Characteristics	Level (1-5)
Performance	+++
Maintenance Cost Effectiveness	+++
Maintenance frequency	++++
Flexibility to change in demands	++
Resilience to droughts	+
Resilience to floods	++
Environmental friendly	+++++
Energy saving	+++++

Weaknesses

- Requires large areas
- Sensitive to toxic chemicals
- Not survival in complete drought
- Requires pre or post treatment

Compatible with:

Pre: BCF, Grit removal, Ozonation, Screening, Solar photocatalysis

Post: Chlorination, Ultrafiltration

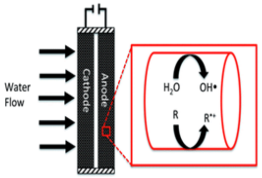
Pretreatment Options

Advanced Oxidation

1 2 3

Cost: 120

Yield: 50



AOP is a disinfection method which treats well hazardous waste by industrial, military and domestic sources. AOPs are a set of processes involving the production of very reactive oxygen species able to destroy a wide range of organic compounds. AOPs are driven by external energy sources such as electric power, ultraviolet radiation (UV) or solar light, so these processes are often more expensive than conventional biological wastewater treatment. It is adaptable to small and big.

Characteristics	Level (1-5)
Performance	++++
Maintenance Cost Effectiveness	++
Maintenance frequency	+++
Flexibility to change in demands	++++
Resilience to droughts	++
Resilience to floods	+++
Environmental friendly	+++
Energy saving	++

Weaknesses

- Relatively high operation costs due to chemicals and/or energy input.

Compatible with:

Pre: Bank filtration

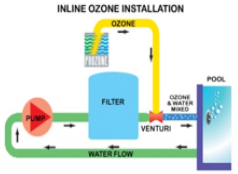
Post: MAR/SAT, Constructed Wetlands

Ozonation

1 2 3

Cost: 170

Yield: 60



Ozone eliminates bacteria, viruses and other organic and inorganic contaminants. It is efficient in degrading organic pollutants leaving more biodegradable products and hence reducing the amount of micropollutants. It reduces levels of dangerous chemicals such as chlorine and aids in the removal of minerals such as iron and manganese. Furthermore ozone can oxidize metallic ions that can be easily separated from water by filtration or sedimentation. It provides an alternative to oxidation with chlorine, absorption (activated carbon) or other separation processes (membrane technology).

Characteristics	Level (1-5)
Performance	++++
Maintenance Cost Effectiveness	++++
Maintenance frequency	+++
Flexibility to change in demands	+++
Resilience to droughts	+++
Resilience to floods	+++
Environmental friendly	++
Energy saving	+

Weaknesses

- Formation of potentially harmful disinfection by-products (DBPs) in the case of brome existence in water
- Potential fire hazard and toxicity associated with ozone generation

Compatible with:

Pre: Bank filtration

Post: MAR/SAT, Constructed Wetlands

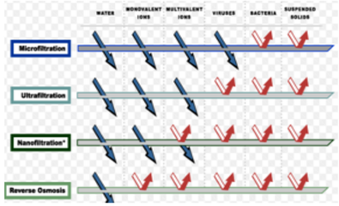
Post-Treatment Options

Reverse Osmosis (membranes)

1 2 3

Cost: 180

Yield: 80



Reverse osmosis can remove many types of dissolved and suspended species from water, including bacteria, and is used in both industrial processes and the production of potable water. It is also one of the methods used to remove the salt from seawater. The result is that the solute is retained on the pressurized side of the membrane and the pure solvent is allowed to pass to the other side. In water reuse applications reverse osmosis is used for the removal of dissolved constituents remaining in wastewater after advanced treatment. Sometimes may requires pre-treatment (depends on the case).

Characteristics	Level (1-5)
Performance	+++++
Maintenance Cost Effectiveness	+
Maintenance frequency	+
Flexibility to change in demands	+
Resilience to droughts	+++
Resilience to floods	+++
Environmental friendly	+++
Energy saving	+

Weaknesses

- Requires good quality of water
- Very large energy consumption

Compatible with:

Pre: Bank filtration

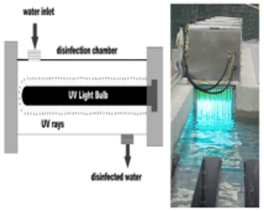
Post: -

UV Disinfection

1 2 3

Cost: 130

Yield: 50



Ultraviolet (UV) rays are part of the light that comes from the sun. UV is known to be an effective disinfectant due to its strong germicidal (inactivating) ability. UV disinfects water containing bacteria and viruses and can be effective against protozoans. Prefiltration is required to remove color, turbidity, and particles that shield microorganisms from the UV source.

Characteristics	Level (1-5)
Performance	+++++
Maintenance Cost Effectiveness	+++
Maintenance frequency	+
Flexibility to change in demands	++
Resilience to droughts	++++
Resilience to floods	+++
Environmental friendly	++++
Energy saving	++

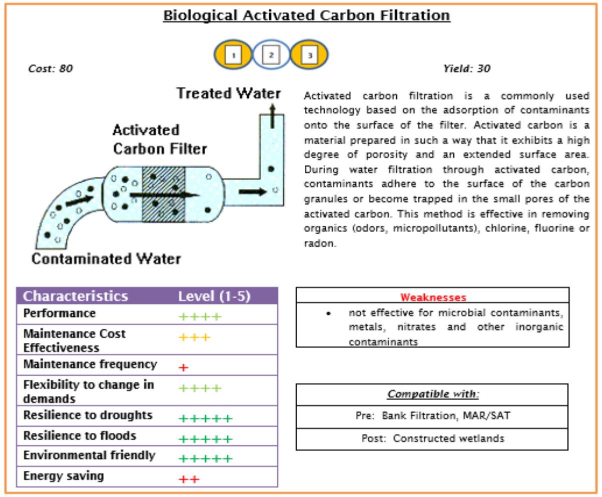
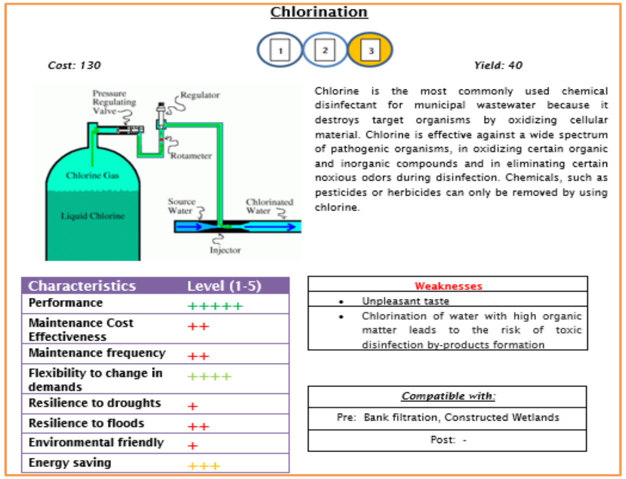
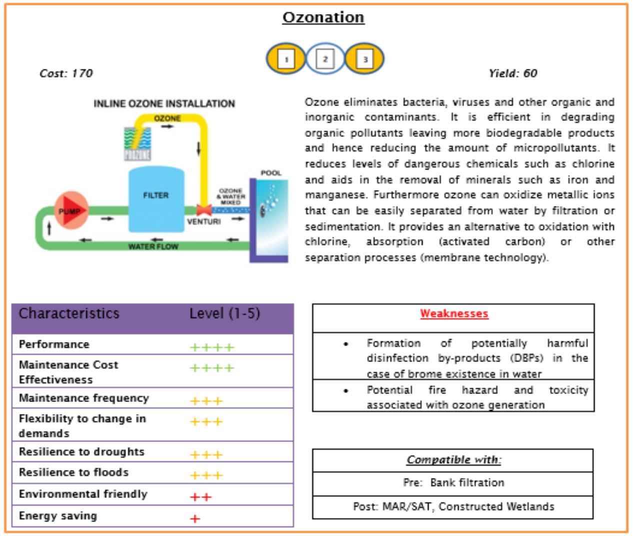
Weaknesses

- A new lamp can lose 20 percent of its intensity within the first 100 hours of operation
- Requires pretreatment

Compatible with:

Pre: Bank filtration, MAR/SAT

Post: -

Natural Systems	Pretreatment Options	Post-Treatment Options
		
		

Biological Activated Carbon Filtration

Cost: 80

1 2 3

Yield: 30

Activated carbon filtration is a commonly used technology based on the adsorption of contaminants onto the surface of the filter. Activated carbon is a material prepared in such a way that it exhibits a high degree of porosity and an extended surface area. During water filtration through activated carbon, contaminants adhere to the surface of the carbon granules or become trapped in the small pores of the activated carbon. This method is effective in removing organics (odors, micropollutants), chlorine, fluorine or radon.

Characteristics	Level (1-5)
Performance	++++
Maintenance Cost Effectiveness	+++
Maintenance frequency	+
Flexibility to change in demands	++++
Resilience to droughts	+++++
Resilience to floods	+++++
Environmental friendly	+++++
Energy saving	++

Weaknesses

- not effective for microbial contaminants, metals, nitrates and other inorganic contaminants

Compatible with:

Pre: Bank Filtration, MAR/SAT

Post: Constructed wetlands

Chlorination

Cost: 130

1 2 3

Yield: 40

Chlorine is the most commonly used chemical disinfectant for municipal wastewater because it destroys target organisms by oxidizing cellular material. Chlorine is effective against a wide spectrum of pathogenic organisms, in oxidizing certain organic and inorganic compounds and in eliminating certain noxious odors during disinfection. Chemicals, such as pesticides or herbicides can only be removed by using chlorine.

Characteristics	Level (1-5)
Performance	+++++
Maintenance Cost Effectiveness	++
Maintenance frequency	++
Flexibility to change in demands	++++
Resilience to droughts	+
Resilience to floods	++
Environmental friendly	+
Energy saving	+++

Weaknesses

- Unpleasant taste
- Chlorination of water with high organic matter leads to the risk of toxic disinfection by-products formation

Compatible with:

Pre: Bank filtration, Constructed Wetlands

Post: -

Ozonation

Cost: 170

1 2 3

Yield: 60

Ozone eliminates bacteria, viruses and other organic and inorganic contaminants. It is efficient in degrading organic pollutants leaving more biodegradable products and hence reducing the amount of micropollutants. It reduces levels of dangerous chemicals such as chlorine and aids in the removal of minerals such as iron and manganese. Furthermore ozone can oxidize metallic ions that can be easily separated from water by filtration or sedimentation. It provides an alternative to oxidation with chlorine, absorption (activated carbon) or other separation processes (membrane technology).

Characteristics	Level (1-5)
Performance	++++
Maintenance Cost Effectiveness	++++
Maintenance frequency	+++
Flexibility to change in demands	+++
Resilience to droughts	+++
Resilience to floods	+++
Environmental friendly	++
Energy saving	+

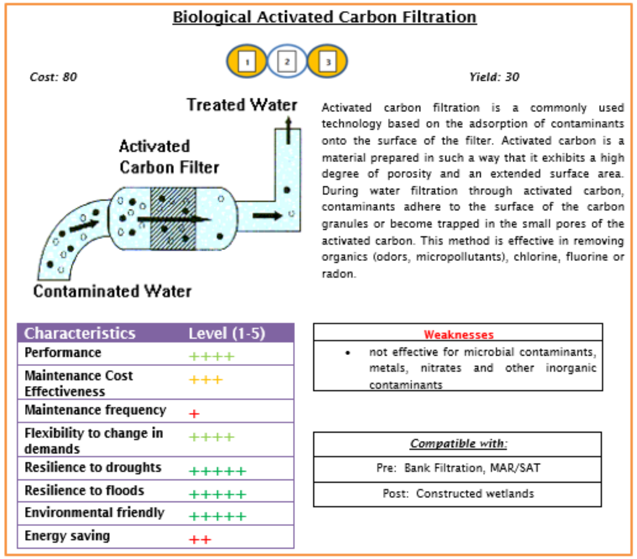
Weaknesses

- Formation of potentially harmful disinfection by-products (DBPs) in the case of brome existence in water
- Potential fire hazard and toxicity associated with ozone generation

Compatible with:

Pre: Bank filtration

Post: MAR/SAT, Constructed Wetlands

Natural Systems	Pretreatment Options	Post-Treatment Options
		

Biological Activated Carbon Filtration

1 2 3

Cost: 80

Yield: 30

Activated carbon filtration is a commonly used technology based on the adsorption of contaminants onto the surface of the filter. Activated carbon is a material prepared in such a way that it exhibits a high degree of porosity and an extended surface area. During water filtration through activated carbon, contaminants adhere to the surface of the carbon granules or become trapped in the small pores of the activated carbon. This method is effective in removing organics (odors, micropollutants), chlorine, fluorine or radon.

Characteristics	Level (1-5)
Performance	++++
Maintenance Cost Effectiveness	+++
Maintenance frequency	+
Flexibility to change in demands	++++
Resilience to droughts	+++++
Resilience to floods	+++++
Environmental friendly	+++++
Energy saving	++

Weaknesses
• not effective for microbial contaminants, metals, nitrates and other inorganic contaminants

Compatible with:
Pre: Bank Filtration, MAR/SAT
Post: Constructed wetlands

AquaNES Super Cards

<table>
<tr><th>Drinking Water</th><th>Wastewater</th></tr>
<tr>
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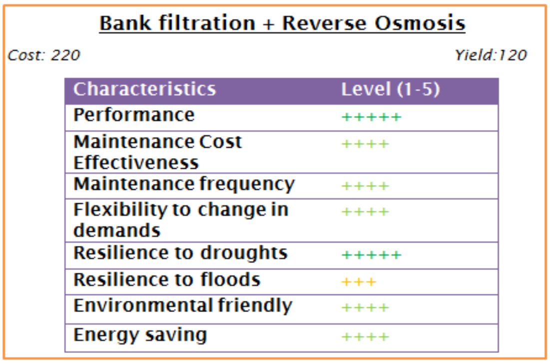
Bank filtration + Reverse Osmosis
Cost: 220 Yield:120
<table>
<tr><th>Characteristics</th><th>Level (1-5)</th></tr>
<tr><td>Performance</td><td>+++++</td></tr>
<tr><td>Maintenance Cost Effectiveness</td><td>++++</td></tr>
<tr><td>Maintenance frequency</td><td>++++</td></tr>
<tr><td>Flexibility to change in demands</td><td>++++</td></tr>
<tr><td>Resilience to droughts</td><td>+++++</td></tr>
<tr><td>Resilience to floods</td><td>+++</td></tr>
<tr><td>Environmental friendly</td><td>++++</td></tr>
<tr><td>Energy saving</td><td>++++</td></tr>
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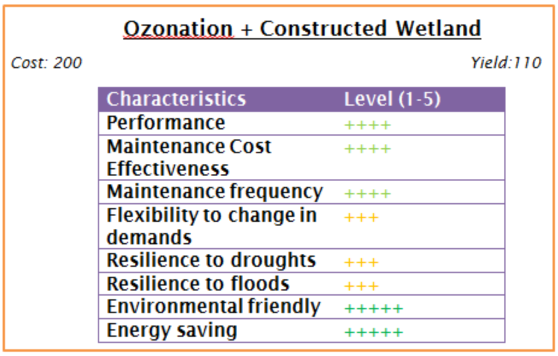
Ozonation + Constructed Wetland
Cost: 200 Yield:110
<table>
<tr><th>Characteristics</th><th>Level (1-5)</th></tr>
<tr><td>Performance</td><td>++++</td></tr>
<tr><td>Maintenance Cost Effectiveness</td><td>++++</td></tr>
<tr><td>Maintenance frequency</td><td>++++</td></tr>
<tr><td>Flexibility to change in demands</td><td>+++</td></tr>
<tr><td>Resilience to droughts</td><td>+++</td></tr>
<tr><td>Resilience to floods</td><td>+++</td></tr>
<tr><td>Environmental friendly</td><td>+++++</td></tr>
<tr><td>Energy saving</td><td>+++++</td></tr>
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</tr>
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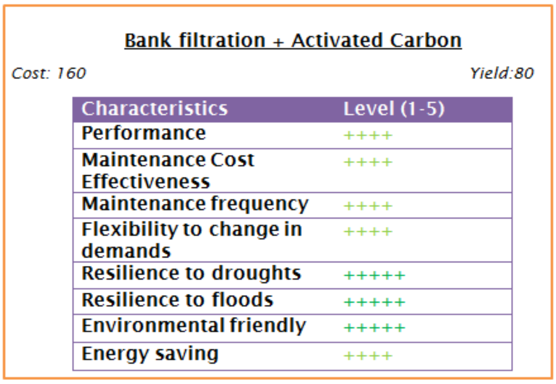
Bank filtration + Activated Carbon
Cost: 160 Yield:80
<table>
<tr><th>Characteristics</th><th>Level (1-5)</th></tr>
<tr><td>Performance</td><td>++++</td></tr>
<tr><td>Maintenance Cost Effectiveness</td><td>++++</td></tr>
<tr><td>Maintenance frequency</td><td>++++</td></tr>
<tr><td>Flexibility to change in demands</td><td>++++</td></tr>
<tr><td>Resilience to droughts</td><td>+++++</td></tr>
<tr><td>Resilience to floods</td><td>+++++</td></tr>
<tr><td>Environmental friendly</td><td>+++++</td></tr>
<tr><td>Energy saving</td><td>++++</td></tr>
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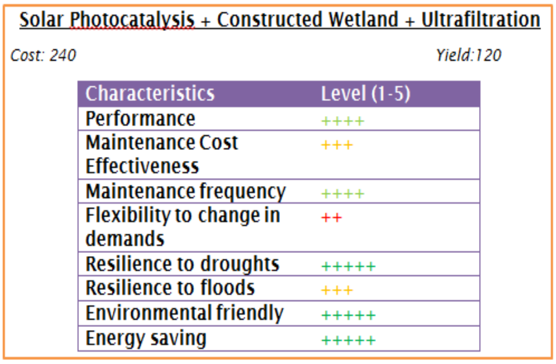
Solar Photocatalysis + Constructed Wetland + Ultrafiltration
Cost: 240 Yield:120
<table>
<tr><th>Characteristics</th><th>Level (1-5)</th></tr>
<tr><td>Performance</td><td>++++</td></tr>
<tr><td>Maintenance Cost Effectiveness</td><td>+++</td></tr>
<tr><td>Maintenance frequency</td><td>++++</td></tr>
<tr><td>Flexibility to change in demands</td><td>++</td></tr>
<tr><td>Resilience to droughts</td><td>+++++</td></tr>
<tr><td>Resilience to floods</td><td>+++</td></tr>
<tr><td>Environmental friendly</td><td>+++++</td></tr>
<tr><td>Energy saving</td><td>+++++</td></tr>
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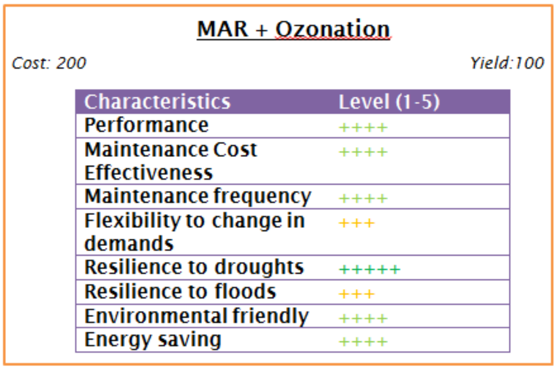

MAR + Ozonation
Cost: 200 Yield:100
<table>
<tr><th>Characteristics</th><th>Level (1-5)</th></tr>
<tr><td>Performance</td><td>++++</td></tr>
<tr><td>Maintenance Cost Effectiveness</td><td>++++</td></tr>
<tr><td>Maintenance frequency</td><td>++++</td></tr>
<tr><td>Flexibility to change in demands</td><td>+++</td></tr>
<tr><td>Resilience to droughts</td><td>+++++</td></tr>
<tr><td>Resilience to floods</td><td>+++</td></tr>
<tr><td>Environmental friendly</td><td>++++</td></tr>
<tr><td>Energy saving</td><td>++++</td></tr>
</table>
</td>
<td></td>
</tr>
</table>

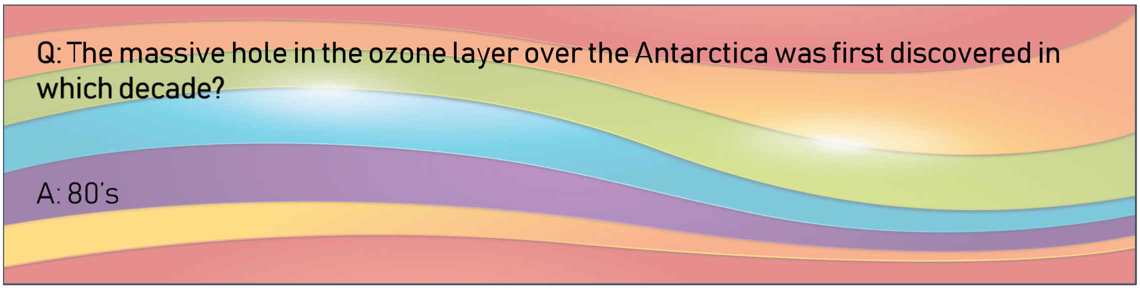
A2.3 Examples of battle question cards

Q: What is removed from water when disinfection is carried out?

A: Pathogens OR Microorganisms

Q: What minerals are found in the run-off from agricultural land and treated and untreated sewage effluents, which are highly responsible for eutrophication of water bodies?

A: Nitrogen and phosphorus

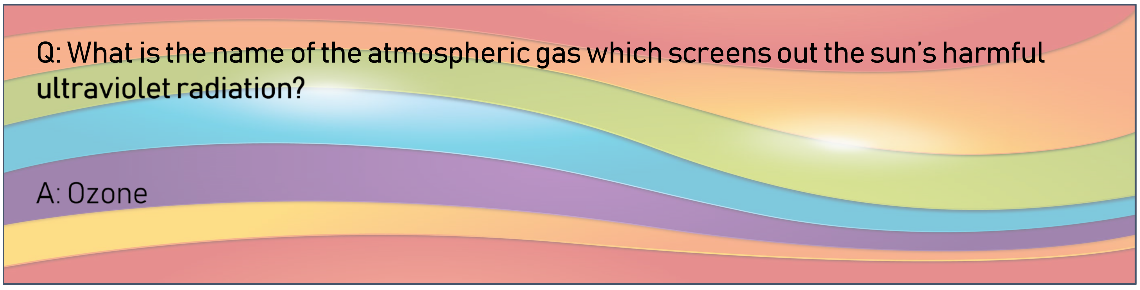


Q: The massive hole in the ozone layer over the Antarctica was first discovered in which decade?

A: 80's

Q: How much of the total cropland globally is rainfed?

A: 80%



Q: What is the name of the atmospheric gas which screens out the sun's harmful ultraviolet radiation?

A: Ozone

A2.4 Examples of challenge events

A rainstorm is coming to the Sites 1,3,5,7,9,11. The owners of the Sites roll the dice to see the level of the rain. If you have lower **Resilience to Floods** than the number you got, pay 35coins.

A period of drought is coming to the Sites 7, 8, 9, 10,11, 12. The owners of the Sites roll the dice to see the level of the drought. If you have lower **Resilience to Droughts** than the number you got, pay 40 coins.

People complain about the quality of the drinking water. Roll the dice and see the required quality of the water. If your **Performance** is lower than the number that you get on the dice then you need to pay 50 coins.

A sudden flood is occurring in Site 1, 6, 7, 8, 9, 10, 11, 12. If you have installed bank filtration to these areas, you need to ensure that you have added a **resilient to floods** supportive system. If not do it otherwise your system will collapse.

The Municipality of Site 2 is very concerned about the increasing quantities of the sewage. Make sure that tour system has **Flexibility to Change in demands** over 3+. If not you need to apply an appropriate supportive system. Otherwise, you will pay to the Government 80 coins.